Performance Analysis of Solar Water Heaters and their Applications for Space Heating

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Certificate

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Dedication

I dedicate this thesis to my teachers for providing me support in studies. Especially to my supervisor Dr. Adeel Waqas and GEC members for providing me enormous support.

Abstract

Pakistan is suffering from energy crisis and situation is worsening day by day due to lack of careful planning and implementation of the energy related policies. Both Electricity and Natural gas load shedding have appeared as major issues on country's economic and social horizon. Natural gas being serving the major resource in Pakistan energy mix, is unable to fulfill industrial and domestic loads demands, especially in winter season due to excessive utilization in space and water heating of domestic and commercial sectors. Although Government has been given priority to domestic and commercial (educational institutes and markets) sectors by continuously shifting the resource to these sectors and supply has increased up to 232 billion cubic feet due to improper planning and utilization. Industrial sector which was relying on natural gas is being unable to continue production and has led to economic crisis.

Pakistan lies in a region of high solar radiations ideally suited for solar thermal projects. So in order to exploit this Potential research must be carried out to for techno-economic evaluation of solar thermal projects for climatic conditions of Pakistan. This research was carried out to analyze the Performance of commonly available solar water heaters for climatic conditions of Pakistan and to optimize their Performance for Space heating systems. Results shows that for educational building situated in climatic conditions of Quetta, if utilizes solar space heating system can save 170 mm Btu natural gas annually. IRR of solar space heating scheme was found to be 20% and payback period is ~6 years which is quite attractive to be considered. Sensitivity analysis shows that fuel cost (base case) is most sensitive parameter. Risk analysis of project input parameters reveals that project is quite safe to consider as IRR is concentrated between 18.5-21 % range.

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Research Publications

1. Adeel Waqas, Shah Mir Ahmad, M.Ali Javed, Mahesh Kumar. "**GHG reduction through domestic solar water heating in Pakistan**", Paper presented in Conference on emerging materials and processes (CEMP) Aug 22-24 (2013), SCME NUST Islamabad Pakistan, P.70*

2. Shah Mir Ahmad, M. Ali Javed, Mahesh Lohano, Adeel Waqas. "**Minimizing Natural gas consumption through optimized solar water heating**". Paper presented in 5th International conference on Environmentally sustainable development, August 25-27 (2013), Comsat institute of information technology Abottabad, Pakistan, P.6.**

3. Shah Mir Ahmad, Adeel Waqas, Mahesh Kumar, M.Ali Javed, "**Techno-Economic Assessment of Solar Water Heating Systems for Natural Gas Savings in the Domestic Sector of Pakistan**".(Under review), Energy Sources, Part A: Recovery, Utilization, and Environmental Effects.***

*Annexure I

** Annexure II

***Annexure III

List of abbreviation

SWH	Solar water heater
FPC	Flat plate collector
ETC	Evacuated tube collector
LPG	Liquefied petroleum gas
TOE	Tonne of oil equivalent
kWh	Kilo Watt Hour
IRR	Internal rate of return
NPV	Net present Value
ASME	American society for mechanical engineers
B.C ratio	Benefit to cost ratio
TRNSYS	Transient energy simulation tool

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I want to thanks Allah Almighty, The Most Beneficent The Most Merciful Who made me able to complete this project. No words are sufficient to express our gratitude to our loving teachers for their exemplary patience, understanding and cooperation during the preparation of this thesis. I express my most sincere gratitude to my advisor, Dr. Adeel Waqas for his guidance. I also like to thank my whole GEC committee and Faculty members.

Chapter 1
INTRODUCTION

1.1 Background

Excessive utilizations of fossil fuels to meet increasing energy demand has led to environmental, economic and future security issues regarding these conventional energy resources. Depleting fossil fuel reserves are misbalancing natural atmospheric compositions [1] which are directly or indirectly linked to health problems, reduced life expectancy and premature mortality [2]. Increasing urbanization has led to severe air pollution problems specially in developing World [3]. In order to focus socio-economic development with environmental protection and energy market liberalization, approach should be optimized with the help of sustainable development. Increasing depletion rate of fossil fuel reserves should be controlled by considering cleaner energy resources while energy planning [4]. Energy sector plays a significant role in this regard since production, distribution and consumption of energy involves environmentally harmful effects. So there is a need to focus on energy resources which are secure, easily available, environmentally favorable and cost effective as well. At this time of emerging environmental issues, renewable energy resources can play their beneficial part to reduce severity of situation [5]. So World is now focusing towards renewable resources to have increased commercial utilizations. Research towards renewable energy technologies in order to have sustainable and environment friendly energy resources has given good outcomes. Renewable energy technologies are growing, there had been a double digit market growth for some renewable energy technologies [6].

1.2 Pakistan energy scenario

Pakistan is among countries where energy crisis is major national issues. Hikes in energy price and uncertainty in energy security are demanding to have proper planning, regarding energy related policies and to search for more suitable options [7-13]. Natural gas has been considered an important energy resource for fulfilling Pakistan's energy need. Natural gas is contributing 49.5% share in Pakistan energy mix as shown in Figure 1.1 and is vastly utilized in general industry, fertilizer production, domestic heating, transport sector as well as power generations shown in

Figure 1.2. Due to excessive utilization in domestic sector, transport sector and industrial burning this resource is now incapable to fulfill energy demand of country. The current natural gas deficit has reached up to ~2000 mmcfd and situation will be more serious in near future. So the situation is demanding to have efficient utilization of natural gas resource and to search for other suitable options [14].

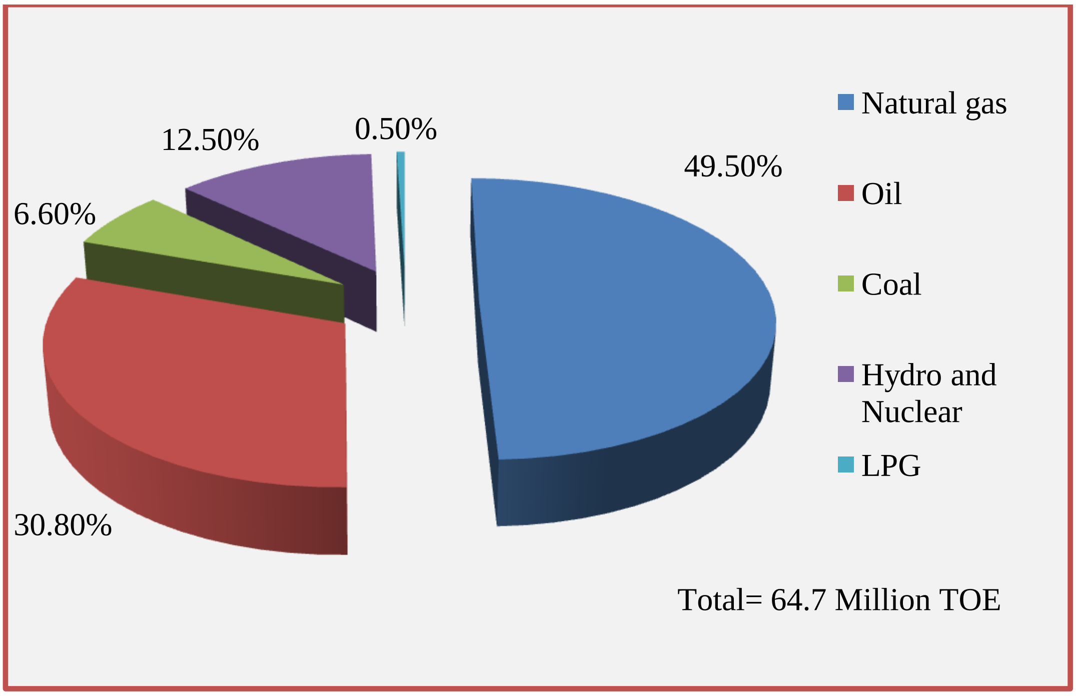

Figure 1.1Energy supplies of Pakistan by source [15].

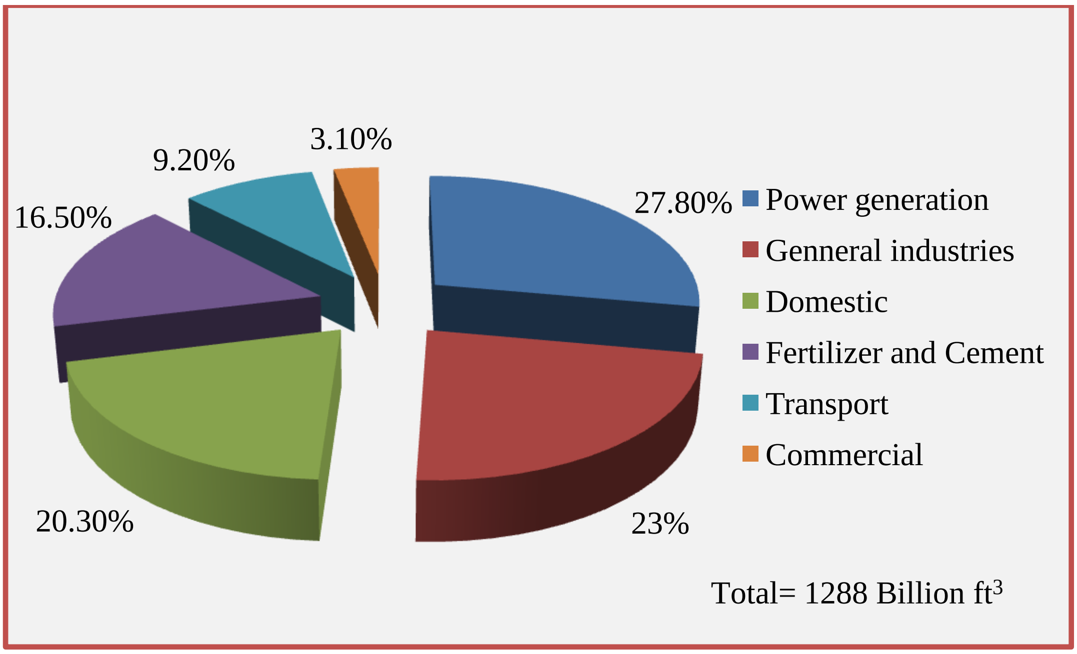

Figure 1.2 Natural gas consumption by sector [15].

1.3 Analysis of solar energy Potential in Pakistan

Geographical Location, climatic conditions and topography of Pakistan are ideal for solar resource utilizations that can be converted to useful form by suitable technologies of energy conversion. Most parts of country have more than 300 sunny days per year, 7.6 sunny hours per day [16]. These values indicate Pakistan is blessed generously for having vast solar potential. This solar potential can beneficially be utilized for solar energy applications such as solar water heating (SWH), photovoltaic, desalination and crop drying applications. Utilization of solar energy for water heating can serve as cost effective and environment friendly [17] alternate of natural gas for domestic and industrial sectors of country [16, 18-20].

In many previous studies, researchers has elaborated about SWH utilization is beneficial for Pakistan [16, 20, 21] and its market is increasing [20] for quantification of SWH potential in Pakistan ten major cities of Pakistan were chosen. Analysis was carried out through RETScreen advance energy software simulations, software has good research penetration, broadly in renewable [22-27]and specifically in solar thermal sector [28, 29]. The annual average daily solar radiations on horizontal as well as tilted surface of 45^{o} slope for these cities are shown in Figure 1.3. Radiations data depicts that country is blessed with solar energy resource.

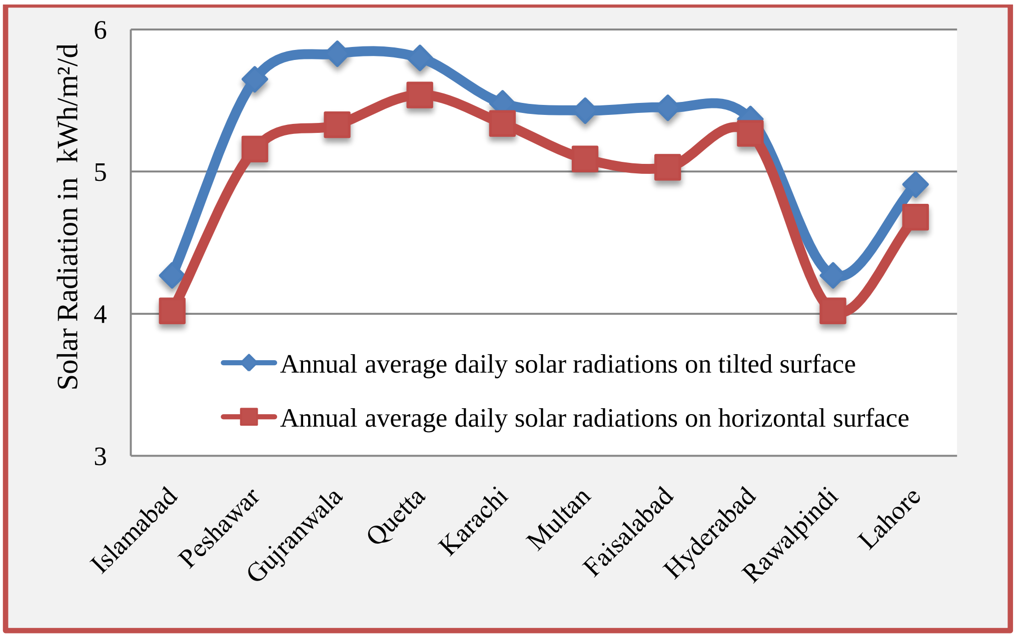

Figure 1.3 Annual average daily solar radiations on horizontal and tilted surfaces of selected cities

1.4 Solar water heaters

Solar water heater captures solar energy and converts this energy into heat. There are mainly two types of solar water heaters, un- glazed and glazed solar water heaters. Un-glazed are simplest collectors with no glazing or insulated collector while glazed collector as the name indicates is properly glazed or insulated. Un-glazed collectors are used where low output temperature is required [30]. Glazed collectors are then further categorized into flat plate and Evacuated tube collectors [31].

1.4.1 Flat plate solar water heaters

The flat plate solar water heater is used for application, where demand of heating is low. A flat plate collector consists of a rectangular housing, which contains a metal absorber and is covered by a glass cover [32]. It also contains insulation on its side surface to reduce thermal losses and tubes for circulating water, which are in contact with absorber surface, thus solar energy collected by absorber is transferred to water through tubes.

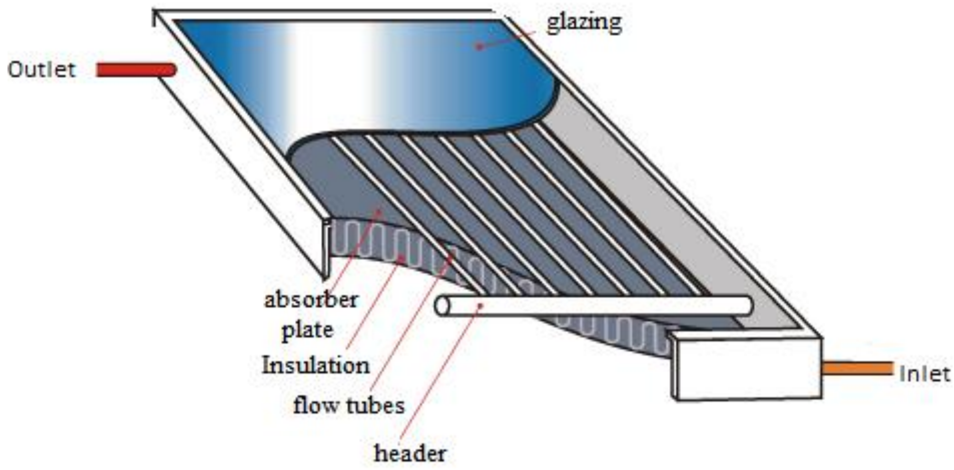

Figure 1.4 Flat plate collector [33]

1.4.2 Evacuated tube collector

Evacuated tube solar water heater consist of rows of tubes placed in parallel to each other [34]. Each tube contains two glass tubes, which are made of strong borosilicate glass. The outer tube of this is of transparent glass, which allows the light to pass through it and the inner tube contains a selective coating, due to which solar energy is absorbed into it and prevents thermal losses. The air in the space between two tubes is withdrawn out to form vacuum. This evacuation of air is important factor for the performance of solar water heater because it forms vacuum, which is a good insulator and prevents the losses due to conduction and convection [35]. The schematic view of single ETC is shown in Figure 1.5.

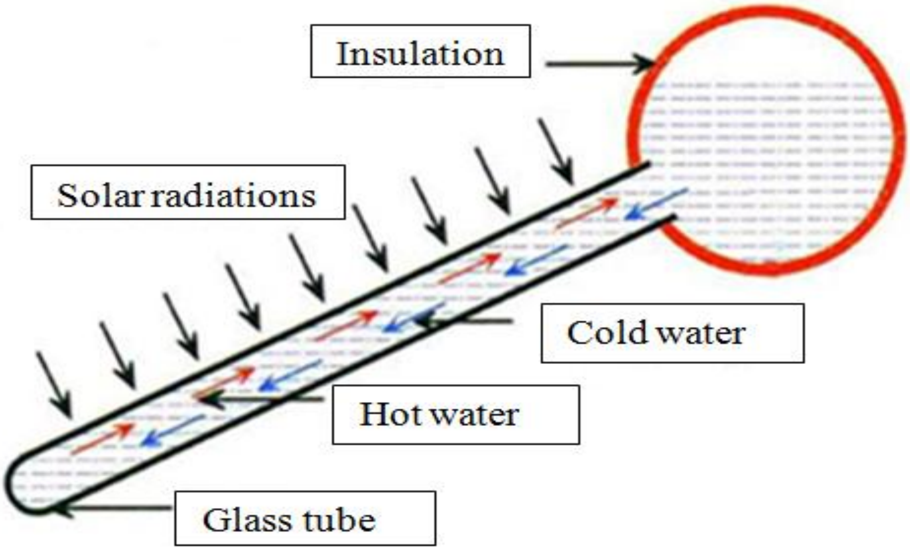

Figure 1.5 Evacuated tube collector [36]

1.5 Objectives

Objectives of the thesis are divided into four steps in first two steps Flat plate collector (FPC) and Evacuated tube collector (ETC) performances are compared and then the better one is selected for further application in space heating scheme.

1. Performance Analysis of FPC
2. Performance Analysis of ETC

   (1–2: To choose better collector)

3. Space heating load Calculations for educational sector
4. Performance analysis of Space heating scheme selected

1.6 Problem statement

This study aims to find a better type of solar space heating scheme for a city of Pakistan where climatic conditions are cold and natural gas consumption is high. A solar collector whose technical and economical features are feasible will be selected first then a suitable solar space heating scheme will be formulated and analyzed. The space heating scheme will be designed for an educational institute where load and source coincides. Technical analysis, economical analysis, environmental benefits and control study will be done in detailed way.

1.7 Scope and Limitations

Scope of this study solely concentrate on performance analysis of solar collectors and space heating scheme for climatic conditions of Pakistan. Weather data, input cost and human behaviors regarding energy consumption are based on Pakistan. Technical and economic analysis are considered in detail while environmental study is not considered in depth. Since analysis has been done specifically for selected cities and selected technical and economical input parameters which constrained the results to be prescribed only for current Pakistan's energy market status.

1.8 Organization of thesis

Thesis is organized in systematic way to analyzed the energy scenario of Pakistan and solar water heating potential available in country. Then performance analysis of different types of solar water heaters will be done and a suitable solar water heater will be selected. Space heating load will be calculated and solar space heating scheme formulation will be done. Then performance analysis of solar space heating scheme will be done in detailed way with special focus on technical and economical features. Organization of thesis is shown in Figure 1.6.

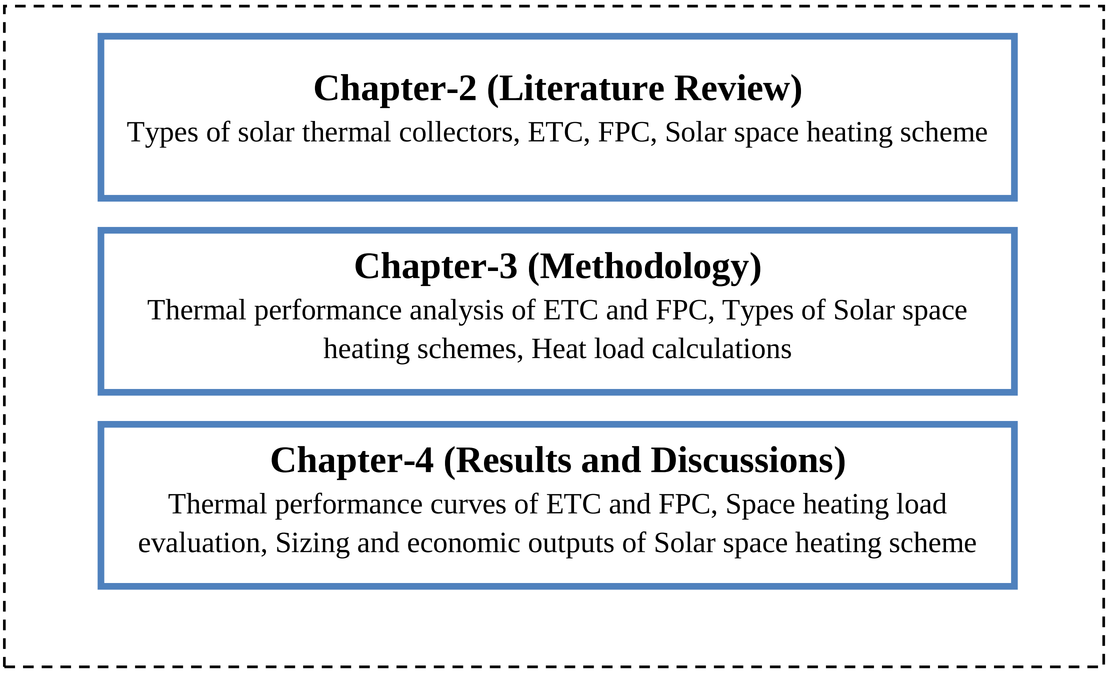

Figure 1.6 Organization of thesis

Summary

Fossil fuels environmental concerns and depletion has been discussed briefly. Current energy scenario of Pakistan is discussed and natural gas importance in Pakistan energy mix has been studied. Solar energy potential in Pakistan has been analyzed and different types of thermal collectors has been revealed. At end of chapter, objectives, scope, limitations and organization of thesis has been discussed in brief way.

References

1. Withagen, C., Pollution and exhaustibility of fossil fuels. Resource and Energy Economics, 1994. 16(3): p. 235-242.
2. Kampa, M. and E. Castanas, Human health effects of air pollution. Environmental Pollution, 2008. 151(2): p. 362-367.
3. Mage, D., et al., Urban air pollution in megacities of the world. Atmospheric Environment, 1996. 30(5): p. 681-686.
4. Omer, A.M., Energy, environment and sustainable development. Renewable and Sustainable Energy Reviews, 2008. 12(9): p. 2265-2300.
5. Dincer, I., Environmental impacts of energy. Energy Policy, 1999. 27(14): p. 845-854.
6. Jacobsson, S. and A. Johnson, The diffusion of renewable energy technology: an analytical framework and key issues for research. Energy Policy, 2000. 28(9): p. 625-640.
7. Kessides, I.N., Chaos in power: Pakistan's electricity crisis. Energy Policy, 2013. 55: p. 271-285.
8. Shah, A.A., et al., Sustainable development through renewable energy—The fundamental policy dilemmas of Pakistan. Renewable and Sustainable Energy Reviews, 2011. 15(1): p. 861-865.
9. Khan, M.A. and N. Latif, Environmental friendly solar energy in Pakistan's scenario. Renewable and Sustainable Energy Reviews, 2010. 14(8): p. 2179-2181.
10. Malik, S.N. and O.R. Sukhera, Management of natural gas resources and search for alternative renewable energy resources: A case study of Pakistan. Renewable and Sustainable Energy Reviews, 2012. 16(2): p. 1282-1290.
11. Sahir, M.H. and A.H. Qureshi, Assessment of new and renewable energy resources potential and identification of barriers to their significant utilization in Pakistan. Renewable and Sustainable Energy Reviews, 2008. 12(1): p. 290-298.
12. Sahir, M.H. and A.H. Qureshi, Specific concerns of Pakistan in the context of energy security issues and geopolitics of the region. Energy Policy, 2007. 35(4): p. 2031-2037.

13. Farooq, M.K. and S. Kumar, An assessment of renewable energy potential for electricity generation in Pakistan. Renewable and Sustainable Energy Reviews, 2013. 20: p. 240-254.
14. Shahbaz, M., H.H. Lean, and A. Farooq, Natural gas consumption and economic growth in Pakistan. Renewable and Sustainable Energy Reviews, 2013. 18: p. 87-94.
15. Yearbook, Pakistan Energy. "Hydrocarbon Development Institute of Pakistan." Ministry of Petroleum and Natural Resources, Government of Pakistan (2012): 39.
16. Shaikh, P.H., F. Shaikh, and M. Mirani, Solar energy: Topographical asset for Pakistan. Applied Solar Energy, 2013. 49(1): p. 49-53.
17. Han, J., A.P. Mol, and Y. Lu, Solar water heaters in China: a new day dawning. Energy Policy, 2010. 38(1): p. 383-391.
18. Asif, M., Sustainable energy options for Pakistan. Renewable and Sustainable Energy Reviews, 2009. 13(4): p. 903-909.
19. Mirza, U.K., M.M. Maroto-Valer, and N. Ahmad, Status and outlook of solar energy use in Pakistan. Renewable and Sustainable Energy Reviews, 2003. 7(6): p. 501-514.
20. Bhutto, A.W., A.A. Bazmi, and G. Zahedi, Greener energy: issues and challenges for Pakistan—solar energy prospective. Renewable and Sustainable Energy Reviews, 2012. 16(5): p. 2762-2780.
21. Muneer, T., S. Maubleu, and M. Asif, Prospects of solar water heating for textile industry in Pakistan. Renewable and Sustainable Energy Reviews, 2006. 10(1): p. 1-23.
22. Harder, E. and J.M. Gibson, The costs and benefits of large-scale solar photovoltaic power production in Abu Dhabi, United Arab Emirates. Renewable energy, 2011. 36(2): p. 789-796.
23. Alam Hossain Mondal, M. and A. Sadrul Islam, Potential and viability of grid-connected solar PV system in Bangladesh. Renewable energy, 2011. 36(6): p. 1869-1874.
24. El-Shimy, M., Viability analysis of PV power plants in Egypt. Renewable energy, 2009. 34(10): p. 2187-2196.

25. Thompson, S. and B. Duggirala, The feasibility of renewable energies at an off-grid community in Canada. Renewable and Sustainable Energy Reviews, 2009. 13(9): p. 2740-2745.
26. Rehman, S., Prospects of wind farm development in Saudi Arabia. Renewable energy, 2005. 30(3): p. 447-463.
27. Alonso-Tristán, C., et al., Small hydropower plants in Spain: a case study. Renewable and Sustainable Energy Reviews, 2011. 15(6): p. 2729-2735.
28. Chalikias, M.S., G. Kyriakopoulos, and K.G. Kolovos, Environmental sustainability and financial feasibility evaluation of woodfuel biomass used for a potential replacement of conventional space heating sources. Part I: a Greek case study. Operational Research, 2010. 10(1): p. 43-56.
29. Purohit, I. and P. Purohit, Techno-economic evaluation of concentrating solar power generation in India. Energy Policy, 2010. 38(6): p. 3015-3029.
30. Burch, J., et al., Simulation of an unglazed collector system for domestic hot water and space heating and cooling. Solar Energy, 2004. 77(4): p. 399-406.
31. Zambolin, E. and D. Del Col, Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Solar Energy, 2010. 84(8): p. 1382-1396.
32. Shitzer, A., et al., Experiments with a flat plate solar water heating system in thermosyphonic flow. Solar Energy, 1979. 22(1): p. 27-35.
33. Chi, S., Heat pipe theory and practice. Washington, DC, Hemisphere Publishing Corp.; New York, McGraw-Hill Book Co., 1976. 256 p., 1976. 1.
34. Morrison, G., I. Budihardjo, and M. Behnia, Water-in-glass evacuated tube solar water heaters. Solar Energy, 2004. 76(1): p. 135-140.
35. Budihardjo, I., G.L. Morrison, and M. Behnia, Natural circulation flow through water-in-glass evacuated tube solar collectors. Solar Energy, 2007. 81(12): p. 1460-1472.
36. Evans, B.L., S. Klein, and J. Duffie, A design method for active-passive hybrid space heating systems. Solar Energy, 1985. 35(2): p. 189-197.

Chapter 2

LITERATURE REVIEW

2.1 Solar thermal energy and solar water heating

Market of solar thermal technologies is increasing day by day. Water heating, space cooling, space heating, crop drying, swimming pool heating, desalinating water and process heat generations are famous applications of solar thermal energy [1, 2]. Solar water heaters (SWH) are mostly utilized to meet domestic and industrial heating load. Solar water heating is the most applicable technology among different solar thermal energy technologies and is growing rapidly in many regions of the world. Easily available solar potential, mature technology, no need of fossil fuels, decentralized generations and environment friendly systems gives solar thermal devices a edge over conventional fossil fuel operated heat generating systems. Performance of solar water heaters are based on certain climatic, technical and social aspects. Climatic conditions are location, topography, ambient temperature and wind velocity. Technical aspects are type of collector, efficiency, area of collector, slope of collector, losses through collector etc. Social aspects are hot water quantity and temperature demand [3, 4].

Industrial manufacturing of SWH took place in early 60s. Then SWH industry flourishes quickly in many regions of the world. Typical SWH manufactured were glazed and unglazed collectors [5, 6]. Then flat plate and evacuated tube collectors were developed in glazed type collectors. Flat plate collectors (FPCs) are collectors with rectangular housing with metal absorber and glass covers[7, 8]. These were typically more beneficial for loads where heating demand is low. Evacuated tube collectors (ETCs) consist of rows of glass tubes placed in parallel to each other. Glass tubes are made of borosilicate glass while inner tube contains selective coatings which prevent thermal losses. Due to these features efficiency of ETCs is more than FPCs while thermal losses are higher in FPCs [9].

Solar collectors are divided in two types on basis of solar flux concentration variation mode, non concentrating and concentrating. Non-concentrating collectors have constant area for absorbing solar radiations, while concentrating solar collector utilizes various types of geometries for enhancing solar radiations coming on unit area of collector [10]. On basis of motion for tracking sun, collectors are divided in two types, tracking collectors and non tracking collectors. Tracking collectors utilizes some kind of mechanical devices in order to track the sun. Tracking can be one, two or three dimensional. Non tracking collectors are just fixed collectors with position of sun changing on them every moment [11]. On basis of presence of mechanical device for boosting fluid flow in collectors, collectors are divided in two types, active and passive systems. Passive systems uses natural convection phenomena to transport hot fluid while in active system an additional mechanical device or pump is installed in order to boost up the transport of hot fluid. Active systems are particularly better suits where heating load is high [12]. On basis of utilization of an extra fluid in solar thermal collector loop, collector system is divided in two types, direct system and indirect systems. In direct systems fluid in collector and load side is same while in indirect systems these two fluids are separate [13].

2.2 Flat plate collectors:

FPCs are commonly utilized in non tracking mode, collectors are oriented towards equator facing south in north hemisphere and facing north in southern hemisphere [10]. In FPCs copper plates are made of Copper or Aluminum. UV resistant plastic extrusions are also used to avoid losses. In order to reduce thermal losses in FPCs, contact of absorber plate and fluid passage must be maximized [14, 15]. Haung has worked on passive flat plate solar water heaters and has described the performance of FPC in more general equations which are function of solar radiations and time [16]. Zerrouki has calculated the thermal outputs of passive FPC and flow rates by assuming linear distribution of temperature over collector surface [17]. Koffi has worked on FPC with internal heat exchanger. He obtained the maximum efficiency of system ~ 58 % at 989 W/m^2 of incident solar radiations [18]. Eze analyzed thermal efficiency of passive FPC system. 42% efficiency at 83^oC in climatic conditions of Nigeria with load conditions were obtained [19]. Dagdougui has worked on effects of number of covers and insulation on performance of FPCs and noticed that by having more covers or better insulation efficiency of FPCs can be enhanced considerably [20]. Taherian et al worked to analyze clear/cloudy day effects on performance of FPCs and observed varying patterns for instantaneous efficiency. Maximum instantaneous efficiency ~ 68% was obtained [21]. Bukola O Bolaji performed his experimentation of natural circulation on FPC system to optimize the flow rate. The system had shown the optimum performance on 0.1 $kg/m^2.s$ flow rate [22]. Volker Weitbrecht had worked on FPCs to analyze the flow distribution patterns in FPCs in laminar flow conditions. Pressure and discharge flow rates were investigated at outlet of collector. Relation between junction losses and local Reynold number was developed. Sensitivity analysis were carried out in research to explain the possible flow patterns inside the natural circulation FPC system [23]. Sivakumar had utilized modified copper tube with zig zag arrangement in riser tubes design. Corrugated sheet absorber with nine riser tubes were utilized in experiments. 3 % improvements in thermal efficiency of natural circulation FPC system was obtained [24]. Ali reza Hobbi had done modeling of FPC with indirect active mode in Trnsys software. The study reveals that for Quebec, Canada systems cover ~97 and ~62 percent requirements (maximum) for summer and winter seasons. For annual hot water requirements analysis, result reveals that nearly 55 percent demand can be met by FPC system [25]. In another study Kolektor software was utilized to study design features of FPC [26]. Duffie, J.A had worked to analyze the effect of flow rates on collector efficiency in controlled conditions. There research revealed that the increase in flow rate results in increased collector efficiency factor but after a certain limit it led to increased mixing in storage tank which had led to reduction in overall system efficiency [27]. Wang X.A worked on parallel combination of FPCs. Through these experimentations it was revealed that several parallel FPCs can be taken as single FPC system with number of risers multiplied for case of single FPC systems [28].

2.3 Evacuated tube collectors

Morrison investigated the performance of a evacuated tube water-in-glass solar water heater using International standard test method ISO 9459-2 and used a tube array whose optical efficiency was relatively low and suggested that stagnant region near sealed end might reduce the performance of ETC [29]. Zhang proposed a collector system in which supercritical CO_2 was used as a working fluid and investigated the performance of SWH. He found that the average daily efficiency was more than 50% and annual average efficiency was 60%, which was more than ordinary ETC [30]. Tang presented a mathematical model to estimate the collectible solar radiations. To obtain maximum solar radiation on surface he suggested that, a collector whose tubes were in titled arrangement can be installed at 10^o less than site latitude and a collector whose tube were arranged horizontally can be installed at 20^{o} less than site latitude. He also suggested that 10^{o} variation in optimal angle of collector facing south results in 5% decrement in annual solar radiations [31]. Chow compared the performance of two types of solar water heater (single phase open thermosyphon and two phase closed thermosyphon system). Results revealed that performance of two phase closed thermosyphon system is more than that of single phase open thermosyphon system. He also investigated the economical parameters and suggested that performance of two phases is more but due to high cost of two phase system, payback period for both is same. From economical point of view these both systems are not competitive then flat plate collector. These both are only suitable for applications in which temperature demand is high [32]. Kim investigated the performance of two layers glass tube collector for different shapes of absorber. He used air as the working fluid and suggested that performance of depends on the solar radiations incidence angle, absorber shape and arrangements of tubes [33]. Nashar investigated the influence of dust accumulation on the collector performance. He installed two collectors and cleaned one collector and suggested that if cleaning was not carried out for one year then performance of heat collection by collector decrease to 60 to 70% [34]. Tang evaluated the influence of tilt angle on the thermal performance of water in glass evacuated tube collector. He suggested that tilt angle has only effect on the solar radiation collection and on the heat gain to the system and has insignificant effect on the solar thermal conversion efficiency and heat stored in the storage tank from tube [35]. The analysis of cylindrical solar water heater was carried out by Al-Madani. Maximum temperature difference between inlet and outlet of SWH was 27.8 ^{o}C, whereas mass flow rate was 9 kg/h. The maximum efficiency achieved by cylindrical tube collector was 41.8%. He also observed that cylindrical tube collector is more cost effective as compared to flat plate collector [36]. Hayek experimentally investigated the performance of water in glass and heat pipe solar water heater from November to January. He observed that heat pipe ETC have 15 to 20% higher efficiency than water in glass ETC. He also investigated the payback period for both collectors and observed that payback period of heat pipe was higher due to larger initial cost [37]. Yap investigated the performance of two commercially available finned evacuated tube collectors and analyzed their heat transfer rates and efficiency in detailed and concluded the certain reasons for parameters that effects the thermal performance of these commercially available collectors [38].

There are various research studies that utilized software tools to analyze the various design, thermal performance and economics features of the ETC [20, 39, 40]. Technical features that can be predicted are energy saved, quantity of fuel saved, solar fraction etc. Economical features are Net present value (NPV), Payback period, internal rate of return (IRR) and benefit to cost ratio (BC ratio). RETScreen, Trnsys and Polysun softwares can effectively be utilized to evaluate certain features among them. RETScreen software provides energy, cost, financial, environmental analysis in user friendly way. Sensitivity and risk analysis options with range of flexible options give it edge over technical analysis softwares. Polysun is a simulation software with various types of solar thermal areas incorporated. It helps to design, configure, optimize, forecast and compare the performance of these thermal energy systems. Trnsys is an energy simulation software tool with very good research penetration in solar thermal as well as other energy systems.

2.4 Heat load and solar space heating

Argiriou has worked to reduce the domestic energy consumption in Hellenic buildings. He has done technical and economical analysis of combined SWH and solar space heating schemes. In environment analysis he has shown that 40 % GHG reductions can be achieved by partial replacement of domestic fossil fuel consumptions through solar resource [41]. Afif Hassan has utilized the Trnsys software to calculate the solar fraction and financial savings of solar space heating system in Palestinian territory. The base case energy consumption for space heating accounts 70% of total domestic energy consumption. Through analysis he has shown that 55 % load can be met by utilizing available solar resource in optimum conditions, which results ~ 40 % reductions in annual heating costs [42]. Chris Scheuer has done whole life cycle analysis of educational building for time span of span 75 years. Analysis shown that generation of waste, environmental pollution, fixed and running cost were directly related to primary energy consumption of building [43]. Farghally1 has done analysis of space heating load calculations for home, hospital and school building. In his study, he utilized basic space heating load equations and had also focused on space heating equipments used to met this load [44]. Santamouris had done analysis of energy utilizations and savings in school of Hellas, Greece. The research had shown that energy consumption was found to be 93 kWh/m^2 and space heating load accounts 72% of this total load while 20% energy saving options was found in space heating load without too much efforts [45]. Abdullah Yildiz has done space heating load analysis of an office building in Izmir, Turkey. Space heating losses and gains were calculated following Turkish standards. Internal and external temperatures were taken as 20^{o}C and 0^{o}C respectively. The base case system was providing 2.5 kW of energy with 5 kW energy was being lost into environment [46]. Matteo has done statistical analysis to relate normalized energy demand of different type of buildings (thermo-physical variations) to their input parameters. Theoretical and experimental validations of statistical model with previous models and experimental data respectively. Results had shown good accuracy of proposed statistical model [47]. Jinghua had done energy and thermal performance study of residential envelopes of China. The research was aimed to study the results of China's five year plan to improve building energy parameters. The study had shown that energy efficiency improvements had been achieved through analysis carried out at various cities of China. The study also provides recommendations for further improvements [48]. In another research he studied the effects of variations of insulations thickness on economical parameters in China. The study had shown that with variation in insulation thickness better payback periods can be achieved up to certain limits. Economic savings were varying from ~ 35 \$/m^2 to 55 \$/m^2 at various locations [49]. Yimin Zhu had done a unique approach to create virtual environment to study the energy load parameters of hypothetical buildings using computer aided softwares. His study utilizes eQuest software for virtual prototype of graphical user interface of proposed building model [50]. Reinhard Haas studied the effects of building thermal quality, building type and consumer behaviors on space heating load. His research showed that up to 30% load can be varied by changing these parameters [51]. So through various studies it is clear that various types of solar thermal collectors are available from which ETC has good thermal performance. These solar collectors can be operated in various modes, for a specific solar space heating system the selected mode will depend on inherent requirement of that heating system. There are various computer tools available from which the thermal performance of the solar space heating system can be predicted and these software tools can help to reveal techno-economic features of the solar space heating, some of these tools are listed in Table 2.1. Figure 2.1 summarizes the conclusions of the whole Literature review.

Table 2.1 Software tools for Solar thermal system techno-economic analysis

Title of Paper	Software Utilized	Work done/Achievement
Solar water heating initiative in Oman energy saving and carbon credits [19]	RETScreen	Ret screen software has been used to analyzed the economical benefits obtained by replacing electric water heaters with solar water heater in seeb district of Oman.
Financial measures Serbia should offer for solar water heating systems [20]	RETScreen	The software has been used for decision of subsidy rate for domestic SWH in Serbia.
Solar water heating in Lebanon: Current status and future prospects [52]	RETScreen	Researchers have utilized RETScreen software to find pay back periods and GHG reductions obtained by utilizing FPC and ETC in Lebonan
Financial analysis of solar water heating systems during the depression: case study of Greece [39]	RETScreen	Software has been utilized to find IRR, Simple and equity payback periods at different level of grants in Greece
Techno-economic evaluation of concentrating solar power generation in India [53]	RETScreen Trnsys	Techno-economic feasibility of CSP in Indian climate has been studied, tower and parabolic trough technology assessment has done at various locations.
A Comparative Simulation Study of Solar Flat-Plate Collectors directly and indirectly Integrated into Building Envelope [54]	Kolektor Trnsys	Analysis of combi systems with different collector types and different façade integrations (direct and indirect), Kolektor was used to assist analysis in integration with Trnsys.
Optimal design of a forced circulation solar water heating system for a residential unit in cold climate using Trnsys [25]	Trnsys	Trnsys has been used to optimized the performance of indirect forced circulation SWH system with flat plate collector.
Economic optimization of low-flow solar domestic hot water plants [55]	Trnsys	Trnsys is used to simulate a system with solar thermal collector, heat exchanger, auxiliary heater, PV pump in three different Italian localities. Economic benefits of three different conventional fuels were compared.
Modelling of an ICS solar water heater using artificial neural networks and Trnsys [21]	Trnsys	Annual performance of Integrated Collector Storage is analyzed with artificial neural networks through the Excel Interface in Trnsys for Athens, Greece.

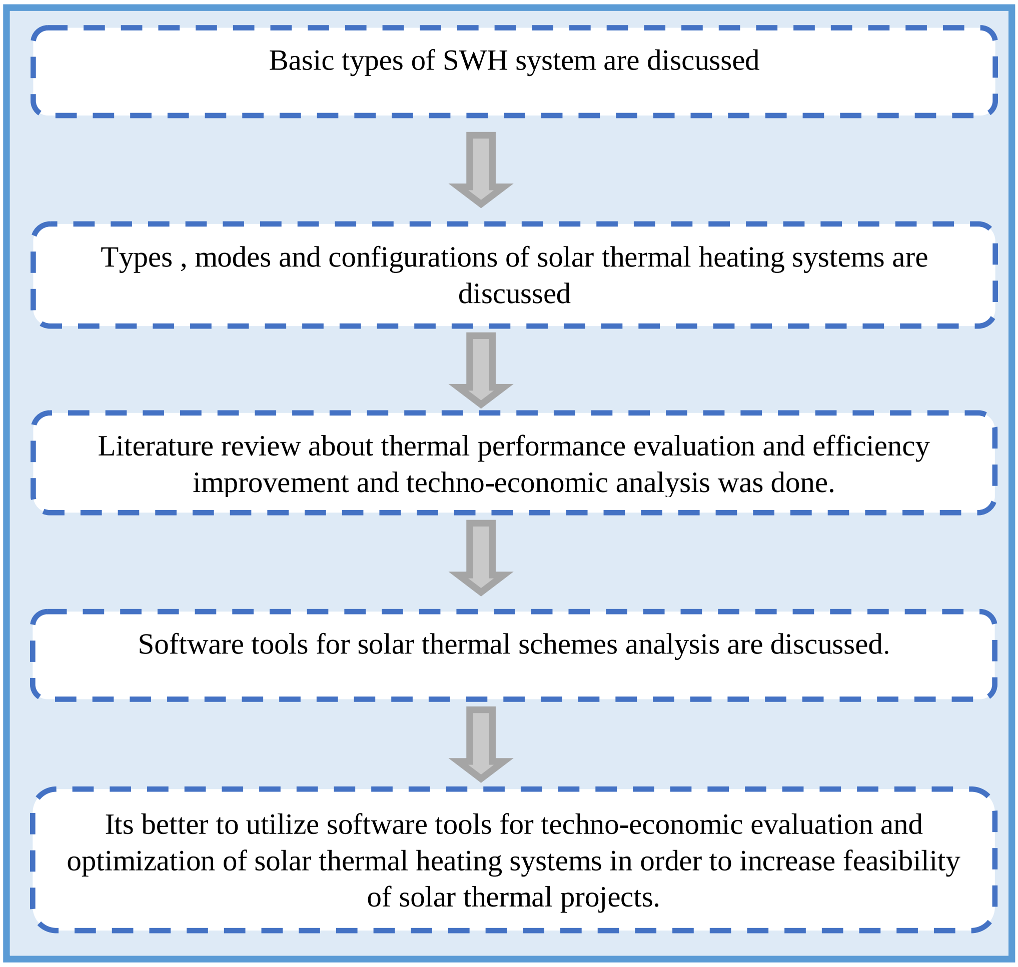

Figure 2.1 Literature review conclusions

Summary

Solar water heating technology and ways of harnessing this technology has been discussed in brief way. Different types, modes and configurations of solar water heating system was discussed. Then review of major collector types (FPC and ETC) has been discussed and present status, ways of efficiency improvements and methods of thermal study evaluation were discussed. Then review of space heating systems and solar space heating systems was done. So it is clear that various types of solar thermal collectors with various operation modes are available that can utilized effectively to harness solar thermal energy. Techno-economic performance evaluation of the solar space heating system can be done with various software tools which will help to have detailed feasibility study of the selected solar thermal space heating system.

References

1. Lunde, P.J., Solar thermal engineering: space heating and hot water systems. New York, John Wiley and Sons, Inc., 1980. 635 p., 1980. 1.
2. Kalogirou, S.A., Optimization of solar systems using artificial neural-networks and genetic algorithms. Applied Energy, 2004. 77(4): p. 383-405.
3. Mosley, R., et al., Penetration of ambient fine particles into the indoor environment. Aerosol Science & Technology, 2001. 34(1): p. 127-136.
4. Rohsenow, W.M., J.P. Hartnett, and E.N. Ganic, Handbook of heat transfer applications. New York, McGraw-Hill Book Co., 1985, 973 p. No individual items are abstracted in this volume., 1985. 1.
5. Kalogirou, S.A., Solar thermal collectors and applications. Progress in Energy and Combustion Science, 2004. 30(3): p. 231-295.
6. Sukhatme, K. and S.P. Sukhatme, Solar energy: principles of thermal collection and storage1996: Tata McGraw-Hill Education.
7. Bliss Jr, R.W., The derivations of several "plate-efficiency factors" useful in the design of flat-plate solar heat collectors. Solar Energy, 1959. 3(4): p. 55-64.
8. Hottel, H. and A. Whillier. Evaluation of flat-plate solar collector performance. in Trans. Conf. Use of Solar Energy;(). 1955.
9. Sheikh, M.A., Renewable energy resource potential in Pakistan. Renewable and Sustainable Energy Reviews, 2009. 13(9): p. 2696-2702.
10. Kalogirou, S., The potential of solar industrial process heat applications. Applied Energy, 2003. 76(4): p. 337-361.
11. Kumar, N., T. Chavda, and H. Mistry, A truncated pyramid non-tracking type multipurpose domestic solar cooker/hot water system. Applied Energy, 2010. 87(2): p. 471-477.
12. Shukla, A., D. Buddhi, and R. Sawhney, Solar water heaters with phase change material thermal energy storage medium: A review. Renewable and Sustainable Energy Reviews, 2009. 13(8): p. 2119-2125.
13. Buckles, W. and S. Klein, Analysis of solar domestic hot water heaters. Solar Energy, 1980. 25(5): p. 417-424.
14. Chaibi, M. and A.M. El-Nashar, Solar Thermal Processes2009: Springer.

15. Shaikh, P.H., F. Shaikh, and M. Mirani, Solar energy: Topographical asset for Pakistan. Applied Solar Energy, 2013. 49(1): p. 49-53.
16. Huang, B., Similarity theory of solar water heater with natural circulation. Solar Energy, 1980. 25(2): p. 105-116.
17. Zerrouki, A., A. Boumedien, and K. Bouhadef, The natural circulation solar water heater model with linear temperature distribution. Renewable Energy, 2002. 26(4): p. 549-559.
18. Koffi, P., et al., Theoretical and experimental study of solar water heater with internal exchanger using thermosiphon system. Energy Conversion and Management, 2008. 49(8): p. 2279-2290.
19. Gastli, A. and Y. Charabi, Solar water heating initiative in Oman energy saving and carbon credits. Renewable and Sustainable Energy Reviews, 2011. 15(4): p. 1851-1856.
20. Stevanović, S. and M. Pucar, Financial measures Serbia should offer for solar water heating systems. Energy and Buildings, 2012. 54: p. 519-526.
21. Souliotis, M., S. Kalogirou, and Y. Tripanagnostopoulos, Modelling of an ICS solar water heater using artificial neural networks and TRNSYS. Renewable energy, 2009. 34(5): p. 1333-1339.
22. Bolaji, B.O., Flow design and collector performance of a natural circulation solar water heater. Journal of Engineering and Applied sciences, 2006. 1(1): p. 7-13.
23. Weitbrecht, V., D. Lehmann, and A. Richter, Flow distribution in solar collectors with laminar flow conditions. Solar Energy, 2002. 73(6): p. 433-441.
24. Sivakumar, P., et al., Performance improvement study of solar water heating system. Journal of Engineering and Applied Sciences, 2012. 7(1).
25. Hobbi, A. and K. Siddiqui, Optimal design of a forced circulation solar water heating system for a residential unit in cold climate using TRNSYS. Solar Energy, 2009. 83(5): p. 700-714.
26. Matuska, T., J. Metzger, and V. Zmrhal. Design tool KOLEKTOR 2.2 for virtual prototyping of solar flat-plate collectors. in Proceedings of EUROSUN. 2008.
27. Duffie, J.A. and W.A. Beckman, Solar energy thermal processes. 1974.

28. Wang, X. and L. Wu, Analysis and performance of flat-plate solar collector arrays. Solar Energy, 1990. 45(2): p. 71-78.
29. Morrison, G., I. Budihardjo, and M. Behnia, Water-in-glass evacuated tube solar water heaters. Solar Energy, 2004. 76(1): p. 135-140.
30. Zhang, X. and H. Yamaguchi, An experimental study on evacuated tube solar collector using supercritical CO_2. Applied Thermal Engineering, 2008. 28(10): p. 1225-1233.
31. Tang, R., Y. Yang, and W. Gao, Comparative studies on thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles. Solar Energy, 2011. 85(7): p. 1381-1389.
32. Chow, T.-T., et al., Performance evaluation of evacuated tube solar domestic hot water systems in Hong Kong. Energy and Buildings, 2011. 43(12): p. 3467-3474.
33. Kim, Y. and T. Seo, Thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tube. Renewable Energy, 2007. 32(5): p. 772-795.
34. El-Nashar, A.M., The effect of dust accumulation on the performance of evacuated tube collectors. Solar Energy, 1994. 53(1): p. 105-115.
35. Tang, R., et al., Optimal tilt-angles of all-glass evacuated tube solar collectors. Energy, 2009. 34(9): p. 1387-1395.
36. Al-Madani, H., The performance of a cylindrical solar water heater. Renewable energy, 2006. 31(11): p. 1751-1763.
37. Hayek, M., J. Assaf, and W. Lteif, Experimental investigation of the performance of evacuated-tube solar collectors under eastern mediterranean climatic conditions. Energy Procedia, 2011. 6: p. 618-626.
38. Ng, K., C. Yap, and T. Khor, Outdoor testing of evacuated-tube heat-pipe solar collectors. Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering, 2000. 214(1): p. 23-30.
39. Fantidis, J.G., et al., Financial analysis of solar water heating systems during the depression: case study of Greece. Engineering Economics, 2012. 23(1): p. 33-40.
40. Metzger, J., T. Matuska, and B. Sourek. Solar Combisystems with Building-Integrated Evacuated Flat-Plate Collectors. in Proceedings of ISES World Congress 2007 (Vol. I–Vol. V). 2009. Springer.

41. Argiriou, A., et al., Active solar space heating of residential buildings in northern Hellas—a case study. Energy and buildings, 1997. 26(2): p. 215-221.
42. Hasan, A., Sizing solar space heating system : A case study. Renewable Energy, 1999. 16(1–4): p. 720-724.
43. Scheuer, C., G.A. Keoleian, and P. Reppe, Life cycle energy and environmental performance of a new university building: modeling challenges and design implications. Energy and buildings, 2003. 35(10): p. 1049-1064.
44. Adelrahim, H.M., F.H. Fahmy, and M.A. El-Fawal, GEOTHERMAL HOT WATER AND SPACE HEATING SYSTEM IN EGYPT.
45. Santamouris, M., et al., Energy consumption and the potential for energy conservation in school buildings in Hellas. Energy, 1994. 19(6): p. 653-660.
46. Yildiz, A. and A. Güngör, Energy and exergy analyses of space heating in buildings. Applied Energy, 2009. 86(10): p. 1939-1948.
47. Caldera, M., S.P. Corgnati, and M. Filippi, Energy demand for space heating through a statistical approach: application to residential buildings. Energy and buildings, 2008. 40(10): p. 1972-1983.
48. Yu, J., et al., Evaluation on energy and thermal performance for residential envelopes in hot summer and cold winter zone of China. Applied Energy, 2009. 86(10): p. 1970-1985.
49. Yu, J., et al., A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China. Applied Energy, 2009. 86(11): p. 2520-2529.
50. Zhu, Y., Applying computer-based simulation to energy auditing: A case study. Energy and buildings, 2006. 38(5): p. 421-428.
51. Haas, R., H. Auer, and P. Biermayr, The impact of consumer behavior on residential energy demand for space heating. Energy and buildings, 1998. 27(2): p. 195-205.
52. Houri, A., Solar water heating in Lebanon: Current status and future prospects. Renewable energy, 2006. 31(5): p. 663-675.
53. Purohit, I. and P. Purohit, Techno-economic evaluation of concentrating solar power generation in India. Energy Policy, 2010. 38(6): p. 3015-3029.

54. Metzger, J., T. Matuska, and H. Schranzhofer. A comparative simulation study of solar flat-plate collectors directly and indirectly integrated into the building envelope. in Proceedings of International Conference of Building Simulation, Glasgow, UK. 2009.
55. Cardinale, N., F. Piccininni, and P. Stefanizzi, Economic optimization of low-flow solar domestic hot water plants. Renewable energy, 2003. 28(12): p. 1899-1914.

Chapter 3

METHODOLOGY

3.1 Performance analysis of flat plate collector

3.1.1 Theoretical background:

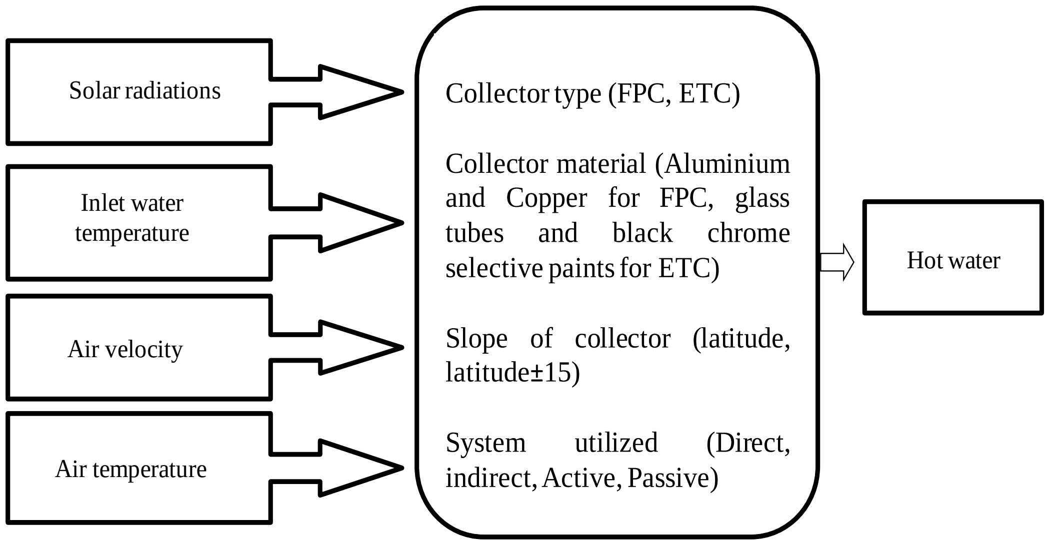

Figure. 3. 1 Energy balance diagram for solar water heater

A solar water heater converts solar energy coming from sun into heat energy being transferred to fluid passing through collector tubes. An energy balance diagram of solar collector is shown in Figure 3.1 [1, 2] which shows input parameters sensitive to performance of solar thermal collectors, these are of two types, first type is of environmental factors at left side of Figure 3.1 while at middle are the factors which are associated solely with solar thermal collector. In performance evaluation of FPC, mainly thermal performance evaluation is carried out which involves evaluation of efficiency, net heat gain, plate output temperature and fluid output temperature. The mathematical model for FPCs heat transfer analysis is composed of several equations constituting climatic conditions, collector geometry, collector system materials, fluid properties and thermal losses. Thermal losses associated with FPC collector are shown in Figure. 3. 2 [2-6] which indicates that two types of losses are associated with FPC, reflection and convection. Reflection of radiation is further divided in to two categories, reflection from glass cover and reflection from absorber surface. The step wise approach for thermal performance analysis of FPCs is shown in

Figure. 3. 3. The whole model consists of several steps and each step further has several governing equations to calculate the desired output of that step. In initial steps of calculations absorbed radiations and overall loss coefficient are calculated then four types of factors are evaluated and then the next steps have desired output results i.e heat gain, efficiency, fluid and absorber plate temperature. Matlab code was developed to analyze the efficiency, heat gain and fluid outlet temperature. For initial run of simulations, the fluid inlet temperature was assumed to be same as that of ambient temperature, further simulations run on the basis of the temperature calculated in previous simulations [7, 8]. In order to simplify the simulation model, some assumptions are needed to be made at start before the simulation process is carried on:

1. Clear sky assumption.
2. Isoflux condition (same radiation for one iteration of simulation)
3. Isothermal condition (same temperature for one iteration of simulation)
4. Fluid flow distribution is linear and in steady state.
5. Temperature distribution is linear and in steady state.
6. No water extraction and external water mixing during one steady state operation.

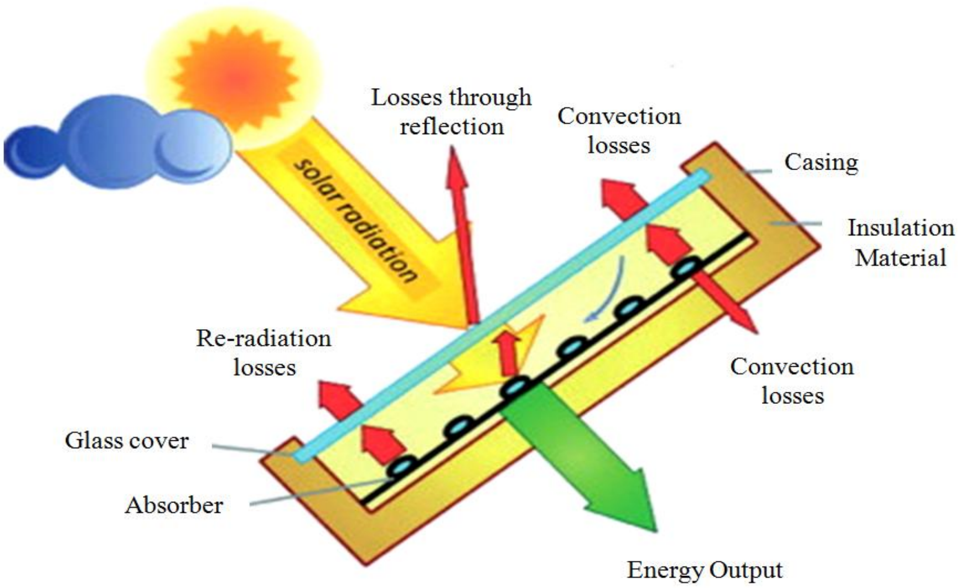

Figure. 3. 2 Thermal losses from FPC

3.1.2 Model description:

$$\eta = \frac{Q_u}{A_c.I} \text{..............................(3.1)}$$

Where η is collector's efficiency, it is the ratio of useful heat gain Q_u to product of collector area A_c and total incident solar radiations I.

$$Q_u = A_c F_r[S - U(T_i - T_a)] \quad \text{.......................(3.2)}$$

Useful heat gain Q_u comes from equation 3.2 T_i and T_a are fluid inlet and ambient temperatures, F_r is heat loss coefficient, S is absorbed radiations and U is overall heat loss coefficient. At start of analysis it is necessary to have absorbed heat on surface of the absorber plate, as required to calculate heat gain. S is sum of beam, diffuse and ground radiations [9, 10].

$$S = I_b R_b (\tau\alpha)_b + I_d (\tau\alpha)_d \left(\frac{1+\cos\beta}{2}\right) + \rho_g I (\tau\alpha)_g \left(\frac{1-\cos\beta}{2}\right) \quad \text{........................(3.3)}$$

I_b is the hourly beam radiations, I_d is the hourly diffuse radiations, $(\tau\alpha)$ is transmittance absorptance product, ρ_g is for ground reflectance and R_b is the ratio of beam radiation on tilted to horizontal surface and is given as :

$$R_b = \frac{\cos\theta}{\cos\theta_z} \quad \text{..(3.4)}$$

$$\cos\theta_Z = \cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta \quad \text{..........................(3.5)}$$

θ is the angle of incidence, θ_z is the zenith angle, δ is the declination, ϕ is the latitude and ω is hour angle.

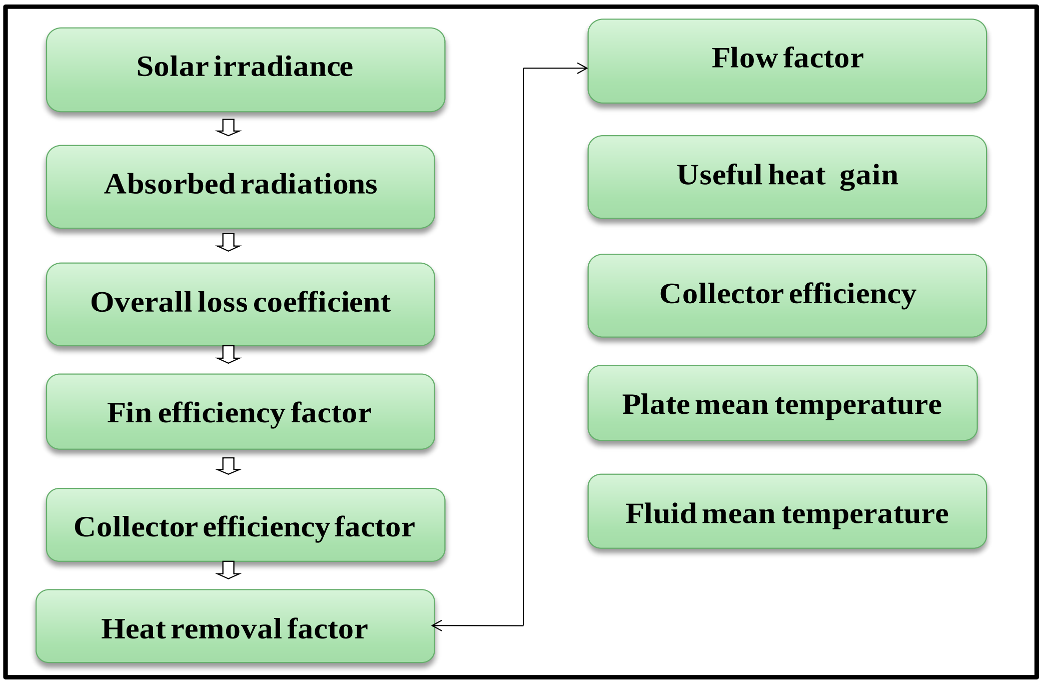

Figure. 3. 3 Thermal performance analysis of FPC

The overall loss coefficient (being required in equation 3.2) is sum of top loss coefficient U_t, bottom loss coefficient U_b and edge loss coefficient U_e

$$U = U_t + U_b + U_e \quad (3.6)$$

Top loss coefficient depends on number of glass cover, plate and ambient temperatures, wind velocity coefficient, emissivity factor and slope of the collector. U_b and U_e are found through equations 3.7 and 3.8. Where K and L are conductivity and thickness of insulator material at back side of collector. $(UA)_{Edge}$ is determined through conductivity, thickness and dimensions of edges of collector.

$$U_b = \frac{K}{L} \quad (3.7)$$

$$U_e = \frac{(UA)_{Edge}}{Ac} \quad (3.8)$$

Next step is evaluation of Fr, first fin efficiency factor F is determined through equation 3.9, which depends on mass flow rate m, tube pitch W and tube mean diameter D. Then collector efficiency factor F' is to be evaluated through equation 3.10. In equation 3.10, C_b is bond conductance D_i and h_i are tube inside diameter and heat transfer coefficient respectively. The Fr is evaluated through equation 3.11, where C_p is heat capacity of water. F'' is flow factor and is evaluated through Fr and F'.

$$F = \frac{\tanh[m(W-D)/2]}{m(W-D)/2} \quad (3.9)$$

$$F' = \frac{1/U}{W\left[\frac{1}{U[D+(W-D)F]} + \frac{1}{C_b} + \frac{1}{\pi.Di.hi}\right]} \quad (3.10)$$

$$Fr = \frac{mC_p}{Ac.U.F'}\left[1-\exp\left(-\frac{Ac.U.F'}{mCp}\right)\right] \quad (3.11)$$

$$F'' = \frac{Fr}{F'} \quad (3.12)$$

Now all the factors for evaluation of useful heat gain Q_u are available so Q_u and η for FPC can be calculated [9]. Next important outputs of FPC system are plate and fluid mean temperatures respectively. These two parameters can be evaluated through equations 3.13 and 3.14

$$T_{pm} = T_i + \frac{Q_u / A_c}{F_r.U}(1 - F_r)....................(3.13)$$

$$T_{fm} = T_i + \frac{Q_u / A_c}{F_r.U}(1 - F'')............................(3.14)$$

3.2 Performance analysis of evacuated tube collector

ETCs have good thermal performance than FPC due to less convection losses and is suitable very load side have high temperature demand. Improved selective coatings on absorber surface of glass for water in glass type ETC system have helped to boost up efficiency of ETC systems. Among two main types 'Water-in-metal' or 'Water-in-glass'. Water in glass type is mostly utilize due to lower losses, low cost and more life. Thermal losses associated with water in glass type ETCs are shown in Figure. 3. 4. These losses are of two types, reflectance from glass cover of tube and coating surface and second is convection from glass surface which are less in comparison to first type of thermal losses. The mechanical geometry has single ended tubes which are connected to horizontal tank. In tube geometry, two concentric tubes are sealed with vacuum inside to prevent thermal losses (water in glass). The transfer of heat energy from tubes to tank is through convection phenomena in mostly used commercial ETCs systems. Each tube has single ended opening in storage tank for this purpose. Distribution of solar radiations around tube varies with tube configurations and geometries (gap, diameter, utilization of reflector etc) [11, 12]. Solar radiations not only effects the thermal performance of ETC but also effects the flow regimes. So in order to have proper evaluation of the thermal behaviors, correlations for flow rates associated to tube geometry and operating conditions are important components for simulations of mathematical models and for analyzing the thermal behaviors of ETCs [13]. Assumptions for analysis are as follows:

1. Clear sky assumption.
2. Isoflux condition (same radiation for one iteration of simulation).
3. Isothermal condition (same temperature for one iteration of simulation).
4. Fluid flow distribution is linear and in steady state.
5. Temperature distribution is linear and in steady state.
6. No water extraction and external water mixing during one steady state operation.

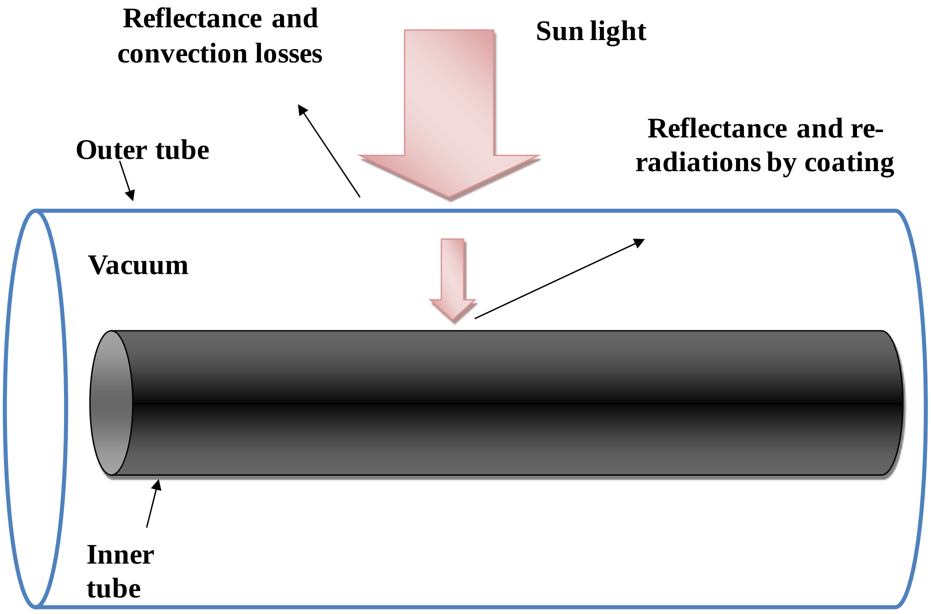

Figure. 3. 4 Energy Losses through ETC

The mathematical model for thermal performance analysis is distributed in following sequence wise arrangement as revealed in Figure. 3. **5**. At start collector and stratified tank temperature is taken from ambient environment temperature which is T_{in} then efficiency is calculated through equation 3.15. Then Q_{col} being dependent on efficiency is evaluated and then heat flux, flow rate and tube outlet temperature are evaluated through equations 3.16-3.19. Whole this iterative scheme can be run for specified time period for which analysis is required. At the end of iterations thermal performance curve along with velocity profile of fluid will be obtained which is beneficial to evaluate thermal performance of specified ETC.

1. T_{in} (^oC)	Inlet temperature to collector tubing
2. η	Collector system efficiency
3. Q_{col}(kJ/h)	Net heat gain (collector)
4. Q_{in} (kJ/h)	Heat flow rate from one tube to tank
5. m (kg/h)	Mass flow rate from each tube to tank
6. T_{out} (^oC)	Outlet temperature from tube

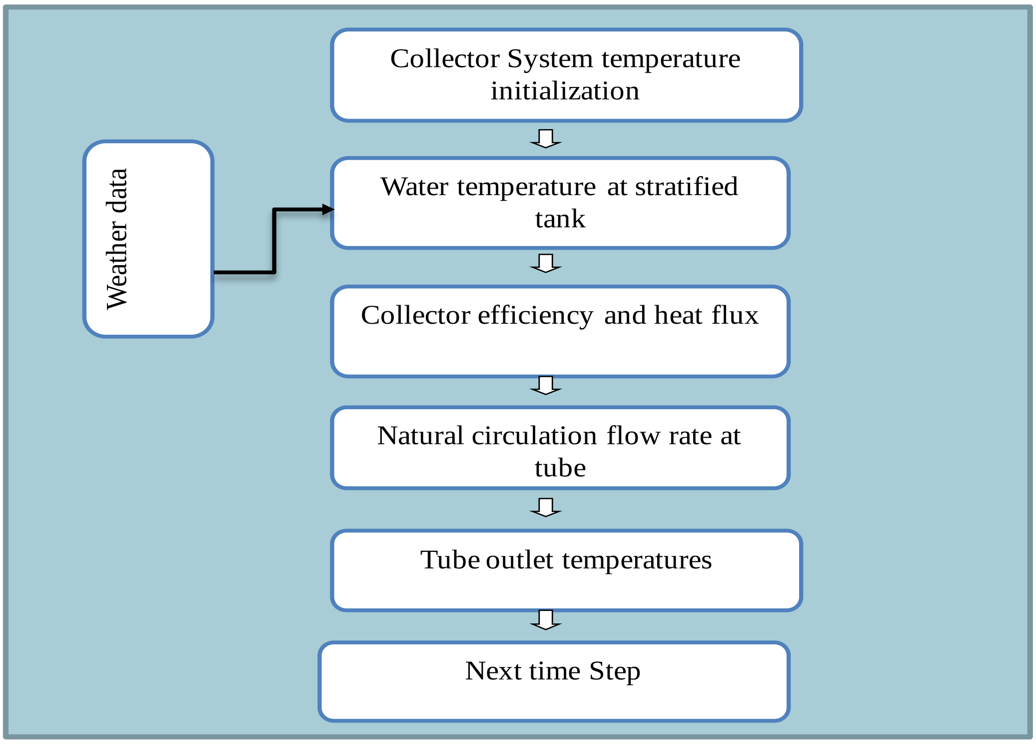

Figure. 3. 5 analysis scheme for ETC

Governing equations for this thermal analysis of ETC system are as follows

$$\eta = [\eta_o - \frac{a_1(T_i - T_a)}{I} - \frac{a_2(T_i - T_a)^2}{I}]k \text{..............(3.15)}$$

$$Q_{col} = \eta.A_a.I \text{..(3.16)}$$

$$Q_{in} = \frac{Q_{col}}{N_t} \text{..(3.17)}$$

$$m = \frac{Re.\pi.D.\mu}{4} \text{...(3.18)}$$

$$T_{out} = T_{in} + \frac{Q_{in}}{mC_p} \text{...(3.19)}$$

In equation 3.15 η_o is reference collector system efficiency, a_1 and a_2 are collector's geometrical parameters, k is incident angle modifier, N_t is number of tubes, m is mass flow rate of water. μ is viscosity of water, C_p is heat capacity of water, A_a is aperture area, Q_{col} is heat gain of collector, Q_{in} is heat gain of single tube, Re is Reynold number and m is mass flow rate of water in tubes. Now the flow rate is evaluated by dimensionless numbers as follows :

$$Re \Longrightarrow Ra^*$$

$$Ra^* \Longrightarrow Gr^*.\ Pr$$

$$Gr^* \Longrightarrow Gr.Nu$$

For this approach formulae are used as:

$$Nu=\frac{hi.D}{K}\text{...}(3.20)$$

$$Pr=\frac{\mu.C_p}{K}\text{..}(3.21)$$

$$Gr^*=\frac{g.\beta.q.D^4}{k.v^2}\text{..}(3.22)$$

$$Re= a(Ra^*)^b\text{..}(3.23)$$

$$Nu=\frac{Re.3.14.D.\mu}{4}\text{...}(3.24)$$

In equation 3.23 Ra* is modified Rayleigh number, Gr* is modified Grashof number, Pr is Prandtl number, Nu is Nusselt number, g is gravitational constant, β is coefficient of thermal expansion, v is kinematic viscosity of water, a and b are coefficient of fluid flow equation [13, 14]. All these dimensionless numbers in equations 3.20-3.24 are required for evaluation of mass flow rate through Reynolds number. Performance of ETC depends on solar radiations, mass flow rate (angle), collector Parameters and fluid utilized.

3.3 Different types of Solar Space heating schemes

Space heating scheme is operated in various modes depending on mechanical construction and ways of operation In active system pump is employed where thermal load is high and to increase the availability of system while passive system is based on natural circulations [15, 16]. In direct systems, same fluid is utilized in collector and load side [17]. In indirect system, fluids are different. Drain back system provides lower elevations to fluid forprotection of collector. In hydronic heater we have a radiator provides space heating through metallic header type radiator operating on original fluid from source side [18, 19].

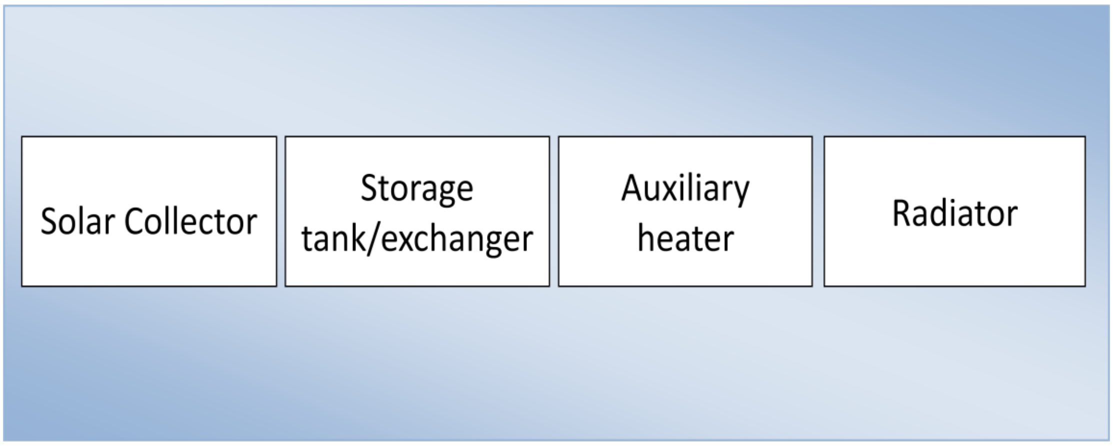

Figure. 3. 6 Main components of space heating

The four main components of selected space heating scheme are represented in Figure. 3. 6. For solar collector among two available options FPC and ETC, ETC was selected. For storage tank which is also serving as exchanger, it's a passive component and not influencing the cost and efficiency of system as high efficiency storage tanks as available at much affordable costs. Auxiliary heater and radiators will be selected through analysis of available options, efficiency and economics [20]. For solar thermal collector (as main component of space heating loop) detailed analysis and result will be carried out. For auxiliary heater electric heater, general gas geyser and instant gas geyser are available option. Due to increasing electric prices and load shedding this option is eliminated. General gas geyser is not good option as generally solar space heating loops are operated on more than 70% solar fraction [21] and for commercial load requirement should be met in as less time as possible so instant gas geyser due to low cost, quick response and flexible load carrying capacity, has been selected. Now selection of radiator is as follows [22-24] (options)

1. Baseboard units
2. Radiant floor heating
3. Hydro-air system
4. Hydronic Radiator type Heater

3.3.1 Base board units

Installed on bottom of the wall on one or more sides of a room (Figure. 3. 7). Less space is required, less initial cost and less duct work needed. Disadvantage is that they can not handle high space heating loads so they are better for insulated rooms.

Figure. 3. 7 Base board units for space Heating Scheme

3.3.2 Radiant floor heating

Concrete floors with metallic tubes embedded are used to maintain the constant space heating load throughout. This technology usually deal with high space heat load due to high cold weather. Disadvantage is that initial cost is high (Figure. 3. 8).

Figure. 3. 8 Radiant floor scheme for space heating

3.3.3 Hydro air system

In addition to thermal energy source blowers and ducts are needed to transmit the thermal energy to load side. Technology has high initial cost. In addition to that high operating cost, more maintenance required and suitable for high space heating loads (Figure. 3. 9).

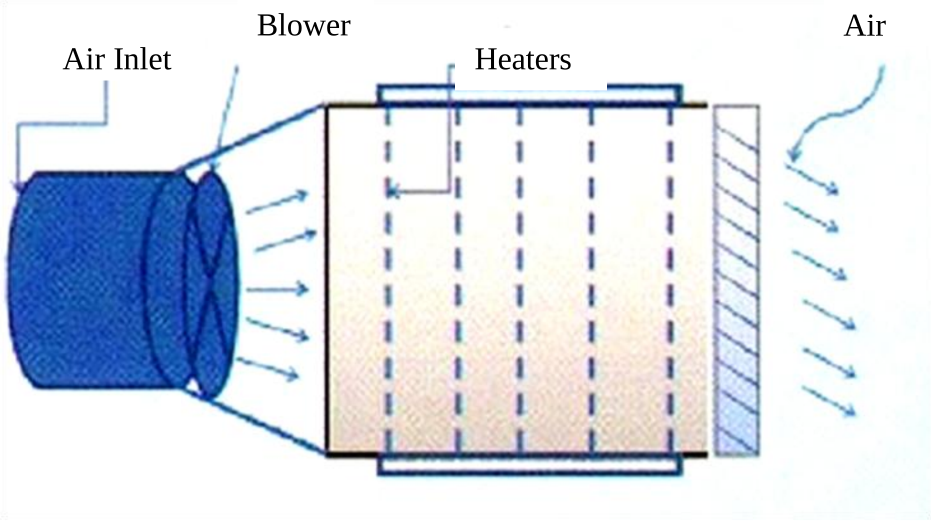

Figure. 3. 9 Hydro air system for space heating [25]

3.3.4 Hydronic Radiator type Heater

Hydronic type stainless steel tubular radiators have flexible features to handle intermediate space heating load. Initial cost is less and running and maintenance cost is also less. Design is modular and has ease of handling features. Durability of radiator is high. All these features make the better economics for space heating system. (Figure. 3. 10).

Figure. 3. 10 Hydronic Radiator scheme for space heating[26]

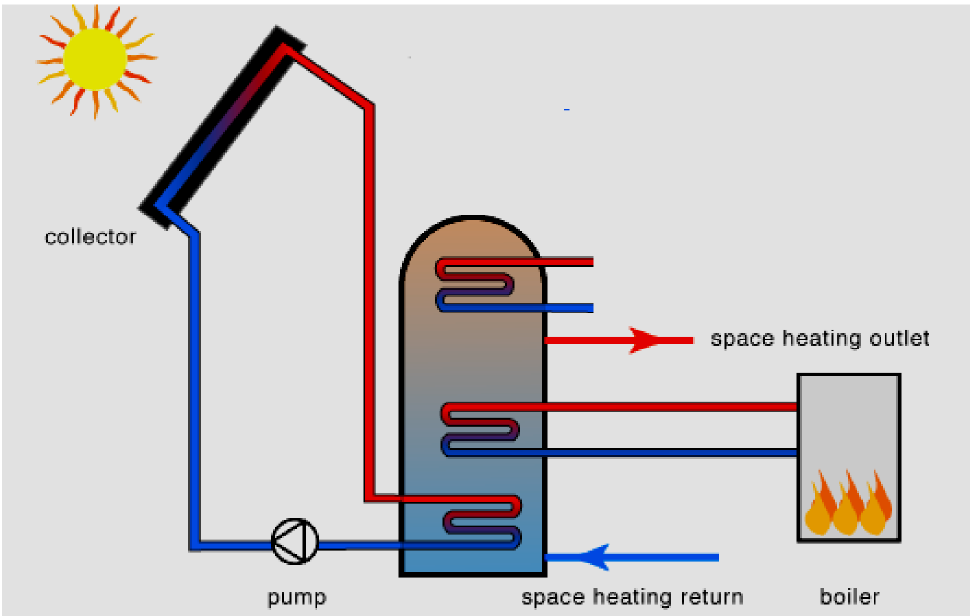

Figure. 3. 11 Solar Space heating scheme[27]

Based on commercial type load, continuous availability of system and less maintenance and protected system with longer life we have chosen active drain back hydronic type system operated in indirect mode. Selected scheme is shown in Figure. 3. 11

3.4 Heat Load Calculations for educational building:

Current study is concerned to calculate space heating load for an educational building. A hypothetical case for Centre for energy systems, National University of Sciences and technology, Islamabad has chosen. Thermal zones are defined in table 3.1. Thermal zones specification gives idea about location of zone under consideration and importantly about comfort zone. Space heating load is dependent on comfort zone specifications, which vary from area to area. For calculating space heating load it is necessary first to analyze factors that affect space heating load and to have idea of space heating load calculation methods [28]. Figure. 3. **12** shows the factors that affects space heating demand of a room. These include material data, design (orientation and geometry), climatic and usage data (opening and closing of door and windows). For educational building space heating loads requirement is not present for whole day [29], so for having space heating load analysis, time scheme for educational building is shown in Table. 3. 2 and heat loss coefficients of different materials are revealed in Table. 3. 3. Both time scheme and heat loss coefficients data is necessary for evaluation of heat load for a building.

Steps for Calculations

1. Define Scenario/Case considered

   (School, area, building specifications)

2. Operating Scheme

   (Days, hours, holidays etc)

3. Load Calculations for single room

   (How Space heating load are calculated)

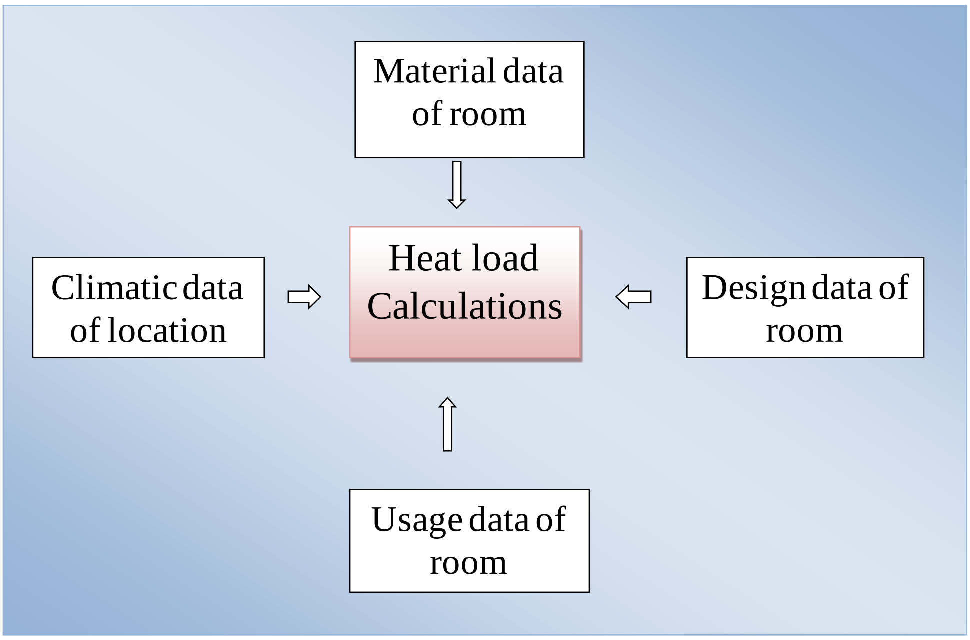

Figure. 3. 12 Parameters influencing heat load

Table. 3. 1 Thermal zones for space heating scheme

Zones	Floor	Category/Usage	Temperature (°C)
Zone 1	Ground floor	Class room/Labs	21 ± 2
Zone 2	Ground floor	Faculty room	21 ± 2
Zone 3	Ground floor	Staff room	21 ± 2
Zone 4	Ground floor	Hod office	21 ± 2
Zone5	Ground floor	Library	21 ± 2

Table. 3. 2 Time schedule for space heating scheme operation

Days	Schedule	Occupancy
Week days	00:00-08:00	0%
	08:00-17:00	100%
	17:00-00:00	0%
Week end	-----	0%

Before calculating space heating load it is necessary to define limits and scope in terms of assumptions. These assumptions will not only help to simplify the complex calculating procedures but also indicates the applicability of model. Assumptions are as follows

1. School building is considered (room)
2. Islamic, National holidays and Sunday are excluded
3. School timings are considered
4. No heat gain is added for windows
5. No latent heat loss is taken for latent heat change (air quality control)
6. Outdoor temperature is continuously varying, Sizing is based on maximum heat loss for coldest weather

3.4.1 Mathematical model for space heating load calculations

For space heating load evaluations, two types of thermal load components are evaluated. Thermal losses through defined building section and heat gain through defined building envelope [30]. These two parameters will then give required space heating load as:

$$Q_{req} = Q_{loss} - Q_{gain} \text{..........................(3.25)}$$

Heat losses through selected building envelope are as:

1. Transmission/Fabrication losses
    1. Walls
    2. Ceiling
    3. Floor
    4. Windows
    5. Doors
    6. Infiltration losses (latent and sensible)

$$Q_{loss} = U \times A \times \Delta T \text{..........................(3.26)}$$

2. Ventilation losses

$$Q_{loss} = N \times V \times C_p \times \Delta T ....(3.27)$$

Where parameters in these equations are as follows:

Q_{loss}(kJ) = Heat losses

N (1/h) = Air change rate

V (m^3) = Volume of room

C_p(kJ/kg.K) = Heat capacity of air

ΔT (^oC) = Temperature difference

U ($W/m^2.^oC$) = Heat transfer coefficient

3. Heat Gains

1. Persons
2. Lights
3. Other Equipments (computers, TV, printers)
4. Through solar

Ventilation and infiltration losses are then calculated one of two given methods .Air change method or Crack length method [31, 32]. Air change method has these features associated:

1. Designers prefer to use because of more available data
2. Airflow into a space can be measured in air changes per hour
3. Room design features are more associated in calculations
4. Total volume of the room

Crack length method has these features associated:

1. The crack method methods involves more complex iterations than air change method
2. Outdoor air infiltrates the indoor space through cracks around doors, windows
3. Total area of the cracks
4. 5-15 % variations in infiltration and ventilation losses for properly ventilated system

Table. 3. 3 Heat loss coefficients for different materials

Category	**Material**	**Loss coefficient (kJ/h.m^2.^{o}C)**	**Area (m^2)**
Walls	Concrete/Bricks	1.6	128.2
Ceiling	Concrete/Bricks	4.2	68.4
Doors	Glass	18	2.6
Windows	Glass	19.3	5.5
Floor	Cement	1.1	68.4

Summary

Mathematical models for FPC (based on flow, fin and collector efficiency factors) and ETC (based on dimensionless numbers) are discussed in detail. The ETC due to better economics and thermal performance was selected for space heating scheme. Indirect active space heating scheme was selected for further analysis. Different types if radiators were discussed and hydronic type radiator was selected as it better suits to the type of building load selected. Heat load calculation methods and parameters influencing heat load of building envelope and their governing equations were discussed in detail. Time scheme for operation of space heating scheme was formulated as a part of solar space heating scheme techno-economic analysis.

References

1. Kalogirou, S.A., Solar thermal collectors and applications. Progress in energy and combustion science, 2004. 30(3): p. 231-295.
2. Mekhilef, S., R. Saidur, and A. Safari, A review on solar energy use in industries. Renewable and Sustainable Energy Reviews, 2011. 15(4): p. 1777-1790.
3. Hottel, H. and B. Woertz, Performance of flat-plate solar-heat collectors. Trans. ASME (Am. Soc. Mech. Eng.);(United States), 1942. 64.
4. Ong, K., A finite-difference method to evaluate the thermal performance of a solar water heater. Solar Energy, 1974. 16(3): p. 137-147.
5. Taherian, H., et al., Experimental validation of dynamic simulation of the flat plate collector in a closed thermosyphon solar water heater. Energy Conversion and Management, 2011. 52(1): p. 301-307.
6. Huang, B., Similarity theory of solar water heater with natural circulation. Solar Energy, 1980. 25(2): p. 105-116.
7. Grossman, G., A. Shitzer, and Y. Zvirin, Heat transfer analysis of a flat-plate solar energy collector. Solar Energy, 1977. 19(5): p. 493-502.
8. Bliss Jr, R.W., The derivations of several “plate-efficiency factors” useful in the design of flat-plate solar heat collectors. Solar Energy, 1959. 3(4): p. 55-64.
9. Duffie, J.A. and W.A. Beckman, Solar engineering of thermal processes2013: John Wiley & Sons.
10. Kreith, F. and J.F. Kreider, Principles of solar engineering. Washington, DC, Hemisphere Publishing Corp., 1978. 790 p., 1978. 1.
11. Morrison, G., I. Budihardjo, and M. Behnia, Water-in-glass evacuated tube solar water heaters. Solar Energy, 2004. 76(1): p. 135-140.
12. Budihardjo, I. and G. Morrison, Performance of water-in-glass evacuated tube solar water heaters. Solar Energy, 2009. 83(1): p. 49-56.
13. Chow, T.-T., et al., Performance evaluation of evacuated tube solar domestic hot water systems in Hong Kong. Energy and Buildings, 2011. 43(12): p. 3467-3474.
14. Kim, Y. and T. Seo, Thermal performances comparisons of the glass evacuated tube solar collectors with shapes of absorber tube. Renewable Energy, 2007. 32(5): p. 772-795.

15. Evans, B.L., S. Klein, and J. Duffie, A design method for active-passive hybrid space heating systems. Solar Energy, 1985. 35(2): p. 189-197.
16. Badescu, V. and M.D. Staicovici, Renewable energy for passive house heating: Model of the active solar heating system. Energy and Buildings, 2006. 38(2): p. 129-141.
17. Tyagi, V.V. and D. Buddhi, PCM thermal storage in buildings: a state of art. Renewable and Sustainable Energy Reviews, 2007. 11(6): p. 1146-1166.
18. Chi, S., Heat pipe theory and practice. Washington, DC, Hemisphere Publishing Corp.; New York, McGraw-Hill Book Co., 1976. 256 p., 1976. 1.
19. Sonderegger, R.C., Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating. Energy and Buildings, 1978. 1(3): p. 313-324.
20. Bezdek, R.H., A.S. Hirshberg, and W.H. Babcock, Economic feasibility of solar water and space heating. Science, 1979. 203(4386): p. 1214-1220.
21. RETScreen Software Online Manual, RETScreen International Clean Energy Decision Support Centre, Ottawa, Canada. Available at http://www.retscreen.net/ang/home.php, (2013).
22. Fiedrich, J., Radiant floor and wall hydronic heating systems, 1999, Google Patents.
23. Olesen, B.W., Radiant floor heating in theory and practice. ASHRAE journal, 2002. 44(7): p. 19-26.
24. Handbook, A., HVAC systems and equipment. American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, GA, 1996.
25. Hydro air system for space heating. Available at www.greenbuildingadvisor.com. (accessed 09.09.2014).
26. Hydronic type radiator. Available at www.radiator24.com. (accessed 09.09.2014).
27. Solar space heating scheme. Available at www.therenewableenergycentre.co.uk. (accessed 09.09.2014).
28. Sartori, I., A. Napolitano, and K. Voss, Net zero energy buildings: A consistent definition framework. Energy and Buildings, 2012. 48: p. 220-232.
29. Hamada, Y., et al., Field performance of an energy pile system for space heating. Energy and Buildings, 2007. 39(5): p. 517-524.

30. Farghally, H., F. Fahmy, and M. EL-Sayed, Geothermal Hot Water and Space Heating System in Egypt.
31. Liu, D.-L. and W.W. Nazaroff, Modeling pollutant penetration across building envelopes. Atmospheric Environment, 2001. 35(26): p. 4451-4462.
32. Mosley, R., et al., Penetration of ambient fine particles into the indoor environment. Aerosol Science & Technology, 2001. 34(1): p. 127-136.

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Thermal Performance curve of flat plate collector

The whole simulation scheme for FPC consists of several equations whose code was developed in Matlab software. In order to analyze authenticity of FPC thermal performance analysis model it was necessary to compare the result from previous research so that authenticity of developed code can be checked. For this purpose the code was run for climatic conditions of Tetuan, Morroco [1] and results were compared with literature.

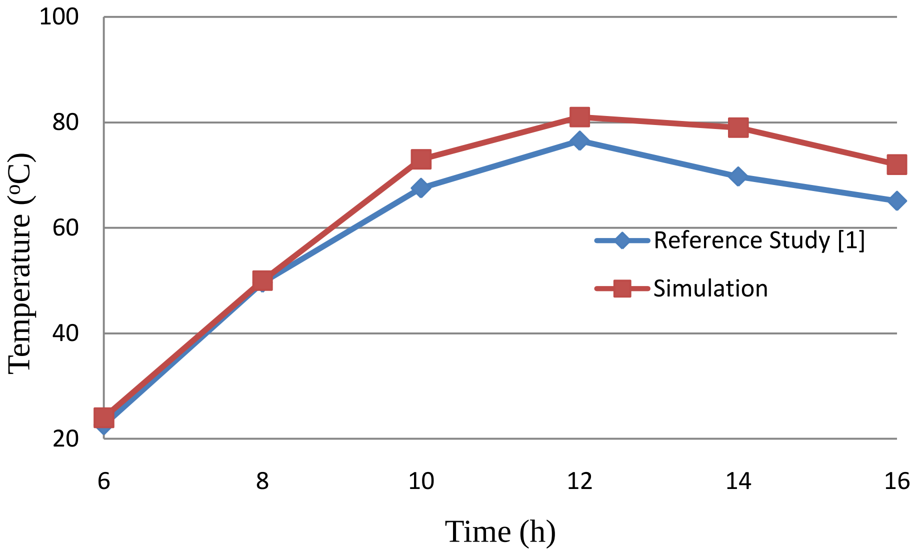

Figure. 4. 1 FPC Output temperature profile

Outlet temperature of fluid is the final thermal parameter in whole simulation scheme of FPC system. In thermal performance analysis of FPC, collector heat gain, efficiency, plate mean temperature and fluid mean temperature are evaluated in sequence. Only final results are compared and shown in Figure 4.1 The results in Figure 4.1 indicate the comparison of mathematical model developed in Matlab and thermal profile of FPC obtained from literature. The statistical approach was used to compare result shows ±8 %variations in both results[1, 2].

4.2 Thermal Performance curve of evacuated tube collector

For thermal performance analysis of ETC, code was developed in Matlab software consisting of various equations regarding climatic conditions, fluid type, collector geometry and collector material specifications. The mathematical model developed have certain dimensionless numbers which governs fluid flow behavior and thermal energy transfer mechanisms in ETCs. In order to verify model the simulations were first carried out for climatic conditions of Honkong. The geometrical parameters and other assumptions and conditions were taken as same as provided in the reference study. The simulations were run and the final results were compared. The thermal performance outputs are heat gain for collector, fluid flow rate and outlet temperatures. The outlet temperature for water was compared from the result in research and shown in Figure 4.2. The statistical approach was used to compare result shows ±3.5 % variations in both results [3]. The variation in the result is due to unavailability of certain factor such as collector's material properties, collector's geometry features and certain assumptions in the model (Reference study) were not listed. After verifying the thermal performance code for FPC and ETC technical and economical comparison was done for Quetta. Weather data, collector's features and other input parameters were added in Matlab model and results were generated again. It was noticed that technical and economical performance of ETC is better than FPC due to certain technical and economical features. Technical features involved are less thermal losses, more exposure to sunlight, modular design while economical features are easily available in market in various sizes and dimensions and less cost [3-6]. These features give ETC technology an edge to FPC technology in solar collectors market of Pakistan. So ETC is selected as thermal energy source component for further considerations in space heating scheme.

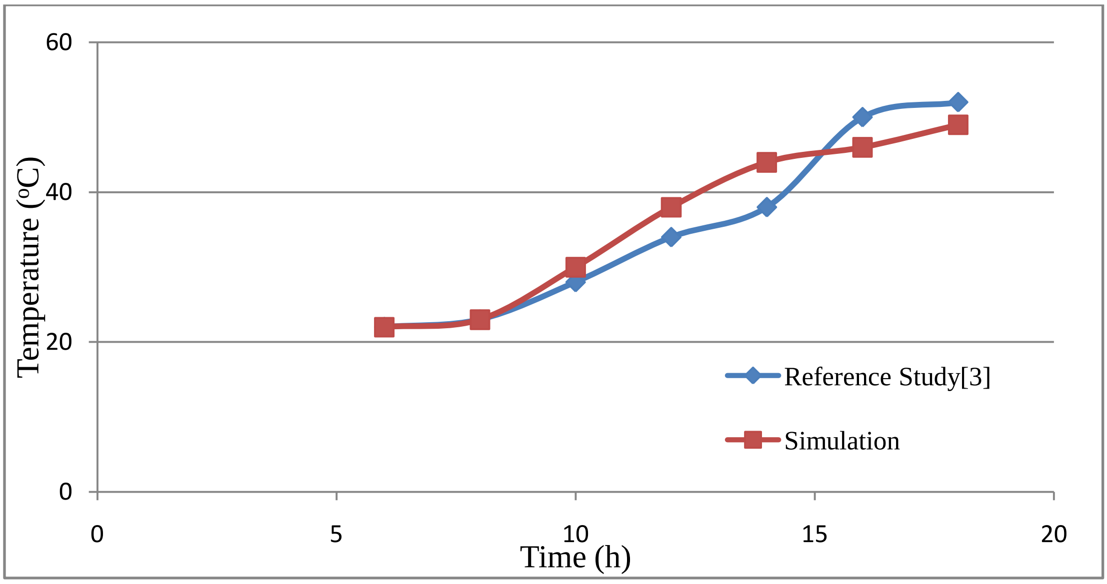

Figure. 4. 2 ETC Output temperature profile

4.3 Space heating load evaluation

4.3.1 Selection of suitable city for optimum savings

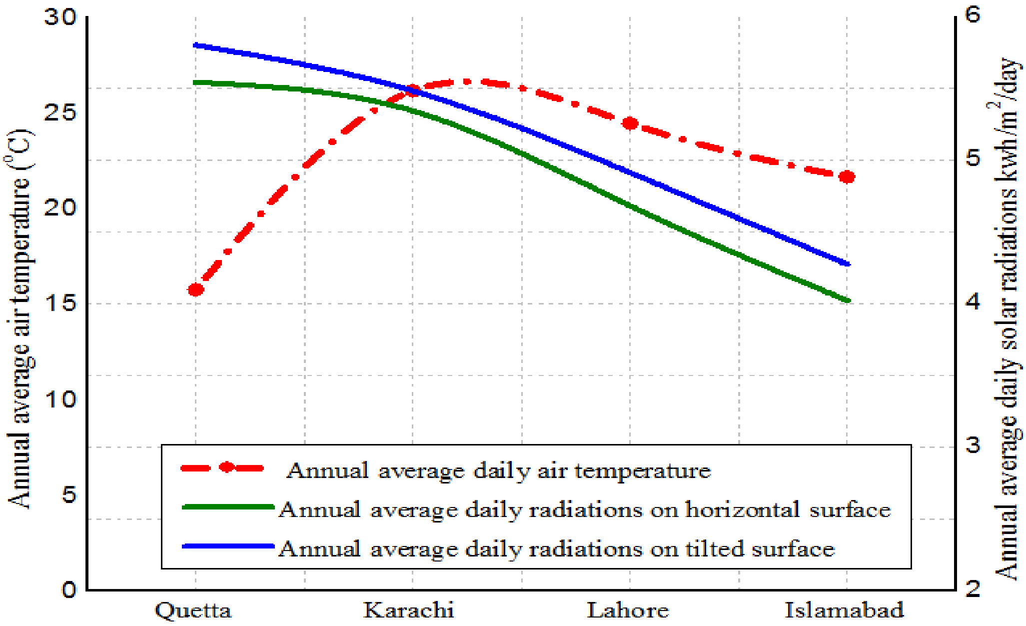

Figure. 4. 3 Climatic data for selected cities of Pakistan

In order to have more economical savings and to have more efficient application of current research, it is necessary to select a suitable site for application of the current research. For this RETScreen software data base was employed and weather data for four climatically different cities were taken [7]. The Figure 4.3 shows that annual average air temperature for Quetta city is minimum so space heating requirement is highest while annual average daily solar radiations are maximum in Quetta which shows that solar space heating scheme will be quite efficient to be employed in Quetta.

In order to evaluate the total heat load of educational building, fabrication and ventilation losses were evaluated first. Heat loss coefficient values for walls, floor etc were taken from ASME heat and ventilation codes [8, 9]. From heat loss coefficient values it can be seen that heat loss values are maximum from door and windows due to less insulation, cracks and opening reasons. Heat losses are minimum from floor due to too much insulation material/thickness available on floor side. Ventilation losses are due to natural circulations of air due to thermal gradients while infiltration losses accounts hot air leakages from sides/cracks of windows, doors, ducts etc [10, 11]. The selection of suitable temperature difference to be utilized in heat load analysis is quite important. The space heating scheme must be sized in a way that space heating system can tolerate load fluctuations and cloudy/rainy weather. For this purpose maximum temperature difference between ambient temperature and required temperature should be taken. Increased over sizing will increase the capital cost as well. Optimization will be required for balanced system. Temperature difference was taken on basis of monthly average temperature of January. As among different months of winter season January have severe cold conditions [12, 13]. This will make our system oversize for the remaining months of winter season. In order to account cloudy day effects of January, auxiliary system will be sized in optimum way to ensure the availability of space heating system. Fabrication losses (Table. 4. 1), ventilation losses (Table. 4. 2) and infiltration losses (Table. 4. 3) were analyzed and added. Then heat gains (Table. 4. 4) were subtracted, this will give total heat load of a room as shown in Table. 4. 5.

Table. 4. 1 Fabrication losses for a single room of a educational building

Fabrication losses/Transmission					
Category	**Heat loss coefficient**	**Area**	**ΔT**	**Heat loss**	
	(kJ/h.m^2.^{o}C)	**(m^2)**	**(^{o}C)**	**kJ/h**	**Btu/h**
Walls	1.6	128.2	17.3	3659	3476
Ceiling	4.2	68.4	17.3	4970	4721
Floor	1.1	68.4	17.3	1302	1237
Window	18	2.6	17.3	810	769
Door	19.3	5.5	17.3	1836	1745
			Total	12577	11948

Table. 4. 2 Ventilation losses for a single room of educational building

Ventilation losses					
	Heat capacity	Volume	ΔT	Heat loss	
Category	(kJ/h.m³.°C)	m³	(°C)	kJ/h	Btu/h
Infiltration	1.2	264	17.3	5480	5206

Table. 4. 3 Infiltration losses for a single room of educational building

Infiltration losses						
	Heat capacity	Volume	ΔT	N	Heat loss	
Category	(kJ/h.m³.°C)	m³	(°C)	(1/h)	kJ/h	Btu/h
Ventilation	1.2	264	17.3	0.8	4384	4165

Table. 4. 4 Heat gain for a single room of educational building

Heat gain				
Category	H.G/Person	Number	Heat generated	
Heat gain	kJ/h	N	kJ/h	Btu/h
Persons	158	30	4740	4503
Lights	30	2	60	57
Total			4800	4560

Table. 4. 5 Total heat load for a single room of educational building

Total Heat Losses	
kJ/h	Btu/h
17641	16738

In order to evaluate the monthly heat load for each month hourly space heating load is multiplied with number of hours and the daily space heating load is then multiplied with number of operating days in each month. The number of operating days are evaluated on basis of public holidays. This gives monthly space heating load, necessary to have an idea about natural gas consumption patterns and solar space heating collectors utilization in each month. The Table. 4. 6 show monthly load patterns of space heating system. These results are plotted in Figure 4.4, it can be seen that monthly load is maximum in January and minimum in April, this pattern is same as that of temperature difference value in Table. 4. 6, as space heating demand is solely related to ambient environment temperature. The Figure 4.4 indicates that maximum number of collectors will run in January and minimum in April.

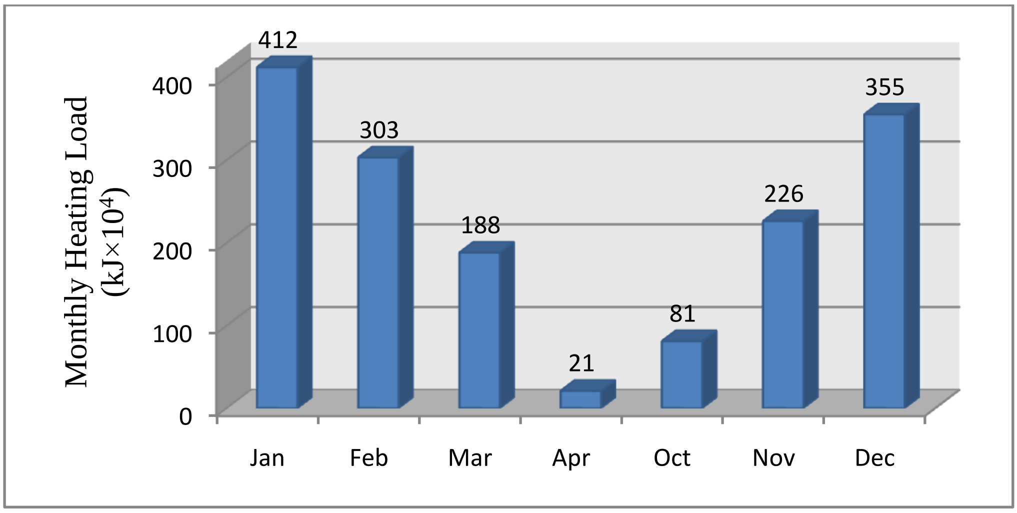

Figure. 4.4 Monthly space heating heat load for a single room

Table. 4. 6 Monthly heat load calculations

Months	Average air temperature (°C)	ΔT (°C)	Heat load kJ/h	Heat load kJ/day	Operational Days/month	Monthly load demand kJ/month ($\times 10^4$)
Jan	3.7	17.3	17619	158571	26	412.2
Feb	6	15	14636	131724	23	302.9
Mar	11.1	9.9	8020	72180	26	187.6
Apr	16.6	4.4	885	7965	26	20.7
Oct	14.6	6.4	3480	31320	26	81.4
Nov	9.2	11.8	10485	94365	24	226.4
Dec	5.1	15.9	15804	142236	25	355.5

4.4 System sizing and specifications

4.4.1 Collectors required for solar space heating scheme

After having an idea of space heating load calculation method and effects of climatic behaviors on space heating load through single room load calculation. Heat load components for whole building was evaluated and shown in Table. 4. 7. Table. 4.7 indicate that faculty and staff room have high space heating load demand due to human heat gain approach. The total heat load then gave the number of collectors required to met this load. In order to evaluate number of collector the most common commercially available collector with optimum performance and cost was selected and heat gain of single collector was used to calculate number of collectors required for whole space heating scheme.

Table. 4. 7 Heat loads for different rooms of educational building

Category/Usage	Load (Btu/h)	Load (kJ/h)
Class room	15983	17581
Lab.1	15983	17581
Lab.2	15983	17581
Faculty room	20780	22858
Staff room	20780	22858
Hod office	8843	9727
Library	15983	17581

- Total load in month of January = 125768 kJ/h
- Heat gain of evacuated tube collector = 3000 kJ/h.m^2
- Area of collectors required = ~42 m^2
- Normal sized collectors available in market = (300 litres/ 3 m^2)
- Collectors required = ~ 14 ETCs

4.4.2 Peak load minimization and availability enhancement

Peak load minimization strategy is a common and effective way to enhance economic optimization of renewable systems. As probability of occurrence of peak load is less and renewable source availability is also have not 100% surety so both these features have given the basis of peak load shift strategy. For this peak load of the system is shifted to a conventional source whose initial cost is less and availability is always present [14]. After proper analyzing the peak load behavior and available base case conventional systems for space heating, 12% load is being shifted to instant natural gas geyser as represented in Figure 4.5.

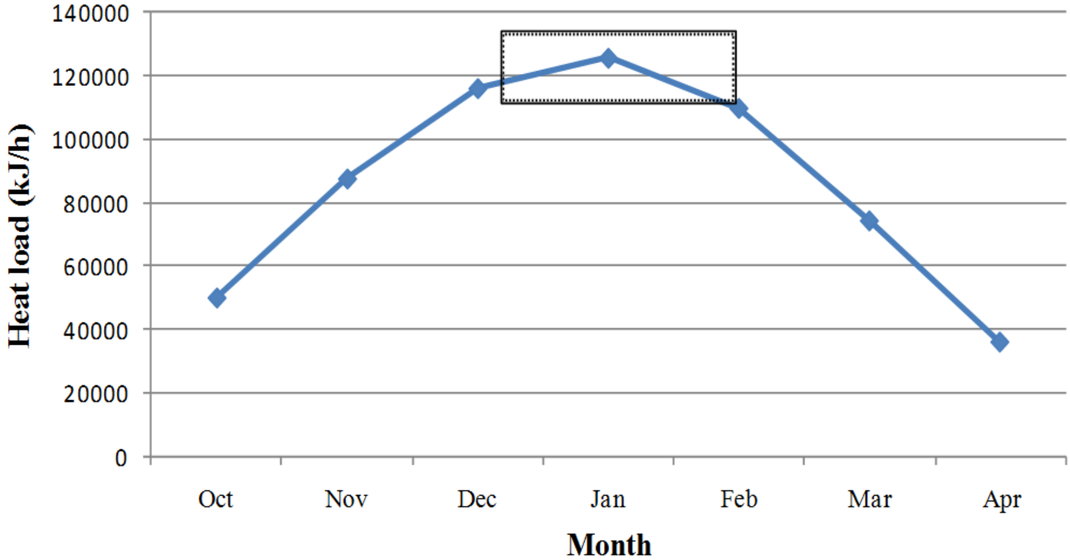

Figure. 4. 5 Peak load minimization for solar space heating scheme.

Load saved = 15903 kJ/h

Instant gas geyser capacity = 15903 kJ/h

4.4.3 System components for space heating

After proper evaluation of heat loads and collectors specifications, its necessary to have an idea of other system components of space heating system. For this market data was collected keeping in account of economics and technical features so that overall cost of space heating scheme must be optimum so that feasibility for installation of space heating system remains attractive. Suitable instruments/space heating scheme components were selected and mentioned in Table. 4. 8. In order to have proper functioning and optimum running of operation, suitable control scheme selection and function is necessary [15-17]. For this feed back, feed forward, cascade control, single and multiple loop systems can be considered as an option for control scheme. After analyzing these available control schemes, Feed forward control system was chosen as a suitable option and applied as shown in Figure 4.6 [18-20].

In feed forward control the control loop will deal with load deviations in pre-defined way at input side of the hydronic radiators. The feed forward control loop is comprised of two thermocouples and two PID (proportional integral derivative) controllers. The main set point for comparison is located at storage tank. The thermocouples measure the set point temperature and through controllers the feed forward control loop start the pump of ETC, instant gas geysers pump and instant gas geyser burner. The advantage for selecting this scheme is that it will help to overcome the load transients more rapidly while keeping the complexity of control system minimum. This improved control scheme being selected will ensure the availability of space heating system at the same time keeping the operational cost of space heating scheme minimum.

Table. 4. 8 Sizing of solar space heating scheme

Unit	Unit.1
ETCs	3
Storage tank	320 Litre
Gas Geyser	4000 kJ/h
Thermocouples	3
Thermocouples type	Pt-100
Heater type	Hydronic radiator type heater
Heater sub-type type	Steel tubular with header

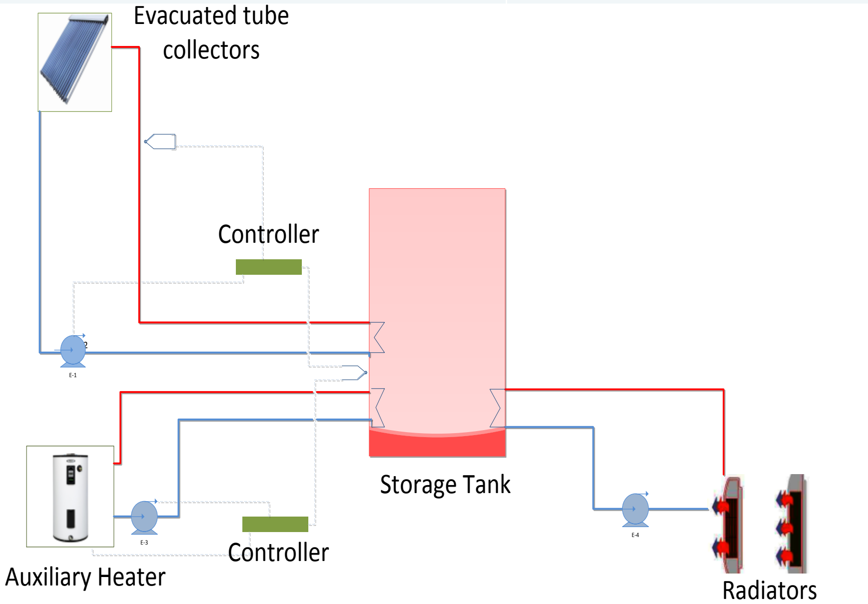

Figure. 4. 6 Control system for solar space heating scheme

4.5 Economic Outputs for solar space heating scheme

4.5.1 Natural gas savings

Through heat load data and solar fraction for different months of winter seasons natural gas savings are calculated and represented in Table. 4. 9. It can be seen that in the months of January and December the space heating system have maximum savings of natural gas while April and October have least savings. The amount of natural gas consumed for the whole winter season for proposed case is ~ 7 mmBtu which is quite less as compared to base case hence the feasibility of solar space heating system is quite high to be considered. Figure 4.7 shows the percentage of space heating load met by instant gas geysers and ETCs system for different months of winter season. It can be seen through Figure 4.7 that instant gas geyser will operate only in months of January and December because monthly average daily solar radiations for these months are less while the ambient air temperature is also less which makes the space heating requirements critical for these months but low value of radiations will result in less solar radiations comparing to the other months of winter season. The load cover by solar space heating system in remaining months is 100%.

Table. 4. 9 Base and proposed case natural gas consumption calculations

	Base case		Proposed case	
Months	**Gas consumption Per month (mmBtu)**	**Gas consumption Per month (PKR)**	**Gas consumption Per month (mmBtu)**	**Gas consumption Per month (PKR)**
Jan	38.2	22932	4.9	2940
Feb	29.5	17718	------	----
Mar	22.5	13536	------	-----
Apr	10.8	6528	-----	-----
Oct	15.1	9078	-----	-----
Nov	24.5	14730	-----	-----
Dec	35.3	21180	1.8	1080

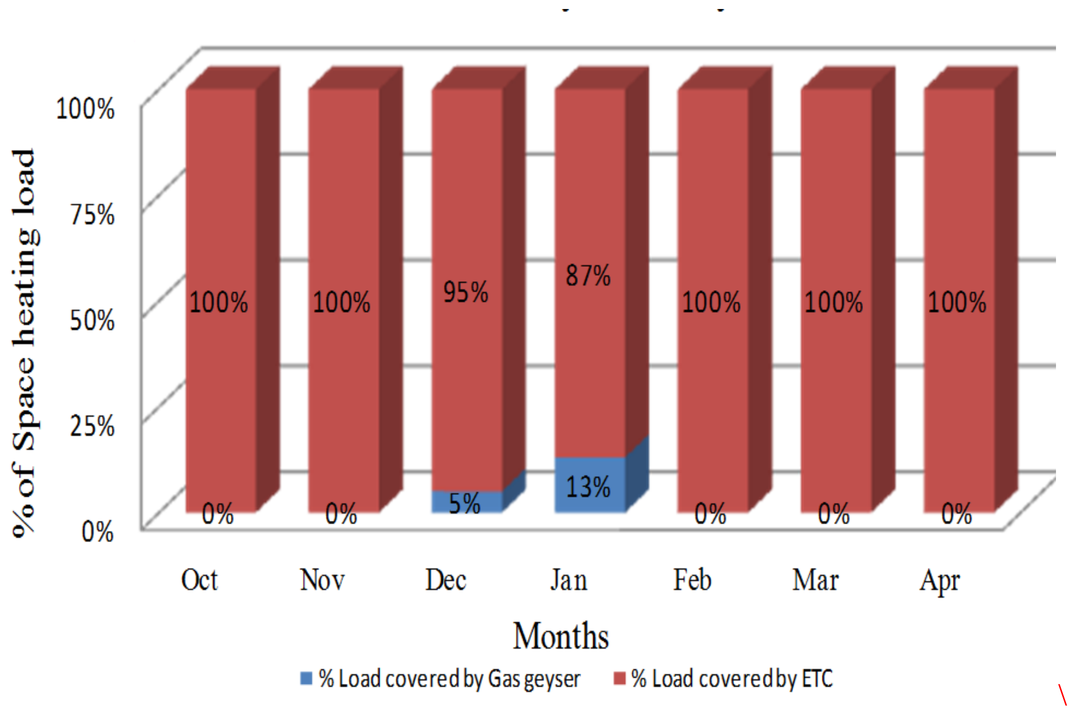

Figure. 4. 7 load distribution on solar and auxiliary sources

4.5.2 Evaluation of project economic parameters

After technical study of project, detailed economic analysis was carried out in order to evaluate the important economic output parameters that serve as decision making parameters for a project. Table. 4. 10 shows initial cost, Net present value (NPV), payback, internal rate of return (IRR) and benefit to cost ratio of project. It can be seen that all these parameters are quite attractive to be considered. Figure 4.8 shows that how cash flows will move across the life cycle of the project. At start this graph is negative in y-axis as in start initial costs is to be recovered. Then cash flow move from negative to positive with time. The value at which it touches the horizontal axis is payback period.

4.5.3 Sensitivity analysis for project input parameters

There are many studies carried out on SWH feasibility and profitability analysis based on IRR and payback period [21-23] but less efforts are being done on risk and sensitivity analysis of projects. It's better to identify parameters sensitive to project performance and evaluate the risks associated with a project in order to have optimum feasibility study. Risk evaluation study is based on investigation of uncertainties associated with input variables of project so that financial outcomes of project can be analyzed in more detailed way and safety can be enhanced for investing finance.

Table. 4. 10 Economic parameters for solar space heating scheme

Parameters	Value
Initial costs (PKR)	~710,000
Net present value (PKR)	6,403,800
Internal rate of return (%)	20%
Payback period (years)	5.9
Fuel cost -proposed case (PKR)	4,020
Fuel cost -base case (PKR)	102,000
Natural gas saved (mmBtu)	~170
Benefit to cost ratio	9

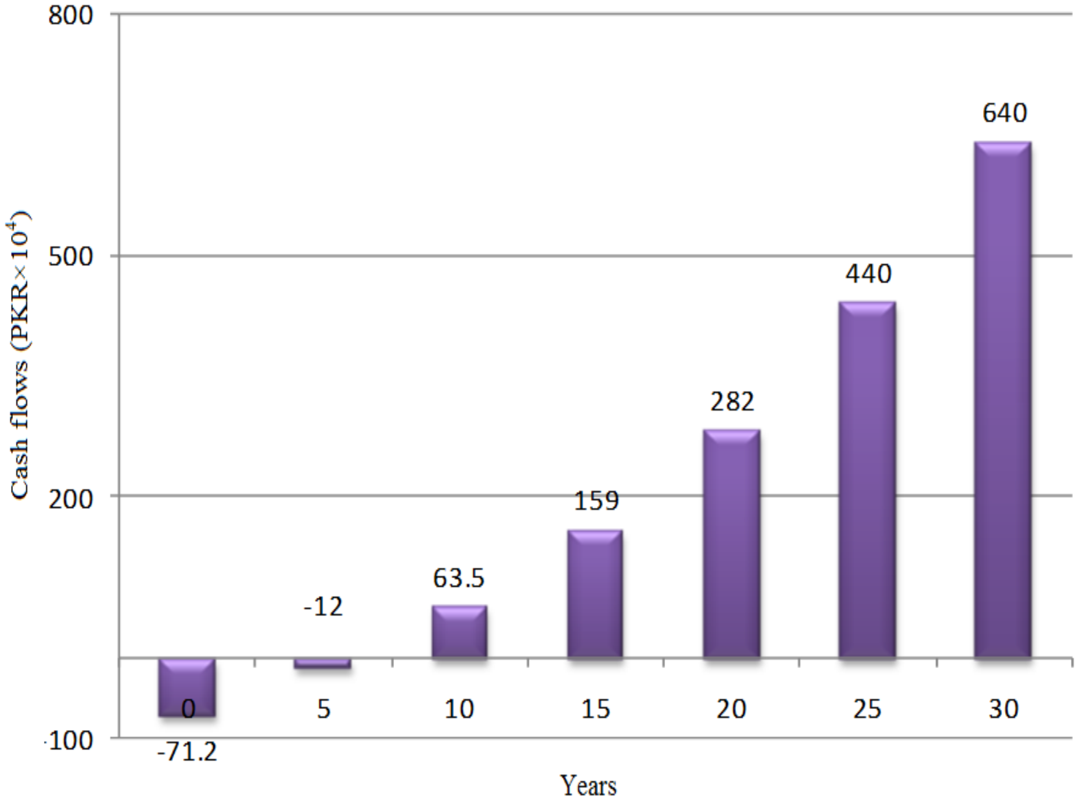

Figure. 4. 8 Cash flow behaviors around life cycle of solar space heating scheme

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Sensitivity analysis shows sensitivity of financial indicator associated with variation of key input technical and economical parameters [24]. It reveals changes in profitability with change of input parameters. Out of economical input parameters, two main influencing parameters are initial cost and base case (fuel cost). Table. 4. 11 shows the variation in values of input parameters for sensitivity and risk analysis. Figure 4.9 is a tornado graph indicating variation of IRR with fuel cost and initial cost variations. It can seen through Figure 4.9 that increase of fuel cost (base case) and decrease in initial costs increases IRR of project and hence increases the project feasibility. Figure 4.10 is a impact graph which shows relative impact of key input parameters on project economics. It can be seen that fuel cost base case is most sensitive parameter to effect project economics while initial cost and fuel cost (proposed case) comes after fuel cost (base case). The positive x-axis in Figure 4.10 shows that increase in the concerned parameter is in favor of the project. For detailed risk analysis Monte Carle simulations were carried out and distribution of IRR is plotted as shown in Figure 4.11. These simulations include various combinations of input parameters and evaluate the output economical parameters for these combinations. As a result a distribution graph or histogram is generated. Those IRR bars which are relatively higher indicates that their probability of occurrence is more than other. While x-axis has frequency class i.e specific values of IRR. The distribution graph or histogram shows that IRR is concentrated between 18.5-21 % range which is quite attractive to be considered for economics of the space heating project.

Table. 4. 11 Sensitivity and risk evaluation parameters

Parameters	Value (PKR)	Range (+/-)	Minimum (PKR)	Maximum (PKR)
Initial costs	~720000	10%	648000	792000
Fuel cost (proposed case)	4020	10%	3618	4422
Fuel cost (base case)	102000	10%	91800	112200
Level of risk	10%			

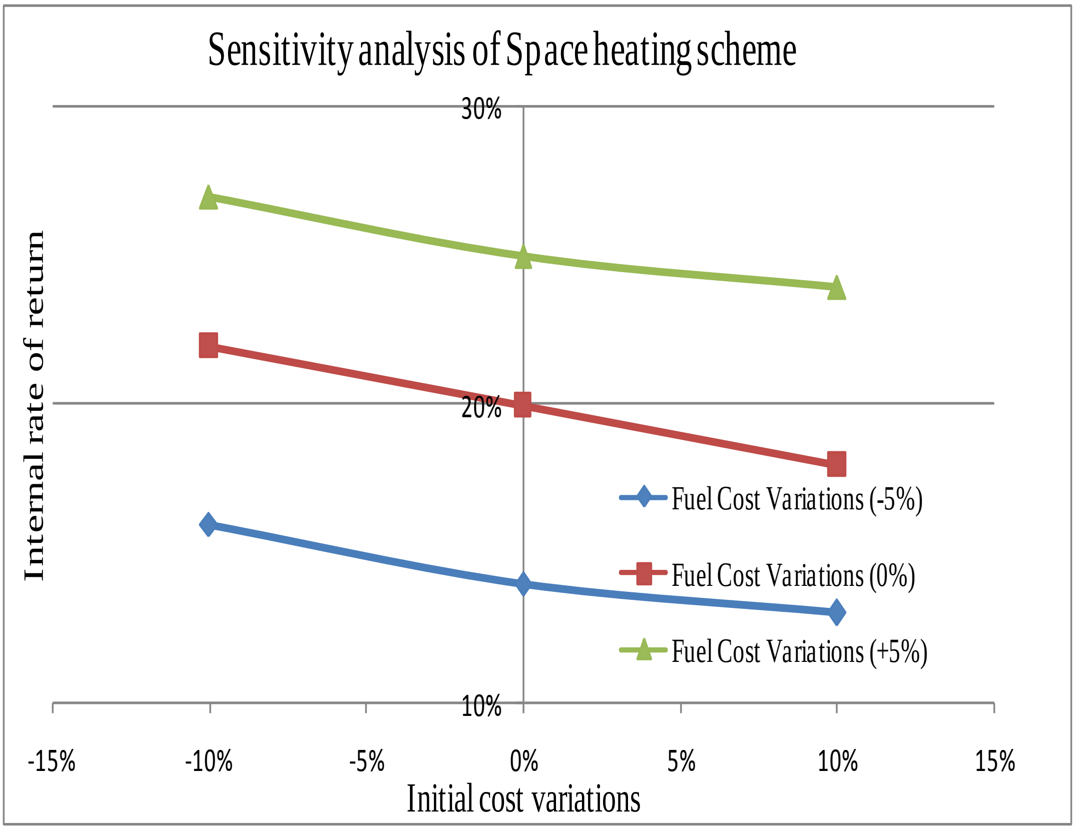

Figure. 4. 9 Sensitivity of IRR to project input parameters

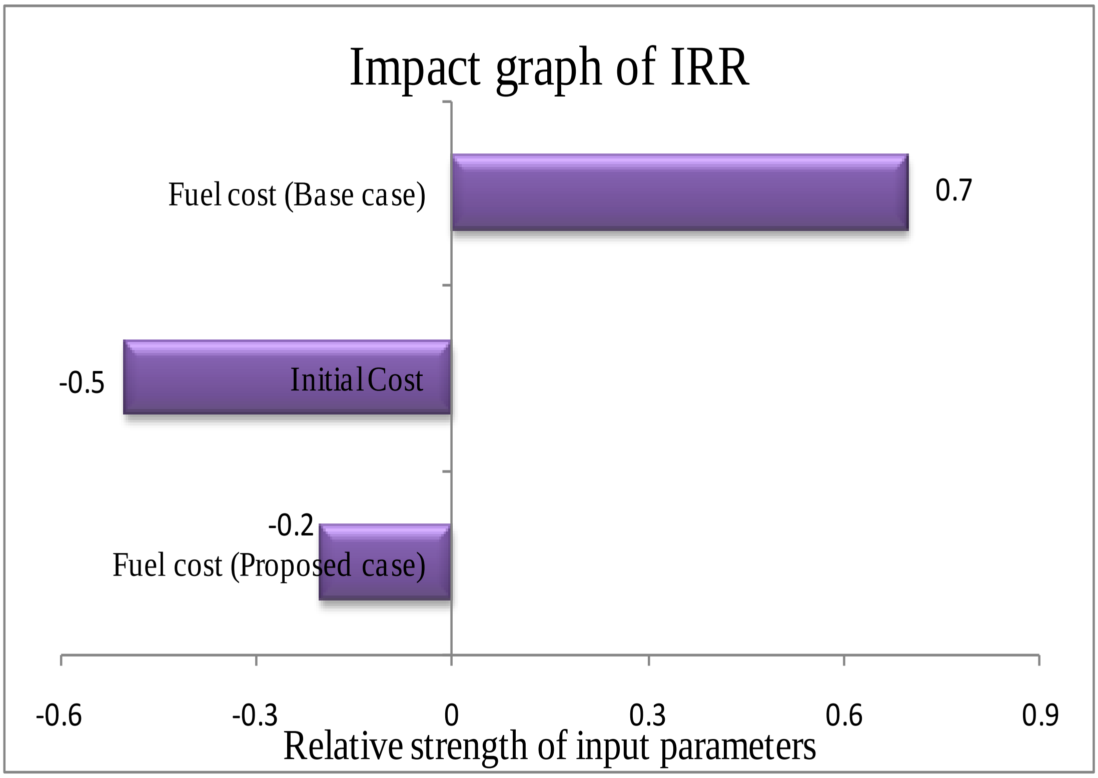

Figure. 4.10 Tornado graph for sensitivity study

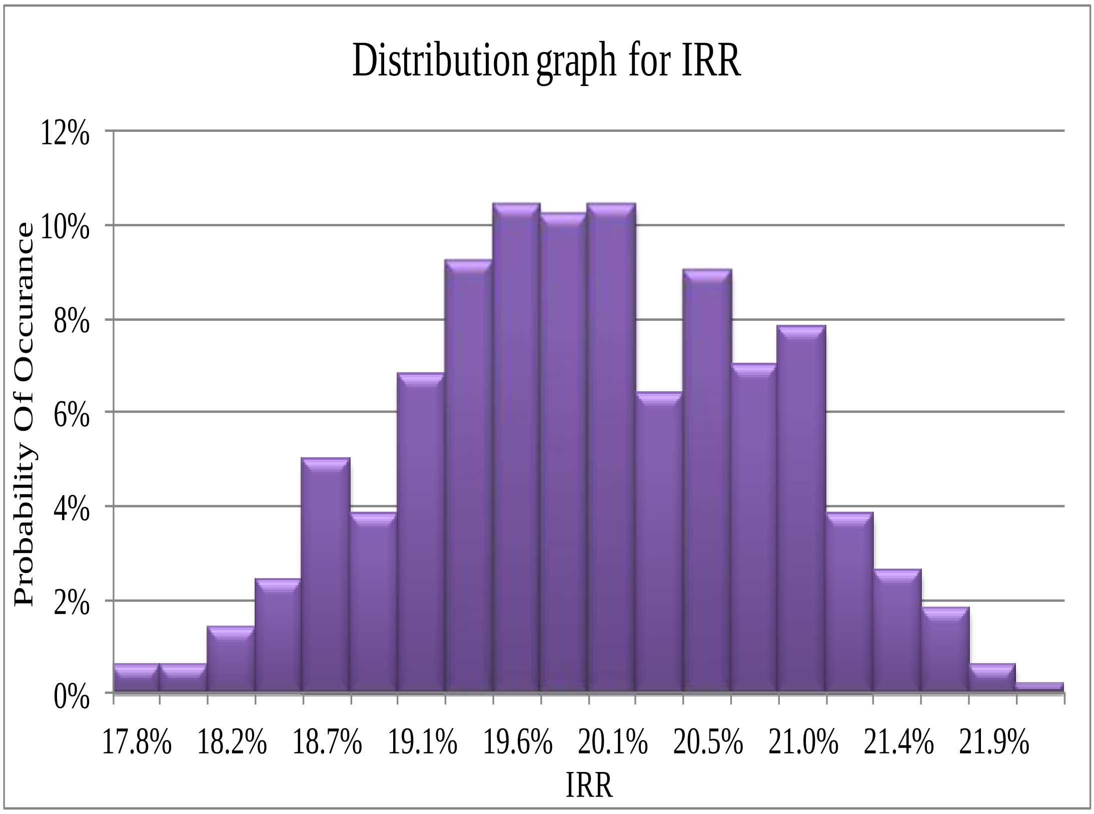

Figure. 4. 11 Histogram depicting IRR distribution for 10% risk level

4.6 Conclusions

1. Solar space heating scheme is technically and economically suitable to be considered for educational institute. (load and source coincides)
2. Mature, available and reliable technology.
3. ~ 170 mmBtu natural gas can be saved annually.
4. IRR of solar space heating scheme is 20% and payback period is ~6 years which is quite attractive to be considered.
5. Sensitivity analysis shows that fuel cost (base case) is most sensitive parameter.
6. Risk analysis of project input parameters reveals that project is quite safe to consider as IRR is concentrated between 18.5-21 % range.

Summary

Thermal performance of ETC and FPC was compared and authenticated with standard literature mathematical models. Heat load for educational building was calculated according to climatic conditions of Quetta city. Solar space heating scheme was sized keeping the view of economic optimization. Control scheme was formulated so that automatic run and shut down of solar space heating scheme can be done in coherence and economic optimization. Major economic parameters were calculated. Sensitivity and risk analysis were carried in detailed way which greatly enhanced and revealed the project stability andrevealed the project economic features

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References

1. Dagdougui, H., et al., Thermal analysis and performance optimization of a solar water heater flat plate collector: application to Tétouan (Morocco). Renewable and Sustainable Energy Reviews, 2011. 15(1): p. 630-638.
2. Dixon, W.J. and F.J. Massey, Introduction to statistical analysis. Vol. 344. 1969: McGraw-Hill New York.
3. Chow, T.-T., et al., Performance evaluation of evacuated tube solar domestic hot water systems in Hong Kong. Energy and Buildings, 2011. 43(12): p. 3467-3474.
4. Morrison, G., I. Budihardjo, and M. Behnia, Water-in-glass evacuated tube solar water heaters. Solar energy, 2004. 76(1): p. 135-140.
5. Budihardjo, I. and G. Morrison, Performance of water-in-glass evacuated tube solar water heaters. Solar energy, 2009. 83(1): p. 49-56.
6. Tang, R., Y. Yang, and W. Gao, Comparative studies on thermal performance of water-in-glass evacuated tube solar water heaters with different collector tilt-angles. Solar energy, 2011. 85(7): p. 1381-1389.
7. RETScreen Software Online Manual, RETScreen International Clean Energy Decision Support Centre, Ottawa, Canada. Available at http://www.retscreen.net/ang/home.php, (2013).
8. Hong, T., S. Chou, and T. Bong, Building simulation: an overview of developments and information sources. Building and environment, 2000. 35(4): p. 347-361.
9. Bell, A.A., HVAC Equations, Data, and Rules of Thumb2000: McGraw-Hill.
10. Balaras, C., et al., Potential for energy conservation in apartment buildings. Energy and Buildings, 2000. 31(2): p. 143-154.
11. Santamouris, M. and F. Allard, Natural ventilation in buildings: a design handbook1998: Earthscan.
12. Liang, R.-H. and J.-H. Liao, A fuzzy-optimization approach for generation scheduling with wind and solar energy systems. Power Systems, IEEE Transactions on, 2007. 22(4): p. 1665-1674.
13. Mills, D., Advances in solar thermal electricity technology. Solar energy, 2004. 76(1): p. 19-31.
14. Deshmukh, M. and S. Deshmukh, Modeling of hybrid renewable energy systems. Renewable and Sustainable Energy Reviews, 2008. 12(1): p. 235-249.

15. Liegeois, A., Automatic supervisory control of the configuration and behavior of multibody mechanisms. IEEE Transactions on Systems, Man, and Cybernetics, 1977. 7(12): p. 868-871.
16. Elliott, S.J. and T.J. Sutton, Performance of feedforward and feedback systems for active control. Speech and Audio Processing, IEEE Transactions on, 1996. 4(3): p. 214-223.
17. Desborough, L. and T. Harris, Performance assessment measures for univariate feedforward/feedback control. The Canadian Journal of Chemical Engineering, 1993. 71(4): p. 605-616.
18. Gouda, M., S. Danaher, and C. Underwood, Quasi-adaptive fuzzy heating control of solar buildings. Building and environment, 2006. 41(12): p. 1881-1891.
19. Kanarachos, A. and K. Geramanis, Multivariable control of single zone hydronic heating systems with neural networks. Energy conversion and management, 1998. 39(13): p. 1317-1336.
20. McQuiston, F.C., J.D. Parker, and J.D. Spitler, Heating, ventilating, and air conditioning: analysis and design. Vol. 6. 2010: Wiley.
21. Stevanović, S. and M. Pucar, Financial measures Serbia should offer for solar water heating systems. Energy and Buildings, 2012. 54: p. 519-526.
22. Gastli, A. and Y. Charabi, Solar water heating initiative in Oman energy saving and carbon credits. Renewable and Sustainable Energy Reviews, 2011. 15(4): p. 1851-1856.
23. Fantidis, J.G., et al., Financial Analysis of Solar Water Heating Systems during the Depression: Case Study of Greece. Engineering Economics, 2012. 23(1).
24. Yu, J., et al., A study on optimum insulation thicknesses of external walls in hot summer and cold winter zone of China. Applied Energy, 2009. 86(11): p. 2520-2529.

GHG reductions through domestic solar water heating in Pakistan

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Abstract

In domestic sector of Pakistan large fraction of gas consumption is due to water heating in winter season. This intense use of Natural gas for space and water heating in domestic sector is the main reason behind severe natural gas shortfall during winter season. Due to increasing pressure on fossil fuels and environmental concerns shifting towards clean energy resources is need of the day for sustainable economic growth. Geological location and climatic conditions of Pakistan are beneficial for solar water heating applications to reduce the load on natural gas. In this study five climatically and geographically different cities are analyzed to find out how much Green House Gas reductions can be obtained by utilizing single unit of evacuated tube solar water heater of similar specifications in these cities. The results show maximum Green House Gas reductions (10 tons) are obtained in Quetta, Karachi and Peshawar while minimum (7 tons) Green House Gas reductions are obtained in Islamabad.

Keywords: GHG, CDM, SWH, CERs , WHO.

1. Introduction

Pakistan is a country whose energy demand is increasing significantly every year. In opposite to this there is no appreciable increase in sources of energy in consequence of which there is demand and supply gap. Natural gas is big source of energy in Pakistan but its reserves are moving toward depletion because of its high demand in industrial and residential sectors. In winters country face sudden increase in demand of natural gas due to its extensive use in residential sector for water and space heating results in term of load shedding. Situation gives boost for ideas of using sun to heat water and to save gas for the productive sector. To deal with this problem

Solar Water Heating (SWH) systems can be installed which can be used in any climate and the fuel they use is sun light that is free of cost [1]. The sun is cleaner, infinite, environmental friendly and sustainable energy source. The theoretical potential of solar energy was estimated about 3900000 EJ, while technical potential is 1600EJ [2] which is a huge value. Pakistan has good Geographical location the climatic and topographical location is ideal while concerning the solar radiations [3] and this energy can be use to heat water. In European Union there are more than 35.9 million m^2 collectors are installed [2]. Solar energy to heat water is reliable and economical alternative in Lebanon more than 100,000 m^2 of installed collector area. [4]. Therefore in Pakistan SWHs can be used efficiently and effectively for heat water. Solar water heater is a mature technology, carbon and heavy metal emissions can b reduced by their use. [5].SWH systems are applicable of clean development mechanism (CDM) and directly involved in the reduction of GHG and participating in sustainable development[1]In India there are 3 projects of SWHs approved by executive board of CD4CDM and Certified Emission Reductions (CERs) potential of solar water heater could theoretically about 27 million tones [1]. Many countries are doing work in such projects as Spain is leading by utilizing solar energy more than other countries. China produces cheapest and efficient evacuated tube collectors [1].

2. Methodology

In the present scenario solar water heater is installed in a house of 6 occupants which was using gas geyser. Calculations are performed by taking 5 different cities of Pakistan which are climatically and geologically at different positions. The selected cities are Multan, Quetta, Karachi, Islamabad and Peshawar. The locations of the cities are shown in the map of Pakistan in figure 1 [6].

Figure 1. Pakistan map indicating 5 selected cities.

Table 1: Climatic data of selected cities

City	Latitude	Annual average, daily solar radiations (H)	Annual average daily air temperature
		kWh/m²/d	^{o}C
Karachi	24.9^{o}	5.34	26.1
Quetta	30.2^{o}	5.46	15.7
Multan	30.2^{o}	5.09	25.3
Islamabad	33.6^{o}	4.02	21.6
Peshawar	34^{o}	5.16	22.7

Table 1 shows the latitude, annual average daily solar radiations and annual average daily air temperature of selected cities of Pakistan. These values are taken from RETScreen software data section which obtained data from NASA satellites [7]. From the Table 1 it is clear that Quetta has highest Annual average daily solar radiations and minimum air temperature.

Solar water heater is not used as stands alone system because of unavailability of sun in cloudy and non sunny days. Gas geyser is used as a back up to meet the requirement of daily hot water. RETScreen software is used for calculating the net GHG emissions reductions by solar water heater in selected cities. Software is designed especially for renewable energy technologies. It is clean energy project analysis tool helps decision makers in determining the technical and financial viability, energy efficiency, energy production, savings, emission reductions and risk of various renewable and cogeneration projects [7]. Table 2 [8] shows the parameters which are used in RETScreen software to perform the calculations of finding GHG emissions reduction for selected cities of Pakistan.

Table 2: Parameters used in the RETScreen software.

Parameters	**Value**
Occupants	6
Occupancy rate (%)	80
Daily hot water usage (L/day)	300
Hot water temperature (^{o}C)	60
Operating days per week	7
Supply water temperature (minimum) (^{o}C)	11.5
Supply water temperature (maximum) (^{o}C)	20
Solar water heater	
Type	Evacuated
Gross area per solar collector (m^2)	1.68
Aperture area per solar collector (m^2)	1.49
Fr (tau alpha) coefficient	0.46
Fr UL coefficient((W/m^2)/°C)	1.57
Number of collectors	3
Capacity (kW)	3.12
Miscellaneous losses (%)	3
Balance of system & miscellaneous	
Storage capacity per square meter (L/m^2)	75
Fuel type	Natural gas
Financial parameters	
Project life (Years)	25

3. GHG emissions

In Pakistan considerable amount of GHG is introduced into the environment through different sectors. Two major constituent of GHG are CO_2 and CH_4. Net CO_2 emissions in the county are about 104.9 million metric tons in which energy sector, industrial processes and forestry & land contributing 74.3%, 16% and 9.7% respectively [9].CH_4 emission in Pakistan is about 5.13 million metric tons and the main emitters are energy (16%), agriculture (74.4%) and waste (9.2%).

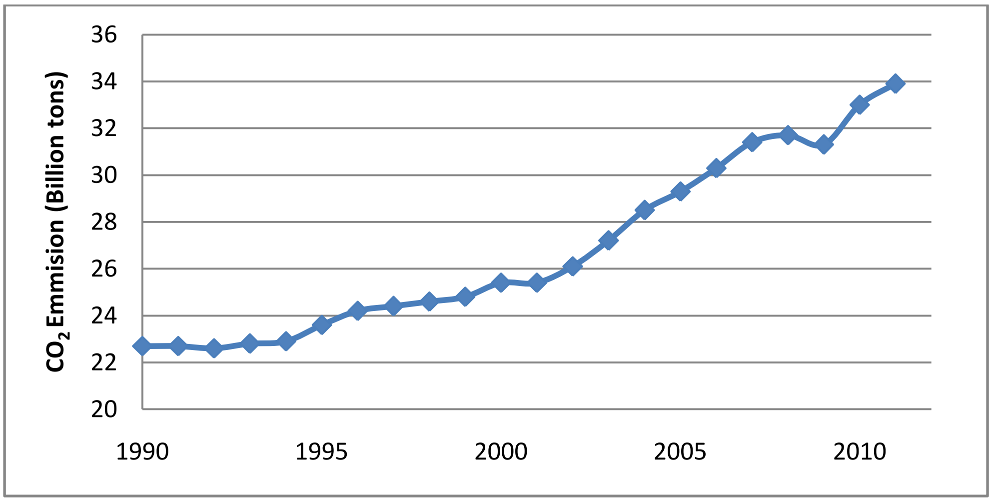


Figure 2. Net Global CO_2 emission in different years.

Figure 2 [10] shows increase in the rate of net global CO_2 emission the increase is very steep after 2002 and amount of CO_2 in atmosphere is directly related to global warming/climate change. In Pakistan its impacts are, rise in the sea level and hundreds of millions of people are affected by floods each year. Un-seasonal rains increased in northern Pakistan. There is 0.6 to 1 ^{o}C temperature rise since early 1900s, decrease in crops yield and diseases are spreading due to floods and droughts. According to World Health Organization (WHO) approximately 160,000 people die every year due to change in climate and the numbers could be double till 2020[11]

Glaciers are melting due to global warming and table 3 [9] shows the % Depleted Snow cover Area of different glaciers of Pakistan.

Table 3: Glaciers of Pakistan and there depleted snow-cover area.

Name of Glacier	**% Depleted Snow-Cover Area**	**Study period**
Yazghil	5	1992-2007
Jutmau	28	1992-2007
Passu	7	1992-2008
Ghulkin	12	1992-2008

The growth of CDM projects in Pakistan is not appreciable according to 2010 report there are total 2431 registered project of CDM in which China has 41%, India 22%, and Pakistan has only 0.37% share and have only 9 CDM registered projects

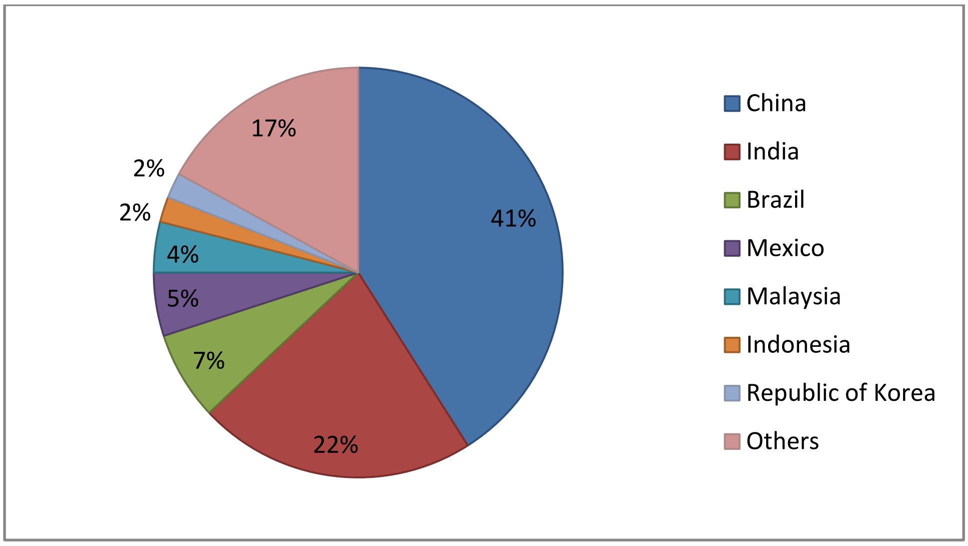
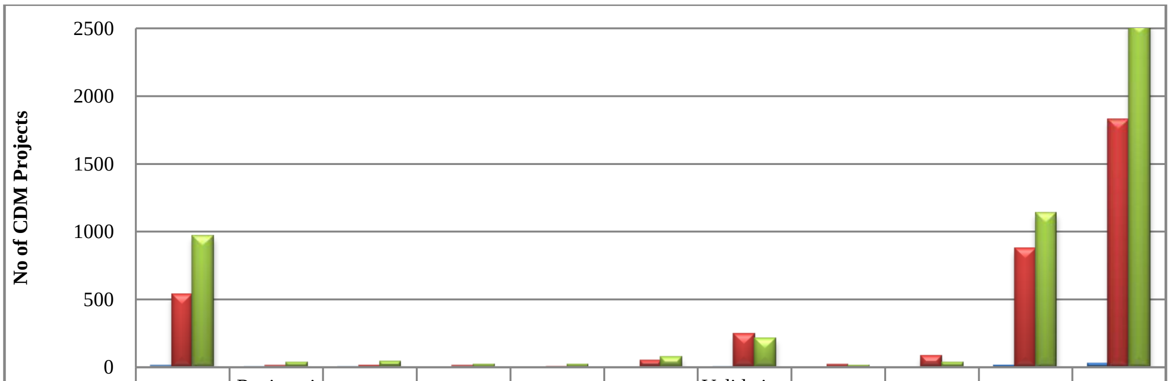


Figure 3. CDM registered projects by different countries.

Figure 3 [11] shows the share of different countries in CDM registered projects according to this data China has maximum share in these projects but in Pakistan there is no appreciable growth in such project and installing SWHs project can contribute in such projects.



	Registered	Registration Request	Correction Request	Requesting Review	Under Review	Rejected	Validation Terminated	Withdrawn	Validation Negative	At Validation	Total
Pakistan	9	1	1	0	0	0	1	0	0	14	26
India	534	9	12	9	3	44	242	15	85	872	1825
China	969	33	37	18	19	71	212	11	31	1135	2536

Figure 4. CDM comparison of Pakistan, India and China.

Figure 4 [11] shows the overall comparison of status of CDM projects which are working in Pakistan, India and China. It is clear from the Figure 4 that Pakistan is very far to compete with these countries therefore it is viable to take initiatives like SWHs to compete with these countries.

4. Results and Discussion

By using climatic data of the selected cities in RETScreen we get the net GHG reduction value for the overall life of the SWH system in tons of CO_2.

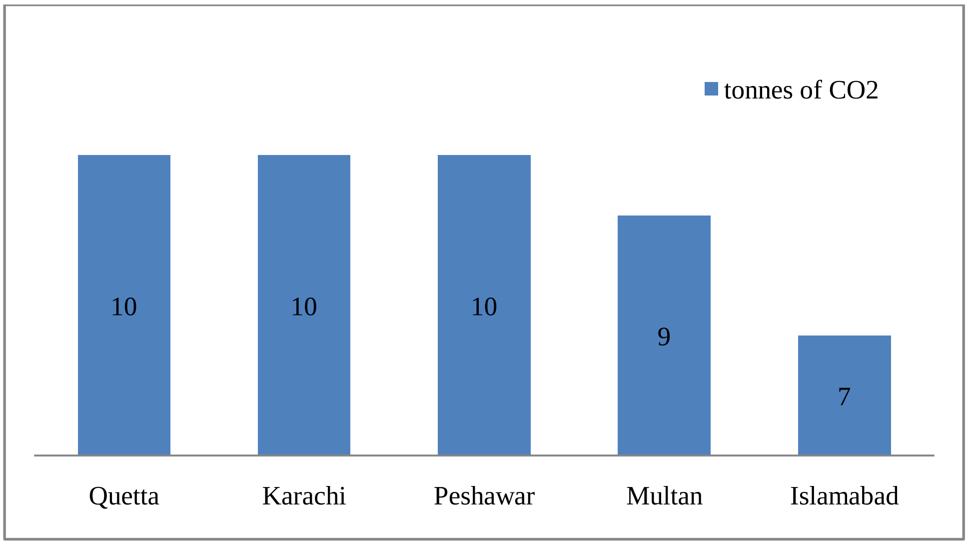


Figure 5. Reduction in net GHG emissions for selected cities.

Figure 5 shows the reduction in CO_2 emissions by installing SWH systems at selected cities of Pakistan. It can be seen that 10 tCO_2 can be reduced during the whole life of SWHs by installing it in Karachi, Peshawar and Quetta because solar radiation values are higher in these cities as compare to Islamabad where 7 tCO_2 emission reduction. It is more beneficial to install SWHs in these 3 cities as compare to Islamabad.

Table 4: Annual natural gas saving and solar fraction value for selected cities.

Sr No	CITY	Annual gas saving (mmBTU)	Solar fraction (%)
1	Quetta	8.1	56
2	Islamabad	5.6	45
3	Peshawar	7.6	62
4	Multan	7.1	62
5	Karachi	8	73

Table 4 shows that annual natural gas saving for Quetta is highest at even low solar fraction it is because Quetta has highest value of annual average daily solar radiation among all selected cities. Therefore it can say that it is more viable to install SWHs in Quetta as compare to other 4 cities.

5. Conclusions

Natural gas can be saved from SWH installations, saved natural gas from domestic sector can be supplied to industrial sector and it will contribute to decrease the gas load shedding of the country by reducing the load on natural gas from domestic sector. From annual natural gas savings and net GHG emission reduction in term of CDM Pakistan can get incentives which can be used to support SWHs projects. The results show maximum Green House Gas reductions (10 tons) are obtained in Quetta, Karachi and Peshawar while minimum (7 tons) Green House Gas reductions are obtained in Islamabad

References

[1] A. Gastli and Y. Charabi, "Solar water heating initiative in Oman energy saving and carbon credits," Renewable and Sustainable Energy Reviews, vol. 15, no. 4, pp. 1851–1856, 2011.

[2] J. G. Fantidis, D. V Bandekas, C. Potolias, N. Vordos, and K. Karakoulidis, "Financial Analysis of Solar Water Heating Systems during the Depression : Case Study of Greece," vol. 23, no. 1, pp. 33–40, 2012.

[3] P. H. Shaikh, F. Shaikh, and M. Mirani, "Solar energy: Topographical asset for Pakistan," Applied Solar Energy, vol. 49, no. 1, pp. 49–53, Apr. 2013.

[4] A. Houri, "Solar water heating in Lebanon: Current status and future prospects," Renewable Energy, vol. 31, no. 5, pp. 663–675, Apr. 2006.

[5] S. Stevanović and M. Pucar, "Financial measures Serbia should offer for solar water heating systems," Energy and Buildings, vol. 54, pp. 519–526, Nov. 2012.

[6] "Pakistan Map." [Online]. Available: www.pakinfo.tripod.com/pakmap.htm.

[7] "Centre Overview." [Online]. Available: www.retscreen.net.

[8] S. W. Heating, RETScreen Software Online User Manual ®. .

[9] N. Ali, "Climate Change Impact Assessment and Adaptation in Pakistan Nazim Ali."

[10] B. Studies, Trends in global co 2 emissions 2012. 2012.

[11] C. Production, "Clean Development Mechanism For Textile Processing And Tannery," 2010.

Minimizing Natural gas consumption through optimized solar water heating

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ABSTRACT

Natural gas is contributing 43.2% share in Pakistan energy mix while 18.7 % of total natural gas is being consumed in domestic sector. According to previous ten years statistics gas consumption in house hold sector has increased from 144 to 232 billion cubic feet. Country is facing extreme natural gas shortages especially in winter season due to increased demand for space and water heating in domestic sector. Utilization of widely available solar resource can solve this problem and effectively contribute to shift the precious energy resource from non productive (domestic) to productive sector (industrial) of country. Therefore current article aims to analyze the natural gas quantity saved, GHG (Green house gas) reduction and economic benefits obtained by solar water heating through RETScreen software analysis. Results shows that by utilizing single unit of evacuated tube solar water heater in Quetta 7.4 mmBtu of natural gas can be saved with Net present value of (NPV) PKR 304,873 is obtained and 10 tones of GHG is saved from entering into atmosphere. Further analysis indicates that if living habits are changed for energy conservations by 10 % reduction in hot water quantity and temperature then additional 2 mmBtu of natural gas is saved.

KEYWORDS

RETScreen, Evacuated tube solar water heater, Net present value.

1. INTRODUCTION

Natural gas is contributing a significant portion in Pakistan energy mix and a major portion is utilized in domestic sector (18.7 %). Being given priority to domestic sector the quantity has increased up to 232 billion cubic feet[1]. As a result of this productive sector (industry) is suffering a lot, especially in winter season because of excessive utilization of natural gas in house hold water heating. Energy and Industry sectors are going through worst gas load shedding. Contrary to many developing and developed world countries where subsidies are given to renewable technologies so that they can be adopted at large scale in these countries, in Pakistan subsidies were given to electricity. For example Government has set 30% grant for SWHs (Solar water heater systems) in Cyprus and reaches up to 50% in Switzerland (Basel city) or in Taiwan (Kaohsiung city). In India soft loans has been introduced with an interest rate of 2–5%. In China central support to SWH technologies is 13% upfront subsidy for SWH installations in rural areas results in varying adoption rates from 8% (national level) to 30% (successful SWH producing areas) while local support varies area to area[2].

Geographical Location, climatic conditions and topography of Pakistan are ideal for solar resource utilizations that can be converted to useful form by suitable technologies of energy conversion. Most of the parts of country have more than 300 sunshine days per year, 7.6 sunshine hours per day, 5–7 kW h/(m^2 day) of average solar radiation and 1900-2200 kW h/m^2 of annual global irradiance. These figures indicate Pakistan is blessed generously in terms of solar potential. This vast solar potential can beneficially be utilized for solar energy applications such as solar water heating, photovoltaic, desalination and crop drying applications[3].

Serious energy crisis of country are demanding to have revolutionary steps to be taken with proper planning. In order to improve the economic conditions of the country it is necessary to move the important power source (Natural gas) from non productive sector (domestic) to productive sectors (industry and power plants). In order to achieve this domestic hot water demand should be shifted from natural gas to solar thermal technologies. Although due to shortage of gas and decrease in price of solar water heaters there installations are increasing but it should be increased significantly. In the present research RETScreen software has been utilized to analyze the Natural gas savings made by utilizing vacuum tube solar water heater in Quetta. RETScreen software has extensively utilized in renewable energy technologies analysis in different areas of world. Literature shows the successful utilization of RETScreen in solar thermal technology as well[2][4][5][6]. The research is also focus on how to enhance these savings by simple technical and social measures.

2. CASE STUDY

In order to elaborate the advantages of solar water heating in Pakistan the selected city is Quetta for having highest solar potential available in Pakistan. Annual average daily air temperature of Quetta city is 15.7 ^{o}C and is less than many major cities of Pakistan (Karachi, Hyderabad, Lahore, Multan, Peshawar and Islamabad) indicate that heating demand is more than these cities because of large temperature difference between ambient and required hot water.

3. Climatic Data

Quetta city have latitude 30°15'N and longitude of 66°55'E[7]. Quetta is Provincial Capital and largest city of Balochistan province. Population of city is 865,125[8]. The detailed analysis of Quetta city weather is taken from RETScreen Software climate data section and shown in Table 1. Software has unique assistance of obtaining data from ground monitoring stations as well as NASA satellite data base. The data shows that monthly average values of air temperature varies from 3.7 °C to maximum value of 27.9 °C and their low annual average values indicates severity of heating requirement is more while high solar radiations values indicates the good potential for solar energy technologies[9].

Figure 1. Pakistan map indicating the position of the selected city.

Table 1: Climatic conditions of Quetta city.

Months	Air temperature (°C)	Relative humidity (%)	Daily solar radiation horizontal (kWh/m²/d)	Wind speed (m/s)	Earth temperature (°C)
January	3.7	56.0	3.42	4.3	6.5
February	6.0	47.5	4.25	4.6	9.2
March	11.1	37.7	4.78	4.6	15.6
April	16.6	26.1	6.25	4.5	23.6
May	21.0	18.4	7.03	5.0	29.5
June	25.6	21.0	7.75	4.7	33.8
July	27.9	38.3	7.00	4.4	34.0
August	26.4	41.9	6.64	4.2	32.1
September	21.1	24.4	6.42	4.4	28.9
October	14.6	20.3	5.42	4.6	21.5
November	9.2	28.1	4.11	4.2	14.5
December	5.1	44.5	3.33	4.3	8.7

4. Software Parameters

RETScreen software has special importance for renewable as well as solar thermal applications. Software provides comprehensive analysis schemes in user friendly way with results that lies in good accuracy.

The case study utilizes typical family of 6 occupants for analysis. In order to ensure hot water availability solar water heater system always uses some back up for our system we have taken natural gas heating system as a backup because in most of the parts of country natural gas is utilized for heating water. The parameters for basic scenario are listed in Table 2[10]:

Table 2: Parameter used in the RETScreen software.

Parameters	**Value**
Occupants	6
Occupancy rate (%)	80
Daily hot water usage (L/day)	300
Hot water temperature (°C)	50
Operating days per week	7 days
Supply water temperature (minimum)	11.5

(°C)	
Supply water temperature (maximum) (°C)	20
Solar water heater	
Type	Evacuated
Gross area per solar collector (m^2)	1.68
Aperture area per solar collector (m^2)	1.49
Fr (tau alpha) coefficient	0.46
Fr UL coefficient ($(W/m^2)/°C$)	1.57
Number of collectors	3
Capacity (kW)	3.12
Miscellaneous losses (%)	3
Balance of system & miscellaneous	
Storage capacity per square meter (L/m^2)	75
Fuel type	Natural gas
Financial parameters	
Project life	25 yr

5. RETScreen Analysis

In this case study two cases are discussed. In case 1 it is analyzed that how much benefits in terms of natural gas units, economics and net GHG reductions will be obtained by utilizing evacuated tube solar water heater for our specified family and parameters.

Keeping the view of global and local scenario of energy crisis, fossil fuel depletion, environmental pollution and increasing health hazards and their resultant increment in demand for energy conservation and energy efficiency research case 2 is designed. In case 2 it is analyzed that if energy conservation is adopted by slightly decreasing hot water quantity and temperature (10 % each) then how it will affect the SWH system performance.

6. RESULTS AND DISCUSSION

Case 1

Figure 2. Gas consumption units for case 1.

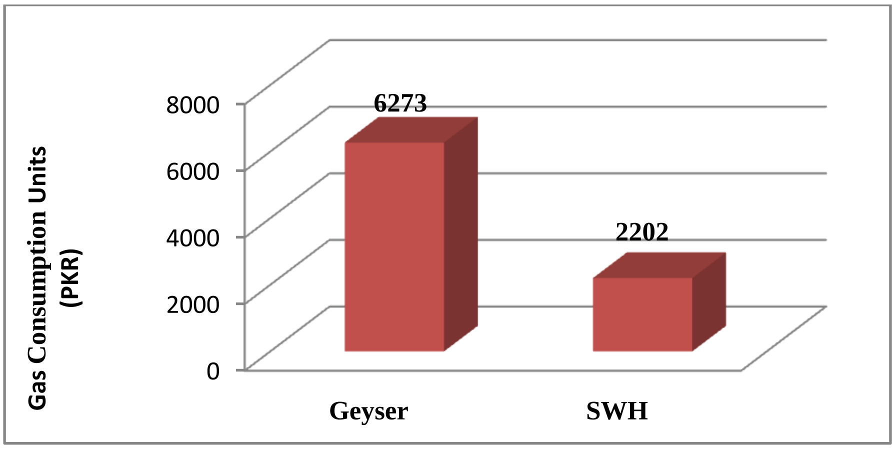

Figure 3. Gas consumption price for case 1.

This analysis essentially involves the calculations of Geyser (base case) system and then compare it with SWH unit. (Proposed case). Figure 1 show that if Natural gas Geyser is replaced by evacuated tube SWH then natural gas consumption reduces from 11.4 mmBtu to 4 mmBtu and 7.4 mmBtu of Natural gas is saved. It must be noted that if we increases the number of panels then we may eliminate proposed case heating but this will not be beneficial in terms of economic parameters and will also causes problem in cloudy days as backup system has been eliminated. Figure 2 indicates that our annual heating cost decreases from PKR 6,273 to PKR 2,202 by using solar water heater. Solar fraction covered by SWH is 65 % as shown in Table 3. Net present value (NPV) of the SWH unit, internal rate of return (IRR), Equity pay back and Net GHG reductions are shown in Table 3 all these figures shows that utilizing SWH is attractive option.

Table 3: RETScreen simulation results.

Sr No	Parameter	Value
1	Solar fraction	65 %
2	NPV	PKR 304,873
3	Equity Pay Back	9.5 Years
4	IRR	14.1 %
5	Net GHG reductions	10 tCO_2

Case 2

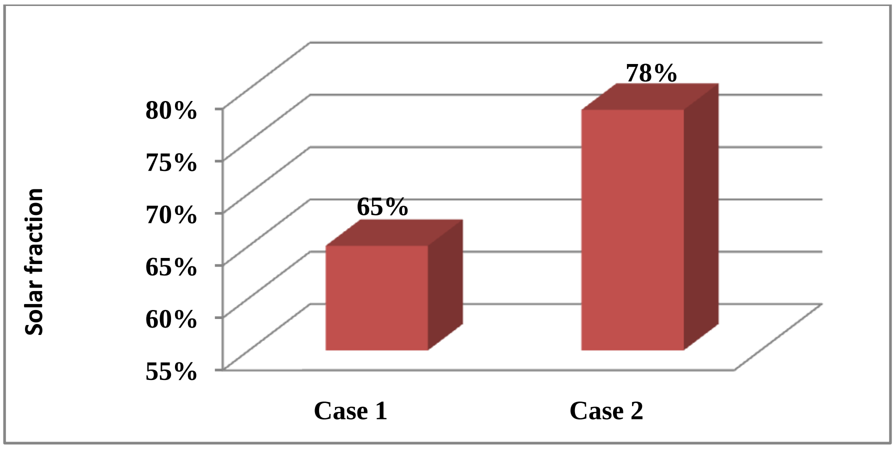

Figure 4. Solar fraction comparison for case 2.

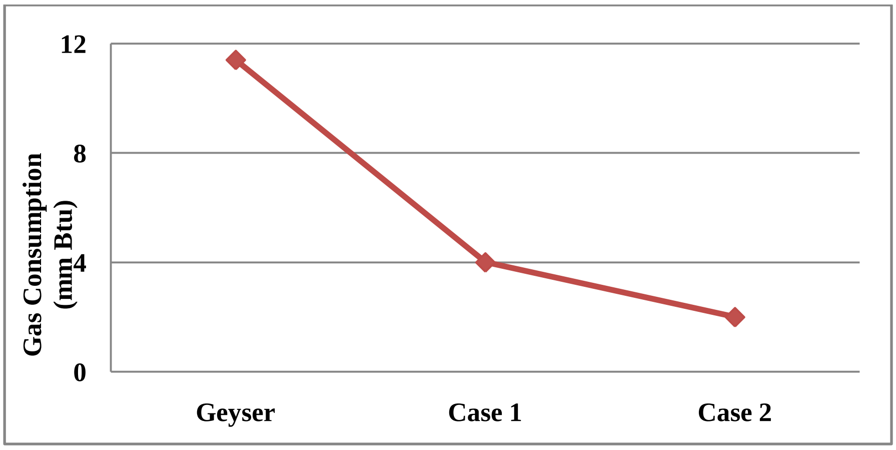

Figure 5. Gas consumption units for case 2.

So in case 2 it is analyzed that if energy conservation is adopted by slightly decreasing hot water quantity and temperature (10 % each) then how it will affects the SWH system performance. Fig. 3 indicates that solar fraction increases up to 78 % and Natural gas demand has reduces up to 2 mmBtu.

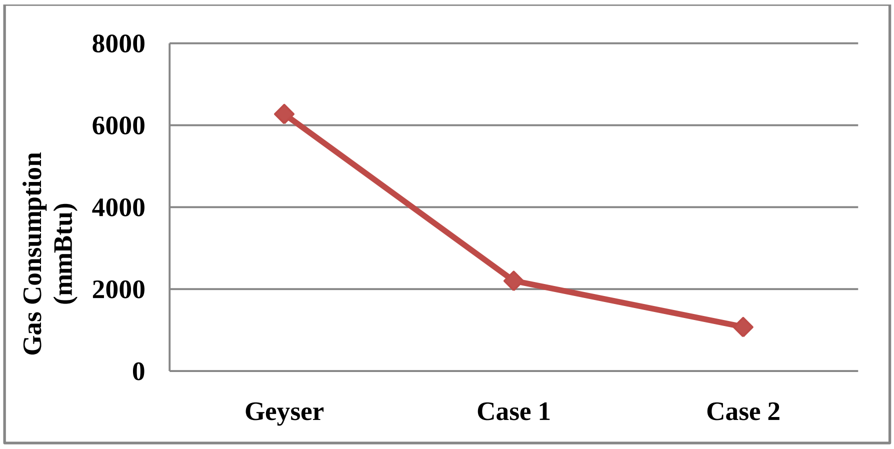

Figure 6. Gas consumption price for case 2.

Table 4: Economical Parameters.

Sr. No	Parameter	Value
1	NPV	PKR 417,483
2	Equity Pay Back	7.7 Years
3	IRR	17.1 %
4	Net GHG reductions	13 tCO_2

Exactly similar trend is observed in Fig 5 which indicates that annual Natural gas price has reduced. While Table 4 indicates additional economic benefits by utilizing energy conservation habits.

7. CONCLUSION

For a typical family of six members if evacuated tube SWH is utilized than 7.4 mmBtu of Natural gas is saved annually with NPV of PKR 304,873 and IRR 14.1 % are obtained and SWH unit covers 65 % of total water heating demand. It was also noted through RETScreen simulation that if 10 % water load and temperature are reduce for energy conservation habits than extra benefits in form of additional 2 mmBtu of Natural gas conservation are obtained and net amount of 13 tCO_2 is saved from being entering into atmosphere.

References

[1] Pakistan Economic Survey, Hydrocarbon research institute of Pakistan (2011-2012). Available at http://www.finance.gov.pk/survey_1112.html.

[2] S. Stevanović, M. Pucar, Financial measures Serbia should offer for solar water heating systems, Energy and Buildings. 54 (2012) 519–526.

[3] P.H. Shaikh, F. Shaikh, M. Mirani, Solar energy: Topographical asset for Pakistan, Applied Solar Energy. 49 (2013) 49–53.

[4] A. Gastli, Y. Charabi, Solar water heating initiative in Oman energy saving and carbon credits, Renewable and Sustainable Energy Reviews. 15 (2011) 1851–1856.

[5] J.G. Fantidis, D. V Bandekas, C. Potolias, N. Vordos, K. Karakoulidis, Financial Analysis of Solar Water Heating Systems during the Depression : Case Study of Greece, 23 (2012) 33–40.

[6] A. Houri, Solar water heating in Lebanon: Current status and future prospects, Renewable Energy. 31 (2006) 663–675.

[7] Location data. Available at http://www.mapsofworld.com/lat_long/pakistan-lat-long.html.

[8] Population data. Available at http://www.world-gazetteer.com).

[9] RETScreen http://www.retscreen.net.

[10] S.W. Heating, RETScreen Software Online User Manual ®.

Techno- Economic Assessment of Solar Water Heating Systems for Natural Gas Savings in the Domestic Sector of Pakistan

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Abstract

Pakistan receives about 5-7 kWh/m^2/day of solar irradiance. Solar energy can be used effectively for domestic water heating and helps in resolving present energy crisis. Current article aims to study the techno - economic viability of evacuated tube solar water heating systems in major cities of Pakistan. Analysis reveals that SWHs can be more attractive for the domestic consumers if 50% to 70% of hot water load is met by solar energy with payback period of 10–12 years. A single unit can save ~7mmBtu of natural gas annually.

1 Introduction

Energy plays a vital role in economic development of any country [1] and globally primary energy demand is expected to increase by 1.5-3.0 times by 2050 with major portion coming from fossil fuels [2]. Developing countries of the world are facing two major energy related challenges one is that to fulfill the needs of billions of people who still lack access to basic and modern energy services and other is to participate in a global shift to clean, green and low-carbon energy economy [3] due to global warming and other environmental concerns. Renewable energy, an alternate to fossil fuels, enables the developing countries to meet their energy and environment related challenges, while also providing several other benefits, including reduced vulnerability to volatile global energy prices, greater energy independence leading to energy security, and a competitive stake in a growing global market. Pakistan is among those developing nations where the economy is severely affected due to the severe energy shortages especially natural gas and electricity [4,5]. In the domestic sector of Pakistan, a major portion of natural gas is consumed by water and space heat heating apart from cooking during winter season. Therefore, alternates of natural gas based water and space heating are essential and necessity to decrease the consumption of natural gas by domestic sector. Climatic conditions of Pakistan are considered ideal for solar energy utilization [6–10] as the mean global irradiation falling on horizontal surface in Pakistan is about 200-250 watt/m^2 per day, thought to be ideal for solar thermal application [6–8,11]. Therefore, solar energy can be effectively used to fulfill the space and water heating requirements.

Solar Water Heating systems (SWHs) are becoming widespread and contributing significantly both domestic and industrial sectors in several countries due to decreasing collector cost, increasing fossil fuel prices and environmental friendly nature [12–19]. SWHs installation may reduce greenhouse gases emissions by ~150,000 tons eCO_2 annually if implemented at large scale[13,16,18,20,21] confirming the capability of SWH system to cut down the GHG emissions which may be used as. certified emission reduction (CERs) under CDM mechanism [15,22]. The technical and the economical evaluation of SWHs are necessary to determine the feasibility these systems [12] for the climatic conditions where these systems are to be installed. Also techno-economic assessment of SWHs is necessary in establishing a strong market strategy for solar water heating systems resulting in gathering necessary information for energy policy decision makers [23].For technical evaluation, f-chart method [24] has been used frequently and thought to be the most authentic way to assess the energy savings due to the installation of domestic SWH systems [15,16,21]. The RETScreen software [25], working on f chart modeling, is being used worldwide to estimate the energy production, energy savings, energy costs, and emission reductions by using solar water heating system [15,16,26–28] considering different technical and financial parameters like Net Present Value (NPV), Internal rate of return (IRR), equity payback period, solar fraction, solar collector area and storage capacity etc. Key technical parameters that are involved in determining the thermal performance of a SWH system include, the amount of solar energy striking he collector, collector area, collector glazing, the azimuth angle and the slope of the collector, and the supply and end-use water temperatures etc[15,16,27].

Since utilization of solar energy mainly depends on the geographical and climatic conditions of the area [13,16,20,21,29,30] therefore current research aims to have a detailed techno economic analysis of solar water heating potential in different areas of Pakistan using RETSCREEN modeling software. Present study work is focused to explore, how natural gas consumption can be reduced or minimized due to the usage of SWH systems in the domestic sector of Pakistan? How much financial benefits will be delivered to the users of these SWH systems in terms of payback period, and internal of return etc? Among varying geographical locations of Pakistan which location is most favorable for solar water heater installation? To answer these questions the article is dived into different sections. Section 2 describes the climatic conditions of the selected cities. In section 3 detailed working methodology along with the data and the assumption used for the analysis is presented while the results are presented and discussed in detail in Section 4.

2 Climatic Data Used for the Analysis of SWH Systems

Five cities that have been selected for the current study are shown in the map in Figure 1 and also tabulated in the table 1. These cities are selected based on their different latitudes, altitudes, population and the nature of the solar radiations [31].

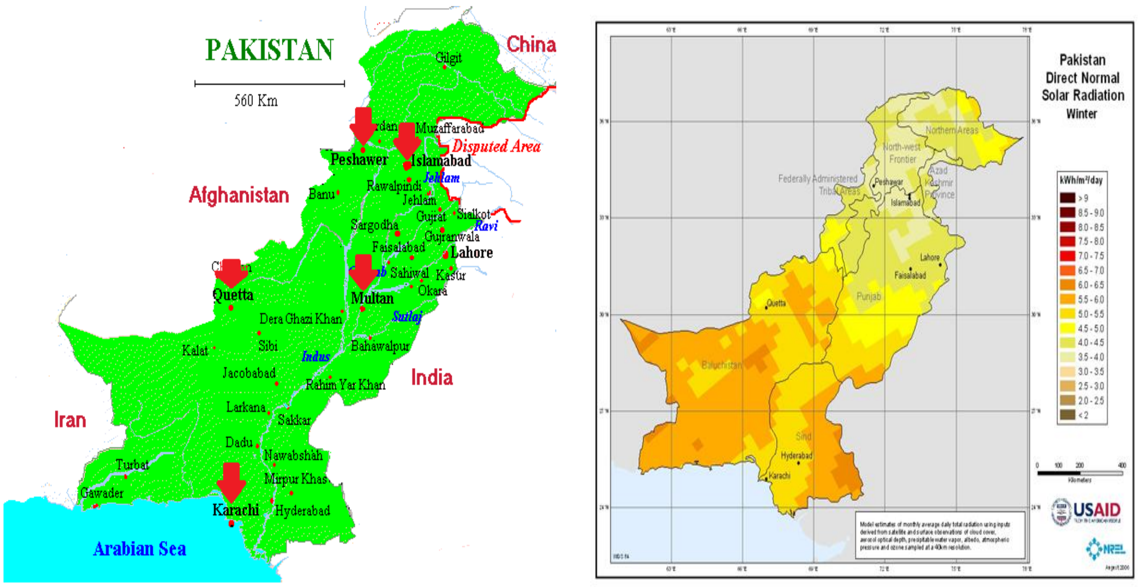

Figure 1: Selected Cities of Pakistan and their Climatic data [31,32].

The climatic data in Table 1 shows that Quetta has highest annual average daily solar radiations compared to any other city of Pakistan, while annual average daily air temperatures are minimum for Quetta [25]. Shown in Figure 1 and tabulated in Table 1. The mean ambient temperatures tabulated in the table 1 clearly show the necessity of the solar water heating systems in the respective areas / cities.

Table 1: Climatic data for selected cites [25].

City	Latitude	Population	Annual average, daily solar radiations	Annual average daily solar radiations	Annual average daily Air temperature
	degrees	Million	kWh/m²/d	kWh/m²/d	^{o}C
Karachi	24.9^{o}	11.24	5.34	5.59	26.1
Quetta	30.2^{o}	0.009	5.46	5.74	15.7
Multan	30.2^{o}	1.6	5.09	5.33	25.3
Islamabad	33.6^{o}	1.13	4.02	4.21	21.6
Peshawar	34^{o}	1.33	5.16	5.57	22.7

3 Methodology and Data used for the Analysis

Techno- economic viability of solar water heating systems for domestic sector of Pakistan has been performed using RETScreen advanced mathematical model tool [25]. RETScreen model compares a proposed clean energy project to a base case scenario, usually involving conventional technology to calculate the energy savings and payback period keeping in view the NPV and IRR values.

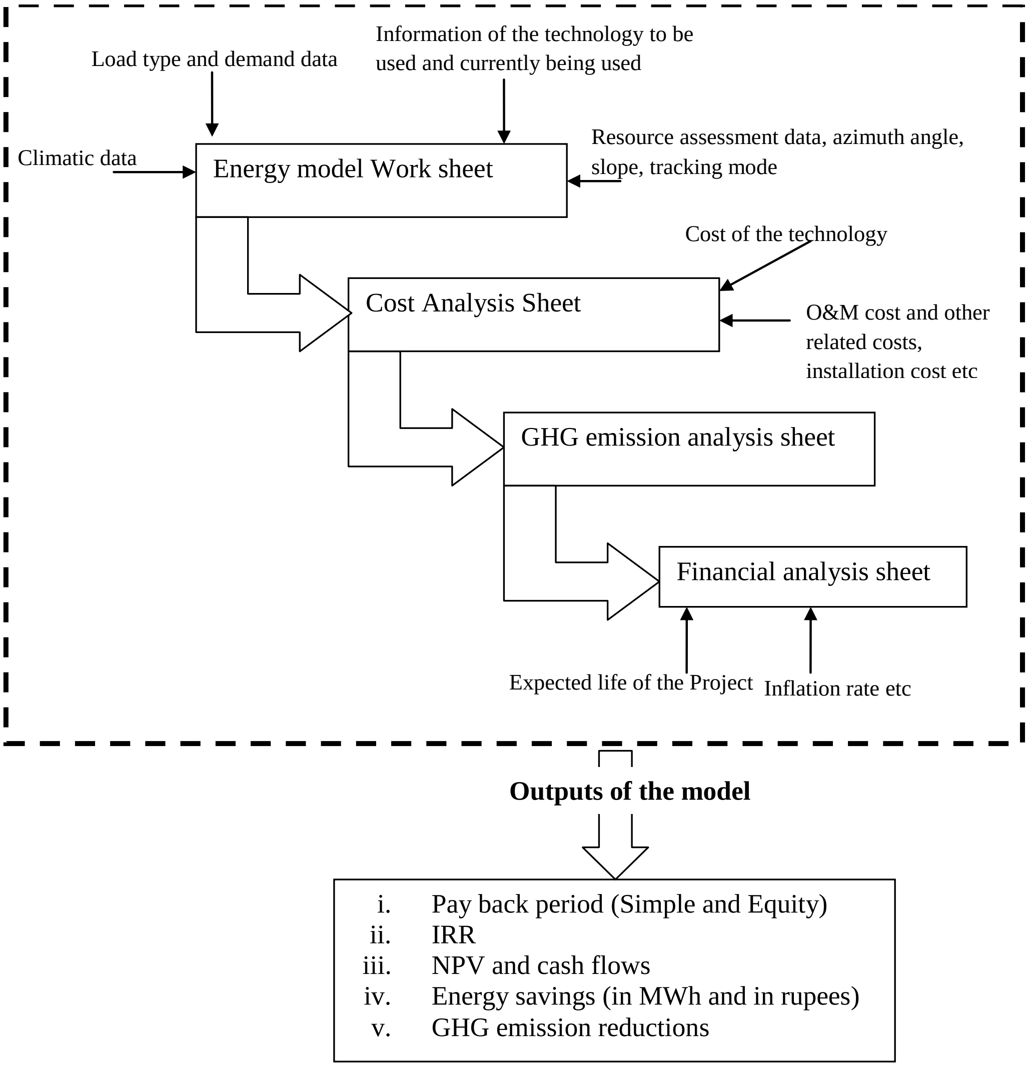

Figure 2: RETSCREEN working model

For the current analysis, proposed case is solar water heating system while the base case is the natural gas based water heating system which is commonly used in the domestic sector of Pakistan. The calculation methodology that the RETScreen follows is explained in detail and shown in Figure 2. The energy performance of the SWH system has been estimated using the *f*-Chart method. *f* chart method estimates the fraction of the total heating load that will be supplied by solar energy for the given heating system. Details of the method is explained by [24].

There are number of factors (shown in Figure 3) which may affect the energy performance of a solar water heating system, these may include resource and design elements such as the amount of solar radiation hitting the solar collectors, the collector type (e.g. glazed, unglazed or evacuated tubes), area and efficiency, as well as the solar tracking mode (i.e. fixed, one-axis, azimuth or two-axis tracker), the slope and the azimuth (physical orientation) of the solar water heater. Other factors include the end-use water temperature required, the supply temperature of the water available, as well as the use of a hot water storage tank.

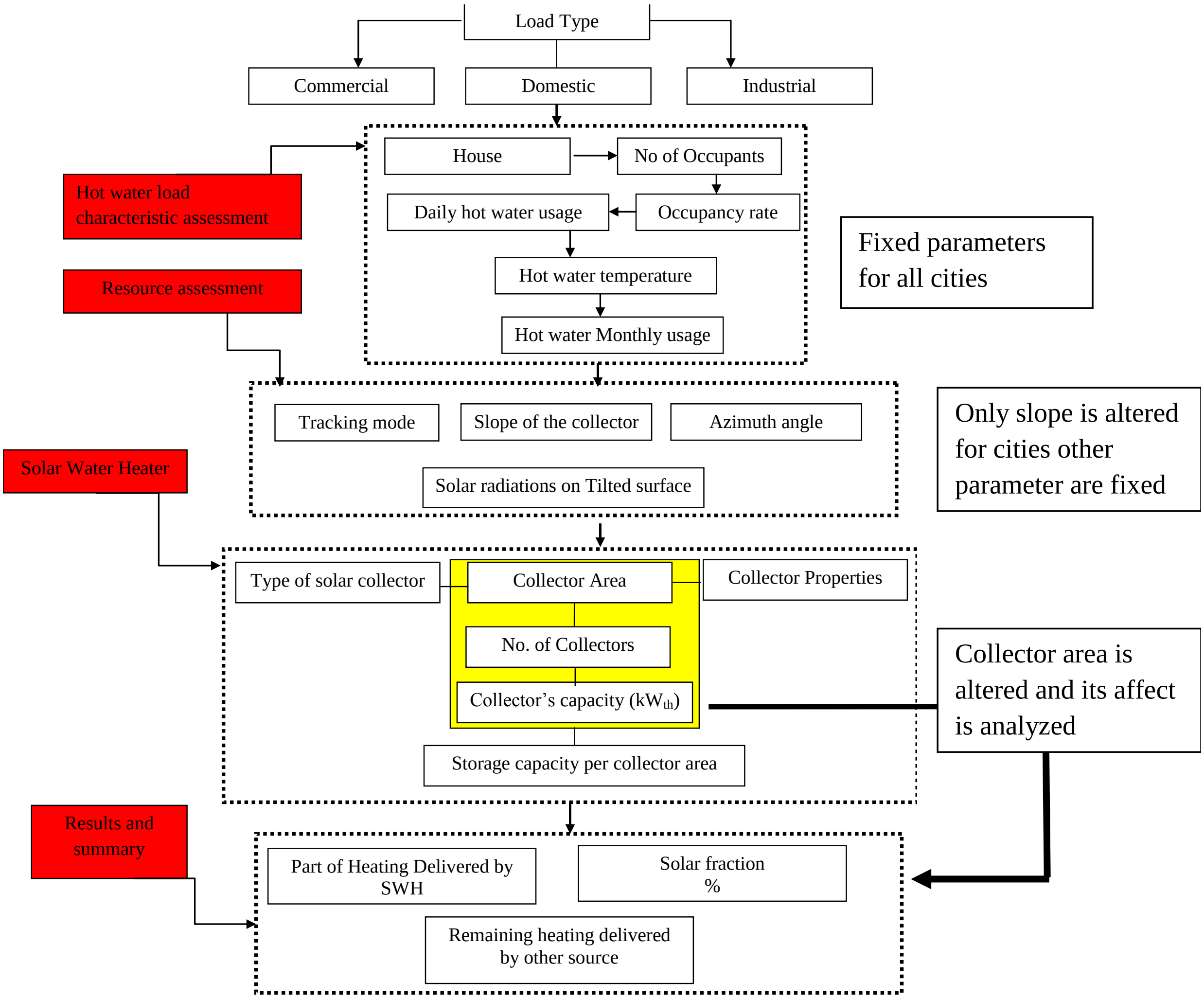

Figure 3: Methodology to assess the techno economic viability of SWHs in different cities of Pakistan

3.1 Assumptions and Data

Following are the assumptions which are used to evaluate the applicability of the SWHs for the domestic sector in different cities of Pakistan [24,25].

- Evacuated type solar water heating systems is used due to their high efficiency and easy availability in the local market of the Pakistan.

- For energy saving calculation lower heating value of the natural gas is considered.
- Technical and economical analysis is performed keeping in view the hot water requirements of single family currently using gas water heating system.

Other data used for the analysis is given in Table 2

Table 2: Input parameters for SWH

Input Parameters		**Remarks**
Load type	House	
Occupant	6	Consumption of a typical house in Pakistan
Occupancy rate	80%	
Daily hot water use	300 L/d	
Temperature	55 °C	Normal gas geyser temperature
Operating days per week	7 days	
Solar water heater		
Type	Evacuated tube	Thermosyphon type
Solar collector area	5.04 m^2	
Storage capacity	75 L/m^2	
F_r (tau alpha) coefficient	0.46	Provided by the manufacturer
F_r U_L coefficient	1.57 (W/m^2)/°C	
Miscellaneous losses	2%	
Financial parameters		
Inflation rate	5%	
Project life	25 yr	Provided by the manufacturer
Initial cost	53086 PKR	Provided by the manufacturer
O&M cost	1000 PKR	

4 Results and Discussion

4.1 Economic Analysis

The economic analysis of solar water heating system (for the given data in Table 2) is performed and discussed in this section. The economic indicators discussed for analysis are NPV, IRR and Payback period [15,16,33–36]. Net present value being sum of present values of individual cash flows is one of the important and decision making financial indicator of any renewable project especially SWH projects

[15,16,33–36]. Higher NPV values indicate the favorableness of that project. While comparing different possible options for investments, preference is given to the investment having highest NPV among them. NPV values for selected SWHs in the selected cities have been calculated using RetScreen financial analysis tool and shown in Figure 3 which ranges from PKR 120089 to 55834 for different cities of the Pakistan (Quetta to Islamabad respectively). Highest NPV is observed for Quetta which is mainly due to the fact that annual average daily ambient temperature of Quetta is minimum compared to other cities (see Table 1) due to which hot water demand is higher in Quetta, causing more energy savings when conventional water heating system is replaced with the solar water heating system with favorable average daily solar radiations (see Table 1) compared to the other cities.

Lowest NPV is observed for Islamabad even the average daily ambient temperature in Islamabad stands at second number after Quetta and also which hot water demand may be higher in Islamabad compared to other cities except Quetta due to ambient temperature. Main reason for the lowest NPV value in Islamabad is the lowest solar radiations among considered cities. To conclude the NPV favors Quetta and Karachi as ideal locations for SWHs utilization. Also that NPV depends both on the available solar radiation and lower ambient temperatures.

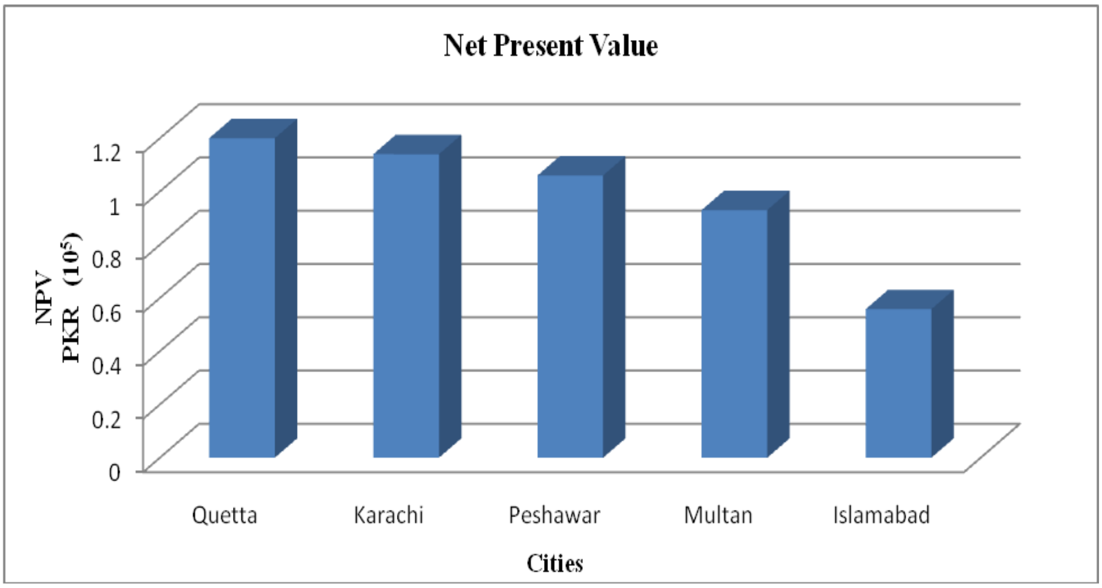

Figure 4: Predicted NPV for selected cities of Pakistan

IRR, time-adjusted rate of return, is the discount rate that makes NPV zero. Similar to NPV, IRR also serves an economic indicator for evaluating an investment of any project. IRR values ranges from 9.3% to 5.1% (Quetta to Islamabad respectively) shown in Figure 4.

Higher value of IRR in Quetta show that Quetta may be an attractive place for the installation of SWH projects while the lower IRR values demonstrate that Islamabad may not be attractive place for the utilization of SWHs.

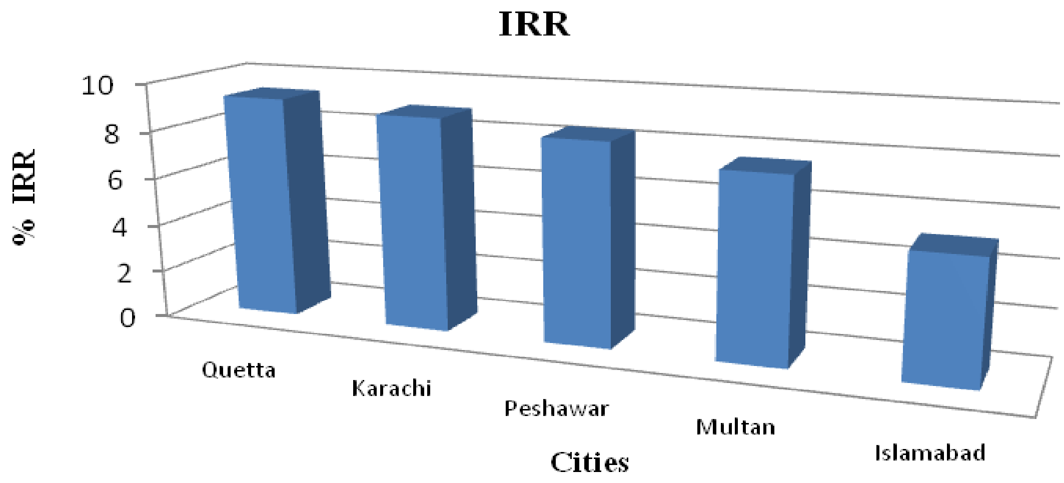

Figure 5: IRR values of SWH projects for the selected cities of Pakistan.

Time length of recoupment of initial costs, out of savings generated, is determined using simple and equity payback periods..It can be observed in Figure 5 that Payback period trend is similar to NPV and IRR, Quetta and Karachi are the favorable places for having low payback periods. Also explained in Table 3 that SWHs in Quetta will save maximum units of natural gas with maximum annual savings compared to the other cities.

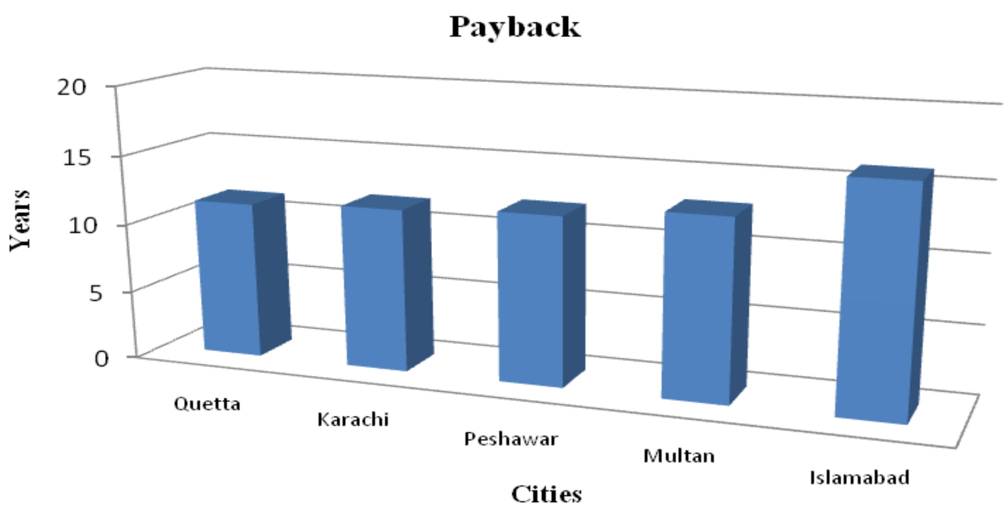

Figure 6: Payback period for selected cities

Table 3: Natural gas consumption for selected cities

Sr No	City	Gas Consumption (mm Btu) ***Without SWHs***	Gas Consumption (mm Btu) ***With SWHs***	Annual Savings (mm Btu /PKR)
1	Quetta	12.2	4.4	7.8/4804
2	Islamabad	11.1	5.5	5.6/2233
3	Peshawar	10.7	3.3	7.4/4243
4	Multan	9.9	3.1	6.8/3722
5	Karachi	9.4	1.8	7.6/4556

4.2 Technical Analysis

Technical parameters which may affect the energy performance SWHs are collector type (unglazed, glazed, evacuated tube, heat pipe) efficiency of the collector, area of collector, slope of collector, losses and storage options [15]. While social aspects are end-use water temperature and hot water quantity used per person at that location. Among these parameters, collector area and slope of the collector has been varied while all other parameters are kept constant. Slope of the collector is varied according to location which is maximized for the winter conditions (Lat+15^{o}). Effect of varying collector area on solar fraction, NPV, IRR and payback period is observed and discussed in selected cities of Pakistan.

i. Affect of Solar collector area on solar fraction

With the increase of SWH collector area solar fraction increases shown in Figure 6. Solar fraction actually tells how much load is met by SWHs. 100% solar fraction mean that whole heating load is met by SWHs and no back up is needed. 80% of solar fraction means that 80% of the load is met by SWHs and rest 20% is met by the given backup. Observed in Figure 6 solar fraction values are highest for Karachi because of high annual average air temperature and moderate solar radiations (see

Table 1) compared to the other cities. For Islamabad low solar radiations are the cause of low solar fraction. Another key observation from Figure 6 is that as the solar collector area is increased, the percentage increase of the solar fraction decreases which is tabulate in Table 4. For example, looking at the Karachi case (Table 4) when solar collector area is increased from $2m^2$ to 4 m^2 increase in the solar gain is 72.5% and when area is increased from $4m^2$ to $6m^2$ increase in the solar gain is reduced to 30.43% and when collector area is increased from $6m^2$ to $8m^2$ solar fraction gain drops to 11.11%.Therefore, it may be concluded that going for 100% solar fraction may not be advantageous from economic point of view. And it may be a good approach to get the 60% to 70% (solar fraction) of the hot water load from SWHs and rest 40% to 30% from hybridization which in this case is gas.

ii. Affect of Solar collector area on NPV, IRR and Payback period.

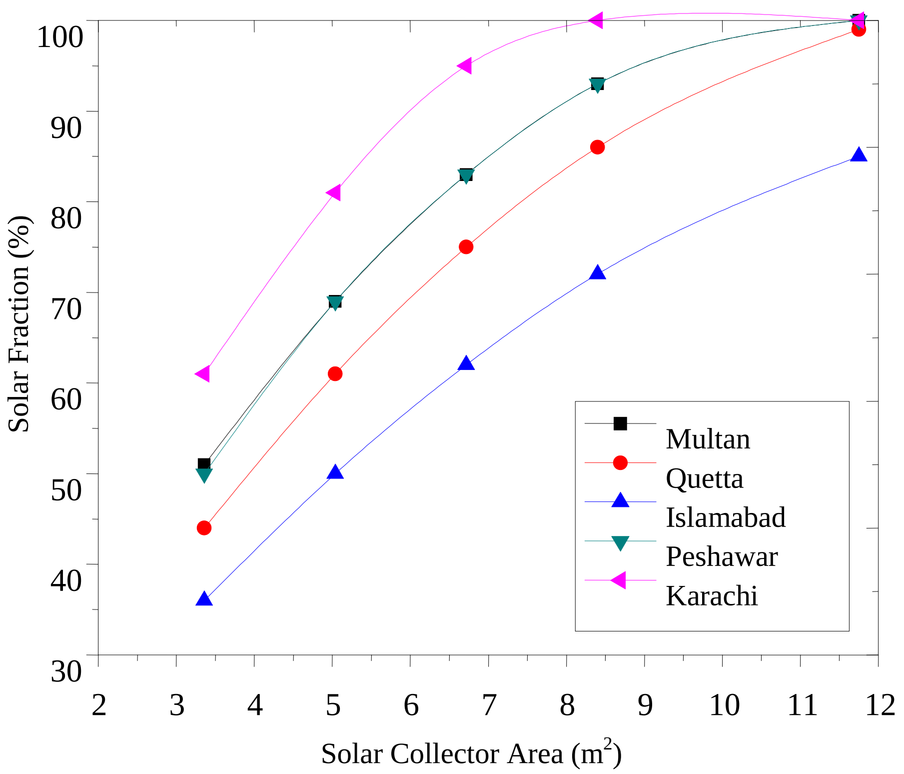

Figure 7: Predicted solar fraction for selected cities across varying solar collector area.

Table 4: Increment of solar collector area vs. increment in solar gain

Annexure III

Sr. No.	Collector Area increment (m^2)	Increment in Solar Fraction (%)				
		Karachi	Islamabad	Quetta	Peshawar	Multan
1	2-4	72.5	78.26	82	81.25	75.8
2	4-6	30.43	39	37.3	32.8	34.5
3	6-8	11.11	22.8	20	18.2	16.7

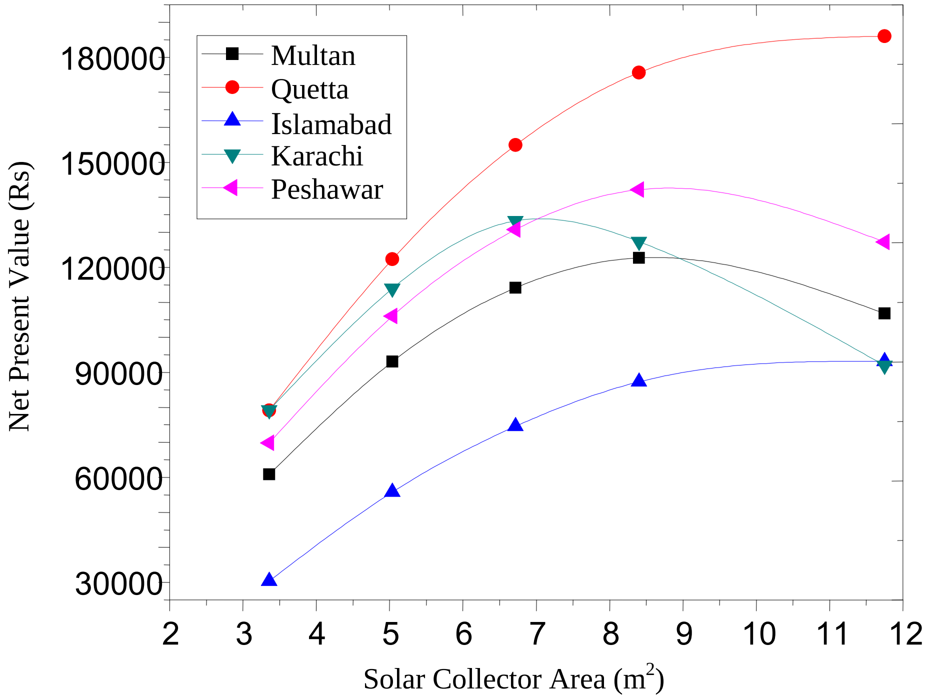

Figure 8: Trend of NPV vs Collector Area for selected cities

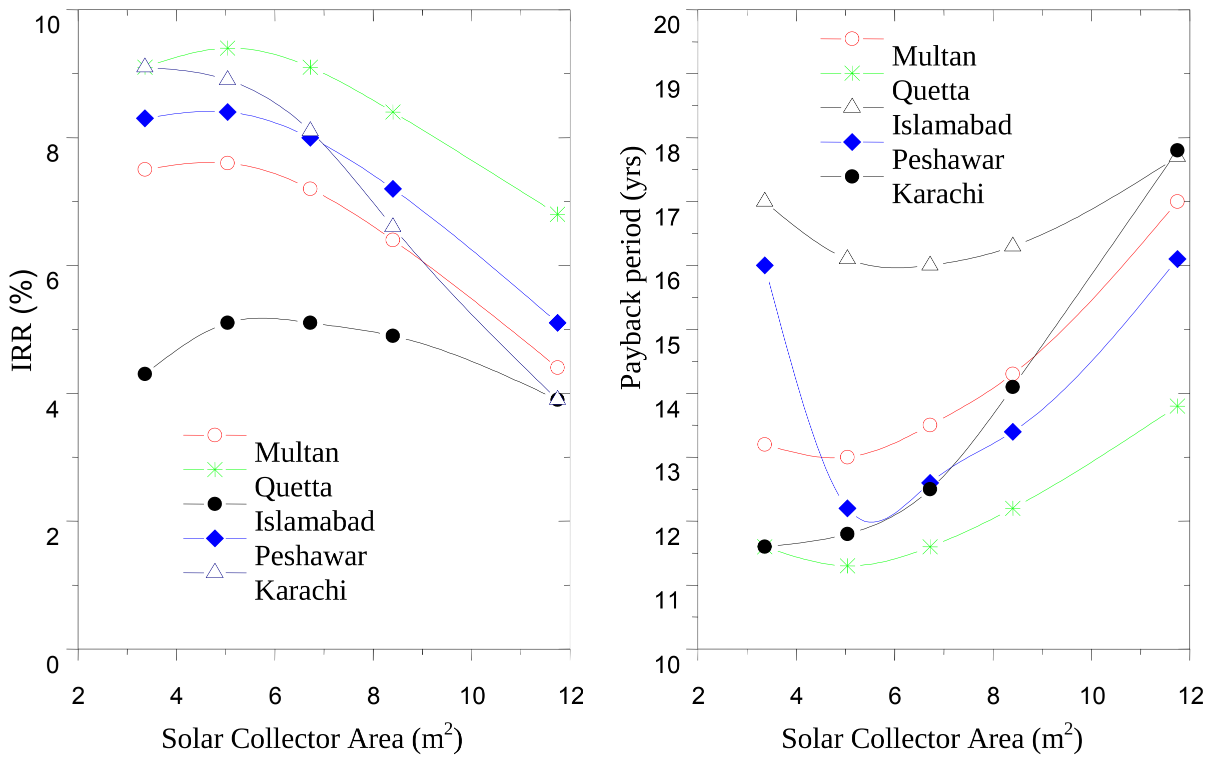

Figure 9: Affect of Solar collector area on IRR and Payback period

Highest values of the IRR is achieved at the collector area of 5m^2-7m^2 for all selected cities (Figure 8,IRR verses collectors area) and after that these value decreases significantly. Also for these collector areas, 5 m^2-7 m^2, payback time period (Figure 8, Payback period verses collectors area) is also minimum for all the cities which increase as the collector area is increased. Increase in Payback period and decrease in the IRR shows that by increasing the collector area from 5m^2-7 m^2 the SWHs may not be an attractive option from the consumer point of view. Also it can be observed that that Payback time period is significantly high for most of the selected cities which can be significantly decreased if government based subsidies are provided for the solar water heating system consumers as in some other countries [14,16,18,29]. In some cases it is found that 20% government subsidy can reduce the payback time period up to five years from ten to eleven years [16].

These economic parameters along with technical parameters favor Quetta as an ideal location where solar water heating system may be used (for domestic sector) with maximum benefits in monetary terms and in terms of fuel savings. Similarly the cost benefit analysis for the installation of SWHs for other cities of Pakistan can be observed easily through the behavior of the curves shown in Figures 8&9.

5 Conclusions and Recommendations

A techno economic analysis has been conducted for solar water heating system for the domestic sector of Pakistan using RETScreen software. The analysis was conducted for different cities having different climatic conditions. It was found that to make SWHs more attractive for the domestic consumer from economic point of view, solar fraction, should be kept within the range of 50% to 70% and rest of the energy should be obtained from other fuels like gas or biomass. Results show that such installation is always profitable, having simple payback period of 10–12 years without any government subsidy. The economic indicators along with technical parameters favor Quetta as an ideal location where solar water heating system may be used with maximum benefits in monetary terms and in terms of fuel savings compared to the other cities. IRR and NPV and payback periods can serve as good indicators to analyze the applicability of SWHs in any area. It is demonstrated that in all the major cities of Pakistan SWHs can share the ~60% water heating load of the domestic sector where natural gas is being used extensively to fulfill this load which can be a good option to reduce the natural shortage that Pakistan’s domestic sector faces during winter season. Also SWHs can be helpful in reducing the building related GHG emissions in Pakistan. RETScreen emission analysis shows that such typical SWH system save 7mmBtu of natural gas. SWHs can be more attractive for the domestic consumer in Pakistan if government provides subsidy on renewable energy related products. These subsidies will be helpful in reducing the net payback period of the SWHs.

References

[1] K. Kaygusuz, A. Kaygusuz, Renewable energy and sustainable development in Turkey, Renewable Energy. 25 (2002) 431–453.

[2] Y. Matsuo, A. Yanagisawa, Y. Yamashita, A global energy outlook to 2035 with strategic considerations for Asia and Middle East energy supply and demand interdependencies, Energy Strategy Reviews. (2013) 1–13.

[3] TWAS, Sustainable energy for Developing Countries, 2008.

[4] I.N. Kessides, Chaos in power: Pakistan's electricity crisis, Energy Policy. 55 (2013) 271–285.

[5] M.A. Javaid, S. Hussain, Z. Arshad, Electrical Energy Crisis in Pakistan and Their Possible Solutions Abstract :, International Journal of Basic & Applied Sciences. 11 (2011) 38–52.

[6] P.H. Shaikh, F. Shaikh, M. Mirani, Solar energy: Topographical asset for Pakistan, Applied Solar Energy. 49 (2013) 49–53.

[7] M. Sheikh, Renewable energy resource potential in Pakistan, Renewable and Sustainable Energy Reviews. 13 (2009) 2696–2702.

[8] M. Sheikh, Energy and renewable energy scenario of Pakistan, Renewable and Sustainable Energy Reviews. 14 (2010) 354–363.

[9] M.A. Khan, N. Latif, Environmental friendly solar energy in Pakistan's scenario, Renewable and Sustainable Energy Reviews. 14 (2010) 2179–2181.

[10] U.K. Mirza, M.M. Maroto-Valer, N. Ahmad, Status and outlook of solar energy use in Pakistan, Renewable and Sustainable Energy Reviews. 7 (2003) 501–514.

[11] M.S. Khalil, P. Minister, Renewable Energy in Pakistan : Status and Trends Pakistan Alternative Energy Development Board ,, (2004).

[12] M. Raisul Islam, K. Sumathy, S. Ullah Khan, Solar water heating systems and their market trends, Renewable and Sustainable Energy Reviews. 17 (2013) 1–25.

[13] I. Ruble, P. El Khoury, Lebanon’s market for domestic solar water heaters: Achievements and barriers, Energy for Sustainable Development. 17 (2013) 54–61.

[14] R. Shukla, K. Sumathy, P. Erickson, J. Gong, Recent advances in the solar water heating systems: A review, Renewable and Sustainable Energy Reviews. 19 (2013) 173–190.

[15] A. Gastli, Y. Charabi, Solar water heating initiative in Oman energy saving and carbon credits, Renewable and Sustainable Energy Reviews. 15 (2011) 1851–1856.

[16] S. Stevanović, M. Pucar, Financial measures Serbia should offer for solar water heating systems, Energy and Buildings. 54 (2012) 519–526.

[17] P.-L. Chang, S.-P. Ho, C.-W. Hsu, Dynamic simulation of government subsidy policy effects on solar water heaters installation in Taiwan, Renewable and Sustainable Energy Reviews. 20 (2013) 385–396.

[18] T.-C. Pan, J.-J. Kao, C.-P. Wong, Effective solar radiation based benefit and cost analyses for solar water heater development in Taiwan, Renewable and Sustainable Energy Reviews. 16 (2012) 1874–1882.

[19] I.R. Pillai, R. Banerjee, Methodology for estimation of potential for solar water heating in a target area, 81 (2007) 162–172.

[20] H. Cassard, P. Denholm, S. Ong, Technical and economic performance of residential solar water heating in the United States, Renewable and Sustainable Energy Reviews. 15 (2011) 3789–3800.

[21] C.J. Koroneos, E. a. Nanaki, Life cycle environmental impact assessment of a solar water heater, Journal of Cleaner Production. 37 (2012) 154–161.

[22] P. Purohit, A. Michaelowa, CDM potential of solar water heating systems in India, Solar Energy. 82 (2008) 799–811.

[23] B. Chandrasekar, T.C. Kandpal, Techno-economic evaluation of domestic solar water heating systems in India, 29 (2004) 319–332.

[24] J. Duffie, W. Beckman, Solar Engineering of Thermal Processes, 2nd Ed, Wiley-Interscience, New York, 1991.

[25] RETScreen Software Online Manual, RETScreen International Clean Energy Decision Support Centre, Ottawa, Canada. Available at http://www.retscreen.net/ang/home.php, (2013).

[26] A. Houri, Solar water heating in Lebanon: Current status and future prospects, Renewable Energy. 31 (2006) 663–675.

[27] J.G. Fantidis, D. V Bandekas, C. Potolias, N. Vordos, K. Karakoulidis, Financial Analysis of Solar Water Heating Systems during the Depression : Case Study of Greece, 23 (2012) 33–40.

[28] F. Atabi, E.M. Namini, A. Rasooli, Investigating the Feasibility of Applying Integrated Photovoltaic and Solar Water Heating Systems in Residential Buildings, 33 (2012).

[29] R. Zeynab, M. Omid, A. Keyhani, Feasibility and Project Viability Analyses for Installing SWH Systems In Greenhouses Of Alborz Province Of Iran Using RETSCREEN, Electronic Journal of Environmental, Agricultural and Food Chemistry. 11 (2012) 565–577.

[30] T. Muneer, S. Maubleu, M. Asif, Prospects of solar water heating for textile industry in Pakistan, Renewable and Sustainable Energy Reviews. 10 (2006) 1–23.

[31] PMD, Pakistan Meteorological and Climatological Data processing centre. Available at www.pakmet.com.pk/, (2013).

[32] USAID, Pakistan Energy Sector Overview Pakistan, (2012) 1–13.

[33] A.H. Mondal, A.K.M.S. Islam, Techno-economic Feasibility of Grid Connected Solar PV System in Bangladesh, (n.d.).

[34] A.H. Mirzahosseini, T. Taheri, Environmental, technical and financial feasibility study of solar power plants by RETScreen, according to the targeting of energy subsidies in Iran, Renewable and Sustainable Energy Reviews. 16 (2012) 2806–2811.

[35] a. H. Al-Badi, M.H. Albadi, a. M. Al-Lawati, a. S. Malik, Economic perspective of PV electricity in Oman, Energy. 36 (2011) 226–232.

[36] A. Khalid, H. Junaidi, Study of economic viability of photovoltaic electric power for Quetta – Pakistan, Renewable Energy. 50 (2013) 253–258.