Power demand optimization potential of solar hot water systems in green buildings

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Abstract –
This paper proposes a dynamic approach based on the simulated model for the domestic hot water system (DHWS) production based on different solar collectors. To optimize the electric energy due to the extensive use of electric showerheads in many dwelling the proposed system uses a two reservoir solar domestic hot water system. The dynamic approach towards the evaluation of hour by hour energy collected by the solar panels and the hot water produced temperature by the system gives a fully fledged report on daily consumption profile with respect to the net thermal energy generated by the solar collectors (SCF).The comparison between the solar coverage factor of different solar collectors (unglazed, glazed and evacuated collectors) and the simulation based on the HOMER AND RET Screen software is shown that the result strictly point out on the daily consumption profile by solar coverage factor and the hourly consumption profile.

Key Words: Domestic hot water system, peak energy optimization, solar thermal system, SCF.

1. INTRODUCTION

Variable energy sources contribute to rise the degree of energy supply due to the improving part of renewable energy sources. Hence energy storage is an important issue related to both thermal storage and electrical storage technology. Compact storage enhances high storage capacities that are needed for an efficient use of both the forms of energy. Domestic space heating hot water stores commonly uses in the field of thermal energy storage system.

The rate of development of solar hot water system is increasing for various industrial, commercial and domestic applications. This results a significant competition on improving the efficiency and developing the new technologies. Evacuated tube collectors among the stationary solar collectors have captivated more attention because of the reliability, cost-effectiveness and its satisfactory performance.

Wide range of using ETCS achieves high efficiency compared with FPCs and also occupied very less area for similar kind of load.ETC are less sensitive to the size of the storage tank it able to deal with a large gap between ambient to fluid temperature due to the insulation caused by the vacuum between outer and inner tubes. All glass direct flow ETC and heat pipe are the two main categories of ETCs, in a heat pipe a volatile fluid is used for the exchange of heat with circulating water as shown in fig.1. the fluid circulating in all-glass direct flow ETC are divided into two categories i.e. forced and natural circulation. Where normal water delivered to individual evacuated tubes by a cold manifold and returned via hot manifold as depicted in fig 1b. In passive circulation water circulates naturally through the single ended tubes as shown in fig.1c

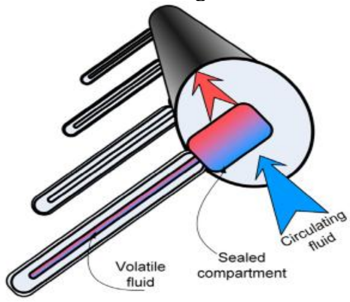

Fig.1a:- Heat pipe for ETC

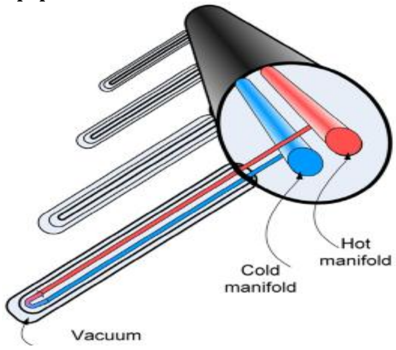

Fig.1b; All glass active circulation for ETC

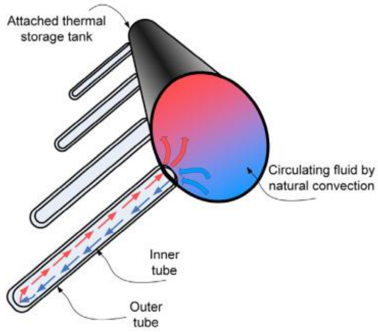

Fig.1c; All glass passive circulation for ETC

2. Optimization of solar hot water system:-

The proposed model for the concentric solar hot water system consists of two parts. The first one is the dynamic sub-model that simulates the solar components by a single evacuated tube at any time interval in the presence of DFR. The proposed sub model is optimized into two stages for each zone. The first stage of optimization is the angular parameters like azimuth (γ),tilt (β), angles of the collector as shown in the figure. 3. and the second optimization is the physical parameters that is the central distance between the centre of tubes to DFR(S) and adjacent tubes(B) as shown in the fig.4.

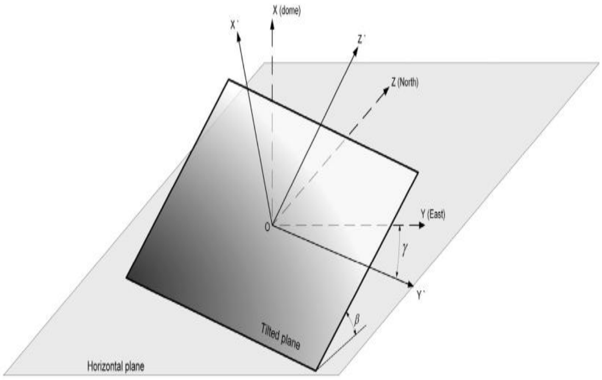

Fig.3:- Angular parameters in xyz-coordinates

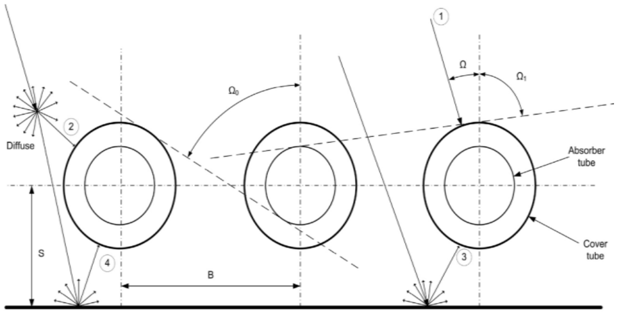

Fig.4:- diffused flat reflector

The second model simulates the heat
Parameters of the solar collector connected to a storage tank with a advanced dynamic hot water load profile. Unlike in passive circulation the fluid flow rate is a natural circulation which fluctuates throughout the day, but the rate of flow in active circulatory system is almost controlled by a constant flow rate of the attached pump. The operation of pump is guided by an external mechanism depending on the various applications. For a building hot water system, the dimension and sizing of the components like storage tank volume, pump flow rate, collector size are directly relevant to the governed load on seasonal and daily load patterns. In active system the use of diffused flat reflector is justifiable when the ratio of thermal input to the heating demand is comparatively low. The cause of low ratio may happen because of various reasons, like the low clearness index or low solar radiation hours (fig.5) especially at winter seasons, large load size, limitations in the feasible area or orientation of the solar collectors.

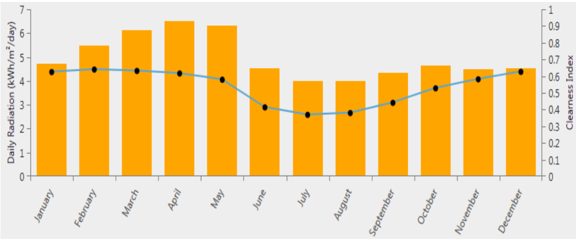

Fig.5:- Daily radiation and clearness index.

In this sub model a solar thermal collector consists of some evacuated tubes connected parallel to the inlet and outlet terminal. the circulating water in the loop is directly mixed with the hot water tank without any heat exchange effect. A controller regulates the circulation of water in the solar controller by using a pump as shown in the fig.6. the hot water flows out from the top of the storage tank to a instantaneous gas booster to measure the temperature of hot water if the temperature is below the pre determined system temperature then the size of the storage tank must be updated.

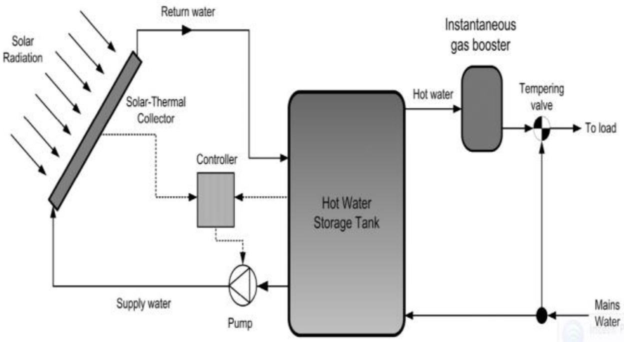

Fig.6: schematic of an solar hot water system.

3. Evaluation standard for solar hot water system in green building:-

To ensure the application, test and evaluation for a renewable energy project for a proposed green building some evaluation standard is required when project construction finished. The evaluation method includes performance qualification, index evaluation and performance grading. Actual testing data of long term or short term tests should be considered for the evaluation. Evaluation should mainly focus on performance, economic benefits, energy efficiency and emission reduction effect.

Different evaluation indexes are solar fraction ratio, solar collector system efficiency, hot water storage tank heat loss, heating water temperature, static payback period, co_2,so_2 dust emission reduction amount etc. Among the list of index solar fraction ratio is the very important index to calculate the performance of solar hot water system. It is the total percentage of solar heat required for the total energy consumption in hot water system. Another method of

calculating the solar fraction ratio is based on the short and long term monitoring of daily solar radiation. Normally short term measures are applied due to the limitations in test cycle.
Solar fraction ratio for different range of solar radiation is given as

$$F=(x_1f_1+x_2f_2+x_3f_3)/(x_1+x_2+x_3)$$

Where x_1,x_2,x_3 are the no of days and f_1,f_2,f_3 are the corresponding solar fraction ratio.

4. SIMULATION PROCEDURE

Designing of solar Hot water systems involves many key parameters. A badly sized or estimated capacity of the Solar Hot water system causes to produce more electricity bills. All the users in GEIT campus are using electricity for hot water purposes.
Manually calculated results are available in chapter 3. But, manual calculations will not give accurate results. Staff quarter's case has been taken for simulation and analyzed with RETScreen software.

4.1 Staring procedure

An analysis has been considered for GIET staff quarters situated in Gunupur; Odisha with latitude of 19.2^0 and longitude of 83.49^0.

Step 1: Starting worksheet

Clean Energy Project Analysis Software

Project information	See project database
Project name	GIET-Gunupur
Project location	Gunupur
Prepared for	B.Tech Project
Prepared by	Batch-B11
Project type	Heating
Technology	Solar water heater
Analysis type	Method 1
Heating value reference	Lower heating value (LHV)
Show settings	☑
Language - Langue	English - Anglais
User manual	English - Anglais
Currency	Rs
Units	Metric units

Fig.4.1 starting worksheet of Software

The project type to be selected Heating, this is of institutional facility type and the analysis method is considered as method 1. The Heating value reference is considered as HHV. This is of International wide software hence we can get the currency what we required. Here currency to be chosen as INR. The climatic data conditions are obtained for this location which is included in Site reference conditions.

Step 2: For selecting climate location:

To access the RETScreen Climate Database click on the "Select climate data location" hyperlink or use the RETScreen menu or toolbar.

	Unit	Climate data location	Project location
Latitude	°N	19.9	19.9
Longitude	°E	83.2	83.2
Elevation	m	498	498
Heating design temperature	°C	14.5	
Cooling design temperature	°C	33.8	
Earth temperature amplitude	°C	16.9	

Month		Air temperature	Relative humidity	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days	Cooling degree-days
		°C	%	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January		20.4	56.0%	4.84	97.2	2.7	22.1	0	323
February		23.4	54.9%	5.54	97.1	2.9	26.1	0	375
March		27.3	49.1%	6.07	96.8	3.2	31.1	0	536
April		28.6	55.7%	6.45	96.5	3.5	32.1	0	558
May		29.5	60.4%	6.21	96.2	3.2	32.6	0	604
June		27.8	74.9%	4.25	95.9	3.4	29.2	0	534
July		26.4	80.7%	3.47	96.0	3.5	27.1	0	508
August		25.9	81.9%	3.39	96.1	3.4	26.4	0	492
September		25.7	79.9%	4.11	96.4	2.5	26.4	0	470
October		24.3	74.7%	4.71	96.8	2.7	25.0	0	443
November		22.2	60.3%	4.63	97.1	3.2	22.9	0	366
December		20.1	53.3%	4.59	97.3	3.0	21.1	0	314
Annual		25.1	65.2%	4.85	96.6	3.1	26.8	0	5,522
Measured at	m					10.0	0.0		

Fig.4.2: Gunupur Climate data sheet

Fig. 4.2 is the extension of first window which show the data of climatic conditions of the considered location. While the latitude and longitude values are entered, the values of Air temperature, Relative humidity, Daily radiation-horizontal, Atmospheric, wind speed, Earth temperature, Heating Degree days, Cooling degree days are obtained for monthly basis. The data obtained is only for reference purpose not to run the model.

Step 3: Energy Model

Heating project

Technology		Solar water heater	
Load characteristics			
Application		○ Swimming pool	
		⦿ Hot water	

	Unit	Base case	Proposed case
Load type		House	
Number of units	Occupant	70	
Occupancy rate	%	90%	
Daily hot water use - estimated	L/d	3,780	
Daily hot water use	L/d	3,000	3,000
Temperature	°C	100	70
Operating days per week	d	4	4
☐ Percent of month used			
Supply temperature method		User-defined	
Water temperature - minimum	°C	15	
Water temperature - maximum	°C	30	

	Unit	Base case	Proposed case	Energy saved
Heating	MWh	56.5	34.6	39%

Fig.4.3: Energy model worksheet

The fuel type is of Electricity at a unit rate of 4.1 Rs/Kwh. The scheduled working days are of 24 days on an average for a month.

Step 4: Selecting the Solar Hot water system

Typical cost data required to prepare RETScreen studies are provided in the RETScreen Online Cost Database and in the Online Manual. This database is built into the "right-hand column" of the Cost Analysis worksheet.

Resource assessment				
Solar tracking mode		Fixed		
Slope	°	40.0		
Azimuth	°	0.0		
Show data				
Solar water heater				
Type		Glazed		INR 272,675
Manufacturer		Tata BP Solar India		
Model		TBTP 24M1		
Gross area per solar collector	m²	2.31		
Aperture area per solar collector	m²	2.31		
Fr (tau alpha) coefficient		0.69		
Fr UL coefficient	(W/m²)/°C	4.20		
Temperature coefficient for Fr UL	(W/m²)/°C²	0.010		
Number of collectors		14	20	
Solar collector area	m²	32.34		
Capacity	kW	22.64		
Miscellaneous losses	%	2.0%		

Step 5: Economical considerations with base case and proposed case

Balance of system & miscellaneous				
Storage		Yes		
Storage capacity / solar collector area	L/m²	93		
Storage capacity	L	3,007.6		
Heat exchanger	yes/no	No		
Miscellaneous losses	%	1.0%		
Pump power / solar collector area	W/m²	0.00		
Electricity rate	INR/kWh	0.110		
Summary				
Electricity - pump	MWh	0.0		
Heating delivered	MWh	23.4		
Solar fraction	%	39%		
Heating system				
Project verification		**Base case**	**Proposed case**	
Fuel type		Electricity	Electricity	
Seasonal efficiency		100%	100%	
Fuel consumption - annual	MWh	99.0	37.2	MWh
Fuel rate	INR/kWh	4.100	4.100	INR/kWh
Fuel cost	INR	405,696	152,529	

Fig.4.4: comparison of base case and proposed case

Here, the entire analysis with the energy saving results will be calculated and compared between base case and proposed case. This section summarizes key information for the base case and proposed case facilities, including detailed information for each fuel type used, as well as fuel consumption and annual energy use information for heating, cooling and electricity. This section also provides a tool to allow the user to benchmark their project for various energy and reference units.

Step 6: payback period calculation

Financial parameters			
Inflation rate	%	2.5%	
Project life	yr	20	
Debt ratio	%	85%	
Debt interest rate	%	5.00%	
Debt term	yr	5	
Initial costs			
Heating system	INR	272,675	87.2%
Other	INR	39,918	12.8%
Total initial costs	INR	312,593	100.0%
Incentives and grants	INR		0.0%
Annual costs and debt payments			
O&M (savings) costs	INR	-10,000	
Fuel cost - proposed case	INR	152,529	
Debt payments - 5 yrs	INR	61,371	
Other	INR		
Total annual costs	INR	203,900	
Annual savings and income			
Fuel cost - base case	INR	405,696	
Other	INR		
Total annual savings and income	INR	405,696	
Financial viability			
Pre-tax IRR - equity	%	447.7%	
Pre-tax IRR - assets	%	71.1%	
Simple payback	yr	1.2	

Fig. 5.5: Summary of the results

Step7: Financial Analysis and summary of results:

As part of the RETScreen Clean Energy Project Analysis Software, a Financial Summary worksheet is provided for each project evaluated. This common financial analysis worksheet contains six sections: Annual Energy Balance, Financial Parameters, Project Costs and Savings, Financial Feasibility, Yearly Cash Flows and Cumulative Cash Flows Graph. The Annual Energy Balance and the Project Costs and Savings sections provide a summary of the Energy Model, Cost Analysis and GHG Analysis worksheets associated with each project studied. In addition to this summary information, the Financial Feasibility section provides financial indicators of the project analyzed based on the data entered by the user in the Financial Parameters section. The Yearly Cash Flows section allows the user to visualize the stream of pretax, after-tax and cumulative cash flows over the project life.

By observing the results of Fig. 5.5 the payback period is 1.2 years only and the total energy saving is 21,900 units.

5.3 Conclusion

The cost of conventional energy sources will continue to increase, and the reliability of foreign energy imports will continue to be questionable at best. We are overdue in making a serious effort to apply the sun's energy to complement a larger portion of our ever-increasing energy needs. The most appropriate and cost-effective large-scale application of solar energy involves the heating of water for domestic use and the generation of electricity for grid-tied residential use. One of the popular devices that harness the solar energy is solar hot water system (SHWS). The design of solar hot water system depends on heat requirement, weather conditions, heat transfer fluid quality, space availability, annual solar radiation, etc. The SHW systems are economical, pollution free and easy for operation. Modeling, prediction and validity of the SHW systems is a complex problem and difficult to analyze with actual working conditions.

REFERENCES

[1] G.R.K.D. Satya Prasad, "Energy and Comfort Management in Energy Efficient Buildings Using RETSCREEN Software-A Case Study Analysis" in International Journal of Engineering Research and Application ISSN: 2248-9622, Vol. 3, Issue 6, Nov-Dec 2013, pp.378-381

[2] Tsai, H. Design and evaluation of a Photovoltaic/Thermal-assisted heat pump water heating system. Energies; 2014; **7**: 3319-3338.

[3] Morini, G.L., Piva, S. The simulation of transients in thermal plant. Part II: Applications. Applied Thermal Engineering;2008; **28**, (2-3), p. 244-251

[4] Da Silva, R. M., Fernandes, J. L. M. Hybrid photovoltaic/thermal (PV/T) solar systems simulation with Simulink/Matlab. Solar Energy; 2010; **84**: 19

[5] Italian Legislative Decree No 28 of 3 March 2011: Implementation of Directive 2009/28/EC on the Promotion of the Use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC; 2011

[6] Klein, S.A. et al. A design procedure for solar heating systems. Solar Energy; 1976; **18** (2): 113-127.

[7] Italian standard UNI/TS 11300-4: Energy performance of buildings - Part 4: Renewable energy and other generation systems or space heating and domestic hot water production; 2012.

[8] Chen, Y. Treado, S. Development of a simulation platform based on dynamic models for HVAC control analysis. Energy and Buildings; 2014; **68**: 376-386