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Optimal Performance Analysis of Hybrid Photo-Voltaic/Thermal-Geothermal System in Critical Geographical Locations

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***Abstract* – Environmentally friendly solar and geothermal renewable energy sources provide space heating, hot water, cold water and electrical energy to residents in cold geographical locations by using hybrid PV/thermal system along with energy efficient ground source heat pump technology. A hybrid geothermal-solar power plant utilizes ground as a heat source or a sink for heating and cooling. This paper presents the simulation studies on hybrid geothermal-solar power plant by using the renewable energy software, POLYSUN, on ground source loop regeneration by hybrid PV/thermal system considering seven critical geographical locations in India. Important parameters which significantly affect the system performance on four geothermal hot spring areas and three non-spring areas are analyzed. Simulation test results of important parameters such as CO_2 savings, power fed to the external grid, total energy demand etc., are compared and the most feasible optimal locations to install the hybrid system which provides space heating, hot water, and electrical energy is selected.**

Keywords-photo-voltaic/thermal technology, geo-thermal hot spring areas, solar-geothermal hybrid system, ground source heat pump, polysun software

I. INTRODUCTION

A hybrid system with two distinct renewable energy sources such as solar and geothermal, offers benefits of full-scale space heating, cooling and hot water in all seasons in rural and remote areas. In addition to the solar assisted geothermal systems, a geothermal heat pump or Ground Source Heat Pump (GSHP) provides efficient heat distribution which is not affected by the outside weather conditions. Since the heat pump uses the ground as a heat source or a sink for heating and cooling, respectively, the excess of heat produced by the solar collectors is discarded by the heat pump and store a part of it for the winter. A GSHP requires drilling boreholes into the soil at depths of about 50 to 115 meters and laying underground pipes type heat collector, in order to be functional.

The potential of a GSHP system is based on groundwater condition and temperature structure of underground. Employing a hybrid renewable energy system and GSHP, energy efficiency and the Coefficient of Performance (COP) can be improved. Hybrid Photovoltaic Thermal (PVT) technology employs solar panels with solar thermal collectors in a wide range of configurations and designs. In addition to PV/thermal collector, the solar-geothermal system model also includes a heat pump, battery and a dc/ac converter. In general, geothermal hot springs are used for space heating in certain places where outdoor temperature falls below 10 ^{0}C. The temperature gradient of most of the hot springs in India varies between 30 ^{0}C to 96 ^{0}C which are low temperature hot springs suitable only for heating applications.

The application of simulation models for space heating and cooling of residential buildings is recently gaining interest and a number of researchers explained the importance of solar assisted geothermal systems with GSHP. The application of geothermal heat pumps with solar thermal collectors is reported in [1, 2]. The importance of system performance with a combination of GSHP and solar collectors for residential purpose is suggested in [3, 4]. Similarly, investigations by experimental and simulation studies on GSHP and solar collectors are carried out in [5, 6]. The authors in [7] analyzed the performance of GSHP and solar collectors with different configurations of plant systems in cold climate by using simulation tool TRANSYS software. A study on the application of GSHP in a double U-tube bore hole using solar PVT collectors is reported in [8]. Investigations carried out on a PVT system which utilizes a small-scale solar heating and cooling system are reported in [9]. A GSHP system integrated with solar PVT collectors for residential applications is developed in [10] by using software tool TRANSYS. A mathematical model developed for a hybrid solar-geothermal air conditioning system to estimate the cooling and heating energy demands of a residential building is reported in [11]. The performance analysis of a hybrid plant operating in two modes, namely, (i) as a binary geothermal power plant and (ii) as a hybrid geothermal-solar power plant, is presented by the authors in [12]. In [13] hybridization of a geothermal power plant and solar parabolic trough collector performance parameters are analyzed by using System Advisory Model software.

The published research study mainly discussed on performance of hybrid PVT-geothermal systems for heating and cooling at one location. The present study proposed a feasible optimal location among seven critical locations for the installation of a hybrid solar-geothermal system. Important parameters such as global irradiation, CO_2 savings, power fed to the external grid, heating energy demand, heat pump fuel/electrical consumption, total energy demand etc., are considered which strongly influence the performance of hybrid system at different locations.

This paper focuses on developing a hybrid **PVT** system together with a geothermal heat pump or **GSHP** that adopts a ground source loop regeneration to produce space heating, cooling and hot water for a small residential building. The heat collected from the hybrid PV/thermal collector can be stored in the borehole which is recovered later. A major advantage of the proposed system is less electricity consumption. In addition, the hot water and space heating are produced by the system itself along with electricity production.

A geothermal heat pump is embedded with two main components, a heat pump situated inside the building and a loop field, the piping system under the earth is arranged outside the building. The heat pump exchanges the heat to and from the ground. Considering several factors such as climate, size of the home, location etc., which decide the total installation cost, the heat pump and ground loop are selected. However, based on the available location area, a horizontal or a vertical loop field is selected [14].

A ground source heat pump, normally called as Earth Energy System (EES) makes use of earth or ground water or sometimes both, as a heat source in winter and as a sink in summer. The ground source heat pump raises the temperature of the extracted heat from the ground by the anti-freeze mixture and transfers to the indoor air. During summer the process gets reversed. Based on the requirement, the pump can be installed like heat only systems, heating with passive cooling and heating with active cooling. The refrigerant which is colder than the outside temperature circulates through the piping and absorbs the heat under the earth. In winter, an anti-freeze liquid solution like propylene glycol with water is pumped into the pipes and the solution is passed which absorbs the surrounding temperature of the earth mostly 10 ^{o}C. In the heated state the anti-freeze solution enters a heat exchanger which is used to transfer the heat to the heat pump which then is transferred to the indoors to heat the space. Then the anti-freeze solution gets cooled and goes back to pipes again and then the cycle repeats.

Both space heating and domestic hot water in residential buildings account for a large portion of energy consumption. Ground source heat pumps are ideal for space heating with less CO_2 emissions. Alternative energy sources like geothermal and solar energy have a great potential to meet the demand of residential buildings as it stores excess solar heat in ground during summer. Particularly in a period of very freezing and snow falling weather in certain areas, hybrid PV/thermal and ground source heat pumps system is the best technology to meet the heating demand along with electricity demand. In recent years, the use of renewable energy systems in buildings, to restrict fossil fuel use and CO_2 emissions, has gained a great attention. However, there are concerns about the system performance reliability as solar energy works intermittently. Hence a GSHP is used along with a hybrid PV/thermal system to provide domestic hot water, space heating, cold water, and offset the need of grid electricity by the use of PV panels. The cogeneration of heating and electricity can produce more renewable energy over a roof area. Seasonal performance of the system can be significantly increased by solar heat and regeneration of ground back to normal temperatures during winter.

In a hybrid PV/thermal collector, the solar panel temperature is reduced by water flow in the collector tubes. Thus, with a single panel the increase in efficiency of the system delivers two productive outputs (DHW, electricity) [15, 16]. The heated water can be used to regenerate the ground source loop and the generated heat can be recovered in both short and long terms. In addition, the solar collector can be more efficient and the elevated temperatures of boreholes improve the efficiency of the heat pump enhancing the overall performance of the system.

Space heating is possible by heat pump as it transfers the heat from the under-ground to the indoors [16]. The heat pump heats the buffer tank thus the water in the buffer tank gets heated up which can be used for hot water. As the hot water density is less, the hot water moves up and cold water is tapped from the bottom of the tank. Power that was generated can be fed to electric grid. But the optimization of the system is a bit difficult as there are number of configurations, parameters, options in design of the system which affect the performance.

The developed model in this paper employs validated system components and sub-component models. This paper mainly focuses on the simulation studies of a hybrid PV/thermal system model by using the renewable energy software tool, POLYSUN computing environment with an easy-to-use, menu-driven, graphical user interface for designing hybrid solar-geothermal heat pump systems. Besides, adopting a ground source loop regeneration the software tool is effectively used to combine solar-thermal, photovoltaic and geothermal systems in seven critical geographical locations of India. Identifying such moderate to low temperature regions of seven geographical critical locations in India, i.e. Sidhapura-Kodagu (Coorg, Karnataka), Kasol (Himachal Pradesh), Chumathang (Jammu and Kashmir), Manikaran (Himachal Pradesh), Araku (Andhra Pradesh), Lamayuru (Jammu and Kashmir), Ooty (Tamil Nadu), component modelling and analysis is carried out on the hybrid solar PV/T-geothermal system model. Temperature at Kodagu varied from 10 ^{0}C to 25 ^{0}C throughout the year. At Kasol, Chumathang, Manikaran, Lamayuru regions, the temperatures vary from -5 ^{0}C to 11 ^{0}C. At Ooty the average temperature is around 16 ^{0}C. Araku experiences moderate climate throughout the year but in winter in the evening the temperature drops below 10 ^{0}C.

The hybrid system model is considered for a seven-member family house. As the average domestic hot water consumption is 50 litres per person per day, the system is designed for 350 litres of hot water per day at 47 ^{0}C. An average/mean temperature of cold-water supply is assumed as 10 ^{0}C which is a constant parameter. The distribution of domestic hot water varied from season to season, day to day and family to family. A flow chart, Fig. 1, is presented to conduct a simulation procedure by POLYSUN on the hybrid system.

The present system as shown in Fig. 2 consists of main components like hybrid PVT collector, heat pump, borehole heat exchanger, storage tank. A total gross area of 35 m^2 is used to generate thermal and electrical output of 5.9 kW. A heat pump of 10 kW is used to transfer the heat from the ground source loop to the portable storage tank. The heating set point temperature was set to 20 ^{0}C. Bi-axial tracking is employed for the system in all the locations to obtain the maximum power. The double U-pipe system is considered as it is better than single U-pipe [17]. hybrid PV/thermal collectors in the ground loop to increase the underground temperatures.

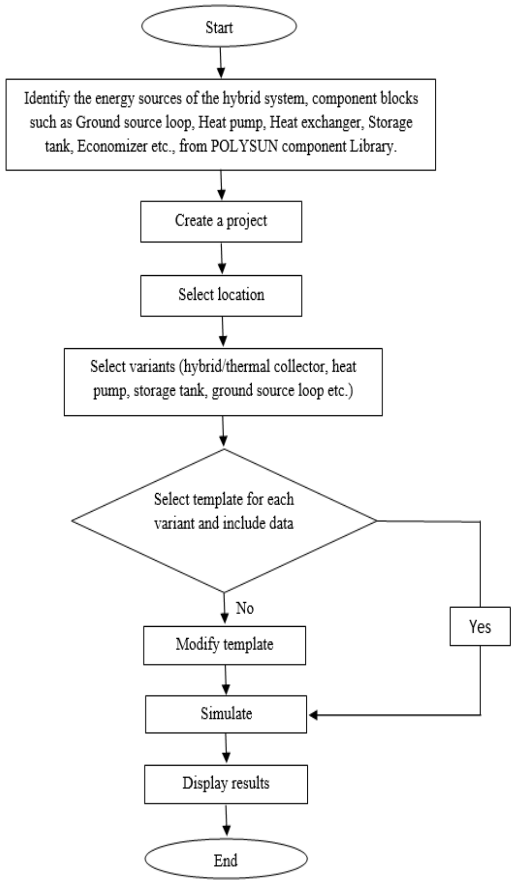


Figure 1. Flow chart for simulation in POLYSUN

The excess heat generated during summer is recovered in winter. Long bore hole heat exchangers provide better heat extraction from the ground thereby high coefficient of performance (COP) for the heat pump is obtained but the initial investments are higher.

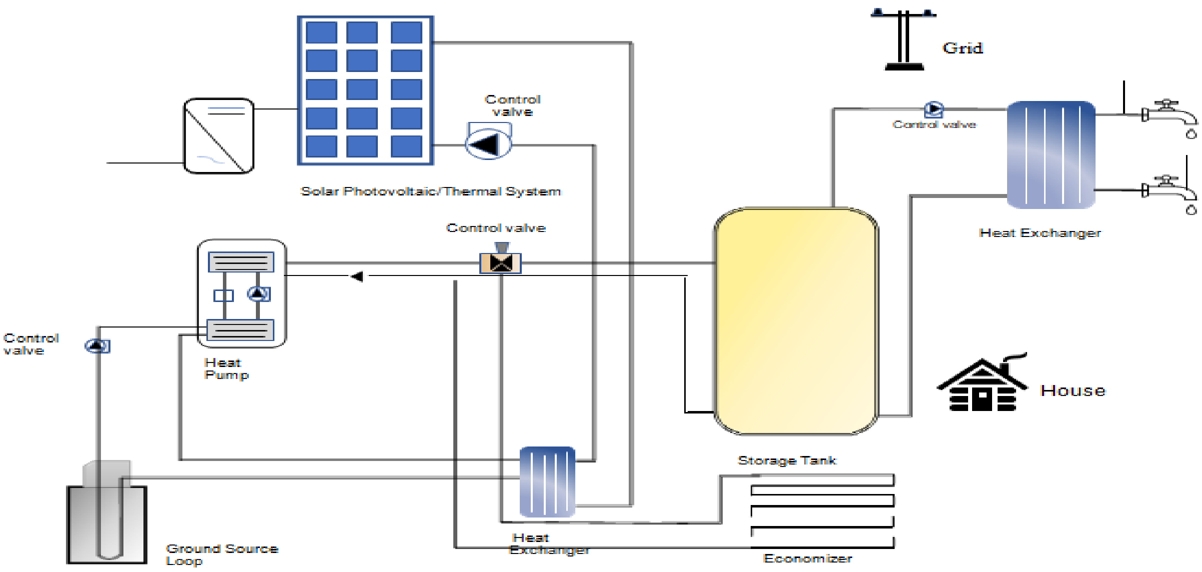


Figure 2. Ground source loop regeneration by hybrid PV/thermal system

The heat that can be extracted from the PV modules improves the performance of the PV cells as well as heat pump.

The performance and efficiency of the PV cells is improved by absorbing the heat from the panel by using the unglazed collector. This system also develops considerably low CO_2 emission. The design considerations and technical specifications of the important components, as listed in Tables I to V, of the hybrid system are presented.

II. Hybrid PV/Thermal Collector

The PVT collectors are the systems that convert solar radiation into thermal and electricity. These systems combine a solar cell with a solar thermal collector. Apart from PV/thermal collector, it includes a pump, battery, DC/AC converter, for the electric system. A monitoring and control system for the conversion process is also provided. Table I shows the design considerations and technical specifications of the hybrid PV/Thermal system.

TABLE I. Hybrid PV/Thermal System

Nominal power (P_{pv})	280 Wp
Total surface area	1.65 m^2
Total aperture area	1.58 m^2
Voltage at maximum power point (MPP)	31.95 V
Current at MPP	8.77 A
Open circuit voltage (V_{OC})	38.88 V
Short circuit current (I_{sc})	9.3 A
Maximum operating pressure	8 bar
Reference PV module efficiency	17.2 %
Temperature coefficient of cell power	-0.44 %/K
Normal operating cell temperature (NOCT)	45 ± 0.2 °C
Type of solar cell	Mono-crystalline (C-Si)

III. Heat Pump

The main factors that control the heat pump are temperatures of heat source and heat sink [18]. Its output depends on the conditions where it is operating, efficiency and capacity of heat. The Coefficient of Performance (COP) is the ratio of useful heat output to the electrical input. Table II presents the heat pump specifications.

TABLE II. Heat Pump

Heat pump capacity	10 kW
COP	4.6
Low pressure failure	-5 ^{0}C
High pressure failure (1 type)	80 ^{0}C
High pressure failure (2 type)	100 ^{0}C
Heat pump operation mode	Heating

IV. Storage Tank

The details of storage tank as presented in Table III is a large water cylinder from which the hot water and cold water can be tapped. Depending on the volume and the type of the tank, the operation varies. The type of the material, thickness of insulation serves to be a part of greater efficiency.

TABLE III. Storage Tank

Volume	400 Litres
Material	Stainless steel tank (Fe(Cr))
Wall thickness	2.5 mm
Insulation	Rigid PU foam
Thickness of insulation	80 mm

V. Ground Source Loop

A heat exchanger is placed in the loop to exchange the heat from the ground to the heat pump through anti-freeze solution such as Propylene mixture. Axial temperature gradient is optimum at 0.03 K/m in the earth. In this study, two ground source loops are considered 5 m apart which is an optimum value. The technical specifications of the ground source are presented in Table IV.

TABLE 1V. Ground Source Loop

Ground source loop	40 mm double U ground loop
Bore hole diameter	0.135 m
Maximum admitted fluid temperature	60 ^{0}C
No of ground source loops	2
Axial temperature gradient	0.03 K/m
Ground loop length	300 m
Distance between ground source loops	5 m
Earth layer 1-moraine firmly deposited	Thermal conductivity -1.8 W/m/K
Earth layer 2-medium sandstone	Thermal conductivity -2.6 W/m/K

VI. Building Specifications

The building model is for a seven-member family low energy accommodation. In order to provide a good comfort zone, cluster free heating and uniform heating, under floor heating is considered. The building specifications are presented in Table V.

TABLE V. Building

Length of the building	10 m
Width of the building	7.4
Area of two floor building	148 m^2
U-value of the building	0.35 W/K/m^2
Window to wall area ratio south	25
Window to wall area ratio north	13
Window to wall area ratio east	25
Window to wall area west	6
G value	0.7

VII. Controllers

The system operation and control are highly dependent on controllers used to maintain a steady flow of heat and water. A brief description of different types of controllers employed in the simulation model is presented.

A. Solar loop controller

It controls the status (on/off) and it controls the flow rate of two pumps based on the temperature difference of two different measured values. The output signals can be digital 0 or 1. It has two inputs with one output. Fixed flow rate is employed.

B. Flow rate controller

A two-channel flow rate controller is employed for ground source loop and a pump which regulates the status of two components and the flow rate of one pump by a flow rate sensor. A constant flow rate is employed and this switch compares with the constant flow rate value and cuts in or off by comparison [19].

C. Auxiliary heating controller

The auxiliary heating controller is a two-channel controller that regulates status and flow rate of the heat pump and the storage tank temperatures. It has two inputs and one output and an. on/off heating device. By using this controller, the heater cuts in when the temperature drops below 53 ^{0}C.

D. Mixing valve controller:

It is a one channel controller that regulates two different inflows and reaches the desired outflow temperature. It has two inputs and one output. In the project, the mixing valve controller is used to provide desired hot water temperature for domestic water. Space heating temperature can also be controlled by the mixing valve controller [19].

E. System modelling

Fig. 2 presents a block diagram representation of hybrid PVT-geothermal system component model. The system model is simulated by using POLYSUN software tool. POLYSUN is a software with graphical user interface that effectively simulates solar-thermal, photovoltaic and geothermal systems. The component models used are the standard models provided in the POLYSUN library.

VIII. RESULTS AND DISCUSSIONS

On the developed system model, simulation studies are carried out at the seven geographical locations considering (i) Global irradiation, (ii) Annual solar fraction to the system, (iii) Annual hybrid PV/thermal CO_2 savings, (iv) Annual heat pump CO_2 savings, (v) Annual power fed to external grid, (vi) Heating energy demand excluding DHW, (vii) Average outdoor temperature, (viii) Annual heat pump fuel/electrical consumption, (ix) Total energy consumption and (x) Total energy demand. Table VI shows some of the extracted features of system simulation results by using POLYSUN software tool. Important parameters such as global irradiation, CO_2 savings, power fed to the external grid, heating energy demand, heat pump fuel/electrical consumption, total energy demand etc., are considered.

A. Global Irradiation:

Global irradiation is the sum of direct and diffuse radiation. It is observed from Fig. 3 that global irradiation is high at Lamayuru in the months of April and May. Ooty experiences high global irradiation in the month of March and September whereas Kasol has its high in the month of April. Along with global irradiation, the inter-related parameters of global irradiation such as outdoor temperature, diffuse and global annual sum for one particular location, Kodagu is presented in Fig. 4.

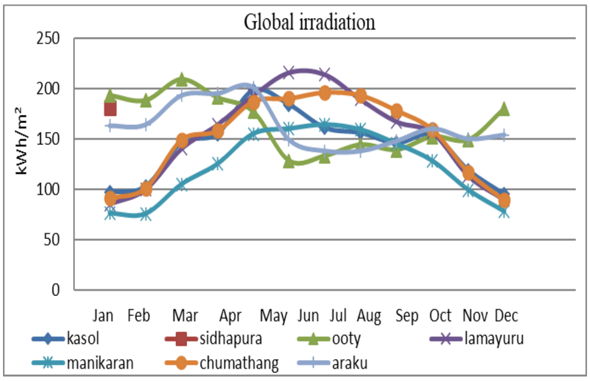


Figure 3. Global irradiation throughout the year at various places.

TABLE VI. EXTRACTED SYSTEM RESULTS BY POLYSUN SOFTWARE

Feature/Location	Kodagu	Ooty	Kasol	Lamayuru	Manikaran	Chumathang	Araku
% Solar fraction	87.4	87	68.2	63.8	53.1	62.3	87.6
% Solar fraction hot water	88.1	88	70.1	65.7	58.3	65.3	88.3
% Solar fraction building	88.1	88	40.7	36.5	29	37.8	88.3
Solar thermal energy to the system, kWh	30,090	30,400	32,197	36,641	27,370	39,085	31,393
Yield photovoltaic AC, kWh	38,284	38,800	39,628	45898.2	3264.7	50,790	38,398
Self consumption, kWh	5448	5441	5822	6703	5832	7454	5677
Power to external grid, kWh	32,836	33,361	33,806	39,195	26,816	43,337	33,295
Power from external grid, kWh	3204	3122	5341	6450	7,638	6,599	3114
Heat generated energy to the system, kWh	4335	4244	15,047	20,796	23,621	23,702	4441
Total energy consumption, kWh	3398	3314	14,335	20,136	22,946	23,085	3515
Energy deficit, kWh	8.6	8.2	57.4	97.4	114	62	9.1
Total fuel/power consumption, kWh	-29,632	-30,238	-28,465	-32,745	-19,177	-36,737	-30,180

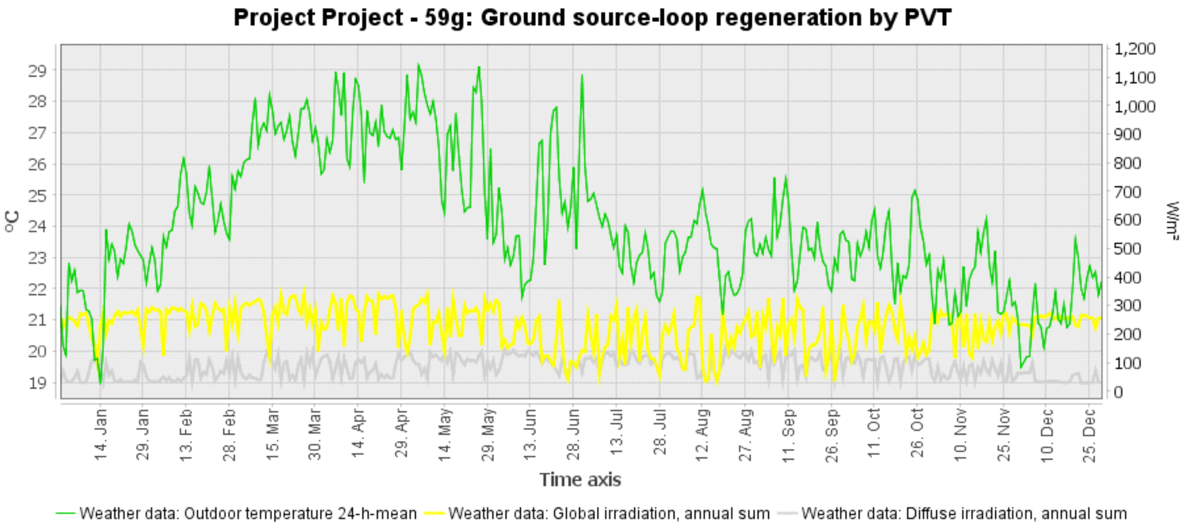
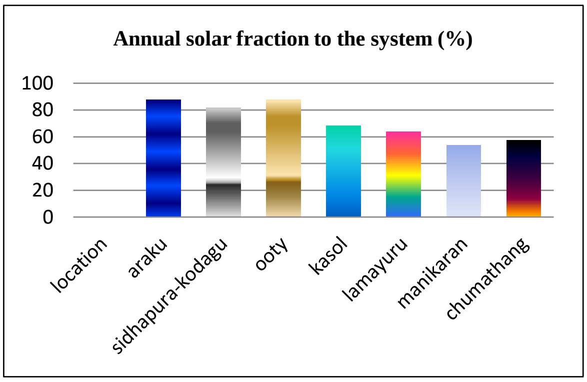


Figure 4. Global, outdoor, diffuse radiation simulated graphical report.

B. Annual Solar Fraction to the System:

Annual solar fraction of solar energy, Fig. 5 is the ratio of amount of solar energy provided to the system with a solar technology to the total energy required. As clearly seen from Fig. 5 the fraction of solar energy to the system is high at Araku and Ooty as the outdoor temperatures at these two areas is high. It is observed that the solar fraction is 88 % at both Araku and Ooty followed by Sidhapura with 80 %. A very less solar fraction on the system is observed at Manikaran and thus the energy demand at this place should be met by ground source heat pump. Besides, the geothermal hot springs present at Manikaran could benefit the system by high underground temperatures. At Kasol, Lamayuru, and Chumathang, the system experiences less solar fraction and thus the operating period of ground source heat pump is high to meet the energy demand.

Figure 5. Annual solar fraction to the system (%)



C. Annual Hybrid PV/Thermal CO_2 Savings:

As hybrid PV/thermal system does not release any toxic gases while generating electricity, it is environmentally friendly with less CO_2 emissions. Thus, the amount of CO_2 liberated is quite less. Fig. 6 depicts the annual savings of CO_2 at different locations. Even though the same system is simulated at every place, the same amount of CO_2 savings could not be observed as it depends on climatic conditions.

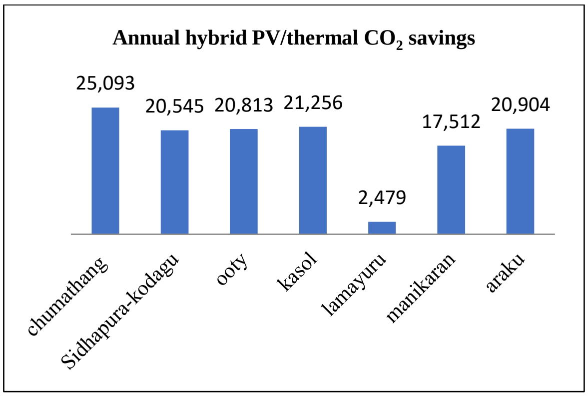


Figure 6. CO_2 savings due to hybrid PV/Thermal system alone

It is observed that CO_2 savings are high at Chumathang followed by Kasol with 25,093 kg and 21,256 kg, respectively, whereas it is very less at Lamayuru.

D. Annual Heat Pump CO_2 Savings

As the heat pump is an energy efficient device, it could have considerably less CO_2 emissions. It is observed from Fig. 7, the annual heat pump CO_2 savings are higher at Chumathang and Lamayuru whereas it is least at Araku. For the remaining locations similar conclusions can be drawn.

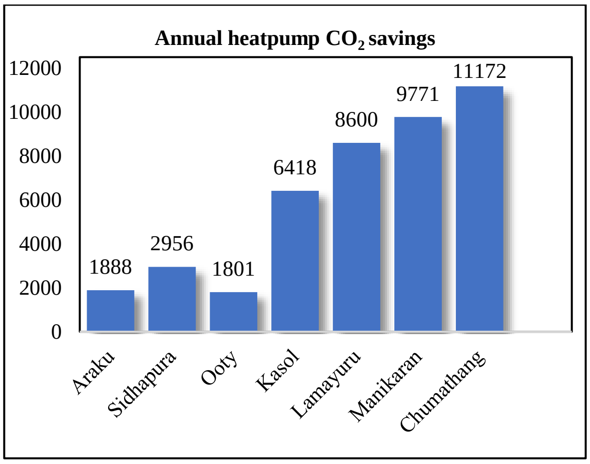


Figure 7. CO_2 savings due to heat pump alone

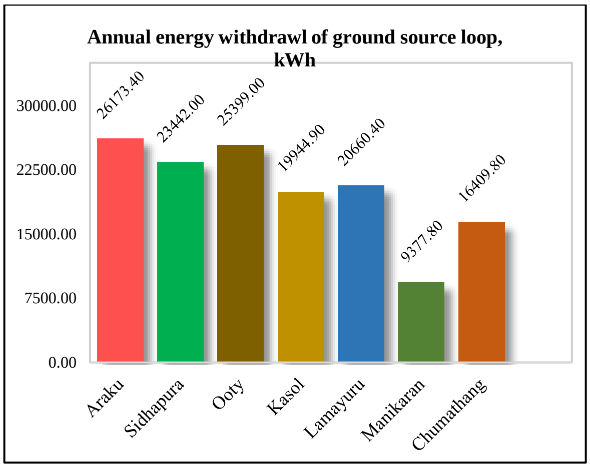


Figure 8. Energy withdrawn by the ground source loop

The energy withdrawn by the ground source loop is shown in Fig. 8.

E. Annual Power Fed To External Grid

The excess power that was generated by the hybrid PV/thermal collector at different locations is fed to the external grid as presented in Fig. 9. It is observed that more annual power was fed to external grid at Lamayuru and Chumathang as the global irradiation is high.

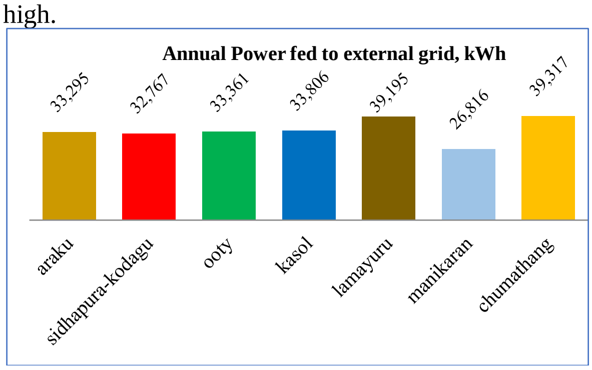


Figure 9. Annual power fed to external grid

In addition, the efficiency of the solar panels is improved by outdoor cooling temperatures at these two places. The locations, Kasol, Araku, Ooty, and Sidhapura-Kodagu, respectively, occupies the next places as the amount of solar fraction on to the system is high.

F. Heating Energy Demand Excluding Dhw

Fig. 10 presents energy demand for space heating at various locations. For analysis purpose considering the first location only, it is observed from Fig. 10 that the space heating requirement excluding domestic hot water is high at Chumathang in the month of January and it gradually decreases from January to May. During the months of June to September the space heating requirement is very less and again increases during October, November and December .The highest heating energy demand excluding domestic hot water is observed in the month of January at Chumathang as outdoor temperature is less. Similar observations can be derived from Fig. 10 for other locations.

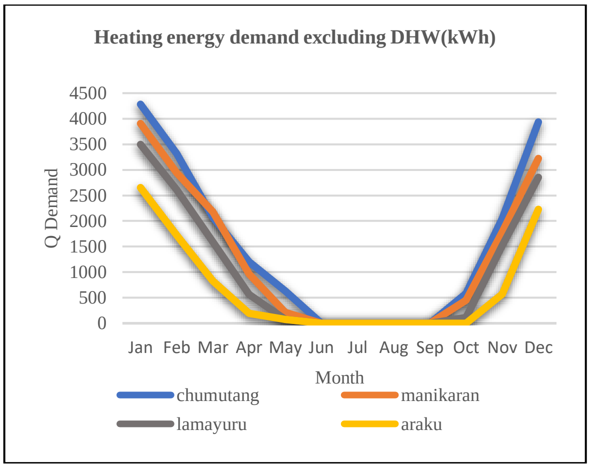


Figure 10. Energy demand for space heating

G. Average Outdoor Temperature

The average outdoor temperature at the seven locations is presented in Fig. 11. It is observed that the average outdoor temperatures are high at Araku, Sidhapura-Kodagu, and Ooty followed by Kasol. A low temperature is experienced by Chumathang and Lamayuru at Jammu and Kashmir in the northern parts of India. Besides, at Lamayuru, Manikaran and Chumathang, as the average outdoor temperature sometimes reaches -10 ºC, the heating requirement is high i.e., the energy demand is high.

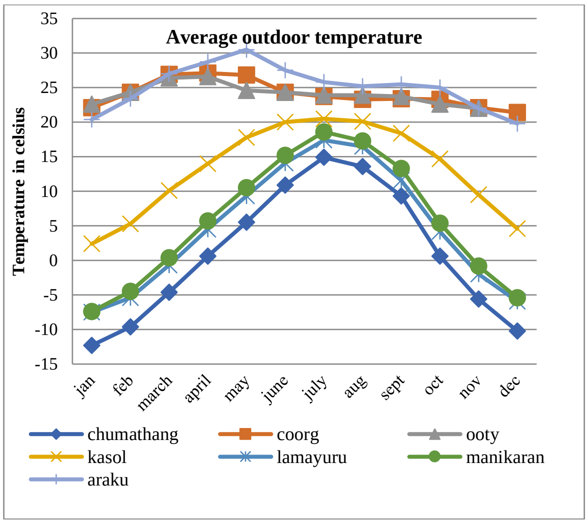


Figure 11. Average outdoor temperature

H. Annual Heat Pump Fuel/Electrical Consumption

As the input of the heat pump is electrical energy, the annual electrical consumption of heat pump at these seven locations is presented in the Fig. 12. It is observed that the annual electrical consumption at Manikaran is 5,405 kWh followed by Lamayuru and Kasol as the heat pump consumes more energy than in the rest of the locations. At Araku and Ooty the electrical consumption to run the heat pump is very less as most of the time these cities rely on the solar energy as the solar fraction is high. Besides, the energy demand is also less in these cities.

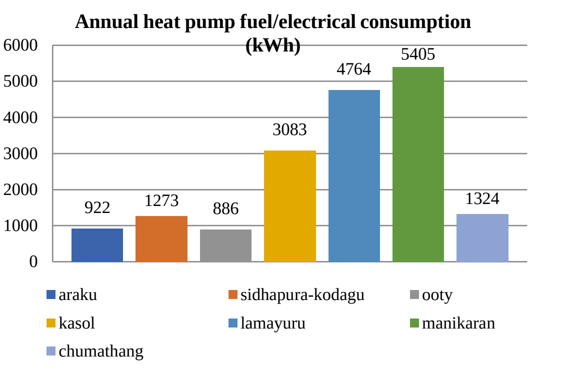


Figure 12. Electrical consumption of heat pump.

I. Total Energy Consumption

Fig. 13 represents the energy effectively consumed by the consumers including domestic hot water and space heating annually It is high at Chumathang which accounts for 27 % followed by Lamayuru, Manikaran, and Kasol which accounts for 24 %, 21 % and 15 %, respectively.

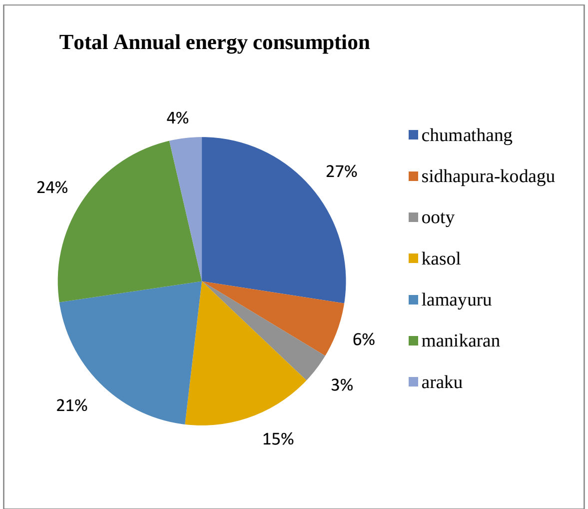


Figure 13. Total annual energy consumption

J. Total Energy Demand

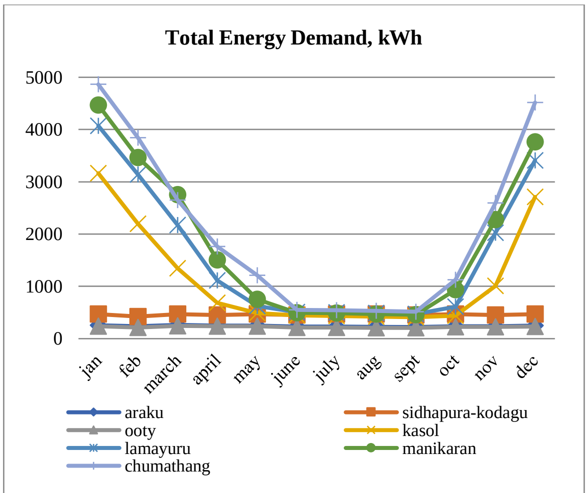


Figure 14. Total energy demand

Fig. 14 explains the total energy demand. It is clearly shown that energy demand by the consumers including domestic hot water and space heating is high at Chumathang, Manikaran, Lamayuru and Kasol in the month of January and gradually decreases from January to June and maintained constant from June to October and again gradually increases in the months of November and December. Thus, extensive simulation studies on hybrid PV/Thermal geothermal system model are carried out at seven different geographically critical locations of India by using the POLYSUN software tool.

The results presented are very close to the practical conditions and satisfactory.

CONCLUSION

This paper has proposed a novel hybrid PV/thermal system together with geothermal energy ground-loop regeneration for space heating and cooling in a residential building located at seven geographical critical locations in India. The selection of feasible locations is mainly based on low temperatures throughout the year and some locations with the availability of geothermal sources. As the energy consumption and demand increases, ground source heat pump systems can decrease the energy use by supplying the hot water and space heating. Solar technology and geothermal technology are combined to become solar assisted ground source systems to obtain better results in an efficient way. As solar energy is intermittent, geothermal energy could supplement the solar energy whenever needed.

Simulation studies are carried out on the model-based hybrid solar-geothermal system by using POLYSUN software. The results obtained by the developed model is also able to accurately determine the most feasible and efficient location to install the system to provide space heating, hot water, and electricity for the residential building at Chumathang followed by Lamayuru, Manikaran and Kasol. In addition, the locations at Chumathang and Lamayuru provided maximum power to the external grid. Besides, it is clearly established that CO_2 savings are higher in these two locations by successfully meeting the energy demand. It is also observed that as the solar fraction on to the system is less at Lamayuru, Manikaran, Kasol and Chumathang, these cities make use of available geothermal hot springs and ground source heat pump system effectively. However, the solar fraction at Araku, Ooty and Sidhapura-Kodagu is high and thus the system mostly relies on solar energy. But the energy demand is quite less in these locations and the installation of the plant is not feasible. Simulation results demonstrated the merits and demerits of the hybrid PV/Thermal-Geothermal energy system at the seven locations. Observing the simulation performance results at all locations, the most feasible optimal location to install the system to provide space heating, hot water, and electricity is at Chumathang followed by Lamayuru, Manikaran and Kasol for the model-based hybrid system.

Abbreviations

PV Photovoltaic
DHW Domestic Hot Water
IEEE Institute of Electrical and Electronics Engineers
RES Renewable Energy Sources
MNRE Ministry of New and Renewable Energy
COP Coefficient of Performance
SPF Seasonal Performance Factor
GW Gigawatt
MW Megawatt
SHP Small Hydro Power
GSHP Ground Source Heat Pump
NGRI National Geographical Research Institute
BHE Borehole Heat Exchanger

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