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An Energy efficient Approach of Developing Hot Water Supply System Suitable for a Residential Building Located in Peri Urban Area of Agartala City

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ABSTRACT: Domestic water is an important component of water demand and during the winter season a good portion of it is being used as hot-water everywhere in the world. To provide a sustainable solution to the domestic hot water supply it is imperative to utilize the naturally available resources as much as possible to minimize the generation of greenhouse gas and also to reduce the carbon foot print. Under favorable condition, the requirement of domestic water can be partially or totally fulfilled by rainwater harvesting of a dwelling or its surroundings. A different system of rain water harvesting especially in rural and peri-urban areas where rainfall is distributed throughout the year is likely to be effective in providing a sustainable solution in many ways. Traditional process of hot water production consumes enough energy coming out of fossil fuel, including coal, gas, and diesel, etc. which does not ensure a sustainable future. In the tropical zones the solar energy may be an effective alternative to this. The paper is an attempt to understand the feasibility of providing hot-water to the residents of a typical apartment house situated in a peri-urban area of the city of Agartala utilizing the solar energy and the rain water collected from a roof for satisfying the daily need of the hot water requirement of domestic purpose. In the present scenario the availability of usable water is very less. Moreover, the production of carbon dioxide and other greenhouse gasses is increasing day by day. In view of the above a different system of rain water harvesting is implemented to reduce the water crisis. For reduction of energy consumption and thereby reducing the uses of greenhouse gasses solar water heating technique has been used.

Keywords: Rain water, RWH, Hot-water demand, solar energy, green building.

I. INTRODUCTION

Water is one of the most valuable resources in the world; due to its vital role in life, recently water demand has been dramatically increased due to the population growth and also to the change in the precipitation patterns because of the climate change. The water consumption for domestic use represents around 10% of the total fresh water demand in the world, and satisfying these domestic demands is really very challenging. Rainwater is a clean source of water that can be harvested to solve the need for potable water in rural areas (About, Inc, 2017). Rainwater is regarded as a clean source of water due to its lack of contaminants and hard metals. Water is reported to be grouped into atmospheric, surface, and ground water where atmospheric water includes moisture contained in the cloud, which precipitates as snow and rain [2]. Rain water, on the other hand, is a form of precipitation in which liquid water falls to the earth's surface [2]. Water scarcity is, therefore, thought to be a serious problem throughout the world and mitigating this problem is one of the biggest challenges of the 21st century. 1.8 billion people are predicted to live in regions with absolute water scarcity by 2025 [8-11]. Lack of access to safe drinking water is an increasing problem in the peri urban area mainly during winter, where salinity in ground and surface-water and arsenic as well as iron contamination of shallow aquifers are supposed to be the two major concerns for this. Such problems are considered to be significant barriers in the way of improving community health.

Drinking water is generally obtained from two sources: ground water (wells, boreholes, etc.) and surface water (rivers, lakes, etc.). However, these sources account for only 40% of total precipitation as depicted by Water Aid. In this regard, Rain Water Harvesting (RWH) can be considered as a probable solution of drinking water crisis in arsenic affected areas, saline zone in the coastal areas, and areas prone to ground water depletion. Ghisi *et al.* (2006] showed a huge potential of potable water savings and preservation of water resources through RWH in as many as 62 cities in Brazil. Rainwater is free from salinity as well as arsenic contamination and is safe too if it is maintained hygienically. Harvested rainwater can be used not only in drinking purposes but also in cooking, washing, and bathing. The main limitation of this option is non-availability of rain water around the year. But it can be widely used as supplementary source if rainwater is properly stored in rainy season. Besides, rain water harvesting is also necessary in the areas lacking runoff water, or the places where groundwater is not of good quality and where the centralized distribution of water is also not satisfactory.

II. LITERATURE REVIEW

Bharathi *et al.* (2022) proposed a smart deep learning of solar water heater model which will improve the performance of solar water heater. They have introduced an automatic device that runs in the direction of sunlight. This device will heat up minimum 10 liters of water within 15 minutes. It will be a cheap cost effective water heating device which can be easily affordable by common people [21].

Gaonwe *et al.* (2022) explained about three renewable energy water heating system; Air source heat pump water heaters, Solar-assisted heat pump water heaters and solar water heaters which will reduce the uses of traditional electric storage tank water heaters through which the energy consumption will be decreased [22].

Hangshing *et al.* (2022) aims rain water harvesting in Nagaland to reduce water crisis in present era and also to reduce different water resources related problems. Due to the increasing population, Global warming and also changing climate condition water crisis increases day by day, to deal with this situation rain water harvesting will play a vital role [3].

III. SOLAR HEATING SYSTEM

A. Solar water heating

To reduce the energy consumption in energy efficient building rainwater harvesting and solar energy utilization has been important steps in this context. With increasing global warming and its effect on recent climate change, adopting environmentally friendly technologies for energy sector has been recognized as a key potential solution to this problem [1-7]. Consequently, buildings, which account for around 40% of total global energy consumption [8], have become the focal point of many institutional energy reduction initiatives and research to make them more sustainable and energy efficient. In this context, and due to the fact that solar energy is one of the most promising ecological solutions to combat catastrophic climate change, photovoltaic (PV) panels have been widely installed in both commercial and residential buildings and facilities for using solar as an alternative source of energy [12-17].

B. Different type of uses of solar energy

Solar power is a non-toxic, environmentally favorable energy source. There will be no hazardous gas emissions from solar energy, such as carbon dioxide or carbon monoxide. It won't have any negative environmental effects of any kind. The primary applications for solar energy rely on their needs, and they typically vary based on their collection and storage methods as well as their intended uses [19]. Depending on how they use, two categories of solar energy and solar energy systems can be identified: passive solar energy systems and active solar energy systems. The sun's light and heat are used directly in passive solar energy systems, but active solar energy systems use technologies to transform the sun's energy into forms that are far more useable, such as heating water and generating electricity [18, 20]. In order to generate electricity, light, and hot water, we primarily use solar radiation, light, and heat. Solar energy is mainly used for given purposes like

a) Electricity production
b) Cooking purpose
c) Lighting purpose
d) Warm green houses
e) Water heating
f) Solar battery charging etc.

There are a few effective uses of solar energy or solar technology in the modern era. The most likely application of solar energy is in the generation of electricity. India is ranked fourth globally in 2021 for solar technology. For the generation of electricity, lighting, and water heating, solar radiation or heat is utilized. The positioning of the windows is crucial for illumination, as is the direction in which they face. The electricity generated by a solar PV array can be utilized for cooking just like an electric wok. Solar energy is quite important for heating greenhouses. Solar energy is being employed in many modern sectors to heat things like water and air. We can simply raise the temperature of water from 60 °C to 80 °C by using solar energy. In 1920, when at least 30% of the population in California installed a solar water heater, the technology first became exoteric. Now More than 20,000 home systems are now installed nationwide each year.

One important solar energy resource for buildings, which is also the topic of this study, is the solar thermal system. Essentially, a solar thermal system uses the sun's energy to generate low-cost and environmentally friendly thermal energy. This energy is used to heat the water being used for different purposes including domestic use.

Fig. 1. Site Location.

C. Effecting Factors of Solar Technology

Factors which affect the solar energy use for different purposes like electricity generation and water heating etc. are given below:

(a) Location
(b) Effect of Tint angle
(c) Orientation of roof and shading
(d) Designed system
(e) Ambient condition
(f) Arrangement of collector array
(g) Flow rate of the transferred fluid
(h) Layout of plant etc.

Solar panels are light sensitive. The amount of light that hits a solar panel is proportional to the output of the solar panel. The manufacturing of solar power plants is impacted by the tilt angle and orientation of the solar panel. Solar panel output current is impacted by the solar panel's heating.

IV. METHODOLOGY

A. Study Location

The research area is situated at AD Nagar, a peri-urban area located in ward number 39 of Agartala municipal Corporation (AMC). The site is located in an peri-urban area having longitude and latitude 23°49' N and 91°15' E respectively. The climate is humid subtropical climate where the rainfall is well distributed the maximum time of the year with a yearly average rainfall of 2200 mm+. The most likely ambient temperature varies from 6 degree to 39 degree C with short winter and prolonged summer. High humidity and rainy days are very common. The area is located on an elevated tilla land where ground water table goes down during the winter season. The sky remains mostly clear in winter and extends the scope of solar energy. The international boundary of India-Bangladesh is very near, approximately 2-3 km from this location and the distance from coastal region of Indian Ocean is approximately 120 KM. Even though Tripura has six seasons (each season consists of two months) in literature, in fact, those are overlapped with each other. Here it receives heavy rainfall during the rainy season, which extends from May to September, with the peak of precipitation taking place during June, July, and August. Rain usually falls in the form of showers that can last for few minutes to several hours. The average annual rainfall under the normal climatic conditions is more than 2200mm. Average monthly Rainfall data for a period of 20 years (from 2002 to 2021) are presented here. Such data indicate that there is a significant amount of rainwater that can be harvested in the later part of the rainy season. On the basis of this rainfall RWH system can be effectively implemented for household usage.

Buildings are important for habitation and human activity. Due to fast urbanization the demand of building is getting higher day by day. Huge amount of natural resources and energy are being consumed unlawfully for these purposes worldwide which is effecting the global climate scenario. The major intensions of the green building are reduction of carbon emission, conservation of water, use of renewable energy, sustainable management of energy and waste, safer materials etc. There are several ways to control the resource consumption of building. Nowadays hot water usage has become an integral part of urban domestic energy consumption.

The study is conducted through some sequential steps,

***Adoption of roof area*:** Most of the residential apartment building in the study area is G+4 structures where Ground floor is kept open for parking etc, and other floors consist of residential flats.

After comparing 4 such apartments in the same locality having 4 nos of flat on each floor, it has been found that the average roof area of a similar apartment is approximately 380.5 sq mt.

Estimating Domestic hot Water Demand: Estimating domestic water demand, in reality, is not so easy. Children and adults use different amounts of water and seasonal water use varies, with more water being used in the summer season. The number of household members staying at home may also vary at different times of the year because during religious as well as local cultural festivals relatives used to visit and stay at home. By estimating the average daily water use these variables should be taken into account. Although harvested rain water can be used in drinking, cooking, washing, and bathing purposes, In this case only for bathing cooking and food preparation purposes in the studied household. The domestic requirement of Hot- water mainly depends on the type of use and the climatic condition. Choosing some references from the studies done in sub-tropical climates it has been found that the HWC for domestic use is 25 litre/capita/day in Greece and 21.2 L/pers/day in Brazil. Keeping the higher side the Hot water demand for this case is assumed to be 25L/Pers/day.

As per the data recorded during census 2011 the household size of West Tripura District is 4.2.

Hence, the Hot water requirement for the apartment may be indicated as

4 floors x 4 flats x 4.2 x 25 L/Capita/Day = 1680 L/day

Hence, Monthly consumption of hot water in the apartment = 1680 x 30 =50400 Litre say 50000 Litres/month.

Harvested water storage capacity: The actual demand of hot water is observed during the winter season mainly during the month of December to February when there is no significant rainfall occurs in Agartala. Hence, to meet the Hot water demand during this entire period may be considered as storage capacity which may be estimated as,

3 months x 50000 Litres= 1,50,000 Litres.

Catchment Area and Runoff: The collection of rain water is usually represented by a runoff coefficient (RC). The runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. Arunoff coefficient of 0.8 means 80% of the rainfall will be collected. The roof runoff coefficient varies significantly on the basis of roof material, slope of the roof, etc. As the roof of the apartment is tiled surface, a runoff coefficient of 0.9 is adopted in this study for the calculation of potential rainwater harvested from the catchment/roof area.

It has been clear from the table that the quantity of harvested water from roof top can easily fulfill the Hot-water demand except for the months of December, January and February. The scarcity during winter may be overcome by the provision of mass storage of harvested Rain water during post –monsoon period.

UG storage and pumping. Two underground storage tank of 80000L capacity placed under the parking area connected with 1 solar pumps of 1HP capacity is proposed to be installed to take the water to the roof top for solar heating and distribution under gravity.

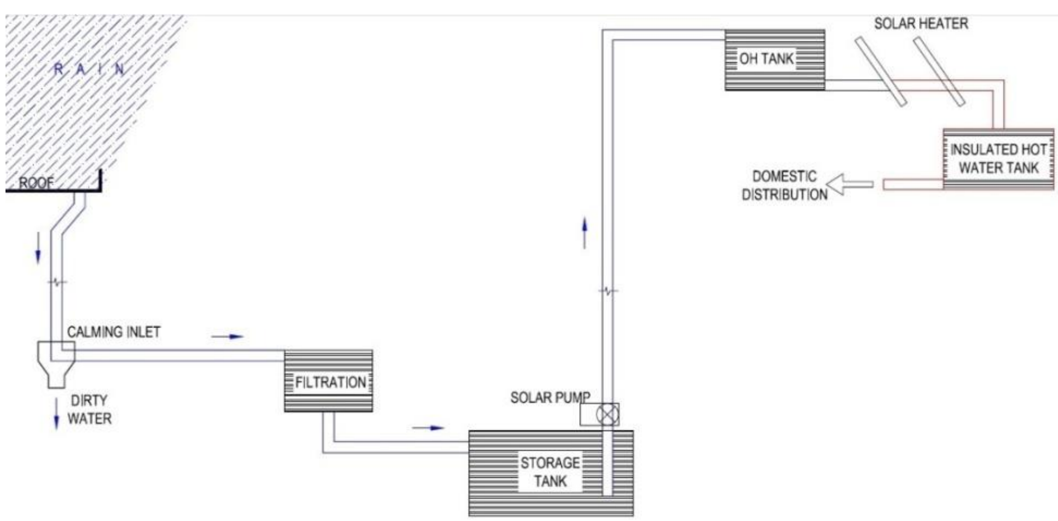

Fig. 1. Schematic diagram of the hot-water supply system

Table 1.

Month	Total monthly rainfall (mm)	Total monthly runoff (cum)	Water volume equivalent in liter
March	78.7	26.95	26950
April	211.1	72.29	72290
May	387.9	132.83	132830
June	460.1	157.56	157560
July	402.8	137.93	137930
August	340.9	116.74	116740
September	254	86.98	86980
October	170.8	58.49	58490
November	39.4	13.49	13490
December	11.6	3.97	3970
January	7.8	2.67	2670
February	27.6	9.45	9450

Storage tank. More often than not, solar water heating technology required a storage tank that was adequately insulated. The storage tank needs one outlet and one inlet point for supplying hot water as needed and one outlet point for collecting cold water from the standard tank. The solar water heating technique warms the water in two tank systems before it enters the conventional water heater. In a single tank system, solar storage is coupled with a backup heating system.

RESULT AND DISCUSSION

Mathematical model is developed in this study. In this model one 5-storeyed building has been considered. It has 4 floors and one ground floor, each floor has 4 flats, i.e.
Total no of flats – 16
Considering no of people in each flat – 4
Total no of people – 64
The G+4 structure requires an amount of 1680 liters of hot water per day(approx.). Now, 4 solar water heaters are installed in the roof top of the 5storeyed building and each tank has the capacity of taking 1680 litter of water.
Here, 1 tank having water capacity of 1680 liter is considered.

Nomenclature

V – Water velocity in m/s
P – Water density in kg/m^3
D – Outer diameter of cu tube in m
L – Length of collector in m
Pr – Prandlt number of water
h – Heat loss in w/m^2
T_{fo}–Water outlet temperature in˚c
T_{fi} – Water inlet temperature in ˚c
Ta –Ambient water temperature in˚c
Cpw – Specific heat at constant pressure in KJ/g˚c
Tw – Tube wall temperature in ˚c
K – Thermal conductivity coefficient
m - mass of water in kg/s
Q- Heat absorbed by the water passing through the tube
S – Solar radiation in w/m^2
τ – Transmissivity of the glass
α – Absorptivity of the plate
U– Collector overall heat loss coefficient in w/m^2
A – Area of the collector in m^2
Fr – Heat removal factor
Q_L- Energy gain of collector
η– Collector efficiency
Re-Reynold's number
μ-Dynamic viscosity

Considering,
Velocity of water = 0.02 m/s

Now, $Re = \frac{PDV}{\mu}$

Here,
P = 997 Kg/m^3
D= 2.5 cm = 0.025 m

$Re = \frac{997 \times 0.025 \times 0.02}{4.7 \times 10^{-4}}$
=1060

As Re<2300, the flow is laminar, following equation for finding out average heat transfer coefficient is to be used.

$Nu = \frac{hD}{K} = 1.86[Re\ Pr\frac{D}{L}]0.33$

Pr = 3.01 m

$\frac{hD}{K} = 1.86[1060 \times 3.01 \times \frac{0.025}{5}]^{0.33}$
= 4.64

$h = \frac{4.64 \times 0.65}{0.025}$

Heat loss= 121 w/m3

Heat gained by the water = Heat given by the tube

$m.Cpw(Tfo - Tfi) = (\Pi DL)\ h[Tw - \left(\frac{Tfo+Tfi}{2}\right)]$

Let, Tfi= 60˚C
Cpw = 4.2 kj/g˚c
m = $\frac{\Pi}{4}D^2V$
= $\frac{\Pi}{4}(0.025)^2X0.02X997$
= 0.01 Kg/s
Substituting value of m,
mCpw(Tfo-Tfi)=$(\Pi DL)h[Tw - (\frac{Tfo+Tfi}{2})]$
0.01x4200(Tfo-60)=Πx0.025x5x121[80- $\frac{60+Tfo}{2}$]
Tfo= 75˚C

The initial temperature of water is 75˚C
mCpw(Tfo-Tfi)=$(\Pi DL)h[Tw - (\frac{Tfo+Tfi}{2})]$
0.01x4200(Tfo-75)=Πx0.025x5x121[80- $\frac{60+Tfo}{2}$]
Tfo = 84˚C

Q= [mCpw(Tfo-Tfi)]xN]
= [0.01x4200(84-60)]x12]
= 12096W
We know,
S= $\frac{Q}{\alpha\tau A}$
Let,
S= 786 W/m^2
T= 0.9
α= 0.95
Now, A=$\frac{Q}{\tau\alpha S}$
=$\frac{12096}{0.9X095X786}$
=18 m^2

Now the final temperature change of water is
=(Tfi-Tfo)˚C
=(84 - 60)˚C = 24˚C

Heat removal factor
F_R= $\frac{mCp(Tfo-Tfi)}{A[s\tau\alpha-U(Tfi-Ta)]}$
=$\frac{0.01\times4200(84-60)}{18[786\times0.9\times0.95-4\times(60-25)]}$
[Ta = Ambient temperature of water= 25˚c]
=0.10
Energy gain of the collector,
Q_L= F_RA[Sτα-U(Tfi-Ta)]
=0.10x18[786x0.9x0.95-4(60-25)]
= 958 W

Now, collector efficiency
=$\frac{F_R\ A[S\tau\alpha-U(Tfi-Ta)]}{AS}$
= $\frac{958}{18\times786}$= 0.677= 7%

According to the calculations above, utilizing a solar water heater, hot water can be obtained by direct solar energy consumption, which lowers the use of electrical energy and lowers the cost of electrical energy consumption. With the help of a solar water heater, water temperature may be modified quickly & simply and readily got warm water from the tank. By using the aforementioned equation, the size of the solar water heater, the change in water temperature, the heat removal factor of the collection, the energy gain of the collector and the collector efficiency can be determined.
In brief, it may be stated that methods have been developed by using Adoption of roof area, Estimating Domestic hot Water Demand, Harvested water storage capacity, Catchment Area and Runoff etc. This solar heater will be cost effective compared to electric geyser.
From this discussion a comparative study between Solar water heater and Conventional Water Heater may be drawn.

- Compared to other conventional water heater, solar water heaters reduce carbon footprint.
- Solar water heater has less maintenance compared to other conventional water heater.
- The initial cost of solar water heater is much higher than other conventional system but the maintenance cost will be very low.
- As solar water heater uses the solar energy for water heating purpose it consumes less electrical energy.
- Solar water heater uses the solar energy which is a free source of energy.

Overall solar water heaters are eco-friendly and pollution free. It will increase the energy efficiency and the water crisis in the environment can be reduced through the rain water harvesting.

CONCLUSIONS

This paper has presented a multi-objective model for Hot-water-supply system suitable for domestic usage. The system is easy to install &likely to provide a sustainable solution. The presented model proposes available area for rainwater harvesting and the installation of storage devices for using this water when it is required for the residential development.
The model will satisfy the domestic demands as well as it will be considered as objective function for the minimization of the total annual cost associated to the fresh water and also the electrical energy consumption.

FUTURE SCOPE

A few future recommendations of the current study may be suggested as per the following points:

- The quantity of harvested water may be increased by collecting the runoff from the surrounding area.
- To introduce solar energy for illumination purposes of the green building of the peri-urban area of Agartala city.

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