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Various Aspects of Solar Energy Utilization: Review

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Abstract

Solar Energy (SE) is accepted as a key resource for the future of the world. The utilization of SE could cover a significant part of the energy demand in the countries. Using of SE in its various aspects, therefore, is very attractive in this part of the world. A comprehensive review of the different designs, details of construction of the wide diversity of practically designs of SE systems reported previously is presented. Therefore, in this review paper, an attempt has been taken to summarize the past and current research in the field of SE technology. The main objectives of this research are to present the current status and future aspects of SE in the world by comprehensively reviewing various SE related studies conducted up to date and to highlight some corresponding available sustainable energy methods towards establishing energy policies.

Keywords*: Solar Energy, Renewable Energy, Application of Solar Energy, Review*

1. Introduction

The solar energy is ubiquitous, freely accessible, and environmental pleasant. Economic aspects of this Renewable Energy (RE) technology are adequately promising to contain it for rising power generation ability in expanding countries [1]. To conquer the negative impacts on the atmosphere and other problems associated with fossil fuels have forced many countries to request and change to alternatives that are renewable to uphold the increasing energy demand [2]. Solar energy is one of the best RE sources with least negative impacts on the environment. More countries have formulated SE policies to reducing dependence on fossil fuel and increasing domestic energy production by SE.

Research and progress efforts in solar and other RE technologies are needed to enhancing their efficiency, establishing techniques for accurately predicting their output and reliably integrating them with other conventional generating resources. In this paper, the latest developments in solar thermal applications are reviewed. Also, the current and future statuses of SE applications are reviewed.

The power from sun intercepted by the earth is about 1.8×1011 MW, which is many times larger than the present rate of all the energy consumption. Photovoltaic technology is one of the finest ways to harness the solar power. Photovoltaic conversion is the direct conversion of sunlight into electricity without any heat engine to interfere [3].

Barton *et al.*, described a novel method of modeling an energy store used to match the power output from a wind turbine and a solar PV array to a varying electrical load and validated the method against time-stepping methods showing good agreement over a wide range of store power ratings, store efficiencies, wind turbine capacities and solar PV capacities [4]

This paper focuses on the latest developments and advances in solar thermal applications, providing a review of solar collectors and thermal energy storage systems. Various types of solar collectors are reviewed and discussed, including both non-concentrating collectors (low temperature applications) and concentrating collectors (high

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temperature applications). Various types of thermal energy storage systems are also reviewed and discussed, including heat storage.

In [5] the review is presents the principal approaches obtainable for seasonal storage of Solar Thermal Energy (STE). It focuses on residential scale systems, and particularly those currently applied in practice which mostly store energy in the form of sensible heat.

2. Background

World energy demands will increase as world energy supplies diminish due to trends in world population and economic growth in the 21st century. In order to save conventional energy supplies while supporting growth in economic activity, especially within developing countries, new energy resources and related technologies must be developed [6, 7].

The potential amount of world solar energy that can be harnessed is sufficient for global population needs during the 21st century. It has been forecast that photovoltaic technology shows promise as a major energy resource for the future. Much potential exists in the world's desert areas. If appropriate approaches are found, they will provide solutions to the energy problem of those countries that are surrounded by deserts [8].

Solar energy technologies have a long history. Between 1860 and the First World War, a range of technologies were developed to generate steam, by capturing the sun's heat, to run engines and irrigation pumps [9]. Solar photovoltaic (PV) cells were invented at Bell Labs in the United States in 1954, and they have been used in space satellites for electricity generation since the late 1950s [10].

The years immediately following the oil-shock in the seventies saw much interest in the development and commercialization of solar energy technologies. However, this incipient solar energy industry of the 1970s and early 80s collapsed due to the sharp decline in oil prices and a lack of sustained policy support [11]. Solar energy markets have regained momentum since early 2000, exhibiting phenomenal growth recently. The total installed capacity of solar based electricity generation capacity has increased to more than 40 GW by the end of 2010 from almost negligible capacity in the early nineties [12]. The increasing efficiency, lowering cost and minimal pollution are the boons of the photovoltaic systems that have led to a wide range of their application.

3. Calculation of Sunshine Duration

Solar radiation data provide information on how much of the sun's energy strikes a surface at a location on the earth during a particular time period. These data are needed for effective research in solar-energy utilization. Due to the cost of and difficulty in solar radiation measurements and these data are not readily available, alternative ways of generating these data are needed. In this paper, a review is made on the solar energy modeling techniques which are classified based on the nature of the modeling technique [13].

Solar energy is the portion of the sun's energy available at the earth's surface for useful applications. The measured solar energy values can be used for developing solar energy models which describes the mathematical relations between the solar energy and the meteorological variables such as ambient temperature, humidity and sunshine ratio. These models can be later used to predict the direct and diffuse solar energy using historical metrological data at sites where there is no solar energy measuring device installed [14].

In study of solar energy, information on solar radiation and its factors at a given location is very necessary. Solar radiation data are needed by solar engineers, architects and agriculturists for many applications for example solar heating, cooking, drying and interior illumination of buildings. For this purpose, some mathematical modeling assuming perfect and specular reflectance can be found in the literature [15]

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During the first step of calculations the basic spatial geometrical characteristics for each pixel are determined. Then it is checked whether the sunshine can theoretically reach the observed grid plot and whether there is no obstacle between the sun and this surface. The plot can be located on the shaded side of the hill itself, or it can be hidden by the slope, which is in front of the observed surface (shadowing effect of terrain). This algorithm is applied for each grid plot.

This calculation is repeated in each time step for the actual sun position (angle and declination), which depends on local time. Output from this subroutine is sunshine duration during the optional time range, e.g. hours, one or several days [16, 17].

3.1. Calculation of Potential Energy Income

During the next step the potential energy income is calculated for each grid plot. The potential energy income is output from this subroutine. For the plot with general slope β the equation (1) was used as it is described in Kittler and Mikler (1986) [17].

$$^{c}E_{b\beta} = {}^{p}E_{b\beta} + {}^{d}E_{b\beta} + {}^{r}E_{b\beta} \qquad [\mathrm{W\ m^{-2}}] \qquad (1)$$

Where $^{c}E_{b\beta}$ global radiation, $^{d}E_{b\beta}$ diffuse radiation,
$^{p}E_{b\beta}$ direct radiation, $^{r}E_{b\beta}$ reflected radiation.

The component of the direct radiation $^{p}E_{b\beta}$ on grid cell with slope β is calculated according (2), based on direct radiation incidence $^{p}E_{bK}$ on surface normal to sun beam

$$^{p}E_{b\beta} = {}^{p}E_{bK} \cos(i), \qquad [\mathrm{Wm^{-2}}] \qquad (2)$$

while

$$^{p}E_{bK} = E_0 \cdot \frac{\sin(h_0) - \frac{0.1T(T_m - 1)}{30}}{\sin(h_0) + 0.106T_m} \qquad [\mathrm{Wm^{-2}}] \qquad (3)$$

$$\cos i = \cos\beta \cdot \sin h_0 + \sin\beta \cdot \cos h_0 \cdot \cos\left|A_n^s - A_0^s\right| \qquad (4)$$

where

$^{p}E_{bK}$ direct radiation incident to plane normal to sun beam direction,

T_m Linke`s coefficient of atmospheric turbidity (mean monthly value),

E_0 solar constant on the upper boundary of the atmosphere (daily value),

h_0 Sun elevation (angle between horizontal plane and sun beam),

i angle of the direct radiation incidence (spatial angle between sun beam and the normal of the given plane),

A_n^s azimuth of the normal of the plane,

A_0^s Sun azimuth.

The Sun azimuth is calculated according (5):

$$A^s_0 = \arccos\left[\cos\delta / \cosh_0 \left(\cos\varphi\ \mathrm{tg}\delta + \sin\varphi \cos(15°.\ H)\right)\right] \qquad (5)$$

where δ declination,
φ latitude,

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H time.

The component of the diffuse radiation ${}^{d}E_{b\beta}$ incident to plane with slope β during cloudless conditions is expressed by (6)

$$ {}^{d}E_{b\beta} = 0.5 \cdot {}^{d}E_{bH} \cdot u_2 \qquad [\mathrm{Wm}^{-2}] \qquad (6) $$

while

$$ u_2 = \sin\beta \cdot \left(0.94 \cdot e^{\cos i} + \frac{1.84}{T_m} - 1.44 \right) + 1 + \cos\beta \qquad (7) $$

$$ {}^{d}E_{bH} = k_b \left(E_0 - {}^{p}E_{bk} \right) \sin h_0 \qquad [\mathrm{Wm}^{-2}] \qquad (8) $$

$$ k_b = \left(0.22 + 0.025 \cdot T_m \right) \qquad (9) $$

where

${}^{d}E_{bH}$ diffuse radiation incident to horizontal plane,

k_b coefficient expressing the portion of the radiation diffused by the atmosphere.

The reflected radiation ${}^{r}E_{b\beta}$ due to surrounding terrain is calculated for the plane with slope β>0

$$ {}^{r}E_{b\beta} = 0.5\alpha \left(1 - \cos\beta\right)\left({}^{d}E_{bH} + {}^{p}E_{bk} + {}^{p}E_{bk} \sin h_0 \right) \qquad [\mathrm{Wm}^{-2}] \qquad (10) $$

Where α is coefficient expressing the portion of the radiation reflected by the surrounding surface [17].

4. Applications

4.1. Photovoltaics

Photovoltaic are solar cells that produce electricity directly from sunlight. The solar cells are made of thin layers of material, usually silicon. The layers, after treatment with special compounds, have either too many or too few electrons. When light strikes a sandwich of the different layers, electrons start flowing and an electric current result [18]. Photovoltaic are used throughout the nation and elsewhere to operate appliances, provide lighting, and to power navigation and communication aids. Photovoltaic panels provide power for equipment in space ships and satellites. PV cells supply power needed to operate many kinds of consumer products such as calculators and watches. Photovoltaic systems provide electricity to remote villages, residences, medical centers, and other isolated sites where the cost of photovoltaic equipment is less than the expense of extending utility power lines or using diesel-generated electricity [19].

Bhuiyan *et al.*, studied the economics of stand-alone photovoltaic power system to test its feasibility in remote and rural areas of Bangladesh and compared renewable generators with nonrenewable generators by determining their life cycle cost using the method of net present value analysis and showed that life cycle cost of PV energy is lower than the cost of energy from diesel or petrol generators in Bangladesh and thus is economically feasible in remote and rural areas of Bangladesh [20].

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Feltrin *et al.*, analyzed several photovoltaic technologies, ranging from silicon to thin films, multi-junction and solar concentrator systems for terawatt level deployment of the existing solar cells, and for each technology, identified improvements and innovations needed for further scale-up [21].

4.2. Solar Thermal

Solar Thermal power is heat energy obtained by exposing a collecting device to the rays of the sun. A solar thermal system makes use of the warmth absorbed by the collector to heat water or another working fluid, or to make steam. Hot water is used in homes or commercial buildings and for industrial processes. Steam is used for process heat or for operating a turbine generator to produce electricity or industrial power [22].

There are several basic kinds of solar thermal power systems including “flat plate” solar water heaters; concentrating collectors, such as central tower receivers; and parabolic trough and dish collectors [22, 23].

4.2.1. Flat Plate Solar Water Heaters – Water flows through tubes that are attached to a black metal absorber plate. The plate is enclosed in an insulated box with a transparent window to let in sunlight. The heated water is transferred to a tank where it is available for home, commercial or institutional use.

4.2.2. Central Tower Receivers – In order to produce steam and electricity with solar thermal energy, central receivers have a field of tracking mirrors called heliostats to focus sunlight onto a single receiver mounted on a tower. Water or other heat transfer fluid in the tower is heated and used directly or converted into steam for electricity.

4.2.3. Parabolic Dishes or Troughs – curved panels which follow the direction of the sun’s rays and focus the sunlight onto receivers. A liquid inside the pipes at the receivers’ focal point absorbs the thermal energy. The thermal energy received can be converted to electricity at each unit or transported to a central point for conversion to electricity.

4.3. Solar Stills

Solar stills are systems designed to filter or purify water. The number of systems designed to filter water have increased dramatically in recent years. As water supplies have increased in salinity, have been contaminated, or have experienced periods of contamination, people have lost trust in their drinking water supply. Water filtration systems can be as simple as a filter for taste and odor to complex systems to remove impurities and toxins. Solar water distillation is one of the simplest and most effective methods of purifying water. Solar water distillation replicates the way nature purifies water. The sun's energy heats water to the point of evaporation. As the water evaporates, purified water vapor rises, condensing on the glass surface for collection [24].

This process removes impurities such as salts and heavy metals, as well as destroying microbiological organisms. The end result is water cleaner than the purest rainwater. Solar energy is allowed into the collector to heat the water. The water evaporates only to condense on the underside of the glass. When water evaporates, only the water vapor rises, leaving contaminants behind. The gentle slope of the glass directs the condensate to a collection trough, which in turn delivers the water to the collection bottle.

4.4. Solar Dryers

Using the sun to dry crops and grain is one of the oldest and most widely used applications of solar energy. The simplest and least expensive technique is to allow crops to dry naturally in the field, or to spread grain and fruit out in the sun after harvesting. The disadvantage of these methods is that the crops and grain are subject to damage by birds, rodents, wind, and rain, and contamination by windblown dust and dirt. More sophisticated solar dryers protect grain and fruit, reduce losses, dry faster and more uniformly, and produce a better quality product than open air methods [25].

The basic components of a solar dryer are an enclosure or shed, screened drying trays or racks, and a solar collector. In hot, arid climates the collector may not even be necessary. The southern side of the enclosure itself can be glazed to allow sunlight to dry the material. The collector can be as simple as a glazed box with a dark colored interior to absorb the solar energy that heats air. The air heated in the solar collector moves, either by natural convection or forced by a fan, up through the material being dried. The size of the collector and rate of airflow depends on the amount of material being dried, the moisture content of the material, the humidity in the air, and the average amount of solar radiation available during the drying season [26].

There are a relatively small number of large solar crop dryers in the United States. This is because the cost of the solar collector can be high, and drying rates are not as controllable as they are with natural gas or propane powered dryers. Using the collector at other times of the year such as for heating farm buildings, may make a solar dryer more cost-effective. It is possible to make small, very low cost dryers out of simple materials. These systems can be useful for drying vegetables and fruit for home use.

Developing efficient and cost effective solar dryer with thermal energy storage system for continuous drying of agricultural food products at steady state and moderate temperature (40–75 8C) has become potentially a viable substitute for fossil fuel in much of the developing world. Solar energy storage can reduce the time between energy supply and energy demand, thereby playing a vital role in energy conservation. The rural and urban populations depend mainly, on non-commercial fuels to meet their energy needs. Solar drying is one possible solution but its acceptance has been limited partially due to some barriers. A great deal of experimental work over the last few decades has already demonstrated that agricultural products can be satisfactorily dehydrated using solar energy. Various designs of small scale solar dryers having thermal energy storage have been developed in the recent past, mainly for drying agricultural food products [27].

Drying is an essential process in the preservation of agricultural products. Food products, especially fruits and vegetables require hot air in the temperature range of 45–60 8C for safe drying. Drying under controlled conditions of temperature and humidity helps the agricultural food products to dry reasonably rapidly to safe moisture content and to ensure a superior quality of the product [4]. Controlled drying is practiced mostly in industrial drying processes. Hot air for industrial drying is usually provided by burning fossil fuels, and large quantities of fuels are used worldwide for this purpose. High cost of fossil fuels gradual depletion of its reserve and environmental impacts of their use have put severe constraints on their consumption [28].

The above discussion emphasizes the fact that the advantages and drawbacks of various designs of solar dryer having heat storage systems for drying of agricultural food products [29].

Jain [30] presented a transient analytical model to study the new concept of a solar crop dryer having reversed absorber plate type collector and thermal storage with natural airflow. The performance of this crop dryer with packed bed was carried out for drying onions in trays. The crop temperature depends on width of the air flowing channel and height of packed bed. The thermal energy storage affects drying during the non-sunshine hours and is very pertinent in reducing the fluctuation in temperature for drying. The proposed mathematical model is useful for evaluating the performance of reversed absorber type collector and thermal storage with natural convective solar crop dryer. It is also useful for predicting the crop temperature, moisture content and drying rate of the crop.

Madhlopa and Ngwalo [31] designed, constructed and evaluated an indirect type natural convection solar dryer with integrated collector-storage solar and biomass-backup

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heaters for drying of fresh pineapple. The major components of the dryer are biomass burner (with a rectangular duct and flue gas chimney), collector-storage thermal mass and drying chamber.

Shanmugam and Natarajan [32] investigated the performance of an indirect forced convection and desiccant integrated solar dryer for drying of green peas and pineapple slices with and without the reflective mirror. The system is operated in two modes, sunshine hours and off-sunshine hours. During sunshine hours the hot air from the flat plate collector is forced to the drying chamber for drying the product and simultaneously the desiccant bed receives solar radiation directly and through the reflected mirror. In the off-sunshine hours, the dryer is operated by circulating the air inside the drying chamber through the desiccant bed by a reversible fan.

4.5. Solar Cooling

Solar cooling consists of using thermal energy collected from the sun as the principal energy input for the cooling system to cool and dehumidify the space [33]. This replaces the existing electrical power input typically required in a vapor compression refrigeration cycle. The benefit of this system is that it has the potential to reduce the amount of electricity used (and carbon dioxide produced from the generation of electricity) during Canada's hot summer months when the demand on the power grid is at its highest. These systems can be effective as the availability of solar radiation coincides with the energy demands imposed on buildings by cooling loads, allowing for the greatest amount of cooling to be generated when it is needed most [34].

4.6. Solar Collector

A solar collector, the special energy exchanger, converts solar irradiation energy either to the thermal energy of the working fluid in solar thermal applications, or to the electric energy directly in PV (Photovoltaic) applications. Solar collectors are usually classified into two categories according to concentration ratios [35]: non-concentrating collectors and concentrating collectors. A non-concentrating collector has the same intercepting area as its absorbing area, whilst a sun-tracking concentrating solar collector usually has concave reflecting surfaces to intercept and focus the solar irradiation to a much smaller receiving area.

After the thermal energy is collected by solar collectors, it needs to be efficiently stored when later needed for a release. Thus, it becomes of great importance to design an efficient energy storage system. Section 3 of the present paper focuses on the solar thermal energy storage, discussing its design criteria, desirable materials and emerging technologies for heat transfer enhancement.

There are three main aspects that need to be considered in the design of a solar thermal energy storage system:

- technical properties,
- cost effectiveness
- environmental impact.

Cost effectiveness determines the payoff period of the investment, and therefore is very important. The cost of a solar thermal energy storage system mainly consists of three parts [5]: storage material, heat exchanger and land cost.

This paper has reviewed the state of the art on solar thermal applications, with the focus on the two core subsystems: solar collectors and thermal energy storage subsystems.

A variety of solar collectors have been discussed, including non-concentrating types and concentrating types. Among non-concentrating collectors, the PVT solar collectors show the best overall performance. Sun-tracking concentrating solar collectors have also

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been examined, in terms of optical optimization, heat loss reduction, heat recuperation enhancement, different sun-tracking mechanisms.

Three different types of concentrating solar collectors have been described and compared: heliostat field collectors, parabolic dish collectors and parabolic trough collectors. The materials used for high-temperature thermal energy storage systems have been compared, and a comparison between different categories of thermal storage systems has been presented.

Heat transfer enhancement is also essential to overcome the poor heat transfer in these applications. For this purpose, graphite composites and metal foams are found to be the ideal materials. Lastly, the current status of existing solar power stations has been reviewed, with potential future research developments being suggested.

Solar cooking is one possible solution but its acceptance has been limited partially due to some barriers. Solar cooker cannot cook the food in late evening. That drawback can be solved by the storage unit associated with in a solar cooker. So that food can be cook at late evening.

5. Conclusion

Solar energy is one of the most promising renewable. It is one of the fastest growing industries worldwide and in order to maintain this growth rate need for new developments with respect to material use and consumption, device design, reliability and production technologies as well as new concepts to increase the overall efficiency arises.

Solar energy can be exploited through the solar thermal and solar photovoltaic (PV) routes for various applications. Power generated by solar energy is not just relatively simpler but is also much more environmental friendly compared to power generation using non-renewable sources like the fossil fuels and coals. Considering that energy usage worldwide has been increasing throughout the years, switching to solar energy can be a viable move.

A review of major solar energy application is presented. This paper would be useful for the solar PV system manufactures, academicians, researchers, generating members and decision makers.

References

[1] J. Kreider and F. Kreith, “Solar energy handbook”, New York, McGraw-Hill, **(1981)**.
[2] T. Khatiba, A. Mohameda and K. Sopianb, “A review of solar energy modeling techniques”, Renewable and Sustainable Energy Reviews, vol. 16, **(2012)**, pp. 2864-2869.
[3] Z. Sen, “Solar energy fundamentals and modeling techniques”, Germany, Springer, **(2008)**.
[4] J. PB and D. GI, “A probabilistic method for calculating the usefulness of a store with finite energy capacity for smoothing electricity generation from wind and solar power”, Journal of Power Sources, vol. 162, **(2006)**, pp. 943-8.
[5] P. Pinel, C. A. Cruickshank, I. Beausoleil-Morrison and A. Wills, “A review of available methods for seasonal storage of solar thermal energy in residential applications”, Renewable and Sustainable Energy Reviews, vol. 15, **(2011)**, pp. 3341-3359.
[6] H. Ghosh, N. C. Bhowmik and M. Hussain, “Determining seasonal optimum tilt angles, solar radiations on variously oriented, single and double axis tracking surfaces at Dhaka”, Renew Energy, vol. 35, **(2010)**, pp. 1292-7.
[7] R. Kuwahata and C. R. Monroy, “Market stimulation of renewable-based power generation in Australia”, Renewable and Sustainable Energy Reviews, vol. 15, **(2011)**, pp. 534-43.
[8] Clean Energy Council. Clean energy fact sheets all about solar photovoltaic. Melbourne, Clean Energy Council, **(2008)**.
[9] C. Smith, “Revisiting solar power’s past”, Technology Review, **(1995)**, pp. 38-47.
[10] M. Hoogwijk, “On the global and regional potential of renewable energy sources”, Faculteit Scheikunde, Universiteit Utrecht, **(2004)**.
[11] T. Bradford, “Solar revolution”, The economic transformation of the global energy industry, Cambridge, MA: The MIT Press, **(2006)**.
[12] REN21. Global status report. Paris: REN21 Secretariat, **(2005)** to **(2011)** Issues.

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[13] M. Ahmad and G. Tiwari, "Solar radiation models-review", Int Journal Energy Environ, vol. 1, pp. 513-32, **(2010)**.
[14] S. Jebaraj and S. Iniyan, "A review of energy models. Renewable and Sustainable Energy Reviews", vol. 10, **(2006)**, pp. 281-311.
[15] K. Bakirci, "Models of solar radiation with hours of bright sunshine: A review", Renewable and Sustainable Energy Reviews, 13, **(2009)**, pp. 2580-2588.
[16] M. M. H. Bhuiyan, M. Ali Asgar, R. K. Mazumder and M. Hussain, "Economic evaluation of a stand-alone residential photovoltaic power system in Bangladesh", Renewable Energy, vol. 21, **(2000)**, pp. 403-10.
[17] A. Feltrin and A. Freundlich, "Material considerations for terawatt level deployment of photovoltaics", Renewable Energy, vol. 33, **(2008)**, pp. 180-5.
[18] J. A. Duffie and W. A. Beckman, "Solar engineering of thermal processes", 3rd ed. Madison, US, John Wiley & Son, **(2006)**.
[19] T. Schmidt, D. Mangold and H. Muller-Steinhagen, "Seasonal thermal energy storage in Germany", ISES solar world congress, **(2003)**.
[20] B. B. Sahoo, N. Sahoo, P. Mahanta, L. Borbora and P. kalita, "Performance assessment of solar still using blackened surface and thermocole insulation", Renewable Energy, no. 33, no. 7, pp. 1703-1708, **(2008)**.
[21] A. Sharma, C. R. Chen and N. Vu Lan, "Solar-energy drying systems: A review. Renewable and Sustainable Energy", vol. 13, **(2009)**, pp. 1185-1210.
[22] R. Smitabhindu, S. Janjai and V. Chankong, "Optimization of a solar-assisted drying system for drying bananas", Renew Energy, vol. 33, **(2008)**, pp. 1523-31.
[23] A. Madhlopa and G. Ngwalo, "Solar dryer with thermal storage and biomass-backup heater", Solar Energy, vol. 81, **(2007)**, pp. 449-62.
[24] P. P. Singh, S. Singh and S. S. Dhaliwal, "Multi-shelf domestic solar dryer", Energy Conversion Management, vol. 47, **(2006)**, pp. 1799-815.
[25] L. M. Bal, S. Satya and S. N. Naik, "Solar dryer with thermal energy storage systems for drying agricultural food products: A review", Renewable and Sustainable Energy Reviews, vol. 14, **(2010)**, pp. 2298-2314.
[26] D. Jain, "Modeling the performance of the reversed absorber with packed bed thermal storage natural convection solar crop dryer", Journal of Food Engineering, vol. 78, **(2007)**, pp. 637-47.
[27] A. Madhlopa and G. Ngwalo, "Solar dryer with thermal storage and biomass-backup heater", Solar Energy, vol. 81, **(2007)**, pp. 449-62.
[28] V. Shanmugam and E. Natarajan, "Experimental study of regenerative desiccant integrated solar dryer with and without reflective mirror", Applied Thermal Engineering, vol. 27, **(2007)**, pp. 1543-51.
[29] H. Henning, "Solar assisted air conditioning of buildings-an overview", Applied Thermal Engineering, **(2006)**.
[30] J. Duffie and W. Beckman, "Solar Engineering of Thermal Processes", Third Edition, Hoboken, New Jersey, John Wiley & Sons, Inc., **(2006)**.
[31] F. De Winter, "Solar collectors, energy storage, and materials, Massachusetts, The MIT press, **(1991)**.

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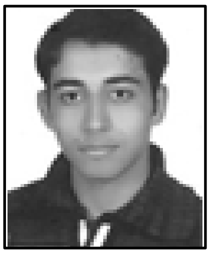

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