AC 2011-1664: SIMULATION TOOLS FOR RENEWABLE ENERGY PROJECTS

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Simulation tools for renewable energy projects

Abstract

In recent years, renewable energy resources have become significant contributors to energy usage among both developed and developing countries. New textbooks dealing with alternative and renewable energy resources have been published recently. Many universities have also started offering classes on renewable and alternative energy course to both undergraduate and graduate students. Simulation and analysis tools on these alternative energy resources may be useful in conducting these classes. This paper compares some of these simulation tools and evaluates their effectiveness based on their use during an elective course at Lamar University. During the course, the students are required to complete a design project on one of the renewable energy sources such as solar, wind, and geothermal.

Some of the simulation tools considered in this paper includes Solar Advisor Model (SAM) from National Renewable Energy Lab (NREL), RETScreen software from Natural Resources Canada, and PolySun from Vela Solaris. Several sample projects on photovoltaic, wind energy, solar water heating and geothermal energy systems were modeled and simulated using these software tools. The comparison and evaluation were done based on various aspects of these tools such as modeling, product databases, validation, and economic analysis. All software tools provide effective modeling and simulation capabilities suitable for class room use.

Introduction

In recent years, renewable energy resources have become significant contributors to energy usage among both developed and developing countries. Rapidly growing economies of developing nations such as China, Brazil and India have significantly increased use of energy in these and other nations. In addition, increasing climate change concerns as a result of increasing use of fossil energy has made the public more aware of the issues and problems associated with energy usage. Figure 1 from Department of Energy[1] clearly shows the increasing trend of energy use and projected increases in energy use. It is interesting to note from Figure 1 that use of renewable energy resources has also increased with an increase in overall energy usage and more and more renewable energy sources are expected to replace fossil fuels in the future. As a result, new textbooks dealing with alternative and renewable energy resources have been published recently[2-4]. Many universities have also started offering classes on renewable and alternative energy course to both undergraduate and graduate students. It is critically important and beneficial to students to incorporate simulation and analysis tools on these alternative energy resources in conducting these classes.

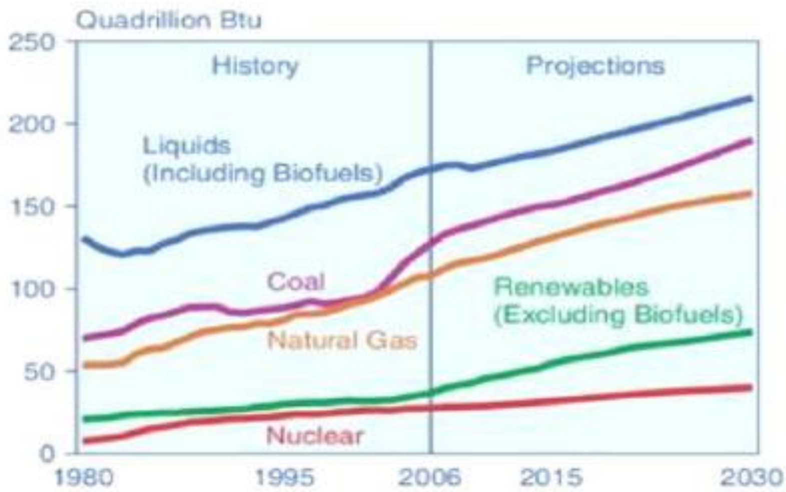


Figure 1 Current and Projected Energy Use by Energy Sources[1]

Energy Engineering is an elective course for mechanical engineering students in the department of mechanical engineering at Lamar University. More details of the course can be found in the 2005 ASEE proceedings paper by the author[5]. In search of simulation tools to be used in the course, the author has found three software tools: Solar Advisor Model (SAM) from National Renewable Energy Lab (NREL), RETScreen software from Natural Resources, Canada, and PolySun from Vela Solaris AG. This paper compares these simulation tools and evaluates their effectiveness based on their use during an elective course, Energy Engineering, at Lamar University. During the course, the students are required to complete a design project on one of the renewable energy sources such as solar, wind, and geothermal.

Simulation Tools

The simulation tools considered in this paper include Solar Advisor Model (SAM) from National Renewable Energy Lab (NREL), RETScreen software from Natural Resources Canada, and PolySun from Vela Solaris. The first two tools, based on Microsoft Excel, are freely available while PolySun is a commercial product. SAM combines a detailed performance model with several financing options for most solar technologies[6]. It can be downloaded from the website of NREL[7]. The RETScreen software can be used to evaluate the energy production and savings, costs, and other aspects for various types of Renewable-energy and Energy Efficient Technologies (RETs)[8]. RETScreen software can be downloaded from the website of Natural Resource Canada[9]. PolySun is a software product that enables users to effectively simulate solar-thermal, photovoltaic, and geothermal systems[10]. It can be downloaded from the website of Vera Solaris[11]. Some detailed discussions on each of the tools and their features and characteristics follow.

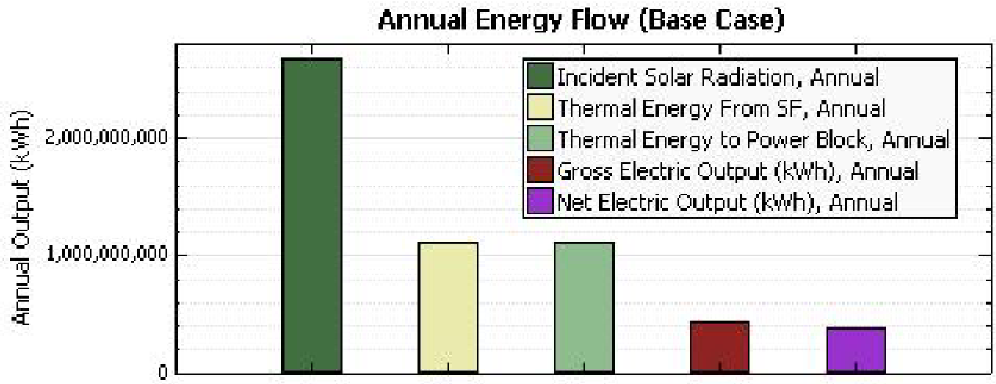
National Renewable Energy Laboratory (NREL), in conjunction with Sandia National Laboratory and in partnership with the U.S. Department of Energy (DOE) Solar Energy Technologies Program (SETP), developed the Solar Advisor Model (SAM) starting in 2004 with ongoing efforts today. The latest version of SAM which now stands for System Advisor Model (SAM), SAM Version 2010.11.9, incorporates models of other renewable energy sources such as geothermal and wind making it more attractive for future uses. Solar Advisor Model is a performance and economic model designed to facilitate decision making for people involved in the solar energy industry, ranging from project managers and engineers to incentive program designers, technology developers, and researchers. Solar Advisor makes performance predictions and economic estimates for grid-connected solar power projects in the distributed and central generation markets[6].

SAM is a Microsoft Excel-based program with an hourly simulation engine that interacts with performance, cost, and finance models to calculate energy output, energy costs, and cash flows. The model calculates the cost of generating electricity based on information you provide about a project's location, installation and operating costs, type of financing, applicable tax credits and incentives, and system specifications. The model provides options for parametric studies, sensitivity analysis, optimization, and statistical analyses to investigate impacts of variations and uncertainty in performance, cost, and financial parameters on model results[6]. Table 1 below shows the results of a sample student project using SAM. The project is based on the data from PS 10, a 10 MW solar power plant presently operating in Seville, Spain. PS 10 uses a solar tower and a conventional steam turbine cycle to generate electricity. The objective of the project is to validate the results of SAM with actual operating data from the PS 10 plant.

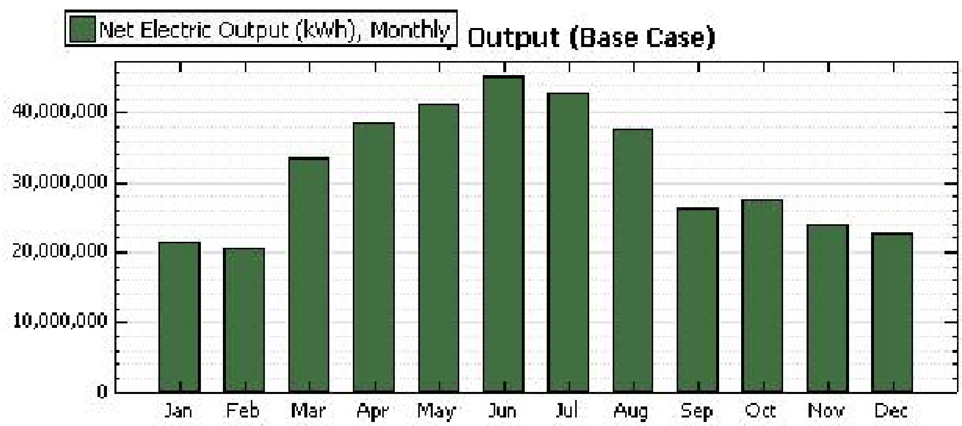
Table 1 Sample results of SAM based on PS 10 solar power plant

Parameter	Actual PS10	Analysis in SAM
Annual electricity production (GWh)	20 – 25	27
Installed cost (US$/kW)	3868	4000
LCOE (¢/kWh)	21	14
Number of heliostats	624	840
Tower height (m)	115	64

In order to run the simulation, the user must provide data such as location of the power plant, type of concentrating solar power plant (tower or parabolic trough), storage options, and other financial data. The simulation results include energy budgets such as incident solar radiation, thermal energy to the plant, gross and net electricity output. Sample outputs of total energy flow and net electricity output are shown in the figure below. The results are from a case study of 100 MW solar power plant included with SAM. For each project, SAM can conduct the financial analysis of the system in terms of LCOE (levelized cost of energy), present worth analysis and life cycle cost analysis.



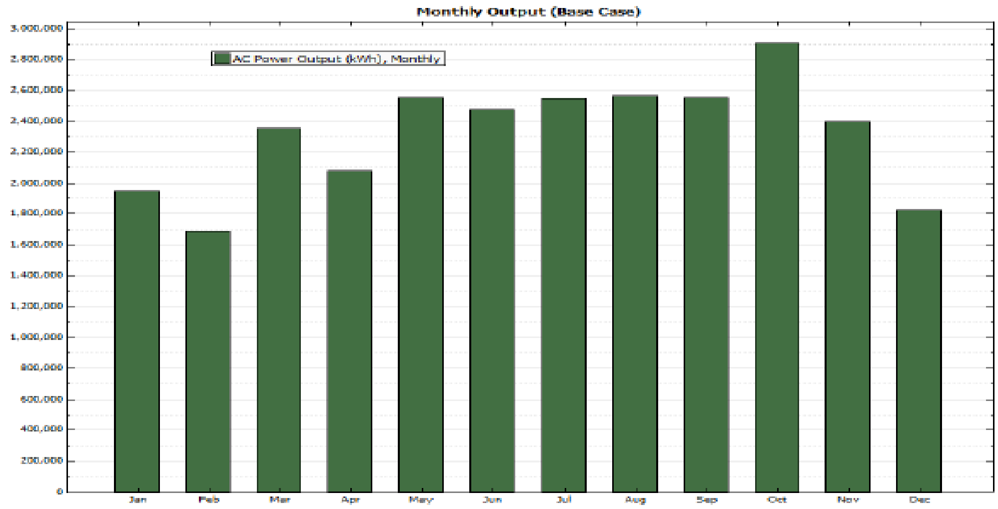
(a)



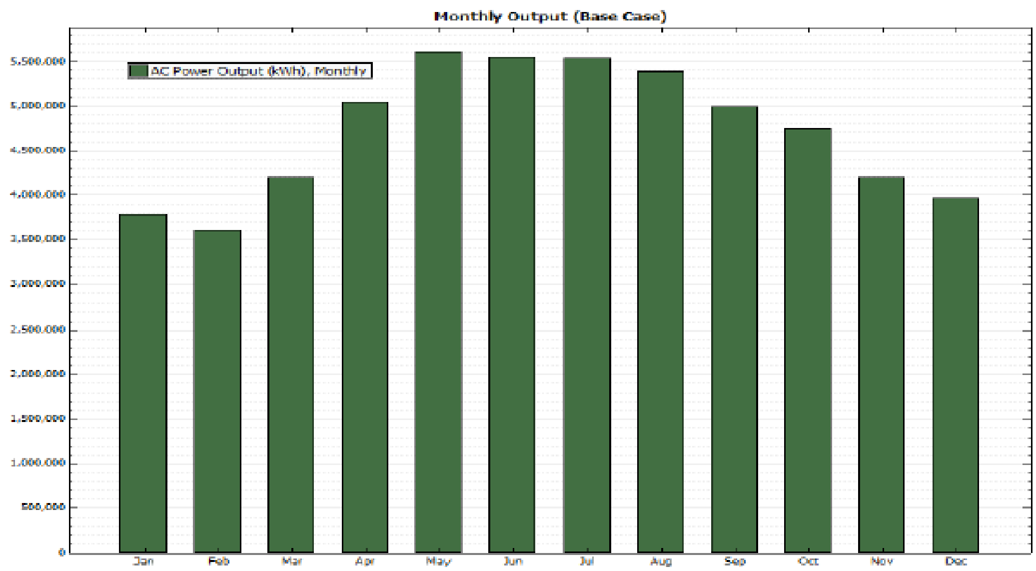
(b)

Figure 2 Sample results (a) Annual energy flow and (b) Net electric output

Another student project deals with comparing LCOE of a 30 MW photovoltaic (PV) plant in two locations: Houston, Texas and Las Vegas, Nevada. The values of LCOE for a 30 MW photovoltaic system at Houston and Las Vegas respectively are 26.5¢/kWh and 13.04 ¢/kWh. Results comparing net electricity output of the 30 MW PV plant for the locations of Houston and Las Vegas are shown in Figure 3 (a) and (b). The comparison shows that Las Vegas with its metrological advantage is much more suitable for a PV power plant than Houston.



(a)



(b)

Figure 3 Comparison of Monthly Net Electricity Output (a) Houston and (b) Las Vegas

The RETScreen International Clean Energy Project Analysis Software is the leading tool specifically aimed at facilitating pre-feasibility and feasibility analysis of clean energy technologies. The core of the tool consists of a standardized and integrated project analysis software product which can be used worldwide to evaluate the energy production, life-cycle costs and greenhouse gas emission reductions for various types of proposed energy efficient and renewable energy technologies (RET). Each model also includes integrated product, cost and weather databases and a detailed online user manual, all of which help to dramatically reduce the time and cost associated with preparing pre-feasibility studies. The RETScreen Software is perhaps the quickest and easiest tool forthe estimation of the viability of a potential clean energy project[12].

Models and sample analyses of different renewable energy sources including wind, small hydro, photovoltaic (PV), solar water heating and ground source heat pump are included with the software. RETScreen Software compares a base case and a proposed case which is typically a clean energy technology. RETScreen is ultimately not concerned with the absolute costs, but rather the incremental costs; the costs of the proposed case that are in excess of those for the base case. RETScreen Software is developed in Microsoft® Excel and the analysis follows five steps for each model:

1. Energy Model
2. Cost Analysis
3. Greenhouse Gas Analysis
4. Financial Summary
5. Sensitivity and Risk Analysis

Steps 1, 2 and 4 are conducted for each renewable technology model but steps 3 and 5 are optional. The five step model of RETScreen software is shown schematically in the figure below.

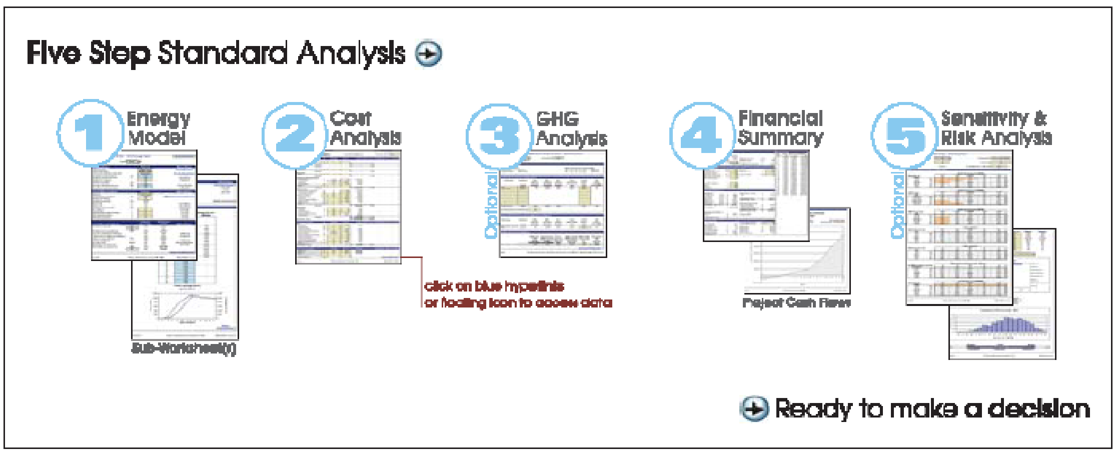


Figure 4 Five step analysis of RETScreen software[8]

One of the student projects deals with a geothermal heat pump for heating and cooling of a building with 3000 square ft of space. The base case consists of natural gas heating and electric cooling. The objective of the project is to find a suitable ground source heat pump for both heating and cooling requirements with possible supplementary system. The project is done with the RETScreen software as there are several case studies available on ground source heat pump for the student to study. Sample figures of heating and cooling load profile and cash flow analysis are given below in Figures 5 and 6.

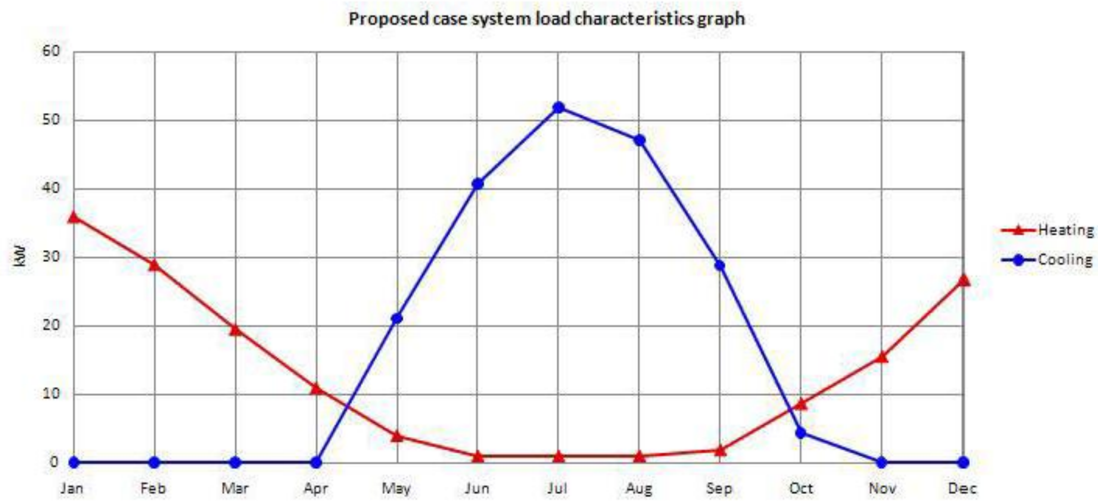


Figure 5 Heating and cooling load profile of a ground source heat pump

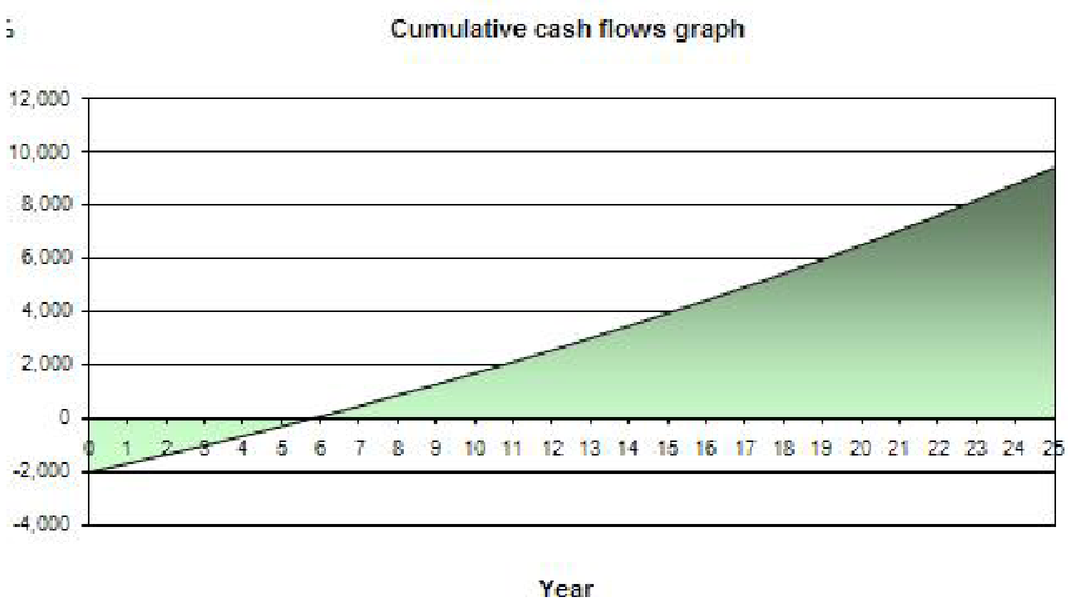


Figure 6 Yearly Cash Flow of the Heat Pump System

PolySun from Vela Solaris AG is a software that enables users to effectively simulate solar-thermal, photovoltaic, solar water heating, and geothermal systems[10]. PolySun is a commercial software package and the demo version allows only the solar thermal heating models and the geographical location is limited to Rapperswil, Switzerland. A sample project on solar pool heating and some results are included here. The following is a schematic of the solar pool heating system with two solar collectors.

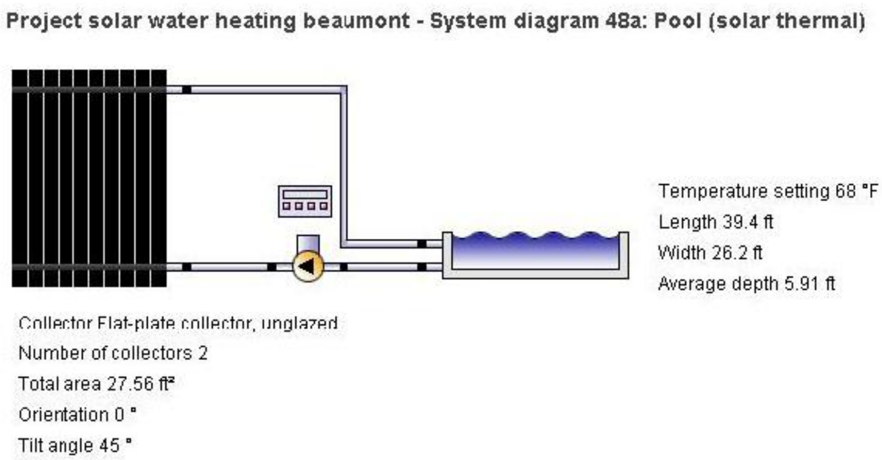


Figure 7 Schematic of a solar pool heating system

Once the project data in terms of the location, the solar model, and other details such as collector orientation are specified, simulation of the system is performed by the software. The simulation results include monthly detailed energy budgets such as solar energy to the pool, heat loss to the surroundings, and total energy consumption. Sample results of the solar energy to the system and total electrical energy consumption are shown in Figure 8 below.

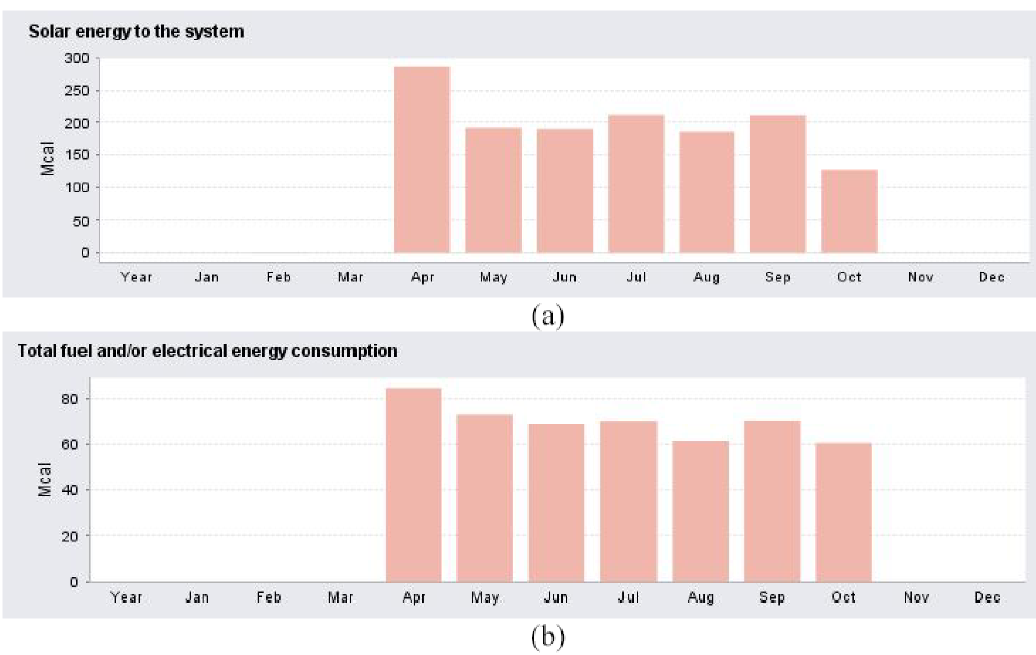


Figure 8 Sample results (a) Solar energy to the system and (b) Total electrical energy

The program also provides simulation results in a graphical format. A sample graphical output of the outdoor, collector, pool, and ground temperatures for the duration of a calendar year can be seen in the figure below.

Figure 9 A sample graphical representation of various temperatures of the system

In addition to the energy analysis, the program conducts a financial analysis of the system life cycle cost that can provide specific results such as payback period, annual savings (costs), and net present value. In order to report the results, the program provides three choices of reports: short, light and professional, with each report available in Adobe PDF, Microsoft PowerPoint and Word, and html formats.

Comparison of Features

This section discusses some features of the three simulation tools and compares them in a tabular format. In terms of geographical data, all three programs have metrology databases for worldwide locations and each database can provide solar radiation, mean temperature, wind speed, heating and cooling days, and other relevant data for each location. All three programs have also included product databases of many manufacturers of solar panels, wind turbines, geothermal heat pumps, and other related parts. All three programs can produce output in tabular and graphical formats but only PolySun software can produce professional reports directly from the simulation output. LCOE is the most common measure to compare different energy technologies but PolySun software does not include LCOE as one of the financial analysis results. The comparison of important features of the three simulation tools are summarized in Table 2.

Table 2 Comparison of program features of SAM, RETScreen and PolySun

Features	Simulation Tools		
	SAM	**RETScreen**	**PolySun**
Energy Model	√	√	√
Financial Model	√	√	√
Solar Model	√	√	√
Geothermal Model	√	√	√
Wind Model	√	√	
Metrology database	√	√	√
Product database	√	√	√
Reports			√
Graphic output	√	√	√
Life cycle cost	√	√	√
LCOE	√	√	
Grenhouse gas model		√	
Parametric/sensitivity analysis	√	√	

Educational Values

Students receive many benefits using these simulation tools in their course whether as assignments or projects. All three tools include a comprehensive meteorology data set and product databases so realistic and actual case studies of different renewable energy sources can be modeled and the system performance can be predicted. Comparing the performance of the simulation model and the actual plant data provide insight into the capabilities of the simulation tools and gains hands-on experience in modern simulation tools. All three simulation programs provide case studies and sample projects so students do not have any problems in completing their design projects in time. At the end of the course, students completed a survey on the general aspects of the simulation tools and their usefulness for the course. The survey form is given in Table 3. The survey consists of 3 yes or no questions and one rating question. On a scale of 1 to 5 with 5 being the highest, students in the class rated these tools 4.67 out of 5 indicating that these tools were very useful for the course and their studies.

Table 3 End-of-Course Survey Form

Questions	Response
	Yes/No
Do you find the simulation tools easy to use?	
Does it take long for you to get familiar with the simulation tools?	
Do the simulation tools facilitate the class project?	
	Rating
	1 to 5
How useful are the simulation tools for the class? Rate in the scale of 1 to 5 with 1 being the least useful and 5 being the most useful.	

Summary

With increasing importance of renewable energy resources in present and future energy scenarios, ability to design and analyze these renewable energy systems becomes essential for engineering educators and students. This paper compares three simulation tools of renewable energy systems and evaluates their effectiveness based on their use during an elective course at Lamar University. During the course, the students are required to complete a design project on one of the renewable energy sources such as solar, wind, and geothermal. The simulation tools considered in this paper includes Solar Advisor Model (SAM) from National Renewable Energy Lab (NREL), RETScreen software from Natural Resources Canada, and PolySun from Vela Solaris. Sample projects on photovoltaic, solar water heating, and geothermal energy systems were modeled and simulated using these software tools. The comparison and evaluation were done based on various aspects of these tools such as modeling capability, product databases, validation, and economic analysis. All software tools provide effective modeling and simulation capabilities suitable for class room use.

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