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Solar Energy Simulator A 'simulation based' Solar, Wind and Battery System simulator and performance predictor web application.

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(71) Applicant(s)
Wolfgang Flatow

(72) Inventor(s)
Flatow, Wolfgang

(74) Agent / Attorney
Wolfgang Flatow, 21 Aherns Road, Conondale, QLD, 4552

Abstract

A Solar System (can include Grid, Wind and Batteries etc) energy and financial performance calculator that uses a "Simulation Core" that accurately simulates real-world behaviour of Appliances and Solar Energy Systems.

Drawings

Figure 1

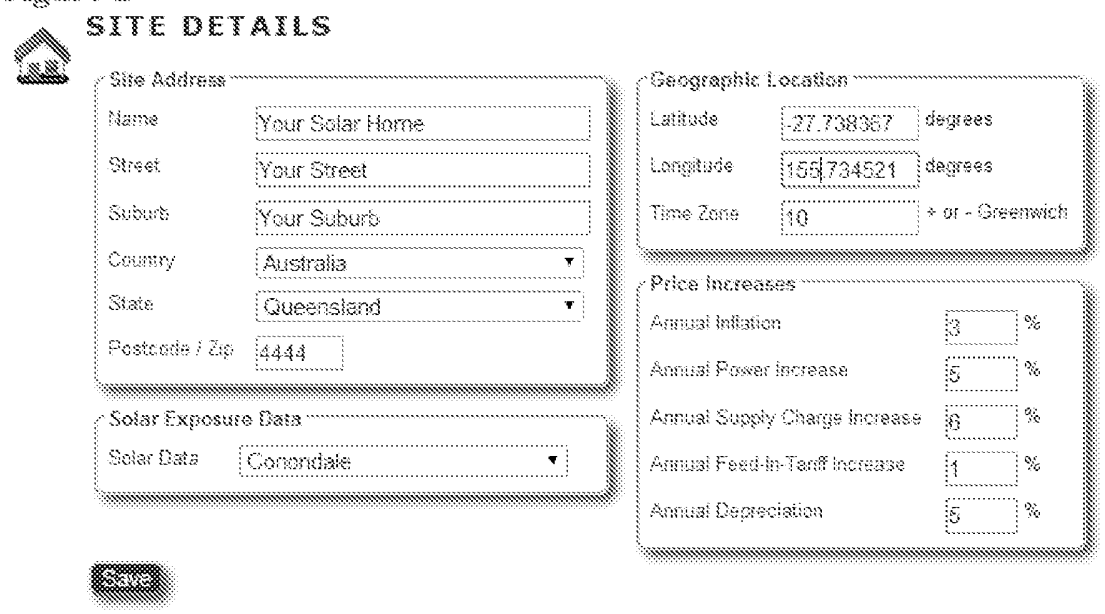
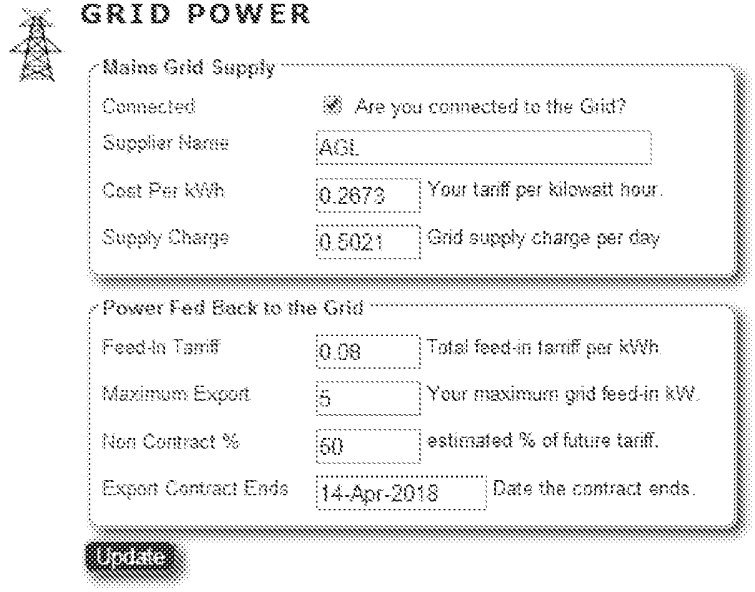


Figure 2



2014100657 16 Jun 2014

EDITORIAL NOTE

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There are ten pages of description only

2014100657 16 Jun 2014

Innovation Patent

Title: Solar Energy Simulator

Inventor: Wolfgang Flatow

June 2014, Conondale, Queensland Australia

Solar Energy Simulator

Description

This **Solar Energy Simulator** (SES) invention is a Web Application that has the purpose of providing investment grade information to people purchasing Solar, Wind and Hybrid Renewable systems.

It is a precision research tool for Solar System Investors, based on a 'simulation engine' at the core of this patent.

By "Solar" we refer to all renewable or non-renewable energy systems and components that can be combined at a site to generate or store electrical or heat energy. We include non-renewable energy systems to cater for the inclusion of petrol or diesel generators in a sites energy profile.

The SES allows the entry of Electric and Heat Appliance information for a given site that allows the SES to precisely simulate electricity consumption and time of consumption of those appliances.

The SES simulates appliance consumption rate and time of consumption at a resolution fine enough to detect on/off states of appliances and sensitive enough to changes in solar radiation changes, around once per minute, over any desired date range for which Solar Irradiation data is available.

Because Solar Systems deliver their power in a roughly 8 hour period, the peak being roughly 6 hours around noon, in a constantly varying intensity according to time of day, season and weather, the simulator must match the varying appliance load with varying Solar Supply in order to determine the exact levels of self-consumption, grid-feed and/or battery storage.

The degree of self-consumption, grid-feed and/or battery storage at any given point in time directly determines the energy and financial performance, and therefore return on investment.

While past electricity bills can be used to roughly size a Solar System, they may not give an accurate sizing and they cannot be used to accurately predict return on investment.

In order to create useful projections and Return on Investment (ROI) predictions, you must have a very accurate baseline, as any errors are multiplied by 20, 25 or 30 years.

The **Solar Energy Simulator (SES)** creates an accurate baseline with a combination of:

- A complete Appliance Audit
- Accurate power consumption and time of consumption simulation
- Accurate Solar, Wind, Battery and Grid System modelling
- Day length and solar irradiation data integration to compute Solar Energy Generation

The SES is used to re-generate a baseline for any number of parameter combinations, allowing one to research as many what-if scenarios as desired to tune a system to a sites appliance energy profile.

Once a **Simulation Run** is complete and a baseline is getting close to the target system, one can generate these reports:

- Simulation Report
- Appliance Consumption Analysis

- Solar Impact Projection
- Solar Investment Cash flow Projection

Battery depth of discharge (DOD) calculated from the simulation is applied in the projection to calculate the number of replacement battery packs.

One can re-run these reports with different annual power and supply charge increase percentages, different battery size and DOD, different Solar System size, Solar Hot Water, Wind etc.

In this way, the SES is used as a research tool to refine the parameters of your desired Hybrid System, and to gather investment grade information upon which to base your decisions.

The Web Application Prototype

The prototype of this invention was privately invented, conceived, designed and programmed by the Inventor beginning in April 2014 in his home studio. There have been no collaborators or co-developers involved, and the inventor, having established by way of industry queries that such a simulator did not exist, built his concepts entirely from basic principles and his own ideas, without reference to any other solar calculators.

The inventive steps and prototype development have been guarded from any public exposure from that date until the date of completing this patent specification.

The prototype has undergone extensive testing at this stage and is being readied for publication as part of a new business web.

Therefore a comprehensive set of screenshots of the fully functioning prototype is included as part of this patent specification, that greatly assists in the understanding of the various invention components.

The core screenshot is Figure 7 that shows the simulation run page. This screenshot is taken mid-simulation run, while all the kWh and Grid $ values are ticking over. Note the Status area where the current simulation date is highlighted in the calendar and a weather condition icon shows a rainy day on the 17th.

Even though the prototype is at a highly advanced stage, it has not been published on the internet at the date of completing and lodging this specification.

Differences from existing calculators

There are numerous "Solar System Sizing" and "Solar System Financial Return" calculators on the Internet, with a great variation in user friendliness and accuracy. While much of the data they collect overlaps somewhat with the data collected by this invention, none of them use a "simulation core" to calculate their results.

They all use a set of generic formulas to perform near instant calculations, which is a benefit if you are looking for speed.

But we are not competing on speed!

The complex simulation calculations performed by this invention are repeated for every minute of the day (1440 times) for every day in the simulation range and take about 45 seconds per month.

The purpose of the simulator is to accurately determine the minute by minute ratio of power consumption / power generation, taking into account real-world solar irradiation records and astronomical sunrise/sunset calculations.

When you purchase power from the Grid at $0.27 and sell it back to them at $0.08, knowledge of how much you self-consume (SC = direct solar to appliance usage), how much you store in batteries (B), how much you feed back into the grid (FI) and how much you purchase from the grid (G) is critical.

This can only be accurately determined by matching appliance consumption with Solar or Wind generation on a minute by minute basis.

Using generic formulas may yield the correct result, but they are far more likely to be way of. They are far less reliable because they cannot determine actual SC/B/FI/G ratios.

Invention Domain

This invention is a combination of methodologies, algorithms, databases, computer software, user interfaces and communications systems.

This combination of elements functions over the Internet between a dedicated server and Internet Browser programs, such as Google Chrome, Firefox, Microsoft Internet Explorer.

The invention can also function as a stand-alone program running on a Personal Computer, Laptop, Smart Phone or Tablet Computer, however, this patent describes only the Internet Web Application.

Invention Scope

This invention defines a unique and inventive combination of elements within a well-known arena of prior art, that is Computer Programming, Internet Communications and Databases.

The scope of the invention is worldwide in reach, and is extensible to financial modelling of all types of energy systems.

The invention delivers a very powerful energy research tool for people who need only internet browser skills, and who do not need to be skilled in electrical or energy engineering.

Database elements

The following set of database stores forms one of the inventive combinations at the core of this invention:

Site

The site on which a Solar energy system is considered (see Figure 1).

The Site data store includes:

- The site address
- The site co-ordinates (latitude and longitude)

- The site timezone

The site also stores the estimated annual price increase percentages for the grid tariff, feed-in-tariff and supply charge.

Grid

The Mains Grid connection (see Figure 2).

The Grid data store includes:

- Supplier Name
- Cost per kWh
- Daily Supply charge
- Feed-in-tariff
- Maximum Export kW

Appliances

The Appliances data store provides for the consumption details of all the appliance used on the site (see Figures 3 and 4)., and includes:

- Appliance Name
- Wattage
- Usage time of Year
- Usage time of Day

A variety of Usage Time settings can be provided, such as:

- Season
- From and To dates
- From and to daily times
- From and to weekly times

Renewable Technologies

This stores the Renewable Energy Systems and Components that can be combined to generate and store a sites energy requirements (see Figures 5 and 6).

The components stored here include:

- Battery
- Solar Hot Water
- Solar Pool Heating
- Solar Photovoltaic Systems
- Wind Generator
- Wind Pump

Different components storage requirements varies. The common ones are:

- Name
- Kilowatt Rating
- Total System Cost
- System Design Life in years

Dedicated storages are:

Battery

- Maximum Depth of Discharge %
- Battery Design Float Life
- Inverter Cost
- Inverter Life

Solar Hot Water

- Orientation
- Tilt
- Shading

Shading can be set at the beginning and end of each day, settable by month or season.

Solar Pool Heater

- Orientation
- Tilt
- Shading

Shading can be set at the beginning and end of each day, settable by month or season.

Solar Photovoltaic System

- Orientation
- Tilt
- Tracking
- Shading

Shading can be set at the beginning and end of each day, settable by month or season.

Environmental Data

To realistically simulate the output of Solar Systems one must use real-world solar irradiation data near the site location being simulated.

Equally, to realistically simulate the output of Wind Energy Systems one must use real-world wind speed data near the site location being simulated.

One of the inventive steps of this invention is to integrate available solar irradiation records and wind speed records with the simulation process.

In the case of Australia, this data is collected and distributed by the Bureau of Meteorology at http://www.bom.gov.au/climate/data/.

This provides daily Solar Irradiation levels on a flat horizontal surface, as well as wind speed data, for a vast number of monitoring sites around Australia free for public access.

One approach to integration is to make a base set of these data sets available and to allow clients to go to the above web, download a dataset closer to the site from the above web and upload it to the SES.

Another approach to integration is to negotiate direct access with the BOM.

The Simulation Process

This invention defines a simulation process that combines at its core a simulation loop, a set of sampling algorithms and accumulators.

The simulation process operates within the users browser application running javascript, processing the simulation using the users CPU. This is an important inventive step, as the simulation process is extremely micro-processor intensive, and would rapidly and seriously degrade server performance should it be run on the server.

In order to deliver the simulation processing capability to users browsers, all of the algorithms and processes in this section are delivered to the browsers in javascript modules, and all of the data store (see above) delivered by way of JSON arrays from the server.

Here follows the description of the Simulation Process:

Simulation Loop

A While loop is defined to run through a user selected date range. The loop contains a simulator-date-time stepping variable that increments (increases) on each cycle iteration by the determined sampling resolution (eg 1 minute).

Prior to the loop starting, a set of totals accumulator variables are set to zero.

The loop is started, and a set of accumulator variables local to the simulation loop are set to zero on each loop iteration (or simulation cycle).

When the simulator-date-time passes midnight to a new day, daily processing occurs that calculates the sunrise and sunset times of that day (using known astronomical equations using site longitude and latitude), and the Solar Irradiation for that day (using the BOM data above).

The simulation loop then performs these steps in order:

1. Appliances Sampling
2. Solar Generator Devices Sampling
3. Wind Generator Devices Sampling
4. Energy Flow Processing
5. Battery Depth of Discharge Processing

Appliances Sampling

The simulator loops through all of the included appliances.

For each one, it performs the following checks against the current simulator-date-time:

- Is the appliance within a selected season
- Is the appliance within a set date range
- Is the appliance within a daily or weekly time range

If all of the above are true, the appliance is on for that sample cycle, and the watt-hours are calculated for the appliance for the current simulation cycle.

If the appliance is an Air Conditioner or a Solar Hot Water Heater, the watt-hours can be modified by the know solar irradiation to better reflect the likely load (an air conditioner will work harder the hotter it is, a solar hot water system will use less booster).

The resulting watt-hours are passed back to the loop accumulator.

Solar Generator Devices Sampling

The simulator loops through all the included Solar Generator Devices.

For each one it performs checks to see if there is any available Solar Irradiation first by checking if the current simulator-date-time is between the current days sunrise and sunset times.

Then the user's seasonal Solar System shading settings are checked.

If there is available solar energy, the following inventive steps are used to determine how much energy there is being generated during the current simulator cycle:

A sine wave is fitted between sunrise and sunset time for that day and normalised from 0 (sunset and sunrise) to 1 (noon) to simulate that days rising and setting solar position.

The x position of the current simulator-date-time is used to read the y point on the sine wave.

The y fraction of 1 is applied to that day's solar irradiation value to yield the irradiation level (i) at that cycle time.

The result (i) is applied to the Solar Systems Kilowatt Rating over the cycle duration to yield watt-hours generated.

The resulting watt-hours are passed back to the loop accumulator.

Wind Generator Devices Sampling

The simulator loops through all the included Wind Devices.

For each one it uses the sites average wind speed and the Wind Generators efficiency over the cycle duration to yield watt-hours generated.

Note: as for Solar Irradiation, this invention includes historical wind data integration at this point.

The resulting watt-hours are passed back to the loop accumulator.

Energy Flow Processing

Once Appliances Sampling, Solar Generator Devices Sampling and Wind Generator Devices Sampling are completed in each simulation loop, the loop accumulators contain the total watt hours consumed by appliances and the total watt hours generated by renewable sources for the current simulator iteration.

The steps taken from here are:

1. Apply watt-hours generated to watt-hours consumed
2. Accumulate self-consumed watt-hours
3. Apply any remaining watt-hours generated to Grid feed-in and/or Battery Charge
4. Accumulate Grid feed-in and battery watt-hours
5. Supply outstanding watt-hours from Grid or Battery
6. Accumulate wasted generation (max battery and max feed-in-allowance)
7. Accumulate un-met usage (off-grid only)

Depending on the feed-in-tariff, the user may have their system set to maximise grid-feed or self-consumption, which is set by the user.
According to this setting, the order of grid feed-in and battery charging is reversed.

Battery Depth of Discharge

When the Battery has remaining storage capacity, it is charged with generated watt-hours remaining after usage has been served.

When there is a deficit of generated power for a simulation cycle, and the battery has available power, it can service some or the entire deficit.

The maximum allowed Depth Of Discharge (DOD) of the battery is controlled by the user setting and is the battery will only discharge to this level.

The simulator tracks the DOD for each daily cycle.

An inventive step is that the battery life, initialised at the design battery float life set by the user, is decreased each day according to that days DOD calculated using and exponential function with a close fit to the battery DOD/Cyles graph.

The formula used is:

```
DOD-Percentage = (battery-watt-rating - maximum-DOD) / battery-watt-rating * 100;
Battery-Life-Used = battery-DOD-Cycle-lookup(DOD-Percentage);
Battery-Life = -Battery-Life - (1 / Battery-Life-Used * Battery-Float-Life);
```

The battery life can then be used to accurately predict battery replacement costs.

Benefits

The inventive steps in this patent combine to deliver an accurate baseline for a sites appliance consumption and any Solar, Wind and Battery systems installed to meet that consumption, over the time span that the simulation was run.

Simulation runs can be repeated with any changes to any of the parameters, inclusion or exclusion of any of the Solar Energy components, Appliances etc (see Figure 7).

The tool is used to approach a desired outcome, such as meeting the sites appliance usage, reaching a desired ROI etc.

As you get close to your target, you can increase the duration of the simulation, ideally to a year, to calculate the most accurate possible baseline.

One purpose of the baseline is to be able to accurately project system performance and financial returns into the future.

Without such an accurate baseline, it is not worthwhile to generate projections as the errors are accumulated 25 to 35 fold.

Therefore, the unique quality of this Simulation Based Solar Energy System Calculator is its capacity to generate highly accurate simulated baselines for any combinations of site appliances and Solar Systems.

Reports

Reports can be run following any simulation run, as the simulation results are always projected to a yearly baseline.

The sample reports included are:

- Simulation Report (see Figure 8)
- Appliance Consumption Analysis (see Figure 9)
- Solar Impact Report (see Figure 10)
- Return on Investment Cash Flow (see Figure 11)

They clearly show the capability of the invention to process the complex combinations of appliance usage and Solar System impact.

Simulated results have been verified against real-world cases and found to match within 4% of actuals.

2014100657 16 Jun 2014

EDITORIAL NOTE

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2014100657 16 Jun 2014

Claims

1) Simulation based Solar System performance predictor

A Solar System (can include Grid, Wind and Batteries etc) energy and financial performance calculator that uses a "Simulation Core" that accurately simulates real-world behaviour of Appliances and Solar Energy Systems.

2) Solar System Simulation Engine

A Solar System (can include Grid, Wind and Batteries etc) simulation engine that functions according to "The Simulation Process" above.

3) Solar Fraction Formula

A formula combining astronomical sunrise and sunset calculations, the fitting of a sine wave (or near sine wave) between the sunrise and sunset times, normalised from 0 to 1, the matching of a sample time with the x axis of the sine wave to yield the Solar Fraction for that simulation cycle by reading the sine y axis at x.

4) Solar Irradiation Formula

Using the result of **3) Solar Fraction Formula**, multiply this by historical Solar Irradiation data for the site location on the simulation day to yield Solar Irradiation level for that simulation cycle.

5) Battery Life Depth of Discharge Simulation Formula

A formula combining the tracking of the simulated battery usage to determine its maximum daily depth of discharge, reading the y axis from an exponential (or near exponential) curve fitted to battery life DOD specifications, where the x axis is depth of discharge and the y axis the number of cycles, and subtracting the product of the y axis and the daily fraction of battery float life in days, from the battery float life in days.

Expressed in code as:

```
DOD-Percentage = (battery-watt-rating - maximum-DOD) / battery-watt-rating * 100;
Battery-Life-Used = battery-DOD-Cycle-lookup(DOD-Percentage);
Battery-Life = Battery-Life - (1 / Battery-Life-Used * Battery-Float-Life);
```

Where `Battery-Life` is the current simulation life.

EDITORIAL NOTE

2014100657

There are eight pages of drawings only

2014100657 16 Jun 2014

Drawings

Figure 1

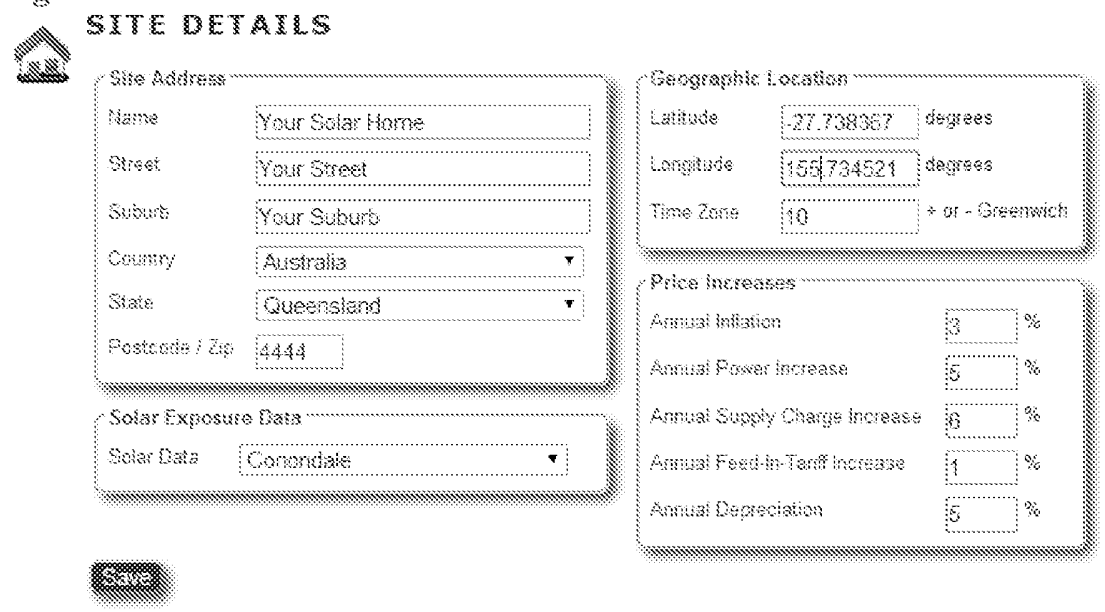


Figure 2

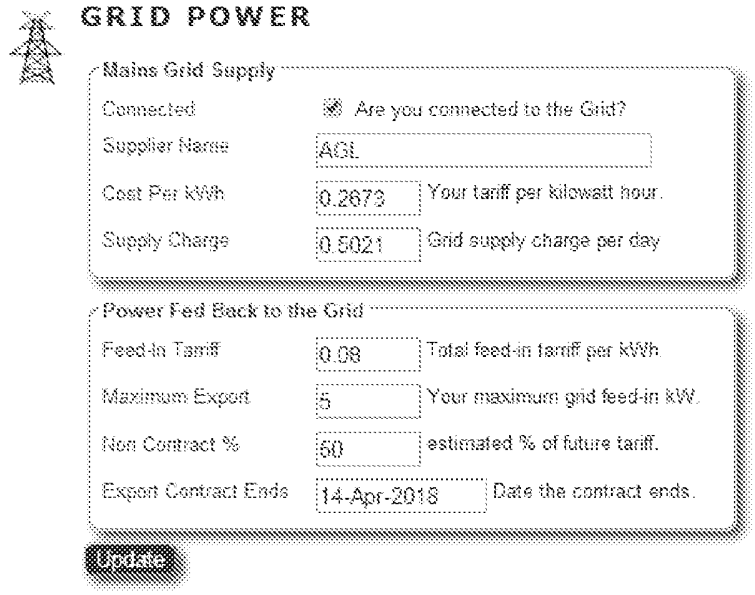


Figure 3

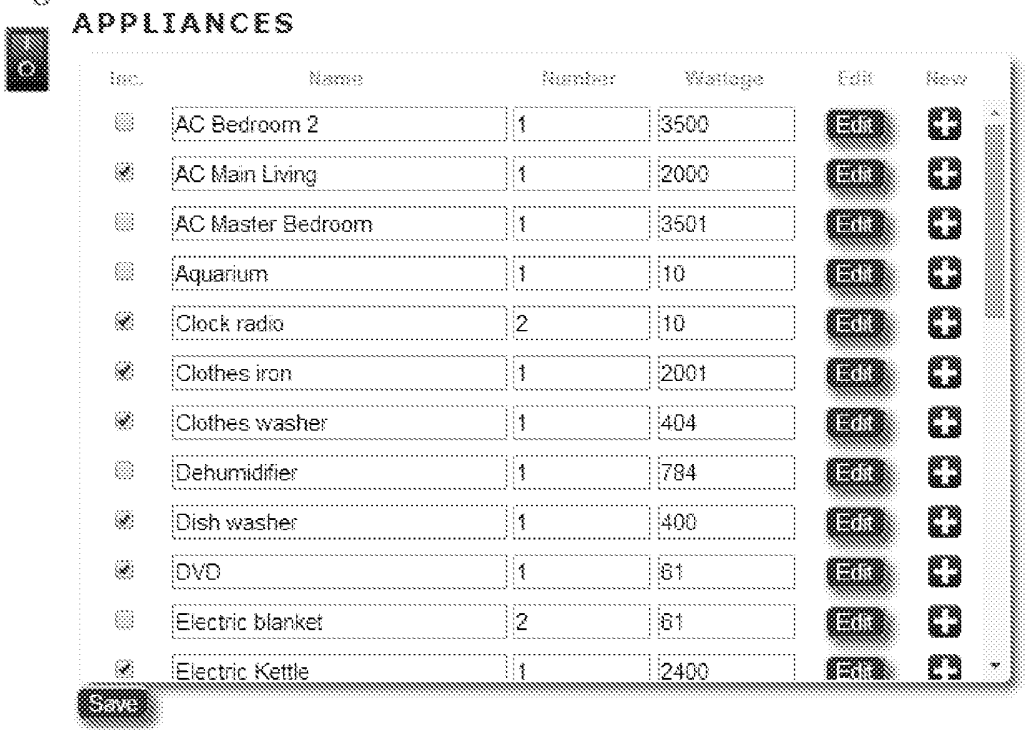

APPLIANCES
Inc.
Name
Number
Wattage
Edit
New
AC Bedroom 2
1
3500
AC Main Living
1
2000
AC Master Bedroom
1
3501
Aquarium
1
10
Clock radio
2
10
Clothes iron
1
2001
Clothes washer
1
404
Dehumidifier
1
784
Dish washer
1
400
DVD
1
61
Electric blanket
2
61
Electric Kettle
1
2400
Edit
Save

Figure 4

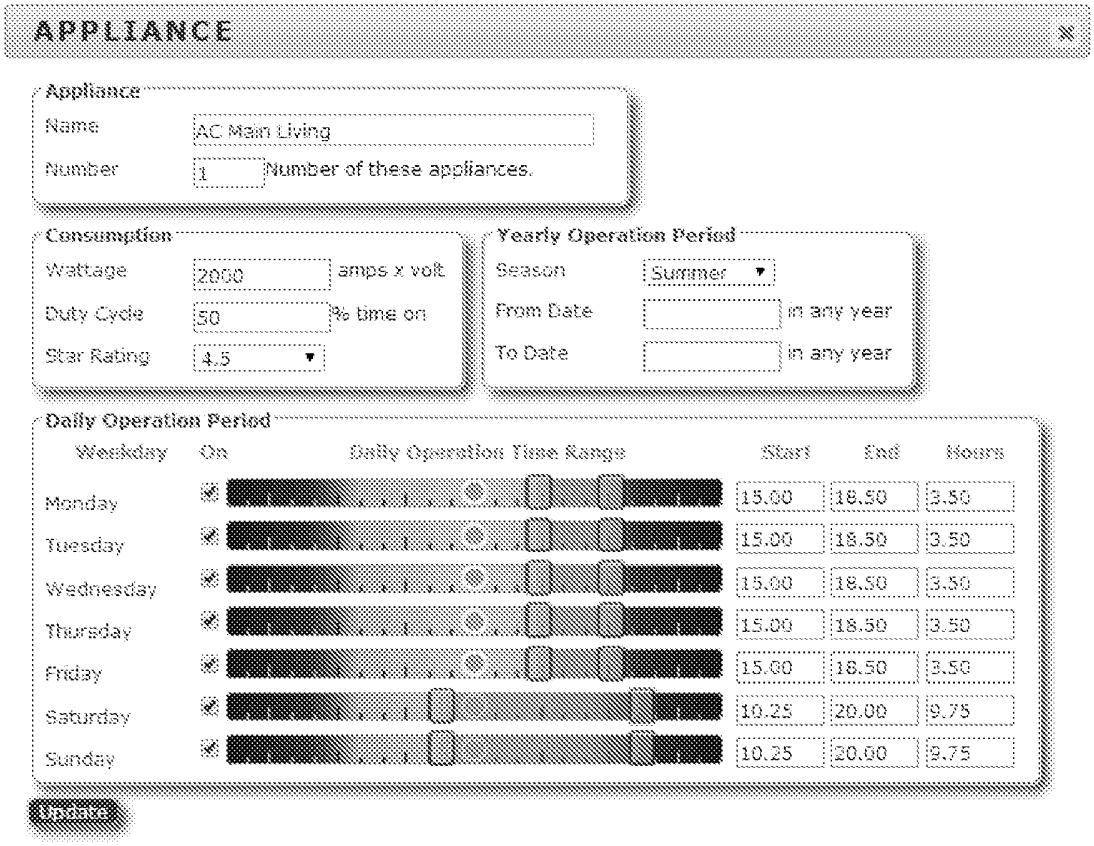


Figure 5

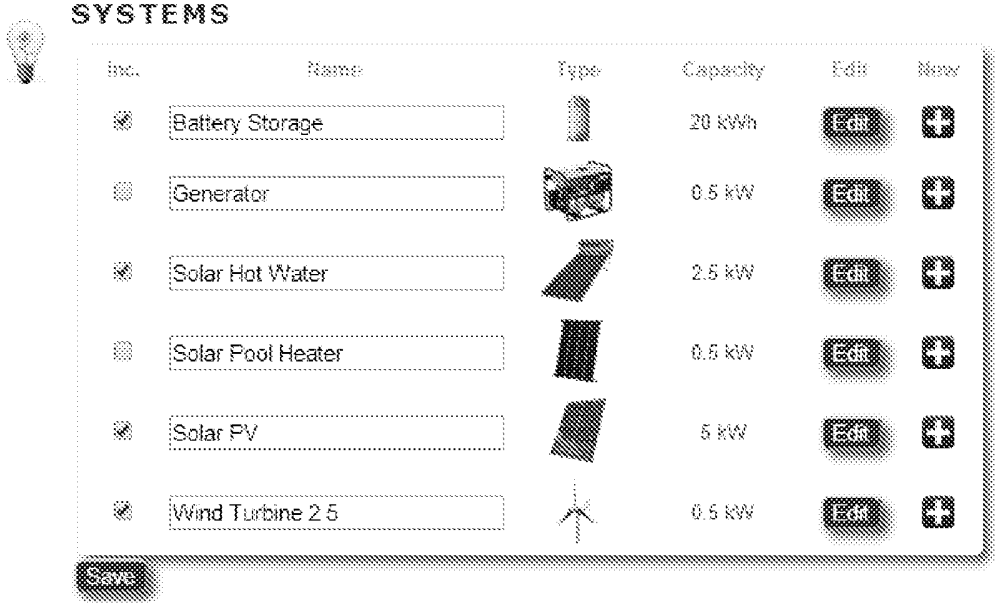


Figure 6

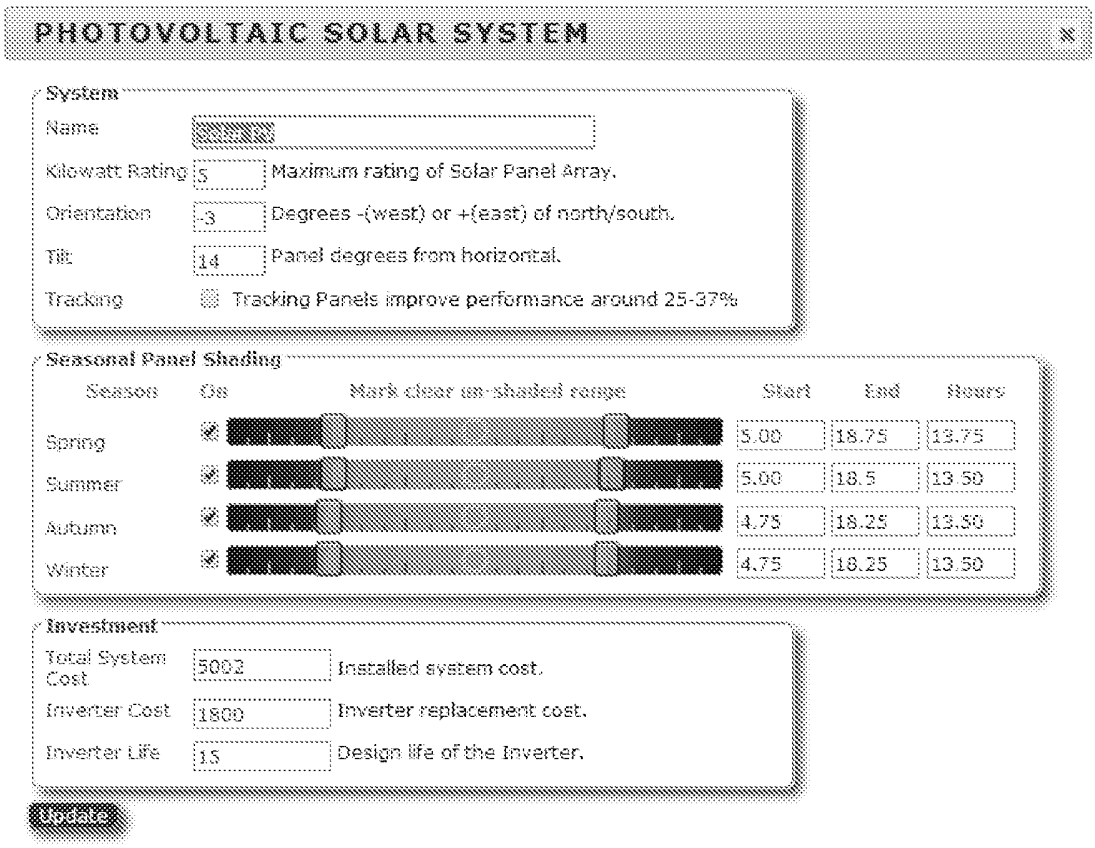
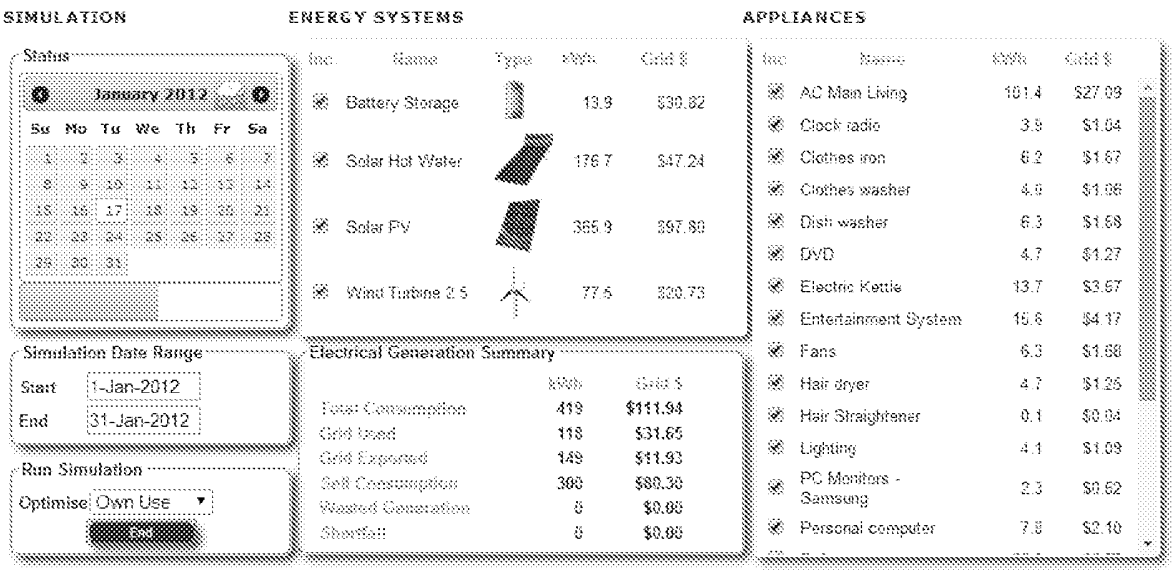


Figure 7



20141100657 16 Jun 2014

Figure 8

Simulation Report

For Your Solar Home at Sunshine Coast.
Simulation from 1-Jan-2012 to 31-Jan-2012, 31 days.

Totals generated by the Simulation Run

Simulation Totals (31 days)	kWh	Gold $	Comment
Total Consumption	[illegible]	[illegible]	Total of all the appliance electricity consumption
Electricity Generated	[illegible]	[illegible]	Total electricity generated by your Solar Electricity system
Grid Used	[illegible]	[illegible]	54.3% of your electricity used was purchased from the Grid
Grid Supply Charge	[illegible]	[illegible]	Supply charge is not included in Solar Systems
Grid Exported	[illegible]	[illegible]	21.2% of the electricity you generated was exported to the Grid
Self Consumption	[illegible]	[illegible]	78.8% of the electricity you generated was self consumed
Battery Stored	[illegible]	[illegible]	0% of the electricity you generated was self consumed via Battery
Heat Generated	[illegible]	[illegible]	Heat generated and self consumed converted to kWh

Projection to One Year

Annual Totals (365.2422 days)	kWh	Gold $	Comment
Total Consumption	[illegible]	[illegible]	Annual appliance electricity consumption
Electricity Generated	[illegible]	[illegible]	Annual electricity generated by your Solar Electricity system
Grid Used	[illegible]	[illegible]	54.3% of your electricity used was purchased from the Grid
Grid Supply Charge	[illegible]	[illegible]	Supply charge is not included in Solar Systems
Grid Exported	[illegible]	[illegible]	21.2% of the electricity you generated was exported to the Grid
Self Consumption	[illegible]	[illegible]	78.8% of the electricity you generated was self consumed
Battery Stored	[illegible]	[illegible]	0% of the electricity you generated was self consumed via Battery
Heat Generated	[illegible]	[illegible]	Annual heat generated and self consumed converted to kWh

2014100657 16 Jun 2014

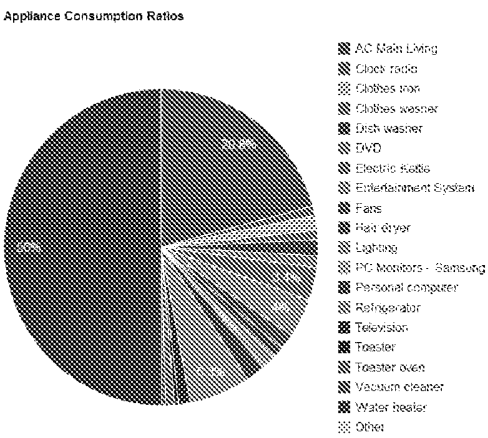
Figure 9

Appliance Consumption Analysis

For Your Solar Home at Sunshine Coast.
Simulation from 1-Jan-2012 to 31-Jan-2012, 31 days.

Appliances

Appliance	Wattage	Number	Watt Hours	Bill Cost	Yearly	5 Yearly	10 Yearly	20 Yearly
AC Main Living	[illegible]	1	[illegible]	$42	[illegible]	[illegible]	[illegible]	[illegible]
Clock radio	[illegible]	2	[illegible]	$2	[illegible]	[illegible]	[illegible]	[illegible]
Clothes iron	[illegible]	1	[illegible]	[illegible]	[illegible]	$216	[illegible]	[illegible]
Clothes washer	[illegible]	1	[illegible]	$2	[illegible]	[illegible]	[illegible]	[illegible]
Dish washer	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DVD	[illegible]	1	[illegible]	[illegible]	$29	[illegible]	[illegible]	[illegible]
Electric Kettle	[illegible]	1	[illegible]	$7	[illegible]	[illegible]	[illegible]	[illegible]
Entertainment System	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Fans	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Hair dryer	[illegible]	1	[illegible]	$2	$27	[illegible]	[illegible]	[illegible]
Hair Straightener	[illegible]	1	[illegible]	[illegible]	[illegible]	$5	[illegible]	[illegible]
Lighting	[illegible]	[illegible]	[illegible]	$2	[illegible]	[illegible]	[illegible]	[illegible]
PC Monitors - Samsung	[illegible]	2	[illegible]	$1	[illegible]	[illegible]	[illegible]	[illegible]
Personal computer	[illegible]	1	[illegible]	$4	[illegible]	[illegible]	[illegible]	[illegible]
Refrigerator	65	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Television	[illegible]	1	[illegible]	$2	[illegible]	[illegible]	[illegible]	[illegible]
Toaster	[illegible]	1	[illegible]	$1	[illegible]	[illegible]	[illegible]	[illegible]
Toaster oven	[illegible]	1	[illegible]	$2	[illegible]	[illegible]	[illegible]	[illegible]
Vacuum cleaner	[illegible]	1	[illegible]	$1	[illegible]	[illegible]	[illegible]	[illegible]
Water heater	[illegible]	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Totals			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

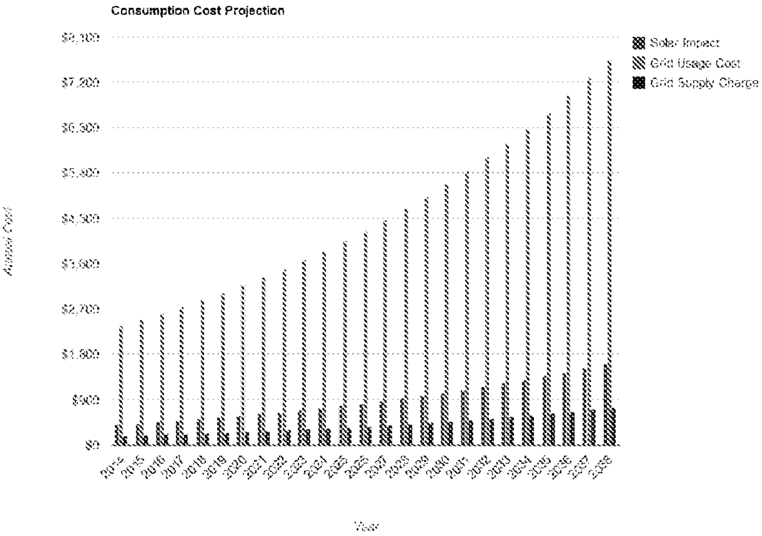


2014100657 16 Jun 2014

Figure 10

Solar Impact Analysis

For Your Solar Home at Sunshine Coast.
Projected annual increases of 5% kWh, 6% Supply and 1% FIT.



Projection Summary

Projection Period	25 years (2014 to 2038)
Normal Grid Cost	$113,244
Solar Savings	$90,890
Remaining Grid Consumption Cost	$22,354
Grid Supply Charges	$10,061

System Components

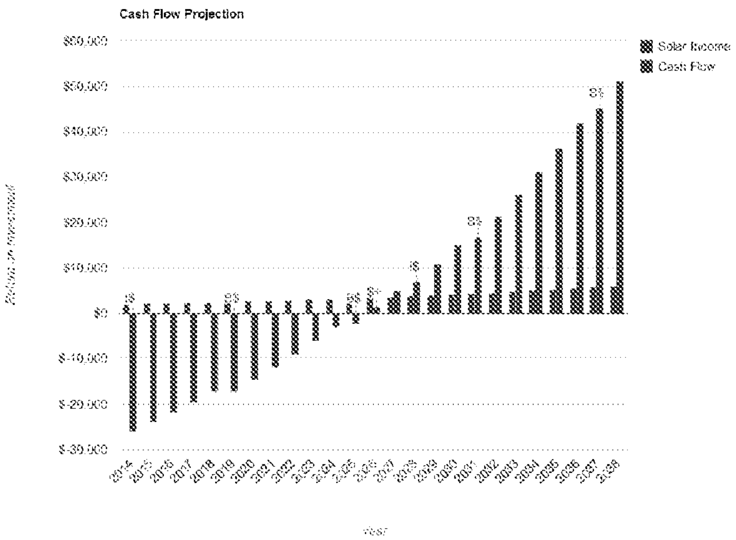
Component	Description	kWh Generated	Investment
Solar Hot Water		[illegible]	[illegible]
Solar PV	[illegible]	[illegible]	[illegible]
Wind Turbine 2.5	[illegible]	[illegible]	[illegible]
Battery Storage		[illegible]	[illegible]

2014100657 16 Jun 2014

Figure 11

Investment Cashflow Projection

For Your Solar Home at Sunshine Coast.
Projected annual increases of 5% kWh, 6% Supply and 1% FIT.



Investment Summary

System Installation Investment	$28,002
1 Replacement Inverter	$1,800
4 Replacement Battery Banks	$10,000
Investment Total	$39,802
Total Gross Income	$90,890
Total Net Income	$51,088
25 Year Return on Investment	(228%) $51,088
Yearly Return on Investment	(9%) $2,044
Investment Projection Period	25 years (2014 to 2038)
Break Even Year	Year 13 (2026)

System Components

Component	Description	kWh Generated	Investment
Solar Hot Water	[illegible]	[illegible]	[illegible]
Solar PV	[illegible]	[illegible]	[illegible]
Wind Turbine [illegible]	[illegible]	[illegible]	[illegible]
Battery Storage		[illegible]	[illegible]