Documentation of `solar-sim`

Introduction

The solar-sim tool simulates a photovoltaic or solar thermic installation for a residential building. It takes building, user and financial parameters as inputs and compute several energetic, financial and environmental indicators as outputs. There is one function for the simulation of a photovoltaic installation (`solarSim`) and another one for a solar thermic installation (`thermicSolarSim`). Both functions take the same input but result in different outputs.

Usage

This simulator was written in Typescript (in `/src/*.ts`). You can compile the code to Javascript using `$ npm run build`. Then, you can run `$ node lib/example.js` to see the simulator in action: e.g., change the values of the inputs or constants in `example.js` and see what is changing at the outputs in the console.

Tests

Units tests were written in `/test`. Run them using: `$ ./node_modules/mocha/bin/mocha`.

Technical description

Classes

The code is organised along 5 classes.

1) The `User` class

The user is understood here as the "person" that want to install some photovoltaic or thermic solar panels on his `Building`. It is characterised by some consumption profile.

2) The `Roof` class

The roof is understood as a single roof unit that is characterised by a unique tilt (inclination), azimuth (orientation) and solar productivity.

3) The `Building` class

A building has one user. It can have one or several Roof. The solar production is aggregated at the building level.

4) The `Financial` class

The `financial` class holds all the information about financial parameters.

5) The `Environmental` class

The `environmental` class holds all the information about environmental parameters.

6) The `Thermic` class

The `thermic` class mixes some user, financial and environmental parameters but only concerns the thermic solar panels, not the photovoltaic ones.

Special functions

In this section we explain the main modelling choices and some complex computation of the solar simulator. For the other functions, we kindly refer to the code of the simulator, reasonably hoping it will be self-explanatory.

Optimisation of the usable areas

- Function: `optimizeRoofAreas(Building, actualArea)`
- In case some area is inputed (in `inputs.pvArea`), some roofs or part of a roof must be chosen. We decided to choose the best roofs first by sorting them by decreasing solar irradiance. Note that only a fraction of some roof area may be chosen in order to have a building photovoltaic area that is strictly equal to the inputed area.

Optimisation of the power of the photovoltaic installation

- Function: `optimizeRoofPowers(Building, potentialPower)`
- The maximal power of a domestic photovoltaic installation is limited (see `constants.max_power`). However, some well-exposed and/or large building may have a potentially higher power installation. In case the potential power is higher than this limit, the `optimizeRoofPowers` function allocate the best roofs for setting the solar panels. First, the function set the total power to zero and then gradually add the best roofs until the limit is reached. When the limit is reached, the remaining roofs receive a power of zero. This function thus allows to select the best roofs (sorted by decreasing solar irradiance) that can be used for photovoltaic production. Once a set of roofs has been chosen, the production of each roof is updated (given the new powers that have been attributed to the roofs).

Photovoltaic autonomy

- Function: `User.computeSelfConsumptionRate()`
- The photovoltaic autonomy is taken from an empirical look-up table. The first key of the table is the ratio of the photovoltaic production by the annual electricity consumption. The second key of the table is a level of “user autonomy”. This level is determined as follows:

    1. the user adopts some energy sobriety behaviours;
    2. the user does some charge shift, i.e., it consumes more electricity during the (sunny) day than during the night;
    3. the user has a electric heater programmed as a function of the solar production;
    4. the user has some home batteries.

Selection of the best roof in thermic

- Function: `getAzimuthBestRoof(constants, Building)`
- In the solar thermic simulator, we consider that the solar panels will be installable on one roof only, i.e., the installation won't be split over several roofs. The roof chosen for the thermic solar panels will be the best roof in terms of solar irradiance (thus accounting for orientation, tilt and shadows) where the following conditions are met:

    1. the roof must be South-oriented (actually with azimuth between 78.75 (East-North-East) and 281.25°(West-North-West))
    2. the roof must have a usable area of minimum `constants.min_thermic_area`.

Solar production in thermic

- Function: `thermic.computeSolarProduction()`
- A contrario of the photovoltaic production, the thermic solar production is empirically determined using a look-up table. This table gives an annual solar production (kWh/year) given the azimuth of the roof and the average hot water consumption (`thermic.literByDay`).

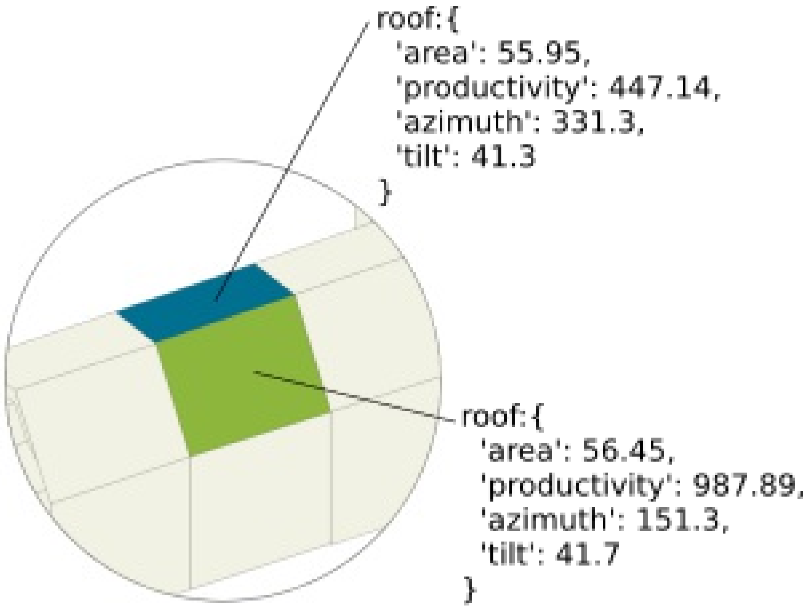
Gain in thermic

- The gain (€) for the solar thermic installation is equal to the sum of the supporting grant and the cost of the saved energy used for producing hot water. The latter is computed for each year using actualised energy prices as:
  `annualGain = t.solarProduction / t.producerYield * actualEnergyBuyingPrice`
  where `t.producerYield` is the yield of the hot water production system (based on a external source of energy, being gas, fuel or electricity) and `actualEnergyBuyingPrice` the actualised price of this energy, depending on both a base price and a price index. The choice of the source of energy used for hot water production (`inputs.thermicHotWaterProducer`) has thus an impact on the solar thermic gain.

Inputs, outputs and constants

Inputs

All the input (with default values) are presented in the following table. The main input, namely, `roofs`, is the collection of the roofs of a building, each of them being characterised by their area, azimuth, productivity and tilt. Here is below is a schema of how the roofs should be modeled for representing a building.



inputs variable	**default value**	**units**	**description**
Photovoltaic			
roofs			Collection of roof objects where the solar potential will be computed. Can be 1 or several roofs. Each roof object must be characterised by the below-mentioned properties: area, azimuth, productivity and tilt.
roof.area		m²	Area of the roof.
roof.azimuth		°	Average azimuth of the roof (aka its orientation), expressed in degree with 0° = North and 180° = South.
roof.productivity		kWh/m².year	Average annual solar productivity of the roof, i.e., the sum of the solar irradiance received by the roof over one year. Typically around 1000 kWh/year.m2 for a well-exposed roof in Bruxelles.
roof.tilt		°	Average tilt of the roof (aka its inclination, or slope) expressed in degree with 0° being a horizontal (flat) roof and 90° being a vertical roof.
pvTechnology	mono		Photovoltaic technology of the solar panels. Can be mono (for monocristallin), poly (polycristallin) or mono_high (high yield monocristallin).
nYears	10	year	Number of years for computing financial benefit. The longer is it, the larger is the benefit.
currentYear	2018		Current year. Should be determined from the browser.
elecSellingPrice	0.03	€/kWh	Price for selling electricity for

			prosumers
CVPrice	85	€	Price of a certificat vert
pvArea		m²	Area of the photovoltaic installation. Can be computed based on roof area or inputed.
annualConsumptionKWh	2036	kWh	Average annual electricity consumption of the building
installationPrice		€	Cost of the photovoltaic installation. It is inputed or computed based on the power of the installation and the photovoltaic technology.
obstacleRate	0.182		Average obstacle rate of the roof surfaces. It is used to decrease the available area for photovoltaic installation
VATrate	0.06		Annual VAT rate
annualMaintenanceCost		€	Annual maintenance cost of the photovoltaic installation. It is inputed or computed based on the price of the photovoltaic installation
loanPeriod	5	year	Duration of the loan
loanRate	0.01		Interest rate of the loan
loan	FALSE	boolean	Was a loan contracted for financing the installation?
energySobriety	FALSE	boolean	Does the user use energy sobriety? It has an impact on the self consumption rate
chargeShift	FALSE	boolean	Does the user do some electrical charge shift (e.g., consume more electricity during the sunny day than during the night)? It has an impact on the self consumption rate.
pvHeater	FALSE	boolean	Does the user have a photovoltaic heater? It has an impact on the self consumption rate.
battery	FALSE	boolean	Does the user store the electricity using a home battery? It has an impact on the self consumption rate.
Thermic			
thermicHouseholdPerson	5	person	Number of person in the household.
thermicLiterByPersonByDay	30	liter/day	Number of hot water liter consumed per day per person
thermicLiterByDay	150	liter/day	Number of hot water consumed per day per household. Unless it is inputed, it is the product of thermicHouseholdPerson by thermicLiterByPersonByDay.
			Source of energy for hot water

thermicHotWaterProducer	gas		production. Can be gas, fuel or electricity.
thermicCost		€	Cost of the solar thermic installation
thermicAnnualMaintenanceCost		€	Maintenance cost of the solar thermic installation
thermicMaintenanceRate	3	year	Periodicity of the maintenance. It means that `thermicAnnualMaintenanceCost` are spent every `thermicMaintenanceRate`.
thermicGrant	2500	€	Amount of the grant for installing a thermic installation

Constants

Constants (with default values) are presented in the following table.

constants	**default value**	**description and units**
# Environmental		
co2_emissions_by_kwh	0.456	CO2 emissions by kWh of electric energy, in kg/kWh
energetic_cost_factor_belgium	2500	Energetic cost for a photovoltaic installation, by origin of the technology, in kWh/kWc
energetic_cost_factor_europe	2600	Energetic cost for a photovoltaic installation, by origin of the technology, in kWh/kWc
energetic_cost_factor_china	2750	Energetic cost for a photovoltaic installation, by origin of the technology, in kWh/kWc
breakdown_cost_factor	cfr table	Breakdown of the energetic cost for a photovoltaic installation, by origin of the technology.
# financial		
meter_cost	289	Cost of the electric meter, in € (21% VAT included)
onduleur_cost_factor	250	Cost of the onduler, in € (21% VAT included)
onduleur_replacement_rate	15	Rate of onduler replacement, in years
redevance_cost	65	Cost of the redevance, in €
inflation_rate	0.02	Yearly inflation rate, in %
elec_buying_price	0.23	Buying electricity price, in €/kWh
elec_index	0.03	Yearly electricity price index, in %
discount_rate	0.04	Discount rate, in %
cv_rate_switch_power	5	Installation power (in KWc) at which the Certificat Vert rate change
		Rate of Certificat Vert for low power

cv_rate_low_power	3	installation, in CV/MWh
cv_rate_high_power	2.4	Rate of Certificat Vert for high power installation, in CV/MWh
cv_time	10	Duration of the Certicat Verts, in years
cv_end_of_compensation_year	2020	Year of the end of the compensation
production_yearly_loss_index	0.0005	Yearly photovoltaic production loss
maintenance_cost_factor	0.0075	Rate of maintenance cost with respect to the total photovoltaic installation price
# roof		
max_power	12	Maximum power of the photovoltaic installation, in kWc
max_solar_productivity	1300	Maximal solar productivity for a roof in Bruxelles, in kWh/m².an
flat_roof_tilt	5	Inclination (tilt) threshold for flat roof, in °. Roofs with a tilt below this threshold are considered as flat.
low_productivity_limit	800	Low limit for roof productivity (kWh/kWc.m²). No photovoltaic production is considered for roofs with a productivity below this limit.
pv_yield_poly	0.13	Yield of the photovoltaic system, for polycristallin panels
pv_yield_mono	0.155	Yield of the photovoltaic system, for monocristallin panels
pv_yield_mono_high	0.22	Yield of the photovoltaic system, for monocristallin high yield panels
pv_cost_poly	1400/1.06	Price of the photovoltaic panel, for polycristallin panels in €/kWc
pv_cost_mono	1500/1.06	Price of the photovoltaic panel, for monocristallin panels in €/kWc
pv_cost_mono_high	1600/1.06	Price of the photovoltaic panel, for high yield monocristallin panels in €/kWc
# user		
annual_consumption_base	600	Base of the annual consumption, in kWh
washing_machine_factor	600	Annual consumption of a washmachine, in kWh
electric_water_heater_factor	2336	Annual consumption of a hot water heater, in kWh
electric_heating_factor	16500	Annual consumption of a heating system, in kWh
self_production	cfr table	Table of self production rates, for different user energetic profiles and self-production ratio
# Thermic		
		Average cost of a solar thermic installation,

thermic_installation_cost	6000	in € (VAT excluded)
thermic_maintenance_cost	100	Average maintenance cost of a solar thermic installation, in € (VAT excluded), applied to a given maintenance rate (3 years)
max_liter_per_day	210	Maximum hot water consumption per day, in liter
min_thermic_area	5	Minimal area for a solar thermic installation, in m². Below this limit, no solar thermic installation is possible
hot_water_producer_yield_gas	0.7	Yield of the hot water production system with gas
hot_water_producer_yield_fuel	0.55	Yield of the hot water production system with fuel
hot_water_producer_yield_electric	0.95	Yield of the hot water production system with electricity
hot_water_energy_cost_gas	0.08	Energy cost (for hot water production) for gas, in €/KWh
hot_water_energy_cost_fuel	0.081	Energy cost (for hot water production) for fuel, in €/KWh
hot_water_energy_cost_electric	0.267	Energy cost (for hot water production) for electricity, in €/KWh
hot_water_energy_cost_index_gas	0.054	Energy cost index for gas
hot_water_energy_cost_index_fuel	0.099	Energy cost index for fuel
hot_water_energy_cost_index_electric	0.04	Energy cost index for electricity
co2_emissions_by_kwh_thermic_gas	0.201	CO2 emissions by kWh of gas, in kg/kWh
co2_emissions_by_kwh_thermic_fuel	0.263	CO2 emissions by kWh of fuel, in kg/kWh
co2_emissions_by_kwh_thermic_electric	0.456	CO2 emissions by kWh of electricity, in kg/kWh
thermic_production	cfr table	Table of solar thermic production, for different hot water consumption and azimuth classes.

The following table is for the constant `breakdown_cost_factor`.

Belgique	**EU**	**Chine**	
Modules	85%	81%	77%
Cadre & support	4%	3%	3%
Onduleur et câbles	9%	8%	8%
Transport - camion BE	2%	2%	2%
(Transport - camion EU)		5%	2%
(Transport - bateau)			8%

The following table is for the constant `self_production`.

dimensionnement (ratio)	**0.6**	**1**	**1.4**	**1.8**	**2.2**	**2.6**	**3**

Situation initiale	25%	30%	34%	36%	38%	39%	40%
Sobriété énergétique	28%	32%	35%	37%	38%	39%	40%
Déplacement de charge	30%	34%	36%	38%	39%	40%	41%
PV heater	43%	49%	54%	55%	57%	58%	60%
Stockage batterie	48%	54%	59%	62%	64%	66%	69%

The following table is for the constant `thermic_production`.

Apport solaire annuel (kWh/an)						
Consommation (l)	60	90	120	150	180	210
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E	519	742	932	1097	1262	1364
E-SE	534	767	968	1145	1321	1432
SE	546	787	997	1183	1368	1487
S-SE	553	800	1015	1207	1398	1522
S	555	804	1022	1215	1408	1534
S-SO	553	800	1015	1207	1398	1522
SO	546	787	997	1183	1368	1487
O-SO	534	767	968	1145	1321	1432
O	519	742	932	1097	1262	1364

Outputs

Outputs for the photovoltaic simulator are presented in the following table.

Output variables	**units**	**description**
Photovoltaic		
installationCost	€	Cost of the photovoltaic installation (panels + meter replacement)
CVAmountYear10	€	Gain by certificats verts. Amount of certificats verts selling during 10 years
selfConsumptionAmountYear10	€	Gain by self-production. Amount of electricity that the user does not have to buy since he produces it, for 10 years.
savedCO2emissions	kgCO2	Saved CO2 emissions corresponding to the electricity that is produced by the solar panels. It uses the ‘constants.co2_emissions_by_kwh` conversion factor.
area	m²	Potential photovoltaic area of the building. It is the sum of the roof areas with a minimal productivity (given by `constants.low_productivity_limit`) minus the obstacle areas.
maxArea	m²	Actual photovoltaic area. It is equal to the potential photovoltaic area unless the maximum power (‘constants.max_power`) of the photovoltaic installation is overpassed. In such a case, roofs are selected starting with highest productivity roofs until

		the maximum power is attained.
power	kWc	Power of the photovoltaic installation
obstacleRate		Obstacle rate of the building (see inputs)
annualProduction	kWh/year	Annual photovoltaic production of the installation
annualConsumption	kWh/year	Annual electricity consumption of the building
autonomy		Autonomy of the photovoltaic installation. See photovoltaic autonomy.
CVAmountYear25	€	Gain by certificats verts. Amount of certificats verts selling during 25 years
selfConsumptionAmountYear25	€	Gain by self-production. Amount of electricity that the user does not have to buy since he produces it, for 25 years.
totalGain25Y	€	Total gain for 25 years. Sum of the certificat verts gains and gains by self-production.
returnTime	year	Return time of the photovoltaic installation using actualised prices.

Outputs for the thermic simulator are presented in the following table.

Output variables	**units**	**description**
Thermic		
installationCost	€	Cost of the solar thermic installation
grant	€	Amount of the supporting grant given in case of a new solar installation
gain	€	Total gain of the solar thermic installation, that is the sum of the supporting grant and the cost of the saved energy used for producing hot water.
savedCO2emissions	kgCO2	Saved CO2 emissions corresponding to the energy that is not consumed for producing hot water.
annualProduction	kWh/year	Annual amount of solar thermic energy effectively used for hot water production.
annualConsumption	kWh/year	Annual amount of energy used for hot water production.
autonomyRate		Solar thermic autonomy. Computed as the ratio of the `annualProduction` by the `annualConsumption`.
productionPriceWithSubsidies	€/kWh	Production price of the hot water energy accounting for the supporting grant.
productionPriceWithoutSubsidies	€/kWh	Production price of the hot water energy without accounting for the supporting grant.
returnTime	year	Return time of the solar thermic installation using actualised prices.