

Research Article

An Improved Solar Cooling System for Date Safety and Storage under Climate of the Maghreb

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As a freely available energy source for managing long-term issues in energy crisis, solar energy (SE) will have to grow more to meet world's energy demands. Maghreb countries have launched international tenders for large-scale solar power projects, confirming north African countries' goals to become green-power leaders, by enforcing renewable energy development policies. This work is aimed at simulating and designing a SE cooler to safely store quality and tasty dates. By optimizing the storage parameters and cooling gas with less energy consumption, R152a has been confirmed as a reliable refrigerant to own high critical temperature, sufficient specific heat capacity, and potential cost-effectiveness of compression. Safe packaging in Tolga-Algeria-Dates food company can be achieved by safe cooling systems that is aimed at wide variation of energy storage and delivery requirements of the manufacturing process. The performance ratio (P_R) and energy losses have been analyzed by using the PVsyst software. The paper is also aimed at studying load requirements of an SE cooler of dates, designing/installing a standalone solar PV system, and modeling the refrigerant gas of the SE cooler, done with INTARCON software and SOLKANE refrigerant software program. P_R and loss analysis has been done using PVsyst. Total amounts of yearly energy injected into grid and nominal PV array energy are estimated to be, respectively, 84.536 and 85.861 MWh, while total yearly losses of the system are estimated to be 15.5 MWh. It reveals that the PV system efficiency set from ~10% in winter to 11.3% in summer, while P_R rises from a 77.5% in July to 89.3% in December. Future research will design of energy consumption monitoring of the PV system, favoring SE cooling of dates. Via PVsyst concrete realities of PV performance and insights for better operational monitoring were well understood.

1. Introduction

Since the beginning of the industrial revolution (renewables could be a dream that time!), clean and reliable energy has continued to increase world's prosperity and economic growth [1]. However, power shortage risk and unstable power supply remain major problems [2]. Wasting foods is

inevitable by modern societies, since nearly a third of food intended for human consumption is lost/wasted through food supply chains [3]. The world is in urgent need to develop and encourage friendly environment sustainable cooling technologies, while it grapples with the energy and environmental crisis [4]. However, traditional cooling technologies utilizing harmful refrigerants consume more energy

and cause peak loads leading to negative environmental impacts, such as CO₂ emissions [5]. Today, the photovoltaic (PV) electricity reducing CO₂ emissions has caught attention for renewable heating and cooling system (CS) [6]. PV electricity is widely used in remote telecom base stations [7–9], water desalination [10–12], building industry [13–15], agricultural for lighting and water pumping needs [16–18], and in refrigerated cold rooms [19].

Besides being performed for vaccine cooling and storage systems [20–22], the SE as source of electricity is widely exploited in food industry [23–25]. In the context of solar cooling in food industries, Joardder et al. [26] reported that integrating SE with the existing food storage system will mediate the dangers of the food crisis in Bangladesh and can offer a zero energy-based food storage system. In India, Panchal et al. [27] have reported important aspects required for solar pasteurization (flat-plate collector, heat exchanger, and solar water heating system) and confirmed that SE can be best used for the dairy industries. Arvanitoyannis et al. [28] reported fish waste management in EU as a problem greatly impacting marine environment with detrimental effects that become an issue of public concern. Controlling temperatures of food packages during transport is needed with the rise of online shopping [29]. Foods while transported require cold temperatures to preserve freshness [30]. A major issue is the undesired warming of food when packages are exposed to warm temperatures on airport tarmacs and temporary unrefrigerated storage during air transportation [31].

The Maghreb lies in a sunny region having sufficient amounts of sunshine that has favored SE investments for solar cooling technology of high reliability and low maintenance costs. Efforts have been made by researchers of the Maghreb to treat SC under climate of the region; such treatment based on simulation tools via performance analysis has exploited carbon and CH₃OH/NH₃ working pairs [32–35]. However, these have the drawbacks of toxicity and pungent smell of NH₃ and non-CO₂-free CH₃OH while storing H₂ in CH₄ [36]. Although CH₃OH and NH₃ pairs are the most used refrigerants paired with activated carbon (C), C–CH₃OH is of large adsorption quantity and low adsorption heat, CH₃OH is of low desorption temperature, and C–NH₃ pair owns the possibility of using heat sources at 200°C or above, adsorption systems have major drawbacks of low energy efficiency due to the thermal coupling irreversibility [37]. Although NH₃ refrigerant is neither ozone depleting nor makes a direct contribution to greenhouse effects, its harmfulness for humans can be avoided by the alternative agent CH₃CHF₂ (R152a); it is recommended due to its sufficient specific heat capacity for an effective thermodynamic cycle, high critical temperature at average pressure, and potential cost-effectiveness of compression [38].

In food industry, drying matured dates (to be consumed over time) is a serious problem for countries where humidity is high during drying seasons. Commercializing dates is of major importance and contributes to local and national economies of the Maghreb countries. For instance, “Deglet Nour” variety from Tolga (Algeria) is of high sensory quality, highly appreciated due to organoleptic characteristics

and nutrient values; however, once harvested, it cannot preserve its attractive appearance in high temperature for a long time. Many studies have been performed to evaluate the feasibility of using solar dryers to dry dates, which is of importance for reducing overall maturation time and minimizing quantity of dates lost during the process [39, 40]. However, drying fruits for long time may result in loss of sensory quality and reduced shelf life of fruits [41]. Since cooling phenomena occur during the initial stage of drying, drying a total heat flux negatively increases the temperature and hence can cause quality degradation of the product due to evaporation [42]. To safely preserve “Deglet Nour” dates, an SE-CS using R152a refrigerant of high heat energy released to gas cold energy during condensation; for effective heat transfer processes, the geometry must be designed so that surface area should be exploited [43]. The PV system used should reduce global warming and reach all climate change goals [44], and the electrical energy obtained from the sun is stored to be supplied during off-sunshine hours [45].

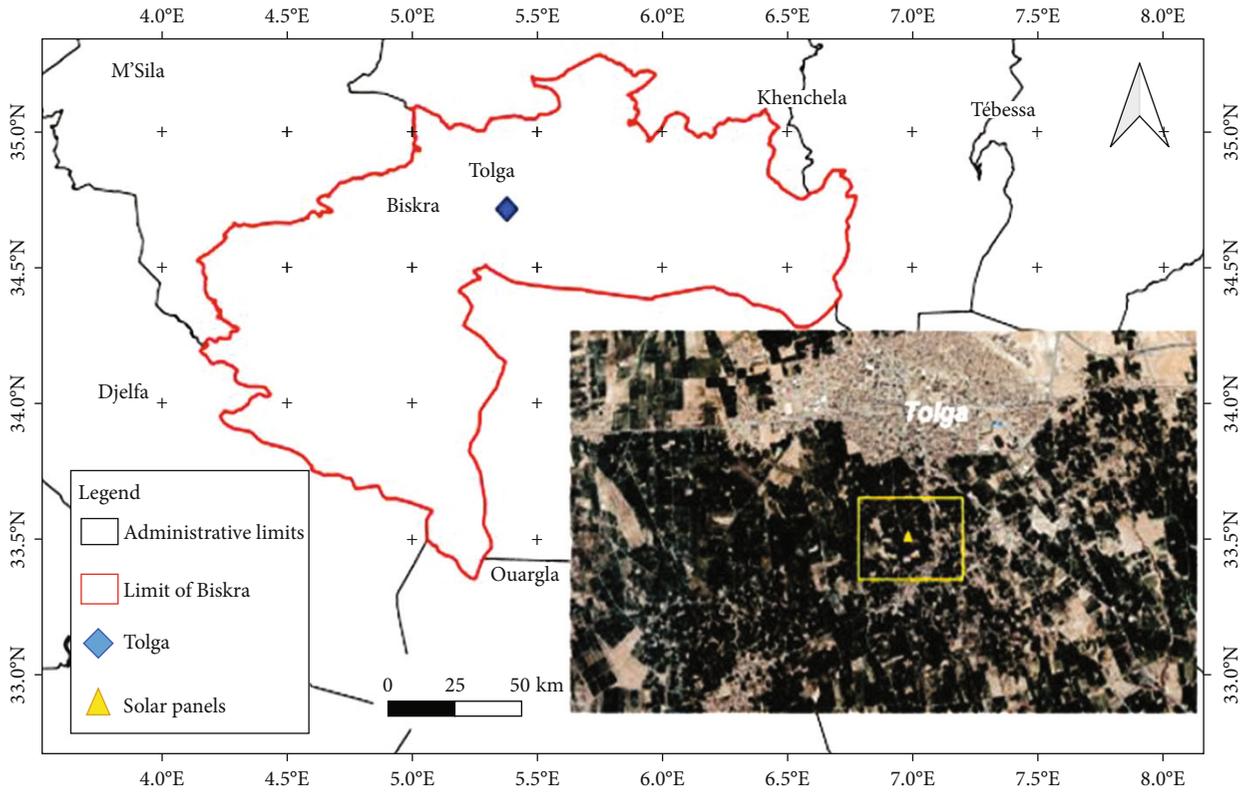
The double-barreled research question to be answered is to what extent does PV cooling will be of benefit and what refrigerant gas with high performance could be environmentally friendly for such optimized PV cooling system. Trying to answer this research question, a hypothesis is put forth: (i) installing solar cooler for drying dates can be an alternative approach to refrigerate dates and receive most benefits in terms of energy savings and (ii) predicting a refrigerant gas that overcome the productivity concerns of date safety and storage, to safely store tasty dates. It is motivated by approaches by [46–49] reporting PV water pumping systems for multiple-crop irrigation uses and heat drying systems reported by [50–53] that this work is accomplished.

The novelty of this study is the very first optimization of an appropriate cooling gas for special date quality of the Maghreb and under its particular climatic conditions, which is not attempted previously. Up to our knowledge, R152a cooling gas has been proposed for PV cooling of dates for the first time.

2. Simulation Tools

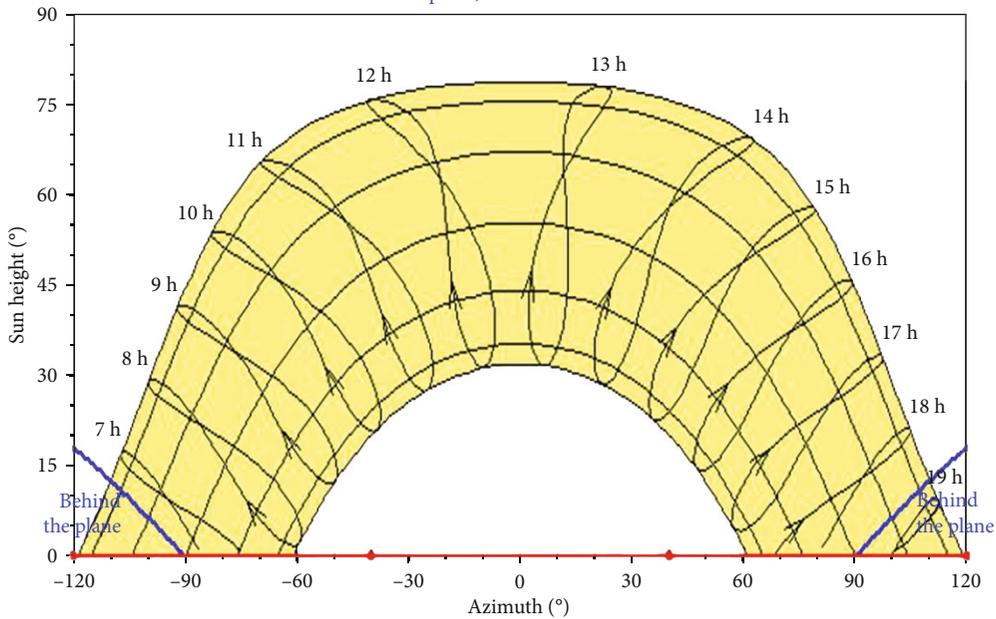
The PVsyst software [54] was used to evaluate the performance of our system. It calculates the overall performance of a PV system and generates data on resources for the entire year. Potential energy resources, component sizing, energy production, and system losses are all explored in relation to our system’s output. The global radiation and temperature are critical factors for performing simulations, as the solar advantages of the installation are highly dependent on the yearly sunlight intensity. PV modules, inverters, and a grid interface network are included in the simulated model, which was created using the PVsyst simulation tool and is technically sized according to the project parameters.

To simulate the cooling part of our system, the INTARCON software [55] was used. It is provided by a company dedicated to design and manufacture refrigeration equipment for commercial and industrial sectors and offer markets a wide range of innovative solutions for the most reliable, efficient, and sustainable operation of refrigeration



(a)

Horizon line drawing - Legal time
 Fixed plane, tilts/azimuths: 33°/0°



(b)

FIGURE 1: (a) Site location of latitude: $34^{\circ}42'59''$, longitude: $5^{\circ}22'33''$, and altitude: 151 m above sea level. (b) Solar horizon line according to inclination angles of panels of the studied PV injected-into-grid system (fixed tilted plane, plane tilt/azimuth and full system orientation: $33^{\circ}/0^{\circ}$).

facilities. INTARCON has valuable experience in refrigeration, air conditioning, and related thermal appliance fields, focusing on creating and developing a wide range of innovative refrigeration solutions and aimed at developing a new

range of cool equipment. It is highly concerned about the environment and carries out many projects to develop environmentally friendly solutions based on energy savings and efficiency.

In turn, SOLKANE [56], new program calculating thermodynamic substance data and transport properties, contains modules for calculations and two-step cycle processes for dimensioning refrigerants and provides comprehensive information on refrigerants from physical properties to transport and packaging. SOLKANE is a strong thermophysical property calculation tool with a large library of gas refrigerants. It was utilized here to optimize the optimal refrigerant for date safety. It analyzes the thermodynamic substance data and transport properties of all SOLKANE refrigerants, as well as some CFCs, and includes modules for the computation of seven (7) different one- and two-step cycle processes, as well as pipe line dimensioning.

3. Hypothesis and Goals

Innovation and productivity in developing countries suffer from electricity interruptions that cause power quality problems; the unbalanced voltages can damage the equipment for food manufacturers and destroy foods to be commercialized, leading to financial losses. Packaging foods like dates traditionally in the Maghreb can negatively impact local economies and deprive Maghreb is of modernizing their agricultural systems. It even may prevent the region from investing in agro-sources. Cooling dates however, beyond having economic impacts, can boost agricultural industry and bring employment opportunities in our countries. Besides, SE cooling of dates may help companies in field of date palm plantation to safely export their ripe fruits, mainly of high quality, and be pioneer in exporting their products on an international level. However, a bad storage may contaminate dates and has a significant negative impact on human health and productivity. The paper provides an overview of a reliable power supply by PVsyst [54] to feed SE coolers and performs an optimization of a refrigerant gas by INTARCON and SOLKANE [55, 56] to safely package dates in palm farms of the Maghreb.

The novelty consists in performing an analysis and feasibility study of SC in agriculture, beyond SE applications limited to light, irrigation pumping, heat pump drying, and predict an alternative approach to refrigerate foods, preserve products, avoid loss of sensory quality, and save shelf life of fruits. Up to our knowledge, almost no work had been done on SE cooling of dates, except traditional drying, which has been undertaken by research groups over the last decades. And it is against this background that the present study was set. It has to meet two main objectives that are

- (i) Exploiting SE cooling in date industry via PV-based renewable energy-based supply systems
- (ii) Overcoming defects of harmful cooler gases by optimizing a proper alternative prediction

4. Methodology

A standalone power system for a SC camp from PV energy resource is simulated and intended to be designed, based on sizing PV array and battery bank from SE resource and

TABLE 1: PV module parameters, specifications, and ratings.

PV module/model	Solar brand Si-poly SC6V 220 P
Manufacturer/year	Canadian Solar Inc/2015
Module power	220 W _p /21 A
Number of modules in series	25
Number of strings	8
Area	271 m ² (cell area: 239 m ²)
Seizing voltage	V _{MMP} 21.6 V (60°C), VOC 35.1 V (-10°C)
Max operating (10 ³ W/m ² , 50°C)	39.6 kW
Produced energy	84.54 MWh/year
Specific production	1921 kWh/kW _p /year
Performance ratio P_R	83.11%
Normalized production	5.26 kWh/kW _p /day
Inverter of operating voltage	500-800 V
Input Max voltage with 12 MPPT	1100 V

load demand, by using PVsyst. The assessed parameters for the SC system location are as follows: array energy, array efficiency, net array energy output, grid energy, net energy output of PV system, capacity factor, performance ratio, degradation rate, losses, and system efficiency. A special solution by INTARCON has been developed for cooling Deglet-Nour dates that require special refrigeration due to high relative humidity. SOLKANE, in turn, optimizes the optimal refrigerant for date safety to avoid their probable toxicity and pungent smell. A high cooling capacity (CC) power should be provided to centralized installations of multiple departments. SC system works well with a heat pump, as the heat is returned to the air, and uses solar thermal collectors to safely store dates. Effects of cooling inlet temperature and cooling mass flow rate upon the system performance are evaluated.

5. Results and Discussions

Since the electricity is almost entirely supplied to cold rooms by conventional hydroelectric or thermal power plants [57], and CO₂ emission among environmental pollution issues is of increasing concern [58], renewable energy technologies, such as SE, are recommended for power supply. The day cycle is a sunrise-sunset period, a path travelling to reach maximum height at noon and yield of the sun that finally descends slowly to bed. To design an SE cooler for dates beginning with solar panels, calculating the position of sun and tracking its path for Tolga location are performed during over the year. Figure 1(a) illustrates such tracking, where the horizon line drawing shows how the sun is accessible and shading around it is shown by a red line, whereas the autoshading of the PV modules (behind the plane) is referred to blue lines.

Since the performances of PV systems depend mainly on geographical locations and types of PV modules used [59], such systems are useful in areas highly exposed to incident

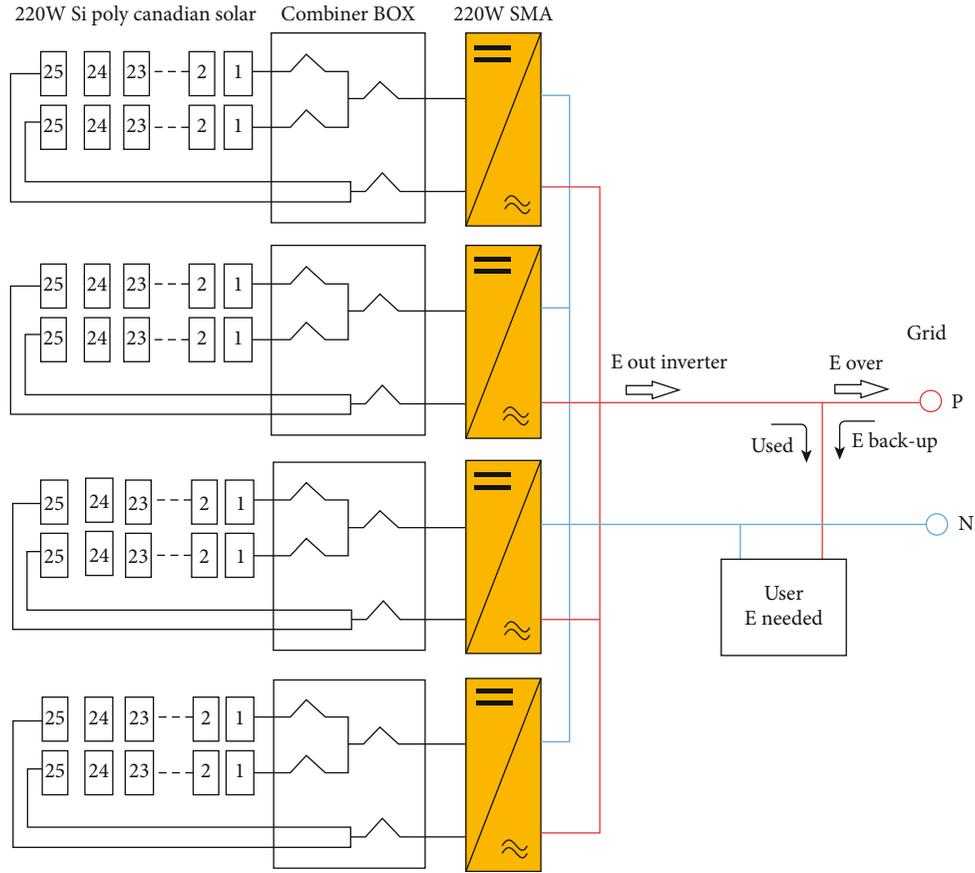


FIGURE 2: Design of the grid-connected PV system.

TABLE 2: Fundamental results of the PV system into-grid.

	Glob. Hot. kWh/m ²	Diff. Hot. kWh/m ²	T _{Amb} °C	Glob Inc kWh/m ²	Glob Eff kWh/m ²	E _{Array} MWh	E _{Grid} MWh	P _R
January	104.0	22.60	10.59	176.5	174.1	7.003	6.895	0.888
February	113.0	35.56	12.88	162.4	159.9	6.369	6.272	0.878
March	170.3	47.95	17.86	211.5	208.1	7.995	7.870	0.846
April	191.6	67.89	21.16	204.3	200.3	7.616	7.498	0.834
May	218.9	86.35	27.01	209.5	204.9	7.645	7.529	0.817
June	229.2	87.92	31.64	210.0	205.2	7.456	7.339	0.794
July	235.9	92.93	35.49	220.8	215.8	7.654	7.534	0.775
August	211.9	89.10	34.50	215.9	211.6	7.528	7.412	0.780
September	165.4	63.11	28.55	191.2	187.8	6.930	6.822	0.811
October	135.7	50.58	24.05	181.1	178.2	6.761	6.657	0.836
November	107.1	26.06	16.14	172.3	170.1	6.668	6.567	0.866
December	90.0	25.55	11.75	156.3	154.1	6.236	6.143	0.893
Year	1973.1	695.62	22.70	2311.7	2270.2	85.861	84.536	0.831

solar radiation [60], like Tolga (Algeria South-East), Figure 1 (b). PV panels of our system can receive solar light from 6 am to 19 pm; however, sun should be outside the plane out this time. The performances of our grid-injected PV system were studied by performing PVsyst simulations [61], to identify the system behavior according to Tolga site databases and all technical parameters of different components, as well.

5.1. PV Power Supply and System Modeling. Widely used to save time and expect benefits, PVsyst, offers specifications of PV array, inverters, and loads, corresponding to different stages of developing a real project, provides a capacity resulting from the cooling process, to optimize more efficient systems, and designs SE panels to produce electrical energy that operating systems could require. It provides location determination, solar beam values, and time of the system

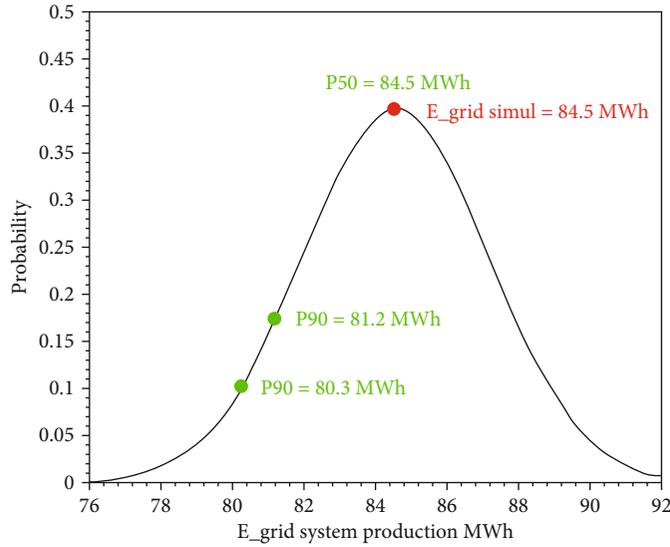


FIGURE 3: P95/P90/P84.5 probabilities for the energy generation forecasts from the SE cooler (PVsyst).

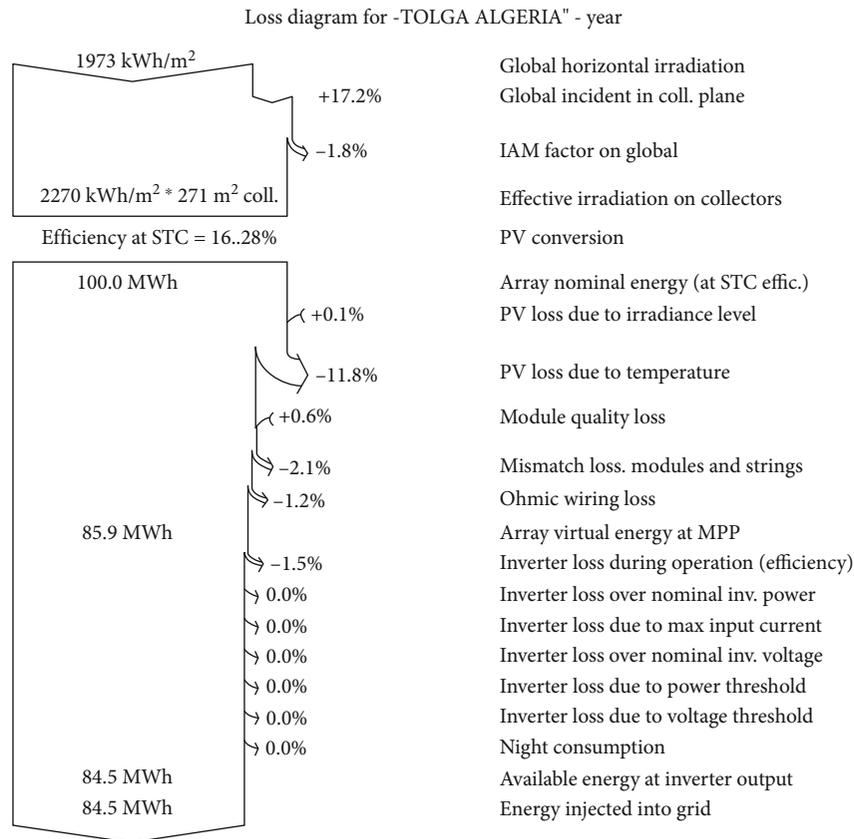


FIGURE 4: Yearly loss diagram for the PV system of the SE cooler.

operation and allows adopting the best calculation method to design solar systems. The present PV system (with details given in Table 1) develops a power rating (array nominal power) of 44 kW_p, a developed maximum voltage of 877 V, a current at maximum power of 69.6 A, and a short circuit current of $I_{SC} = 73.7$ A.

The studied PV system at that location is to receive an average annual solar radiation (SR) about 4.4 kWh/m²/day, and an 1kW_p PV system injected into the grid is designed, using PVsyst and measured site data. The total amount of energy generated by the system and various losses occurring in the system are analyzed. The system performance rate for

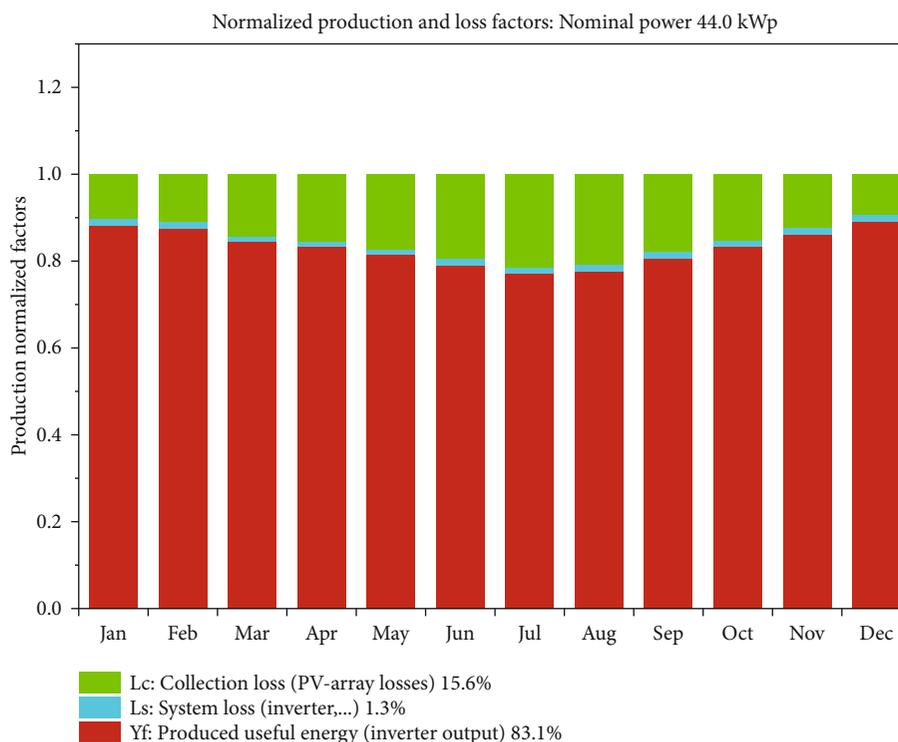


FIGURE 5: Monthly normalized productions with losses.

the entire year is estimated at 0.831, which shows that electricity production from PV systems is a viable option for Tolga to meet growing energy needs. The grid-connected systems, mainly building integration that are architecturally-oriented, require information on available surface area, PV technology (colors and transparency), and power exigencies or desired investments. For a standalone system, this tool allows the necessary PV power and battery capacity to be sized, taking into account the charging profile and probability of users who are not satisfied (probability of charge loss).

For pumping systems (considering water requirements and pumping depth and specifying some general technical options), this tool evaluates pump powers and sizes of PV networks required. Like for standalone systems, such sizing can be done due to the fact that water requirements will not be met during the year. Tolga has a specific horizon line according to the site characteristics, a significant height of sun between 45 to 90°, and sun always reaches at the top negligible shade values. For an inclination of our solar modules of 23°, a continuous solar production is mentioned from 8 am to 6 pm. The fixed inclination angle is near 27°. For our panels, angle inclination necessary for sun to fall on the receiving surface is observed, so as it stays upwards for longer and then gives optimal field production. This allows taking max advantage of sunlight during the day. For our system, a fixed inclined plane is chosen with a south-facing orientation, to avoid an additional investment, because of the solar tracking system that can increase the yield with 30 to 40%. Simulating a PV system consists in determining the energy that systems require and the necessary PV module number to generate such energy. PV systems must gen-

erate sufficient energies to cover the load consumptions of equipment and the energy that such systems should consume [62]. Within an into-grid PV framework, inverter modules have to be chosen from databases. Associated PV module strings should be homogeneous, and the same presentation and number of modules in a course of action have to be considered. Figure 2 shows a schematic diagram of an injected into grid framework, so as the power that the PV system produces should be used with minimum of losses, and components producing these losses must be removed. The operators of the system have to be aware about natural variables such as temperature, dust, and rain that cause losses in PV systems and their components (mostly cables and inverters).

5.2. Performance Analysis. Table 2 lists the power characteristics as well as annual global sun radiation. DC power injected-into-grid, PV array losses, and system efficiency are computed. Monthly and yearly averages daily, the main obtained results as normalized production, array losses, and system losses are 5.26, 0.99, and 0.08 kWh/kWp/day, respectively. And the yearly produced energy and the specific production are, respectively, 84.54 MWh/year and 1921 kWh/kWp/year. PVsyst also analyzes the probability distribution for total annual energies to be injected into power grids. Such probability (Figure 3) depends on parameter modeling PV modules, inverter efficiency, soiling and mismatch and degradation uncertainties, and grid systems producing energy. P95, P90, and P50 probabilities of the annual energy delivered to the grid, respectively, found to be 80.3 and 81.2 and 84.5 MWh.

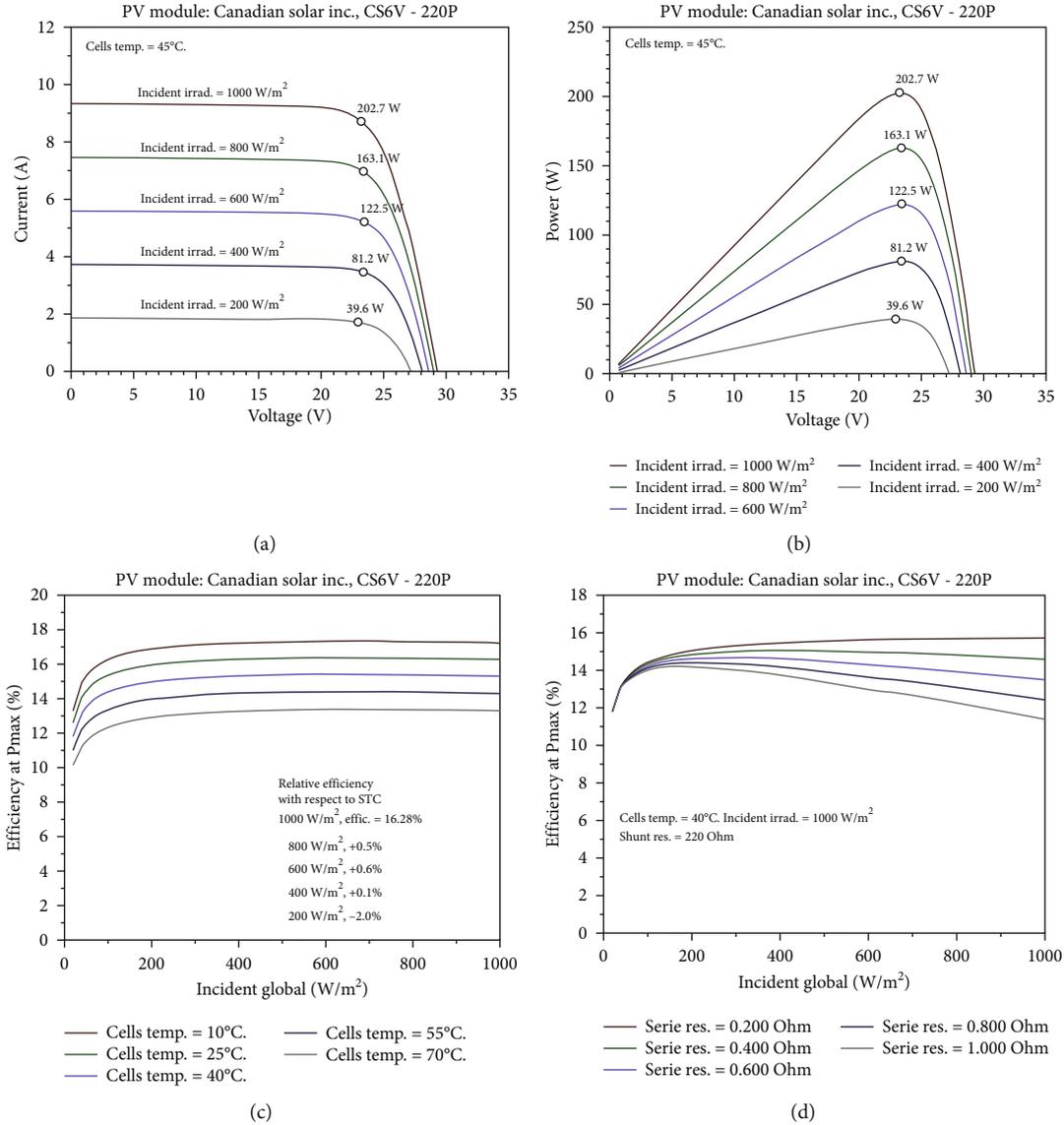


FIGURE 6: Technical characteristics of PV panels. Variations of the (a) current as a function of the voltage; (b) power as a function of the voltage; (c) efficiency with the global incident for different cell temperatures; (d) efficiency with the global incident for various series resistances.

Figure 4 depicts all types of losses that occur over the course of a year in the injected-into-grid PV system. As can be seen, the results of PV system sizing took into account technical specifications and energy converters, as well as meteorological and geographical data from the chosen location.

Beside losses, normalized productions of the SE cooler are illustrated in Figure 5. The measured monthly solar PV electricity generation from the combined 44 kWp system is in the range of 0.78–0.89 MWh per month with a total annual generation of 85.9 MWh. Analysis of other performance parameters revealed a performance ratio of 83.1%. The PV array and system losses are reported to be, respectively, 15.6 and 1.3%. An annual average daily useful energy produced at the inverter side is 83.1%. A maximum monthly average daily production was observed during July, reaching 0.89 kWh/kWp/day.

The worst monthly average daily production amounts to 0.76 kWh/kWp/day in December. With CS6V-220P PV module, global array losses in March, for example, are estimated to be 13.4%, with 800 W/m^2 , 25°C, and P_{MPP} of 35.4 kW. Maximum-minimum energies of 7.87 MWh and 6.143 MWh are injected into grid and recorded, respectively, in March and December, at ambient temperatures of 17.86 and 11.75 (°C), with P_R of 0.846 and 0.893.

Current- and power-voltage characteristics are as illustrated in Figures 6. I–V and P–V characteristics of the PV module under different radiations and constant temperature (45°C), efficiencies (at P_{MAX}) of PV panels under different incident irradiance conditions and temperatures, and series resistances (with an irradiance of 103 W/m^2 , a shunt resistance of 220 Ω , and at 40°C) are given upper and lower and left and right panels, respectively.

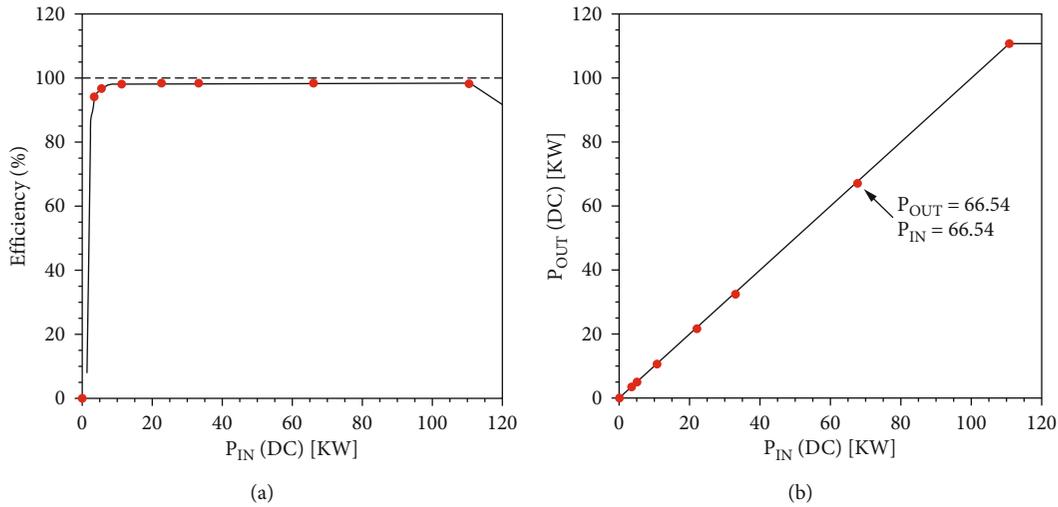


FIGURE 7: (a) Efficiency and (b) P_{OUT} (DC) power linked to P_{IN} (DC) for the inverter (Sunny Tripower STP 110-60-CORE2).

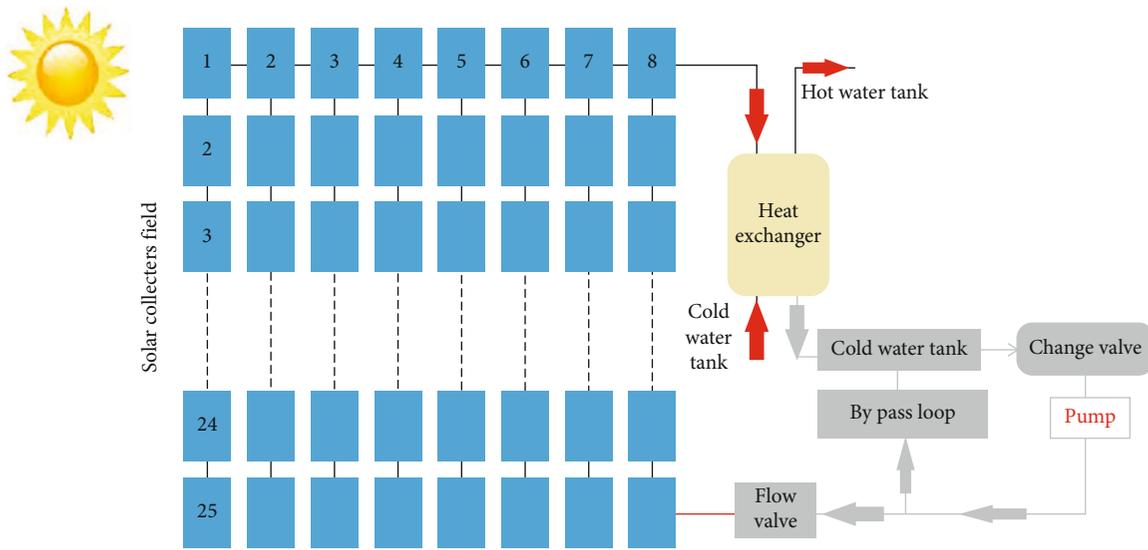


FIGURE 8: Schematic of solar absorption cooling system.

Under an incident irradiance of 10^3 W/m^2 , the power injected-into-grid is also depending on cell temperature and P_{MPP} power. With a variation step of the temperature of 15°C in the range $10\text{-}70^\circ\text{C}$, P_{MPP} is decreasing from 233 to 179.7 W with a decrement of $\sim 13.5 \text{ W}$, with an increase of the voltage 26.4 to 33 V. It is worth to be mentioned that the results proved that simulated I-V and P-V characteristics accurately match with those provided by fabricants, and acquiring I-V parameters from accurate discrete model with system functions is possible.

In turn, the efficiency is an essential parameter to analyze the performance of the system taking into consideration losses that occur in it, and the more cell temperature decreases, the better efficiency is. For an incident irradiance of 10^3 W/m^2 , the efficiency is estimated to be 16.28%.

Furthermore, with a shunt resistance of 220Ω , 10^3 W/m^2 , and at 40°C , the more series resistance increases, the bet-

ter the efficiency is. As for the inverter (Sunny Tripower STP 110-60-CORE2), it is of a 98.6% maximum efficiency with $P_{IN}(\text{DC}) = 66 \text{ kW}$ (at 25°C). Figure 7 summarizes the efficiency of the inverter (in %) and P_{OUT} (AC in kW) with regard to the input power P_{IN} (DC in kW). The efficiency of the inverter is almost stable for an input power in (20-110) kW range.

Due to population increment in Maghreb countries, needs for food industry increase, but classical energy sources are still used. Moreover, the governments of such countries are searching for reliable sources like wind and solar for food industry, due to increment in global warming. Designing solar coolers for foods, with SE widely highlighted solar power and abundantly accessible, becomes a must. Solar coolers generating cold air are needed for keeping foods fresh and avoiding wastes. For given cooling requirements, compressors increase consuming power unless refrigerants are more efficient [63].

TABLE 3: Stored goods conditions and cold room features.

Cold room calculation	Stored goods	
Storage conditions	0°C/RH 85%	
Freezing point	-1°C	
Specific heat (PT/NT)	3.53/1.85 kJ/(kg·K)	
Latent heat	266.8 kJ/kg	
Cold room features		
Ambient conditions	37.5°C/20.2°C WT	
Cold room internal volume	48 m ³	
Internal sizes	3 m (length) × 4 m (width) × 4 m (height)	
Isolation thickness	150 mm	
Heat transmission rate	0.025 W/(m·K)	
(1) Goods refrigeration loads		537840 kJ/day
Goods rotation	1200 kg at 25°C each 24 hours	105840 kJ/day
Packaging cooling	96000 kg/day	432000 kJ/day
(2) Transmission heat gain		45092 kJ/day
Walls	$59.1 \text{ m}^2 \times 0.16 \text{ W}/(\text{m}^2 \cdot \text{K}) \times 37.5^\circ\text{C}$	31035 kJ/day
Roof	$13.1 \text{ m}^2 \times 0.16 \text{ W}/(\text{m}^2 \cdot \text{K}) \times 37.5^\circ\text{C}$	6835 kJ/day
Floor	$13.1 \text{ m}^2 \times 0.15 \text{ W}/(\text{m}^2 \cdot \text{K}) \times 37.5^\circ\text{C}$	6424 kJ/day
Door	$1.52 \text{ m}^2 \times 0.16 \text{ W}/(\text{m}^2 \cdot \text{K}) \times 37.5^\circ\text{C}$	798 kJ/day
(3) Air renewal heat gain		31908 kJ/day
Air renewal rate	10.1 renewals/day × 48 m ³ × 65.8 kJ/m ³	
(4) Internal loads heat gain		155779 kJ/day
People	272 W	
Lighting	540 W	
Defrosting	198 W	
Evaporator fans	793 W	
Total cooling needs		770619 kJ/day
Security margin	10%	
Compressor operation time per day	24 h	
Cooling capacity needed		9811 W
Recommended unit (horizontal version series-SH-QF*)		MSF-QF 9136*

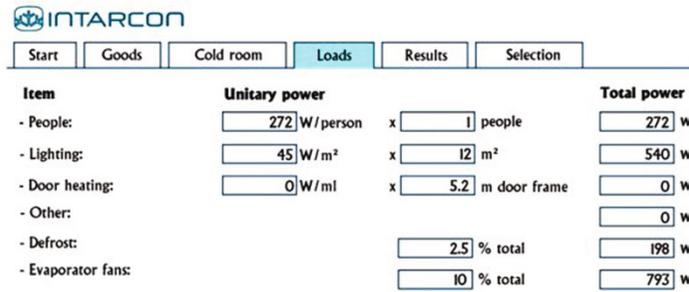
*Split units with silent condensing unit and cubic evaporating unit, designed for the preservation of generic products at positive or negative temperature in or negative temperature in medium size cold rooms. The condensing units are designed to be installed outdoors, with too low noise emission level due to silent design and tropicalized battery. MSF-QF 9136 owns compressor with 400 V-III and frigorific powers of 10260, 12300, 14500, and 17050 W for volumes of cooling compartments of 160, 220, 320, and 500 m³, respectively [55].

5.3. Cooling Gas Optimization. Single-effect absorption CS is based on a basic absorption cycle (Figure 8) with a single absorber and generator, in which a refrigerant is separated from the absorbent by heat generated by a solar collector. In the evaporator, the vapor-refrigerant is condensed in a condenser, laminated in a valve, and evaporated at low pressure and temperature. Weak-solution that returns from the generator after the lamination in the expansion valve absorbs the cooled refrigerant in an absorber. The rich-mixture formed in the absorber is pushed back to the generator by the pump. Solar refrigeration uses solar collector-based thermally driven cycles and PV-based electrical cooling systems to provide a variety of cooling options [63].

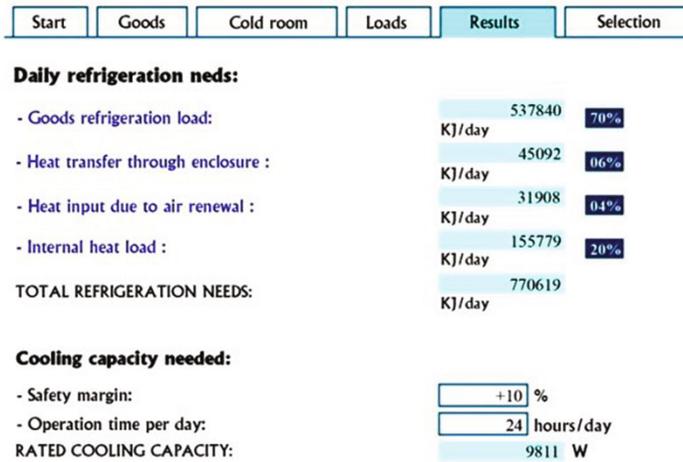
Here, after several analyses, we have selected INTARCON to meet the requirements of refrigeration equipment [55]. To design the SE cooler, the area on which the freezer is built has to be accurately calculated to control the humidity and temperature impacts, and the door dimensions of such area and the types of insulators used should be assessed, as well.

The operators frequent the fridge have to assess the thermal energy resulting from lighting. Here, a unique user should control the power estimated to be ~793 watts. The units selected of the equipment own the characteristics [55] listed in Table 3.

Figure 9 below illustrates loads to be considered, and focus on results obtained from simulations. The cooling



(a)



(b)

FIGURE 9: Details on (a) loads and (b) daily refrigeration needs of considered loads (results from INTARCON outputs).

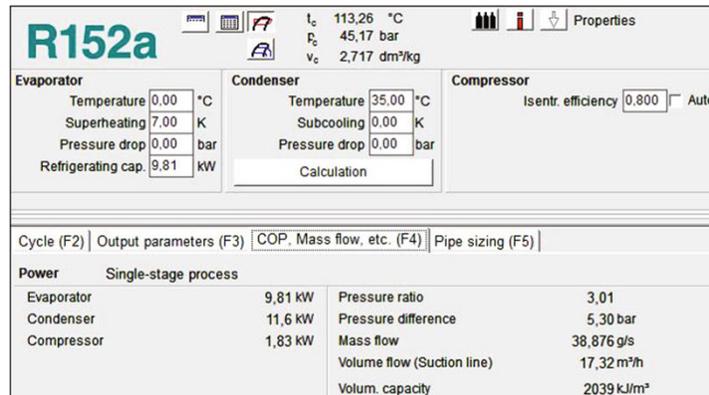


FIGURE 10: Simulation details on the optimized refrigerant gas R152a from SOLKANE interface.

safety margin, estimated by INTRACON to be 10%, shows CC required to operate cooling systems whose CC is required to cool the fridge is determined to be 9811 watts.

Figure 10 focuses on details from SOLKANE program [56] of the R152a refrigerant gas, optimized to remedy the problems of toxicity and pungent smell of NH₃ and non-CO₂-free CH₃OH while storing H₂ in CH₄. As can be seen, R152a refrigerant gas produces a power of 11.6 kilowatts to be used to supply other equipment to take advantage of the wasted power. From SOLKANE interface (Figure 9), it

can concluded that electrical capacity required to operate the electric fridge in one room is 1.83 kWh per hour, i.e., the provided daily capacity over 24 hours is 43.92 kW/day. It is be mentioned that R152a can be a promising refrigerant gas with high performance and an environmentally friendly choice for the cooling systems. It is found to be the most efficient refrigerant compared to C-NH₃ and C-CH₃OH refrigerants. Such refrigerant is a highly effective choice for the cooling vapor compression cycles. With nontoxicity, R152a has a low global warming potential and a reasonable cost.

But its issue of increased flammability, even of no great impact, remains to be remedied. All predictions can make R152a a reliable choice for future cooling systems, to meet health needs [64, 65]. It is worth to mention that a higher cooling weakly impacts the cost-effective investment in solar PV for low-carbon electricity system storing dates under the climate of the Maghreb. But a technoeconomic modeling of cost optimization either solar, wind, or hybrid source should be used for cooling stored dates is required. A cost-effective investment in solar PV in SC remains contingent on CO₂ emission threatening environment.

6. Conclusion

Cooling demand is increasing as a result of recent climate change, and cooling solutions based on SE should be promising in the future. Solar CSs are more suitable than conventional refrigeration systems because they use pollution-free working fluids as refrigerants. PV systems and thermally activated CSs are widely used by food manufacturers for industrial cooling. The electrical power required to cool the dates in fridges is given under precise temperature and adequate gas cooling, with low consumption predicted by PVsyst. R152a is optimized as an appropriate gas for cooling. Due to high energy consumptions of refrigerators, our optimized SE system can be used to safety storage of dates, and solar panels may give a normalized power production of 44 kWp, but with PV-array losses of 15.6% ($L_c = 0.99$ kWh/kWp/day) and a system loss is 1.3% ($L_s = 0.08$ kWh/kWp/day). A yearly produced energy of 84.5 MWh and L_c of 5.26 kWh/kWp/day are predicted. PV fridges for SE coolers should own a very thick insulation for heat generating to compressors and are able to save energy. SE cooling dates with low DC voltages require inverters and batteries and to continuously operate necessitate no generators like conventional fridges and freezers. Finally, these are some required SE recommendations that allow for our PV system, optimized for SC, to be efficient:

- (i) Entities must establish databases on solar radiation, temperature, dust volume, and other periodic information necessary for SE coolers to be applied in dates storage
- (ii) Carrying out large-scale pilot projects should be encouraged for Maghreb countries' benefits as additional sources of energy to take advantages of SE for SC of dates
- (iii) Providing researchers in the Maghreb with more opportunities to interact with their counterparts from the globe is needed to encourage researchers to participate in global conferences focusing on PV renewable energy for SC applications
- (iv) Enact laws to reward all those who produce clean and reliable energies for SC, which are expected in the future, so that material and moral supports and research movement activation in SE fields should be launched

Nomenclatures

E_{Array} :	Effective energy at the output of the array (kWh)
EffArrR:	Efficiency of the array (Effic.Eout array/rough area) (%)
EffSysR:	Efficiency of the system (Effic.Eoutsystem/rough area) (%)
E_{Grid} :	Energy injected into grid (kWh)
GlobEff:	Effective global, correction for IAM shadings (kWh/m ²)
GlobHor:	Horizontal global irradiation (kWh/m ²)
GlobInc:	Global incident in collector plane (kWh/m ²)
L_c :	Collection loss (PV-array losses) (kWh/kWp/day)
L_s :	System loss (kWh/kWp/day)
P_R :	Performance ratio
Si-poly:	Silicon poly-crystalline
T_{Amb} :	Ambient temperature (°C)
Y_f :	Reference incident energy (PV-array losses) (kWh/m ² /day)
Y_r :	Produced useful energy (inverter output) (kWh/kWp/day).

Data Availability

No data were used in this study.

Conflicts of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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