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Title

Study of multi-agent system in the management of hybrid renewable energy system to supply demand of a green building

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Abstract

Hybrid Renewable Energy System (HRES) constitutes a promising solution to reduce GHG emission and saving fossil fuels in the building sector. However, finding the optimal sizing and management of the HRES is a big challenge. This study presents a Multi Agent System (MAS) based method for optimal sizing and management of HRES to meet the electricity demand of green buildings in Algeria. The proposed HRES consists of PV/Wind turbine /Batteries/DG or utility grid it depends on the application. First, the Multi Objective problem is formulated as single objective. Hence, a Particle Swarm Multi Objective Optimization algorithm (MOPSO) code is developed on MATLAB software to solve the problem. The proposed method is applied to different locations of the country. The results show that the load demand has a strong effect on the size of the HRES. In addition, applying the demand side management on the heating ventilation and air conditioner (HVAC) system by controlling the set point temperature in cooling mode can reduce the size of the HRES and the cost of energy. Comparing the results of the three studied locations, Bechar gives the best results in terms of cost of energy, and renewable fraction. The proposed method makes the management of the energy in multi sources energy system more reliable, cost-effective and allows increase the share of renewables. Therefore, it will contribute to convert building sector to sustainable and green sector.

Key words: HRES, Energy management, MAS, Multi Objective Optimization, Green building.

ملخص :

يشكل نظام الطاقة المتجددة الهجين (**ن ط** م ه) حلاً واعداً للحد من انبعاثات الغازات الدفيئة وتوفير الوقود الأحفوري في قطاع البناء. ومع ذلك، فإن إيجاد الإدارة المثلى ل(**ن ط** م ه) يمثل تحديًا كبيرًا. لهذا السبب تقدم هذه الدراسة نظام متعدد الوكلاء (ن م و) لتحديد التقييس الأمثل وإدارة الموارد لتلبية الطلب على الكهرباء في المباني الخضراء في الجزائر. يتكون (**ن ط** م ه) المقترح من (لواقط شمسية / توربينات الرياح / بطاريات / مولد ديازل أو شبكة الكهرباء). أولاً ، يتم صياغة مشكلة متعددة الأهداف كهدف فردي، كما يتم تطوير خوارزمية تحسين الجسيمات متعددة الأهداف على برنامج ماتلاب لحل المشكلة.لقد تم تطبيق الطريقة المقترحة على مواقع مختلفة من البلاد. تظهر النتائج أن الطلب على الحمل له تأثير قوي على حجم الموارد. بالإضافة إلى ذلك ، فإن التحكم في درجة الحرارة المرغوبة للتبريد يمكن أن يقلل من حجم النظام وتكلفة الطاقة.إنطلاقا من مقارنة نتائج المواقع الثلاثة التي شملتها الدراسة، تعطي منطقة بشار أفضل النتائج من حيث تكلفة الطاقة ومشاركة الطاقات المتجددة. تجعل الطريقة المقترحة إدارة الطاقة في نظام متعدد المصادر أكثر فعالية وأقل تكلفة.

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Nomenclature

Nomenclature	Definition
HRES	Hybrid renewable energy system
LPSP	Loss of power supply probability
COE	Cost of energy
GHG	Greenhouse gas
MAS	Multi agent system
PSO	Particle swarm optimization
PV	Photovoltaic panel
WT	Wind turbine
DG	Diesel generator
AD	Autonomy day
C_b	Capacity of battery
P_g	Power of diesel generator
P_{WT}	Power of wind turbine
P_{PV}	Power of Photovoltaic panel
P_{ch}	Power of charging
P_{disch}	Power of discharging
P_l	Power of load
DOD	depth of discharge
E_b	Energy of battery
E_{bmax}	Energy of battery maximum
E_{bmin}	Energy of battery minimum
AC/DC $_{bus}$	Alternative courant/ Directly courant
HVAC	Heating ventilation and air conditioner

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Introduction

1. Background

In the last years, the global energy consumption in the building sector is rapidly increased and has exceeded 40% of the total energy (Fan, Huang, and Sun 2018). Besides that, buildings contribute to one-third of greenhouse gas emission worldwide (Wei et al. 2018). Exclusively, Residential buildings account for 27% of overall final energy consumption and 17% of global carbon emissions (Leibowicz et al. 2018). This amount expected to continue increasing due to population growth, economic development, and urbanization. In Algeria, residential sector responsible of about 38% of the total energy consumption (Bey et al. 2016). Natural gas is responsible for 97% of the primary energy used for electricity generation which load to high fraction of CO_2 emission in this sector (Haddad, Liazid, and Ferreira 2017). Thereby, integration of renewable sources in buildings is mandatory to address energy and environment issues. In this context, the Algerian government has lanced the renewable energy and energy efficiency program which aims to provide at least 40% of final energy from renewable sources by 2030(Belabes et al. 2015). However, the intermittence of renewable sources, and its highest cost of investment make this solution not effective alone. Therefore, hybrid renewable energy system “HRES” is still the promising solution to transit toward more renewable energy utilization and promotion. However, finding the optimal sizing and management strategy for HRES with respecting several objectives is a big challenge.

2. Literature review

Many research papers are carried out in this scope of research. For example, in [(Mohamed et al. 2018), (Singh and Fernandez 2017)], a new meta-heuristic algorithm called Ckuckoo Search is applied for solving the problem of techno-economic sizing of hybrid PV/wind/ diesel/battery for remote buildings. Barun (B. K. Das and Zaman 2019) investigated the performance of hybrid PV/Diesel/ Lead Acid-LA and Lithium-ion battery system to supply a remote community in Bangladesh. His study aims to find the optimal configuration where minimizing system costs. F. Fodhil et al. (Fodhil, Hamidat, and Nadjemi 2019) presented a methodology for analyzing an autonomous hybrid PV-diesel-battery energy system. In his study, particle swarm optimization (PSO) and ε-constraint method are used to minimize total system cost and CO_2 emissions. Monotosh et al. (M. Das et al. 2019) developed a met heuristic optimization algorithm to determine the optimal design of an off-grid HRES with the goal of minimization of the total net present cost. The studied HRES, which consists of solar PV/biogas generator /pumped hydro and battery storage system, is proposed to supply a radio transmitter station in India. Zhang et al (Zhang et al. 2019) also proposed a new hybrid optimization algorithm based on the combination of chaotic search, harmony search and simulated annealing algorithms for optimal sizing of stand-alone hybrid solar and wind energy system. The main objective is to minimize the total life-cycle cost. Besides that, in (Jafar et al. 2019), the optimal design of the hybrid renewable energy with hydrogen storage system are discussed to minimize the total net present cost using an intelligent flower pollination algorithm. Bhatt and Sharma (Bhatt, Sharma, and Saini 2016) studied the techno-economic feasibility of different hybrid energy systems in rural areas in India using HOMER software. Technical-economic factors include the cost of energy, net present cost, and renewable fraction and CO_2 emissions. In the study of (Moradi et al. 2018), an optimal energy management and optimization of a standalone HRES with battery storage under system uncertainties is investigated. The main objectives of this work are decrease system fuel cost and gas emissions reduction, and improve energy utilization efficiency. The system is solved as a constrained single-objective optimization problem using an advanced dynamic programming method. In order to satisfy load demand, to minimize the energy cost, to maximize renewable energy integration, to minimize loss of supply, a new parallel hybrid GA-PSO algorithm is developed in (Mellouk et al. 2019) for optimal design and management of HRES in Laayoune region, Morocco. The results of this work are very satisfied, where the obtained energy cost is close to fossil fuel energy cost. The author in (Eriksson and Gray 2019) proposed a multi-objective approach by the implemented of Particle Swarm meta- heuristic optimization algorithm for achieving a compromise between several technical, economic, environmental and socio-political objectives in the optimization of any configuration of renewable energy system.

Despite to above works, recently, there has been an increase attention to multi agent system based methods for optimal sizing and energy management in HRES. In (Jun et al. 2011), a multi-agent solution to energy management in distributed HRES generation system is proposed. The proposed MAS solution is developed on JADE (Java Agent Development). The results emphasize that MAS is a suitable solution for the energy management of the distributed HRES. Similarly, in (Khan et al. 2018), a novel multi-agent system (MAS) based model for optimal management of HRES at distributed level is implemented. The proposed technique is used for the optimal operations of the HRES and offer intelligence to the system. The results emphasize the robustness of the model for the management of such system based on MAS technique at distributed level.

3. Objective

This purpose of this work is develop a multi agent system “MAS” based method for optimal design and management of HRES for green buildings at different locations in Algeria. The selected locations are based on the study of (Mokhtara et al. 2019), which has found the optimal locations to set up plus energy buildings in Algeria. The main objective of this work is to minimize the energy costs of the hybrid renewable energy system taking into account certain economic, technical, and environment criteria. The proposed method is applied to different case study for both grid-connected and off-grid applications.

4. Structure of the thesis

For best organization, this work is divided to many chapters as follows. Firstly we give a general introduction, and states the problem definition and objectives. In first chapter, HRES is presented, and then the mathematical modelling of different components of the proposed system are provided in detailed. Chapter two is dedicated to optimization strategies and methods for HRES sizing and energy management of load supply in buildings. It is also describe objective functions and constraints. In chapter three, many applications are carried out, and then the key results with discussion are presented. Finally, conclusions and future work are summarized.

Chapter I

Modelling of Hybrid Renewable Energy System

1. Introduction

Hybrid renewable energy systems (HRES) have been used extensively in last years to supply residential buildings, saving fossil fuels, as well as to reduce GHG emissions. Generally, HRES include renewable sources (solar photovoltaic (PV), wind, biomass, etc…), energy storage system (such as hydro systems, super-capacitors, and fuel cells, which are used to stored excess energy produced by renewable energy sources), and/or conventional sources mainly diesel generator and utility grid. The choice of these components depends mainly on climatic data, and type of application of HRES (Off grid or grid connected). In off grid application, which are located almost on isolated and remote areas, the secure source is mostly diesel generator. However, in urban areas, where the utility grid is available, HRES is attached to the grid. In this case, a meter must be used to measure the amount of energy that is sold and purchased. Further, many laws and regulations that manage the connection of HRES to the grid. Some countries offers incentives to their residences in order to encourage them to install renewable energy systems and other countries buy excess produced energy from their customers by introducing feed in tariffs.

This chapter was dedicated for modelling of HRES' components, and providing the main data and characteristics of each system. The proposed HRES consists of solar PV, Wind turbine, batteries bank, and Diesel generator (Off-grid) or utility grid (On-grid). The schematic of HRES for off-grid and on-grid application are shown in Fig.1 and Fig.2 respectively. In addition, the evaluation of load profile of the selected buildings was carried out in detailed taking into account thermal comfort criteria. In this chapter, each part of the hybrid energy system is modeled and investigated.

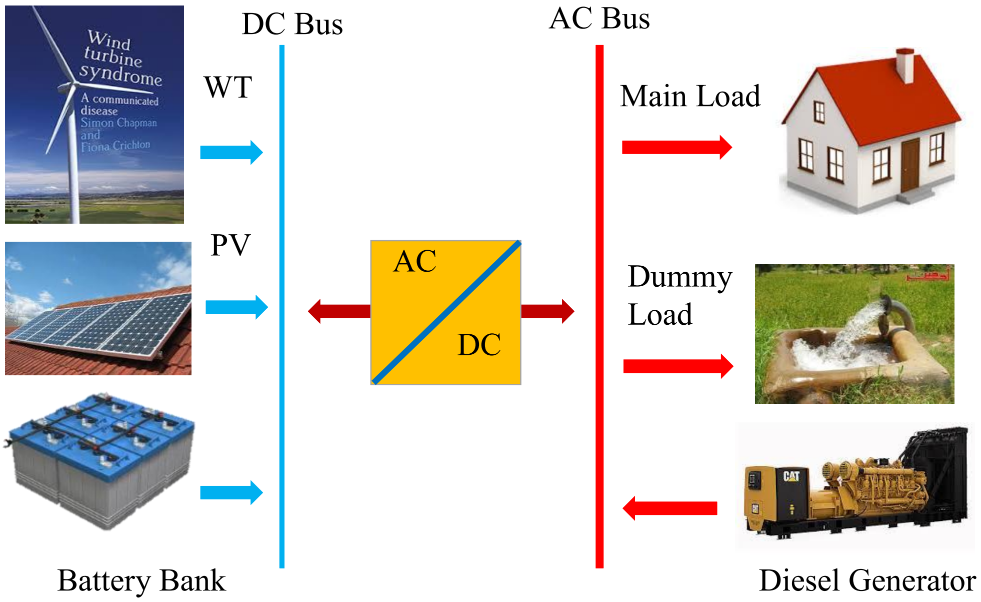

Figure 1 Schematic of Off-grid HRES

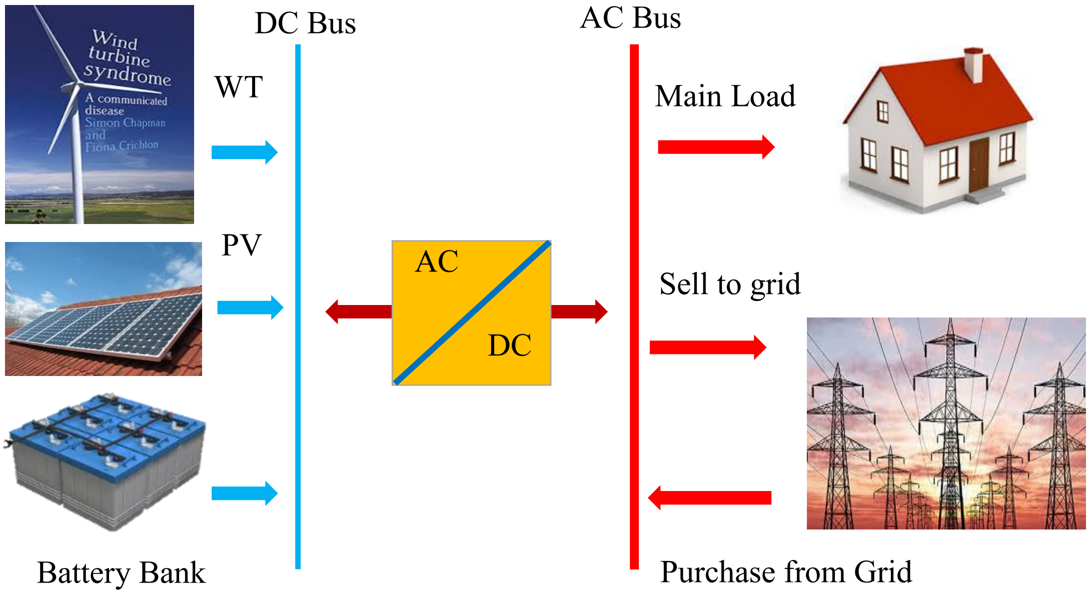

Figure 2 Schematic of Grid-connected HRES

2. Modelling of renewable energy sources

Renewable energy sources are mostly have the priority to supply the demand. In the literature, there has been different equations, which used to evaluate the hourly energy production of renewable energies. In this work, a simple model including solar radiation and ambient temperature variables is used to characterize the PV system power output. Similarly, for the wind turbine, a simple cubic model is selected.

2.1. Wind turbine:

Wind can be considered as an available and free energy source that can be used to produce electricity. The kinetic energy is converted into electrical energy where the wind speed is high, as in the southern regions of Algeria. The power output of wind turbine can be approximated using Eqs. (1), (2), and (3) as follows (Borhanazad et al. 2014):

$$\mathrm{P_{wt}} \Leftrightarrow 0 \qquad \text{if} \qquad \mathrm{V < Vcut_{in} or\, V > Vcut_{out}} \tag{1}$$

$$\mathrm{P_{wt}} \Leftrightarrow \mathrm{V^3}\left(\frac{\mathrm{Pr}}{\mathrm{Vr^3 - Vcut_{in}}^3}\right) - \left(\frac{\mathrm{Vcut_{in}}^3}{\mathrm{Vr^3 - Vcut_{in}}^3}\right) \text{ if } \mathrm{V > Vcut_{in}} \text{ and } \mathrm{V < V_{rated}} \tag{2}$$

$$\mathrm{P_{wt}} \Leftrightarrow \mathrm{P_r} \qquad \text{if } \mathrm{V > V_{rated}} \text{ and } \mathrm{V} < V_{cut\_out} \tag{3}$$

Where:

P_r : Is the rated power of wind turbine which delivered by the Manufacturer

V_{rated} : Represents the speed at which the machine produces its rated energy.

V_{cut_in} : Represents the speed at which the wind turbine starts work.

V_{cut_out} : Represents the maximum speed allowed for wind turbine working.

2.2. Solar PV

Solar PV panel is a device that converts solar energy into electrical energy. The power supplied by the PV can be calculated as a function of the solar radiation and ambient temperature by using the following formula Eq. (4) (Abo-elyousr and Nozhy 2018):

$$\mathrm{P_{pv} = PN_{pv}} \times \frac{\mathrm{G}}{\mathrm{G_{ref}}} \times \left[1 + \mathrm{Kt} \times (\mathrm{T_c - T_{ref}})\right] \tag{4}$$

Where, Ppv_out is output power of PV, PNpv is rated power under reference conditions, G is solar radiation (W/m^2), Gref and Tref are solar irradiation and ambient temperature under reference conditions, which are 1000 W/m^2 and 25 °C respectively. Kt is temperature coefficient of power (-3.7^{-3} (1/°C)), and Tc (°C) can be calculated by Eq. (5).

$$T_C = T_{amb} + \left(\frac{NOCT - 20}{800}\right) \times G \tag{5}$$

Where: NOCT is the nominal temperature at operation conditions (20°C and 800 W/m^2), its value is (45 ±2) °C.

2.3. Diesel Generator

A diesel generator (DG) is used in the hybrid energy system to meet the load demand in case the total available renewable energy (PV and Wind) generated power and batteries bank stored power are not sufficient. The fuel consumption of the diesel generator depends on its output power and can be expressed by Eq. (6) (Etamaly, Mohamed, and Alolah 2015):

$$q(t) = a\times P_{DG} + b\times P_r \tag{6}$$

Where P_{DG} (t) is generated power by DG (kW) at t (hour), q (t) is fuel consumption (L/h), P_r is rated power of DG, and b are constant parameters (L/kW), which represent the coefficients of fuel consumption, with standard values of 0.08415 and 0.246 respectively.

2.4. Utility Grid

In urban area, the majority of buildings are connected to utility grid in order to meet its required electricity demand. This electricity provided by the grid is derived mainly from gas or steam turbine stations, which are still the common source of GHG emissions. In Algeria, the unit cost of purchased electricity is 0.21 $/KWh (Ghedamsi et al. 2015).

2.5. Converter

Converter is the device that converts the electrical energy from AC into DC or vice versa. The rated power of the convertor is depends on the peak load. The efficiency of the converter can be approximated by Eq. (7).

$$\eta_{\mathrm{inv}} = \frac{P_{\mathrm{output}}}{P_{\mathrm{input}}} \tag{7}$$

The efficiency of the Convertor is set 95%, and its lifetime is 12 years.

2.6. Battery bank

Excess electricity power generation from renewable and/or diesel generator is used to charge the battery bank whereas the shortage of energy can be supplied from battery bank or/and diesel generator. The state of charge of the battery either on charge or discharge mode can be evaluated using Eqs. (8), (9) as follows (Mohamed et al. 2018).

$$E_b(t+1) = E_b(t) \times (1-\sigma) + \text{surplus power X } \eta_{Bc} \qquad \text{Charging mode} \tag{8}$$

$$E_b(t+1) = E_b(t) \times (1-\sigma) - \text{deficit power / } \eta_{BD} \qquad \text{Discharging mode} \tag{9}$$

Where, E_b is the energy of the battery bank, η_{BC} and η_{BD} are the charging anddischarging efficiency of the battery bank (in this book η_{BC} and η_{BD} have beenconsidered as 90% and 85%, respectively).σ is the battery self-discharge rate; it is assumed as 0.2% per day for most batteries. At each hour (t), the state of charge of the battery (Eb) is governed by minimum and maximum capacity of storage battery, $\mathrm{Eb_{min}}$ and $\mathrm{Eb_{max}}$, as specified in Eq. (10).

$$\mathrm{Eb_{min}} \leq Eb(t) \leq \mathrm{Eb_{max}} \tag{10}$$

The maximum battery capacity (kWh) ($\mathrm{Eb_{max}}$) is designed according to the days of autonomy, the average daily demand, and the depth of discharge (DOD) parameter using the following equation Eq. (11) (Abo-elyousr and Nozhy 2018):

$$\mathrm{Eb_{max}} = \frac{\mathrm{E_l \times AD}}{\mathrm{DOD} \times \eta_{\mathrm{inv}} \times \eta_{\mathrm{B}}} \tag{11}$$

Where AD is autonomy days (typically 3 to 5 days). η_{inv} and η_B are the inverter (95%), and battery (85%) efficiencies. For lithium ion batteries, DOD is (80%). Thus, the minimum state of discharge ($\mathrm{Eb_{min}}$) of the battery can be assumed using Eq. (12).

$$\mathrm{Eb_{min}} = (1 - \mathrm{DOD}) \times \mathrm{Eb_{max}} \tag{12}$$

In another hand, DOD parameter was also used to control turning ON/OFF the diesel generator.

2.7. Load profile

Load profile is the main factor for sizing and management of HRES. This demand is divided in different loads type, including demand for space cooling, heating, domestic hot water, lighting and other electric appliances. Only electricity demand was considered in this work. Fig.3 shows the different parts of loads in buildings.

Figure 3 Different load in the residential building

3. Conclusion

In this chapter, the mathematical equations of different HRES components have been presented. Further, the evaluation of load profile is also discussed. This part of the thesis were used in the simulation of the proposed HRES in the experiment section.

Chapter II

Multi agent system based method for sizing and management of HRES

1. Introduction

In this chapter, a multi agent system (MAS) based method was proposed to sizing and control of the HRES. The method was developed to solve of multi objective optimization (MOO) problems dealt with HRES. In addition, a particle swarm optimization (PSO) algorithm is implemented to find the optimal HRES sizing and configuration. In this chapter it is set the objectives function and the constraints which use in simulation part.

2. Concept of Multi-Agent System

The Multi-Agent Systems approach, which has developed a great deal over the last twenty years, makes it possible to understand, model and simulate complex systems, i.e. systems made up of numerous components that interact dynamically with one another. With the outside world. She is studying how to coordinate a set of agents so that these agents collectively solve a global problem. These agents are autonomous and interact via an environment. The collective aspect in MAS is essential and requires the study of new concepts related to the coordination, the cooperation and the interaction between the agents.

3. Classification of agents

Classification of agents are very important and the literature includes numerous agent's classification. Three different forms of agents: cognitive, reactive, and hybrid agents were discussed(Khan et al. 2018):

Cognitive agents: These have a capability of reminiscence, interaction and reasoning ability. They perform in a supplementary "imitated" method derived from a selection among a set of conceivable activities. This selection is the outcome of the intellect.

Reactive agents: Such agents usually have a limited/low communication capability and have insignificant or not any classical model about environment, other agents, or even for themselves. Their performance arrangement is something like stimulus-response.

Hybrid agents: Such agents can be categorized according to their degree of autonomy, agent's actions, adaptation, and assistance. As a hybrid agent, they practice both types of actions: reactive and cognitive.

4. Multi-Agent System for the energy management of HRES

The objective of this work is to design a home energy management system consisting of software agents controlling equipment and sources, all agents constituting a multi-agent home automation system. By this is meant an energy management system that is able to find dynamically a production and consumption policy while taking into account the criteria posed by the user and the various constraints of equipment and sources.

The architecture of the MAS for the management of the proposed HRES includes information flow and energy flow. The main architecture of the system and flow interactions between the agents are presented in Fig.4.

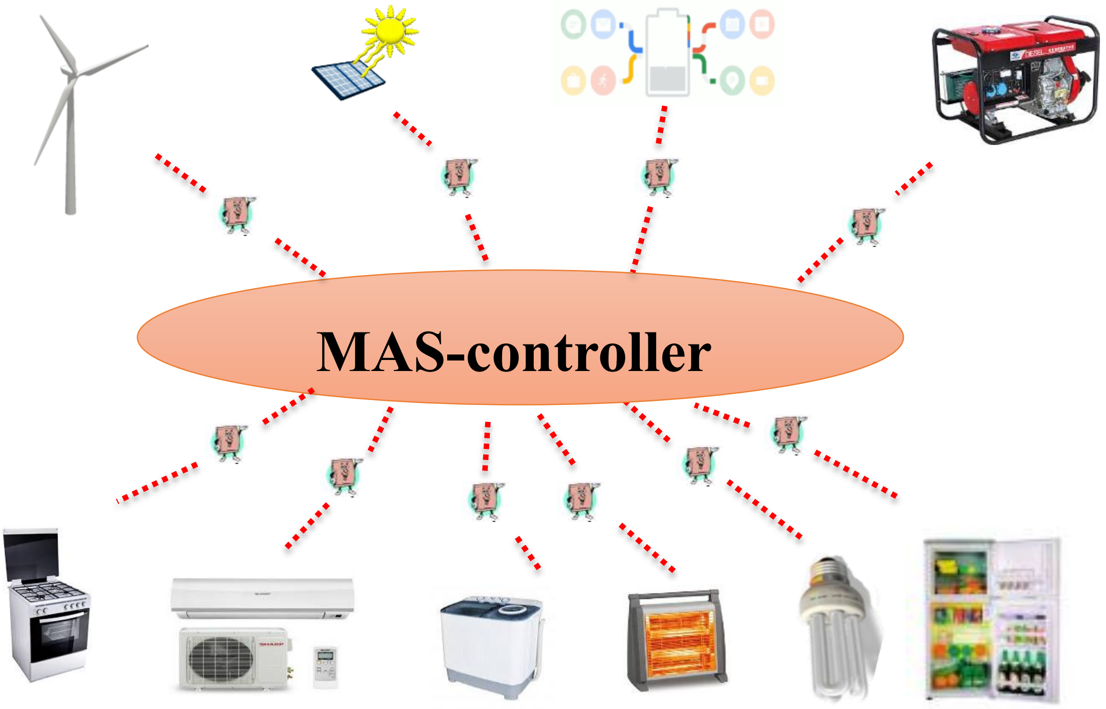

Figure 4 MAS-controller for HRES management in the building

5. Design of Multi agent system for the HRES management

In this part, five different types of agents were proposed. Fig.5. Shows the design of the proposed HRES' agents.

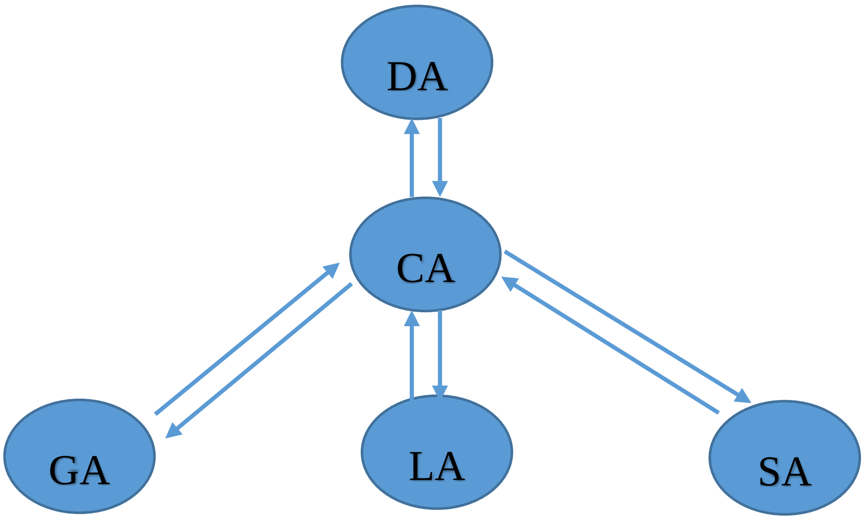

Figure 5 Design of Multi agent system

The operational approach within the HRES and agent's specification and associated functionalities are given as follows:

1. **Control agent (CA):** CA is mainly responsible for the management of different information that are received from the DA, SA and LA at each hour of the year.
2. **Design agent (DA):** DA is an independent system operator which responsible to optimize the HRES.
3. **Generation agent (GA):** GA consist of WT, solar PV, and FC generation. GA is primarily responsible for monitoring the generation of electrical power, controlling of the set-up, and performing tasks according to the generation capability of the renewable energy RE. The information that this agent contains is an agent identifier, low and high-power production restrictions, and active statistics such as control setting and power delivery capabilities.
4. **Storage agent (SA):** The SA are available at an active/inactive condition. The SA stays at an active condition during the consumption of energy. Its state can be altered or moved based on availability of energy from the RE. Constraints are mostly operated accordingly within the system.
5. **Load agent (LA):** LA comprise critical and non-critical load agents. LA is largely responsible for controlling and governing the consumers' status and load demand and sending the required data to the GA to enhance and fulfill the anticipated demand of the consumers.

6. Interaction between agents

The interactions and swapping of data among intelligent agents in the Micro-Grid arrangement is very important to identify the current operational status of the system. The communication among different agents of the HRES is the responsibility of CA. Fig.6. Shows the sequence diagram of different interactions between agents of the HRES.

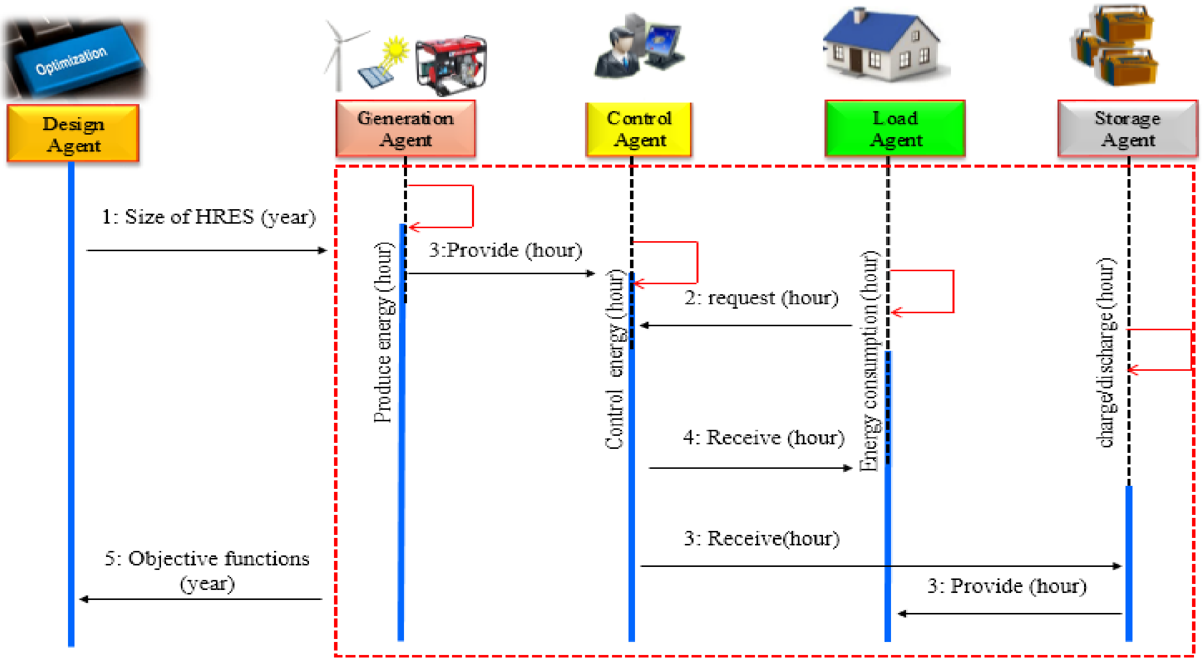

Figure 6 : Sequence diagram of interactions between agents of the HRES

7. Control Agent

The control agent (CA) is the responsible agent for the energy management of the HRES. The management of HRES is one of the main steps for designing of HRES. The energy management strategy which is applied in this work is as follows:

Case 1: Sufficient generated energy is provided by renewable sources and the extra energy is used to charge a battery bank.

Case 2: Same as case 1 but the surplus energy generated by renewable resources is greater than the need to supply the load and the battery bank. Therefore, in this case the surplus of power is consumed in a dump load.

Case 3: Renewable resources fail to provide sufficient energy to meet the load. The priority in this case, is to use the stored energy in the batteries rather than operating the diesel generator. In this case, the shortage of power generation is supplied from a battery.

Case 4: The generated energy from the renewable sources is not sufficient to meet the demanded load and the battery bank is also depleted. In this case, the diesel generator is switched on to supply the load and to charge the battery.

7.1. Flowchart of the main energy management strategy of the HRES

The general description of the energy management strategy for controlling the proposed HRES is presented as schematic in Fig.7.

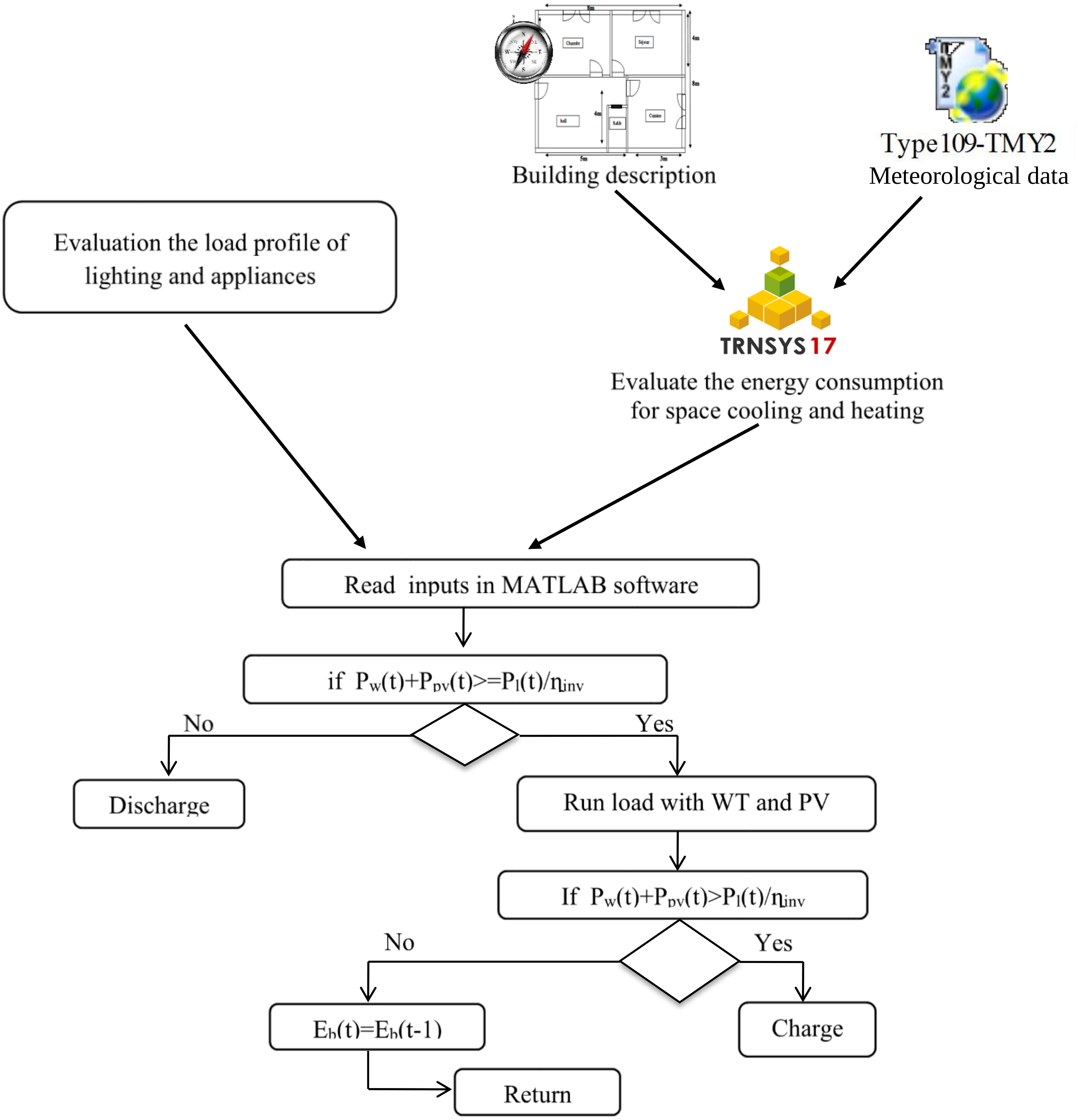

Figure 7 Flowchart of the energy management strategy in the HRES

7.2. Flowchart of the charging mode of operation

As presented above, the battery bank is used to store the excess of energy produced from renewable energy sources. Fig.8. Shows the flowchart of charging mode.

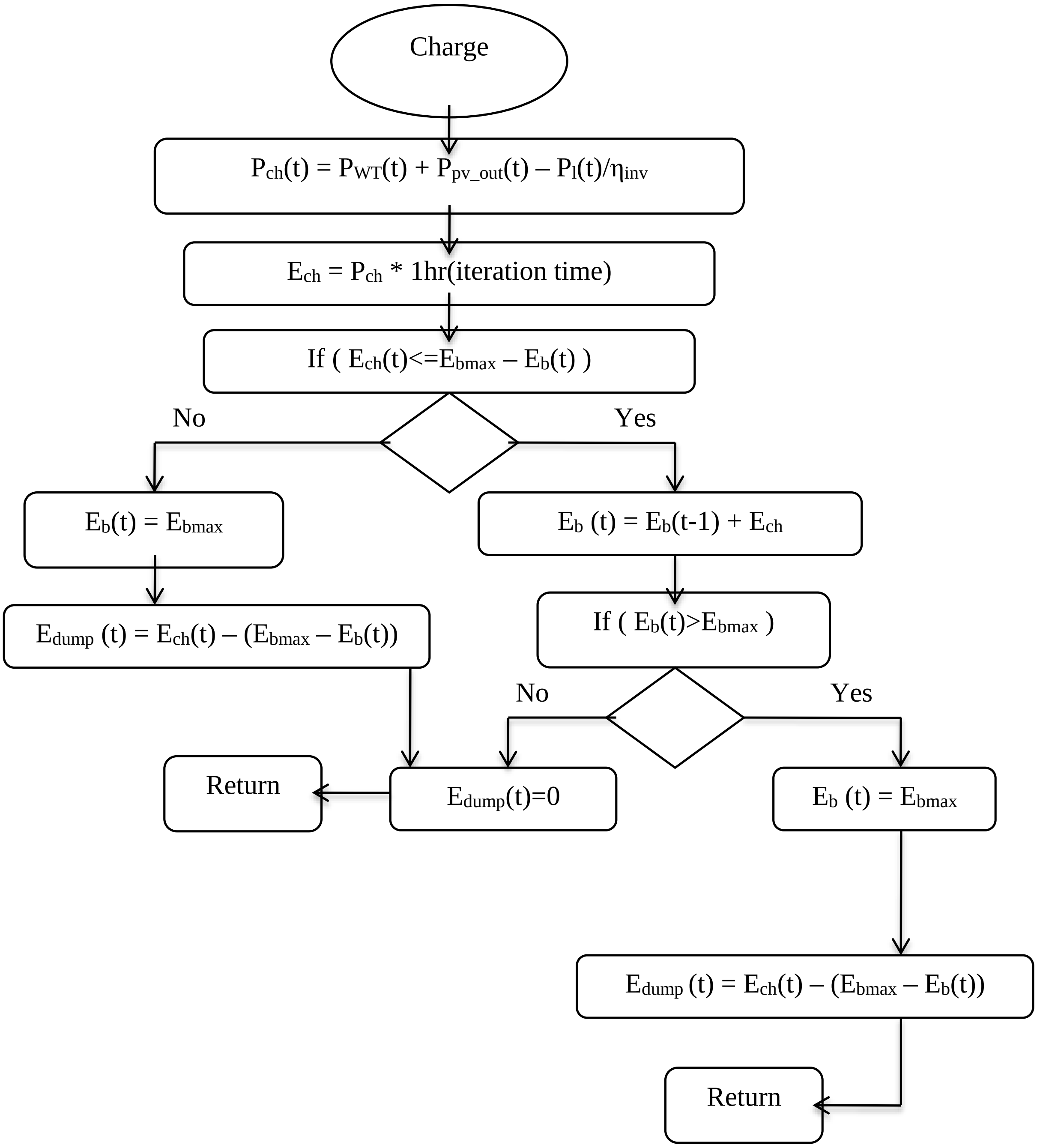

Figure 8 Flowchart of the charging mode of operation

7.3. Flowchart of the discharging mode of operation

The flowchart of discharging mode of operation is presented in Fig.9.

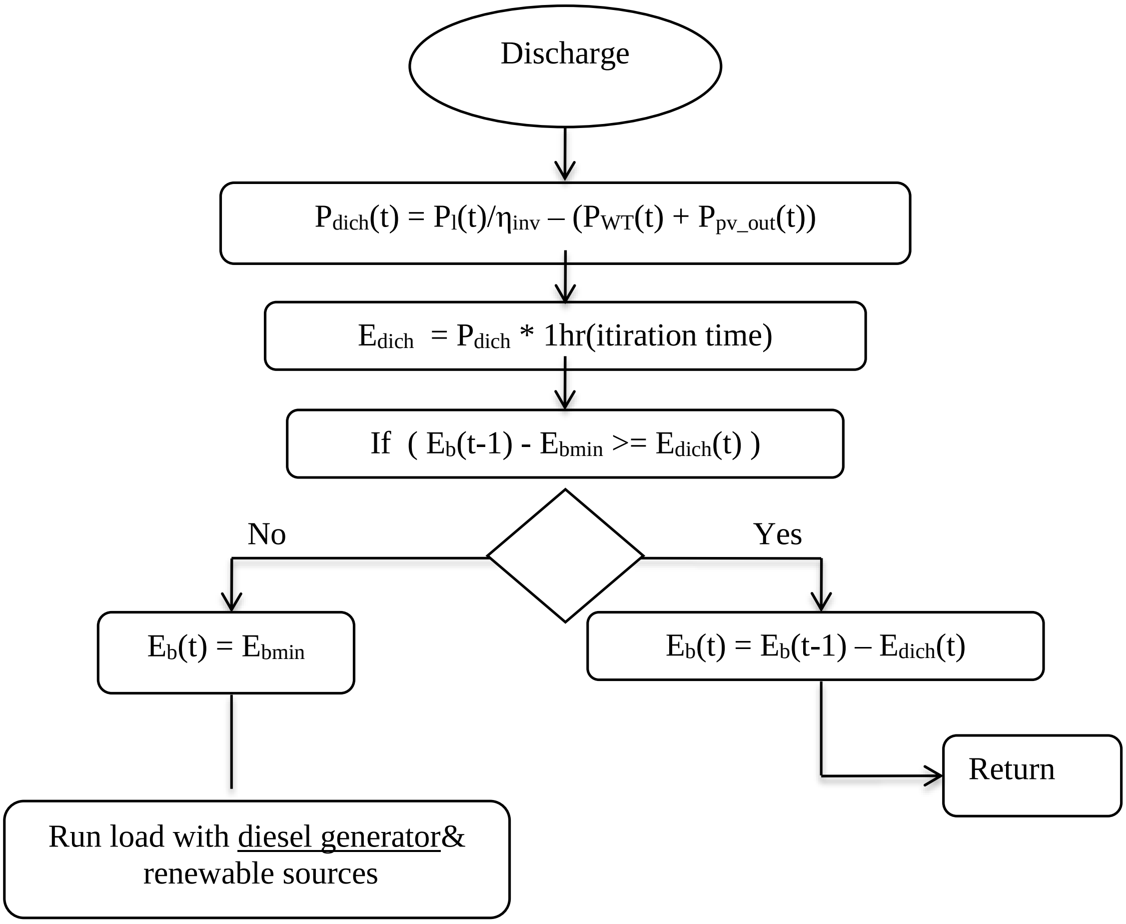

Figure 9 Flowchart of the discharging mode of operation

7.4. Flowchart of the diesel/grid mode of operation

In the HRES, diesel generator in Off-grid applications or the utility grid in grid connected are used as backup system or in case of deficit from renewable sources. Fig.10 shows the flowchart of diesel/grid mode of operation.

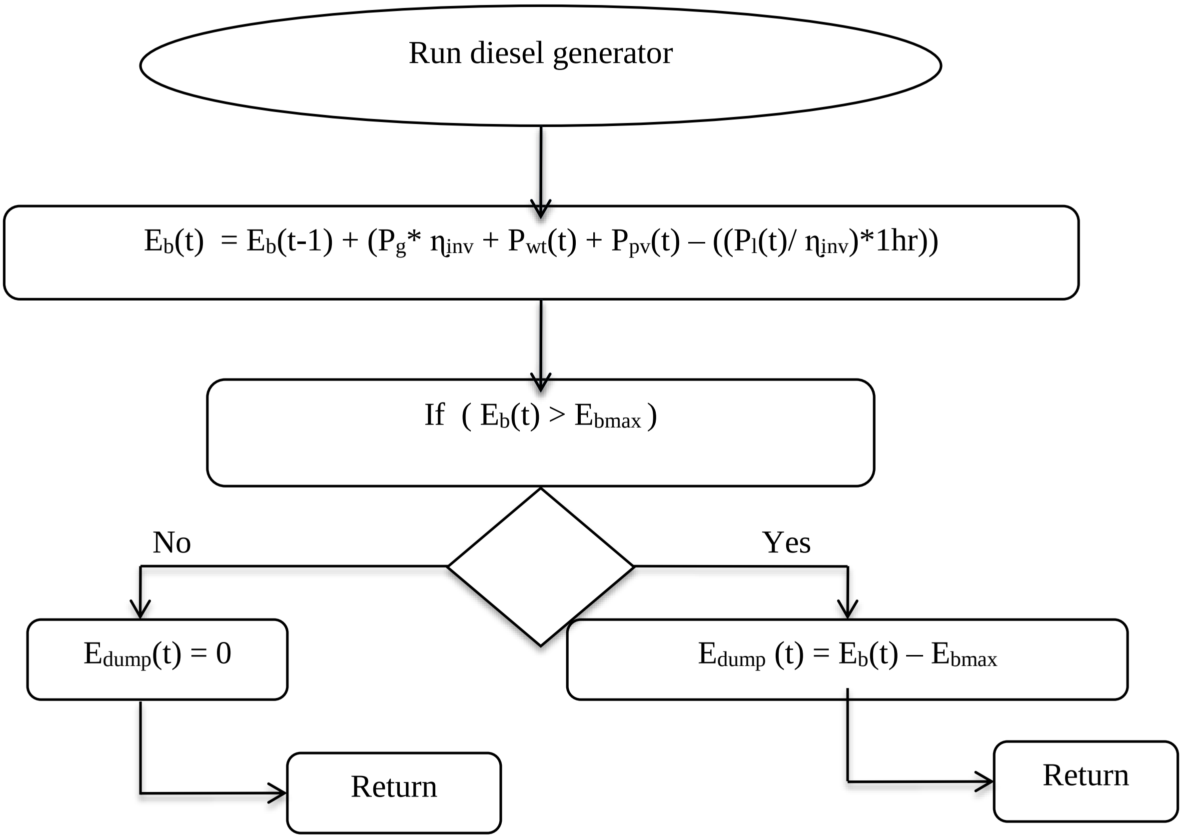

Figure 10 Flowchart of the diesel/grid mode of operation

8. Design agent

Design agent (DA) is the agent that make the optimization of the HRES. In this study, DA is a multi-objective PSO based program, which is implemented for the optimal sizing of the hybrid renewable energy system. In this study, three objective functions to be minimized, are LPSP (Loss of power supply probability), COE (Cost of Energy), and maximum RF (Renewable Fraction) under several inequality constraints and criteria. To simplify the calculation, the studied multi objective problem is reformulated as one objective function by using the ε-constraint method. This method is widely used by the researcher for the resolution of MOO problems. The main program of the proposed algorithm is developed in MATLAB (2016) software based on the mathematical modelling of the HRES components and objective functions.

8.1. ε-constraint method

This method is widely used in literature which allow converting MOO problem to single objective problem. This method based on making one of the other objectives the main objective function to be minimized or maximized and the rest objectives are defined as constrained. The main challenges in applying this method is to determine the main objective function and the adequate constraints which needs to well known of the problem.

8.2. Particle swarm optimization (PSO)

PSO first described by Kenney and Eberhart in 1995, was inspired by two separate concepts: the idea of swarm intelligence based on the social interaction exhibited by swarm, and the field of evolutionary computation. In PSO algorithm, two best values determine each particle's position. The first one is the best value that the particle achieved so far and has been stored. This value is named as individual best. Another one is obtained by the PSO optimizer among the population so far, which is called global best. Also each particle has a position representing the value of variables and a velocity that directs the particle towards the individual and global bests. The fitness function is a particular type of objective function to find the best solution from among all feasible solutions. In PSO, the constraints can also be included in the fitness function. The PSO algorithm consists of three main steps, as follows [7]:

- Evaluate the fitness of each particle.
- Update individual and global best fitness and position.
- Update velocity and position of each particle.

Each particle remembers the best fitness value it has achieved during the operation of the algorithm. The particle with the best fitness value compared to other particles is also calculated and updated during iterations. The process is repeated until some stopping criteria, such as the number of iterations or predefined target fitness values are met. The position of each particle in the swarm is updated using the following equation:

$$\boldsymbol{X_{k+1}^{i} = X_{k}^{i} + v_{k+1}^{i}} \tag{13}$$

Where x is particle position and v is particle velocity in the iteration k. The velocity is calculated as follows:

$$\boldsymbol{v_{k+1}^{i}} = \boldsymbol{k\ x}\ [\boldsymbol{v_k^i} + \boldsymbol{C_1 r_1}(\boldsymbol{P_k^i} - \boldsymbol{X_k^i}) + \boldsymbol{C_2 r_2}(\boldsymbol{P_k^g} - \boldsymbol{X_k^i})] \tag{14}$$

$$K = \frac{2}{2 - \emptyset - \sqrt{\emptyset^2 - 4\emptyset}} \tag{15}$$

$$\emptyset = \boldsymbol{C1} - \boldsymbol{C2} \quad \emptyset > \boldsymbol{4} \tag{16}$$

Where, $\mathbf{P^i}$ is the best individual particle position and $\mathbf{P_g}$ is the best global position, $\mathbf{C_1}$ and $\mathbf{C_2}$ are the cognitive and social parameters, respectively; $\mathbf{r_1}$ and $\mathbf{r_2}$ are random numbers between 0 and 1. $\mathbf{C_1}$ and $\mathbf{C_2}$ are usually close to 2 and affect the size of particle's step towards the individual best and global best, respectively. In this study, both values are assumed to be 2 in order to attract the particle towards the best points equally.

$\boldsymbol{V_k^i}$, Called inertia, makes the particle move in the same direction and with the same velocity.

$\boldsymbol{C_1 r_1}(\boldsymbol{P_k^i} - \boldsymbol{X_k^i})$, Is called the cognitive component, and causes the particle to return to a previous position in which it has experienced higher individual fitness. $\boldsymbol{C_2 r_2}(\boldsymbol{P_k^g} - \boldsymbol{X_k^i})$, is called the social component, which causes the particle to tend to return to the best region the swarm has found so far and to follow the best neighbor's direction. If $\mathbf{C_1} >> \mathbf{C_2}$ then each. Particle is more attracted to individual best positions, conversely, if $\mathbf{C_2} >> \mathbf{C_1}$, then the particles are more attracted to the global best position.

The complete flow of the algorithm applied for techno economic analysis of HRES is given below.

Step1) Initialization.

a) Load meteorological data (hourly wind speed, solar radiation, and ambient temperature during one year).

b) Load component's characteristics.

d) Set the constants: Number of houses for a hybrid system (load) = 1 Personal and global learning coefficients, $C_1 = C_2 = 2.05$, Inertia weight, W = 0.5, and Inertia weight damping ratio

$W_{damp} = 0.99$.

e) Set the constraint: Renewable energy fraction (equation (21)) not exceed the value of 0.99

f) The list of tasks is as follows. The dimension of the PSO algorithm is the number of tasks. Upper bound and lower bound of nominal power of (PV (kW), Capacity of the battery (C_b (KWh)), the number of wind turbines, the Power of diesel generators (DG (KW))).

g) The position and velocity of particles are randomly selected in order to generate the initial population and then applied to the objective functions to find the optimum fitness value...

h) If the positions of randomly chosen particles exceed the limitation of renewable factor, return to (d).Evaluate each particle in the swarm and find the best fitness value among the whole swarm (minimum COE, LPSP and maximum RF).

i) Set the global best value. The particle with minimum price of electricity (COE) and loss of power supply probability (LPSP) and maximum RF is chosen as the global best.

Step2) Update iteration variable.

Step3) Update inertia weight.

Step4) Update velocities.

Step5) Update positions.

Step6) Apply the updated values of the objective function to find COE, LPSP and RF.

Step7) Update individual best position.

Step8) Update global best position.

Step9) Stopping criterion. If the number of iterations exceeds the maximum number of iterations then stop; otherwise go to step 2. It is noteworthy that the idea in Step 1.f is to define our search space. In each iteration, LPSP, COE and RF of generated particles are calculated and if they meet our constraint (Step 1.e), then they will be accepted as PSO particles in the population.

8.3. Reliability model based on LPSP conception

Reliability is the main concern of any hybrid system possible. Reliability is used to evaluate the quality of pregnancy donates. Reliability is defined in the LPSP term.

LPSP indicates that the power source does not succeed in meeting the load demand either because of technical or renewable energy resources. If the LPSP value is zero, the fully generated power source fills the required load request we can calculate the LPSP by the flowing formula(Sawle, Gupta, and Bohre 2017):

$$\mathrm{LPSP} = \frac{\sum_{k=0}^{n}(P_{load} - (P_{pv}+P_{wind} + P_{diesel}))}{\sum_{k=0}^{n}(P_{load})} \tag{17}$$

8.4. Cost of energy

In this propose hybrid system design, objective function of the feasible design issue is to reducing the cost of energy (COE). The cost of energy is the ratio of total annual cost (the total annualized cost minus the cost of serving the thermal load). The hybrid system design issue is mention in equation and resolved by partial swarm optimization method(Abo-elyousr and Nozhy 2018).

$$\mathrm{COE} = \frac{C_{ta}}{E_{la}} \tag{18}$$

Where, E_{la} is the annual demand load in kWh. The total net preset cost is calculated according to Eq. (19)

$$\mathrm{TNPC} = \frac{C_{ta}}{CRF} \tag{19}$$

Where

$$C_{ta} = C_{int} * CRF + C_{OM} \ * C_{rep} * RF \tag{20}$$

Where,

C_{int}: initial, operating and maintenance, and replacement costs of HRES respectively. C_{OM} C_{rep}

CRF, *PWF*, *RF*: the capital recovery, present worth of maintenance and replacement factors.

8.5. Renewable Fraction

The renewable fraction is the fraction of the energy delivered to the load that originated from renewable power sources. In proposed hybrid system renewable fraction, explain as limit of power supply as compared to nonrenewable energy source to renewable energy source. Ideal hybrid system, which has hundred percent renewable fractions, means total generated power supply to the load from renewable energy source. Renewable fraction is calculated by given equation. According to this equation if value of renewable fraction is zero means power supply through non-renewable source (as PV, wind) is equal to supply of generator we can approximated the renewable fraction as(Sawle, Gupta, and Bohre 2017):

$$\mathrm{RF}(\%) = \left(1 - \frac{\sum_{\mathrm{k=0}}^{\mathrm{n}}(\mathrm{P_{diesel}})}{\sum_{\mathrm{k=0}}^{\mathrm{n}}(\mathrm{P_{WT}} + \mathrm{P_{PV}})}\right)\mathrm{x}100 \tag{21}$$

8.6. Renewable contribution

The renewable contribution coefficient is defined as follows(Sawle, Gupta, and Bohre 2017):

$$\text{Renewabel Contribution }(\%) = \left(1 - \frac{\sum_{k=0}^{n}(P_{\text{diesel}})}{\sum_{k=0}^{n}(P_{\text{WT}} + P_{\text{PV}} + P_{\text{diesel}})}\right)x100 \qquad (22)$$

8.7. Decision variables and Constraints

The decision variables of the optimization problem are the capacity of PV system (P_{PV}), the number of wind turbines (nWT), the capacity of battery bank (C_b), and the capacity of diesel generator (P_{DG}). Tab.1 shows the lower and upper bounds of decision variables.

Table 1 Decision variables

Parameters	P_{PV}	nWT	C_b	P_{DG}
Upper limit	20	10	20	10
Lower limit	0	0	0	0

Table 2 Constraints

Parameters	LPSP	RF
Upper limit	5 %	99 %
Lower limit	0 %	0 %

9. Conclusion

In this chapter, the management of HRES and The energy management strategy was defined, besides that the interactions and swapping of data among intelligent agents was clarified, in addition it is set the objectives functions and the constraints of Particle Swarm Optimization (PSO) algorithm which use in simulation part.

Chapter III

Cases Study Simulation and Results

1. Introduction

In this chapter, two different cases studies are investigated. In the first case study, the method is applied to find the optimal sizing of hybrid renewable energy system to supply residential buildings in isolated area. The studied HRES consists of PV panels, wind turbines, batteries and diesel generator.

The application is tested under three different regions of the country (Ouargla, Adrar and Bechar). The selection of these locations is based on the study of (Mokhtara et al. 2019), which has found the optimal locations to set up plus energy buildings in Algeria. The detailed results of this research are provided in Annex 1, in which the best locations for promoting the installation of plus energy buildings in Algeria are analyzed. In addition, the impact of controlling set point temperature of cooling is also discussed.

However, in the second case study, the optimal management and sizing of grid-connected hybrid renewable energy system in university building is carried out. The studied HRES consists of PV panels, wind turbines, batteries and utility grid.

2. Case study 1 : Optimal sizing and management of off-grid HRES

2.1. Location and climatic data

To apply the method, three different provinces of Algeria are selected, namely Ouargla, Bechar and Adrar. This climatic data for the studied locations are extracted from Meteonorm 7 software database. The climatic data of the three locations, which are wind speed, ambient temperature, and solar radiation, are presented in Fig.11, Fig.12 and Fig.13 respectively.

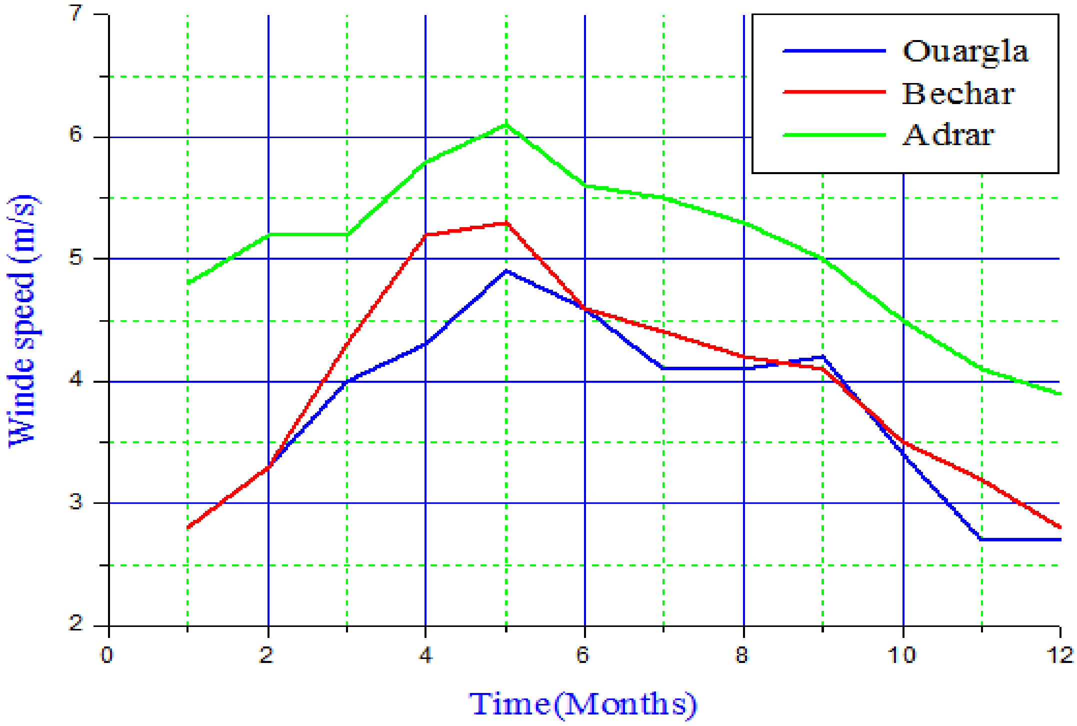

Figure 11 Climatic data (wind speed)

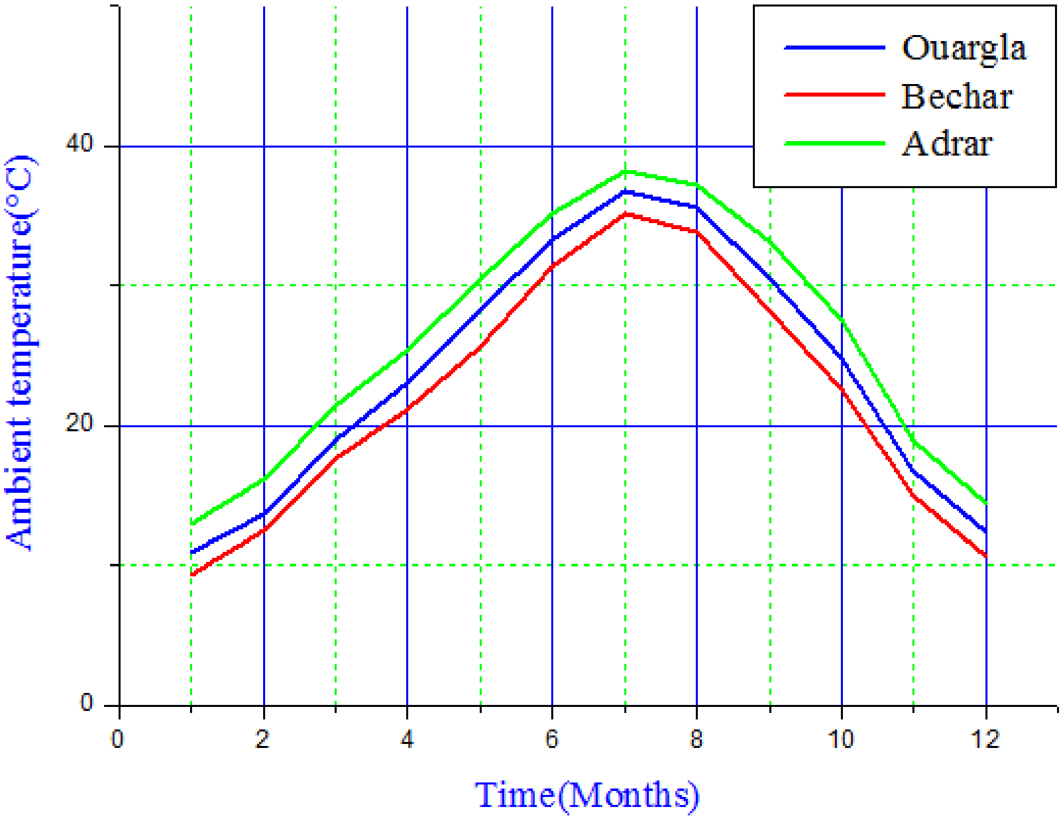

Figure 12 Climatic data (ambient temperature)

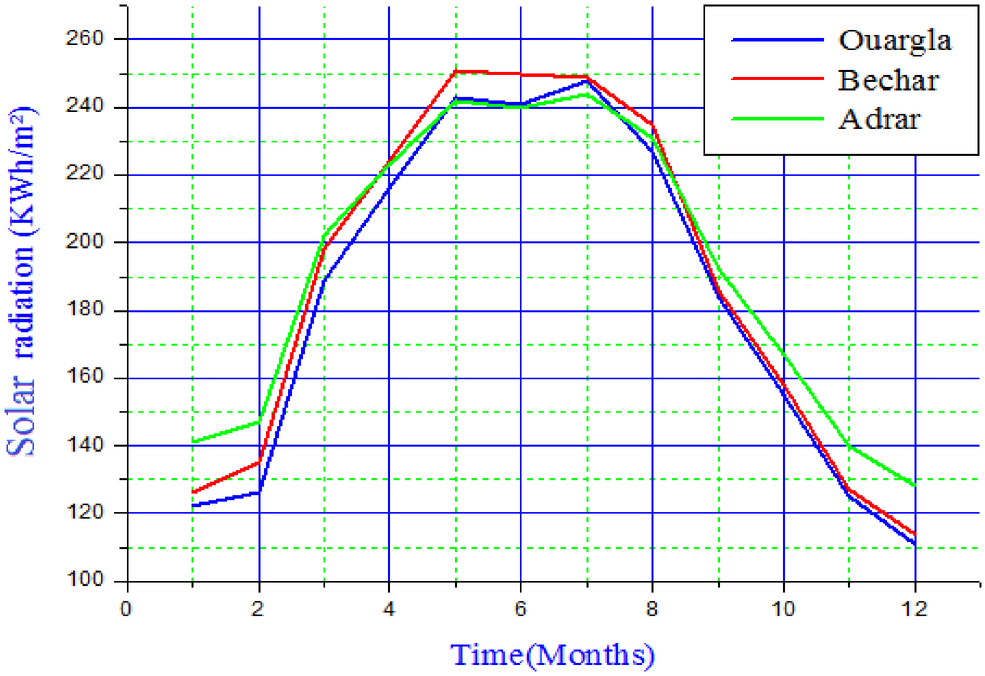

Figure 13. Climatic data (solar radiation)

2.2. Building description

The studied building is a single family residential building (F3) according to Algerian standards of construction. The schematic of the building is shown in Fig.14. Tab.2 shows the characteristics of building envelop.

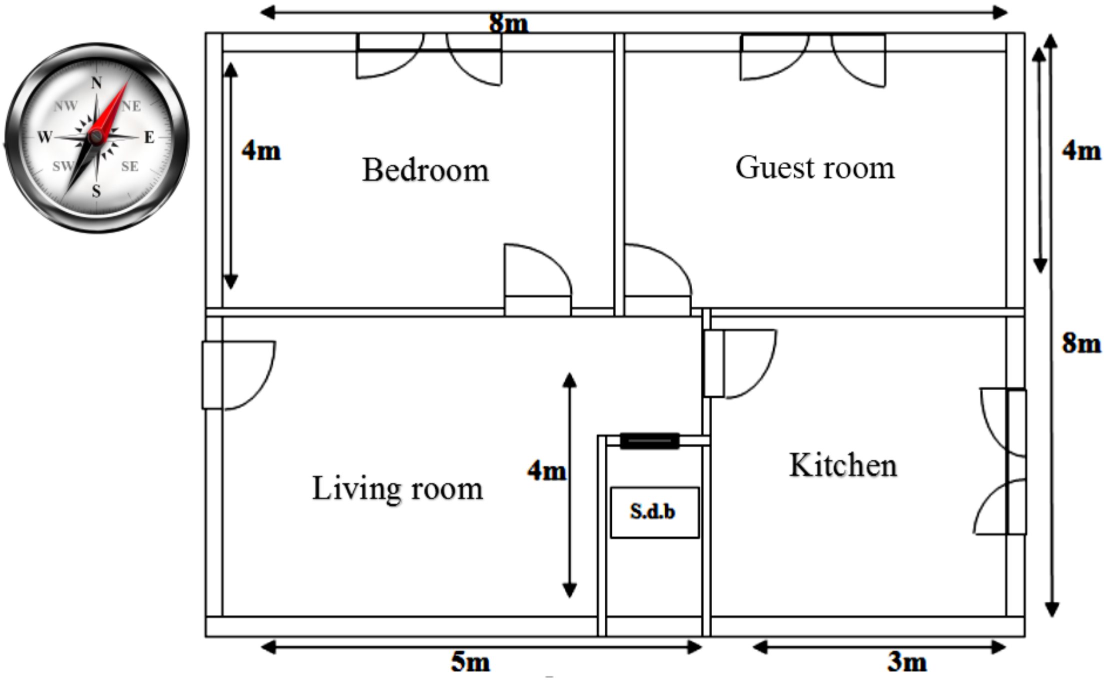

Figure 14 Schematic of the building

Table 3 Characteristics of building envelop

Wall type and layers	Thickness (m)	Conductivity (W/m K)	Specific heat (kj/h.kg K)	Density (kg/m^3)
From internal to external				
External and partition wall				
Cement-coating	0.01	1.15	1.0	1800
Brick	0.1	0.5	0.92	1100
Insulation	0.04	0.03	1.45	20
Brick	0.1	0.5	0.92	1100
Cement-coating	0.01	1.15	1.0	1800
Roof				
Cement-coating	0.01	1.15	1.0	1800
Ceiling block	0.16	1.14	0.65	1850
Concrete	0.04	1.75	0.92	2300
Insulation	0.02	0.03	1.45	20
Waterproofing coating	0.03	0.04	0.67	200
Floor				
Gerflex coating	0.003	0.31	1.046	1190
Concrete	0.1	1.75	0.92	2300
Insulation	0.04	0.03	1.45	20
Concrete	0.1	1.75	0.92	2300

2.3. Evaluation the load profile of lighting and appliances

The load used in the investigation of this chapter represents a typical house according to standard construction in Algeria. It has five major rooms (1 bedrooms, 1 guest room, and 1 living room), bathroom and kitchen. The list of equipment and parts used in the house and their relative power consumption per hour are shown in Table 2. The number of each part used per room in the house is described in Table 3. Note that it is assumed that all bedrooms have the same parts. The power consumption is calculated for every day in a week for each room based on the following process. The 24-hours of the day are divided into hourly intervals of operation, except the period in the night time between 11:00 PM to 6:00 AM it is defined as a single interval. Each part in the house contributing to the power consumption in every time interval is identified and its usage period is used in the hourly load calculation. The power consumption per hour is identified based on common usage of equipment and parts in the house. The power consumption calculations in each interval is performed over one day and have repeated for full year. Finally, in order to find the total yearly power consumption, the total average daily power consumption is multiplied by the number of days of the year. The load profile of appliances and lighting system is presented in Fig.15. In addition, the characteristics of Electric appliances and their placement in the building are given in Tab.3 and Tab.4.

Table 4 Characteristics of Electric appliances

Equipment/Part	**Power Consumed Per hour (W)**	**Brand**
Light bulbs	36	Fluorescent lamp
Air conditioner	1500	General company
TV	150	Benq
Refrigerator	350	Goldstar

Table 5 Placement of electric equipment in the building

Part	Bedroom	Living room	Guest room	Kitchen	Bathroom
Light bulbs	1	1	1	1	1
Mobile	1	0	2	0	0
TV	1	1	0	0	0
PC	0	1	0	0	0
Refrigerator	0	0	0	1	0

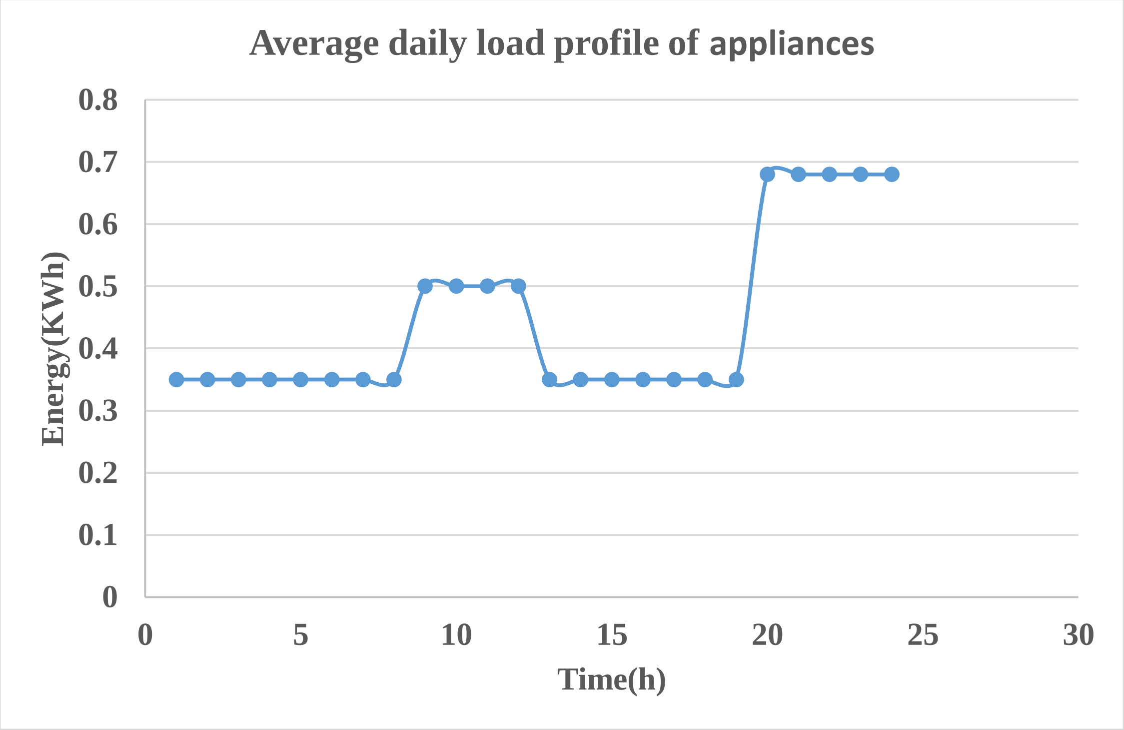

Figure 15 Load profile of lighting and appliances

2.4. Evaluation of energy demand for space cooling

TRNSYS software was used to evaluate the energy demand for space heating and cooling. The required inputs for doing simulation are building geometry and meteorological data (ambient temperature, solar radiation and wind speed). Fig.16 shows the TRNSYS model for the studied building.

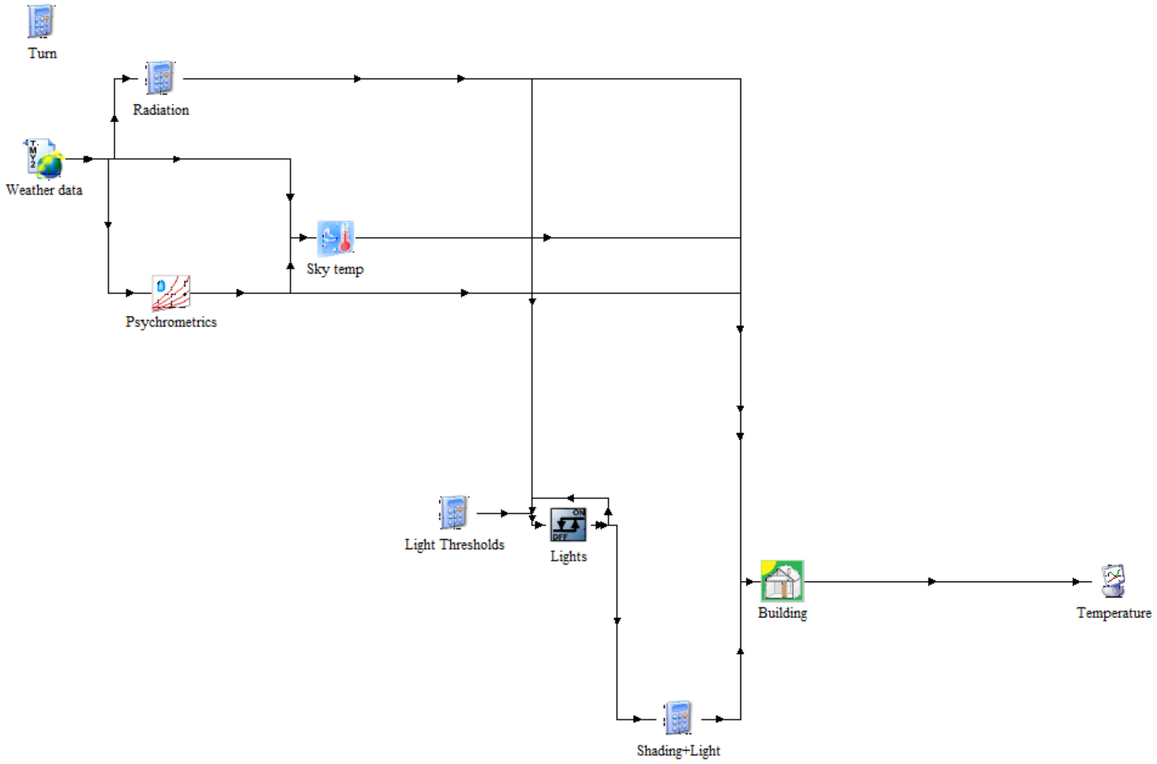

Figure 16 TRNSYS model of building simulation

2.5. Results of Off-grid HRES without controlling set point temperature

2.5.1. Ouargla region

The Result of the simulation of the Off-grid HRES without controlling set point temperature in Ouargla are illustrated in Fig.17. The figure shows the contribution of different sources of the HRES in supply of the demand.

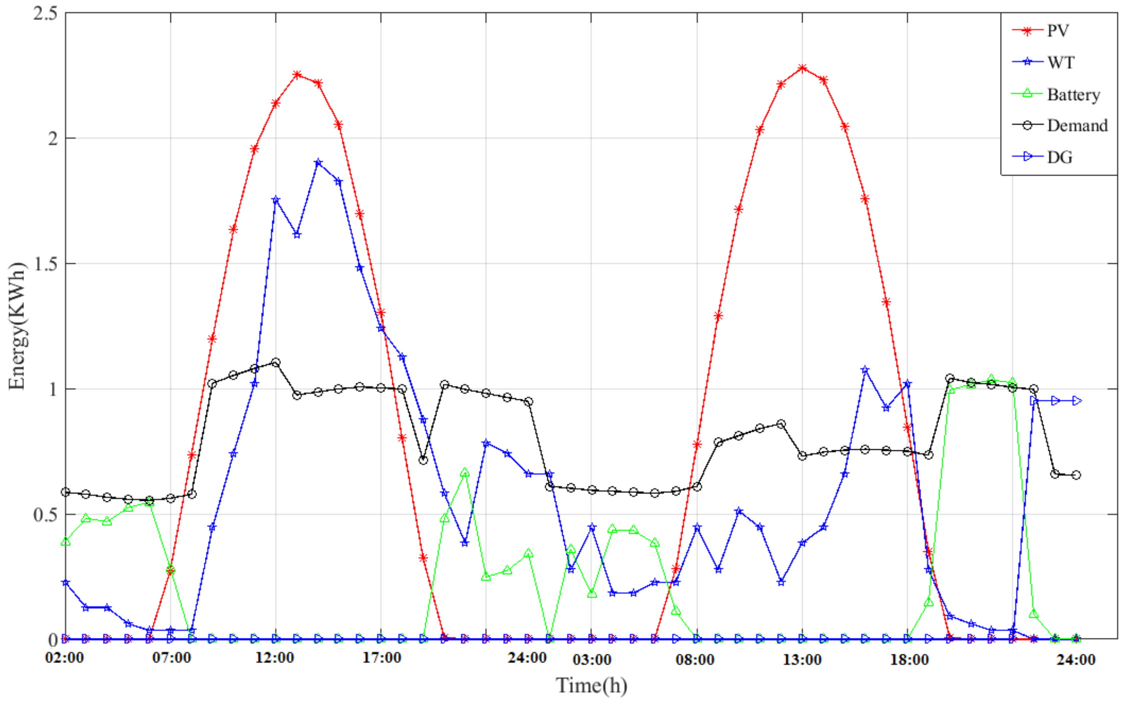

Figure 17 Result of Off-grid HRES (Ouargla) in 17 Avril

Discussion:

We observe that the system produces energy in daylight hours by PV. This is due to the priorities set within the system, so that priority is given to renewable energies (PV and WT). And we notice clearly that at night the battery is used and in case the battery is depletion the system use the diesel generator as alternative energy, this is explained by the management of the system.

2.5.2. Bechar

The Result of the simulation of the Off-grid HRES without controlling set point temperature in Bechar are given in Fig.18. The figure shows the contribution of different sources of the HRES in supply of the demand.

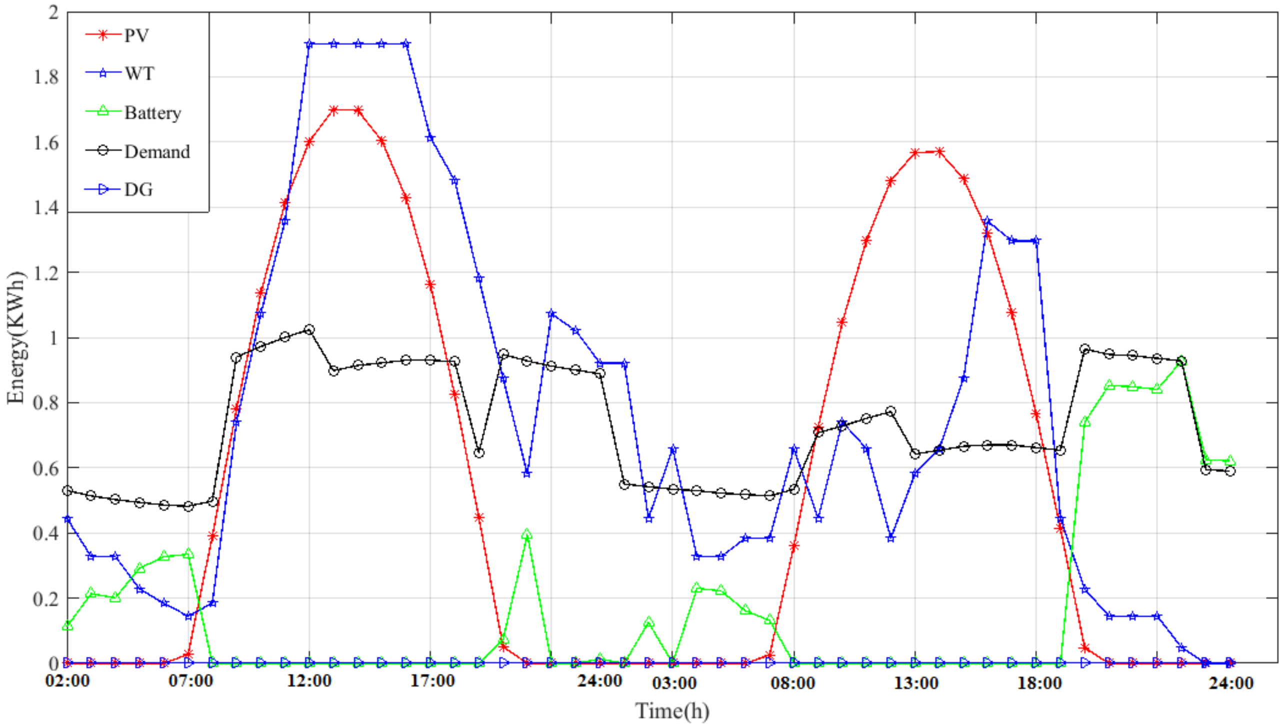

Figure 18 Result of Off-grid HRES (Bechar) in 17 Avril

Discussion:

The figure shows that in the morning (06:00 → 20:00), the energy demand is supplied by the PV. However, WT contributes in energy supply at all period of time which lead to less contribution of batteries (20:00 → 08:00). We notice clearly the contribution of wind turbines to energy production due to climatic conditions in this region

2.5.3. Adrar

The Result of the simulation of the Off-grid HRES without controlling set point temperature in Adrar are given in Fig.19. The figure shows the contribution of different sources of the HRES in supply of the demand.

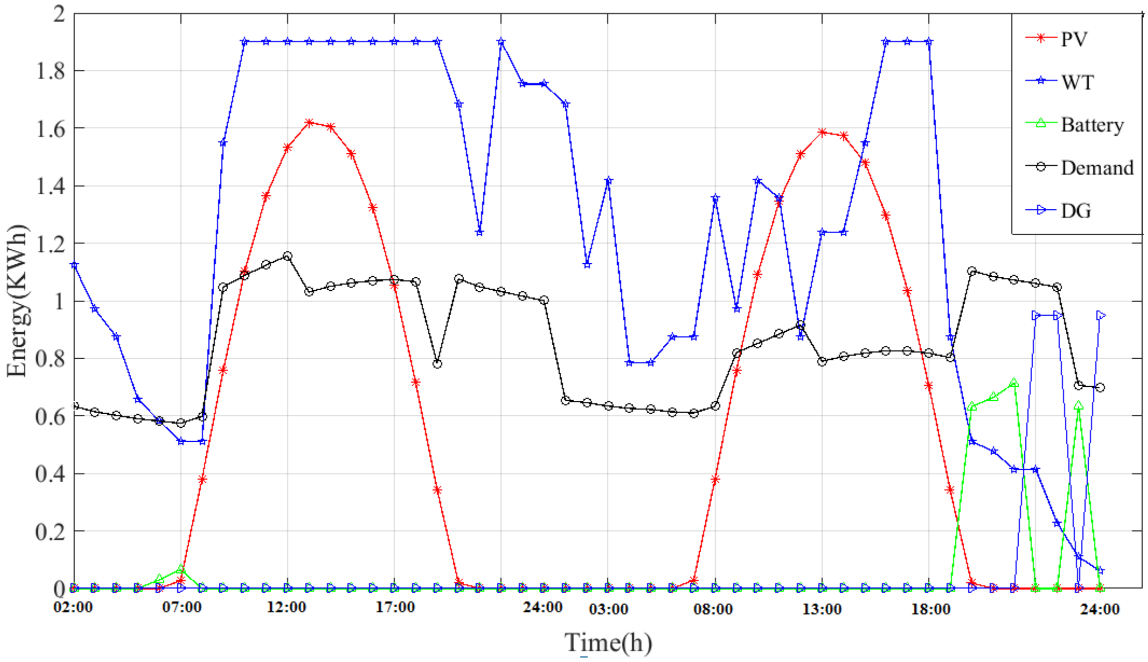

Figure 19 Result of Off-grid HRES (Adrar) in 17 Avril

Discussion:

The figure shows the high contribution of WT in Adrar. Furthermore, solar PV system also have an important contribution especially in the morning (06:00 → 20:00). However, batteries have a small contribution due to high potential of renewable energies at all time. In other hand, DG has the smallest share on energy supply.

2.5.4. Comparison of results

The comparison of results of off-grid HRES sizing between the investigated locations are presented in the Tab.5.

Table 6 Comparison of sizing of HRES for Off-grid applications without controlling set point temperature

Station	Ouargla	Bechar	Adrar
Number of iterations	35	35	35
Capacity of PV system (kW)	3	2	2
Capacity of Battery (KWh)	4	5	2
Number of wind turbines	1	1	1
Power of diesel generator (kW)	1	1	1
LPSP (%)	4.28	4.18	4.34
COE ($/kWh)	0.172	0.172	0.131
Renewable fraction (%)	83.86	80.66	81.34

Discussion:

It is clear from the comparison of results between the studied locations that Adrar has the smallest cost of energy with 81% of renewable fraction. The reason is the high potential of solar and wind energy in Adrar. Besides that, the results for Ouargla and Bechar are so closest due mainly to the same climate conditions.

2.6. Results of Off-grid HRES with controlling set point temperature

In this application, the impact of controlling set point temperature is investigated. In this application, the desired temperature is 25°C, if the energy produced by the renewable energy resources is not sufficient to meet the required demand at this temperature, the controller will set the desired temperature to 29°C to reduce the energy demand for space cooling.

The results of sizing of the Off-grid HRES with controlling set point temperature and their comparison with the previous results are given in Tab.6.

Table 7 .The results of Off-grid HRES with controlling set point temperature

Station	Ouargla		Bechar		Adrar	
Study	Control of set point temperature		Control of se point temperature		Control of set point temperature	
Case	No	Yes	No	Yes	No	Yes
Number of iterations	35	35	35	35	35	35
Power of PV panels (kW)	3	3	2	3	2	2
Capacity of the battery(KW)	4	3	5	6	2	1
Number of wind turbines	1	1	1	0	1	1
Power of diesel generator (kW)	1	1	1	1	1	1
LPSP (%)	4.28	4.68	4.18	3.73	4.34	4.24
COE ($/kWh)	0.172	0.174	0.172	0.147	0.1317	0.1306
Renewable fraction (%)	83.86	83.52	80.66	84	81.34	81.45

Discussion:

The results show that the management of set point temperature has an important effect on the sizing and contributions of the HRES’ components. For example, in Bechar the cost of energy is extensively reduced compared to other locations. This reduction is due to exclusive of the wind turbine from the HRES. Although, the renewable fraction in Bechar is raised to 84%.this is due to increasing the power of PV. The effect of controlling set point temperature on the contribution of the different components of the HRES are presented in Fig.20, Fig.21, Fig.22, Fig.23, Fig.24.

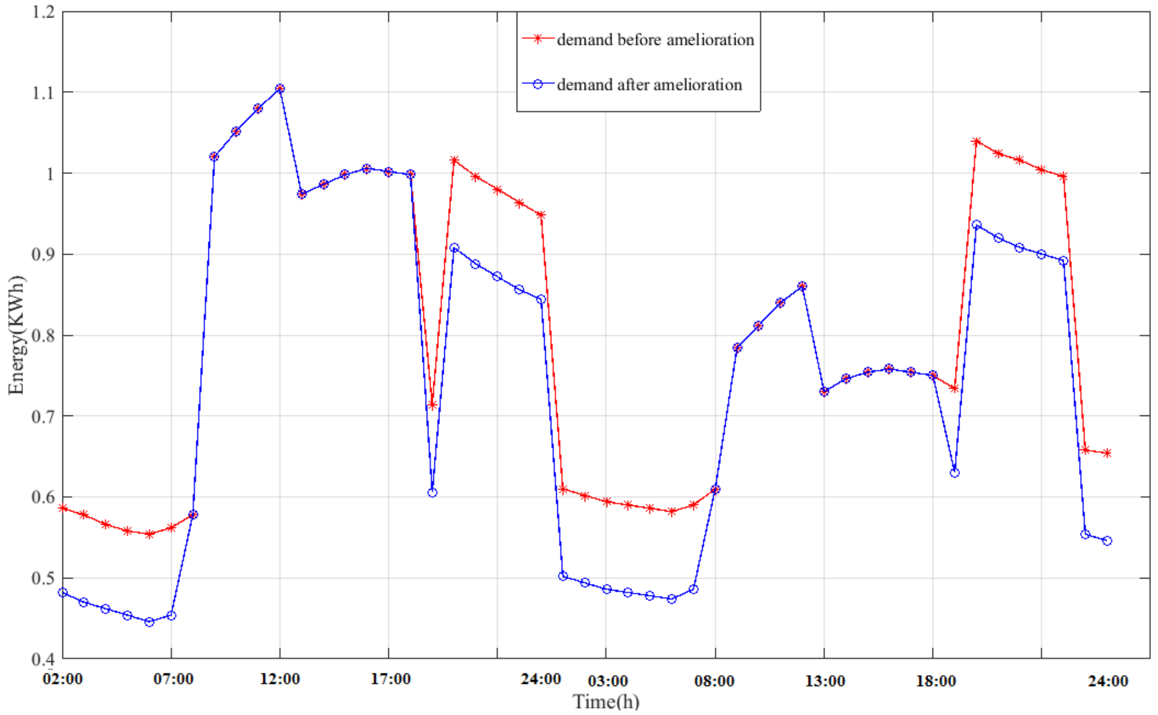

Figure 20 Effect of controlling set point temperature on energy demand (Ouargla)

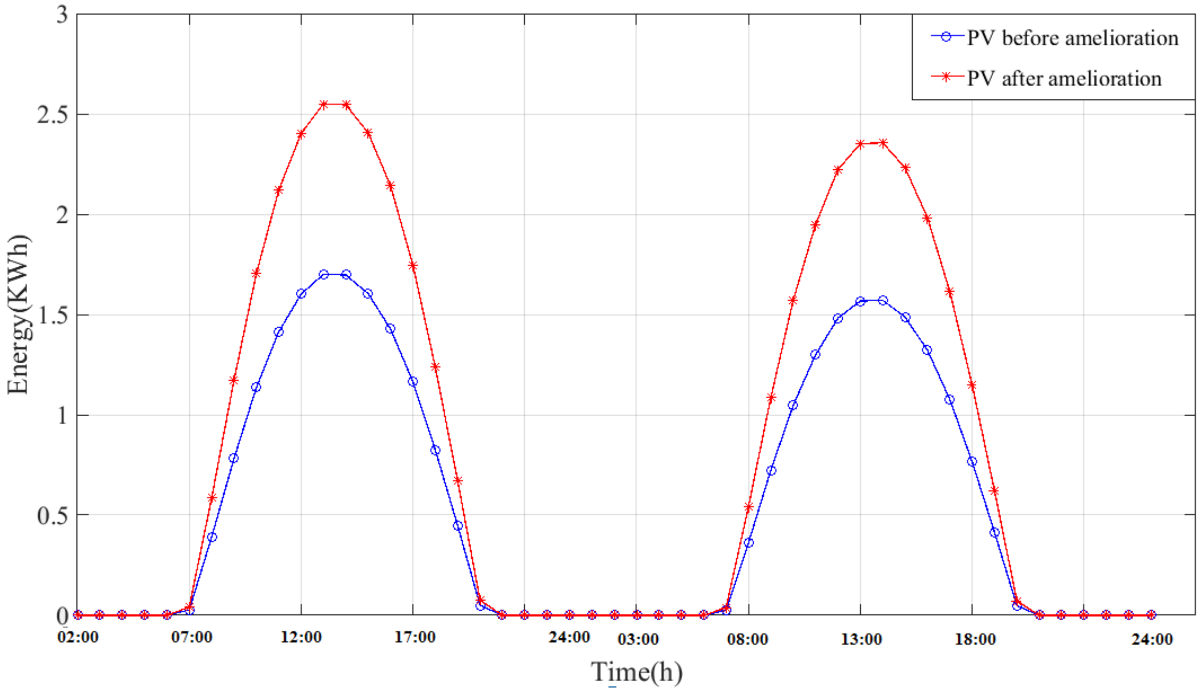

Figure 21 Effect of controlling set point temperature on PV system contribution (Bechar)

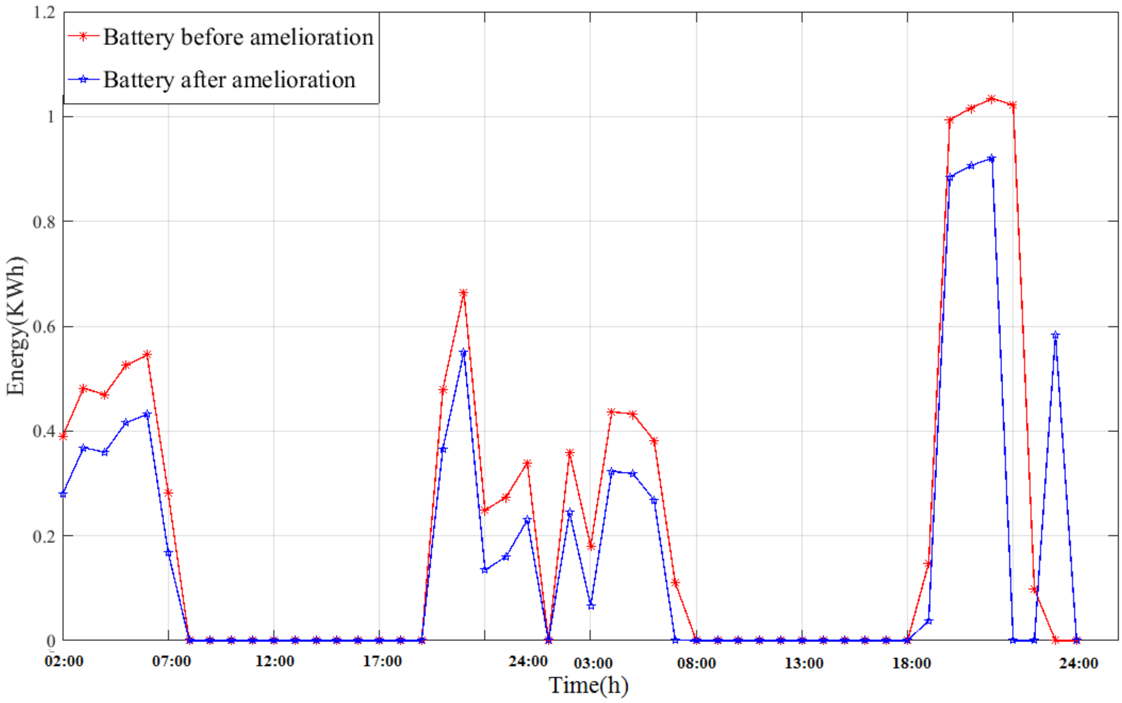

Figure 22 Effect of controlling set point temperature on battery contribution (Bechar)

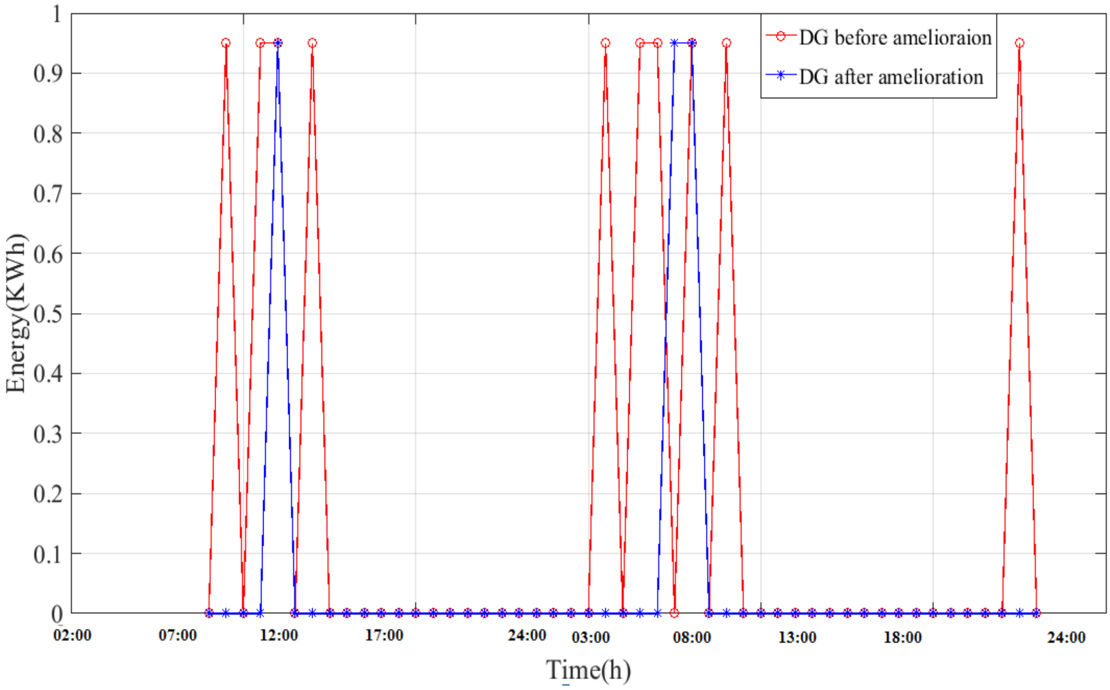

Figure 23 Effect of controlling set point temperature on DG contribution (Bechar)

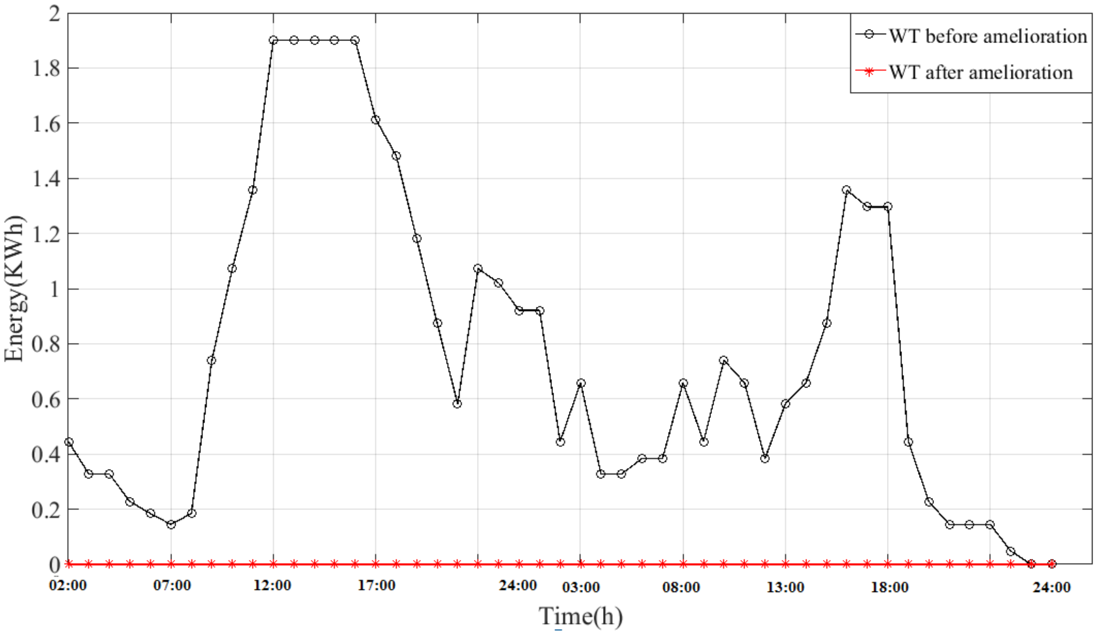

Figure 24 Effect of controlling set point temperature on WT contribution (Bechar)

Discussion

From the figures, the effect of controlling set point temperature on the contribution of PV, WT, DG, and batteries is more important especially for WT that is excluded from the HRES configuration. Although, it has been a slight change on the load profile after applying the control of the set point temperature, the change in the size and the contribution of the HRES components is more important.

3. Case study 2: Optimal sizing and management of grid-connected HRES

In this application, the developed method is applied to optimal sizing and management of a grid-connected HRES to electricity supply of the faculty of applied sciences of Ouargla University.

3.1. Building description

The faculty of applied sciences (FAS) is belong to pole three of Ouargla University. This faculty has a roof area of about 5000 m². Therefore, the faculty has a big potential to installing PV panels on the roof. The photos of the faculty FAS is illustrated in Fig.25.

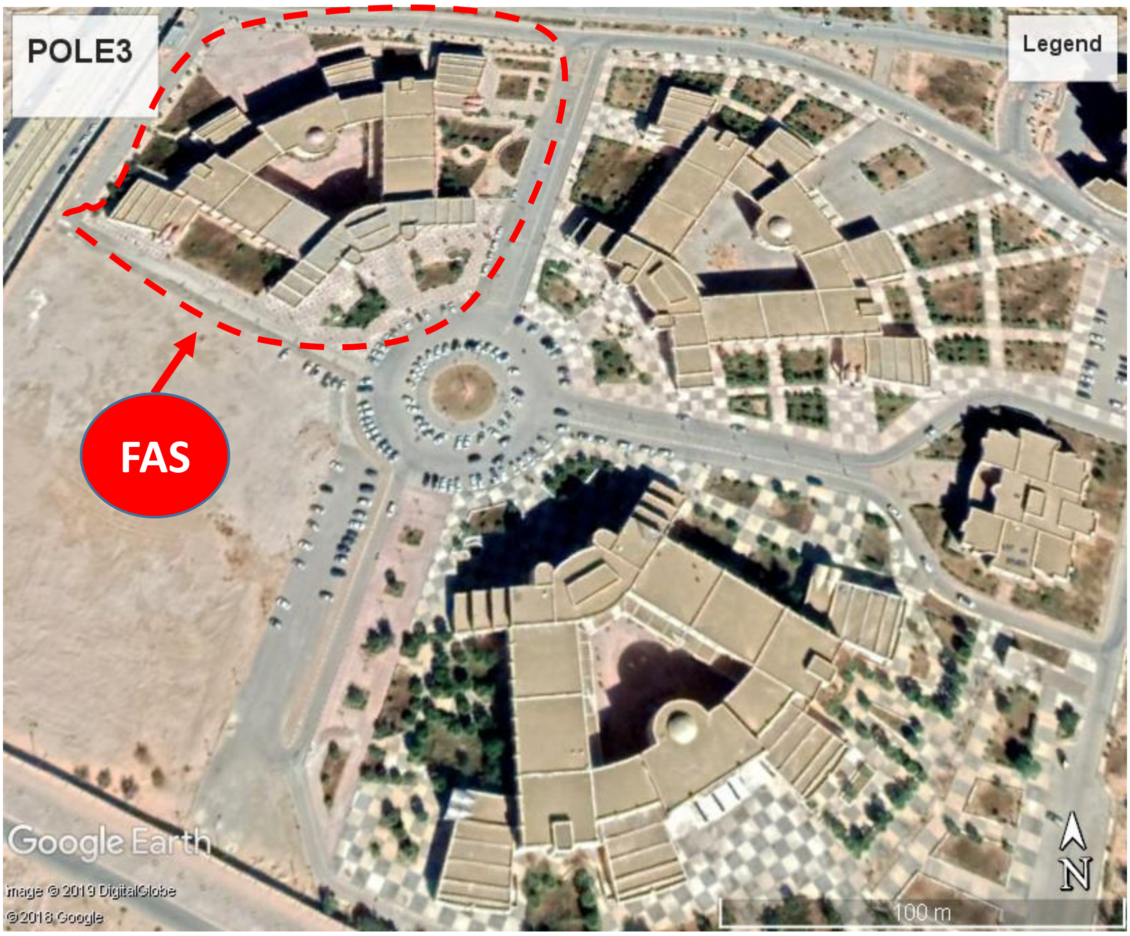

Figure 25 Faculty of applied sciences

3.2. Load profile

The load profile of the faculty FAS is obtained from SONELGAS Company. The annual energy demand of the faculty is about 495783 KWh per year (2016). Fig.26 shows the load profile of the faculty FAS.

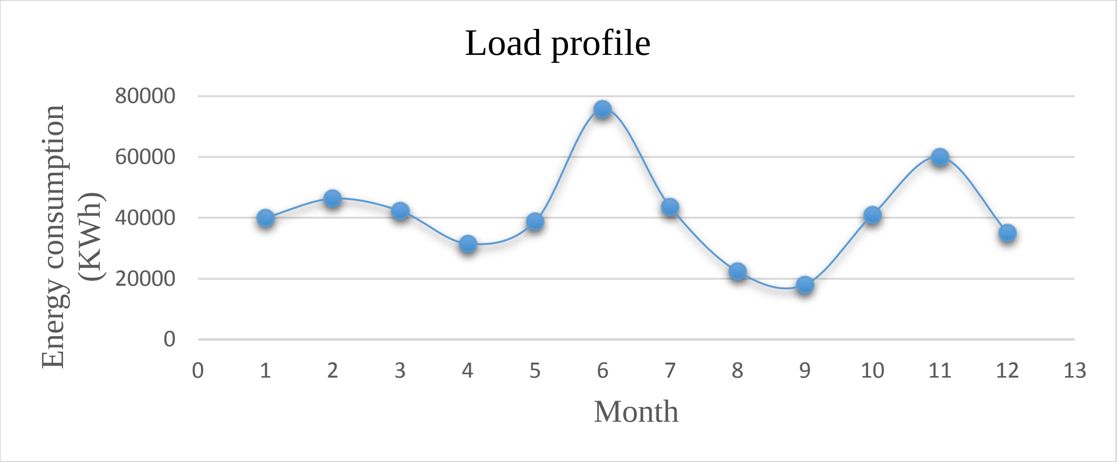

Figure 26 Load profile of the faculty of applied sciences

3.3. Results and discussion

The contributions of the different components of the Grid-connected HRES are presented in Fig.27. However, the sizing and objective function results of the grid-connected HRES are summarized in Tab.7.

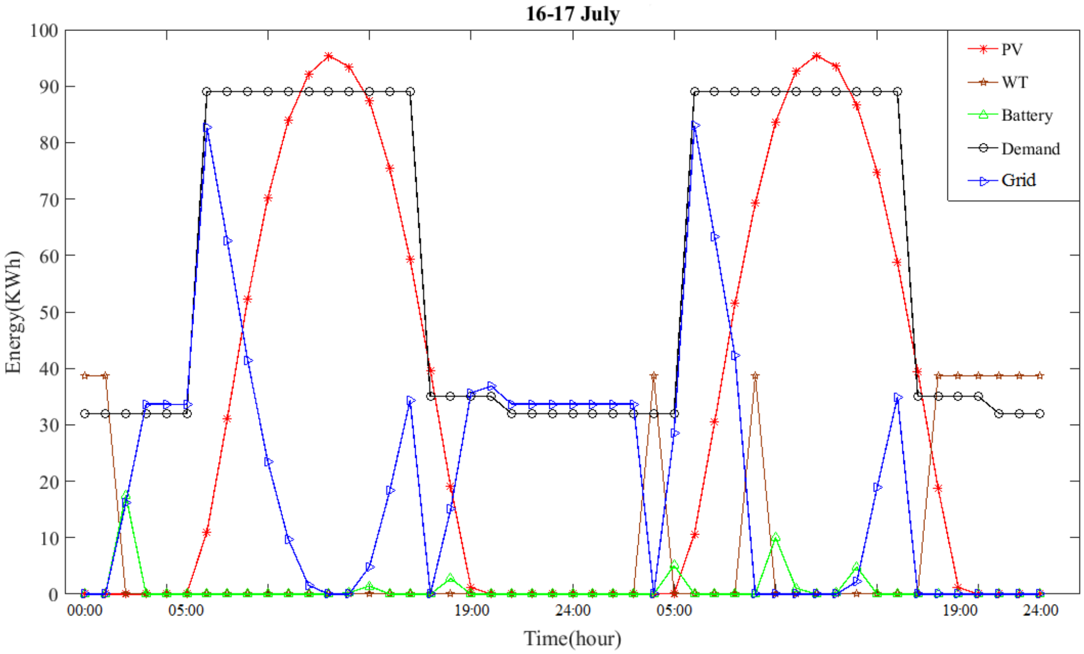

Figure 27 Results of simulation of Grid-connected HRES

Table 8 The results of grid-connected HRES sizing

Place of study	Faculty of Applied Sciences, Pole3 at Kasdi Merbah University Ouargla	
Case	Power grid only	Grid-Connected HRES
Number of iterations	50	50
Number of Population	40	40
Power of PV panels (kW)	0	126
Capacity of the battery(KW)	0	15
Number of wind turbines	0	8
LPSP (%)	0	0.9
Renewable contribution (%)	0	40
Cost of energy ($/KWh)	0.23	0.114
CO_2 emission (Kg/year)	297470	138053
Quantity of natural gas consumed(m^3)	14873490	6902640
Percentage of CO_2 reduction (%)	54	
Natural Gas saving (m^3)	7970850	

Discussion

The results show that the proposed grid-connected HRES is a viable solution to the case study. The main benefits of the HRES compared to using only the utility grid are reducing the consumption of fossil fuels, as well as reducing CO_2 emissions. In addition, the proposed grid-connected HRES allows the use of more renewable energy with high reliability.

4. Conclusion

In this section, the optimal sizing and management of the hybrid renewable energy system for both Off-grid and On-grid application is investigated. A MATLAB code is developed to achieve the goal, where the main objectives are minimizing the cost of energy, increase the system reliability, and increase the contribution of renewable energy. In the first case study (Off-grid), the results show that PV system is the main source for all the studied locations. However, Bechar presents best results compared to Adrar and Ouargla. Furthermore, the effect of controlling set point temperature of the cooling system is more important in Bechar than the other locations. Generally, HRES is found a feasible solution to supply remote areas in the studied locations. These results emphasized the selection of the studied locations, which have a big potential to deploy such energy solution. In other hand, grid-connected hybrid renewable energy systems are more cost effective in particular in universities buildings where the size of storage system is not large. For both applications, HRES able to reduce energy costs and GHG emissions in the building sector. Therefore, it will help to transit toward green and sustainable buildings in Algeria

Conclusion and future work

Conclusion

The main objective of this thesis was to develop an optimal method based on multi agent system approach to optimal sizing and management of hybrid renewable energy system in green buildings. The proposed method is applied to different locations of Algeria, Adrar, Ouargla and Bechar. In addition, the method is applied to both on grid and off-grid areas. The key results obtained after simulation are summarized as follows:

- The results show that the installation of HRES in the studied locations (Adrar, Ouargla and Bechar) is more cost effective and can reduce GHG emissions extensively in particular in isolated areas of the country. These results have emphasized the outcomes of the research work that we have based on in this thesis.
- HRES can support and deliver energy to isolated areas with lowest cost and high reliability
- Controlling set point temperature has in important impact on energy consumption so that on the sizing of HRES.
- The size of the HRES depend extensively on climatic conditions and the load profile of the building.

For the future work, we recommend to applying the proposed method to different type of buildings and for community level despite to single buildings. Further, we recommend using real time data in the simulation.

Appendices

Annex 1. The optimal locations for setting up plus energy buildings in Algeria

Abstract

In recent years, net zero or plus-energy buildings (PEB) have been widely analyzed and discussed for their benefits of increasing energy savings and reducing greenhouse gas emissions. A successful transition to energy-efficient buildings must, however, develop an efficient method that examines technical, economic, environmental and social criteria. In this paper, a method for design optimization based on spatial analysis combined with multi-criteria decision-making was proposed for achieving plus-energy buildings in Algeria. To apply the proposed method, a single family residential building was chosen. First, the annual energy consumption of the building at 40 locations was evaluated and the results are then interpolated for the whole country. The best energy efficiency measures and renewable energy are then chosen using the Analytic Hierarchy Process (AHP) method. Finally, energy balance and spatial analysis were carried out based on the geographical information system. The results showed the energy plus target was achieved in large parts of the country using a high-performance envelope, more efficient appliances and solar energy (solar photovoltaic and thermal). In addition, the southern provinces, mainly Adrar, Tindouf, Bechar, Ouargla, and Illizi, have identified the most suitable areas for setting up new buildings with an energy-plus target. In addition, applying the method will reduce the overall energy demand by 43 % and reduce GHG emissions in the country by around 23 % by 2030. Therefore, the method will have a significant impact on sustainability locally and worldwide.

1. Introduction

The energy demand in buildings has increased rapidly in recent years and exceeded 40% of global consumption. Furthermore, buildings account for one-third of GHG emissions [1]. Residential buildings in Algeria consume about 38 % of the total [2]. Since 97 % of energy consumption based on fossil fuels [3], Algeria is one of the main emitters of CO_2 in Africa. The integration of renewable energy sources and the improvement of energy efficiency are therefore crucial. In this regard, Algeria and many countries are looking for serious solutions to these energy and environmental issues. For instance, European institutions have developed strategies for reducing annual primary energy consumption by 27 % by 2030[4] and reducing GHG emissions by 80 % by 2050 [5]. In the same way, Algeria has decided to diversify its energy mix by announcing a 40 % share of renewable energy by 2030 [6]. Thus, the transition to zero or plus-energy buildings (PEB) must be reached. Because PEB is highly efficient buildings, produces energy from renewable sources and transfers more energy to the grid than they import from it in the year [7]. PEB has recently received growing interest from researchers. As a result, many design strategies have been identified to achieve PEBs, including envelope insulation, HVAC system renovation and smart and high-efficiency lighting and appliances…ect. [8][9][10]. On the other hand, the introduction of renewable energy, namely solar photovoltaic/thermal (PV / T), wind and geothermal [11]. The main challenge, however, is to find the best combination of design strategies to achieve PEB in a specific case study subject to different conflict criteria.

2. Methods

2.1. Data collection and Building description

Algeria is Africa's largest country with an area of 2,381,741 km² [24]. In 2018, the population has exceeded 42.2 million. First, climate data for 40 Algeria' stations were imported, then, the interpolation of the entire area was made. The distribution of climatic stations, annual average temperature, annual average wind speed, and global radiation of Algeria were presented in Fig.1.

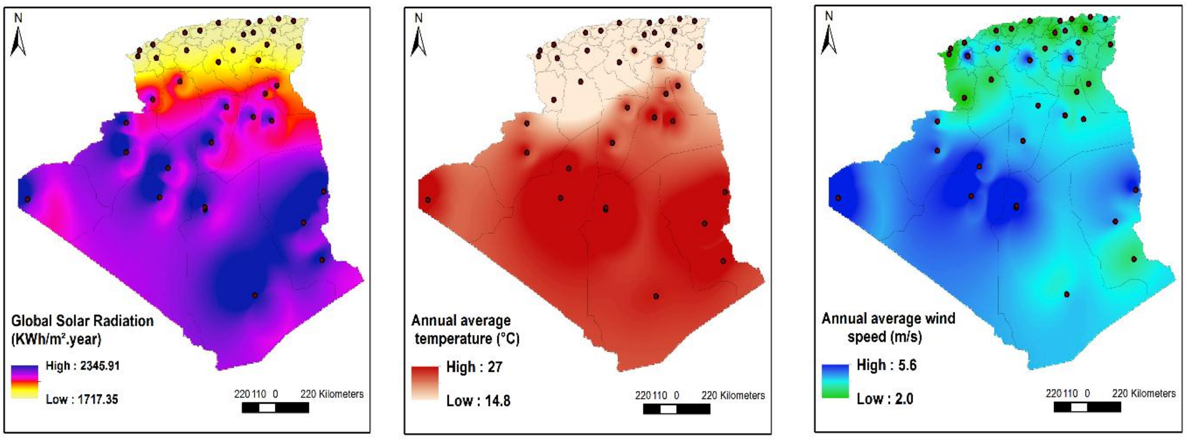

Fig. 1. (a) Annual Global radiation; (b) Annual Average temperature; (c) Annual Average wind speed.

The number of population and households in Algeria for each Algerian province (48 provinces) between 2018 and 2030 has been assumed, based on ONS statistics [25] and UN reports [26]. A typical residential building according to Algerian standards of construction was selected to apply. The plan of the building and the number of household projections until 2030 are shown in Fig.2. In addition, the main features of the building envelope are given by Table.1.

Table 1. Envelop characteristics before and after renovation

Wall type	Before Renovation (from inside)	U (W/m²°k)	After Renovation (from inside)	U (W/m²°k)
Wall	Cement, Brick, air layer, Brick, Cement	1,827	Cement, Brick, Insulation, Brick, Cement	0,48
Roof	Cement, Ceiling bloc, concrete, Bitumen	3,863	Cement, Ceiling bloc, concrete, Insulation, Bitumen	0,519
Floor	Gerflex coating, concrete, Insulation, concrete	0,686	Gerflex coating, concrete, Insulation, concrete	0,686

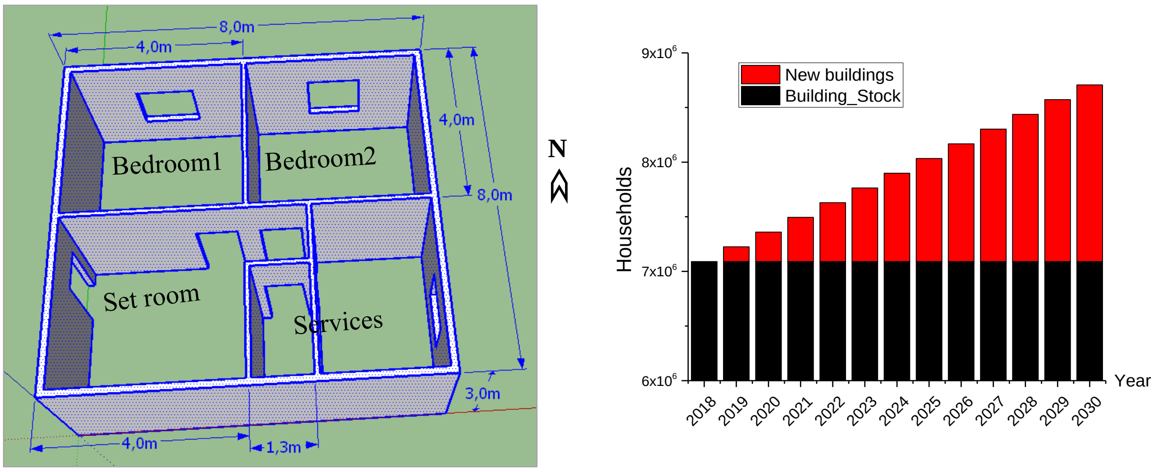

Fig. 2. (a) Plan of the building; (b) Algerian Households projection.

2.2. Energy demand for space cooling and heating, cooking, and appliances

TRNSYS software was used to evaluate the annual energy demand for space heating and cooling. The temperature set for cooling and heating is 27 ° C and 21 ° C respectively [27]. Accordingly, annual electricity and NG consumption have been calculated based on the gas boiler efficiency (0.93) and the chiller COP (2.5) [28]. The energy demand for cooking in a single-family home in Algeria is 7925 kWh / year and for lighting and appliances is 2400 kWh / year [28]. However, if efficient lighting and appliances are used, it will be 1788 KWh / yr.

2.3. Solar PV

Recently, PV modules prices have fallen by 80 %, and are expected to continue to fall in the future [29]. Since residents often have plenty of roof area [30], a solar rooftop PV system was proposed. The energy produced by a PV panel can be calculated using the eq.1 [31]. The simulation was carried out using MATLAB software.

$$P_{pv} = Y_{pv} . f_{pv} \left(\frac{G_T}{G_{T,STC}} \right) \left[1 + \alpha_p \left(T_c - T_{c,STC} \right) \right] \tag{1}$$

Two PV panels were used. The first is a standard PV panel of 15.5 %. The second is a 22 % high-efficiency PV panel, which is expected to be on the local market by 2030. The investment cost of both PV panels is $ 1382/kW. The O&M costs are $ 88 per year [32]. The PV panel's lifetime is also fixed for 25 years. The derating factor for PV was 88 %. The area of the standard PV panel and the high- efficiency PV panels are 1.94 and 1.63 m² respectively. In this study, the distance between rows to avoid inter-row shading was considered.

2.4. Solar Thermal

In this work, a solar thermal system (Solar T) were used for producing heat for space heating and domestic hot water. A DHW solar heating system and a buffer space heating system (Type A.5) were chosen and simulated using TSOL software. A flat plate collector with an efficiency of 77.6 % and a surface area of 1 m2 was selected.

2.5. Wind Turbine

The electricity generated by the wind turbine (WT) was calculated using a simple model of eq.2.

$$P_{wt} = \frac{1}{2} . \rho . C_{over} . A . V^3 \tag{2}$$

C_over is the overall wind turbine power coefficient. Its value is about 0.30 [33]. Here, Sky Stream 3.7 small scale WT was used. This model's rated capacity and swept area are 2 KW and 10.87 m² respectively. The investment cost of the WT is 2600 $/kW. The O&M cost is $ 160 per year [31]. The WT’s lifetime is 25 years.

2.6. Geothermal energy

In this paper, an Earth to air heat-exchanger (EAHE) has proposed. Based on literature review, EAHE was used for cooling in this work. EAHE is more useful in hot climates such as Adrar than in cold climates or in Mediterranean climates such as Oran [27], [34]. Hence, the efficiency of AEHE was interpolated elsewhere in the country.

2.7. Economic and GHG emission calculation

Cost of energy (COE) measures lifetime costs divided by energy production. This factor allows the comparison of different energy sources. COE was calculated based on the formula of eq.3 [35].

$$COE = \frac{Cost_{lifetime}}{Energy_{produced}} \tag{3}$$

The real discount rate is set at 6%. The lifetime of the project is 25 years. In addition, in Algeria, the unit cost of electricity is \$0.247 per kWh. However, the unit cost of natural gas is \$0.085/KWh [28]. Besides, the CO_2 emission is evaluated. Where, Natural Gas boiler produces 0.22 kg / kWh, but the unit of electricity produces 0.5 kg / kWh.

2.8. Geographic information system and multi-criteria decision-making

Energy planning requires considering of various criteria, which lead to doing a MCDM study to attain the objective. AHP was therefore used, which is widely used in decision-making [36]. In addition, a MCDM which associated with spatial entities requires another method such as the GIS, which is increasingly popular in the selection of sites and energy planning processes [29]. Thus, ArcGIS 10.2.2 software was used in site selection and spatial analysis.

3. Results and discussions

3.1. Results of multi-criteria decision-making

The evaluated criteria and the results of MCDM analysis for selecting the best solutions are shown in Fig.3. Fig.4.

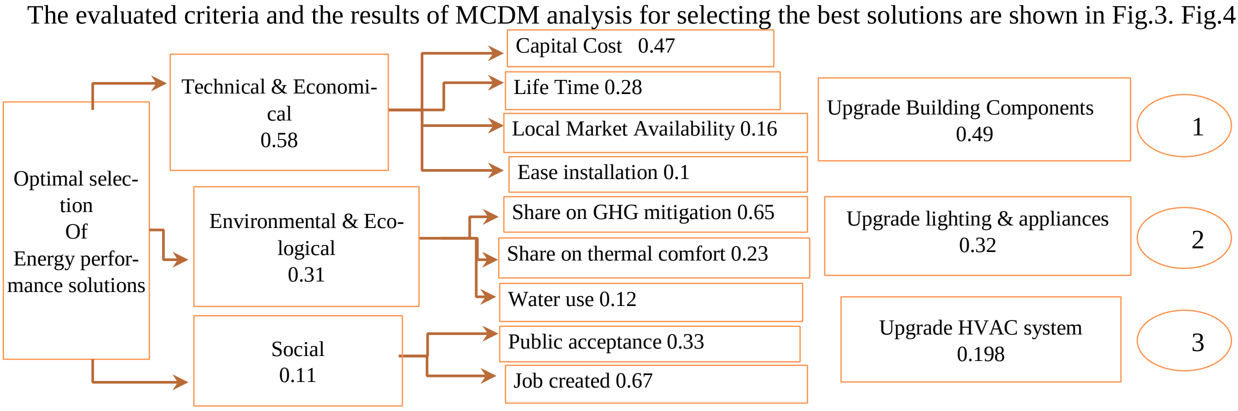

Fig. 3. Results of MCDM method for selecting Energy efficiency measures

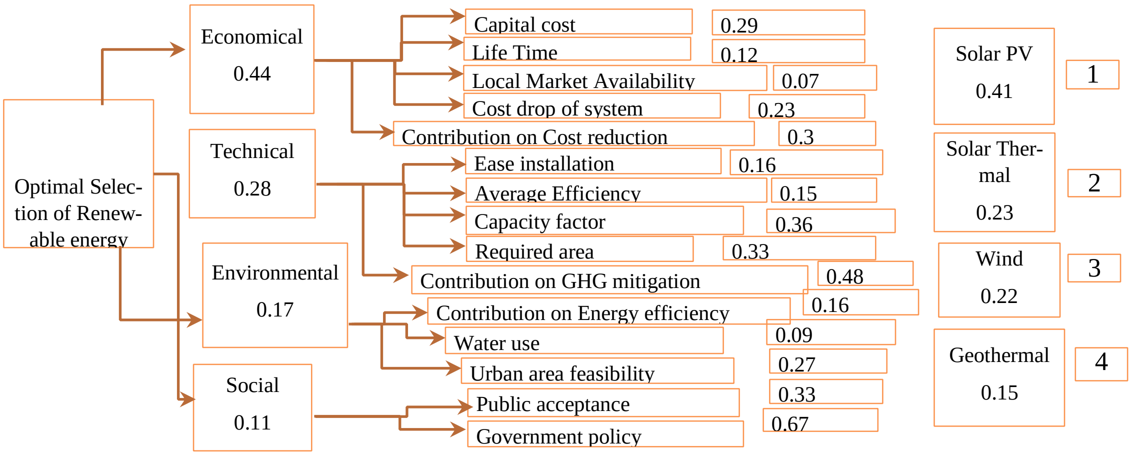

Fig. 4. Results of MCDM method for select best Renewable energies

Based on MCDM results, adding insulation to the roof and walls have proposed. Lighting and appliances were also upgraded. Fig.5 showed the annual demand of the building before and after renovation. Further, the plus energy balance is carried out between energy produced from renewable sources and the building' demand. Many scenarios have been proposed based on current and future assumptions. The results of PEB balance are shown in Fig.6.

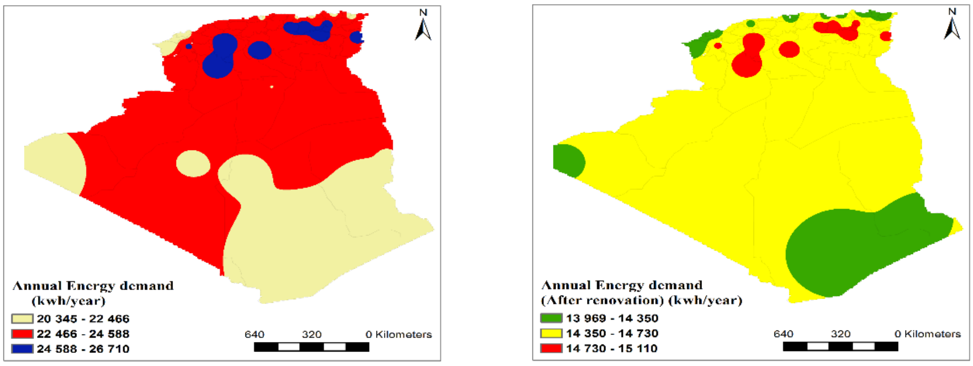

Fig. 5. (a) Global demand (before renovation); (b) Global demand (after renovation).

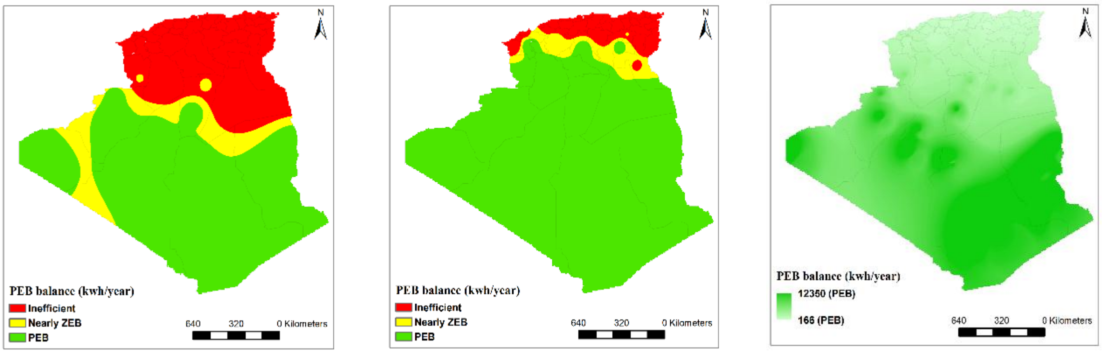

Fig. 6. Plus-energy balance; (a) using Solar T./Standard PV; (b) using Solar T./Standard PV/WT; (c) using Solar T./High efficient PV

The maps showed that after renovation, the annual demand has decreased dramatically. Because the improvement of the envelope declines the need for heating and cooling, which accounts the half of the total demand. Furthermore, after integrating renewable sources, the plus-energy target was achieved in all the Sahara of the country for all scenarios. However, by 2030, PEB can be achieved for the overall country using high efficient PV panels.

3.2. Suitable locations for plus energy buildings

The raster calculation tool, included in the ArcGIS toolbox, was used to identify the best places to set up PEB. Fig.7, Fig.8 and Fig.9 showed the maps of evaluated criteria. The weights of the criteria assumed by the AHP method are shown in Table.2. After doing calculations, the results are shown in Fig.10.

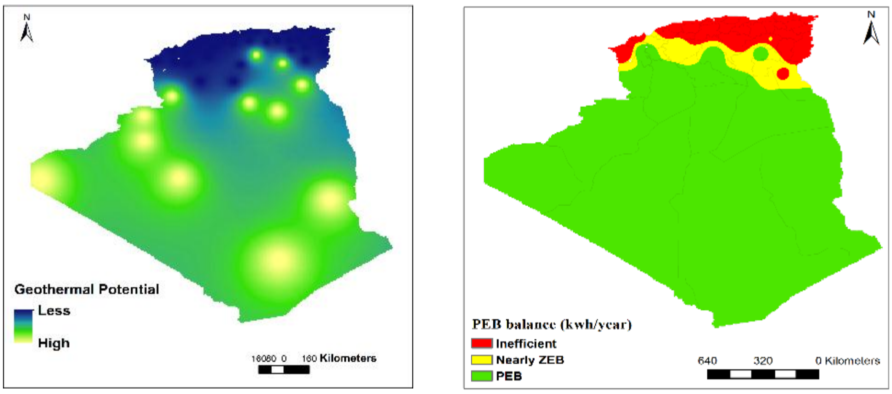

Fig. 7. Technical Criteria: (b) Geothermal energy potential; (a) plus-energy balance.

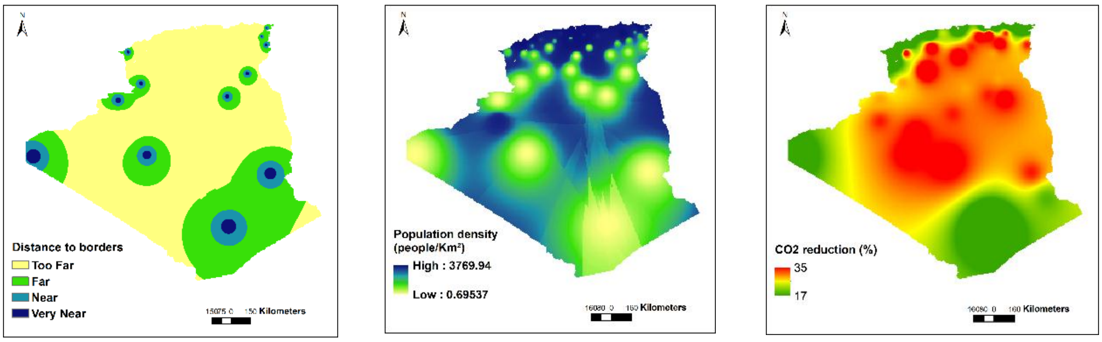

Fig. 8. Social Criteria: (a) Distance from borders; (b) Population density; (c) Environmental Criteria (CO_2 reduction).

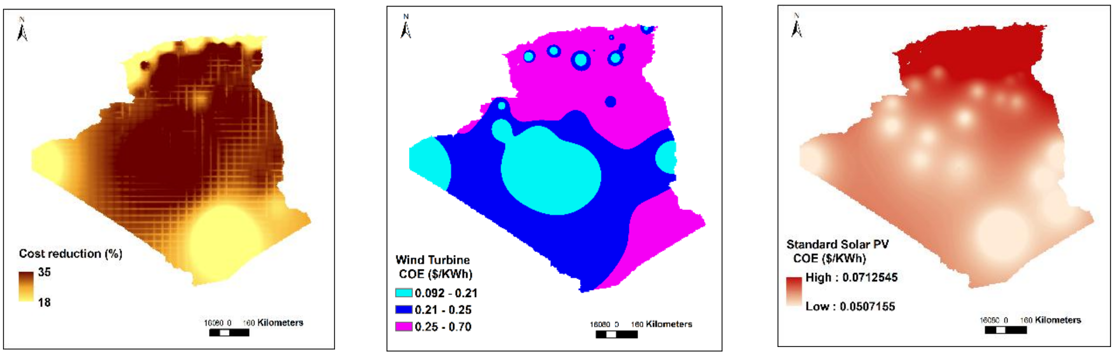

Fig. 9. Economic Criteria: (a) Overall Cost reduction; (a) COE of WT; (b) COE of PV

Table 2. Criteria and sub-criteria weights for raster calculation.

Criteria (Weights (W1))	Sub-criteria	Sub-criteria weight (W2)	Sum-weights (W1*W2)
Technical (0.4)	PEB Balance	0.8	0.32
	Geothermal potential	0.2	0.08
Economic (0.2)	COE of PV	0.3	0.06
	COE of WT	0.2	0.04
	Cost reduction	0.5	0.1
Environmental (0.2)	CO_2 reduction	1	0.2
Social (0.2)	Distance from borders	0.5	0.1
	Population density	0.5	0.1

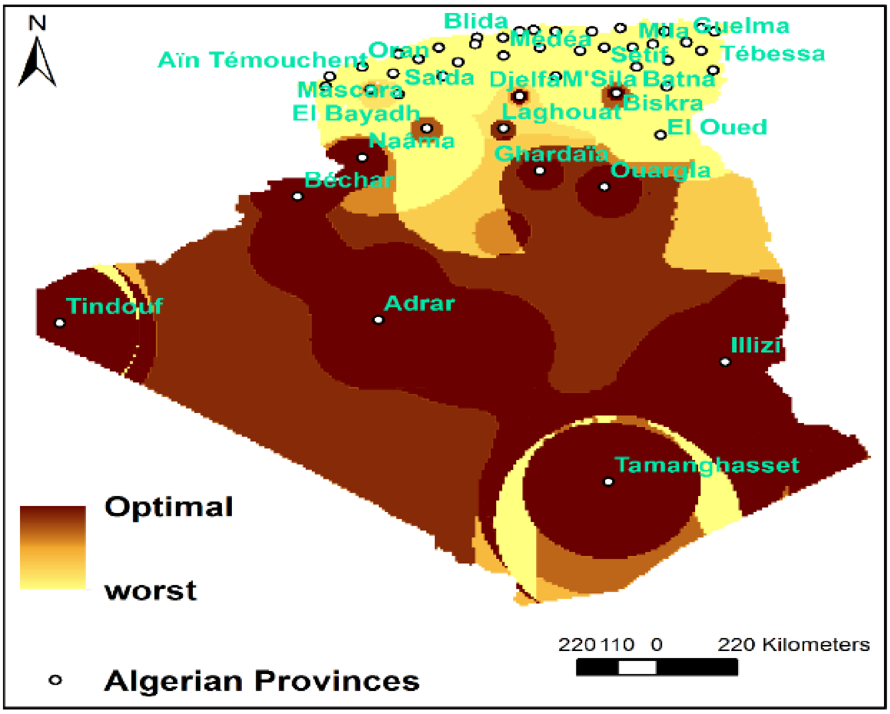

Fig. 10. MCDM result of optimal locations for achieving new plus-energy buildings

The results showed that the best places are in the Sahara of the country, which has great potential to build new PEB. Excessively, Adrar, Tamenrast, Ouargla, Tindouf, Bechar, and Illizi present the most optimal locations.

3.3. Estimating the global energy reduction and GHG reduction

A road map scenario was proposed. 50% of the existing building stock (before 2019) should be renovated before 2025 and the rest completed by 2030. Where 20 % of existing buildings in optimal locations must be PEB. Furthermore, all new buildings must be high-performance buildings from 2019. In which 25 % of new buildings at the best locations must be PEB before 2025. More than 40% of new buildings, however, must be PEB by 2030. Fig.11 showed the country's overall energy demand until 2030 following this scenario.

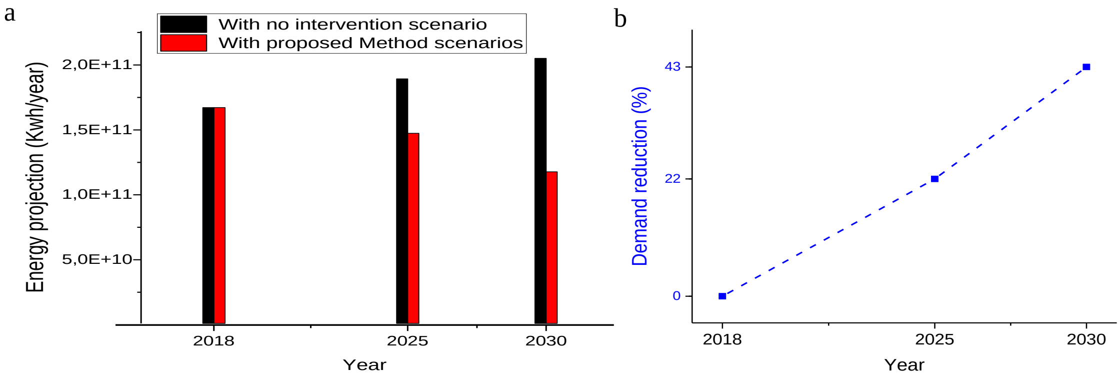

Fig. 11. (a) Energy demand projection; (b) Demand reduction

Annex 2. Technical-economic data

Generation source	Parameters	Specification
Solar PV system	Nominal power (KW)	1
	Capital cost ($/KW)	1400
	O&M cost (% of Capital cost)	2
	Temperature coefficient of power (%/°C)	-0.0037
	Life time (Year)	24
Wind system	Nominal power (kW)	5
	Capital cost ($/KW)	2000
	O&M cost (% of Capital cost)	2
	Cut-in speed (m/s)	2.7
	Cut-out speed (m/s)	20
	Rated speed (m/s)	11
	Life time (Year)	24
Diesel generator	Rated power (KW)	1
	Capital cost ($/KW)	700
	O&M cost (% of Capital cost)	2
	Fuel price ($/L)	0.18
	Life time (hour)	20000
Battery system	Battery capacity (KWh)	1
	Capital cost ($/KW)	180
	O&M cost (% of Capital cost)	2
	DOD (%)	80
	Charge efficiency (%)	95
	Discharge efficiency (%)	100
	Life time (Year)	12
Converter	Capital cost ($/KW)	500
	O&M cost (% of Capital cost)	2
	Efficiency (%)	95
	Life time (Year)	12
Economic	Project life time (Year)	24
	i: Interest rate (%)	5

Annex 3. Particle swarm optimization algorithm

```
LB= [0 0 0 0 0 0];                % Lower bound of problem
UB= [20 10 20 10 5% 99%];   % Upper bound of problem
max_it=50                    % Maximum number of iterations
NPOP=40;                     % Number of population
%%  Determine the maximum step for velocity
for d=1:3
   if LB(d)>-1e20 && UB(d)<1e20
      velmax=(UB(d)-LB(d))/NPOP;
   else
      velmax=inf;
   end
end
%% PSO initial parameters
phi1=2.05;
phi2=2.05;
phi=phi1+phi2;
chi=2/(phi-2+sqrt(phi^2-4*phi));
w1=chi;                                 % Inertia weight
c1=chi*phi1;                            % Personal learning coefficient
c2=chi*phi2;                             % Global learning coefficient
%% Read Load Profile
load('load1.mat');

 %% Particles Initialization
empty_particle.position=[];
empty_particle.velocity=[];
empty_particle.cost=[];
empty_particle.best.position=[];
empty_particle.best.cost=[];
particle=repmat (empty_particle,NPOP,1);
globalbest.cost=inf;
globalbest.position=[];
for i=1:NPOP
% …………………………………………..
% …………………………………………..
% …………………………………………..
End
%% PSO main loop
for u=1:max_it
% …………………………………………..
% …………………………………………..
COE(u)=globalbest.cost;
Xmin=globalbest.position;
p_npv=round(globalbest.position(1));
ad=round(globalbest.position(2));
nwt=round(globalbest.position(3));
end
%% Results
Fmin=min (Fminn);
Xmin;
result=[p_npv,CPB,nwt, PDG,LPSP, renewable_fraction, COE];
% …………………………………………..
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