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MECHANICAL ENGINEERING

THERMO-ENERGETIC

By

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THEME

Modelling and Development of an Optimal Methodology for Design A Multi-Sources System in Plus Energy Buildings

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On 09/12/2020 in front of the jury committee:

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Abstract

In recent years, net zero or plus energy building is gaining increased attention worldwide due to its high potential to address the increase of energy consumption and CO_2 emission, fossil fuels depletion risks and global warming issues. In fact, plus energy target can be achieved by increasing the energy performance of the building, then using renewable energy sources to provide at least the required demand of the building. However, the non-continuity of renewable sources and their high cost of investment lead researchers to combine two or more energy sources including renewable sources, conventional sources and/or energy storage units to form a hybrid or multi sources energy system (HES). The objective of this thesis is to develop a methodology to carry out design studies of plus energy buildings in Algeria. In this thesis, our contribution focused on the optimal design of multi-sources energy system taking into account the improvement of energy performance and thermal comfort of buildings as well as reducing the costs and CO_2 emissions in the environment. The design process of HES includes the selection of components, energy planning and spatial analysis, optimal sizing and energy management. To achieve all these goals, many tools software and optimization techniques and algorithms were used including geographical information system, multi-criteria decision-making, CAD software and optimization software and algorithms. The proposed optimization method was applied to optimal design of HES for different off-grid and grid-connected buildings located in different regions of our country chosen for their climate diversity. In this work, we seek to study the potential of available renewable energies mainly solar and wind energy to achieve sustainable and green buildings in wide areas of the country. In addition, to contribute to successful transit toward low dependent buildings on fossil fuels by promoting renewable energy usage in the country. The findings of this thesis are promising and helpful for policy makers to make best decisions on the deployment of renewable energy based-systems in the building sector in Algeria and other countries.

Key words: Plus energy buildings, net zero energy building, modelling, building design methodology, renewable energies, storage, optimization algorithms.

ملخص

في السنوات الأخيرة، اكتسب بناء الطاقة الصفرية أو الزائدة اهتمامًا متزايدًا في جميع أنحاء العالم نظرًا لقدرته العالية على معالجة زيادة استهلاك الطاقة وانبعاثات ثاني أكسيد الكربون ومخاطر استنزاف الوقود الأحفوري وقضايا الاحتباس الحراري. في الواقع، يمكن تحقيق بيوت الطاقة ا الزائدة من خلال زيادة أداء الطاقة في المبنى، ثم استخدام مصادر الطاقة المتجددة لتوفير ما لا يقل عن الطلب السنوي للمبنى. ومع ذلك، فان عدم استمرارية الإنتاج من المصادر المتجددة وتكلفتها العالية يجعل الباحثين يؤولون إلى الجمع بين اثنين أو أكثر من مصادر الطاقة بما في ذلك المصادر المتجددة، والمصادر التقليدية و / أو وحدات تخزين الطاقة لتشكيل نظام طاقة هجين أو متعدد المصادر ((Hybrid Energy System (HES). تهدف هذه الأطروحة الى تطوير منهجية لإجراء دراسات التصميم لمباني الطاقة ال الزائدة في الجزائر. في هذه الأطروحة، ركزت مساهمتنا على التصميم الأمثل لنظام الطاقة متعدد المصادر مع مراعاة تحسين أداء الطاقة والراحة الحرارية للمباني وكذلك تقليل التكاليف وانبعاثات ثاني أكسيد الكربون في البيئة. تتضمن عملية تصميم HES اختيار المكونات، تخطيط الطاقة والتحليل المكاني، التحجيم الأمثل وإدارة الطاقة. لتحقيق جميع هذه الأهداف، تم استخدام العديد من أدوات البرمجيات وتقنيات التحسين والخوارزميات بما في ذلك نظم المعلومات الجغرافية، واتخاذ القرارات متعددة المعايير، وبرمجيات CAD وبرامج التحسين والخوارزميات. تم تطبيق طريقة التحسين المقترحة على التصميم الأمثل لـ HES لعدة مباني سواء المباني خارج الشبكة أو المرتبطة بالشبكة والتي تتواجد في مناطق مختلفة إقليميا ومناخيا من البلاد. في هذا العمل، نسعى إلى دراسة إمكانات الطاقات المتجددة المتاحة بشكل رئيسي منها الطاقة الشمسية وطاقة الرياح لتحقيق المباني المستدامة والخضراء في مناطق واسعة من البلاد. بالإضافة إلى ذلك، المساهمة في النقل الناجح نحو المباني منخفضة الاعتماد على الوقود الأحفوري من خلال تشجيع استخدام الطاقة المتجددة في البلاد. النتائج التي توصلنا إليها في هذه الأطروحة جد مهمة ومفيدة لواضعي السياسات لاتخاذ أفضل القرارات بشأن نشر الأنظمة القائمة على الطاقة المتجددة في قطاع البناء في الجزائر وفي دول أخرى.

الكلمات المفتاحية: مباني الطاقة الزائدة، مباني الطاقة الصفرية، النمذجة، منهجية تصميم المباني، الطاقات المتجددة، تخزين الطاقة، خوارزميات التحسين.

Dedicated to

MY PARENTS

MY FAMILY

MY COLLEGES

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Charafeddine Mokhtara

Contents

Nomenclature

AC	Alternating current
ACL	Agent communication language
AI	Artificial intelligent
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BS	Battery storage
CA	Control agent
CHP	Combined heat and power
CO_2	Carbon dioxide
COE	Cost of energy
CRF	Capital recovery factor
DA	Design agent
DC	Direct current
DG	Diesel generator
DHW	Domestic hot water
DOD	Depth of discharge
DOE	U.S. department of energy
DSM	Demand-supply management
EPBD	European Directive on Energy Performance of Buildings
FIPA	Foundation of intelligent physical Agents
G	Solar radiation (W/m2)
GA	Genetic algorithm
GHG	Greenhouse gas
GIS	Geographical information system
Gref	Solar radiation at reference conditions (1000 W/m2)
HESs	Hybrid Energy Systems
HPB	High performance building
HRES	Hybrid Renewable Energy System
HVAC	Heat Ventilation and Air Conditioner
JADE	Java agent development framework
kt	Temperature coefficient of power
LA	Load agent
LPB	Low performance building
LPSP	Loss of power supply probability
MAS	Multi-agent system
MCDM	Multi criteria decision making
MOO	Multi-objective optimization
MOPSO	Multi-objective Particle Swarm Optimization
NASA	National aeronautics and space administration
Nbr	Number
NOCT	Nominal operating condition temperature
NREL	The National Renewable Energy Laboratory
NZEB	Net zero energy building
O&M	Operation and maintenance
PDG	Amount of power generation from DG at time (t)

PDG_r	DG maximum power generation at time (t)
PEB	Plus energy building
PNpv	The rated power of PV system under STC
Ppv	Amount of power generation from solar PV at a time (t)
Pr	WT rated power
PSO	Particle swarm optimization
PV	Photovoltaic
PWT	Amount of power generation from WT at time (t)
RE	Renewable energy
REHVA	Federation of European Heating, Ventilation and Air-conditioning Associations
RER	Renewable energy resources
RES	Renewable energy sources
rg	Ramping factor
SA	Storage agent
SOC	State of charge of the battery
STC	Standard (reference) test conditions
t	Time interval (one hour)
Tc	Cell temperature
Tref	Reference temperature
Vci	Cut-in wind speed
Vco	Cut-out wind speed
Vr	Rated wind speed
WT	Wind turbine
ZEB	Zero energy building

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Chapter 1.

Introduction

1. Introduction

1.1. Background

Global energy demand grew by 2.1% in 2017, more than twice the growth rate in 2016 (IEA, 2018a). These estimations are expected to keep increasing in the coming years because of the increase in population, modernization and industrial developments. Electricity and natural gas represent 19 % and 16 % of the global energy demand, respectively (IEA, 2018b). Buildings (residential, commercial and public services) consumed around 42 % (29 % of which is by residential) and 49 % (in which 27 % by residential) of the world's natural gas and electricity total consumption in 2017, respectively (IEA, 2018b). As most of the consumed energy is derived from fossil fuels, buildings emit about 21% (residential sector alone emits around 15%) of global CO_2 emissions (Harkouss, 2018). Nonetheless, if appropriate measures and strategies are adopted, there is a significant potential to reduce energy consumption and CO_2 emissions in the building sector.

In Algeria, the final energy consumption of the building sector grew annually by 8.3 % between 2007 and 2017 (MINISTERE DE L'ENERGY, 2019). In 2018, buildings used approximately 43% of total energy consumption as illustrated in Fig.1 (MINISTERE DE L'ENERGY, 2019)(APRUE, 2017). Within the present situation, the energy demand in building sector is expected to continue to expand in the coming years. The main reason is the exceptional growth of population (latest estimates indicate 42.2 million people) and urbanism (8,548,080 building, of which, 70 % are located in urban areas and 65 % are detached single family buildings) (APRUE, 2017). In addition, low prices of conventional energy, increased number of electrical equipment in each house, use of non-economic electrical equipment (such as incandescent lamps and cheap air conditioners), absence of awareness of energy saving policies and lack of energy control devices also have a strong effect on the increase of energy end use in the building sector (Missoum et al., 2014). Like most countries, Algeria's energy mix is almost based on fossil fuels, mainly natural gas (NG) (93 %) (Rahmouni et al., 2016). As 99 % of buildings are connected to the national electricity grid, and 65% of them are supplied by natural gas (for heating and cooking purposes, which represent 69 % of energy end use of buildings), this sector is responsible of one third of the country's CO_2 emissions (APRUE, 2017).

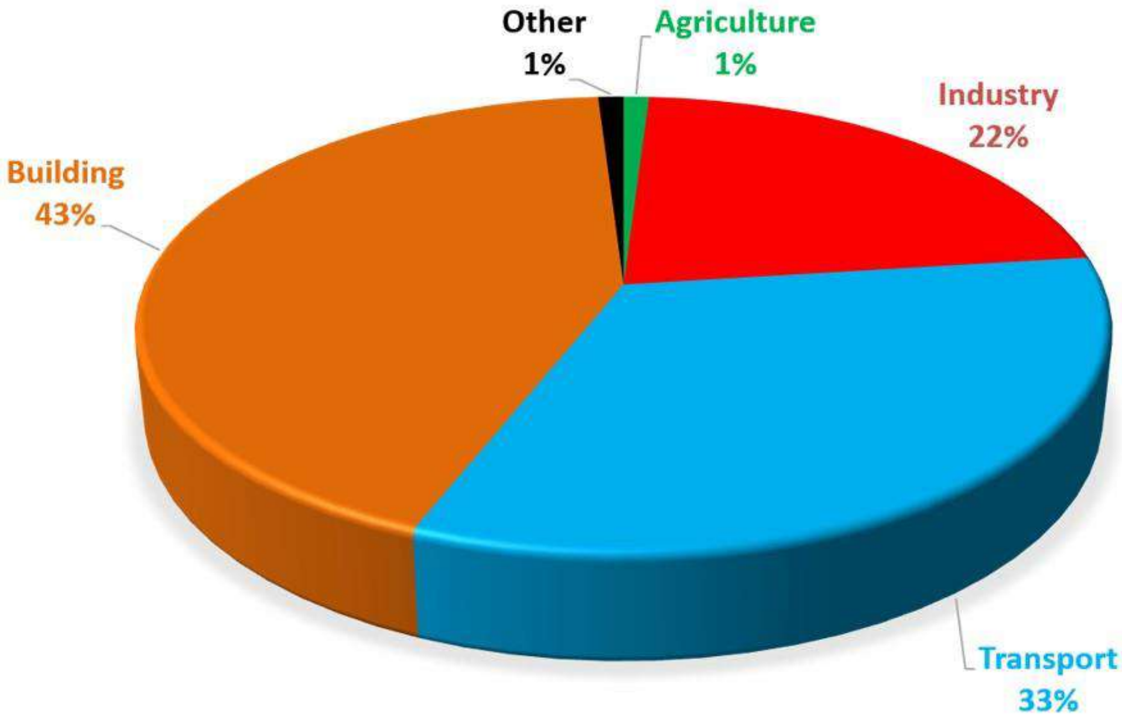

Figure 1. Distribution of energy consumption by sectors in Algeria (2017) (MINISTERE DE L'ENERGY, 2019).

Nowadays, Algeria and many countries and international organizations have set new policies and strategies to limit energy consumption and greenhouse gas (GHG) emissions in the building sector. For instance, the Algerian government has established the Renewable Energy and Energy Efficiency Program (in 2011 and its updated version in 2015). This program intends to achieve about 40% of energy supply from renewable resources by 2030 using the vast renewable sources, mainly solar thermal, photovoltaic, and wind power (Rahmouni et al., 2016). In addition, this program gives solutions for improved energy efficiency in buildings by using efficient building components and appliances. Further, the Algerian Ministry of Energy and Mines have developed a program that aims to encourage the implementation of innovative practices and technologies, and is centred on thermal insulation of buildings, and adequate measures that are scheduled at the architectural and design phases of housings. It is also concerned about fostering the introduction of efficient equipment and devices on a massive scale in the local market, such as solar heaters and economic lamps (Ghedamsi et al., 2015).

In this regard, recently, net zero or plus energy buildings (NZEB) or (PEB) have gained an increased interest worldwide. In fact, there is no particular definition for PEB; however, in light of some applications in different countries and based on a Bibliometric analysis performed by the author, the definition and main steps for achieving the concept of NZEB are defined.

1.2. Bibliometric analysis on zero energy buildings

For making an outline about the main issues and important investigated topics in NZEB, a Bibliometric analysis is firstly carried out. As Science direct is the only scientific database available for free for Algerians researchers, the author performed his researches in Elsevier to get relevant papers to his thesis topic by introducing four general and important key words (net zero energy building, design, optimisation, and renewable energy). The result of research gives more than 6000 papers (including original and review papers). Hence, the RIS files of these papers are exported to VOS Viewer to make the Bibliometric analysis. The results for the Bibliometric analysis are given in the following figures. Fig.2 and Fig.3 presente the most indexed key words. However, the most discussed and used words in the papers' titles and abstracts are presented in Fig.4 and Fig.5.

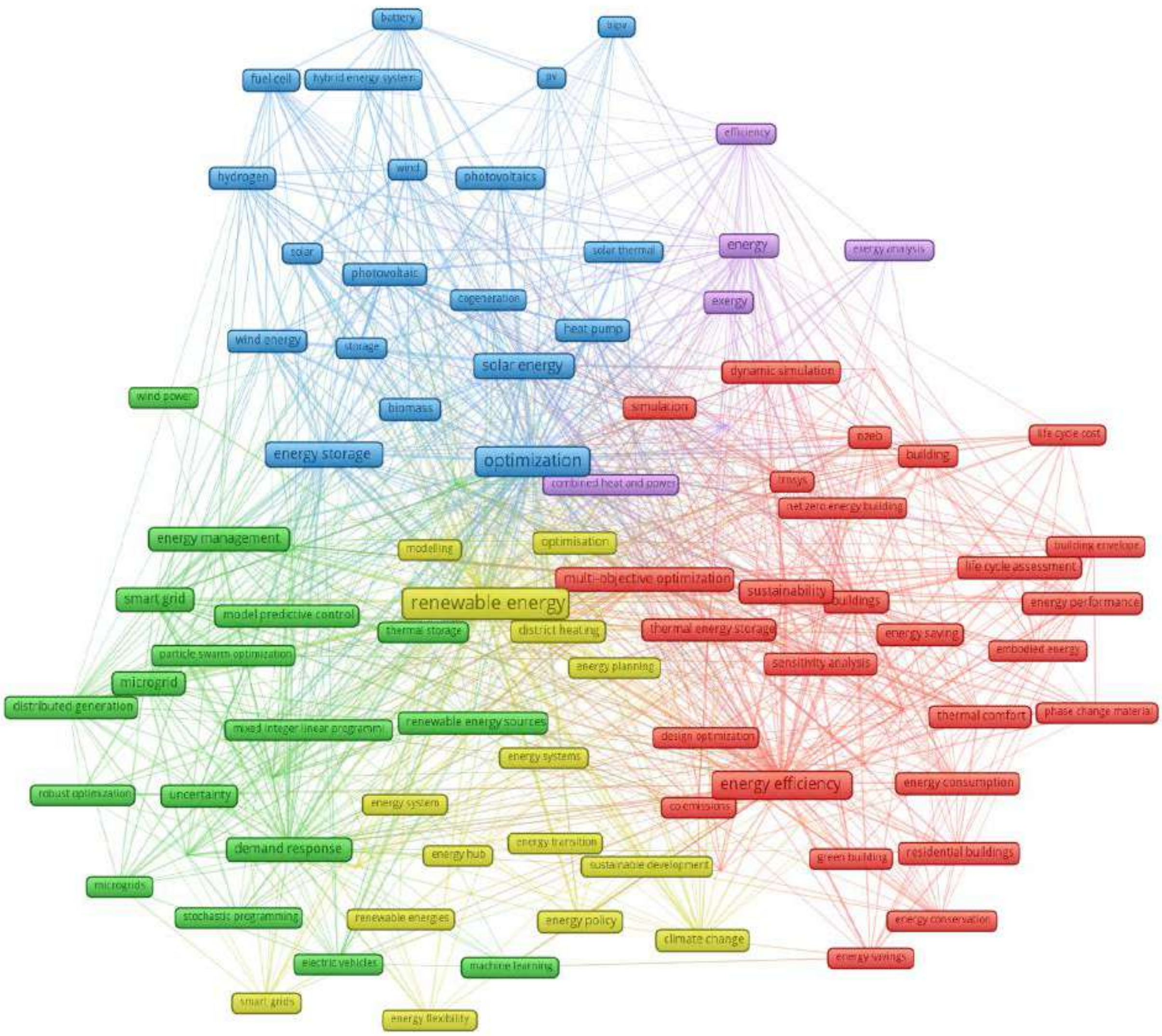

Figure 2. The most indexed key words.

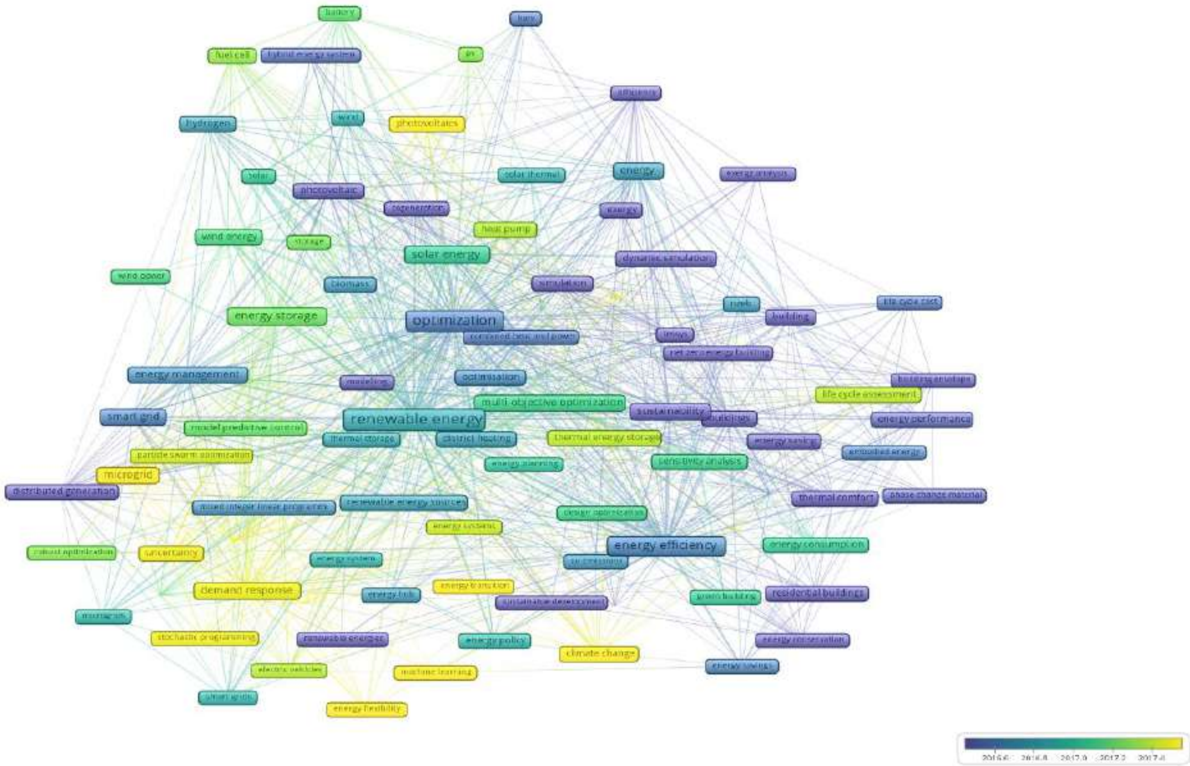

Figure 3. The most indexed key words in function of publication time.

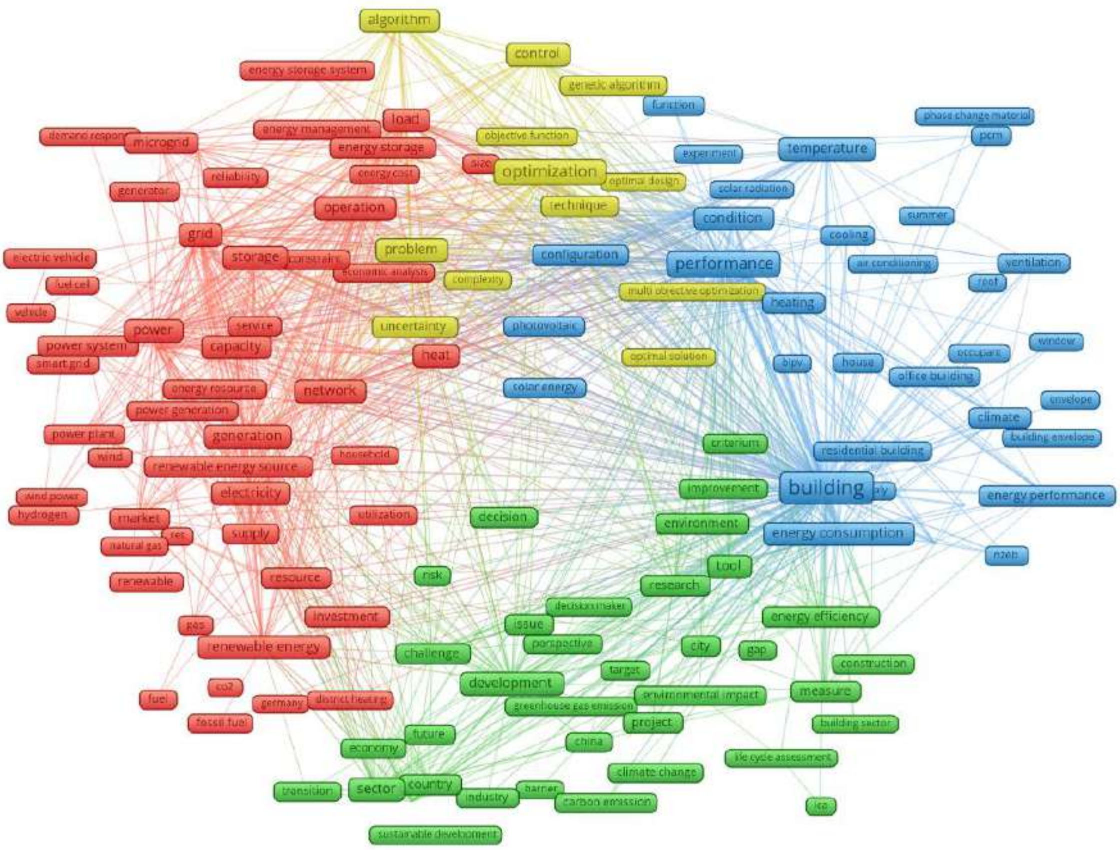

Figure 4. The most occurring words in the titles and abstract section.

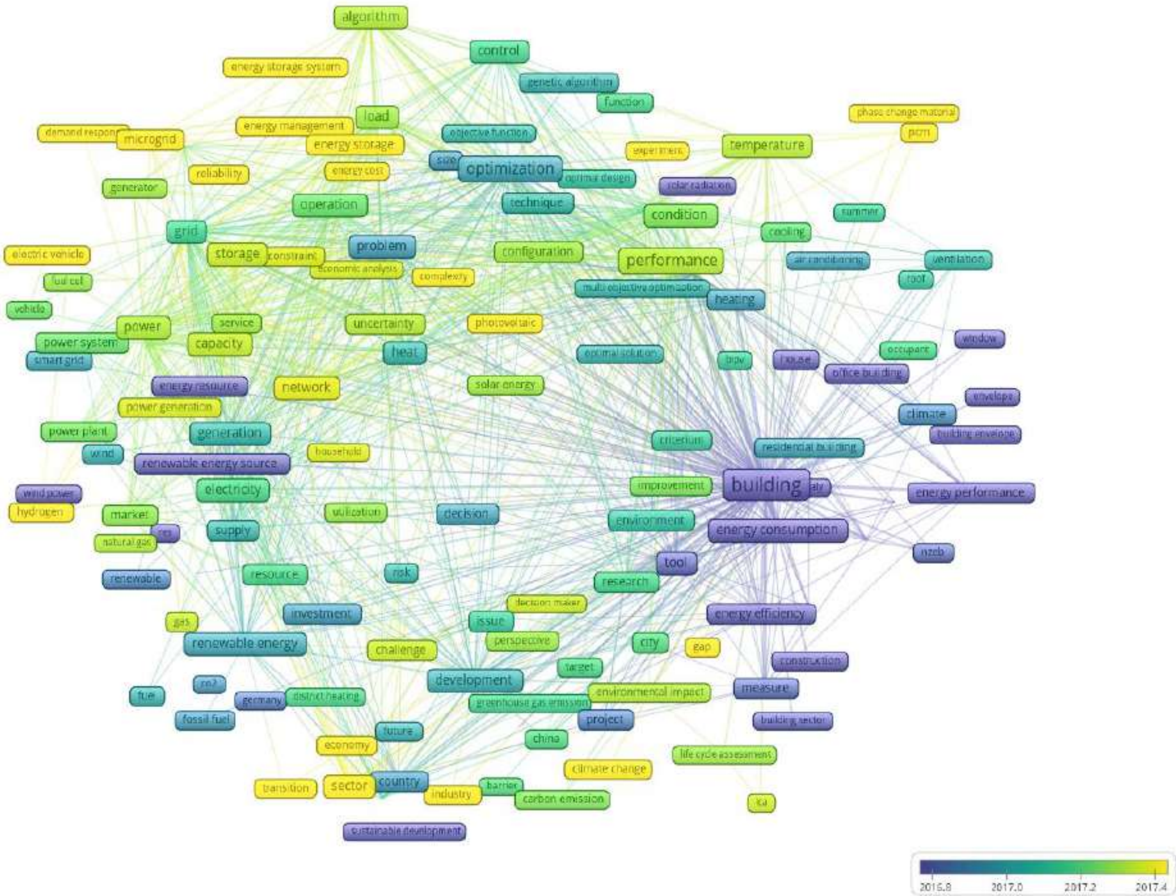

Figure 5. The most occurring words in the titles and abstract section in function of publication time.

By a deep observation and analysis of the obtained maps (from VOS Viewer), it is agreed that the two standard essential steps to achieve the PEB target in a particular building are: 1) Energy efficiency measures (include the use of passive design techniques and energy-efficient technologies) (Rodriguez-Ubinas et al., 2014); 2) renewable energy sources (mainly wind and solar PV). Multi-objective optimization (MOO), decision-making and energy management strategies (include demand response) are gained an intense interest by researchers, as their capability to solve complex energy optimization problems in NZEB, considering many evaluating criteria including technical, economic, environment and social. Researchers worldwide are investigating the applicability of these optimization techniques in order to enhance buildings' energy performance and ensure high reliability for the supply system. As shown in the obtained maps, the supply system is commonly consisted of multi sources of energy (wind turbines, solar PV, energy storage (batteries, fuel cell…), diesel generator, electric vehicle...etc. In the literature, multi sources energy systems are commonly known as hybrid energy systems.

Beyond its natural gas reserves, Algeria intends to exploit his available renewable energies, especially solar energy (global solar irradiation exceeds 2400 kWh/m² in Sahara of the country) (SolarGIS, n.d.); Hence, we would have multi source energy systems. In addition, integrating these renewable sources into building level is also a promising way to transit toward PEB in the country. However, because of the vast surface area of the country, which stretches from the Mediterranean Sea in the North to the hot deserts in the South, implementing effective design strategies for each climate zone is a crucial way to promote high-performance buildings. In addition, a proper selection of configurations and capacities of renewable energy sources is needed to ensure economic and environmental objectives. The design optimization process must also consider the government policies and social variables such as public acceptance, job opportunities and so on.

1.3. Thesis objectives and contributions

The main aim of this thesis is to develop an optimization method that is able to provide best decisions for achieving PEB at different locations in Algeria. The developed method takes into account all aspects of sustainability and considers the local available capacities to make the study more applicable, and encourages the implementation of such buildings over a wide area. The thesis focused on the optimal design of multi-sources (hybrid) energy systems in PEB. Hence, the following contributions are undertaken to achieve the thesis objectives:

- Energy planning and spatial analysis will be performed to evaluate energy potential; that is, to study the technical and spatial feasibility of renewable energy sources using geographical information system.
- Analytic Hierarchy Process technique of multi-criteria decision-making will be used to select the best alternatives for energy sources, storage, and building energy efficiency strategies.
- New maps for Algeria including climatic data, energy consumption, and renewable potential, and feasible area for achieving PEB were developed using ArcGIS.
- Particle swarm optimisation (PSO) algorithm was used for optimal sizing of hybrid energy systems in off-grid and grid connected areas at many case studies, under different climate in Algeria was carried out.
- Study the techno-economic, and environment feasibility of stand-alone HES for supply mobile buildings was investigated using HOMER software.
- Study the feasibility of using hybrid storage system (batteries and hydrogen) to enhance the system reliability at an educational building is carried out.

1.4. Structure of the thesis

The remaining parts of this thesis are structured as follows:

Chapter 2 gives a comprehensive review on net-zero (plus) energy buildings (NZEB) definitions that exist up-to-date, to the best of the author's knowledge. In this chapter, the most commonly used renewable energy based system and energy efficiency strategies are provided, focusing on HESs. Further, different applications of HES and NEZB are reviewed, where the optimization techniques, algorithms and software tools, objective functions, optimization variables and constraints are presented.

Chapter 3 presents the thesis methodology including mathematical modelling of the HES's components, description of the used optimization techniques and software tools.

Chapter 4 conducts a comprehensive investigation on the optimal passive and active design for achieving plus energy residential buildings in Algeria. This chapter aims to assist designers to select the most suitable RE solution sets and energy efficiency measures based on different evaluation criteria. Different maps for energy consumption as well as for renewable energy sources potential and PEB balance are developed. This chapter constitutes a general map and a decision support to identify the different applications to test the proposed methodology of this thesis.

Chapter 5 is dedicated to design off-grid HESs. Three different applications are investigated in this chapter, in which, different energy management strategies and size optimization approaches are used.

Chapter 6 suggests a combined method based on geographical information system and multi-objective particle swarm optimisation for optimal design of grid-connected HES considering hybrid battery-hydrogen energy storage system.

The last chapter outlined the key findings of this thesis, with suggesting future work.

Chapter 2.

Optimal Design of Multi-Sources Energy System in Plus Energy Buildings: A Review

2. Optimal Design of Multi-Sources Energy System in Plus Energy Buildings: A Review

2.1. Introduction

Globally, more than 40% of the total energy consumption comes from households (Sun et al., 2019). In which, residential buildings are responsible for the major share (70%) of energy consumption in this sector (Landi et al., 2019). Therefore, improving the energy efficiency of existing buildings and integrating renewable energy sources into electricity generation have become crucial for the reduction of greenhouse gas emissions and limiting the increase of energy consumption in buildings. However, both of these solutions are almost discussed separately. Hence, the combination of both energy efficiency strategies with renewable energy technologies is therefore needed to ensure efficient energy planning at all stages of the design process. Moreover, further efforts are required to encourage the deployment of renewable energy sources instead of using fossil fuels.   In this regard, zero-energy or plus-energy building (ZEB) concept must be adopted, which constitutes a key solution to overcome most energy and environmental problems in the building sector. PEB is a high-efficiency building, where renewable energy sources such as wind and solar can provide at least what it consumes at specific period, commonly one year. In general, it is traditionally agreed that there are two main steps to reach the PEB target, starting by energy efficiency solutions (including passive strategies and energy efficient technologies), and then renewable energy sources. In fact, reducing energy consumption in buildings by using energy efficient strategies is an important action. However, according to literature review, it is evident that decarbonizing of energy generating system is prior. Many governments and organizations worldwide providing attractive policies and incentives to encourage the integration of renewable energy sources (RES) in their energy mix. As a result of the discontinuity of renewable energy sources (RES) and difficult to predict their variation, the deployment of RES leads to high costs and so energy losses. To overcome these problems, renewable energy sources are mostly hybridized and/ or combined within conventional sources and/or adding a storage system, consisting multi sources (hybrid) energy system. In recent years, there has been a progress interest in HES. Nevertheless, design optimization of HES by taking into account several technical, economic and environmental criteria and objectives is a complex problem. It is therefore necessary to develop a methodology able to support engineers during the design and management phases of HES to make them attractive and competitive. Moreover, in the design stage of HES in buildings, many aspects have to be considered including building energy performance, environmental impact, and reliability issues. Therefore, simultaneous optimization of these conflicting objectives is needed to provide accurate decisions. In literature, there are numerous approaches for the design and optimization of HES. In this chapter, an intense review was made to outline most design strategies for design of PEB as well as HES. First, the main existing definitions related to PEB are highlighted, and then a state of the art and intense review of existing optimization technics and tools that have been used for optimal design of HES are outlined. Finally, the evidence gaps in existing works have been identified in order to set the main contributions of this thesis.

2.2. PEB definitions

A large number of international organizations and institutes around the world are trying to find a specific definition for ZEB or PEB to allow their implementation. Until now, there has been no common definition to this concept. For instance, REHVA defines the NZEB as a grid-connected energy-efficient building that meets its total annual energy requirements through on-site energy generation (Harkouss, 2018). However, EPBD defines "nearly zero-energy building" as a building with high-energy performance, by which the small energy consumption of the building must be maintained by RE resources whether on-site or in the nearby [17]. DOE defines NZEB as a building with reduced energy needs and a balance of energy requirements provided by RE technologies. According to ASHRAE, NZEB is defined as a building which produces as much RE as its annual consumption. Where the building can transfer energy to the utility grid as long as the net energy balance is zero on an annual basis. The term "Net" has been used only in case of grid-connected building, so that it is possible to classify buildings as NZEBs, nearly NZEBs or Net plus energy buildings. However, in grid independent buildings, the "net" term does not used (Harkouss, 2018). In order to meet the ZEB goal in this case, the building must produce at least as much electricity as it uses on an annual basis by using renewable technologies, large energy storage system and reducing the overall use of energy using highly efficient equipment, HVAC and lighting systems (NREL, n.d.).

2.2.1. Zero Energy (stand-alone) Building (ZEB)

Such buildings do not need to be linked to the electricity grid. So, they are self-independent, they provide the energy needed to meet their energy needs, and are able to store energy produced for night-time or in other periods.

2.2.2. Net Zero Energy Buildings (NZEB)

These are yearly neutral buildings; the electricity exported from the building to the grid is equivalent to that imported from it. These buildings use renewable energy sources such as solar and wind, while at the same time reducing the overall use of electricity with high-efficient appliances, HVAC and lighting systems.

2.2.3. Plus Energy Buildings (PEB)

Over the year, these buildings produce a surplus of electricity. This means that they are transferring more electricity to the supply grid than they are importing annually from it, because they produce more RE than they need. Thereby, PEB contribute significantly to reduce CO_2 emissions than other buildings.

2.3. Main steps for achieving PEB

Achieving PEB has been gaining an increase popularity worldwide. In response to regulatory mandates, federal government agencies and many state and local governments have pushed private commercial property owners to move toward ZEB targets. Generally, there are two main steps to reach the plus energy balance, starting by energy efficiency measures (including passive strategies and energy efficient technologies), and then using renewable energy technologies (Harkouss et al., 2018a). Fig.6 shows the main steps and methods most used to reach PEB concept. In addition, Fig.7 displays the schematic road to PEB achievement.

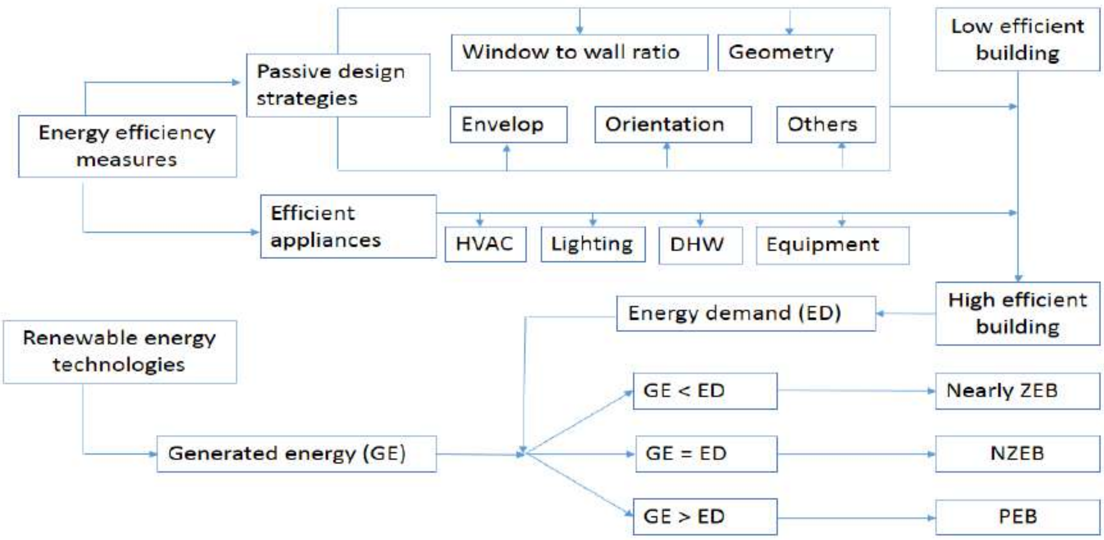

Figure 6. Main steps for achieving PEB.

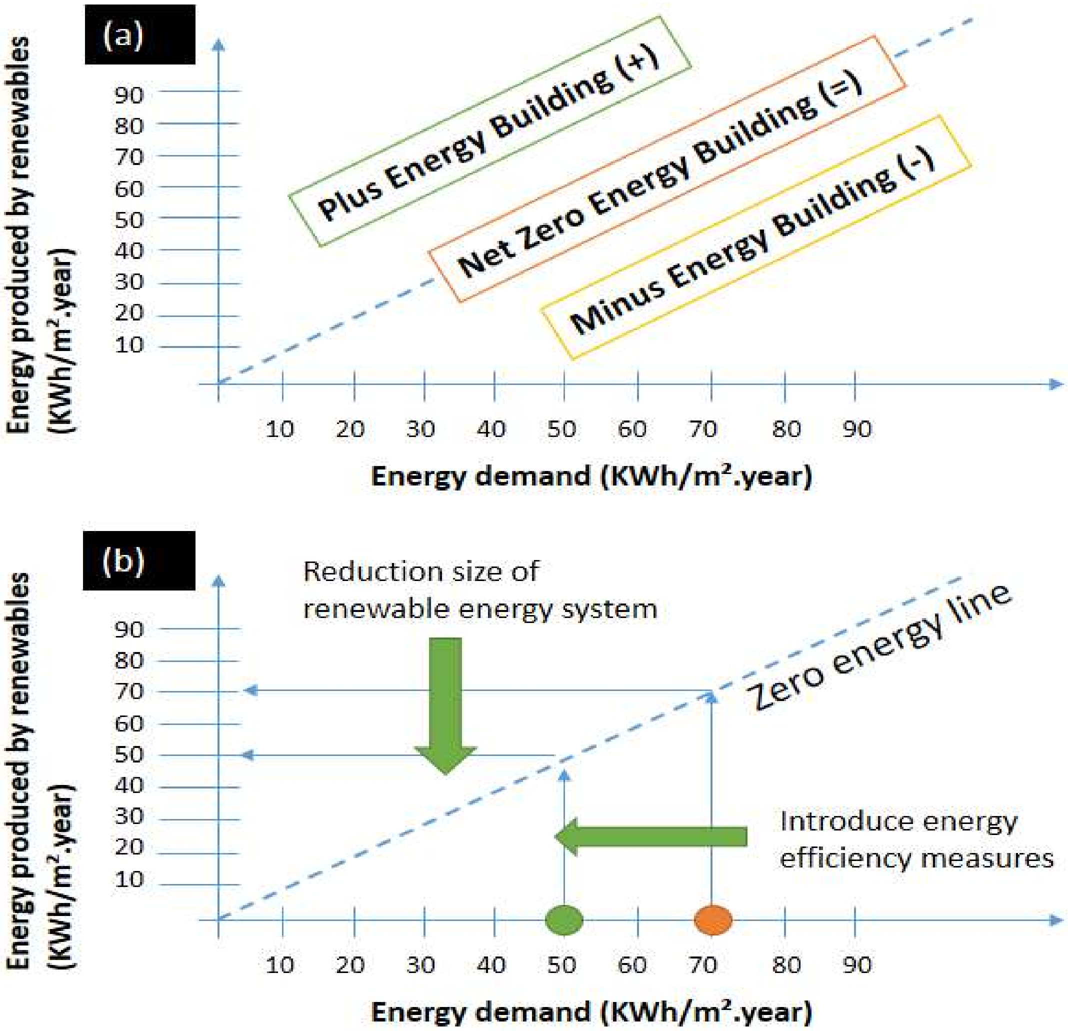

Figure 7. Schematic path for achieving PEB (Ascione et al., 2016).

2.3.1. energy efficiency measures

In the literature, five principal classes of energy efficiency strategies can be identified, including interventions relating to the entire building, the building's envelop (roof, wall, ceiling and floor), windows and shading devices, HVAC systems and finally, appliances and lighting system (Boeck et al., 2015).

2.3.1.1. passive strategies

Passive strategies including envelop insulation, building orientation, building geometry, window to wall ratio and daylighting, and other solutions.

2.3.1.2. energy efficient technologies

Including HVAC systems, domestic hot water (c), Lighting and divers building equipment.

2.3.2. renewable energy technologies

In buildings, solar PV and small wind turbines are the most used renewable energy technologies for electricity generation. However, for providing the required heat for space heating, cooling and DHW, solar thermal collectors and ground air exchanger are commonly used. In addition, biomass and other sources are also employed but in limited applications.

2.4. RE supply options and classifications in ZEB

2.4.1. RE supply option hierarchy in ZEB

According to (Torcellini et al., 2006), the possible renewable energy supply options for achieving NZEB are presented in Tab.1 as follows.

Table 1. Renewable energy supply options for achieving NZEB

Option	Improvement strategies	Solutions
Option 0	- Building envelop improvement - Efficient energy measures & demand side RE technologies	Insulation, efficient equipment, lighting, passive solar heating, day lighting, solar ventilation, evaporative cooling…
Option 1	- RE within building footprint	Thermal solar collector, Rooftop and facade solar PV, building mounted WT
Option 2	- RE at boundary of building's site not mounted on building nor within building footprint	Parking lot PV, ground mounted thermal solar systems, tower based WT, on-site solar driven chiller
Option 3	- RE from off-site to produce electricity on-site	Wood pellets, biodiesel, waste, and vegetable oil imported to the site, combined heat and power (CHP) systems, to produce electricity & heat
Option 4	- Purchased installed off-site certified RE source	PV panels installed off-site, utility-based wind turbines….

2.4.2. Classification of NZEB

NZEB were classified according to RESs application with respect to the Building into different categories (Pless and Torcellini, 2010). This categorization system is based on the fact that the building must primarily use all passive and energy-efficient strategies (building envelope improvement, efficient equipment, lighting...etc.) and then use RE technologies that exist within the building footprint (on the roof of the building, integrated within the building walls). After that, if necessary, the building may use on-site RE approaches to fulfil its requirements. In addition, if the building had used all the cost-effective passive and energy-efficient strategies and needed more energy, then the off-site resources could be used. In the building ranking system, producing RE within the building footprint is better than bringing off-site renewable energy on-site, even though both are called renewable energy. Tab.2 provides the NZEB classifications.

Table 2. Classifications of NZEB

Classification	Description
Class-A	They are buildings with a well-improved envelope and energy efficient systems. Their energy needs are offset using RE technologies available within the building footprint.
Class-B	If the methods described in a Class-A cannot cover buildings' energy needs, buildings might employ on-site RE technologies.
Class-C	If both footprint and on-site RE technologies are not sufficient to cover the building energy needs, then off-site renewable sources can be imported.
Class-D	If all above mentioned RE technologies are exploited to the maximum extent without covering the needed energy, so the building may purchase certified RE such as utility-based wind and RECs from certified sources.

By fact to these classifications, we must also take issue that the supply system is often made up of at least two sources of energy. These are the implications of taking into account the technical, economic and environmental constraints and the complexities of the energy transition. In this regard, multi-source (hybrid) energy systems are therefore being implemented as a more suitable supply system. The remainder of this chapter has focused on the study of the most discussed topics in the HES.

2.5. Multi sources (hybrid) energy system

Despite to their benefits to the environment, using one source of renewable energy for generating the required energy demand of the building is still not a techno-economic viable option, particularly in isolated areas where the building is not connected to the utility grid. As a result, several researchers are trying to combine multiple energy sources to make an HES able to meet the building loads continuously and at low energy costs. The majority of HESs consist of renewable energy sources, conventional source and/or storage system. Due to their advantages, HES has gained increased attention from researchers and decision makers over the last decade. In fact, various HESs have been studied and implemented for different applications in variety of climates and regions.

2.5.1. Classification of HESs

From the literature, several classifications have been proposed according to some defined criteria. HESs are classified according to the operating mode, the size of the HES and its configuration as shown in Fig.8 and Tab.3 (Kartite and Cherkaoui, 2019). In the literature, solar-wind based HESs are the most widely used because they remain technically and economically advantageous for electrical generation, particularly in isolated areas (Anoune et al., 2018).

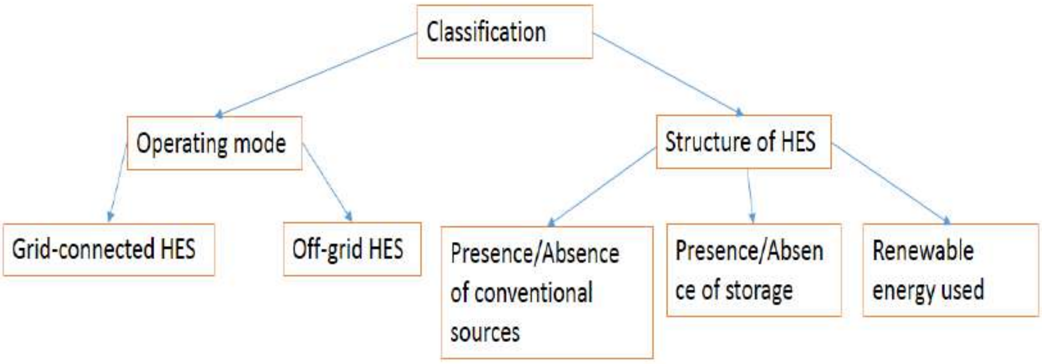

Figure 8. Classification of HES (Kartite and Cherkaoui, 2019).

Table 3. Classification of HES based on their size

Type	Size	Typical load
Small-scale	Lower than 5 kW	Suitable for buildings, telecommunication systems…
Medium-scale	Between 5 and 100 kW	Remotely communities, commercial buildings…
Large-scale	Upper than 100 kW	Regional loads, factories…

2.5.2. HES' components

The HES mostly comprises of renewable sources (solar PV, wind turbine) and non-renewable source and/or storage component for back up and some additional devices (Sawle et al., 2018).

2.5.2.1. Conventional sources

Depends on the application, Off-grid or grid connected. In off grid HES, diesel generator is mostly used where diesel fuel is needed for their operation. However, in grid connected HES, building is connected to utility grid. In this case, no fuel is consumed; but the customer have to install a meter to calculate the imported energy from the grid. In the study of (Faccio et al., 2018) reveals that almost 70% of the research projects have been devoted to developing the off-grid HESs.

2.5.2.2. Renewable sources

The main renewable energy sources that are commonly used in HES includes solar, wind, biomass, small hydro etc.

2.5.2.3. Energy storage

Energy storage is becoming extremely exciting in the sense of high-efficiency energy systems. Storage enables the control of energy flows, and eliminates the volatility between energy demand and the supply system. (Guelpa et al., 2019). Depends on configuration size (small scale, large scale...) and energy recovery time (short, medium and long term). There are many storage options, such as batteries, hydrogen storage, hybrid storage, etc. Hybrid storage systems would reduce the size of both technologies and provide a more affordable, safer and reasonable solution to the energy storage problem.

2.5.2.4. Electronic devices

Depends on the configuration of the system, the usable electric bus (AC, DC or both), the form of energy demand (Heat and/or Power) ... etc.

2.5.3. Topologies and configurations

The structure of the HES is an important metric influencing its function and performance. Many choices of HES have been reviewed in the literature as shown in Fig.9 (Faccio et al., 2018). For off-grid applications, PV-WT-battery HES is the most investigated one. Nevertheless, for grid-connected applications, grid connected PV-storage is commonly developed due to its high suitability in urban areas. It is evident that PV-WT-battery HES is the most investigated configuration. However, in grid-connected applications, PV-grid is large used because of their high suitability in urban areas.

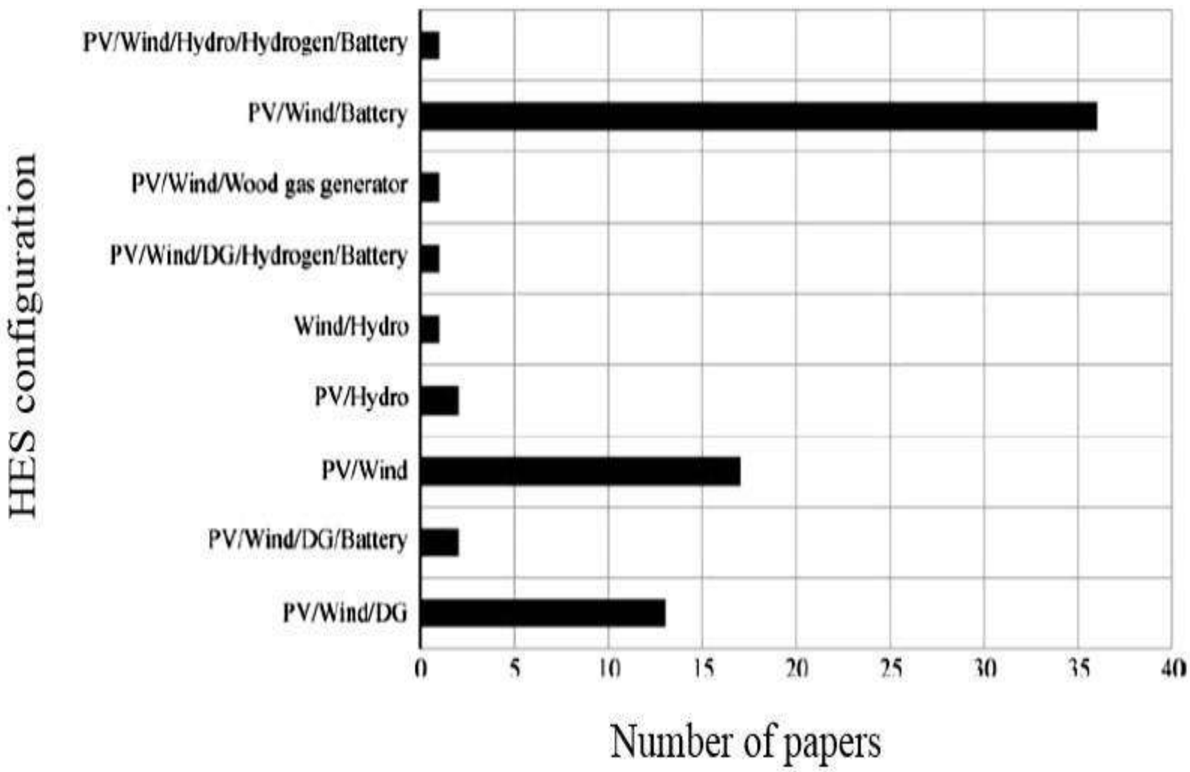

Figure 9. The common configurations of HES (Faccio et al., 2018).

2.5.4. Advantages and disadvantages of HES

As with any alternative solution, HES has many advantages and disadvantages like described in Tab.4 (Faccio et al., 2018).

Table 4. Advantages and disadvantages of HES.

Advantages	Disadvantages
Utilization of natural and renewable sources	Investment cost of HES is higher than traditional sources
Low operation and maintenance costs	Complexity of design procedure (energy management, optimal sizing…)
No pollution or wastes produced	Required energy storage to manage peak load
Minimizing intermittency and increase supply system reliability	
Fuel saving	

2.6. Optimal design of HES

The design of the HES involves the various tasks, starting by selecting component, optimization and controlling the exchanges between the different parts of the HES to ensure reliable and cost-effective energy system. On the other hand, other factors, such as environmental and social benchmarks, must be considered within the achievement of these goals. Hence, an efficient decision making approach is usually required to provide best decisions.

2.6.1. Optimimization objectives and evaluating criteria in HES

The main objective of any generation system is to meet the demand. However, additional priorities will be defined by the possible options that the structure and topology of the HES would provide. Various indicators and criteria have been reported in the literature for the assessment of HES. Such assessments criteria can be classified into technical, economic, environmental and social criteria as listed below (Al-falahi et al., 2017).

2.6.1.1. Economical assessment

Evaluate HES's initial, operation, maintenance and total costs and any relevant parameters.

2.6.1.2. Technical assessment

Evaluates the HES's reliability and their ability to satisfy load demand at the defined period of operation.

2.6.1.3. Environmental assessment

Evaluates the amount of CO_2 and other obnoxious emissions produced by the system throughout a given period.

2.6.1.4. Social assessment

Evaluates the capability of the HES to produce energy for increasing the human development index. Moreover, it evaluates the social acceptance of installing hybrid system and job creation.

The literature review stated that among all optimization objectives, loss of power supply probability (LPSP), cost of energy, net present cost, size (configuration), energy generation, fuel consumption and environmental emissions, are the most frequently cited, as shown in Fig.10 (Faccio et al., 2018).

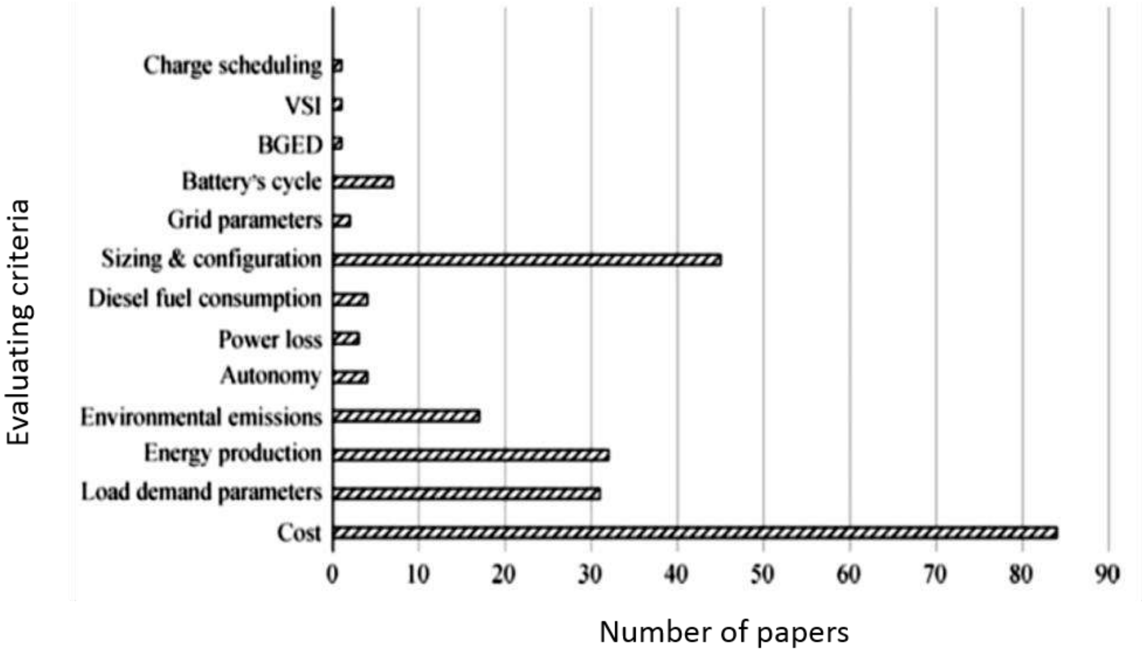

Figure 10. Frequency of the common optimization goals (Faccio et al., 2018).

2.6.2. Energy management strategies in HES

Energy management problems, associated with rapid social and economic development, have been of critical concern to both national and local governments worldwide [22]. Increasing numbers of energy issues can lead to a variety of impacts on and liabilities in public health and sustainable regional development; additionally, energy problems can affect economic growth [23]. With the demands of both the advancement of regional development and the need to raise public awareness of energy problems, increasing pressures are being imposed on planners and decision makers for a more robust response to a number of energy concerns. Consequently, the identification of decision protocols with sound environmental and socio-economic efficiencies is desirable in order to promote effective energy management practices. A number of factors need to be considered by the planners and decision makers in environmental management systems, such as social, economic, technical institutional and political issues, as well as environmental protection and resource conservation. The complexities involved in generating the desired environmental management decisions may be exacerbated by uncertainties existing in the related system components. In view of the classification of energy management strategies according to their integration level of design process, the following tasks are found.

2.6.2.1. Energy management techniques at early design step

According to literature review, at early design step of HES, the main goal of an energy management strategy consists of: 1) selecting best HES's components using MCDM techniques; 2) evaluating energy potential of renewable energy sources and identify best area for their installation using spatial analysis tools. Energy management techniques and strategies generally are complicated procedures, incorporating multiple knowledge bases such as social, physical, technological, political, and economical. Moreover, it can be applied to either spatial or non-spatial problems. Multiple criteria decision-making (MCDM) provides a systematic methodology that aids decision makers in combining these inputs with the benefit/cost information and the stakeholders' perspectives in order to rank all alternatives.

2.6.2.1.1. MCDM techniques for select best HES's components

The most popular model of decision-making was proposed by Simon (1960) and defines decision-making as a process comprising the steps of: intelligence, design, selection, and implementation. The stage of intelligence is associated with the question: What is the decision we face? The design stage allows you to propose alternatives and criteria to evaluate them while the selection stage consists of applying the proposed criteria to choose the best alternative(s) to the problem. Finally, the last step is to implement the chosen alternative. Distribution of paper based on MCDM approaches. Based on results and findings provided in literature review, the MCDM and fuzzy MCDM approaches have used more than other approaches. In addition, AHP and fuzzy AHP approaches had the second rank. However, ELECTRE, fuzzy ELECTRE had the third rank. TOPSIS, fuzzy TOPSIS, PROMETHEE and fuzzy PROMETHEE are found in the last rank.

2.6.2.1.2. Evaluate energy potential of renewable energy sources

One of the useful tools to model and forecast the renewable energies sources over a region is Geographic Information Systems (GIS) based methods. Among the GIS related techniques, GIS-based Multi-Criteria Decision Analysis (MCDA) integrated methods contain physical information, criteria weights, and an MCDA operator. This operator mix spatial information and criteria weights together. ArcGIS software is constitute the leader to carry out spatial analysis and select best renewable sources in urban areas. This goal is achieved by evaluating technical economic and environment parameters related to RES, and then performed MCDM calculations to rank areas according to their suitability considering the decision objectives. A number of studies have been focused on the application of MCDA in the renewable energy resource assessment (Firozjaei et al., 2019)

2.6.2.2. Energy management techniques at the operation stage

HESs are presented as a viable, safe and effective solution to minimize the associated problems on the integration of renewable energies with the existing energy systems. Nevertheless, making them operate together in a comprehensive way by establishing synergies between them is a major challenge (Vivas et al., 2018). This problem cannot be solved without applying an energy management strategy. However, in order to ensure a proper operation mode of HES, guaranteeing energy demand and increasing system performance, it is necessary to establish an energy management strategy. Although, the choice of a correct energy management strategy that guarantees an optimum performance of the whole HES is a hard task, specifically in situations of excess and energy deficit, stochastic renewable generation and other technical constraints. Hence, applying an efficient energy management strategy enables to overcome these problems and allows the system to continuously supply demand, improve the life of the components, minimize operating costs and thus optimize system performance, offering a technically and economically feasible solution. Meanwhile, relatively small changes with such an energy strategy can have a significant effect on the result of the optimisation. In fact, it is essential to take into account multiple criteria and constraints in order to define the appropriate management strategy that ensures the best solution.

The different energy management strategies are based on the achievement of different optimization objectives, based on different technical and economic criteria. These strategies are intended to define the energy flows during the normal operation of the system, and therefore to determine which equipment must operate. Depending on the optimization objectives and the topology and configuration of the system, the strategy can be more or less complex, requiring the use of more or less complex optimization algorithms. In many energy management problems, a number of criteria and/or objectives have been considered, leading to the development of multiple criteria decision-making approaches (Mardani et al., 2016). As follows, a summary and analysis of different energy management strategies for HESs is provided (Vivas et al., 2018). According to evaluating objectives, energy management strategies are classified into four categories:

2.6.2.2.1. Simplest strategies

Here, the objective is to satisfy the demand. For that, it bases its control algorithm mainly on three design criteria: power balance, state of charge of the batteries and/or hydrogen stock, depending on the elements that integrate the system. The main advantage of this strategy is the simplicity in design and control, governed mainly by algorithms based on simple flow chart diagrams. In the same way, sizing applications that include this strategy are also simplified. However, these strategies do not optimize the use of equipment or operating costs.

2.6.2.2.2. Strategies incorporated technical criteria

These strategies take into account technical criteria in order to ensure the proper use of the equipment. The main target of these strategies is to reduce the degradation of the equipment more susceptible during operation of the system. In order to perform the control algorithm, power balance, state of charge of the storage system and degradation parameters are defined as design constraints. Other objectives that can integrate these strategies are increasing the useful lifetime, increasing the efficiency of a certain element, etc. These strategies are shown as an incomplete solution, due to the need for more competitive systems from an economic point of view.

2.6.2.2.3. Strategies incoprporated economic criteria

These strategies include an economic analysis in addition to a guarantee of the power balance. These economic parameters will help to determine an optimal solution from an economic point of view. Although there is an apparent cost reduction with respect to the previous strategy, it is an incomplete analysis, since it does not take into account some technical criteria associated with certain operation modes.

2.6.2.2.4. Strategies incorporated both technical and economic criteria

These strategies are complex because they consider technical and economic criteria to increase equipment life and reduce operating costs. However, these strategies need to use complex optimization algorithms, which increases the complexity to develop real applications.

2.6.3. Sizing optimization techniques in HES

For the most applications, renewable energy-based hybrid systems do not have competitive costs against traditional fossil fuel systems. Nonetheless, in view of the need for alternative energy sources and reducing GHG emissions, HESs have good potential to provide appropriate support for different applications in both off-grid and grid-connected areas.

Optimal sizing of HES is an important step to improve the efficiency of such solution. This goal is performed by employing diverse ranges of the optimization techniques, which aid the designers to achieve the minimum expected total cost, while satisfying the load demand and the reliability. The sizing optimization can be formulated as single objective or as a multi-objective problem with economic, technical and environmental criteria; it depends on defined criteria and the optimization method. Besides, for the multi-objective problems, there have been two approaches. The first one consists of merging all the individual objective functions into a single composite and in the second approach consists of the determination of Pareto optimal solution.

Sizing optimization techniques must perform an effective search for an optimum combination of the critical parameters like system cost, system reliability, PV array size, the tilt angle of PV panels BS size, WT size, it is recognized that over-sizing causes an increase of system costs and under sizing causes insufficient power supply. In this section, a review of most used optimization technics for determine the optimal sizing of HES's components

Size optimization techniques can be classified into classical techniques, modern techniques and software tools. Classical techniques use iterative, numerical, analytical, probabilistic, and graphical construction methods. These methods utilize differential calculus in deriving the optimum solution. Modern techniques use artificial and hybrid methods. These methods can determine the global optimum system and has better convergence and accuracy in finding a set of optimal solutions. The third size optimization approach for HES sizing include computer software tools. The most widely used software tool in size optimization for HES is Hybrid Optimization Model for Electric Renewables (HOMER) (Al-falahi et al., 2017). An overview of the optimization techniques discussed in this study is shown in Fig.11 (Twaha and Ramli, 2018). In addition, Fig.12 illustrates the frequency of the common used optimization techniques.

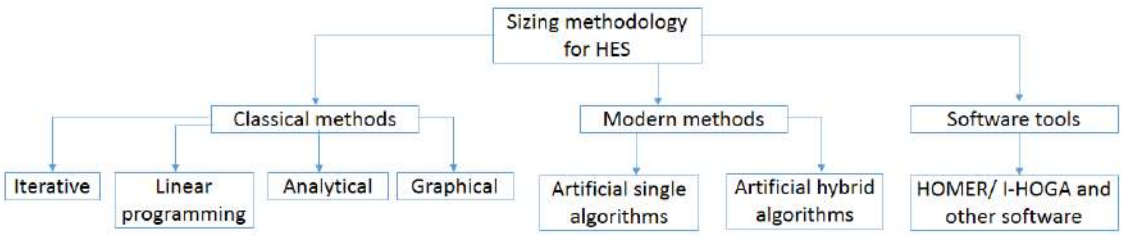

Figure 11. Classification of size optimization techniques for HES (Al-falahi et al., 2017).

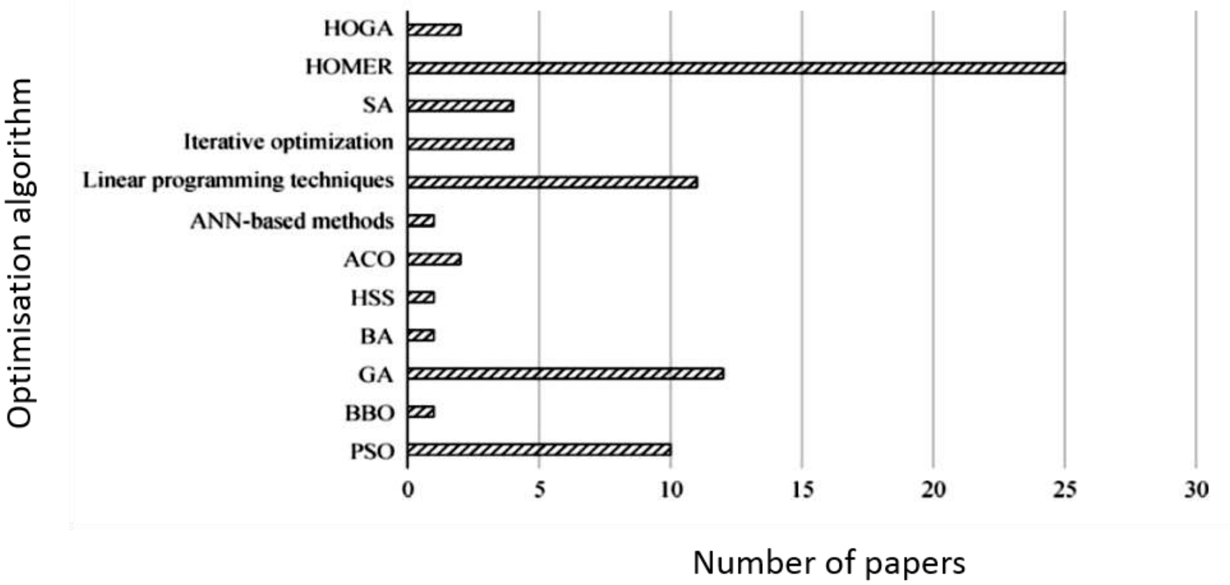

Figure 12. Frequency of the most used optimization techniques in HES (Faccio et al., 2018).

2.6.3.1. Size optimization algorithms

With the advancement in computer technology, artificial intelligent (AI) methods have become very popular (Twaha and Ramli, 2018). Artificial intelligence approaches need no availability of weather data for sizing of integrated energy systems in remote sites. Numerous approaches are reported in literature such as Genetic Algorithms (GA), Particle Swarm Optimization Technique (PSO), Harmony search algorithm (HSA), Simulated annealing (SA), Ant colony algorithms (ACA), Bacterial Foraging Algorithm (BFO), Artificial bee colony algorithm (ABC), Cuckoo Search (CS), or a hybrid of such techniques. These algorithms can handle the non-linear variation of system components of HES (Anoune et al., 2018).

2.6.3.1.1. Genetic Algorithm

Genetic Algorithm is a search process that mimics the process of natural selection and was developed by John Holland in 1960–1970 period. GA generates solutions to optimization problems using techniques inspired by natural evolution such as inheritance, mutation, selection, and crossover. GA has several advantages: it can solve problems with multiple solutions, easy to understand and can easily be transferred to existing simulation and models etc. It has some limitations like a tendency to converge towards local optima or even arbitrary points rather than the global optimum of the problem, cannot assure constant optimization response time etc.

2.6.3.1.2. Particle Swarm Optimization

PSO is a meta-heuristic optimization technique, was firstly developed by Kennedy and Eberhart in 1995. PSO is inspired firstly by general artificial life (Fodhil et al., 2019). PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). It is a "multi agent parallel search technique" that is inspired by the idea of swarm intelligence which is based on social behaviour and evolutionary computation. PSO algorithm is able to solve both continuous and discrete problems.. PSO has many advantages such as a very fast speed of the researching. Simple calculation compared to another method. The problems of non-coordinate system present limitations of this optimization algorithm because it cannot work out.

2.6.3.1.3. Harmony search algorithm (HSA)

Harmony search is a derivative-free, real-parameter optimization technique algorithm employed for the optimization, with several evolutionary meta-heuristic optimization techniques. HSA is one of the most recent population-based optimization technique that may be adopted in various fields of engineering applications.

2.6.3.1.4. Simulated annealing (SA)

Simulated annealing, which mimics material annealing processing, was developed by Kirkpatrick, Gelatt, and Vecchi in 1983 [99]. It is a trajectory based on random search technique for global optimization. The main advantage of simulated annealing is its ability to avoid being trapped in local minima. Simulated annealing is a robust and versatile technique that can deal with highly nonlinear models, chaotic and noisy data and many constraints. The main weakness of SA is that the quality of the outcome may be poor. Until now, little literature has been reported using SA in this field.

2.6.3.1.5. Ant colony algorithms (ACA)

Ant colony algorithms are initially proposed by Marco Dorigo in 1992 in his Ph.D. thesis. The algorithm was aiming to search for an optimal path in a graph.

2.6.3.1.6. Artificial bee colony algorithm (ABC)

Artificial bee colony algorithm (ABC) is an optimization algorithm based on the intelligent foraging behaviour of honey bee swarm, proposed by Karaboga and Basturk [61,106,107]. In ABC, the position of a food source represents a possible solution to the optimization problem and the nectar amount of a food source corresponds to the quality (fitness) of the associated solution.

2.6.3.1.7. Cuckoo Search (CS)

Cuckoo Search is a new meta-heuristic algorithm and solving optimization problems, which based on the obligate brood parasitic behaviour of some cuckoo species in combination with the Lévy flight behaviour of some birds and fruit flies.

From a general observation, it became evident that the application of the heuristic-based algorithms namely, particle swarm optimization (PSO), tabu search (TS), simulated annealing (SA), and harmony search (HS) were much more significant compared with other optimization methods (Faccio et al., 2018), because of their ability to search local and global optima, good calculation accuracy and faster convergence speed. In the review paper of (Wagh and Kulkarni, 2018) has mentioned that for multi-objective optimization of HES, genetic algorithm and particle swarm optimization are most popular applied methods. Besides, a review of Multi-Objective Optimization for Sizing of Solar-Wind Based HES is done by (Chauhan and Saini, 2014)and they suggested that for multi-objective optimization, Particle swarm optimization (PSO) tool can be a good approach for solving these types of problems. PSO is considered as one of the most used algorithm in HES size optimization due to its good performance, flexibility, and simplicity.

2.6.3.2. Sizing Software

There is several software for optimal sizing of HES. Tools such as the Fortran programming, HOMER, and linear programming have been frequently used to perform optimization analysis of these systems (Faccio et al., 2018). Here, the most used software in this area were presented (Kartite and Cherkaoui, 2019) (Anoune et al., 2018).

2.6.3.2.1. HOMER

HOMER (Hybrid Optimization Model for Electric Renewable), was developed by NREL (national renewable energy laboratory). It is a means for optimizing the design of micro-grids in all sectors of electricity, from public services in the villages to campuses and military bases connected to the network. HOMER integrates three powerful tools in single software, the engineering and the economy work side by side.

2.6.3.2.2. Hybrid2

Hybrid2 was developed by CEERE (centre for energy efficiency and renewable energy). It allows the study of different hybrid systems. It is a tool for performing detailed, long-term economic analyses on a wide variety of hybrid power systems. Hybrid2 is a probabilistic / temporal computer model, using time series for loads, wind speed, sunshine, temperature and the power system designed or selected by the user.

2.6.3.2.3. HYBRIDS

HYBRIDS is produced by Solaris Homes, it is based on Net Present Cost for determining the potential of the Hybrid System, and it requires a daily average of environmental data and load demand.

2.6.3.2.4. TRNSYS

TRNSYS (Transient Energy System Simulation Program) is a simulation software for energy system, developed in Fortran in 1975 by the University of Wisconsin and the University of Colorado (USA). It was initially developed to simulate thermal systems, but, over the years, it has also become a hybrid system simulator, including photovoltaic, thermal solar and other systems. The standard TRNSYS library includes many of the components commonly found in thermal and electrical renewable energy systems. The simulation is carried out with great precision, allowing the viewing of graphics with detail and precision. However, it does not allow the carrying out of optimizations. It is not free of charge.

2.6.3.2.5. HYDROGEMS

It is not a program, but a series of libraries developed at the Institute for Energy Technology (IFE, Norway). Libraries are used by TRNSYS and by Engineering Equation Solver (EES) software. Libraries are developed by HYDROGEMS model the following components: photovoltaic generators, wind turbines, diesel generators, polymeric and alkaline fuel cells, Electrolysers, hydrogen tanks, lead-acid batteries, and DC/AC converters. It is possible to carry out economic optimization if it is used by the GenOpt software, using the simplex linear optimization method. These libraries are free for TRNSYS users

2.6.3.2.6. RAPSIM

RAPSIM (Remote Area Power Supply Simulator): This is free and open source micro-network simulation software for a better understanding of power flow behaviour in smart micro-grids with renewable sources. It is able to simulate grid-connected or autonomous micro-grids with solar, wind or other renewable energy sources. The proposed software calculates the power generated by each source in the micro-array, and then performs a power flow analysis. This software is useful for the optimal placement of distributed production units in a micro-network. A summary for the most used software tools in HES and their characteristics is given in Tab.5.

Table 5. Summary for the most used software tools in HES.

Characteristics	HOMER	HYBRID2	I-HOGA	HYDROGEMS +TRNSYS
Free download and use	x	x	x	x
PV, Diesel, Battery	x	x	x	x
Wind	x	x	x	x
Mini hydro	x	x	x	x
Fuel cell, Electrolyzer and H2 tank	x	x	x	x
Hydrogen load	x	x	x	x
Thermal load	x	x		
Control strategies	x	x	x	x
Simulation	x	x	x	x
Economic optimization	x	x		x
Multi objective optimization	x			x

2.7. Conclusion

This chapter analysed the most used methods and techniques to achieve PEB, concentrating on the optimisation of HES. According to the literature review, we concluded that, in order to achieve the plus energy goal, two key steps must be taken, beginning by increasing the energy performance of the building by using different energy-efficient strategies in the first step, and then by implementing renewable sources to satisfy its needs. Because of the random nature of renewable sources, HES is a promising solution for generating clean energy to supply both grid-connected and off-grid regions economically and efficiently. In fact, this review shows that the most frequently used combination of HES for off-grid and remote areas is that consists of PV-WT-BS. Nonetheless, in urban areas, grid-connected PV with and without energy storage is more widespread. Different evaluation criteria are considered for the optimum design of HESs including economic, technological, environmental and social criteria. The selection of some of these criteria is basically to achieve an appropriate combination for the HES. From the analysis, it is observed that most researchers are looking at the cost, environmental objectives and reliability indicators in the assessment of HESs. In addition, social factors such as job creation and social acceptance are also taken into account in certain studies.

Nonetheless, the design optimization of HES cannot be accomplished without taking an energy management strategy capable of making the right decisions on choosing suitable solutions at an early stage of design or on controlling the different energy flows between the components of HES in the operation phase. It is therefore very important to define a proper energy management strategy to find an optimum solution when designing HES. Furthermore, the integration of several criteria into the design of HES can provide accurate results, however, it leads to the implementation of more complicated energy management techniques and strategies. Researchers and decision-makers, thereby, use MCDM technologies to rank alternatives and choose best options in case of spatial or non-spatial data. In this context, AHP and fuzzy AHP methods are identified as the most prominent techniques used to solve multi criteria problems incorporating non-spatial entities. However, for doing spatial analysis with multiple criteria, ArcGIS software is the most used tools especially in urban areas.

Chapter 3.

Optimal Design of Multi-Sources Energy System in Plus Energy Buildings: A Methodology

3. Optimal Design of Multi-Sources Energy System in Plus Energy Buildings: A Methodology

3.1. Introduction

This thesis presents a methodology for optimal design of multi-sources energy systems for achieving plus energy building under diversity of climate in Algeria. The proposed methodology includes several tasks: optimal sizing of components, energy management and multi-criteria decision-making (MCDM) for select best alternatives in term of costs and energy efficiency. The methodology is applied to reduce energy costs and CO_2 emissions at different case study buildings in both grid-connected and isolated areas. The proposed methodology is a useful tool to facilitate decision making in early design phase of building as well as in the operation within multi sources of energy. Despite to the important role of energy efficiency measures (passive design strategies and energy efficient HVAC and appliances) on improving building energy performance, this thesis was focused on optimizing supply sources that is an essential step to move toward low carbon emission buildings. First, this chapter provides the mathematical modelling and description of the different used components (energy sources, storage systems and other necessary devices). In addition, description of the used approach for the assessment of load demand of the investigated case study buildings. Moreover, providing a description to different design optimization technics used in this work, including multi-criteria decision-making technics, optimization algorithms and software and energy management and planning procedures.

3.2. Modelling of the hybrid energy system

As described above, HES includes different components. The main energy sources, energy storage, and electronic devices that are used in this work are described and modelled as follows.

3.2.1. Solar PV

Solar PV panel is a device that converts solar energy into electrical energy. The power supplied by the PV can be calculated by a function of the solar radiation and ambient temperature using Eq. 1 (El-bidairi et al., 2018) (Kumar et al., 2019):

$$P_{pv} = P_{Npv} \times \frac{G}{G_{ref}} \times \left[1 + K_t \times \left(\left[T_{amb} + \frac{NOCT - 20}{800}\right] \times G - T_{ref}\right)\right] \quad (1)$$

Where Ppv and PNpv are the output power and rated power of PV module respectively. G and Tamb are the solar radiation and ambient temperature at time step simulation. However, Gref (1 kW/m²) and Tref (25°C) are solar radiation and ambient temperature at standard conditions. Kt is the temperature coefficient of power depends on PV's panel technology. NOCT (nominal operation cell temperature).

Solar PV panel is a device that converts solar energy into electrical energy. Solar energy is the abundant renewable source in Algeria. Photovoltaic panels are used to convert this energy into electricity. Energy output of the PV panel have simulated using the one-diode model (Tu et al., 2019) (Boudoudouh and Maârou, 2018). The I-V curve can be expressed by Eq. 2-4 as follows:

$$I(V) = I_{ph} - I_o[e^{\left(q\frac{V+IR_S}{nkTN_{cs}}\right)} - 1] - \frac{V+IR_S}{R_{sh}}. \quad (2)$$

$$I_{ph} = \frac{G}{G_O}[I_{ph,STC} + \gamma(T - 298)]. \quad (3)$$

$$I_O = I_{O,STC}\left(\frac{T}{298}\right)^3 e^{\left[\left(\frac{qE_g}{nk}\right)\left(\frac{1}{298}-\frac{1}{T}\right)\right]}. \quad (4)$$

Where I and V are respectively current and voltage of the PV module their values are varied according to available solar irradiation and ambient temperature. Hence, the output power of the PV module is evaluated. I_{ph} is the photocurrent, I_o is the diode reverse saturation current.

Where G is the available irradiance, G_O reference irradiance (1000 W/m²) and T is the ambient temperature. γ is the temperature coefficient of short-circuit current.

3.2.2. Wind turbine

Wind turbine is a renewable energy source that can be used to convert the kinetic wind energy into electrical energy. The electricity generated by the wind turbine (WT) was calculated using a simple model of Eq. 5.

$$P_{wt} = \frac{1}{2}.\rho.C_{over}.AV^3 \quad (5)$$

Where: ρ is the standard air density of 1.22 Kg/m3. A is the area swept. C_{over} is the overall wind turbine power coefficient. Its value is about 30% (Sunderland et al., 2016). On the other way, the power output of the wind turbine can be calculated using Eq. 6-8 as follows (Mandal et al., 2018a) (Borhanazad et al., 2014):

$$P_{wt} \Leftrightarrow 0 \qquad if \qquad V < Vcut_{in} or\ V > Vcut_{out} \quad (6)$$

$$P_{wt} \Leftrightarrow V^3\left(\frac{Pr}{Vr^3 - Vcut_{in}{}^3}\right) - \left(\frac{Vcut_{in}{}^3}{Vr^3 - Vcut_{in}{}^3}\right)\ if\ V > Vcut_{in}\ and\ V < V_{rated} \quad (7)$$

$$P_{wt} \Leftrightarrow P_r \qquad if \qquad V > V_{rated}\ and\ V < Vcut_{out} \quad (8)$$

3.2.3. Battery storage

The Excess electricity power generation from renewable sources is used to charge the battery storage (BS) whereas the shortage of energy can be supplied from battery bank or/and diesel generator. The state of charge of battery is evaluated according to discharge and charge mode by Eq. 9-10 respectively (Mohamed et al., 2018) (B. Wu et al., 2018).

$$E_b(t+1) = E_b(t) \times (1-\sigma) - \left(\frac{E_l(t)}{\eta_{cnv}} - E_g(t)\right) \times \eta_{BD} \tag{9}$$

$$E_b(t+1) = E_b(t) \times (1-\sigma) + \left(E_g(t) - \frac{E_l(t)}{\eta_{cnv}}\right) \times \eta_{BC} \tag{10}$$

The operation of BS depends on charging and discharge limits, depth of discharge (DOD) and solar energy availability. This means that the BS must operate according to the permissible SOC limits specified by each manufacturer and with respect to the DOD which depends on battery technology. The operation of the BS is described following to Eq. 11.

$$Eb_{min} \leq Eb(t) \leq Eb_{max} \quad \text{Where } Eb_{min} = (1-DOD) \times Eb_{max} \tag{11}$$

Where El(t) and Eg(t) are the energy demand and generated power by renewable sources (solar PV) respectively. $\boldsymbol{\eta}$BD and $\boldsymbol{\eta}$BC represent the discharge and charge efficiencies of the battery. However, σ is the self-discharge of the battery, which is neglected in this study. $\boldsymbol{\eta}$cnv is the converter's efficiency.

3.2.4. Hydrogen storage

Hydrogen storage system includes three main parts, are the Electrolyzer (Ele), hydrogen storage tank (ST), and Fuel cell (FC). A simplified FC and Ele models are used in this study. However, we assume that the FC and Ele work at a following operation point, which depends on generated and energy demand at time step simulation (t). Similarly, the size of the hydrogen storage tanks (ST) needs a deep analysis inclusive the Ele, FC, total energy generated and energy demand requirements. In this work, Ele is only operated in vacancy periods, hence, if the generated energy Pg (t) ≥ Energy demand El(t), then Ele is operated to produce hydrogen gas and fill ST. The state of charge (stored hydrogen) of ST is calculated using Eq. 12. However, if Pg (t) ≤ Energy El(t), and the BS is at minimum state of charge or cannot meet the shortage power, therefore, FC is used to supply the rest load. In this case, the state of charge of ST is calculated using Eq. 13 (Zhang et al., 2019).

$$\mathrm{ST}(t+1) = \mathrm{ST}(t) + \left(E_g(t) - \frac{E_l(t)}{\eta_{cnv}}\right) \times \eta_{Ele} \tag{12}$$

$$\mathrm{ST}(t+1) = \mathrm{ST}(t) - \left(\frac{E_l(t)}{\eta_{cnv}} - E_g(t)\right)/\eta_{FC} \tag{13}$$

Where ST(t+1) and ST(t) are the energy stored (kWh) in the ST at hour t+1 and t, respectively. ST state of charge has a maximum limit (STmax), which represents the capacity of ST. $\boldsymbol{\eta}$Ele and $\boldsymbol{\eta}$FC are the efficiency of Ele (90%) and FC (50%), respectively (Samy et al., 2019a).

3.2.5. Diesel generator

Diesel generator (DG) is used in a hybrid energy system to meet the load demand in case the total available renewable energy generated power and batteries bank/hydrogen stored power are not sufficient. The fuel consumption of the diesel generator depends on its output power and can be expressed by Eq. 14 (Mohamed et al., 2018):

$$F_{cons} = a \cdot P_{DG} + b \cdot P_{DG\_r} \tag{14}$$

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

3.2.6. Grid

Grid. When the PV system and storage devices are not sufficient to supply the load, the grid is used to supply the deficit power. In Algeria, the purchase price of electricity (EPR) without subsidies is 0.1 $/kWh.

3.2.7. 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 ($\boldsymbol{\eta}$Cnv) can be approximated by Eq. 15.

$$\eta_{Cnv} = \frac{P_{output}}{P_{input}} \tag{15}$$

Generally, the converter’s efficiency is assumed 95 % with lifetime of 15 years.

3.2.8. Load energy demand

The energy demand (including heat and electricity) of the building is one of the main determining factors in size optimization of HESs. The electricity demand of the building can be divided into two types. First type includes energy demand for lighting and electric appliances. Here, this load is assessed based on the rated power of equipment’s and the time of operation. Second load represent the energy demand for space cooling and heating. In this work, this load is evaluated using either simple calculation as the first type or using detailed calculation by using building simulation software (Energy Plus and TRNSYS). Despite of TRNSYS that includes library for building components, a 3D model of the building must be imported to Energy Plus to do the calculation. Therefore, other software such as Design Builder and sketch up are used to build the 3D model of the building and to define the building's components. Thus, the energy demand for cooling and heating are evaluated according to climate data at building's location, building's characteristics, desired temperatures and thermal comfort requirements.

3.3. MCDM analysis

A decision-making process involves a main objective, two or more comparable alternatives and many criteria (Karatas et al., 2018). Energy planning requires to fulfil several economic, environmental, technical and social criteria (Haddah et al., 2017) (Eriksson and Gray, 2017). Therefore, applying multi-criteria decision-making (MCDM) methods helps us to simplify sites and components' selection, calculate criteria weights and select best strategies and solutions.

For performing a multi criteria decision-making analysis, an MCDM technique is needed to solve the problem and make adequate decisions. In this thesis, Analytical hierarchy process (AHP) technique was used to select between alternatives and rank feasible solutions and determine criteria weights. AHP, which was developed by Professor Thomas Saaty in 1980 allows for structuring the decision hierarchically (to reduce its complexity) and shows relationships between objectives (criteria) and alternatives. In fact, AHP constitutes one of the most widely used multi-criteria decision-making methods worldwide due to its intuitiveness and mathematical rigor (Yan et al., 2019). The analytic hierarchy process has been used by institutions in over 50 countries worldwide and the Super Decisions software (Super Decisions, 2015), available free of charge from the Creative Decisions Foundation, allows a user-friendly application of the AHP methodology (Creative Decisions Foundation, 2015). The Creative Decisions Foundation and Super Decision software websites provide information on the latest developments and news of the method and its applications.

3.4. Energy planning and spatial analysis

Energy planning of renewable energy sources is an interested task. This goal cannot be achieved without doing spatial analysis. As this type of analysis is solved with much variables associated with spatial entities, an effective method is needed. Recently, Geographic Information System (GIS) has become increasingly popular to solve such type of analysis specifically for site selection and energy planning (Al Garni and Awasthi, 2017). In this work, geographical information system (ArcGIS software) was used to select best zones and create required maps. In addition, Autodesk Ecotect software was used to evaluate sunlight hour distribution and determine shading effect or exposer area at building's rooftop.

3.5. Optimal sizing of HES using PSO

According to literature review, PSO is known to be the most used artificial intelligence meta-heuristic technics for solving sizing problems in HES (Twaha and Ramli, 2018). Therefore, PSO was used in this work to find optimal sizing of HES's components. In PSO, a set of particles or swarms which are described by their position and velocity vector fly through the search space by following the current optimum particle. In addition, two best values determine each particle's position. The first one is the best value that the particle has achieved so far and has been stored. This value is named as local maximum. Another one is obtained among the population so far, which is called global maximum. In addition, each particle has a position representing the value of variables and a velocity that directs the particle towards the local and global maximum. 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 main steps are as follows: (1) Initialization of particle' velocity and position for all the population, (2) Evaluation of the fitness of each particle, (3) Updating individual and global best fitness and position, and (4) Updating velocity and position of each particle. The process is repeated until some pre-defined criteria met, such as the number of iterations or predefined target fitness values are met. The position and velocity of each particle in the swarm are updated using the following Eq. 16-17 (Shara and Elmekkawy, 2014):

$$X_{k+1}^{i} = X_{k}^{i} + v_{k+1}^{i} \tag{16}$$

where X is particle position and v is particle velocity in iteration k:

$$v_{k+1}^{i} = [\omega v_{k}^{i} + C_1 r_1 (P_{k}^{i} - X_{k}^{i}) + C_2 r_2 (P_{k}^{g} - X_{k}^{i})] \tag{17}$$

where, V_{k}^{i}, called inertia, makes the particle move in the same direction and with the same velocity. The term $C_1 r_1 (P_{k}^{i} - X_{k}^{i})$ is called the cognitive component, and causes the particle to return to a previous position in which it has experienced higher individual fitness. $C_2 r_2 (P_{k}^{g} - X_{k}^{i})$, is called the social component, Pi is the best individual particle position and Pg is the best global position, C_1 and C_2 are personal (cognitive) and global (social) learning coefficients, respectively; r1 and r2 are random numbers between 0 and 1, ω is a coefficient. To determine ω, C_1, and C_2 the following coefficient must be calculated using Eq. 18-19 (Eriksson and Gray, 2018):

$$\varphi = \frac{2K}{2 - \emptyset - \sqrt{\emptyset^2 - 4\emptyset}} \tag{18}$$

$$\emptyset = \emptyset_1 + \emptyset_2 \quad \geq \; 4 \tag{19}$$

where φ is the constriction coefficient. Typically, $\emptyset_1$ *and* $\emptyset_2$ are set 2.05. Hence, ω, C_1, and C_2 are calculated using Eq. 20-22.

$$\omega = \varphi \tag{20}$$

$$C_1 = \varphi \cdot \emptyset_1 \tag{21}$$

$$C_2 = \varphi \cdot \emptyset_2 \tag{22}$$

3.6. Optimal sizing of HES with HOMER

HOMER software is a powerful tool for designing of HES in order to determine optimal size of its components through carrying out the techno-economic analysis. Many components such as WT, PV array, fuel cells, small hydropower, biomass, converter, batteries, and conventional generators are modelled in HOMER (Bahramara et al., 2016). HOMER can solve the optimization problem of HES in grid- connected and off-grid modes. HOMER design hybrid system according to the detail of cost parameters used in the system such as principal cost, substitute cost, operation & maintenance (O &M) cost (Sawle et al., 2018).

3.7. Energy management of HES

The configuration of the HES has different components and many components are of a dynamic type, such as conventional sources, renewable sources, DG and storage devices. It is therefore important to monitor each component. When applying a proper control strategy, an optimal solution can be obtained at high reliability and lower HES costs. In HES, the control system is necessary for monitoring and controlling different parameters according to load specifications.

3.7.1. Hybrid energy management strategy

The energy management strategy that is applied for all the thesis work followed the hybrid management strategy, which aims to satisfy the required load with taking into account both technical and economic criteria.

3.7.2. MAS for optimal management of Hybrid System

The optimal management of Hybrid System that should be robust, flexible. This thesis proposes a Multi-agent system (MAS) for home energy management and piloting. The agent-based systems employ distributed intelligence to solve complex problems and facilitate the implementation of multiple control algorithms for the household.

3.7.3. Demand Side Management

Demand side management (DSM) concerns measures taken on the consumers' side of the energy system, including improvements in energy efficiency, energy conservation and demand response (DR) (Ringkjøb et al., 2018). Demand Response (DR) is the procedure of shifting certain loads from hours when the demand is higher than the supply to hours with surplus generation. This helps balancing the fluctuating output from variable renewables, and is a good complement to energy storage. It also reduces the highest load peaks for which the electrical grid is designed, thus reducing the need of expensive grid-development. As an example, the charging of electric vehicles can be shifted from the peak in demand usually experienced in the afternoon to the night when the consumption is much lower. In terms of modelling, DR can be treated as a negative storage, by "storing" the demand rather than excess energy. It can also be modelled by shifting unmet flexible loads (e.g. charging EVs) to following time- steps. A third possibility is to model DR as a negative generating unit, with associated maximum capacities, costs etc.

3.8. Conclusion

This chapter provides a description of thesis methodology, which aims to optimal design of HES in different case study buildings under different climate of Algeria. Its main features include four steps: building energy simulation, MCDM analysis, size optimization and energy management of HES.

For the building simulation, TRNSYS and Energy plus software were used. In addition, AHP and ArcGIS tools are used to carry out MCDM analysis. However, for the size optimization of HES, PSO was used. Different energy management strategies are implemented to ensure the best operation of HES's components. Furthermore, most recent energy management strategies including DSM and multi agent system are defined and investigated in different topologies.

Chapter 4.

Pathways for Achieving Plus Energy Buildings in Algeria

4. Pathways for the optimal design of PEB in Algeria

4.1. Introduction

4.1.1. Background

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 (Hu, 2019). Residential buildings in Algeria consume about 38 % of the total (Bey et al., 2016). Since 97 % of energy consumption is based on fossil fuels (Haddah et al., 2017), Algeria is one of the most important CO_2 emitters among developing countries (Bouznit and Pablo-romero, 2016). 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 (V, 2018) and reducing GHG emissions by 80 % by 2050 (Blumberga et al., 2018). In addition, the 2010/31/EU, EPBD provides a set of binding energy efficiency strategies and sets the Nearly Zero Energy Building (nZEB) target for all new buildings by 2020 (Lisitano et al., 2018). Besides, in the U.S., Energy Independence and Security set a zero-energy target of 50% for new commercial buildings by 2040 (Cao et al., 2016). Similarly, in Algeria, the government has decided to diversify its energy sources by announcing the national program on renewable energy and energy efficiency (Bekkar et al., 2017). This program aims to achieve a share of renewable energy of 40 % of the total energy produced by 2030 (Belabes et al., 2015). 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 (Harkouss et al., 2018a). 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…etc. (Rabani et al., 2017) (Saleh et al., 2017)(Cabeza et al., 2018) (Lou et al., 2017). The strategies used to increase energy efficiency include insulation of the envelope, use of high-efficiency windows, using shading device, and renovation of the HVAC system. Design of smart and high-efficiency lighting and appliances. On the other hand, the introduction of renewable energy, namely solar photovoltaic/thermal (PV / T), wind and geothermal (such as ground source heat pump system) (Liu et al., 2019). 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..

4.1.2. State of the art review on PEB's design

Many studies have been conducted on this topic. Some studies focused on improving the energy efficiency in buildings. In (Lizana et al., 2016) the authors developed a multi-criteria method for environmental, economic and social assessment of different energy retrofit measures to improve the energy performance of a residential building. However, the study carried out by (Delgado et al., 2017) (Pallis et al., 2019) examined the cost-optimally and technical assessment of system solutions for the zero-energy target. Similarly, the study of (Corrado et al., 2017) proposed a new cost optimization procedure to identify energy efficiency measures that lead to the global minimum cost of transforming a school in Torino into a nearly zero energy building. In the same, (Matthew and Leardini, 2017)examined the socio-economic feasibility of effective retrofit strategies to improve the energy efficiency of older apartment buildings in Brisbane to achieve the net zero energy target. Besides, the author in (W. Wu et al., 2018) has studied how HVAC systems can be selected for cost-effective net zero energy in residential buildings. In the same context, the author of (Shirazi et al., 2018) reviewed solar chillers and found the use of present solar chillers cannot compete economically with conventional systems. However, the study (Gao et al., 2018) showed that ground heat exchangers (GHEs) have great potential to achieve the zero- energy objective. In addition, other works studied renewable energy sources selection and planning to achieve PEB. For instance, a Multiple Criteria Decision Making (MCDM) analysis through geographic information system (GIS) coupled to Analytical Hierarchy Process (AHP) have been used to model the solar photovoltaic potential and identify optimal sites (Huang et al., 2018)(Doorga et al., 2019)(Doorga et al., 2018). The author of (Sadiq et al., 2019) also proposed a multi-criteria method for selecting renewable sources for net zero energy communities. In addition, the study of (Tsalikis and Martinopoulos, 2015) examined the potential of solar energy systems in different locations for net zero energy residential buildings. The results showed that solar energy systems are a viable solution for achieving NZEB. In other studies, similar to (Nikolic et al., 2011), the author has worked on converting the Serbian residential building into a PEB based on a grid-connected PV system installed on the south-facing roof of the building. Despite this, the author in (Mohammadi et al., 2018) proposed an optimal planning approach based on a 100% on-site renewable energy system for a residential house. This study is similar to(Leonard and Michaelides, 2018) (Bingham et al., 2019), which studied the grid-independent residential buildings with renewable energy sources. However, such buildings have used a storage system that steel is not yet cost-effective. Further, the research of (Lu et al., 2018) explores the design improvement of RES by presenting penalty costs. The results discovered the owners of NZEB need to pay half of the first expense due to the introduction of penalty costs. Besides, there have been other studies in the literature that combine energy efficiency strategies and renewable sources. In (Dracou et al., 2017) The possibility of nearly ZEB in Cyprus was discussed by using innovative technology of energy efficiency and renewable. Similarly, the author in (Alajmi et al., 2016) has proved the possibility of converting a public building from an inefficient building into a net-zero energy building using efficient chillers and solar energy system on the roof. This study is similar to(Wu and Skye, 2018), which analysed the HVAC system powered by PV systems for residential net-zero energy buildings. However, the author in (Harkouss et al., 2018b) proposed a multi-target to find best solutions for building envelope design and renewable energy integration to achieve NZEB at different locations. The same, the author in (Albadry et al., 2017) proposed several retrofitting measures to increase the building's energy performance and using PV panels to cover rest demand to reach the goal of net zero energy in a residential building. In addition, the study (Hall and Geissler, 2017), proposed different balancing methods in which a single family building is designed as an NZEB with a 6.9 kW PV system on the roof. His results show the PV system is enough for the final energy and primary energy balance of NZEB. Also, in (Hejtmánek et al., 2017) a deep renovation of residential buildings to NZEB was carried out using prefabricated renewable material panels, including smart HVAC systems, completed with renewable energy sources.

Although the advantages and significance of existing studies, these deficiencies have been highlighted:

- No studies have examined the achievement of PEB at the entire of the country.
- Up to now, far too little attention has been paid to the policy aspects and social criteria. In addition, no research has been found that study spatial and temporal diffusion of plus energy buildings.
- Most of the published papers are focusing on retrofitting of the existing building stoke.
- No single study exists which considering the energy demand pattern (heat, electricity or the both). In addition, the variation of components' costs and energy demand in next years has not examined.

4.1.3. Objective and contributions

The aim of this work was to develop a new method for the design of plus-energy buildings in Algeria, considering various technical, economic, environmental and social criteria. The main contributions to this work are:

- Evaluate the overall country's annual energy demand.
- Select the best passive and active strategies to build more energy.

- Identify high potential locations for constructing new plus- energy buildings.
- Giving pathways to the spatial and temporal diffusion of energy- energy buildings in Algeria.
- Evaluating method's contribution to overall energy consumption and GHG emissions.

Three renewable energy sources are examined, namely solar, wind and geothermal energy. However, to improve the building's performance, the following energy efficiency measures were proposed: improving envelope insulation, upgrading the HVAC system and appliances. In addition, many scenarios have been discussed until 2030.

4.2. Materials and methods

This work proposes an alternative method for designing plus-energy buildings in Algeria. The method is based on spatial analysis and multi-criteria decision-making. The proposed method aims to select the most strategies and solutions for achieving PEB in Algerian territory. From the definition of plus energy buildings, we have to increase the building energy efficiency at first step, and then we exploit onsite renewable sources to provide the required energy of the building. Firstly, we select a detached residential building. Hence, we estimate the annual demand of this building. The energy consumed by the selected building is for heating, cooling, domestic hot water, cooking, Lighting and appliances. We have used TRNSYS to assess the annual heating and cooling demand for standard and optimized envelop. After, the annual production of renewable sources is evaluated based on the climate data provided by Algerian meteorological stations. Thus, a geographic Information System (GIS) software was used to achieve certain spatial calculations. Finally, the energy balance between energy demand and supply were investigated, and many scenarios have been discussed considering several criteria. The flowchart of our methodology is shown in Fig.13.

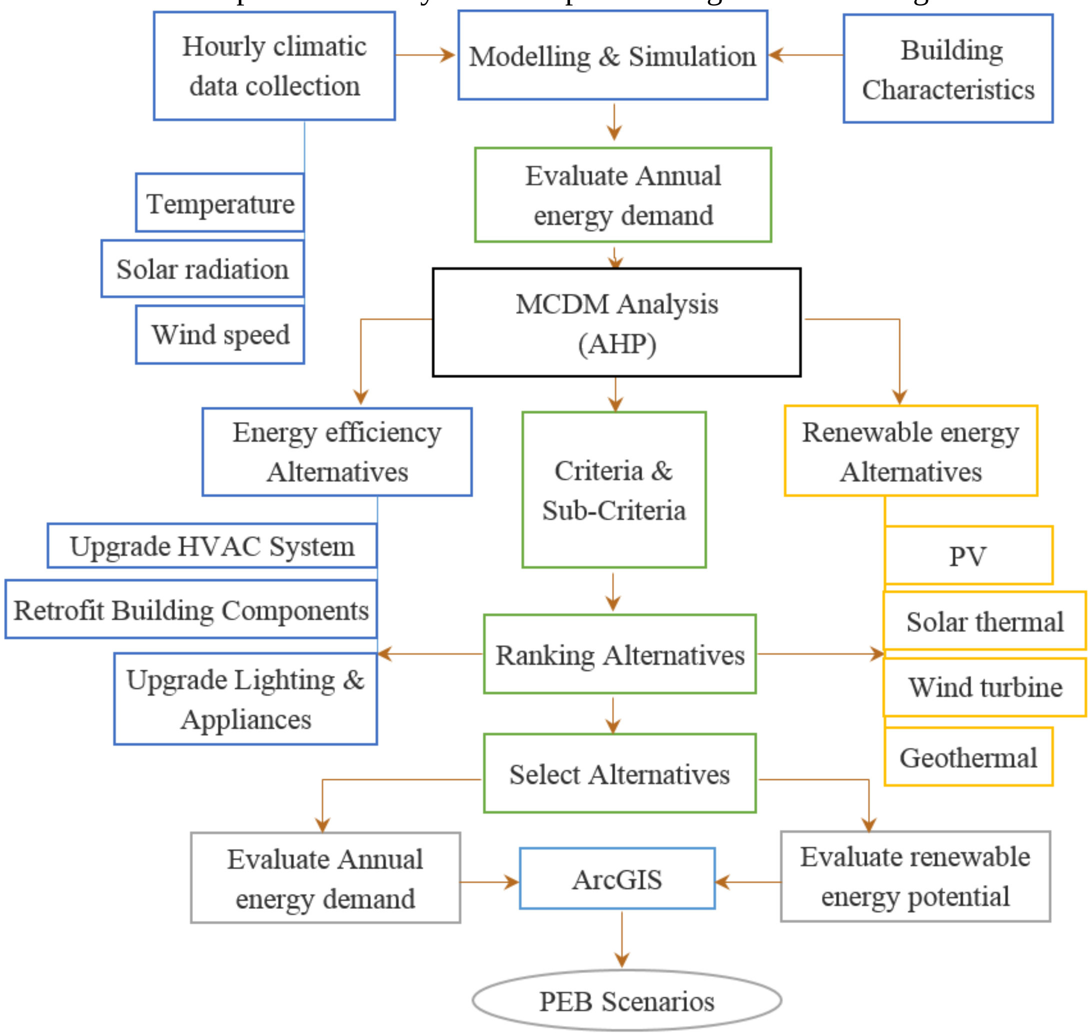

Figure 13. Flowchart of the methodology.

4.2.1. Site description and data collection

Algeria is the gate of Africa and Africa's largest country with an area of 2,381,741 km² (Gouareh et al., 2015b), where Sahara occupies 86 % of its total area. Algeria has a strategic location in the north facing Europe. It is situated between the 35° and 38° of latitude north and 8° and 12° longitude east. It is divided into 48 provinces. The country is bordered from the north by the Mediterranean Sea, to the south by Mali and Niger, to the East by Tunisia and Libya, to the west by Morocco, Western Sahara, and Mauritania (Bouraiou et al., 2019). In 2018, the population has exceeded 42.2 million people. Over 90 % of them spread over 10 % of the national territory(Bekkar et al., 2017). The number of population and households for Algeria and for each Algerian province (48 provinces) between 2018 and 2030 has been assumed, based on ONS statistics (Office National des Statistiques (ONS), 2008) and UN reports (Nation, 2018). The number of households' projections until 2030 are shown in Fig.14.

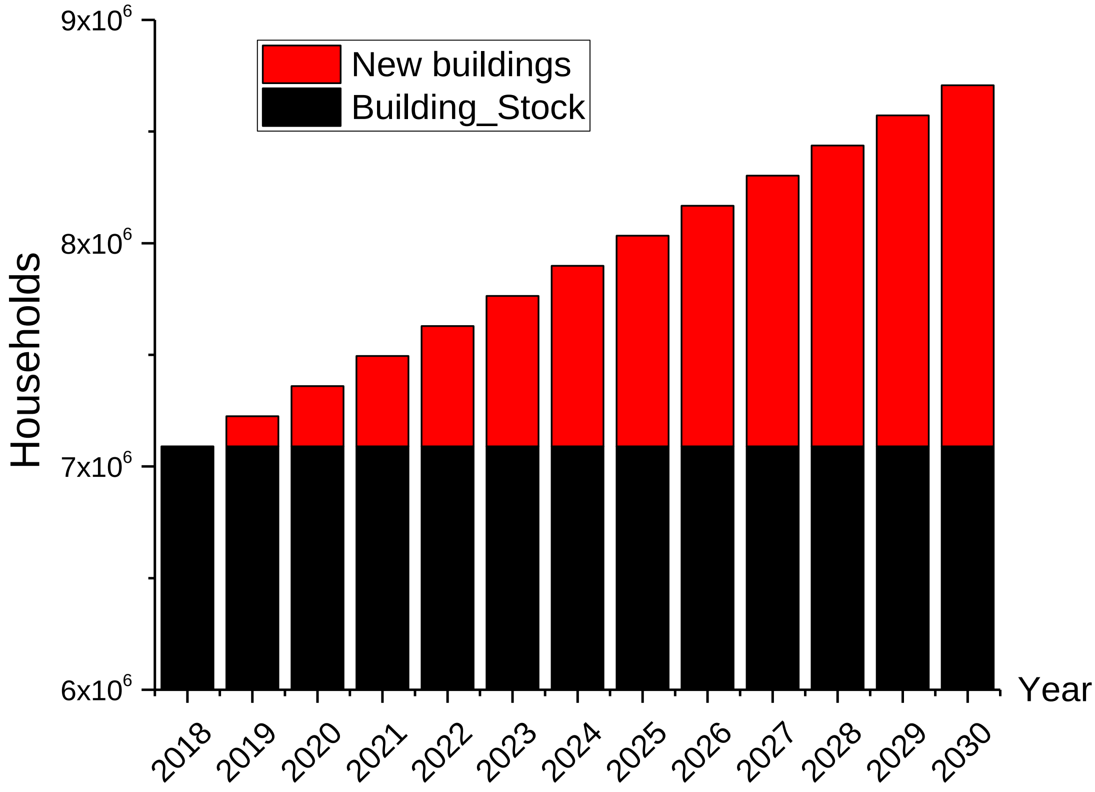

Figure 14. Number of households' projection.

The required data for this work have been extracted from Metronome 7. Only 40 climate stations are available in a software database. Therefore, the interpolation of the entire area for all the data is carried out. The main climate resources are the annual average temperature, solar radiation, and wind speed. The distribution of climatic stations, annual average temperature, annual average wind speed, and annual global radiation of Algeria were presented in Fig.15, Fig.16 and Fig.17.

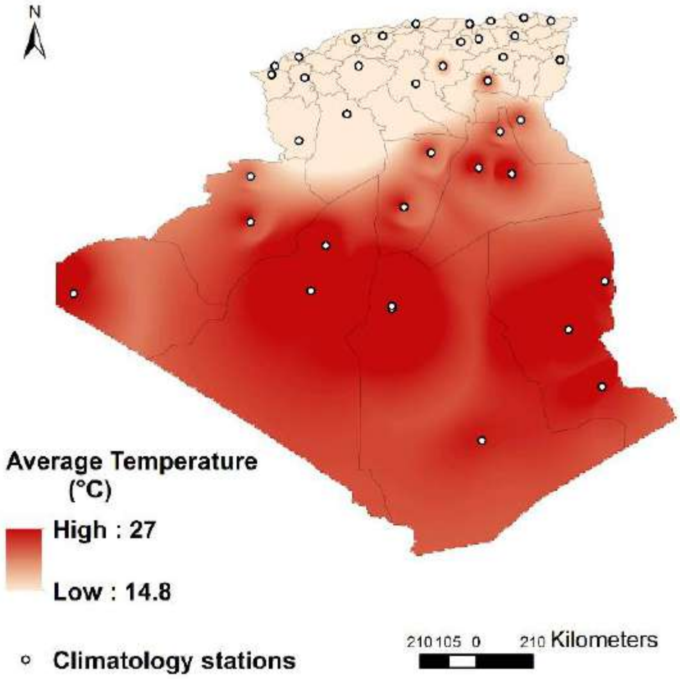

Figure 15. Annual average ambient temperature.

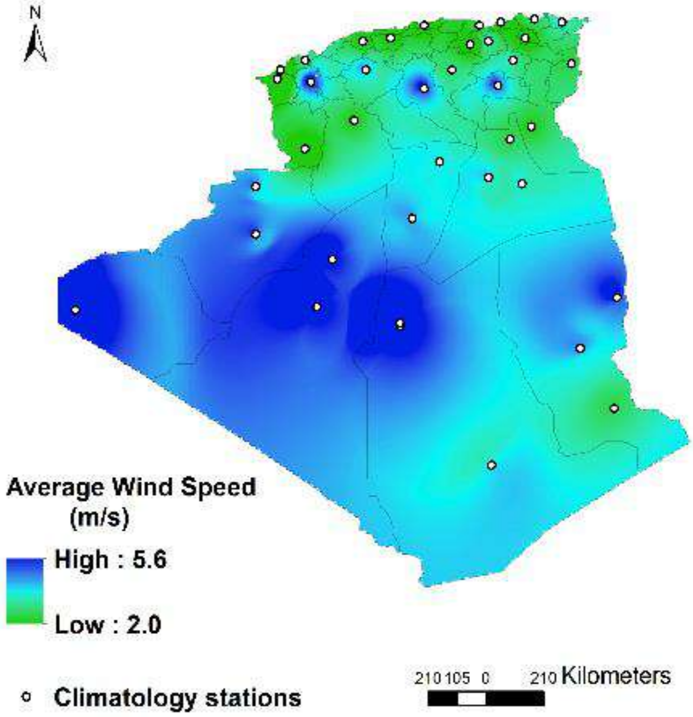

Figure 16. Annual average wind speed.

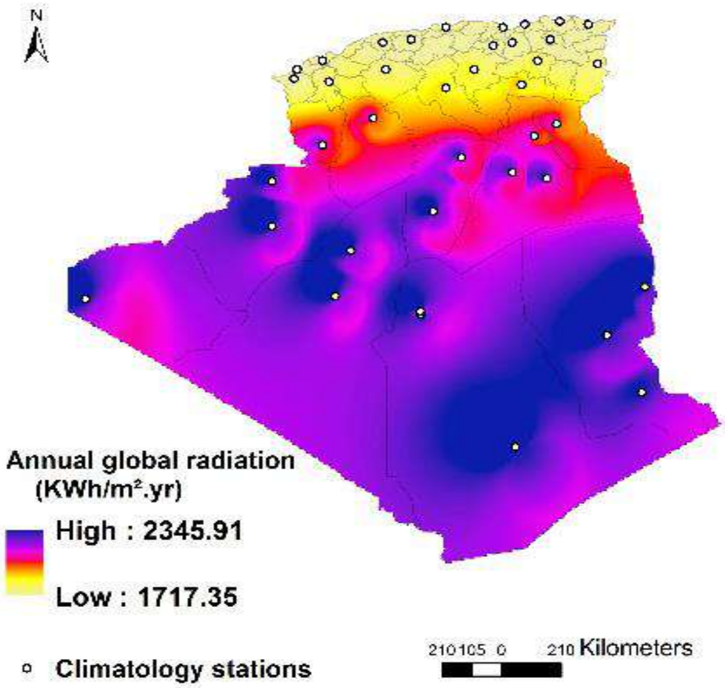

Figure 17. Annual global radiation.

4.2.2. Building description

A typical residential building (F2) according to Algerian standards of construction has been selected. The plan and parts of the building with a square area of 64 m² are shown in Fig.18. In addition, the main features of the building envelope were shown in Tab.6.

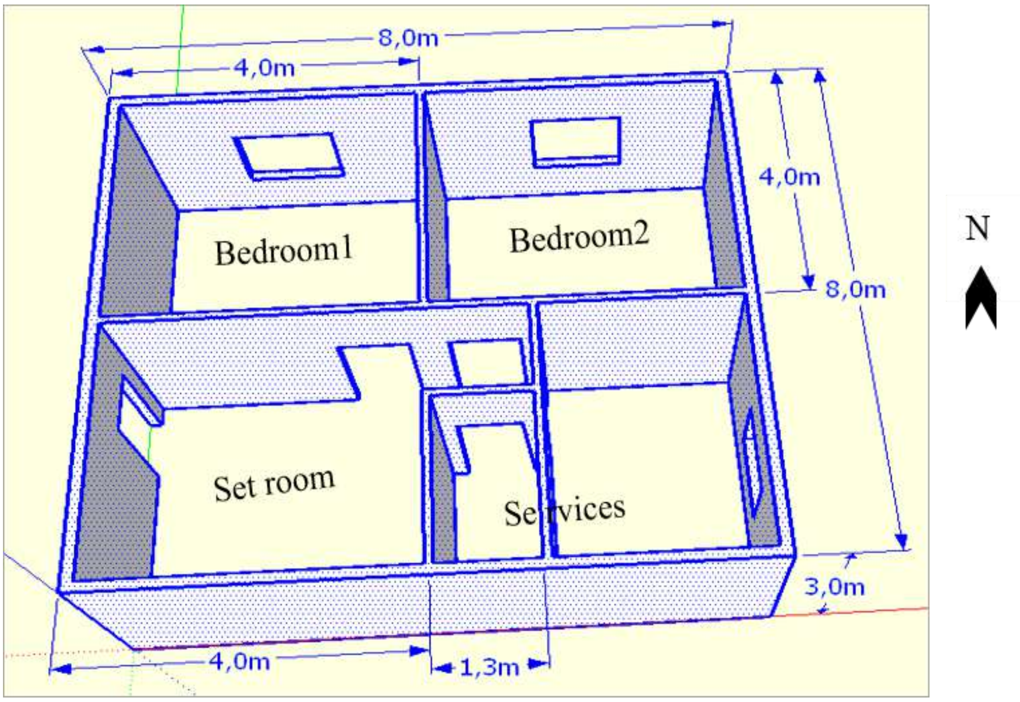

Figure 18. Sketch of the selected building.

Table 6. Envelop characteristics before and after renovation

Wall type	Before Renovation (from inside to outside)	Thickness (m)	After Renovation (from inside to outside)	Thickness (m)
External & Internal wall	Cement	0,01	Cement	0,01
	Brick	0,1	Brick	0,1
	air	0,05	Insulation	0,05
	Brick	0,1	Brick	0,1
	Cement	0,01	Cement	0,01
	Overall Resistance (m²°k/W)	0,547	Overall Resistance (m²°k/W)	2,084
	U value (W/m²°k)	1,827	U value (W/m²°k)	0,48
Roof	Cement	0,01	Cement	0,01
	Ceiling bloc	0,16	Ceiling bloc	0,16
	concrete	0,04	concrete	0,04
	/	/	Insulation	0,05
	Bitumen	0,02	Bitumen	0,02
	Overall Resistance (m²°k/W)	0,259	Overall Resistance (m²°k/W)	1,926
	U value (W/m²°k)	3,863	U value (W/m²°k)	0,519
Floor	Gerflex coating	0,003	Gerflex coating	0,003
	concrete	0,1	concrete	0,1
	Insulation	0,04	Insulation	0,04
	concrete	0,1	concrete	0,1
	Overall Resistance (m²°k/W)	1,457	Overall Resistance (m²°k/W)	1,457
	U value (W/m²°k)	0,686	U value (W/m²°k)	0,686

4.2.3. Assessing energy demand for the building

4.2.3.1. Energy demand for space cooling and heating

TRNSYS software has been used to assess annual space heating and cooling energy demand. The set temperature for cooling and heating are 26 ° C and 21 ° C respectively (Cherif and Mejedoub, 2018). The TRNSYS model of the building is presented in Fig.19.

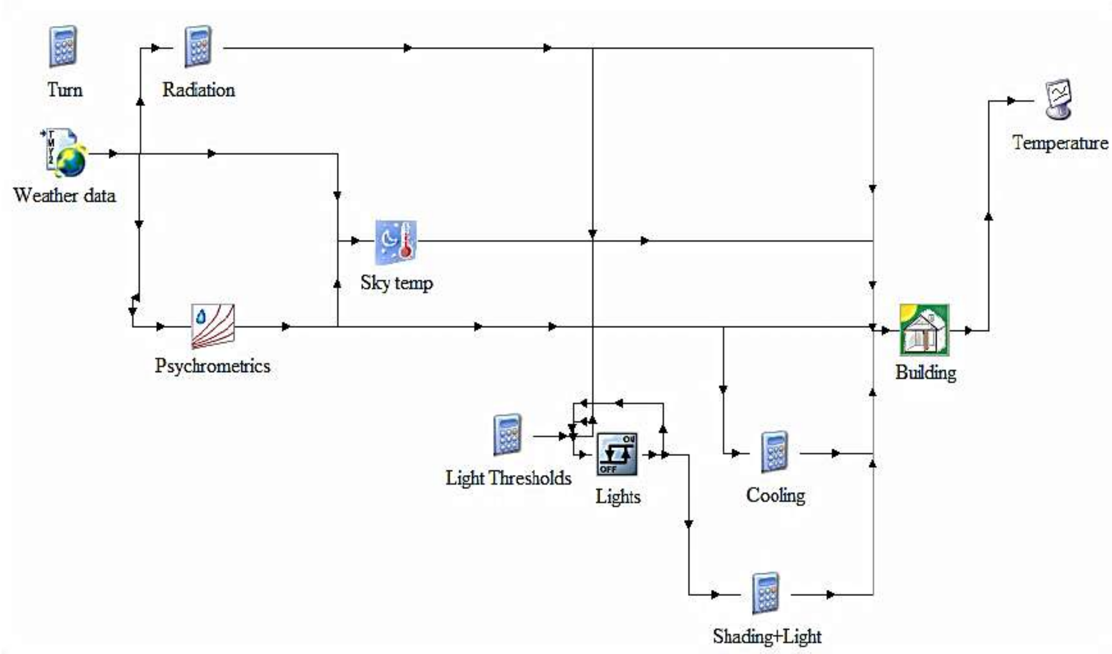

Figure 19. Sketch of the selected building.

Annual electricity and NG consumption have therefore been calculated using Eq. 23-24. The efficiency of the gas boiler η_{boiler} is 0.93. The performance coefficient of the air conditioner was taken 2.5 (Ghedamsi et al., 2015).

$$Electricity \text{ demand} = \frac{Energy \text{ demand for space cooling}}{\text{COP}} \tag{23}$$

$$NG \text{ demand} = \frac{Energy \text{ demand for space heating}}{\eta_{boiler}} \tag{24}$$

4.2.3.2. Energy demand for cooking, lighting, and appliances

The average annual cooking demand for a single-family home in Algeria is around 7,925 KWh per year. The annual energy consumption of lighting and equipment is 2400 KWh per year (Ghedamsi et al., 2015). However, after the renovation, the energy consumption of lighting and appliances was assumed 1788 KWh / yr.

4.2.4. Renewable energy sources

4.2.4.1. Solar PV

One of the main applications of distributed energy is the installation of photovoltaic panels on the building roof (Talavera and Mu, 2019). This system offers many advantages, including cost-effectiveness, technological potential, capacity, accessibility and zero emissions(Rathore et al., 2019). Recently, PV modules prices have fallen by 80 %, and are expected to continue to fall in the coming years (Al Garni and Awasthi, 2017). The residents often have plenty of roof area (Chen et al., 2018). In this study, a solar rooftop system was proposed.

In this study, two PV panels were used. The first is a standard PV efficiency panel of 15.5 %. The second is a 22 % high-efficiency PV panel, which is expected to be on the local market by 2030. In this study, the average initial investment cost per KWp of a residential PV system of less than 10 KW of capacity ranges from $1100 to $1700/KWp (Talavera and Mu, 2019) (Mohammadi et al., 2018). The investment/replacement cost of both PV panels is $ 1382/kW. The operating and maintenance costs are $ 88 per year (Maatallah et al., 2016). 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. The technical specification of selected panels are given in Tab.7.

Table 7. Technical specification of solar panels

Model	Standard PV: TSM-300PE14A_SiPoly	High-Efficiency PV: SPR-X22-360-SiMono
Efficiency (%)	15,46	22,1
Nominal Power (Wp)	300	360
Icc (A)	8,77	6,43
Voc (V)	45,4	70
Impp (A)	8,28	6,05
Vmpp (V)	36,23	59,52
Temperature coefficient of power (%/°C)	0,0044	0,0027
Module area (m²)	1,94	1,631

4.2.4.2. Solar Thermal

In this work, solar thermal collectors were used for producing heat for space heating and domestic hot water. The TSOL software was used to simulate the solar thermal system. First, TSOL assesses the demand for domestic hot water (DHW) based on the average daily demand for water and temperature of supply. Besides, space heating demand was imported from TRNSYS. A DHW solar heating system and a buffer space heating system (Type A.5) were chosen here as shown in Fig.20. A flat plate collector with an efficiency of 77.6 % and a surface area of 1 m2 was used.

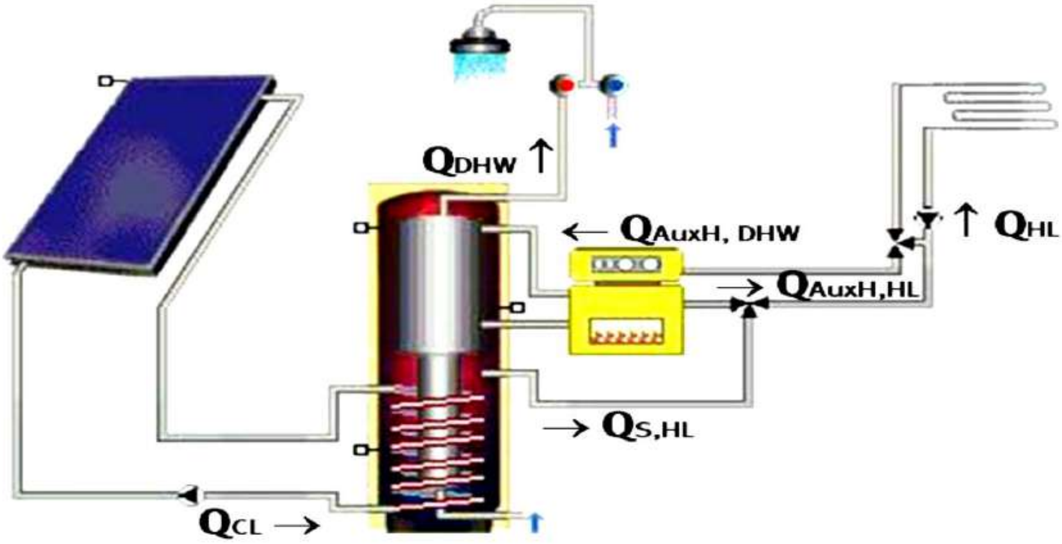

Figure 20. Thermal Solar system.

For building application, PV panels can generally be placed directly on the roof at optimum inclination. Therefore, for flat roofs, it is important to study the distance between the panel rows to avoid inter rows shading. The greater the distance between the rows is, the fewer hours in a year the panels will be shaded by a row in front of them (Verso et al., 2015).The minimum distance of mounted panels is calculated on the condition that the panels should not shade each other at 12.00 pm on the winter solstice. The suggested distance is a function of the tilt ß (beta), the solar angle γ (gamma) at 12.00 pm 21/12, and the installation height (b) of the panel as shown in Fig.21. Hence, the minimum distance between rows d, and the free distance d1 between the panels are calculated for each location.

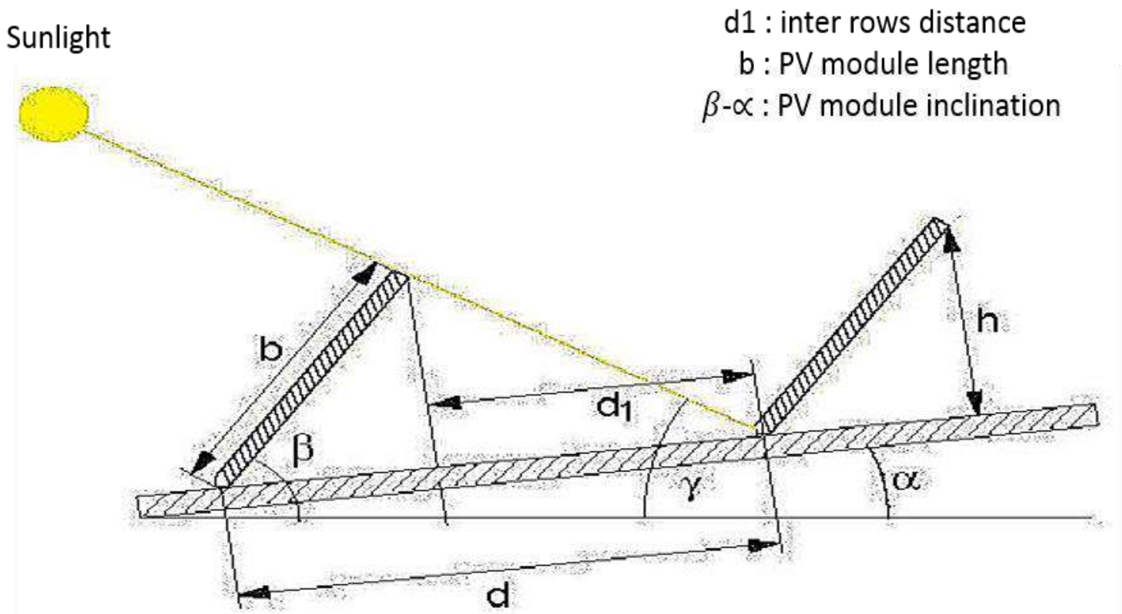

Figure 21. Calculation of the distance to avoid inter rows shading.

4.2.4.3. Wind Turbine

Sky Stream 3.7 small scale WT was used in this study. This model's rated capacity and swept area are 2 KW and 10.87 m² respectively. The investment / replacement cost of the WT is 2600 $/kW. The operating and maintenance costs are $ 160 per year (Amrollahi and Bathaee, 2017). The WT's lifetime is 25 years.

4.2.4.4. Geothermal energy

In this study, an Earth to air heat exchanger (EAHE) has proposed. This system uses the Earth's underground soil temperature. This system uses the soil temperature of the Earth. EAHE can be used for space heating or cooling(Lund and Boyd, 2016). Many studies have shown that EAHE is feasible in Mediterranean climates and in hot-dry climates (Khabbaz et al., 2016). In this paper, EAHE was used for cooling. According to the literature, EAHE is more useful in hot climates such as Adrar than in cold climates or in Mediterranean climates such as Oran (Cherif and Mejedoub, 2018)(Benzaama et al., 2018)(Menhoudj et al., 2018)(Benhammou et al., 2015)(Hacene et al., 2015). The efficiency of AEHE was achieved elsewhere in the country based on these results and the annual average temperature.

4.2.5. Economic and environment evaluating indices

4.2.5.1. Cost of energy

In this work, the economic comparison between renewable energy technologies was made based on cost of energy (COE), which is commonly used (Rubert et al., 2019). HOMER software was used to evaluate this parameter. Here, COE was calculated with real discount rate of 6% and project lifetime of 25 years. In Algeria, most of the residential buildings have been connected to the national utility grid (electricity and natural gas source). In Algeria, the real unit cost of electricity is $0.247 per kWh. However, the unit cost of natural gas is $0.085/KWh (Ghedamsi et al., 2015).

4.2.5.2. CO_2 emissions

CO_2 emission has been the main source of global warming. The amount of carbon dioxide that is emitted from natural gas is about 0,22 kg / kWh, however, electricity grid generates more than 0,5 kg / kWh (Amponsah et al., 2014). Hence, based on these two emission factors, the amount of emitted or avoided CO_2 was evaluated.

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

In this work, AHP is used to select best solutions for achieving PEB. Several economic, environmental, technical and social criteria are considered to compare between available alternatives. Besides that, ArcGIS 10.2.2 was used to determine optimal sites for implementing

PEB. In Tab.8, the criteria and sub-criteria used in this study were defined, most of which are reported in the literature and in the country's official publications.

Table 8. Criteria and sub-criteria definition.

Criteria	Definition
Capital Cost	Is the system's initial investment cost ($)
Lifetime	The time a system is to be maintained
Local Market Availability	It refers to the availability of the system, i.e. the system available locally or imported
Ease installation	i.e. it is easy or difficult to set the system
Share on GHG mitigation	The contribution of the proposed solution to the GHG reduction
Share on thermal comfort	The contribution of the proposed system to thermal comfort
Water use	Using water is a constraint because using water to operate energy systems can influence human needs
Public acceptance	It refers to the public's desire to use such a system, it depends on several factors
Job created	I.e. if the system can create jobs on the site where this system will installed
Cost drop of the system	I.e. the cost of the system will decrease in the next few years, depending on many factors
Contribution to Cost reduction	In Algeria, electricity costs are extremely high compared to NG, so selecting a system that replaces electricity supply is better than a system that replaces NG.
Average Efficiency	The average efficiency of the system which indicates the performance of the system
Capacity factor	The ratio of the actual electrical energy output over a period to the maximum electrical energy output possible over that period
Required area	The area or land use required to install the system
Contribution to Energy efficiency	The contribution of the supply source to minimize energy consumption for space cooling and heating (i.e. the co-benefit of the system)
Urban area feasibility	the system's feasibility in urban areas considering system noise and safety

4.3. Results and discussions

4.3.1. Results of multi-criteria decision-making

The results of the MCDM analysis for selecting energy performance measures are shown in Fig.22.

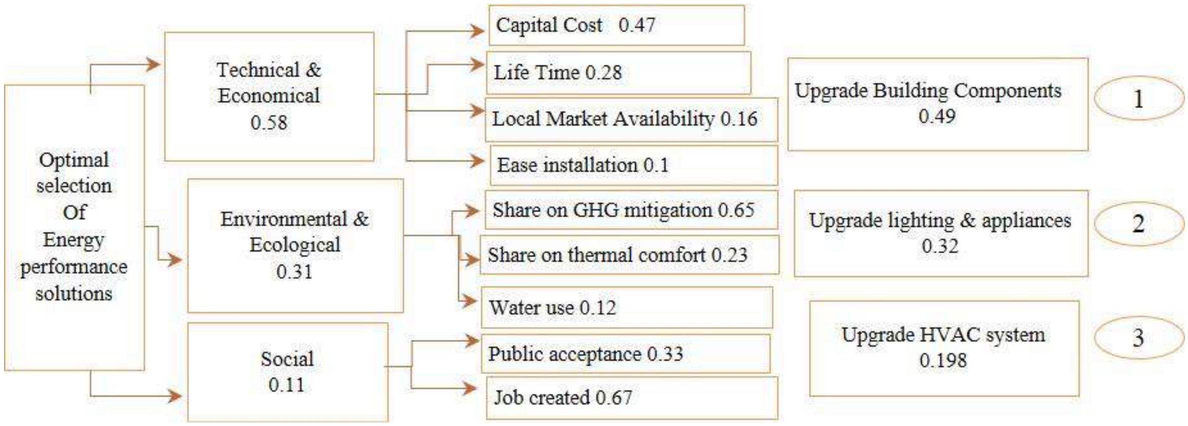

Figure 22. Results of MCDM method for selecting Energy efficiency measures.

The results showed that adding insulation layers to the envelope is the first step to increase the building's performance. The use of high-efficiency appliances also has a remarkable effect. However, upgrading the HVAC system is not feasible at present. Although, EAHE and absorption chiller must be introduced in new constructions. Besides, Fig.23 presents the results of the ranking of renewable sources. The results showed that solar energy, including solar photovoltaic and thermal collectors, is classified the first among other available sources in Algeria, followed by wind then geothermal energy.

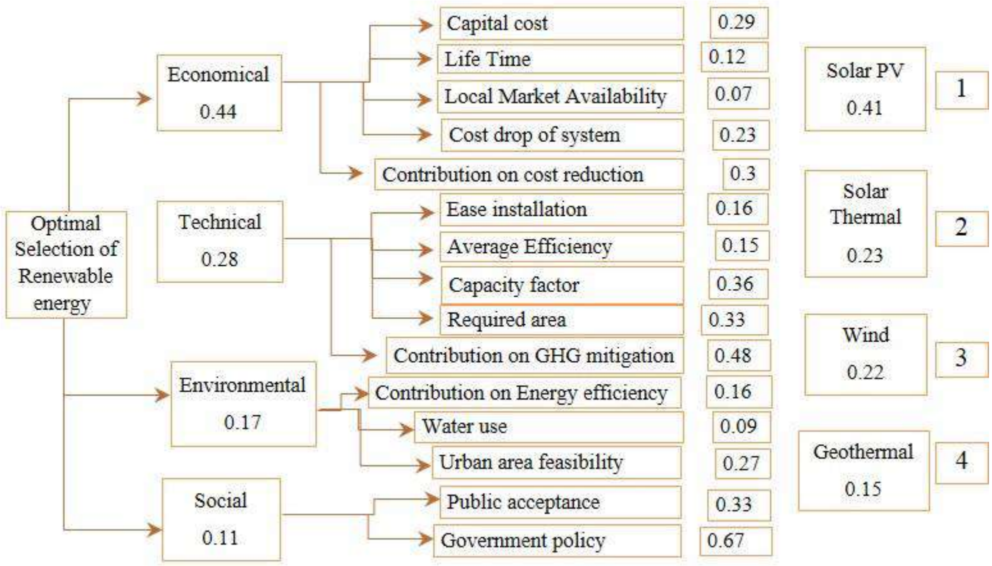

Figure 23. Results of MCDM for the ranking of renewable energy sources.

4.3.2. Effect of energy performance measures on building's energy demand

Based on results, adding insulation to the roof and walls was performed. Further, the lighting and appliances were upgraded and replaced with high-efficient appliances. Fig.24 presents the energy consumption for space heating and cooling before taking any renovation. Fig.25 has shown the annual demand for space heating and cooling after renovation. Hence, Fig.26 showed the global annual demand of the building before and after renovation.

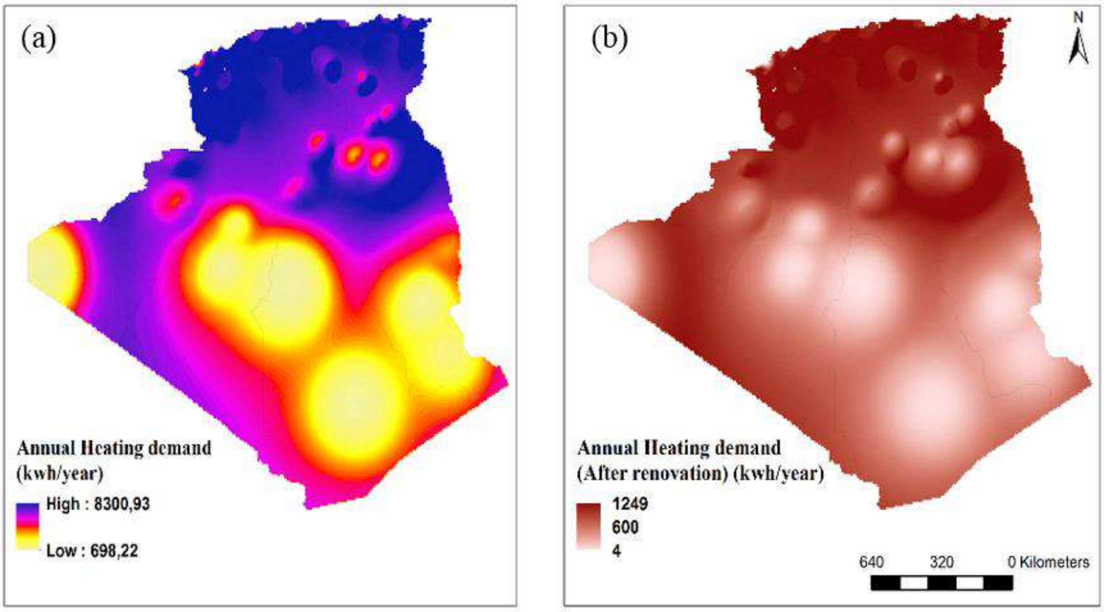

Figure 24. Annual energy demand for heating: (a) Before renovation; (b) After renovation.

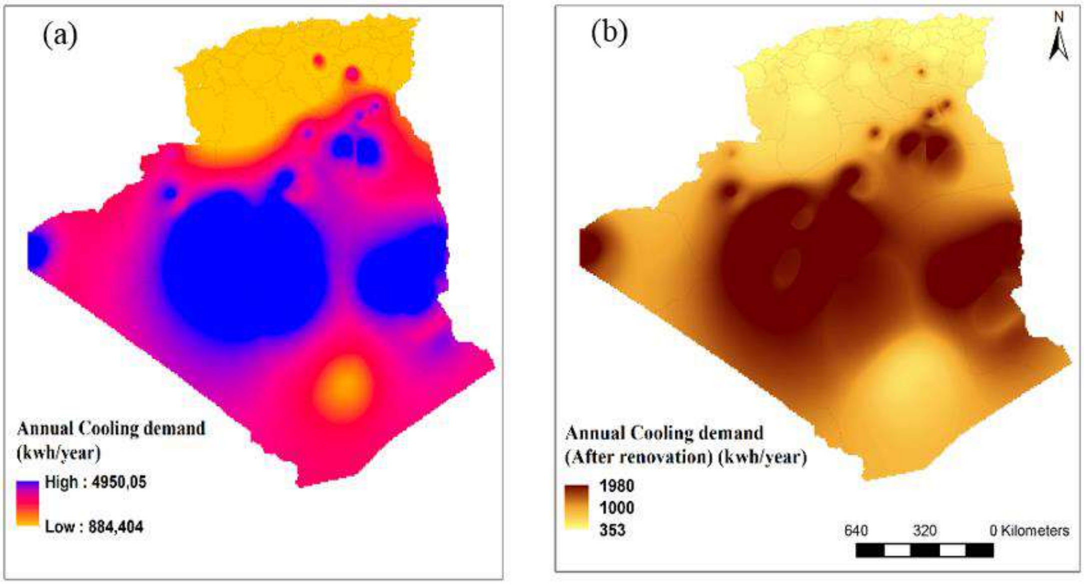

Figure 25. Annual energy demand for cooling: (a) Before renovation; (b) After renovation.

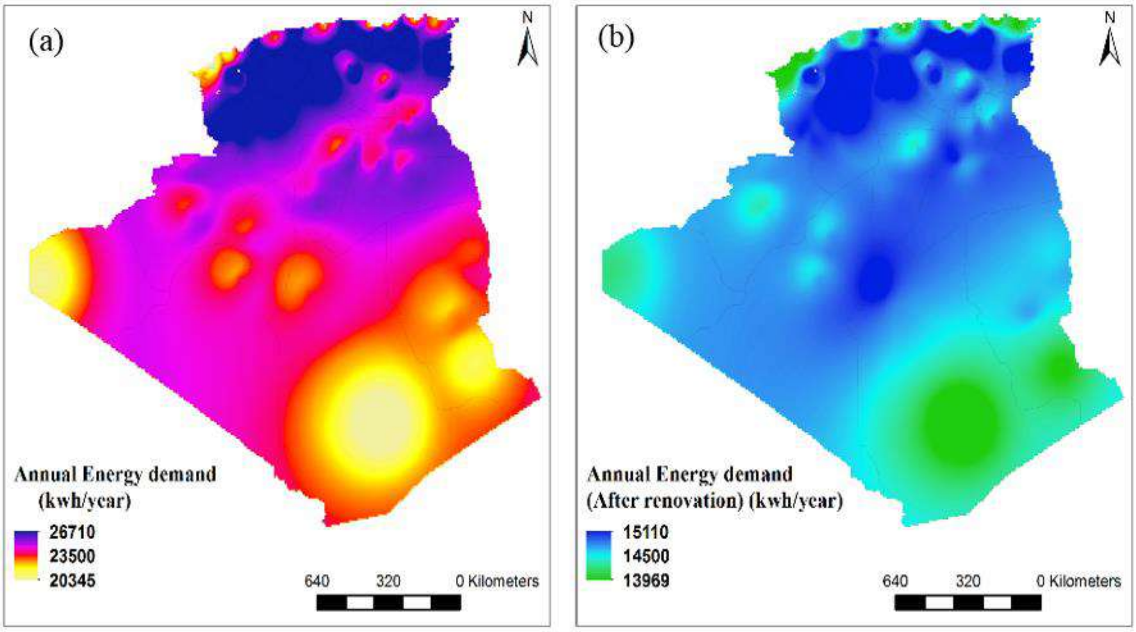

Figure 26. Total annual energy demand of building: (a) Before renovation; (b) After renovation.

The maps show that the energy demand for cooling is high in the southern locations. Despite the southern areas, the demand for heating is the highest. However, after introducing energy efficiency measures, the demand for heating and cooling are decreased dramatically. The results have shown that the annual demand of the building after renovation has decreased dramatically. Because using a high-performance envelope, LED lighting and efficient appliances.

4.3.3. Results of achieving PEB after integrating renewable energy solutions

After reducing building demand through applying set of energy efficiency solutions, two scenarios were proposed for constructing plus-energy buildings. The first scenario is based on current data, whereas the second scenario represents future data. In both cases, the energy balance is achieved between renewable energy sources and energy consumption. The results of the two scenarios are shown in Fig.27 and Fig.28.

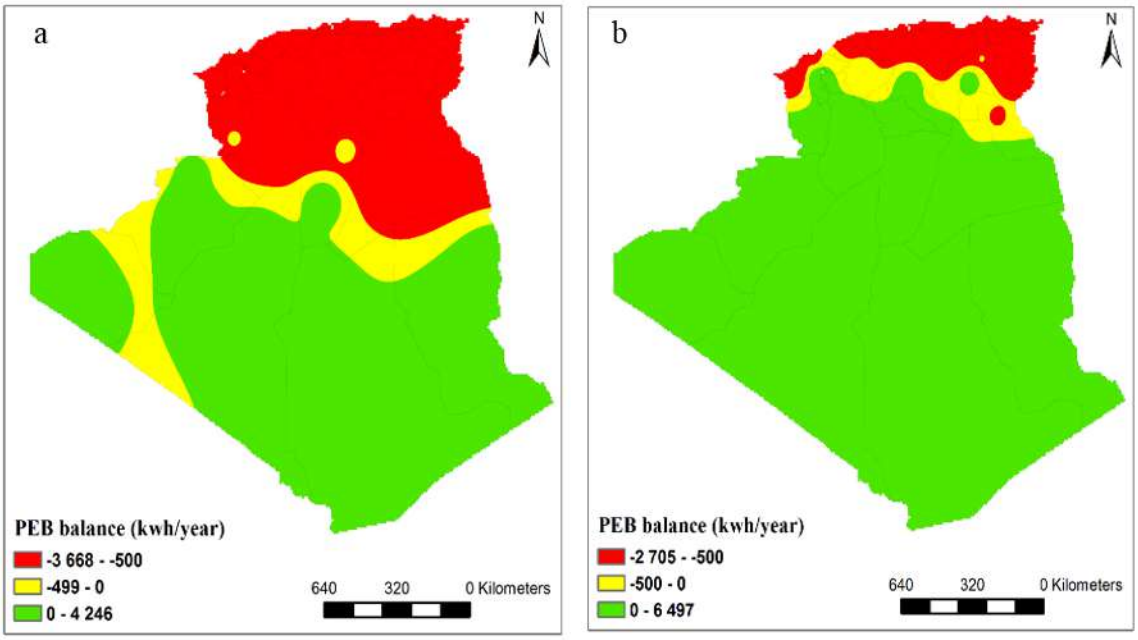

Figure 27. PEB balance; (a) using Solar Thermal/Standard PV; (b) using Solar Thermal/Standard PV/WT.

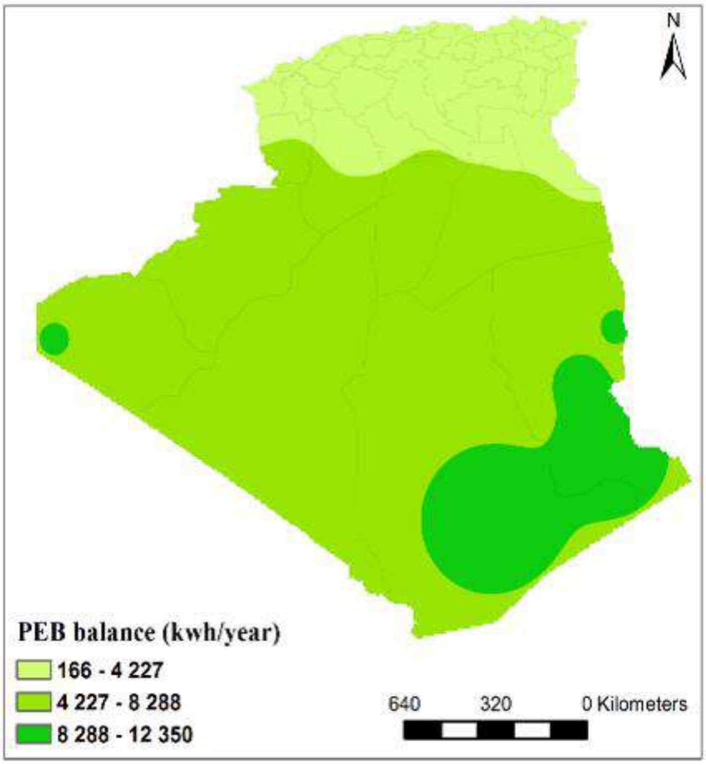

Figure 28. PEB balance based on future data (using solar thermal/High-efficiency PV panels).

The maps showed that the plus- energy target has been achieved in the Sahara for all configurations. In addition, the energy-plus target for all areas of the country can be achieved by using highly efficient PV panels by 2030. Therefore, the diffusion of plus-energy buildings in Algeria depends heavily on the efficiency of PV panels.

4.3.4. Suitable locations for plus energy buildings

ArcGIS was used to identify the appropriate locations for the installation of new buildings with a plus- energy target based on the selection criteria and their weights. The maps of all criteria taken in this study are shown in Fig.29, Fig.30 and Fig.31. The AHP was used to determine the weights of eight selected evaluation criteria. The weights of criteria are given by Tab.9. Following the raster calculation, the results are shown in Fig.32.

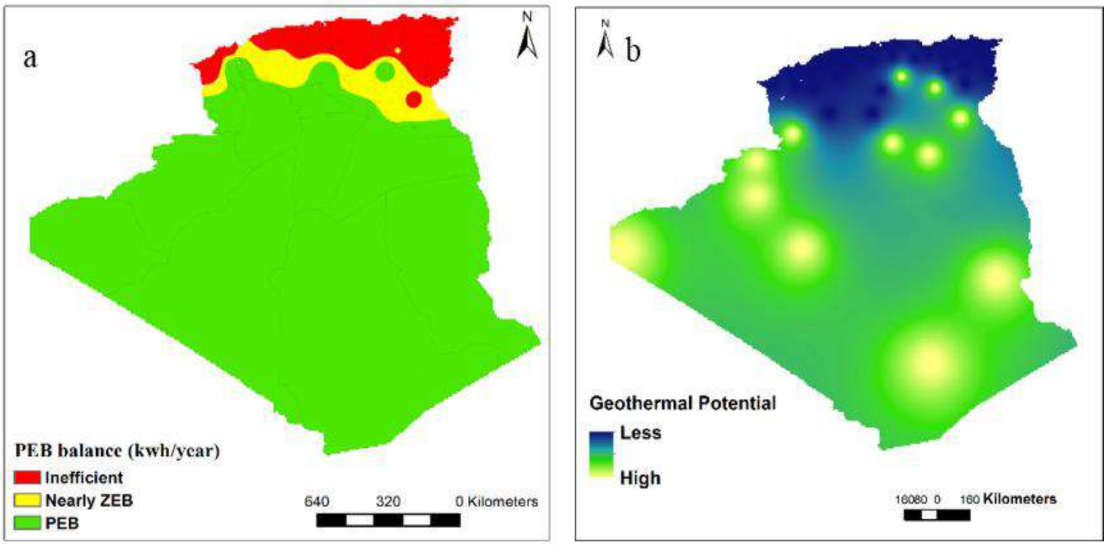

Figure 29. Technical Criteria; (a) plus-energy balance; (b) Geothermal energy efficiency.

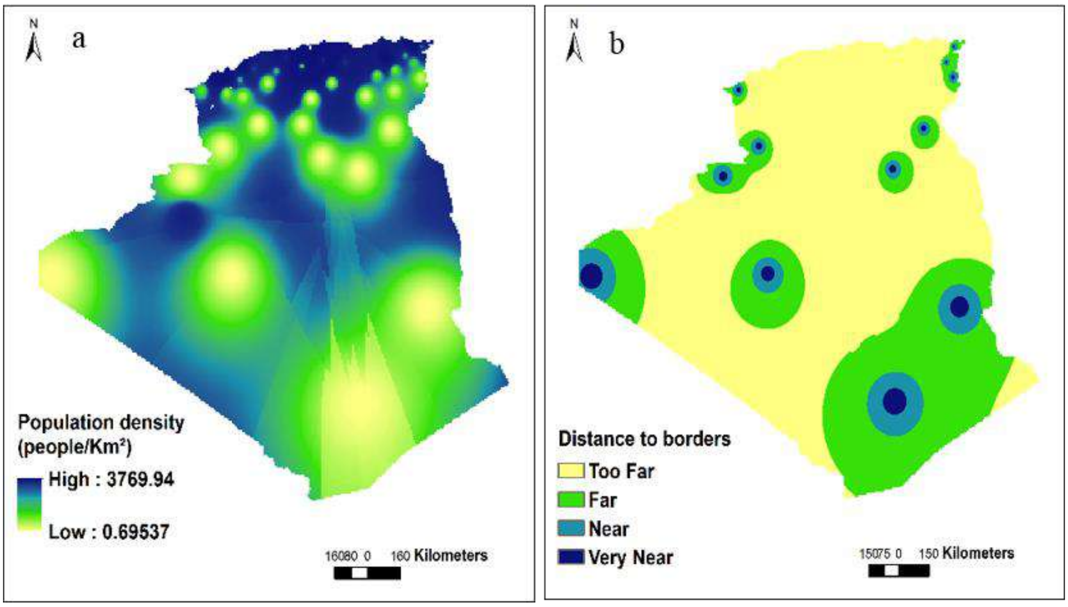

Figure 30. Social Criteria; (a) Population density; (b) Distance from borders.

Table 9. 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

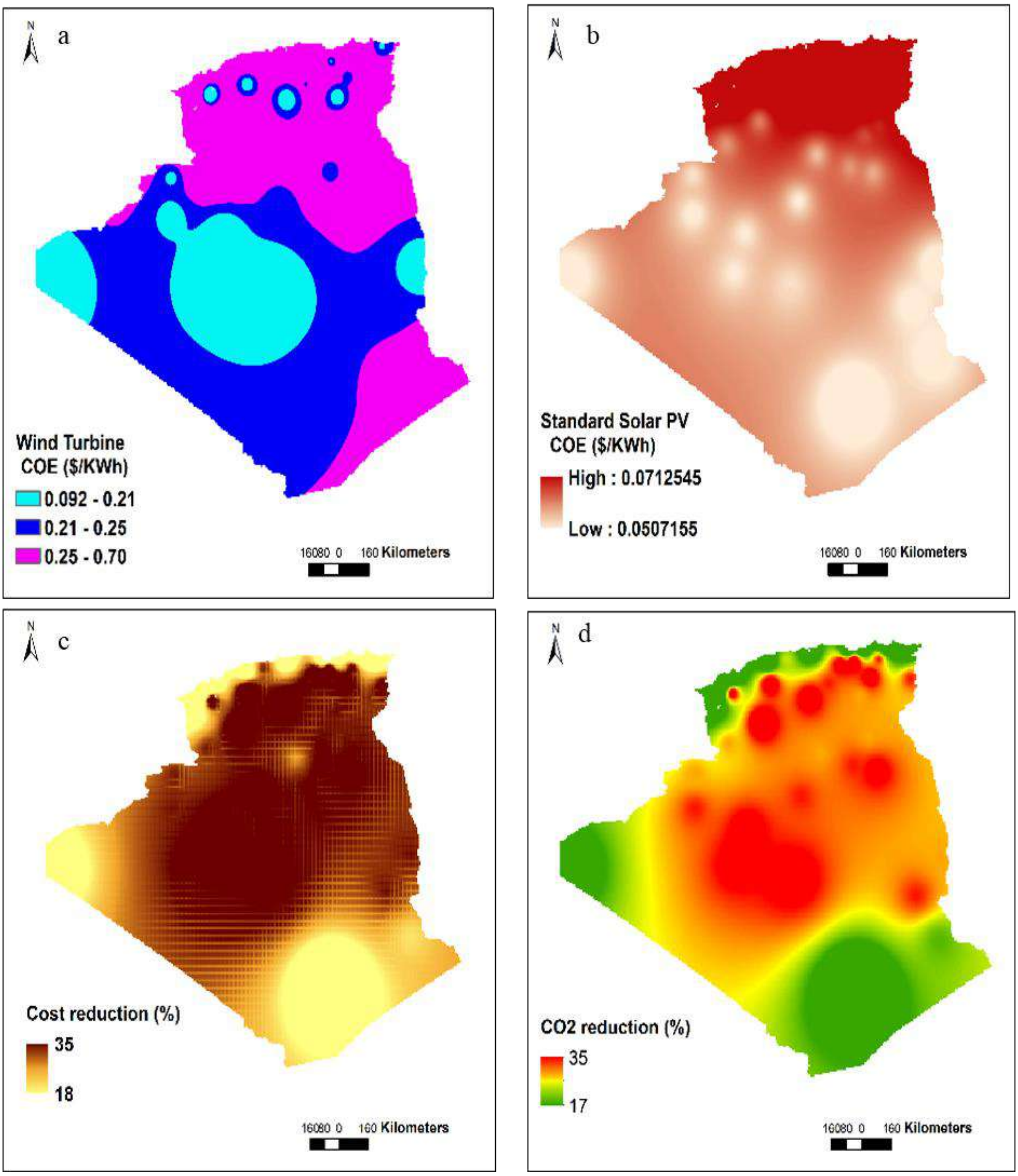

Figure 31. Economic Criteria: (a) COE of WT ; (b) COE of PV ; (c) Overall Cost reduction; (d) Environmental Criteria (CO_2 emission).

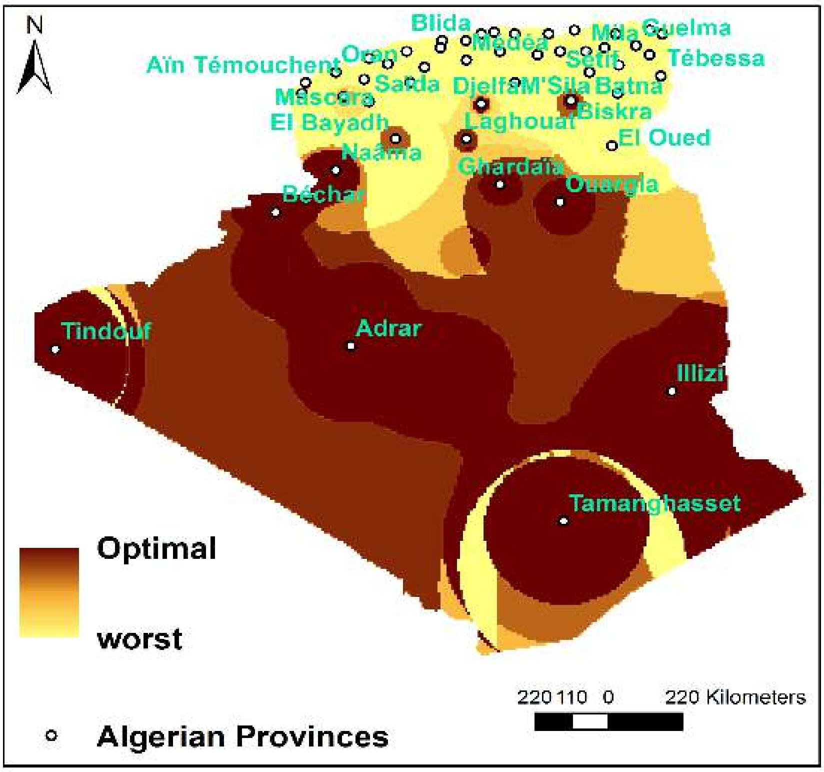

Figure 32. MCDM result of optimal locations for achieving new plus-energy buildings.

The results showed that the best places are in the Sahara of the country, which has great potential to build new buildings according to the concept of plus-energy buildings with satisfying all criteria. Excessively, Adrar, Tamenrast, Ouargla, Tindouf, Bechar, and Illizi are the key provinces for Algeria to move towards high-security energy.

4.3.5. Estimating the global energy reduction and GHG reduction

A road map scenario was proposed to test the efficiency of the method. For existing buildings, 50% of the Algerian building stock should be renovated in each province before 2025 and the remainder completed by 2030. By 2030, 20% of existing buildings in the best locations must be plus energy buildings. However, all new buildings must be nearly zero energy buildings. In which, 25 % of new buildings in the best locations (provinces) must be plus-energy buildings before 2025. By 2030, over 40 % of new buildings must be PEB. Fig.33 showed the energy demand projection and demand reduction for the overall buildings of the country by following this scenario.

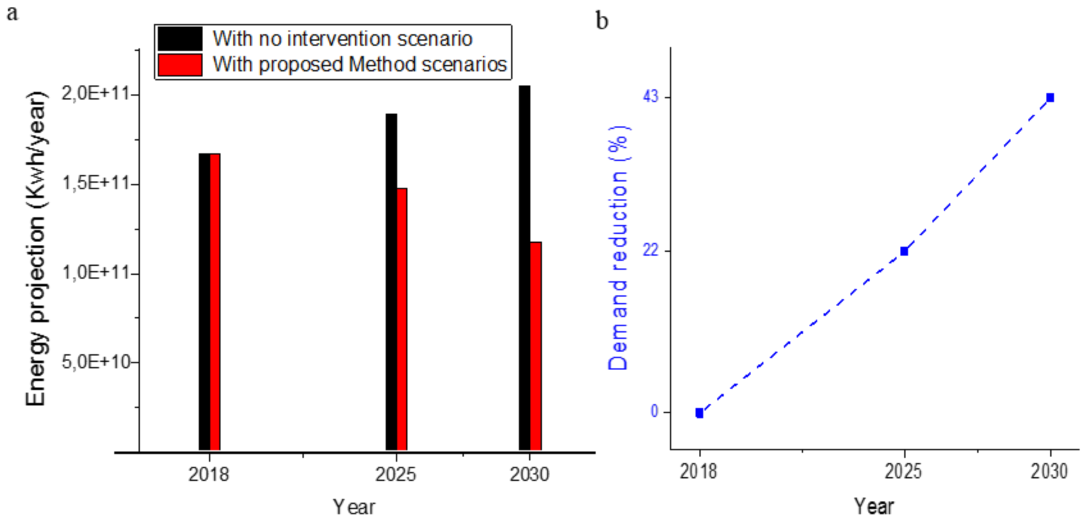

Figure 33. (a) Energy demand projection; (b) Demand reduction.

The figures showed that applying the proposed method allows reducing the overall energy demand by 43% and decreasing of about 23% of GHG emission in the country by 2030.

4.4. Conclusions

This work was conducted on achieving plus-energy buildings in Algeria using a design optimization methodology based on spatial analysis and multi-criteria decision-making. The key results of this study are:

- Plus-energy target has been achieved at large areas of the country by using a high-performance envelope, more efficient appliances, and solar energy (solar PV and thermal).
- Southern locations are the most suitable areas to construct new buildings with the plus-energy target.
- Until 2030, the plus-energy target is feasible for only single floor buildings, because of low PV panel's efficiency, but after 2030, for multi-floor buildings, the plus-energy goal will be possible.
- Small-scale Wind turbines are not attractive for most locations of the country.
- Applying the proposed method will allow reducing the overall energy demand of the country by 43% and decreasing of GHG emission by 23% by2030.

In addition, the following recommendations and future work are taken:

- Reducing the subsidies for classical sources, and making subsidies for renewable sources to encourage the achievement of plus-energy buildings in Algeria is mandatory.

- Feed in tariffs for residential buildings must be introduced, in particular for the optimal locations.
- Geothermal energy should be promoted, because of its potential to reduce the energy demand for cooling which responsible for a high portion of energy costs.
- Create/develop local companies for investing in production, maintenance, and integration of solar energy with the utility grid which still one of the main challenges of residential solar systems.

Finally, the proposed method is considered an earlier decision before implement of PEB at any location of the country. It will help decision-makers, policymakers and investors to well decide for changing the energy situation of the building sector in Algeria. Further, applying the method have benefits not only for reducing energy demand and cost and GHG emissions, but it will share on developing the country and creating more opportunities of jobs, and why not, exporting the excess of energy to neighbouring countries. The method can be applied at any location. Therefore, it will share significantly on sustainability locally and worldwide.

Chapter 5.

Optimal Design of Multi-Sources Energy System for Off-Grid Buildings

5. Optimal Design of Multi-Sources Energy System for Off-Grid Buildings

5.1. Introduction

Due to the need for reducing GHG emissions and saving fossil fuels, renewable energy sources becoming necessary to meet the electricity demand of buildings specifically in isolated areas, where classical sources such as diesel generators, have becoming unattractive solution. However, the non-continuity feature of renewable energy has driven researchers to use HES that brings many advantages from technical, economic and environment point of view. In this chapter, the optimal design of HES for off-grid areas was investigated under three different case study buildings in different climate of Algeria.

The first case study, an alternative methodology for the optimal design of hybrid PV / WT / energy storage and diesel generator backup, for the supply of electricity to oil and gas drilling camps in Adrar, southwest of Algeria. The simulation is performed using HOMER software. In addition, the multi-criteria decision-making method of the analytical hierarchy process (AHP) is used to select between renewable technologies and to determine optimal HES options by considering technical, economic, environmental and social criteria. A sensitivity analysis is performed based on the cost variation of fuel and components up to 2030.

In the second case study, the techno-economic feasibility analysis of 100 % renewable energy system, which includes PV, Wind and Battery for electrification of off-grid residential building in Algeria's Sahara, was carried out. The case study building was investigated under two distinct locations namely Bechar and Adrar. The parts of the HES are modelled and optimally sized using particle swarm optimization (PSO) algorithm. The optimal solutions were acquired based on the smallest energy cost while the loss of power supply probability (LPSP) not exceed 1%. Finally, the results were compared with the true unit cost of electricity in our country to evaluate the viability of the suggested HES.

Finally, a new architecture based on a MAS concept for optimal sizing and management of a was proposed in the last application. The aim of this work is to achieve an intelligent and instantaneous compromise between the supply and the demand in smart buildings. Within the proposed architecture, the main goals are to minimize energy usage, cost and harmful emission, as well as to increase the system reliability.

5.2. Case study 1: Decision-making and optimal design of off-grid HES for mobile buildings using HOMER

5.2.1. Introduction

Nowadays, Electricity has become an essential thing to ensure the best life for communities anywhere. In 2017, the global electricity demand in the world increased by 3.1 %. In Algeria, the overall electricity consumption reflecting an increase of 8 % compared to 2016, due to the increase of population and fast development of the industry sector. Around 99% of Algerian consumers are connected to the grid (L'Energie, 2018). However, there is an important number of communities and houses, which located in isolated areas, especially in the Sahara of the country, suffer unavailability of the utility grid. Temporary buildings largely spread in these locations such as drilling camps which are quarterly moved from place to another it depends on their activity (exploration, drilling, work-over…etc.). Drilling camps are a small community, which provide all necessities of living for workers, including bedrooms, cafeteria, catering facilities, bathrooms, kitchen, and other services. Therefore, the diesel generator is the only source used to meet the electricity demand of these camps. ENTP, which works in the drilling field, owns about 67 drillers, has reported that the average fuel consumption of a drilling camp is around 250m3/year or 17,000m3/year for all its own camps. Thus, the annual cost of diesel is US$ 2.5 million and the annual cost of transport is around US$ 60,000, so the total cost of diesel is US$ 2.56 million a year (ENTP, 2019). These costs with accounting the government subsidies to diesel fuel, which affect the economy of Algeria that is fully dependent on hydrocarbon incomes. Despite the challenge of fuel costs, which increase day per day, conventional sources, has faced some barriers to use, mainly environmental concerns, and the depletion of fossil fuels. For that reason, the transition toward more renewable resources integration to power generation will be mandatory. Fortunately, the country is blessed by a huge solar energy potential, the equivalent of more than 30 times the annual world energy consumption(Negrou et al., 2010). In this regard, the Algerian government has adopted different policies and programs to promote the use of renewable energies and to diversify energy sources in the country and electricity supply of isolated areas. In 2015, Algeria adopted an update to its Renewable Energy and Energy Efficiency program, which was firstly launched in 2011. The updated version of the Program aims to achieve about 27% renewable generation share in total electricity production (Government, 2015). Besides that, this program aims to reduce its GHG emissions by 7% before 2030 (Haddoum et al., 2018).

Solar energy is the primary renewable source recognized by the Algerian government to be developed. However, wind, biomass, geothermal is comparatively very small. Following this program, ENTP has set itself the challenge of achieving the ENTP Green Cabin project, a prototype of an autonomous Saharan cabin, totally powered by solar energy Fig.34. However, the intermittent and unstable nature of such renewable electricity generation affects the supply-demand balance and cannot replace definitely fossil fuels. Therefore, the HES, which constituted of renewable sources, conventional source and/or energy storage system, constitutes a promising solution. Recently, electrification using HES, in particular, Solar wind based HEShas been largely exploited in isolated areas because it is more cost-effective and more reliable than only diesel based system (Anoune et al., 2018). Although, researchers face a big challenge in finding optimal sizing and configuration of HES taking into account various constraints. Many research papers have been done on this topic using either optimization algorithms or commercial software such as HOMER, RETSCREEN, and HOGA, which are widely used (Fodhil et al., 2019).

For example, Haratian et al. (Haratian et al., 2018) proposed a method based on techno-economic analysis to find feasible options for zero-emission HES in Iran. It is found that the most economical configuration is a PV battery with an energy cost (COE) of 0,546 $/kWh. A new meta-heuristic algorithm called Cuckoo Search is applied in (Mohamed et al., 2018) and (Singh and Fernandez, 2017) for solving the problem of techno-economic sizing of hybrid PV/wind/ diesel/battery for remote buildings. On the other hand, Das and Zaman (Das and Zaman, 2019) examined the performance of PV, Diesel, Lead Acid and/or Lithium-ion battery systems in a remote community in Bangladesh using HOMER software. They studied the effects of the dispatch strategy, fuel and component costs on the cost of energy (COE) of the optimal HES. F. Fodhil et al. (Fodhil et al., 2019)presented a methodology for analysing an autonomous hybrid PV-diesel-battery energy system. In his study, particle swarm optimization (PSO) and ε-constraint method were used to minimize total system cost and CO_2 emissions. Monotosh et al. (Das et al., 2019) developed a meta-heuristic optimization algorithm to determine the optimal design of an off-grid HES with the goal of minimization of the total net present cost. The studied HES, 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 optimisation 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) and (Jamshidi and Askarzadeh, 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 et al., 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. Differently, in the study of Luta (Luta and Raji, 2019), PV based hybrid energy system, including hybrid hydrogen fuel cell / super-capacitor storage system is examined. He is based on technical feasibility and cost-effectiveness to find the optimal size of HES.

Despite stationary application, in (Cristóbal-monreal and Dufo-lópez, 2016), a new method is proposed for optimizing stand-alone hybrid systems consisting of PV /diesel/battery to supply mobile system electricity using multi-objective evolutionary algorithms. It is found that the hybrid system of flexible crystalline PV /diesel/battery is the solution that minimizes the weight of the system. This work is similar to the study of (Atmaca and Atmaca, 2016), which compared the life cycle energy and cost analysis of temporary housing after a disaster.

Highlight literature review, technical economic factors, mainly lower cost of energy, maximum reliability, renewable fraction …are the essential parameters in size of HES in stand-alone applications. However, the successful design of HES needs to take all aspects of sustainability which include technical, economic, environmental and social criteria (H. Lagha, 2018), have to be considered to make better decisions. Further, a limited number of papers that study the design of HES for mobile buildings. In several locations of the world, these types of buildings are widely spread. On the other hand, selecting appropriate components before sizing of HES is an important process that must be included. In the present work, a diesel based HES with different energy storage alternatives is analysed to find optimal configurations for the electrification of temporary buildings in Algeria. The feasible HES options are compared from technical, economic, environmental and social criteria. In this regard, this study presents a design optimization method for optimal sizing of an HES for electrification of temporary buildings in Algeria. The proposed HES configurations are evaluated and compared considering technical, economic, environmental and social criteria. To achieve this goal, HOMER software and AHP multi-criteria decision-making technique were used. The method is applied on gas and oil-drilling camps of ENTP, the case study of Adrar fields, Algeria. The main contributions of this work are:

- Selection of the optimal configuration among the feasible options is made based on various criteria linked to technical, economic, environmental and social criteria. To achieve these goals, HOMER software and Analytic hierarchy process (AHP) technique were used.
- A comparative analysis is conducted between LA and Li-ion batteries and hydrogen as energy storage alternatives for PV/WT/Diesel-based hybrid system based on technical, economic, environmental, and social indicators.

- A sensitivity analysis is demonstrated to examine the effects of various input cost parameters for the selection of best configuration for the proposed HES.

Figure 34. Drilling camps example in Sahara of Algeria.

5.2.2. Materials and methods

This work presents a methodology for the optimal design of an off-grid HES for the supply of electricity to a drilling camp in Adrar, southwest of Algeria. The proposed hybrid system consists of PV panels, small wind turbines, diesel generators, batteries, hydrogen storage system and converters. HOMER software is used to size the hybrid system proposed. However, the AHP technique is used to select the best components and find the optimal HES configuration for the case study.

5.2.2.1. Location and climaticdata

Adrar is an Algerian province, located in the Sahara, southwest of the country. Fig.35 shows Adrar's geographical location. This region contains important oil and gas fields(Abada and Bouharkat, 2018). The required climatic data for Adrar are extracted from the NASA database via

HOMER (from 1983 to 2005). The hourly data for ambient temperature and wind speed and the average monthly clearness index and solar radiation are shown in Fig.36, Fig.37, and Fig.38 respectively.

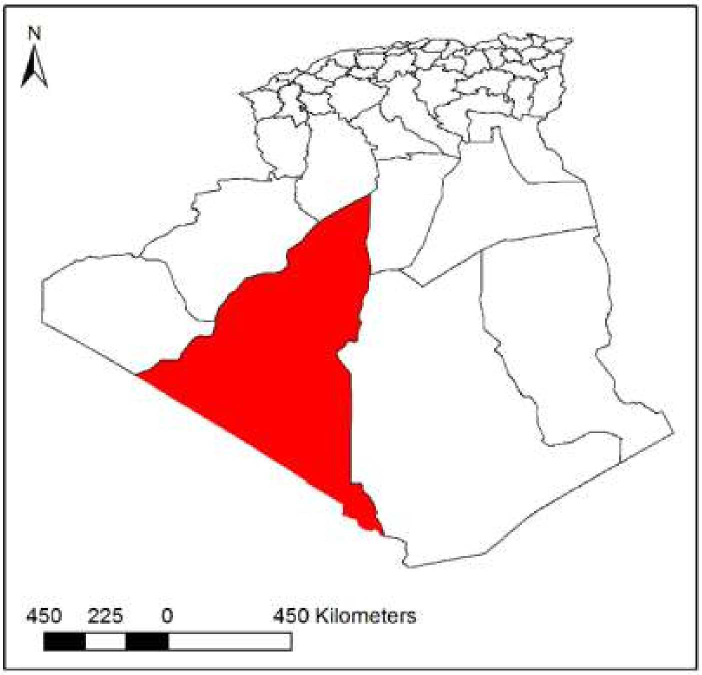

Figure 35. The geographic location of Adrar.

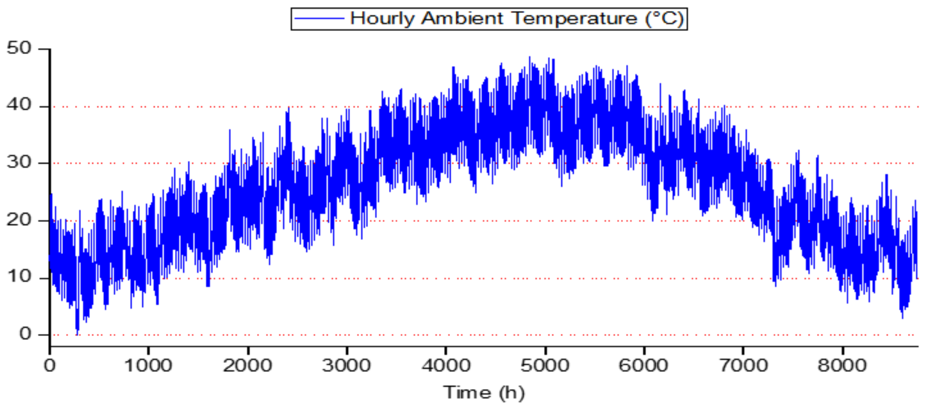

Figure 36. Hourly Ambient Temperature at Adrar.

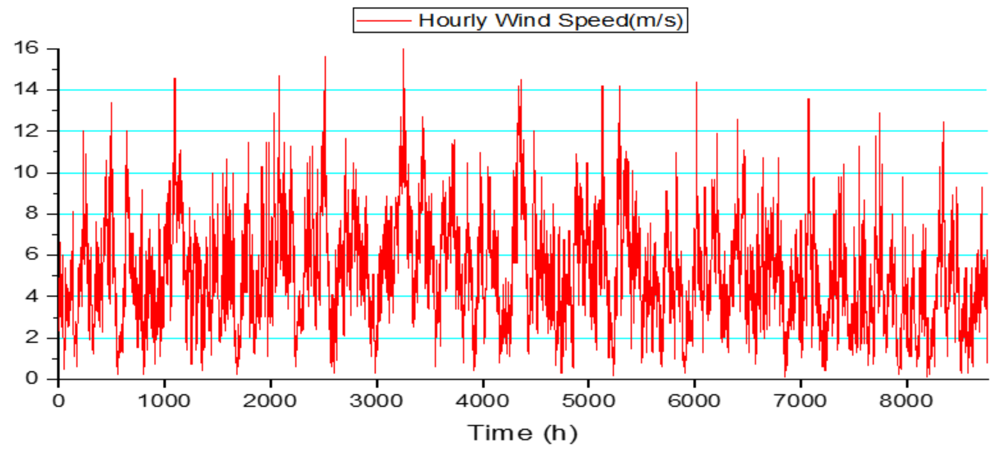

Figure 37. Hourly Wind Speed at Adrar.

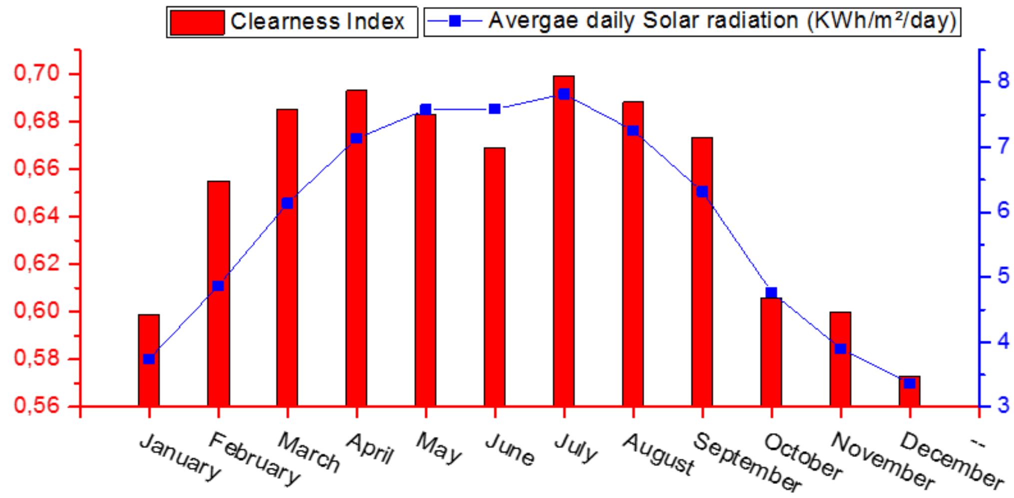

Figure 38. Solar radiation and Clearness Index at Adrar.

5.2.2.2. Case study description and load estimation

In this study, a typical drilling camp is selected. Many local companies have been involved in the construction of drilling camps, such as CLEMCA, SAFCAS... etc. CLEMCA is specialized in the construction of drilling camps by providing all life needs, such as accommodation cabin, administration and catering. Fig.39 shows a typical drilling camp sketch. The overall roof area of the camp is 1446 m², which will be used to install solar panels. The energy demand of this camp is assumed based on the data collected from Clemca Company, the characteristics of the equipment and the information provided by some ENTP workers in the case study. The average daily demand of the camp is 1635 KWh / day, with a peak power of 225 kW. The seasonal load profile for the studied camp is provided by Fig.40.

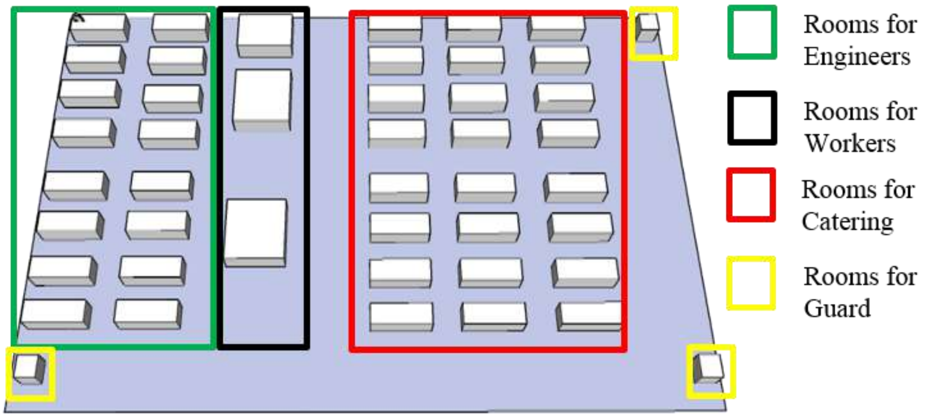

Figure 39. Sketch of a typical drilling camp.

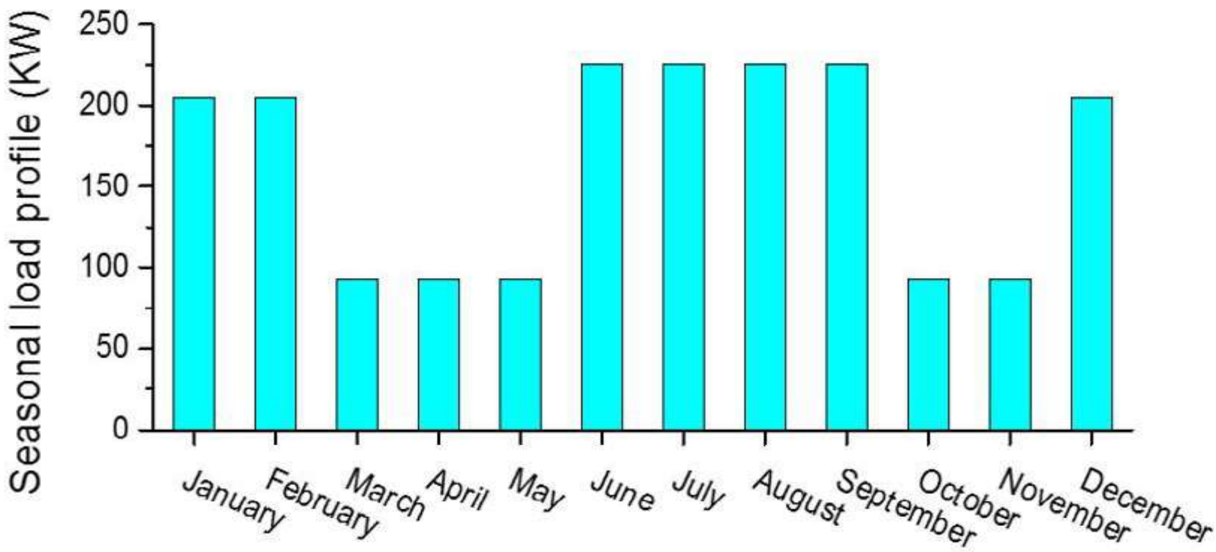

Figure 40. The seasonal Load profile of the camp.

5.2.2.3. Simulation of the hybrid energy system

HOMER software is widely used in literature to optimize hybrid power systems. HOMER was developed by the National Renewable Energy Laboratory (NREL). HOMER's calculation after three stages is a simulation, then an optimization, if any, sensitivity analysis. HOMER offers a wide library of various components, including conventional and renewable sources, storage systems and controllers. HOMER requires climatic data, component costs and load profile as main inputs for calculation. HOMER ranks solutions based on minimum energy costs (COE). In this study, the cycle-charging (CC) strategy is chosen to control the hybrid system in which, using Electrolyzer, the surplus energy is used to recharge the batteries or produce hydrogen gas. Fig.41 shows the schematic of the proposed hybrid system.

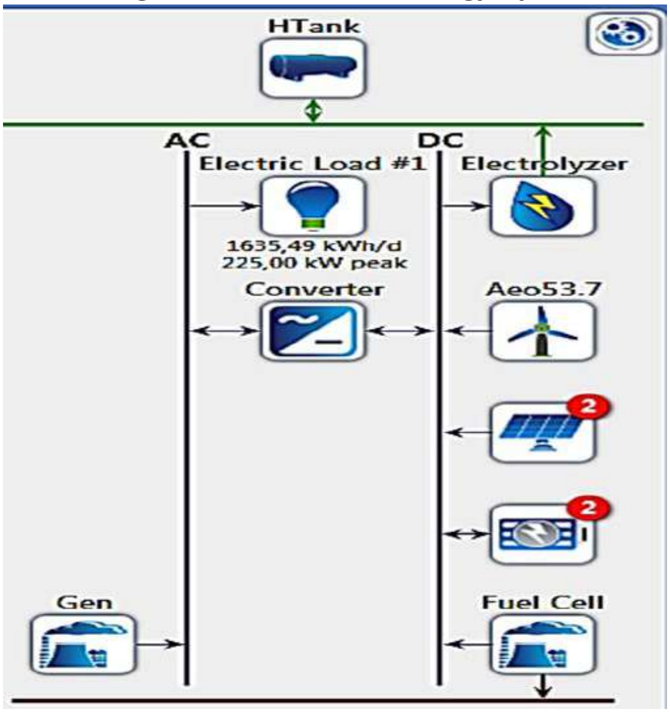

Figure 41. Schematic of the studied system.

5.2.2.4. Solar PV

The solar PV panel is a device that converts solar energy into electrical energy. Two PV panels were used in this study, multi-crystalline silicon and cadmium telluride (CdTe) thin film module. The cost of capital and replacement, operation and maintenance (O&M) for both PV panels is \$1200/kW and \$10/KW respectively(Fu et al., 2017). Tab.10 shows the characteristics of the panels selected. Due to techno-economic constraints, solar panels are installed on the camp's roof at the yearly optimum inclination angle for Adrar, as calculated by HOMER (27 °).

Table 10. Technical economic data of PV panels.

Component	First Solar-108Wc	Condor-300Wc
Model	CdTe	Multi-crystalline
Capital cost($/KW)	1200	1200
Capital cost at 2030 ($/KW)	800	800
O&M Cost ($/KW/year)	10	10
Lifetime (year)	25	25
Efficiency (%)	14,9	15,5
Efficiency at 2030 (%)	-	20 (Zubi et al., 2016)
Module area (m²)	0,72	1,94
Weight (Kg/KW)	111	78
Derating factor (%)	88	88
Maximum Capacity (KW)	217	224

5.2.2.5. Wind turbine

Wind turbine (WT) can be considered as an available and free energy source that can be used to produce electricity by converting the kinetic energy into electrical energy. This source is more reliable in locations where wind speed is high, likewise the south-western regions of Algeria. HOMER software calculates the wind turbine power output based on wind speed data at the hub high and the wind turbine power curve delivered by the manufacturer. In this work, The Aeolos 50 KW wind turbine model is selected. Capital and replacement costs and O&M costs for the WT are $1500/KW and $12/kW / year respectively (Smaoui et al., 2015). The selected WT has a lifespan of 20 years and a hub height of 30 m. The WT's weight is 6800 Kg, i.e. 136 Kg / KW.

5.2.2.6. Diesel generator

Diesel generator (DG) was used in the hybrid energy system to meet the load demand in case of deficit power from renewable energy and/or from stored energy. Generic DG's capital / replacement costs and O&M costs are 500 $/KW and 0.03 $/h respectively (Duman and Güler, 2018a). DG's lifetime is 60 000 h (Peerapong and Limmeechokchai, 2017). The current and expected price of diesel fuel in Algeria up to 2030 is 0.19 $/L and 0.65 $/L respectively. The diesel fuel prices forecasting at 2030 represent the prices of non-subsidized diesel fuel. Because the real diesel fuel prices in Algeria as mentioned by the government and a lot of expertise are about 0.65 $/L. These assumptions according to many economic researchers and following the Algerian government plans which intends to give up fuel subsidies in the coming years. This scenario is emphasized by the increase on fuel prices from 2016 by 50% (Haddoum et al., 2018).

5.2.2.7. Converter

Converter is the device that converts electrical energy from AC to DC or vice versa. The converter's rated power depends on the peak load. The Converter's efficiency is set at 95 % and its lifetime is 12 years. The converter's capital cost and replacement cost are the same and are taken at $115/KW (Singh et al., 2016). This converter has an efficiency of 95 % and a lifetime of 15 years.

5.2.2.8. Battery storage

Battery storage (BS) is the common storage feature and is highly acceptable. Two types of battery are analysed and compared, Lead-acid (LA) and L-ion (LI). The costs and specifications of both batteries are summarized in Tab.11. The excess electricity that is produced by renewable and/or diesel generator is used to charge the battery bank whereas the shortage of energy can be supplied from a battery bank or diesel generator.

Table 11. Technical-economic data of Batteries.

Type of battery	(LA)	(LI)	References
Capital cost ($/kWh)	110-200	350	(Mandal et al., 2018b)(Renewable and Agency, 2017)
Capital cost at 2030 ($/kWh)	50	145	(Renewable and Agency, 2017)
O&M cost ($/kWh/year)	10	10	
Lifetime (year)	10	15	
Current Specific energy (Wh/Kg)	40	274	(Renewable and Agency, 2017)((EASE), 2015)(Durand et al., 2017)
Specific energy at 2030 (Wh/Kg)	60-100	350	(Renewable and Agency, 2017)((EASE), 2015)(Durand et al., 2017)
DOD (%)	60	80	
Round trip efficiency	80-85	90-95	((EASE), 2015)
Round trip efficiency at 2030	90	98	(Renewable and Agency, 2017)

5.2.2.9. Hydrogen storage

The hydrogen storage (HS) system consists of Fuel Cell (FC), Electrolyzer (EL), and Storage Tank (ST).

Fuel cell: FC is a device that converts stored hydrogen gas into electricity. The polymer electrolyte membrane (PEM) fuel cell is selected because is the most promising types of fuel cells due to its simplicity and low operating temperature (Khelaifa Khaoula, Abdelmalek Atia,*, Hocine Ben Moussa, 2018).

Electrolyzer: An EL generates hydrogen through the electrolysis of water.

Storage tank: The hydrogen generated from the Electrolyzer is stored in a tank. Hydrogen gas storage is very environmentally friendly and has no GHG emissions. However, hydrogen gas needs a high level of safety, because the lower flammability limit of hydrogen is 4.1 % in normal air condition and its release incidences can lead to massive losses (Mukherjee et al., 2017). In Tab.12, the technical economic data for hydrogen storage components are summarized.

Table 12. Technical-economic data of hydrogen storage.

Component	Electrolyser	Fuel Cell	Storage Tank	References
Capital cost($/KW)	1000-1500	2000	500/kg	(Smaoui et al., 2015)(Jacob et al., 2018) (Luta and Raji, 2018)(Rahimi et al., 2014)
Capital cost at 2030 ($/KW)	800	800	300/Kg	(Hinkley et al., 2016)("Hydrogen and Fuel Cells IEA Roadmap targets," 2013) (Rahil et al., 2018)
O&M Cost ($/KW/year)	10	0.01/h	0	
Lifetime (hour)	40000 (20 year)	30000	25	(Zhang et al., 2017)
Lifetime at 2030 (hour)	80000	50000	-	(Hinkley et al., 2016)("Hydrogen and Fuel Cells IEA Roadmap

				targets," 2013)
Efficiency (%)	Up to 85	50	-	(Luta and Raji, 2018)(Gökçek and Kale, 2018)
Efficiency at 2030 (%)	90	>50	-	("Hydrogen and Fuel Cells IEA Roadmap targets," 2013)
Weight (Kg/KW)	15	5	20 Kg/Kg stored H2 at 700 bars	(Hydrogenics, 2018)("5000 W Fuel Cell Stack User Manual," n.d.) (Hua et al., 2017)

In this work, HOMER simulation is carried out with a 20-year project lifetime, a 6 % interest rate, and a minimum renewable fraction of 30 %. Other CO_2 emissions are only linked to DG, as they have the largest and most dominant Lifecycle emissions of 0.88 Kg CO_2-eq / Kwh (Mandal et al., 2018b). Solar energy has the priority than wind energy, so we have set 60 % of the total share of solar energy in renewable energy. However, the available roof area, panel area, and inclination are the constraints that determine the maximum allowable capacity of PV panels.

5.2.2.10. Levelized cost of energy

The cost of energy (COE) is commonly used to compare different energy producer technologies. HOMER determines the optimal solutions according to lower energy Costs. Despite to COE, total net present cost (NPC), fuel consumption, CO_2 emission, and others parameters are also extracted for all the feasible options. Because, in this study, a MCDM analysis was carried out to select the best configurations for the HES.

5.2.2.11. Multi-criteria decision-making

In order to make the best decisions, it is necessary to consider various criteria, mainly technical, economic, environmental and social criteria (Sadiq et al., 2019). However, analysing different conflict criteria needs to use an MCDM method. Therefore, the Analytic Hierarchy Process (AHP) technique is used. AHP method based on weights calculation, compare of alternatives according to its available data. The evaluated criteria in this work, which have reported in (Malkawi et al., 2017)(Eriksson and Gray, 2017) are given in Tab.13.

Table 13. Evaluation criteria definition.

Criteria	Sub-criteria	Definition
Economic	Initial Capital cost (ICC)	The investment cost of the system (Decrease this cost make the system attractive by investors)
	Cost of energy (COE)	The lifetime cost of the system divided by Energy produced during its lifetime
	Fuel consumption (F-Cons)	Yearly fuel consumption(minimize fuel consumption is our goal)
Technical	The Weight (Wt)	The weight of the system in Kg (the weight must be minimized as possible for mobile buildings)
	Renewable Fraction (Ren-Fr)	Increase RE fraction is our goal
Environmental	CO_2 emission (CO_2-E)	CO_2 produced by the system (we have to minimize CO2 emissions)
	Safety Aspect (Safety)	Safety Requirement to avoid damage and system menace (must be minimized)
	Water use (Water)	Need water for working (using water is a big problem in the Sahara, must be minimized)
Social	Government policy (Gvr-P)	Support Local policy priorities (Algeria support local producer, and we have to follow RE program trends)
	Local market availability (L-M-A)	Availability of product in the Algerian market is crucial because our country limits the exportation of some products to develop the national economy.
	Social benefits (Soc-B)	Benefits for the local producer (encouragelocalproducerbybuyingitsproductsandincreasingthenumberofworkers/contributiontocreatingjobsthatis a big problem in Algeria nowadays.

5.2.3. Results and discussion

5.2.3.1. Results for solar PV panel's selection

Before comparing the feasible HES' options, the best renewable energy components are selected. Since there are several PV panels on the market. Select adequate components such as PV panel, influenced by different factors and depending on many criteria. Tab.14 and Tab.15 shows the required data and MCDA results.

Table 14. Input data of selected PV technologies.

Criteria	FS-CdTe	Condor multi-crystalline
COE ($/Kwh)	0,056	0,058
Weight (Kg/KW)	111	78

Annual production (Kwh)	411 432	420 000
Local market availability	Low	High
Social benefits	Low	High
Government policy	Not Supported	Highly Supported

Table 15. Results of MCDM for PV technology selection.

Criteria	Criteria Weights	FS-CdTe	Condor-multi-crystalline
COE ($/Kwh)	0.2	0.100	0.100
Weight (Kg/KW)	0.2	0.050	0.150
Annual production (Kwh)	0.15	0.050	0.101
Local market availability	0.15	0.026	0.125
Social benefits	0.15	0.021	0.129
Government policy	0.15	0.020	0.131
Sum of Weights	1	0.27	0.73
Rank	/	2	1

From the results of MCDA, multi-crystalline PV panels are the most appropriate PV panels for the present case study. Thereby, only multi-crystalline PV panels are used for the simulation.

5.2.3.2. HOMER results

After select the components of the HES, the simulation was carried out in HOMER software. Two different scenarios are investigated. For both scenarios, the feasible configurations are compared. For all the obtained configurations, the size of DG and PV system are found 250 KW and 224 KW respectively. In addition, for the hydrogen based configurations, Hydrogen storage (HS) system includes FC (500 KW), EL (200 KW), and ST (100 Kg). The composition of the all-possible HES' configurations and their representation indices are given in Tab.16.

Table 16. Indices of possible configurations of HES.

Index	Configuration components	Index	Configuration components
HYB-0	DG	/	/
HYB-1	DG/PV	HYB-7	DG/PV/LI/HS
HYB-2	DG/PV/WT	HYB-8	DG/PV/WT/LA
HYB-3	DG/PV/LA	HYB-9	DG/PV/WT/LI
HYB-4	DG/PV/LI	HYB-10	DG/PV/WT/HS
HYB-5	DG/PV/HS	HYB-11	DG/PV/WT/LA/HS
HYB-6	DG/PV/LA/HS	HYB-12	DG/PV/WT/LI/HS

Before doing the comparison between the feasible HES' configurations, some configurations are eliminated which either have no PV panels, or with renewable fraction smaller than 30%, or with COE greater than 0.23 $/KWh (that represents the COE for the configuration with DG alone with taking current data). Hence, a multi-criteria decision analysis is carried out to select the best options. Here, many technical, economic and environmental evaluation criteria are taken into account. The weights of these criteria are given in Tab.17.

Table 17. Criteria' weights.

Criteria	Criteria-Weight (1)	Sub-criteria	Sub-Criteria-Weight (2)	Final-Weight (1*2)
Economic	0.4	Initial Capital cost	0.25	0.1
		Cost of energy	0.5	0.2
		Fuel consumption	0.25	0.1
Technical	0.35	The Weight	0.8	0.28
		Renewable Fraction	0.2	0.07
Environmental	0.25	CO_2 emission	0.4	0.1
		Safety Aspect	0.3	0.075
		Water use	0.3	0.075

5.2.3.3. The first scenario (at present)

In this scenario, the current technical-economic data of components and diesel fuel price are used. The results of the feasible hybrid energy system are summarized in Table A.1. However, the ranking of hybrid energy system configurations based on MCDA analysis for this scenario is presented in Tab.18.

Table 18. The result of HES ranking (First scenario).

Criteria	HYB-2	HYB-3	HYB-4	HYB-8	HYB-9
ICC	0.016	0.031	0.031	0.006	0.016
COE	0.012	0.030	0.056	0.038	0.064
F-Cons	0.005	0.009	0.016	0.027	0.043
Weight	0.028	0.045	0.120	0.017	0.073
Ren-Fr	0.003	0.010	0.010	0.024	0.024
CO_2-E	0.004	0.014	0.014	0.034	0.034
Safety	0.015	0.015	0.015	0.015	0.015
Water	0.015	0.015	0.015	0.015	0.015
Sum-Weight	0.098	0.169	0.277	0.176	0.284
Rank	5	4	2	3	1

5.2.3.4. The second scenario (at 2030)

In this scenario, the assumption of technical-economic data of components and diesel fuel price is used. The results of the feasible hybrid system are summarized in Table A.2. The result of MCDM for ranking hybrid system configuration for this scenario is presented in Tab.19.

Table 19. The result of HES ranking (Second scenario).

Criteria	HYB-3	HYB-4	HYB-8	HYB-9	HYB-11	HYB-12
ICC	0.025	0.041	0.010	0.014	0.005	0.003
COE	0.048	0.026	0.048	0.048	0.016	0.014
F-Cons	0.006	0.004	0.015	0.011	0.033	0.033
Weight	0.118	0.045	0.014	0.073	0.008	0.025
Ren-Fr	0.004	0.004	0.012	0.007	0.022	0.022
CO_2-E	0.004	0.004	0.015	0.009	0.034	0.034
Safety	0.017	0.017	0.017	0.017	0.004	0.004
Water	0.016	0.016	0.016	0.016	0.005	0.005
Sum-Weight	0.238	0.157	0.147	0.195	0.127	0.140
Ranking	1	3	4	2	6	5

In the first scenario, HYB-9 (DG/PV/WT/LI) and HYB-4 (DG/PV/LI) are the best configurations. We have shown that hydrogen storage is not included in the competitive configurations of this scenario, because of its high COE, capital cost, and the overall weight of the system. Other, these configurations have COE smaller than the COE obtained by only using DG. Therefore, the hybrid system is highly feasible.

In the second scenario, HYB-3 (DG/PV/LA) and HYB-9 (DG/PV/WT/LI) are the best configurations. However, other configuration has more advantages and have COE smaller than the COE obtained using DG alone. In addition, Hydrogen storage is included in HYB-11 and HYB-12, which gather battery and HS. Thus, there is no feasible configuration with only HS. Therefore, Battery storage has been stilled the optimal storage system for building application, especially for mobile buildings until 2030. Besides, in the next year, DG will be the infeasible solution for mobile buildings, especially with the rise of diesel fuel prices higher than one dollar.

5.2.4. Conclusion

The aim of this work is to develop an optimal methodology to design off-grid HES to electrify temporary buildings in isolated areas of Algeria, HOMER software and AHP method of multi-criteria decision-making are used to achieve this goal. The method is applied to case study of gas and oil drilling camps in Adrar, Algeria. The main objectives of this study were to minimize fuel consumption, reduce energy costs, mitigate GHG emissions and minimize system weight. In addition, a comparison was made between different storage systems and renewable energy technologies in order to select the best solutions. Sensitivity analysis is carried out taking into account two scenarios that represent current and future assumptions of technical-economic data. The results show that DG / PV / WT / Li-ion battery is the best configuration for the case study when considering the present scenario. However, for the future scenario, the optimal HES' configuration consists of DG / PV / Load acid battery. In addition, hydrogen storage system is not currently a viable solution for energy storage in such remote locations. Nevertheless, if no significant improvements are made with batteries, hydrogen storage will be more competitive in next years. The proposed method will help decision-makers to make better decisions in the future to determine optimal configurations of the HESs for the electrification of remote areas. The method is not only feasible for the location studied, but it can be applied to any location in Algeria and around the world. It will therefore contribute significantly to transit to sustainable communities by saving fossil fuels and reducing GHG emissions locally and worldwide.

5.3. Case study 2: Techno-economic feasibility study of PV-WT-battery HES for off-grid buildings in Sahara of Algeria using PSO

5.3.1. Introduction

Worldwide, energy consumption is rapidly increased and it is predicted that in the next five years will be increased by five times than the present energy consumption (Masud et al., 2019). Exclusively, residential buildings account for 27% of global energy consumption and 17% of GHG emissions (Leibowicz et al., 2018). In Algeria, residential sector responsible of about 38% of the total energy consumption (Bey et al., 2016). As this energy is almost extracted from fossil fuels mainly natural gas, buildings contribute to high fraction of CO_2 emission. Moreover, many locations of the country especially in the Sahara have been suffering from a lack of electricity grid that makes these locations highly dependent to diesel fuel and its relevant costs. Thereby, integration of renewable sources is mandatory to address current energy and environment issues. In this context, Algerian government has lanced the renewable energy program which aims to provide at least 40% of its final energy from renewable sources by 2030 (Belabes et al., 2015). However, renewable energy systems are limited by the intermittent because of unpredictable nature of the weather (Onwe et al., 2019). Therefore, HES constitutes a key solution to supply off-grid and remote areas (Bourdoucen, 2012). However, finding the optimal sizing of such multi-source energy system that leads to lowest cost of energy is a big challenge. In last decade, there has been a large number of papers, which focused on optimal sizing of HES. For example, in (Abo-elyousr and Nozhy, 2018), a multi-objective ant colony optimization algorithm was performed for optimal sizing of HES considering multiple fuel options for supply islanded Areas with lowest cost and GHG emissions. In (Ma et al., 2015) the optimal configuration of a grid-connected wind–solar–battery HES is carried out using a multi objective approach. Similarly, Optimal Sizing of a Grid-Connected PV/Wind/Battery System is investigated in (Mahesh and Sandhu, 2019) using Particle Swarm Optimization (PSO). In (Zhang et al., 2019), an improved hybrid optimization algorithm coupled with neural network weather forecasting method is proposed for the optimal sizing of a stand-alone HES. In (Khare et al., 2015) a HES is optimized by HOMER and PSO. In (Moradi et al., 2018), the optimal management and optimization of a standalone HES with battery storage under system uncertainties is performed using an advanced dynamic programming method. In (Al-Badi, 2011) the techno-economic feasibility study of wind–PV–diesel hybrid energy system is carried out by HOMER software to meet the load of an Island. The author in (Eriksson and Gray, 2018) proposed a multi-objective approach by the implementation of Particle Swarm optimization (PSO) algorithm for achieving a compromise between several technical, economic, environmental and socio-political objectives in the optimization of any HES. In (Zhang et al., 2018), developed a simulated annealing algorithm for the optimization of a hybrid system incorporated battery and hydrogen storage for electricity supply of a residential building in remote area of Iran. In (M., 2012), a comparative study of diesel PV–wind hybrid energy system for rural areas in Oman is carried out. In (Rullo et al., 2019), An bi-level optimization framework based on Genetic Algorithm is suggested for size optimization of hybrid wind/PV energy system with hybrid energy storage. In (Rajoriya and Fernandez, 2013) a Hybrid diesel-PV-WT-battery energy system size optimization for sustainable supply of a remote area in India is investigated using HOMER. Similarly, HOMER was used in (Baniasad Askari et al., 2014) for techno-economic feasibility analysis of hybrid PV/wind/fuel cell energy system is performed with considering the effects of energy storage and load demand. In the same way, the study of (Muh and Tabet, 2019) presented a comparative analysis of HES for off-grid applications in Cameroons using HOMER. A multi-objective PSO optimization of a HES is proposed in (Eriksson and Gray, 2019). Similarly, in (Jamshidi and Askarzadeh, 2019) a multi-objective optimization of a hybrid system PV, fuel cell and diesel generator to supply electric demand of an off-grid community in Iran. Optimal sizing and energy management of stand-alone PV/WT/ hydrogen energy system using flower pollination algorithm is carried out in (Jafar et al., 2019). In (Mellouk et al., 2019) a new parallel hybrid Genetic Algorithm-PSO algorithm is developed to solve both sizing and energy management problems in HES.

Highlight the literature review there have been limited number of papers that discussed the potential of using 100 % renewable energy systems to supply off-grid areas. In addition, the reduction of PV panels costs for next years are not widely investigated. In the majority of works, the cost of energy and loss of power supply probability are the evaluating objectives.

Here, a techno-economic feasibility analysis of PV-WT-Battery HESto supply remote areas in the Sahara of Algeria is carried out using particle swarm optimization (PSO) algorithm. The optimal sizing of the proposed HES is made at two neighbour provinces namely Adrar and Bechar. Here, the best solution is obtained based on lowest COE while LPSP is at minimum value. Thus, a sensitivity analysis and comparison of results between two scenarios at the studied locations are performed.

5.3.2. Materials and Methods

In this study, the optimal sizing and techno-economic feasibility evaluation of a HES for supply off-grid buildings in the Sahara of Algeria was investigated. The optimization problem is solved using PSO algorithm. The modelling of the HES's components, evaluating criteria and optimization method are provided in following sections.

5.3.2.1. Location and climatic data

Sahara of Algeria has a big potential of solar and wind energy as shown in Fig.42 (with red colour) (Mokhtara et al., 2019). Two different locations of the Sahara are selected as case study, namely Bechar and Adrar. The geographic location of Adrar and Bechar is shown in the map of Fig.43.

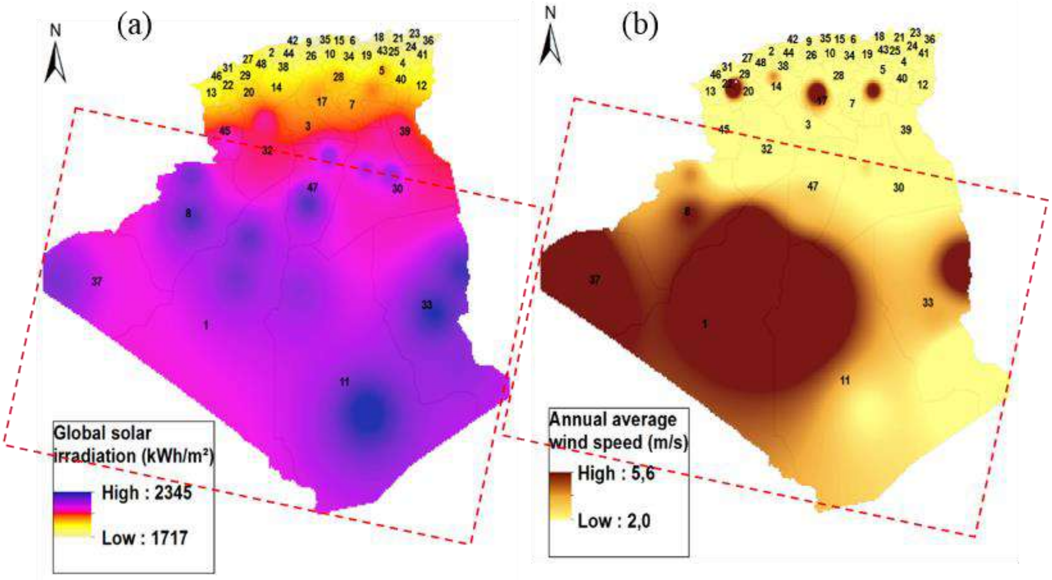

Figure 42. Renewable energy potential in Sahara of Algeria: (a) solar radiation; (b) wind speed.

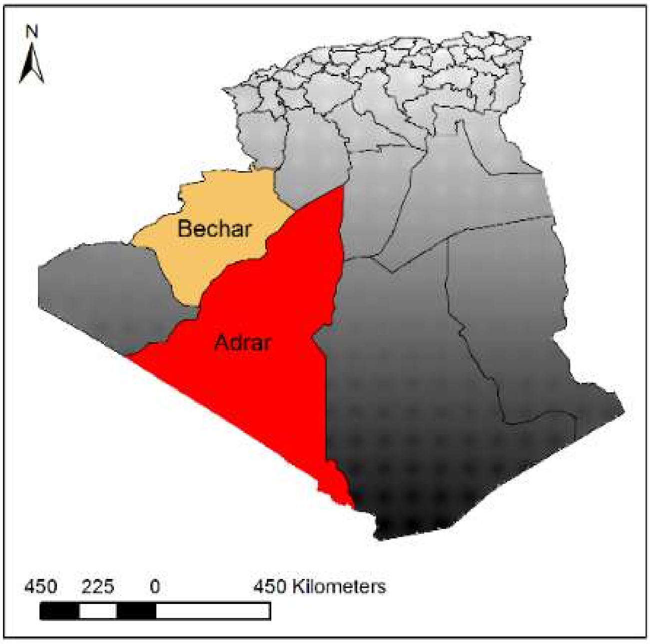

Figure 43. Geographic location of the studied regions.

5.3.2.2. Assessing Building's load demand

The studied building represents a typical detached residential building, which is commonly existed in the Sahara of the country. The electricity demand of the studied building for the two case studies is assessed based on the parts of the building, available equipment and its electric properties that are summarized in Tab.20 and Tab.21.

Table 20. Characteristics of equipment used in the studied building.

Equipment/Part	Power Consumed Per hour (W)
Light bulbs	20
Air Conditioner	1500
TV	80
Fan	40
Water heater	2000
Refrigerator	200
Microwave oven	1450
Washing machine	512

Table 21. Number of each equipment used per room in the studied building.

Part	Bedroom	Living room	Guest room	Bathroom	Kitchen
Light bulbs	1	1	1	1	1
A/C	1	0	0	0	0
TV	0	1	0	0	0
Fan	0	0	0	0	1
Water heater	0	0	0	1	0
Refrigerator	0	0	0	0	1
Microwave oven	0	0	0	0	1
Washing machine	0	0	0	1	0

Based on the available data of the Table 1, and according to seasonal variation of usage, the load profile of the studied building is evaluated. Fig.44 presents the load profile of the building at typical day in winter, summer and temperate months.

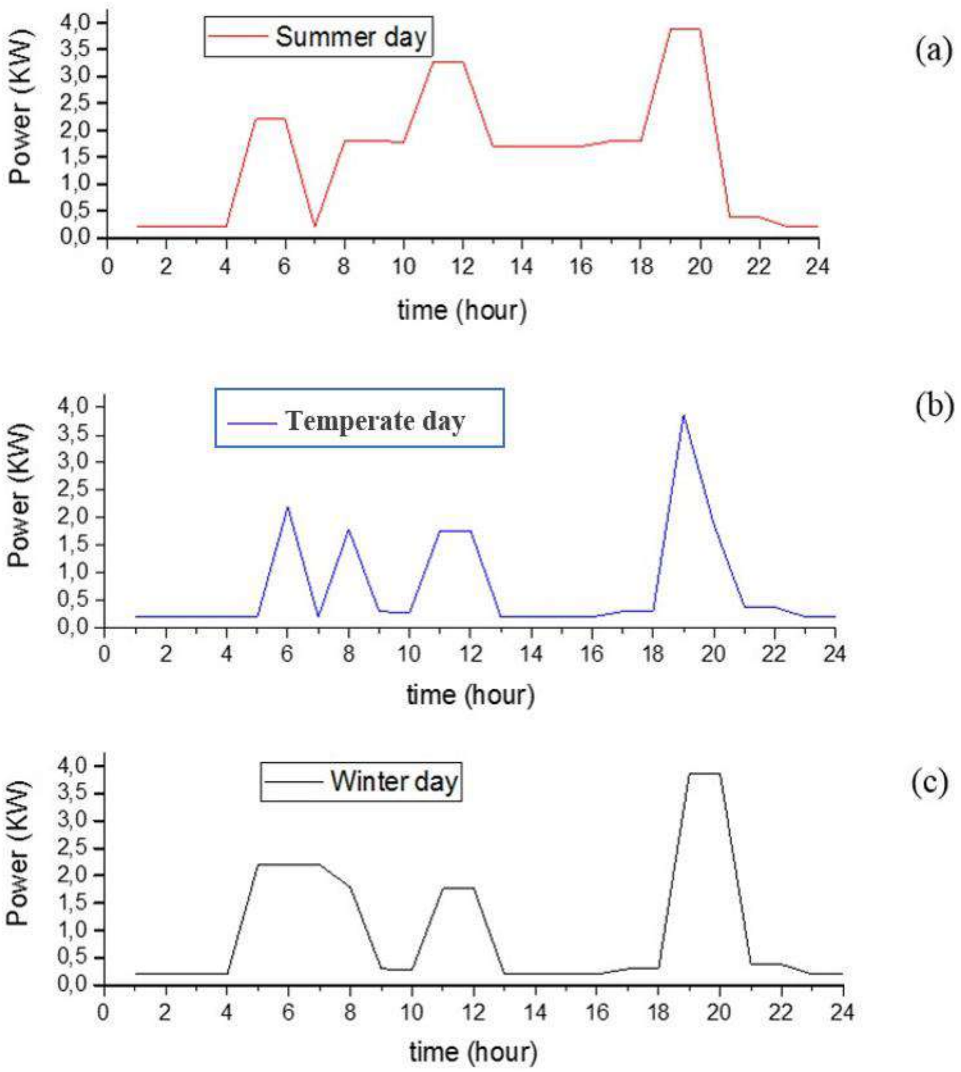

Figure 44. Load demand at typical day in : (a) summer; (b) temperate seasons; (c) winter.

5.3.2.3. Modelling of the hybrid renewable energy system

In this work, the HES that is shown in Fig.45 includes only renewable sources (solar photovoltaic (PV) and small wind turbine (WT)), and battery storage. The proposed HES is used for supplying off-grid buildings in the Sahara of the country.

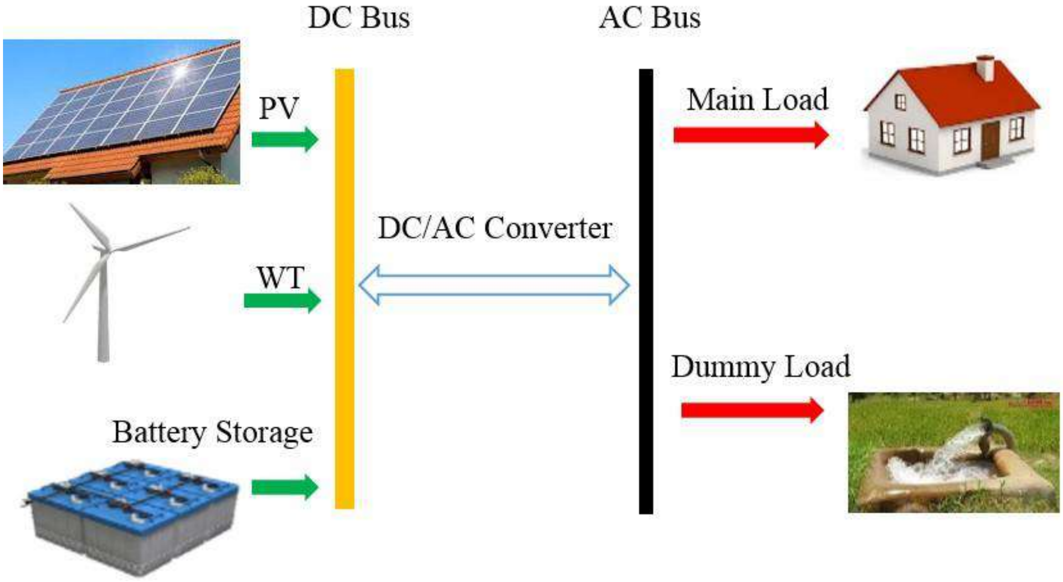

Figure 45. Schematic of the HES.

5.3.2.3.1. Solar PV

Solar PV panel is a device that converts solar energy into electrical energy. Solar energy is the abundant renewable source in Algeria. Photovoltaic panels are used to convert this energy into electricity.

5.3.2.3.2. Wind turbine

Wind turbine (WT) was used to produce electricity from the available and free kinetic energy of the air. The kinetic energy is converted into electrical energy where the wind speed is high, as in the southern regions of Algeria. A small WT of 5kW rated power is used.

5.3.2.3.3. Battery storage

The 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.

5.3.2.3.4. Converter

Converter is the device that converts the electrical energy from AC into DC or vice versa. The rated power of the convertor depends on the peak load.

The economic parameters that are used in this study are given in Tab.22.

Table 22. Components characteristics and economic parameters.

Generation source	Parameters	Specification
Solar PV	Nominal power (KW)	1
	Capital cost ($/KW)	1400
	O&M cost (% of Capital cost)	2

	Temperature coefficient of power (%/°C)	-0.0041
	Life time (Year)	20
Wind Turbine	Nominal power (kW)	1
	Capital cost ($/KW)	1500
	O&M cost (% of Capital cost)	2
	Cut-in speed (m/s)	2.5
	Cut-out speed (m/s)	20
	Rated speed (m/s)	11
	Life time (Year)	20
Battery system	Battery capacity (KWh)	1
	Capital cost ($/KW)	160
	O&M cost (% of Capital cost)	2
	DOD (%)	80
	Charge efficiency (%)	95
	Discharge efficiency (%)	100
	Life time (Year)	10
Converter	Capital cost ($/KW)	500
	O&M cost (% of Capital cost)	2
	Efficiency (%)	95
	Life time (Year)	10
Economic	Project life time (Year)	20
	i: Interest rate (%)	5

5.3.2.4. Objective functions and constraints

The optimal sizing and techno-economic feasibility of the proposed HES is evaluated by considering economic and reliability criteria. In this study, the cost of energy (COE) is the objective function to be minimized while satisfy the load of building. The mathematical modelling equations for the objective function and constraints are provided in following subsections.

5.3.2.4.1. Cost of energy

The cost of energy (COE) is commonly used to compare different energy producer technologies. The COE, that is considered an economic evaluating objective to be minimized, was calculated using Eq. 25-28 (Das and Zaman, 2019) (Eriksson and Gray, 2018).

$$COE(\$/kWh) = \frac{C_{A\_cap} + C_{A\_O\&M} + C_{A\_rep} + C_{A\_fuel}}{E_{served}} \quad (25)$$

$$C_{A_{cap}}(\$) = (P_{Npv} * C_{PV} + P_{WT_r} * C_{WT} + Eb_{max} * C_B + P_{Cnv} * C_{Cnv}) * \ CRF \quad (26)$$

$$C_{O\&M}(\$) = 0.02 * C_{A_{cap}} * \sum_{k=1}^{T} \frac{1}{(1+j)^k} * CRF \quad (27)$$

$$C_{A_{rep}}(\$) = \left(Eb_{max} * C_B * \sum_{k=10}^{T} \frac{1}{(1+j)^k} + P_{Cnv} * C_{Cnv} * \sum_{k=12}^{T} \frac{1}{(1+j)^k} \right) * CRF \quad (28)$$

Where CRF is the capital recovery factor, is defined by Eq. 29 (Eriksson and Gray, 2018).

$$CRF = \frac{[i(i+1)^T]}{[(i+1)^T - 1]} \quad (29)$$

Where CA_cap, CA_rep, CA_O&M, CA_fuel are the annualized cost of investment, replacement operation and maintenance and cost of fuel respectively. PNpv, PWT_r, PCnv, Ebmax represent the rated power and capacity of PV, WT, converter, and the battery respectively. CPV, CWT, CCnv, CB represent the investment and replacement cost of PV, WT, converter, and the battery respectively.

5.3.2.4.2. Loss of power supply probability

Generally, Loss of power supply possibility or probability (LPSP) is defined as the ratio of the total energy deficit by the total energy demand for a period of time (T) commonly one year. LPSP can be evaluated by Eq. 30 (Ma and Javed, 2019).

$$LPSP(\%) = \frac{\sum_0^T P_{load} - P_{PV} - P_{WT} - (Eb(t) - Eb_{min})}{\sum_0^T P_{load}} \quad (30)$$

Where t is the simulation time step (one hour). In the present work, loss of power supply is constrained; in which LPSP must be less than 1%.

5.3.2.5. Particle swarm optimization algorithm

PSO is a well-known and popular meta-heuristic optimization technique which has attracted significant attention for solving complex optimization problems (Jamshidi and Askarzadeh, 2019). PSO algorithm was used here to solve the optimization problem.

5.3.2.6. Energy management strategy

The energy management strategy that is applied in this work is described as follows:

Case 1: First, the required energy is supplied by renewable sources and the excess energy is used to charge batteries. If there is a surplus of power greater than the need to fully charge batteries, then the rest power is consumed in a dump load.

Case 2: Renewable resources fail to provide sufficient energy to meet the load; therefore, the stored energy in the batteries is used.

Case 3: Both renewable sources and stored energy fail to meet the demand, and then, loss of power supply is evaluated.

5.3.2.7. Simulation

MATLAB software was used to implement the PSO algorithm and modelling the HES components in order to find the optimal sizing of the proposed HES at the studied locations. Based on climatic data, components' characteristics, and economic parameters, the simulation is carried out and the results are obtained after reaching a specific number of iterations. First, MATLAB needs the hourly time step of climatic data (ambient temperature, solar radiation and wind speed) and load profile of the studied building for the selected locations. At each hour time step of simulation, for over 8760 hours of the year, and during the project lifetime (20 years), MATLAB calculates the energy balance between supply sources and electrical load. Furthermore, the annualized costs of investment, replacement, operation and maintenance for HES' components were evaluated. Based on defined evaluating criteria and constraints, the feasible solutions are determined. Hence, the HES' configurations with the lowest COE are selected as the best solutions. The obtained results are presented and discussed in the following subsections.

5.3.3. Results and Discussion

5.3.3.1. Results of optimal sizing of the HES

The results of optimal sizing of the HES for both locations are summarized in Tab.23. In addition, Fig.46, Fig.47 and Fig.48 show the contribution of HES' components in Bechar and Adrar at typical three days in January (winter), April (temperate) and July (summer) respectively.

Table 23. Results of optimal sizing of HES.

Location	PV (kW)	WT (kW)	Battery (kWh)	LPSP (%)	COE ($/kWh)
Adrar	11	5	19	0,0098	0,26
Bechar	11	0	19	0,0058	0,24

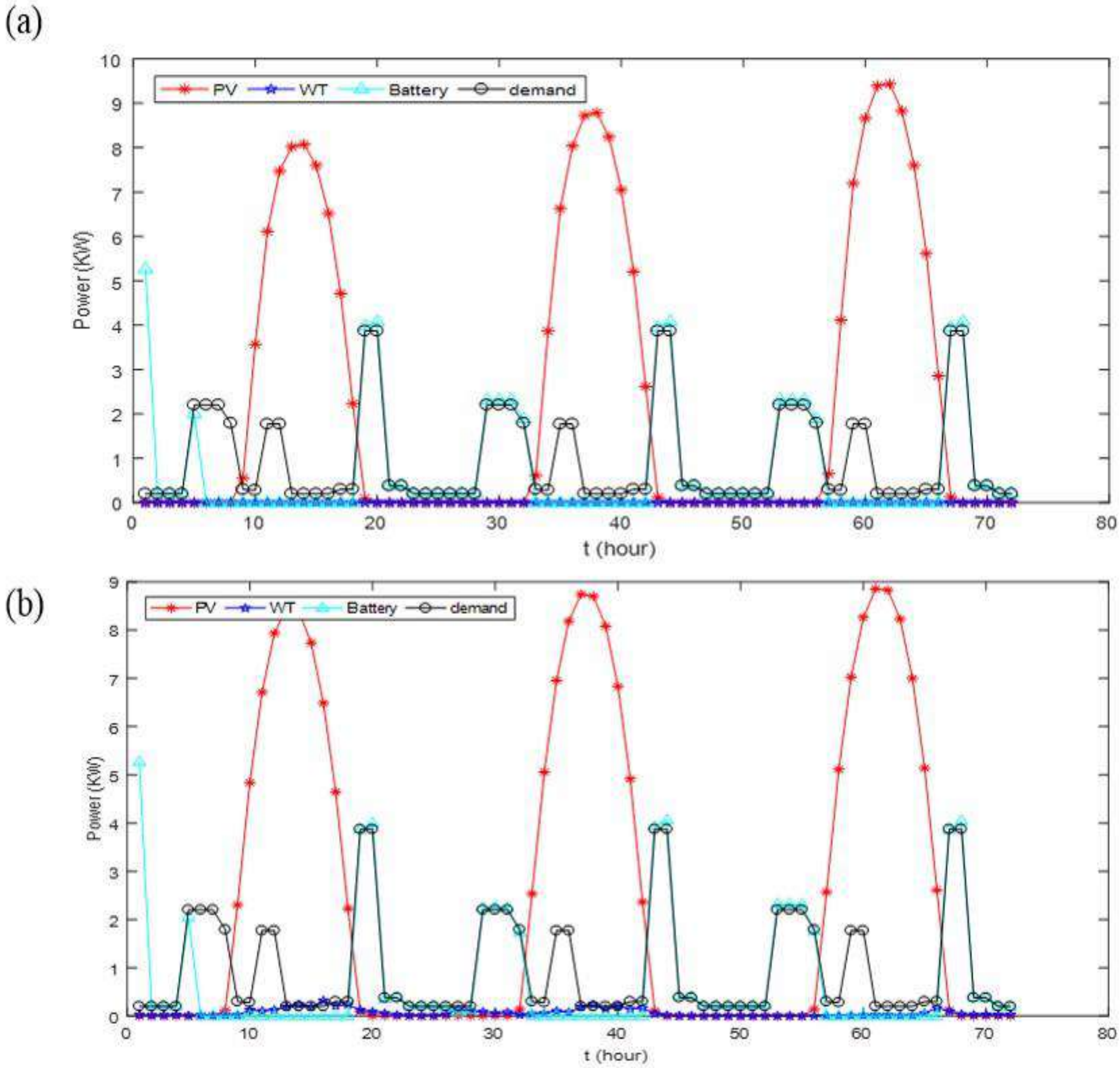

Figure 46. Contribution of HES' components (January) in: (a) Bechar, (b) Adrar.

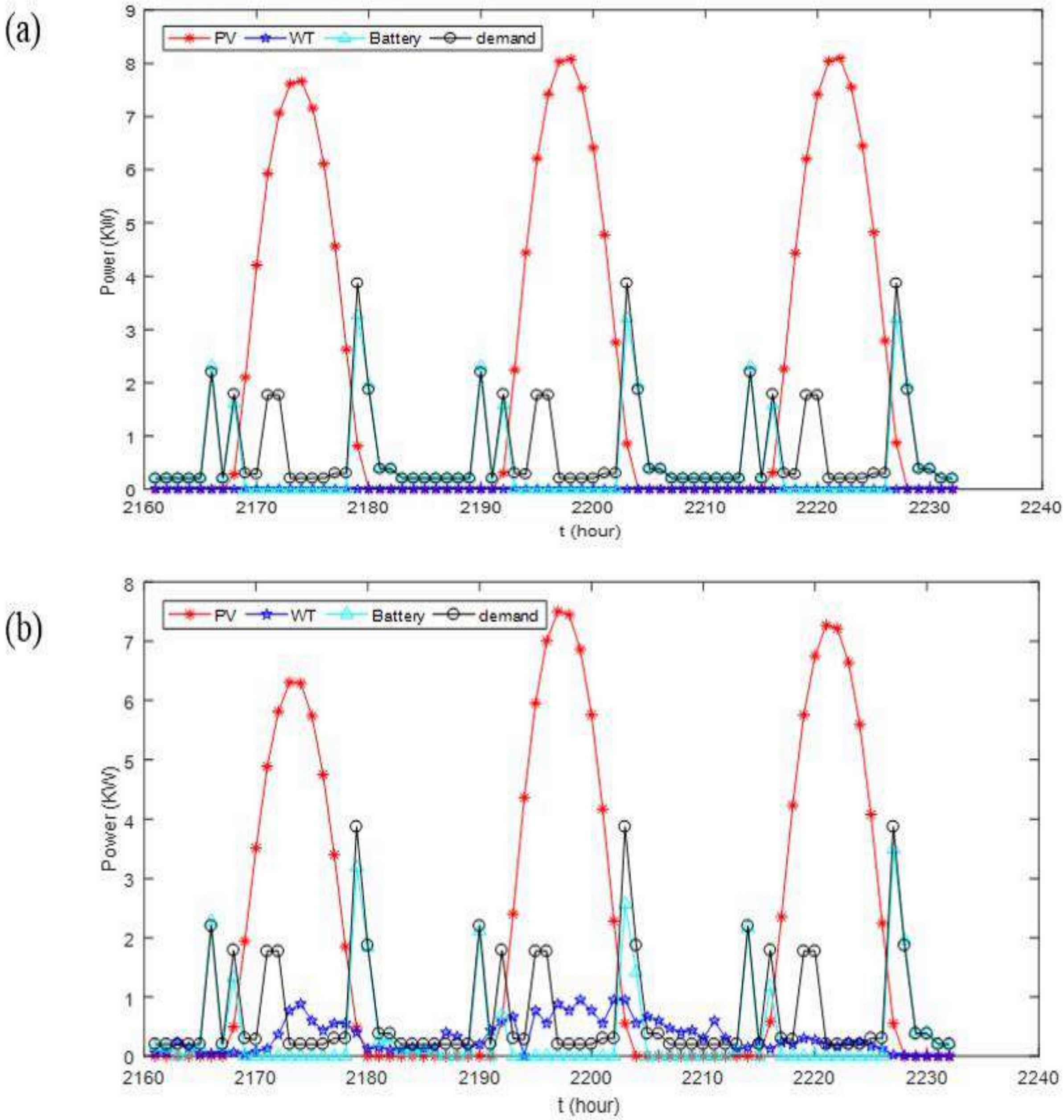

Figure 47. Contribution of HES' components (April) in: (a) Bechar, (b) Adrar.

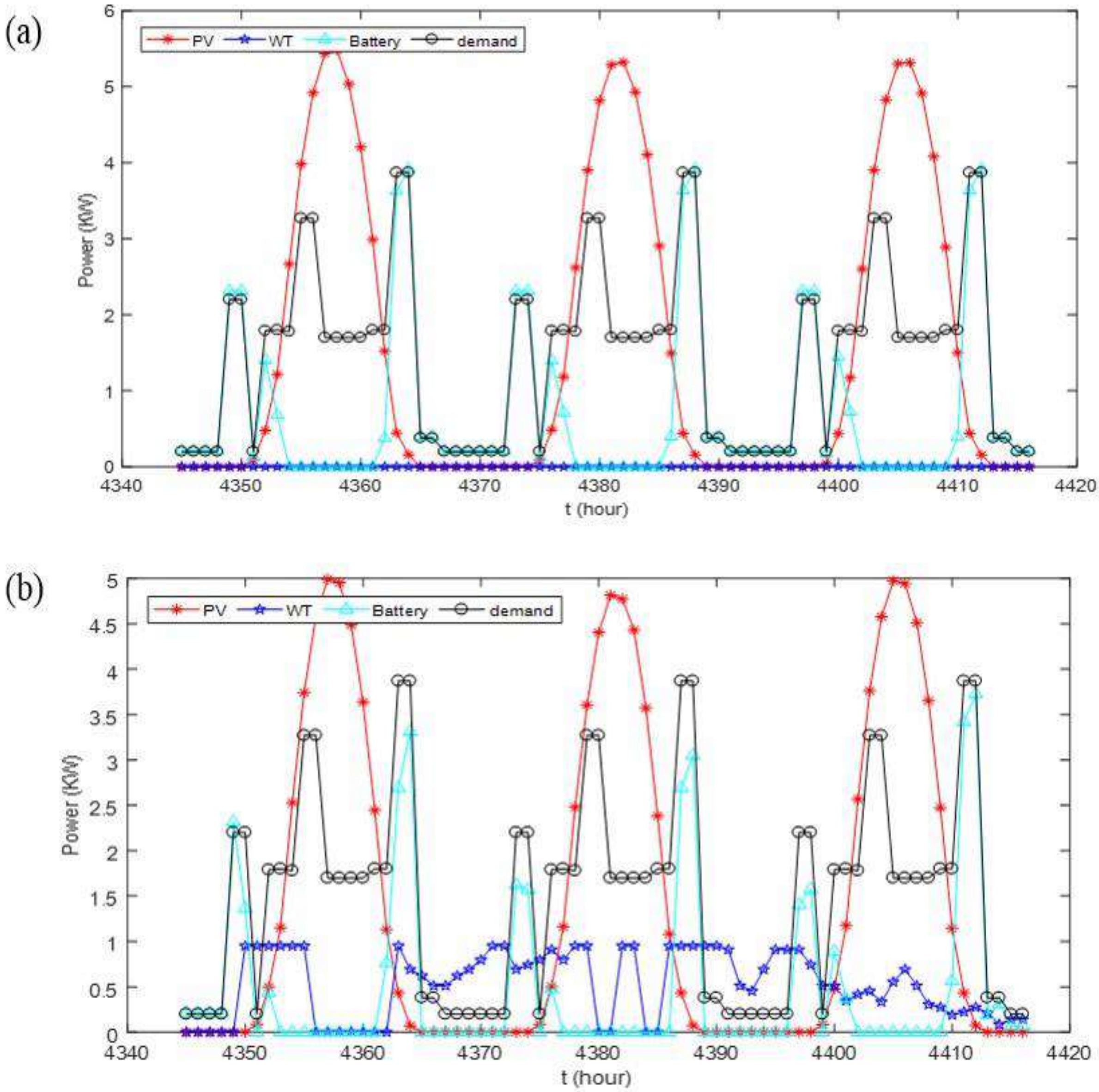

Figure 48. Contribution of HES' components (July) in: (a) Bechar, (b) Adrar.

From the figures, we can see that with same capacity of PV, the energy produced from PV in Bechar is greater than in Adrar. Because the effect of high temperature values in Adrar reduce significantly the performance of PV panels. In addition, in Adrar, unlike to PV which contribute at all the year, there is no contribution of WT in January (typical month of winter), which decreases the annual production of WT. Therefore, the COE in Adrar is greater than in Bechar. However, combine PV with WT still the best choice for Adrar than using only PV because of the high cost of investment of PV panels at present. In this scenario, PV-battery HES is an attractive solution to supply off-grid buildings in Bechar.

5.3.3.2. Sensitivity analysis

The cost of PV is declined rapidly year by year; therefore, the sensitivity analysis is carried out based on future assumption of PV panels' investment cost. Until 2030, the cost of PV panels will decreased extensively. In this regard, the investment cost of PV panels is assumed about 900$/kW by 2030. The results of this scenario for studied locations are presented in Tab.24.

Table 24. Sensitivity analysis results.

Location	PV (kW)	WT (kW)	Battery (kWh)	LPSP (%)	COE ($/kWh)
Adrar	13	0	18	0,0057	0,203
Bechar	11	0	19	0,0058	0,189

We can show that the investment cost of PV has a large effect on the cost of energy, which is extensively decreased. Comparing this value of COE to unit price of electricity in Algeria, we can conclude that in next years, the use of 100% HESis viable solution to supply so remote area in the Sahara of our country. Further, with certain subsidies to PV panels' costs, the proposed HES will be more cost effective. Similarly to first scenario, Bechar has a big opportunity to supply their buildings with only PV-battery HES in next years. However, for Adrar, where there has been a high potential of wind speeds, we recommend using large scale WT than using small WT, because small WT have high cost of investment and unable to work for low wind speeds. The findings of this work are significant and can help policy makers to make best decisions for HES deployment in the Sahara of the country.

5.3.4. Conclusion

This work aims to study the techno-economic feasibility of hybrid PV-WT-Battery energy system to supply off-grid buildings in isolated areas, Sahara of Algeria. A PSO algorithm is implemented to find the optimal solutions based on lowest cost of energy. The method is applied to isolated areas of Bechar and Adrar. The key results of this study can be summarized as follows:

- The cost of energy in Adrar and Bechar is found 0,26 and 0,24 respectively.
- The sensitivity analysis based on the future assumption for the cost of PV panels leads to energy cost less than the unit price of electricity in our country, which makes the proposed HES a more cost-effective solution.
- The proposed HES will help to convert the buildings in the Sahara of the country into green and sustainable buildings.

5.4. Case study 3: Multi-agent based-method for optimal sizing and management of hybrid renewable energy systems for isolated areas in Algeria

5.4.1. Introduction

Global electricity demand rose by 4% in 2018 alone, and at its fastest pace since 2010(IEA, 2018a). The main reasons are the increase of population, development of many electric equipment and the intense use of smart equipment such as robots. In Algeria, the demand for electricity has increased by 8 % in 2018 compared to 2016. Although around 99% of Algerian consumers are grid-connected (L'Energie, 2018), there remain large numbers of small communities who do not have access to the national electricity grid mainly due to their living far distances from urban areas. The majority of these areas are located in the Sahara, where it has a hot dry climate weather and hence the demand for space cooling represents over half of the total requirement of building (Mokhtara et al., 2019). Diesel generator (DG) is so far the only source used to meet the electricity demand for these locations. Despite of the challenge of fuel cost, which continues to increase year by year, this conventional source has faced some critical barriers against its use, in particular due to its CO_2 emission, and the use of depleted fuels. In addition, connecting these villages to the grid utility is not cost effective, and thus it is not an environment friendly solution. Therefore, the integration of renewable energy systems becomes the most suitable alternative to the current energy generation systems. In this regard, the Algerian government made many efforts to promote renewable energy sources mainly solar and wind by adopting different policies and programs such as the renewable energy program of 2011 and its updated version of 2015, which aims to achieve about 27% of electricity generation from renewable sources by 2030 (Government, 2015). In addition, this program intends to reach 7% of greenhouse gas (GHG) emission reduction by 2030 (Haddoum et al., 2018). Due to the fact that the non-continuity feature of power generation will result in uncertainty and low-level reliability when using solely renewable sources for supplying remote areas, a HES, which consists of renewable sources, a conventional source and/or energy storage system, would be a promising solution to address these challenging problems. HESs are usually PV and wind based renewable energy, combined with a battery storage (Gonzalez et al., 2018) and a conventional source like diesel generator. The main challenge for such a solution, however, concerns the optimal sizing and management of HES. Many researchers have investigated the optimal sizing and management of HES, where one or multiple target objectives are the system cost, reliability, CO_2 emission, fuel consumption, etc. All of those previous works were based on either optimization algorithms or commercial software (Fodhil et al., 2019). In (Abo-elyousr and Nozhy, 2018), a multi-objective optimization algorithm was used to study the feasibility of HES with Multiple Fuel Options for Islanded Areas in Egypt. In that study, the optimal sizing of the HES was carried out based on an ant colony optimization (ACO) algorithm to reduce the cost and emissions. In (Mahmoudimehr and Shabani, 2017), a straightforward quasi-steady operational strategy and genetic algorithm (GA) were combined to achieve an Optimal Design of PV/Hydroelectric HES for North and South regions of Iran, where the investment cost and the loss of power supply probability (LPSP) are the two main objectives to be minimized. A bi-level optimization framework for optimal sizing of a hybrid wind/PV energy system with a hybrid energy/battery? storage was developed in (Rullo et al., 2019). In that work, the proposed GA-based sizing method was integrated with an energy management system, which is based on economic predictive control. The results of that proposed methodology have shown an investment saving as well as a reduction of operation costs. In (Jamshidi and Askarzadeh, 2019), size optimization of an off-grid PV, fuel cell and diesel generator hybrid system was carried out, considering the operating reserve (OR) and uncertainties of load and supply. In that study, the total net present cost (TNPC) and LPSP were the objectives to be minimized. In the study of (Moradi et al., 2018), an optimal energy management and optimization of a standalone HES with battery storage with system uncertainties was investigated. The main objectives of the work were the reduction of system fuel cost and greenhouse gas emissions, and the improvement of energy utilization efficiency. The resultant system was solved as a constrained single-objective optimization problem using an advanced dynamic programming method. In order to satisfy the required energy demand, together with minimize the energy cost, maximize renewable energy integration, and minimize loss of supply, a new parallel hybrid GA-PSO (particle swarm optimization) algorithm was developed in (Mellouk et al., 2019) for optimal design and management of HES in Laayoune region, Morocco. The authors in (Eriksson and Gray, 2018) proposed a multi-objective approach by implementing a Particle Swarm meta-heuristic optimization algorithm for achieving a compromise between several techno-economic, environmental and socio-political objectives for the optimization of any configuration of renewable energy system. In (Zhang et al., 2019), an improved hybrid optimization algorithm coupled with neural network (NN) weather forecasting method was proposed for the optimal sizing of a stand-alone HES. The total life cycle cost was used to evaluate the feasibility of the HES, taking into account the system reliability constraint. In (Zhang et al., 2018), a simulated annealing (SA) algorithm for optimization of HES including battery and hydrogen storages for the supply of residential electrical load was developed. The method has been applied to a size of six schemes of HES for a remote area in Iran. The optimization results demonstrated that a wind and solar energy based hybrid system with electrochemical storage could offer the most cost effective and reliable energy system. In (Zheng et al., 2018), the optimization of a biomass based micro grid with DSM using load shifting algorithm based on economic linear programming with model predictive control was performed to minimize the operating cost of a biomass combined heat and power micro grid. The method was developed to manage the supply and the demand of both electrical and thermal energy sources. The proposed algorithm enhanced the performance of the micro grid, reduced the operating cost by 6.06% and increased the renewable energy fraction by 6.34% compared to no-load shifting case. Similarly, a techno-economic and environmental optimization of a PV/battery hybrid energy system within DSM was carried out in (Yang and Xia, 2017). The control system aimed to minimize the residential energy cost, energy consumption from the grid, while considering the thermal comfort inconvenience level within the building. The multi-objective problem was solved using a mixed-integer nonlinear programming (MILP). The study was similar to that in (Tu et al., 2019), where a multi-layered demand scheduling using MILP was carried out for the optimization of hybrid PV/WT/DG/Battery system. The main objective of the study was to minimize the total cost of energy. In (Haratian et al., 2018), HOMER software was employed to examine the techno-economic feasibility of a stand-alone HES power generator. Similarly, the feasibility of PV-biomass and PV-diesel power generation hybrid generation system in Mozambique were analysed in (Garrido et al., 2016) using HOMER software. At the same time, in (Duman and Güler, 2018b), HOMER software was used to perform the techno-economic analysis of an off-grid PV/wind/fuel cell hybrid system for meeting the electric energy demand of off-grid vacation homes under different geographic and climatic conditions in Turkey. In (Jafar et al., 2019), the optimal sizing and energy management of a stand-alone hybrid photovoltaic/wind system was made based on a hydrogen storage, considering different reliability indices using a flower pollination algorithm (FPA). In (Assaf and Shabani, 2019), a novel HES solution was investigated using MATLAB software for energy supply to remote areas with cost effectiveness and more reliability. In (Das et al., 2019), techno-economic analysis for optimal design of an off-grid HES using water cycle algorithm and moth-flame meta-heuristic optimization techniques was carried out to supply a radio transmitter station in India. PSO and ε-constraint method were used in (Fodhil et al., 2019) for optimal design of PV/DG/Battery hybrid energy system for rural electrification in Algeria. Minimization of total system cost, unmet load, and CO2 emissions were the primary objectives of that work.

Despite those aforementioned works, recently, there has been an increased attention towards using MAS based methods for optimal sizing and energy management in HES. In (Jun et al., 2011), a MAS for energy management in distributed HES generation is proposed. The proposed MAS solution is developed on JADE (Java Agent Development) framework. The results emphasize that MAS is a suitable solution for the energy management of the distributed HES. Similarly, in (Khan et al., 2018), a novel MAS based model for optimal management of HES at a distributed level is implemented. The proposed technique is used for the optimal operations of HES and offers extra intelligence to the system. The results obtained emphasize the robustness of the model for the management of such system based on MAS technique at the distributed level. In the study of (Khan et al., 2019), the optimal energy management and the control of distributed HES based on MASs is presented. In addition, the authors have provided the recent research work on multi-agents-based coordination for the optimal management of electric energy at the distributed level. The analysis of that paper shows that PSO is the most useful and effective technique that has been applied to HES. In (Boudoudouh and Maârou, 2018), the authors presented a new architecture based on MAS for the energy management of distributed HES generation and distributed consumption. An interactive MAS-PSO based method was applied in (Mohseni and Moghaddas-tafreshi, 2018) for optimal sizing of HES in micro grid. Simulation results demonstrate that the proposed system can reduce the overall cost of the system in comparison with non-interactive methods.

Based on the literature review above, it is clear that the majority of works neglected the load profile effects and only used simple and average estimations. Furthermore, the DSM strategies are not applied according to the case study location and climate conditions. Besides that, the control of set point temperature such as a DSM strategy is not widely applied. To address these issues, a MAS-based method for optimal sizing and management of HES is proposed in this study. The method is applied to a residential building, which is located in the hot dry climate of Algeria. The main contributions of this study are the development of an optimization algorithm based on the MAS concept for determining the optimal sizing of the proposed HES for energy supply in remote areas of Algeria. In addition, application of a demand-side energy management strategy based on controlling of set point temperature of a HVAC system to minimize energy consumption in buildings in hot dry environments. In addition, various scenarios are investigated to evaluate the efficiency of the proposed method.

This work is organized as follows. Section 2 defines the proposed HESand describes the proposed method. Section 3 describes the MAS, and provides its main concepts. In Section 4, a case study simulation is made to test the proposed method, and results and discussions are provided. Finally, Section 5 summarizes the key conclusions and proposes some future work.

5.4.2. Material and methods

In order to obtain a good compromise between the costs of energy, system reliability, environment constraints and the optimal sizing of such HES, an effective energy management strategy must be integrated (Rullo et al., 2019). In this work, a MAS based approach is proposed as an energy management and control approach for size optimization and energy management of an off-grid HES to supply energy to isolated buildings. The studied hybrid system is shown in Fig.49, including solar PV panels, wind turbine, diesel generator and battery storage that are modelled and optimally sized for electrification of studied building in Ouargla, Algeria.

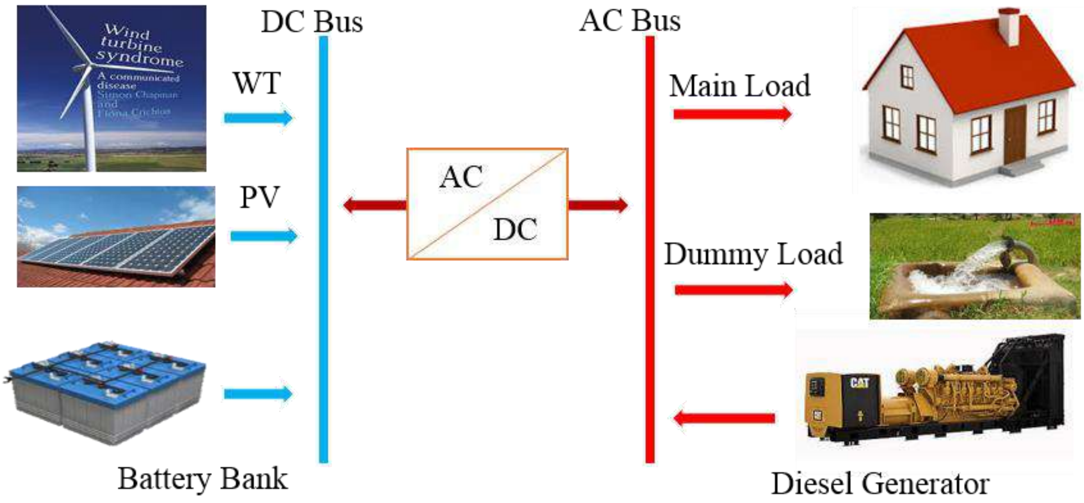

Figure 49. Area suitability for installing PV panels on three buildings of the campus (from ArcGIS).

5.4.2.1. Multi-agent system

MASs come from Artificial Intelligence Distributed, a branch of Artificial Intelligence. The MAS approach, which has developed extensively over the last twenty years, makes it possible to understand, model and simulate complex systems. However, there is no strict definition about an agent until now. According to Wooldridge, an agent is a software (or hardware) entity that is situated inside certain environments and is able to autonomously react to changes in that environment. Agents are classified into three categories as reported in (Khan et al., 2018):

- Cognitive agents: They have a capability of reminiscence, interaction and reasoning ability.
- 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. As a hybrid agent, they practice both types of actions: reactive and cognitive.

However, MAS is defined as a loosely coupled network of problem-solving agents that work together to find answers to problems that are beyond the individual capabilities or knowledge of each agent. These agents are autonomous and interact via an environment. In MAS, agents have roles; often perceive their environment through messages. There are many tools for the implementation MAS such as JADE, ZEUS, JANUS, and others. JADE Framework is an open source middleware and is the most widespread agent-oriented middleware. It supports key features required by agents, the core logic of agents themselves, and a rich suite of graphical tools. Communication among agents in JADE is implemented based on FIPA-specified Agent Communication Language (FIPA-ACL), which is the most important standardization activity conducted in the field of agent technology.

5.4.2.1.1. MAS concept in HES

The MAS applied to the distributed control of electrical systems presents a major issue for the management of the complexity and flexibility of the control (Mbodji et al., 2016). MAS technology is now attracting more and more attentions from researchers due to its promise as a new paradigm of applications in distributed artificial intelligence. Management of the multi energy sources in a home or building is an important task for assuring the best operation of the different components of the HES. The use of MASs for the management of electrical energy is a powerful solution to make the HES operation more reliable. The reason is that the distributed control approach in the MAS can solve the uncertainty and the intermittence of renewable energy sources simultaneously. In addition, MAS works adequately with such a system where the components can be changed, damaged, replaced, deleted, added any time when needed. Hence, the role of MAS is to improve the management of electrical energy sources in the HES for assuring the continuity of energy supply. In this study, the MAS based method for optimal sizing and management of an off-grid HES consisting of five agents are defined as follows.

5.4.2.1.2. Generation agent (GA)

This agent includes all energy-produced sources, namely WT, solar PV, and diesel generator. GA is responsible for controlling the generation sources and providing information about the available energy produced at each hour. It is responsible for adding, deleting, changing, connecting or disconnecting any energy source.

5.4.2.1.3. Load agent (LA)

LA comprises HVAC load agent and electric appliances agent. LA is responsible for controlling loads at each hour, and provides the required information to other agents. It also receives climatic data from the environment.

5.4.2.1.4. Storage agent (SA)

The SA includes a battery bank. The SA has a permanent behavior, because it can work in case of charge and discharge. However, this agent has two limits of charge, at each hour the SA supervising the state of charge of batteries and receive information from GA and LA to decide when batteries could run on charge or discharge mode.

5.4.2.1.5. Control agent (CA)

CA is the manager of the system, and mainly responsible for the management of different information from/to other agents according the priorities.

5.4.2.1.6. Design agent (DA)

DA is an independent system operator responsible for optimizing the HES. This agent selects and sizes the HES' components to find the optimal configuration of HES.

The sequence diagram for the energy management in the studied HES, which illustrates the different interactions between agents, is presented in Fig.50.

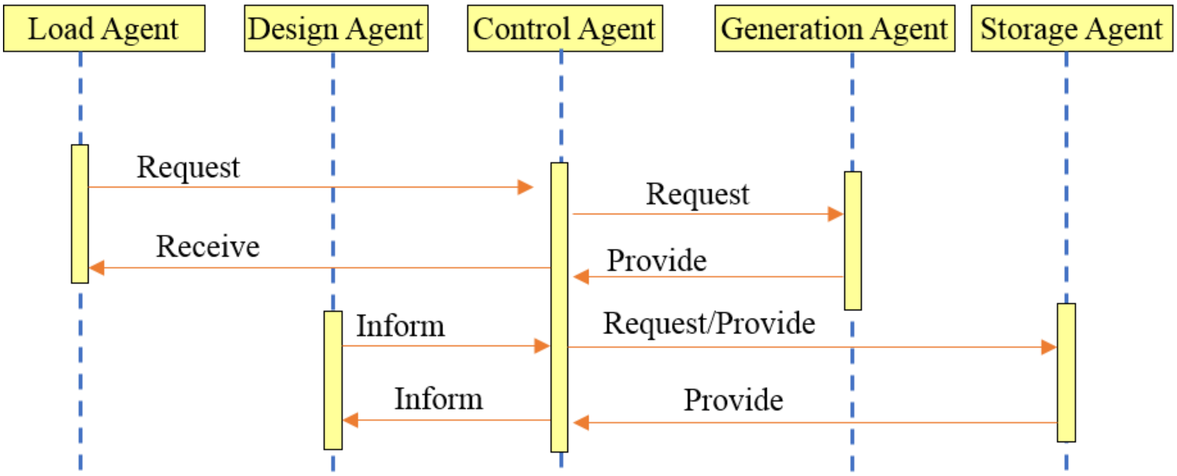

Figure 50. The sequence diagram of MAS for HES.

5.4.2.2. MAS modelling for the studied HES

In this section, the design of MAS for the proposed HES is performed. Each agent will be described and modelled based on HES' components and their task.

5.4.2.2.1. Generation agent

Generation agent includes all produced sources, including renewable and non-renewable sources. Mathematical modelling of this agent and their component are provided as follows.

5.4.2.2.2. Solar PV

One diode model with four parameters was used in this work to evaluate the power output of the PV system.

5.4.2.2.3. Wind Turbine (WT)

Wind turbine is a renewable energy source that can be used to convert the kinetic wind energy into electrical energy. A simple cubic model was used here to calculate the generated electricity from the WT.

5.4.2.2.4. Diesel generator (DG)

Diesel generator is used as a backup unit in a hybrid energy system to meet the load demand in case the total available renewable energy generated power and batteries bank/hydrogen stored power are not sufficient.

5.4.2.2.5. Storage agent

In this work, storage agent includes solely batteries, which are commonly used for storage as is highly acceptable. 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 a battery bank or a diesel generator.

5.4.2.2.6. Control Agent

Control agent (CA) responsible for the energy management of the HES. The management of HES is one of the main steps in the design of HES. 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.
- Case 4: The generated energy from the renewable sources is not sufficient to meet the demanded load and the battery bank is depleted. In this case, the diesel generator is switched to supply the load and to charge the battery.

1.1.1. Design agent

Design agent (DA) is the agent that performs the optimization of the HES. In this study, the DA consists of a PSO based program, which is implemented for the optimal sizing of the HES. The objective function to be minimized is the cost of energy of the HES, with respect to critical value of LPSP (Loss of power supply probability). The critical value of LPSP is set at 5%, which represents the allowable loss of power at the entire yearly demand. Further, the fuel consumption is also to be minimized which can be achieved by increasing the share of renewable energy. The main program of the proposed algorithm is developed in MATLAB software based on the mathematical modelling of the HES components and objective functions.

5.4.2.2.7. Objective function

The present problem has a single objective function, which is the cost of energy (COE), widely used in size optimization of HES. COE can be evaluated using the following equations, Eq. 31-35 (Das and Zaman, 2019).

$$COE(\$/kWh) = \frac{C_{A\_cap} + C_{A\_O\&M} + C_{A\_rep} + C_{A\_fuel}}{E_{served}} \tag{31}$$

$$C_{A_{cap}}(\$) = (P_{PV\_r} \cdot C_{PV} + P_{WT\_r} \cdot C_{WT} + P_{DG\_r} \cdot C_{DG} + P_{B\_r} \cdot C_B + P_{Conv} \cdot C_{Covn}) \cdot CRF \tag{32}$$

$$C_{O\&M}(\$) = 0.02 \cdot C_{A_{cap}} \cdot \sum_{k=1}^{T} \frac{1}{(1+j)^k} \cdot CRF \tag{33}$$

$$C_{A_{rep}}(\$) = \left(P_{B_r} \cdot C_B \cdot \sum_{k=10}^{T} \frac{1}{(1+j)^k} + P_{Conv} \cdot C_{Covn} \cdot \sum_{k=12}^{T} \frac{1}{(1+j)^k} + P_{DG\_r} \cdot C_{DG} \cdot \sum_{k=a,2a,\dots\dots<T}^{T} \frac{1}{(1+j)^k} \right) \cdot CRF \tag{34}$$

$$C_{A\_fuel}(\$) = fuel_{Cons} \cdot C_{fuel} \cdot \sum_{k=1}^{T} \frac{1}{(1+j)^k} \cdot CR \tag{35}$$

5.4.2.2.8. Constraints

As the HES contains none continuous energy supply sources such as renewable energy, it is often found to suffer deficits of power supply, which leads to consideration of the reliability factors. Many evaluation parameters allow evaluating the reliability of the HES that are used in literature. In this study, LPSP is used to evaluate the system reliability as it is widely used. Generally, LPSP is the ratio of the total energy deficit by the total energy demand for a period of time (t) commonly one year. LPSP expresses the rate of non-satisfaction of the load and its value can be given by Eq. 36 (Ma and Javed, 2019):

$$LPSP(\%) = \frac{\sum_0^T P_{load} - P_{PV} - P_{WT} - P_{DG} - P_{SOCm}}{\sum_0^T P_{load}} \tag{36}$$

5.4.2.2.9. Environment and renewability indices

Two factors are defined to evaluate renewable energy contribution and GHG emissions produced from the proposed HES. For evaluation of renewability, renewable fraction (RF) parameter is used and defined by Eq. 37 . However, GHG emission is evaluated based on the amount of CO_2 generated by the HES. CO_2 generated amount is calculated using Eq. 38 (Shara and Elmekkawy, 2014).

$$RF(\%) = 1 - \frac{P_{DG}}{P_{PV} + P_{WT}} \tag{37}$$

$$CO2(Kg) = EF. \sum_{t=1}^{8760} fuel_{cons}(t) \tag{38}$$

Where EF is the emission factor for diesel generator, which depends on type of fuel and diesel engine characteristics. The value of this factor is in the range of 2.4 - 2.8 kg/lit (Shara and Elmekkawy, 2014).

5.4.2.3. Case study and simulation

This work concerns the sizing and optimal management of an HES, which can meet the electricity demand of a residential building in an isolated area of Algeria. The selected residential building is located in El Borma municipality, Ouargla, Algeria. The majority of residential buildings in El Borma are not connected to the utility grid, because El Borma is a too isolated area of Ouargla' province. This district is located in the Sahara with a very hot dry climate, where the temperature can exceed 50°C, and relative humidity can be less than 5 % in summer. The hourly climatic data for El Borma (Ouargla) for the entire year are extracted from Meteonorm software (NASA 2005). Fig.51, Fig.52 and Fig.53 present the hourly solar radiation, ambient temperature, and wind speed respectively for El Borma, Ouargla.

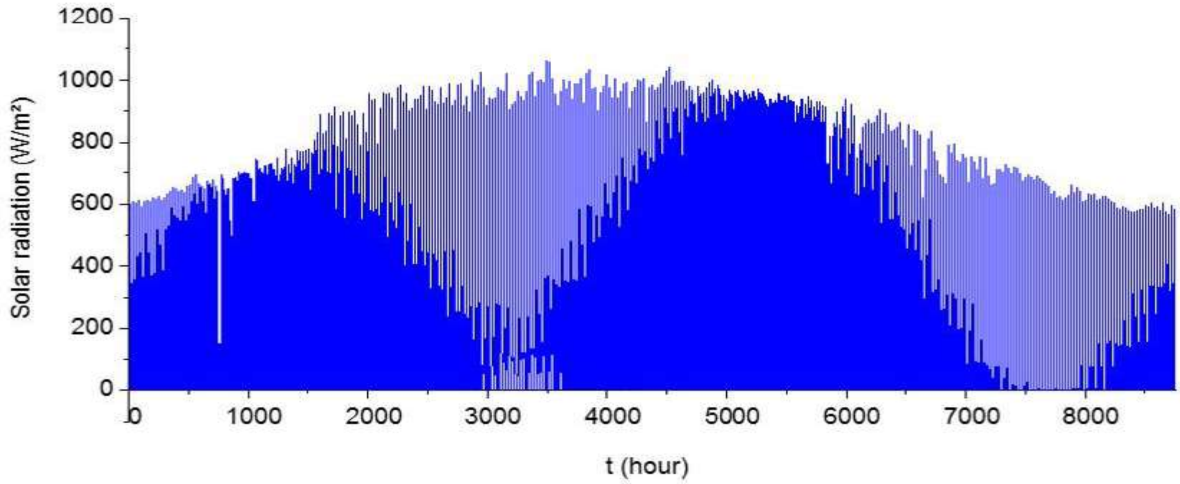

Figure 51. Solar radiation at El Borma.

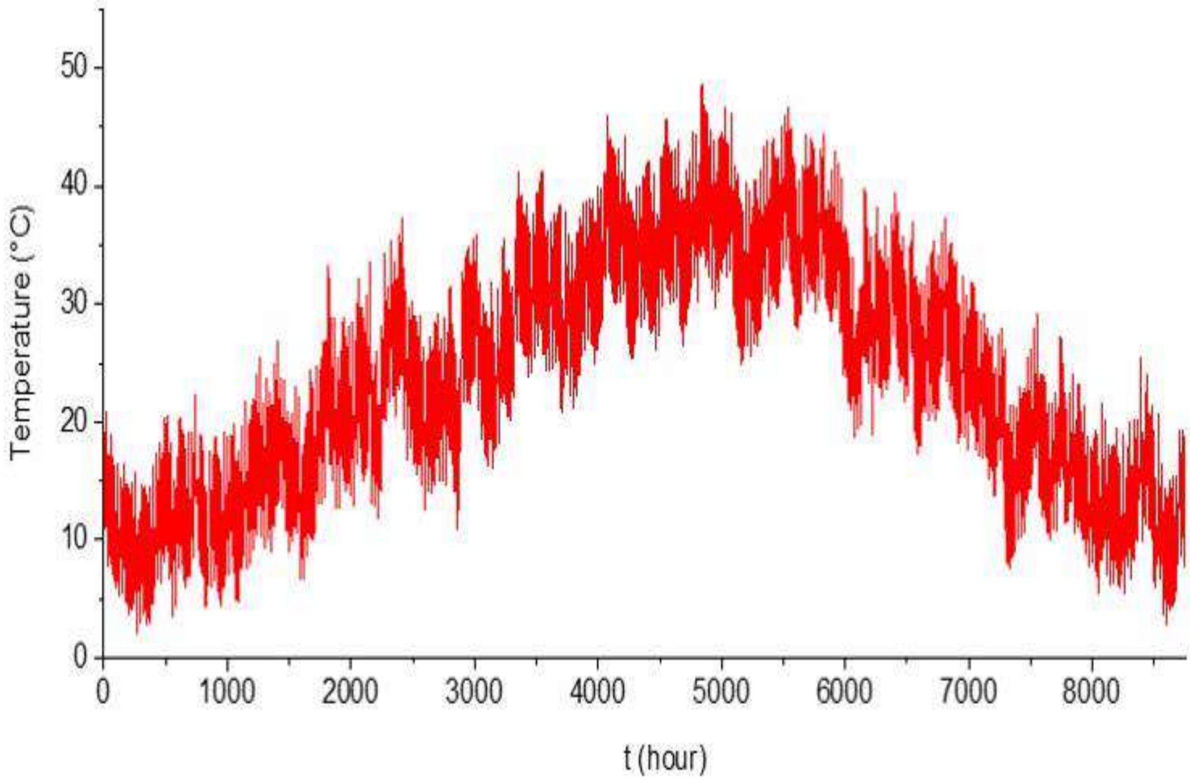

Figure 52. Ambient temperature at El Borma.

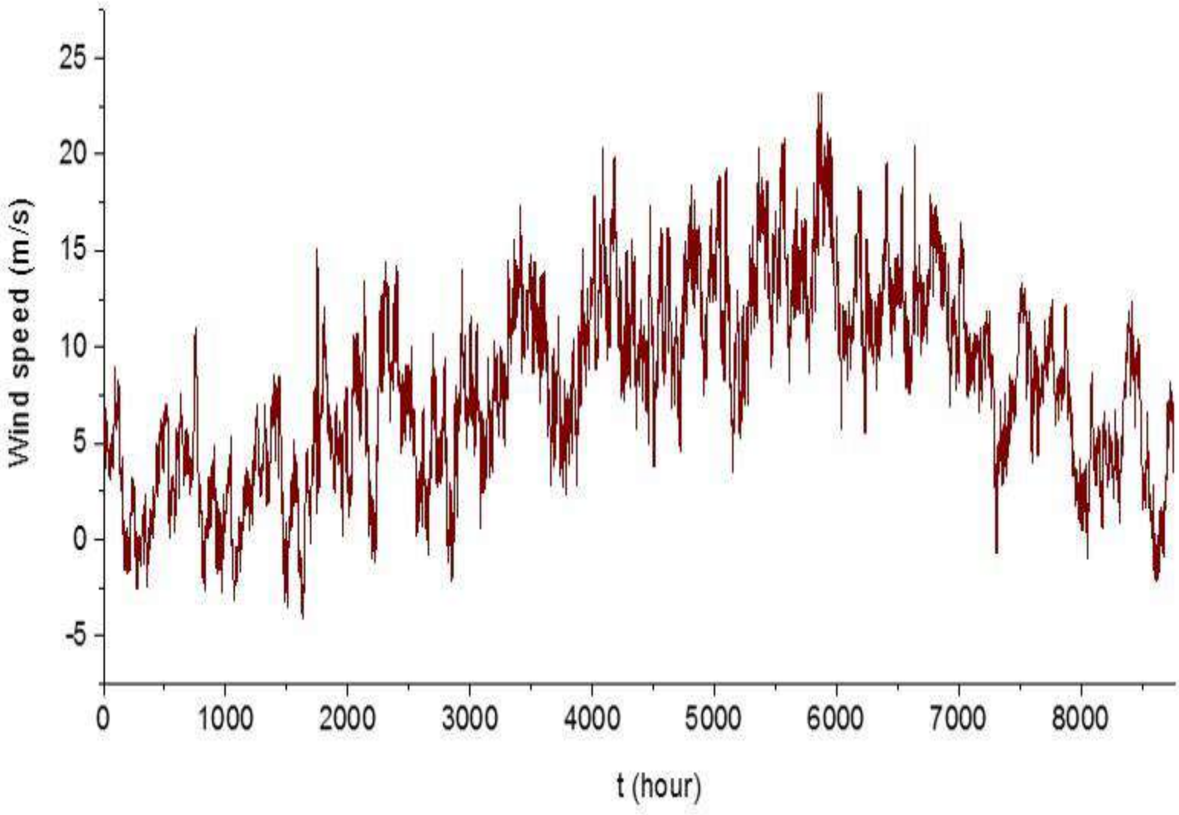

Figure 53. Wind speed at El Borma.

5.4.2.4. Building description

The studied building is a typical residential building, which is known as F3 according to Algerian standards of construction (Mokhtara et al., 2019). The building includes one bedroom, one sitting room, a corridor, kitchen and bathroom. The entire area of the floor is 64 m². The height of the building is 3m. The 2D plan and design builder 3D model of the building are illustrated in Fig.54. Furthermore, the properties of the building' envelop are summarized in Tab.25.

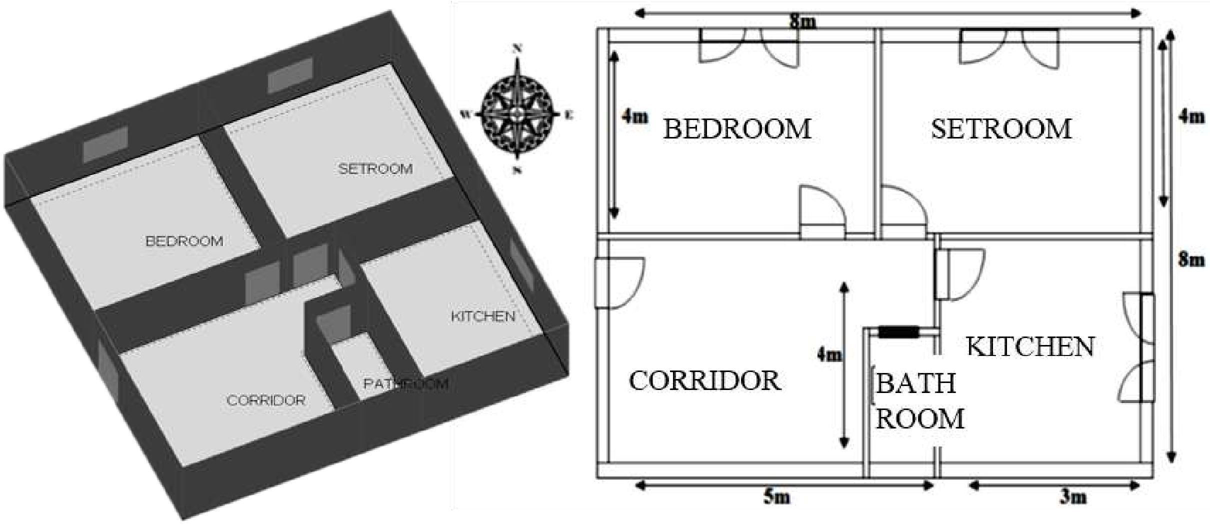

Figure 54. Plan of the building.

Table 25. Building components and characteristics of walls.

Element	Construction (outside to inside)	U-Value (W/K-m2)
Ground floor	Concrete(0.1m), Extruded Polystyrene(0.04m), Concrete(0.1m), Ceramic floor tiles (0.02m)	0.573
Roof	Bitumen (0.01m), Cement(0.01m), Concrete Block (0.2m), Cement(0.01m)	2.994
Internal Wall	Cement(0.01m), Brick(0.1m), Cement(0.01m)	2.079
External Wall	Cement(0.01m), Brick(0.1m), Air gap (0.01m), Brick(0.1m), Cement(0.01m)	1.39
Glazing	/	1.978
Door	/	2.823

5.4.2.5. load profile

The load profile of the studied building is divided into two parts. The first part includes all different electric devices, except for the cooling chiller. Hence, the second part includes the load profile of space cooling which is evaluated by energy plus.

5.4.2.5.1. Electricity demand for appliances

The hourly electricity demand profile for appliances, which includes refrigerator, lighting system, and TV, is evaluated based on the number and rated power of each device, and the usage time of occupants. Fig.55 shows the hourly demand for appliances on an average day of the year. Tab.26 gives the summary of the building' appliances and their characteristics.

Table 26. Building' appliances and their characteristics.

Element	Rated power (W)	Number	Daily use (hours)
Refrigerator	320	1	24
Light	40	5	18
TV	100	1	8

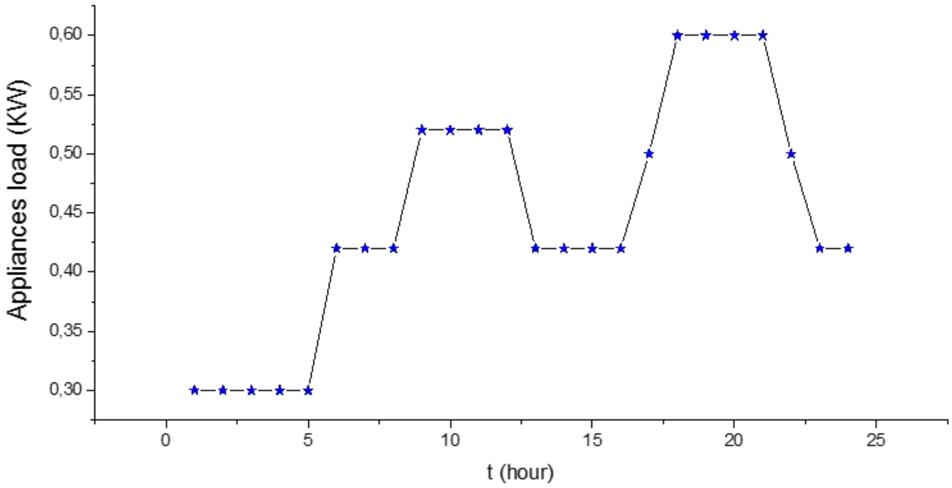

Figure 55. Electricity demand for appliances.

5.4.2.5.2. Electricity demand for space cooling.

In hot dry regions like Ouargla, the required demand for space cooling is assumed more than half of the total electricity demand. Therefore, it is mandatory to evaluate this load adequately. In this regard, Energy plus and Design Builder software are used together to calculate the hourly demand for space cooling at the studied building. Only the bedroom and sitting room include air conditioners. Thus, the conditioned floor area is 32 m². Fig.56 shows the hourly demand for space cooling for the case of 24°C and 29°C set point temperature.

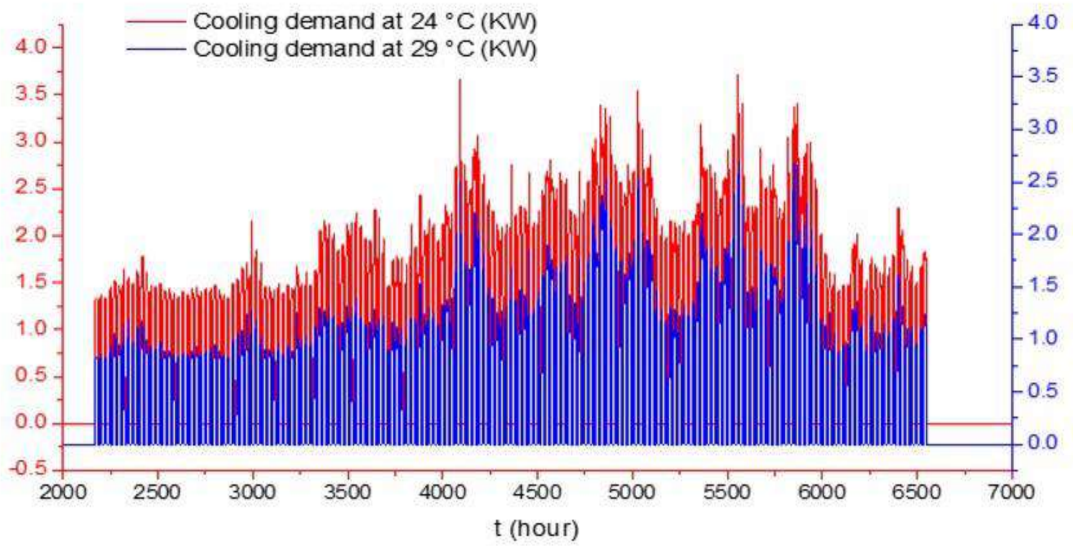

Figure 56. Energy demand for space cooling (summer period).

The annual demand for 24 °C is 8244 kWh. However, for 29 °C is 6673 kWh. The demand after applying DSM in which the set point temperature is controlled between 24°C and 29°C is obtained after doing the simulation.

5.4.2.6. Component description

The economic parameters of the HES are the essential inputs when the objective function is to minimize the cost of energy of the system. Hence, the required economic parameters are provided in Tab.27. In addition, constraints are also recommended, which present restrictions imposed on the available resources and environment (e.g. time restriction, physical limitation), and are defined as dependencies among the parameters and decision variables that are involved in the problem. A constraint may be of inequality or equality type and restricts a variable to be between a lower and upper bound in a decision space. The upper and lower limits of the HES' components and parameters are provided in Tab.28.

Table 27. HES' components and economic parameters.

Generation source	Parameters	Specification
Solar PV	Nominal power (kW)	1
	Capital cost ($/kW)	1300 (Mandal et al., 2018a)
	O&M cost (% of Capital cost)	2
	Temperature coefficient of power (%/°C)	-0.0041
	Life time (Year)	20
Wind turbine	Nominal power (kW)	5
	Capital cost ($/kW)	3000 (Mohamed et al., 2015)
	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)	20
Diesel generator	Rated power (kW)	1
	Capital cost ($/kW)	800 (Tu et al., 2019)
	O&M cost (% of Capital cost)	2%
	Fuel price ($/L)	0.2
	Life time (hour)	30000
Battery	Battery capacity (kWh)	1
	Capital cost ($/kW)	200 (Ghenai and Bettayeb, 2019)
	O&M cost (% of Capital cost)	2
	DOD (%)	80
	Discharge efficiency	95%
	Charge efficiency	100%
	Life time (Year)	10
Converter	Capital cost ($/kW)	700 (Mohamed et al., 2015)
	O&M cost (% of Capital cost)	2
	Efficiency (%)	95
	Life time (Year)	10
Economic parameters	Project life time (Year)	20
	i (%)	5

Table 28. Decision variables and constraints limits.

Parameters	PV [kW]	WT [Nbr]	Battery [kWh]	DG [kW]	LPSP [%]	RF [%]
Lower bound	0	0	0	1	0	0
Upper bound	7	2	20	10	1	1

5.4.2.7. Simulation

MATLAB software is used to implement the five agents for the proposed HES. Each agent is defined as a function file. Design agent, includes two agents. First agent is created for developing particle swarm algorithm, which is used to solve the multi objective problem. However, second agent is created for evaluating objective functions namely COE, LPSP, and NRU. In control agent, the energy management strategy is implemented including the proposed DSM applied on set point temperature in cooling mode. In generator agent, mathematical equation for energy sources are developed to evaluate the hourly produced energy. Storage agent consists of two agents, charge and discharge agent. In these two agents, state of charge of battery bank, and hydrogen system are evaluated based on their modelling equations. The communication between the agents is defined by call functions. The required data for simulation including component parameters, climatic data, and load profile are imported to MATLAB software as vectors for one-year simulation. Finally, one-year simulation (8760 hours) is performed. In this work, simulation-stopping criterion is the number of iterations. After the calculation is finished, the target results are obtained and then plotted. The presentation and discussion of results are provided in the following subsections.

5.4.3. Results and Discussion

5.4.3.1. First scenario

In this scenario, the optimal sizing of the HES is performed without introducing DSM in the management strategy. Here, the annual electricity demand of the studied building is evaluated for a desired set point temperature of 24 °C (High thermal comfort condition in cooling mode). Tab.29 provides the results of this scenario. Furthermore, the hourly contributions of each source on typical days of the year are presented in Fig.57.

Table 29. Optimal sizing of HES (First scenario).

LPSP (%)	COE ($/KWh)	Fuel consumption (L/Year)	CO_2 (Kg/year)	RF (%)	CPV (KW)	WT (KW)	CDG (KW)	Cb (KWh)
0.4	0.266	3672	9549	20	1	0	3	0

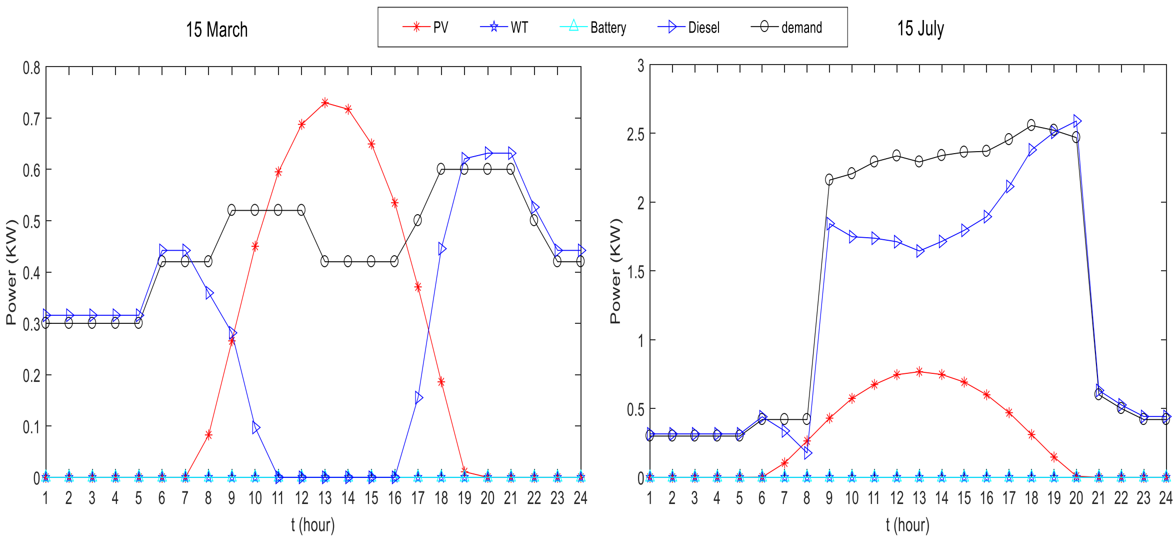

Figure 57. Hourly energy contribution of each source (first scenario).

In this scenario, the obtained optimal configuration includes PV panels and DG. Results show the contribution of DG is important, hence, fuel conception is very high. Here, because of large energy demand in daytime (High-energy demand for space cooling), the energy produced by PV panels is insufficient to provide the required demand; therefore, DG is often operated. In addition, because there is no more surplus energy, no storage component is needed. Furthermore, within this energy management strategy, wind turbine is not included in the obtained configuration. The obtained HES is more reliable and could provide the required energy demand for almost time of operation. However, it is not friendly to environment. Therefore, another energy management strategy is suggested to increase the share of renewable sources so that reducing fuel consumption and CO_2 emissions.

5.4.3.2. Second scenario

In this scenario, the set point temperature in cooling mode is controlled at each hour according to renewable sources availability and ambient air temperature. Tab.30 provides the results of this scenario. However, the hourly energy contributions of each source on a typical day for this scenario are presented in Fig.58.

Table 30. HES' results (Second scenario).

LPSP (%)	COE ($/KWh)	Fuel consumption (L/Year)	CO2 (Kg/year)	RF (%)	CPV (KW)	WT (KW)	CDG (KW)	Cb (KWh)
0.7	0.233	48	125	99	7	0	1	7

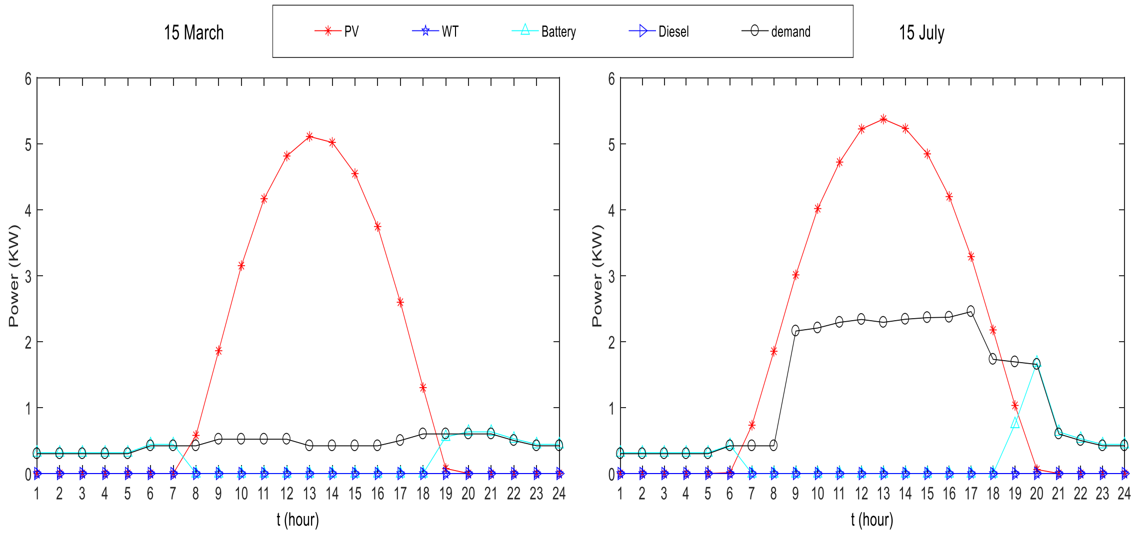

Figure 58. Hourly energy contribution of each source (Second scenario).

By applying the proposed DSM strategy, the annual electricity demand of the building is reduced from 8244 kWh to 7728 kWh. In addition, the peak points of the load profile are shaved compared to first scenario. In this scenario, the optimal HES's configuration includes DG, battery storage and large capacity of PV panels. WT remains excluded. Here, the cost of energy is reduced from 0.26 $/kWh in first scenario to 0.23 $/kWh. Besides, fuel consumption as well as CO_2 emissions are dramatically reduced. Hence, renewable energy sources (Solar PV) contribution become close to 100 %. Furthermore, this HES configuration is more reliable with LPSP less than 1 %. The obtained results have emphasized the effect of the suggested DSM strategy on size optimization of the HES in hot dry climate conditions.

5.4.3.3. Third scenario

In this scenario, at least a small wind turbine is added to the hybrid system. The annual electricity demand for this case is the same as first scenario, which is evaluated at 24°C. Tab.31 provides the results of this scenario. Besides, Fig.59 presents the hourly energy contribution of each component for typical days of the year.

Table 31. Optimal sizing results (Third scenario).

LPSP (%)	COE ($/KWh)	Fuel consumption (L/Year)	CO_2 (Kg/KWh)	RF (%)	CPV (KW)	CDG (KW)	Cb (KWh)	NWT (Nbr)
0.8	0.313	38	98	99.4	7	1	10	1

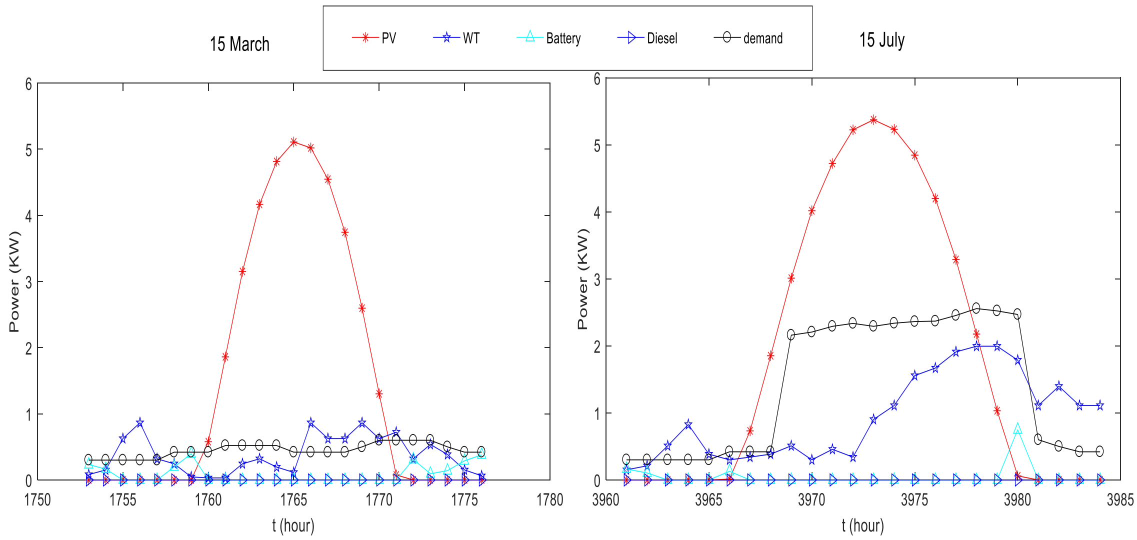

Figure 59. Hourly energy contribution of each source (Third scenario).

In this scenario, after adding a small WT, both COE and renewable fraction are increased. Considering economic aspect, this HES becomes not cost-effective, however, the high fraction of renewable energy, which is close to 100 %, makes this configuration more attractive environmentally. Comparing to other scenarios, here, the obtained HES present high renewable energy contribution even with considering high thermal comfort level. We can conclude that if the investment cost of small WT is reduced in next years, this HES becomes more attractive, because, in addition to be economically viable solution, it will ensure high level of thermal comfort and present a friendly solution to the environment.

The obtained results of the proposed method are more significant and could help to increase the deployment of renewable sources and limit the fossil fuel dependency in isolated areas where, the grid is unavailable, and diesel generator becomes unsuitable solution from economical and environmental aspects.

5.4.4. Conclusions

The aim of this work was optimal design and management of HESusing MAS based method. The proposed method was applied to electrify an isolated residential building in hot dry climate (Ouargla), Algeria. In this work, control of set point temperature in cooling mode, demand supply energy management, size optimization of the HES while the cost of energy is the main to be minimized are all investigated. The key findings of this work are summarized as follows:

- In case of high-energy demand for space cooling (as high level of thermal comfort), PV/DG is found to be the best hybrid energy configuration for supply the studied building.
- By applying DSM strategy, which is based on controlling set point temperature in cooling mode, hybrid PV/DG/Battery is found the best option. In addition, energy demand, COE, fuel consumption as well as CO_2 emission are decreased significantly, while, renewable energy share is increased.
- By adding at least a WT to the hybrid system and without applying DSM, the obtained configuration present the highest COE. However, renewable fraction is near to unit.

The obtained results demonstrate the ability of the proposed method to deal with energy home management and optimization issues. MAS based approaches constitute an efficient trend for optimal management and control of energy flows in the building. The proposed DSM strategy has an important effect on the sizing of HES.

5.5. Conclusion

This chapter was dedicated to optimal design of HESs for off-grid and isolated areas of the country. Three case studies are investigated using different approaches. The key findings for each application are as follows.

For the first case study, the hybrid energy system with battery storage is found to be the most viable solution to supply mobile buildings in isolated areas taking into account both current and future assumptions. Furthermore, lead-acid batteries are found to be more cost-effective than Li-ion batteries for future assumptions. However, configurations based on hydrogen storage are still ineffective before 2030, mainly due to high investment costs, water needs to operate and difficulties in providing the required levels of security. Although hydrogen storage will be a feasible solution after 2030, but in limited applications.

In the second case study, the energy cost is found in Adrar at 0.26 $/KWh and in Bechar at 0.24 $/KWh. The sensitivity analysis referred to the investment cost of PV panel loads to energy cost less than $0.21/KWh, which is the true unit price of electricity in Algeria. The implementation of the suggested HES in Algeria's Sahara, in specific by reducing the prices of PV panels or by providing certain subsidies to PV panels in the coming years, is a more cost-effective option. It will therefore assist to make Algeria's Sahara green and sustainable.

The results of the last case study indicate that in case of excess energy demand for space cooling (for a high level of thermal comfort), PV/DG is the best hybrid energy configuration for supplying the studied building. By applying a DSM strategy, which is based on controlling set point temperature in cooling mode, hybrid PV/DG/Battery is the best option. This can significantly decrease energy demand, cost of energy (COE), fuel consumption, as well as CO_2 emission respectively, and meanwhile, renewable energy share is increased. By adding at least a wind turbine to this hybrid system and without applying DSM, the obtained configuration present the highest COE. However, renewable fraction is close to unit.

The applied method in this work is more effective in making better decisions in designing HES for off-grid applications. It will therefore help decision-makers and investors on optimal exploit renewable sources locally and anywhere. It will therefore contribute to transiting to sustainable buildings locally and worldwide.

Chapter 6.

Optimal Design of Multi-Sources Energy System for Grid-Connected Buildings

6. Optimal Design of Multi-Sources Energy System for Grid-Connected Buildings

6.1. Introduction

Electricity has now become one of the most important elements of modern life. However, the electricity sector faces three major challenges: maintaining a sufficient supply to meet ever-increasing demand for electricity, reducing CO_2 emissions and global warming issues due to high use of conventional sources (Mellouk et al., 2019). Urban areas are known to be major contributors to CO_2 emissions as they account for over 70% of energy-related emissions, and 60%-80% of final energy consumption (Moghadam et al., 2017). Currently, more than 99% of the generated electricity in Algeria comes from fossil fuel sources (natural gas) (Gouareh et al., 2015a). Buildings, which are mostly located in urban areas, and 99% are grid-connected, consume 43% of this generated electricity. Therefore, the integration of renewable sources is mandatory to reduce CO_2 emissions by reducing the use of fossil fuels. In this context, the Algerian government aims to increase renewable energy generation share to 27% of the total power generation in the country (Government, 2015). In fact, Algeria has a big solar energy potential especially in the Sahara (Abada and Bouharkat, 2018). Using PV panels to produce electricity in buildings is the best choice in our country for buildings in urban areas (Mokhtara et al., 2019). However, due to uncertainty of this source, it is mandatory to add other sources or and storage system. As the popularity of fuel cell vehicles continues to rise in the global market, (Aki et al., 2018) and the limitation of using batteries for long term storage, solar-hydrogen-battery HES is one of the most promising solutions for meeting energy requirements of buildings in next years. The design optimization of such HES includes mainly two tasks. The first concerns to evaluation of the energy potential of solar PV systems for both electricity and hydrogen production. The second one is related to optimal sizing and energy management of HES's components.

For energy potential evaluation of solar PV system, the majority of studies have used geographical information system (GIS) (Romero et al., 2017) or CAD software (Desthieux et al., 2018). In (Verso et al., 2015) developed a multi-criteria approach based on Geographic Information Systems (GIS), and Light Detection and Ranging (LIDAR) to explore the possibility of installing photovoltaic (PV) systems on the roof of buildings in urban environments. In (Kurdgelashvili et al., 2016) detailed the multi-level estimation methodology used to estimate rooftop PV potential in the commercial and residential sectors. In (Verso et al., 2015) developed a multi-criteria decision support based on GIS, Light Detection and Range (LIDAR) and solar radiation data to look into the possibility of implementing photovoltaic (PV) systems in urban areas and to assess the resulting annual electricity production. In (Kurdgelashvili et al., 2016) a multi-level estimation methodology was used to evaluate rooftop PV potential in the commercial and residential sectors in three leading states in USA. Similarly, in (Koo et al., 2014) proposed a framework for the analysis of the potential of the rooftop photovoltaic system to achieve the net-zero energy solar buildings. In (Huang et al., 2019) presented a novel approach to detect the city solar potential using image segmentation with deep learning technology. Similarly, in (Jurasz et al., 2019) formulated a methodology for estimating rooftop PV potential in urban areas based on LiDAR data. In (Dehwah and Asif, 2019)assessment of rooftop photovoltaic potential systems and their contribution to buildings electricity supply in hot-humid climates was investigated. In (Bódis et al., 2019) applied a high-resolution methodology for evaluating rooftop solar PV potential in the European Union building stock. In (Xu et al., 2019) evaluated the energy potential of PV in urban area considering the effect of urban block typology. In (Poruschi and Ambrey, 2019) investigates the impact of built environment and feed-in tariffs on the installation of solar rooftop PV in capital cities of Australia. In (Lee et al., 2018) proposed a method based on the technical and economic suitability criteria and using cluster analysis for developing a rooftop solar PV rating system for buildings. In (Bazán et al., 2018) determined the potential of electricity self-sufficiency production and GHG emissions mitigation in urban environment in Peru by using rooftop PV. In (Aboushal, 2018) applied an improved method to identify the potential areas at buildings' rooftop surface for installation of PV units and to optimally select between different PV modules for a specified city based on spatial data analysis using GIS.

For optimal sizing of PV-hydrogen based HES, researchers have solved the optimization problem as a single-objective or multi-objective function using software tools such as HOMER or meta-heuristic algorithms such as particle swarm optimization (PSO). In (Kalinci et al., 2015) a PV-WT HES using hydrogen energy as energy storage option is modelled and techno-economically investigated for an Island in Turkey using HOMER software. Here, the size optimization of the HES is carried out based on the geographical and meteorological data of the island. In (Zhang et al., 2018) a HES including battery and hydrogen storage is optimized using simulated annealing algorithm. In (Gharibi and Askarzadeh, 2019) a multi- objective crow search algorithm is used for size and power exchange optimization of a grid- connected diesel generator-photovoltaic-fuel cell hybrid energy system is carried out considering reliability, cost and renewability. In (Samy et al., 2019b) an off-grid PV-Fuel cell HES is optimized using a flower pollination algorithm. Similarly, in (Jamshidi and Askarzadeh, 2019) the techno-economic analysis and optimal sizing of PV-fuel cell-diesel generator system for an off-grid building using multi-objective crow search algorithm. In (García-Triviño et al., 2016) an energy management system for optimal operation of a grid-connected WT-PV with hybrid battery-hydrogen storage is presented. The multi-objective optimization problem is solved using particle swarm algorithm. In (Jafari et al., 2019) a thermo-economic analysis is performed for a standalone solar-hydrogen-battery HES to meet the annual electrical and heat demand. In (Samy et al., 2019a) a technical-economic optimization of solar PV/WT/Fuel Cell HES for a small-scale countryside area in Egypt is optimized using Firefly Algorithm. The authors compared their results with those obtained from particle swarm optimization and Shuffled Frog Leaping Algorithm. In (Behzadi and Niasati, 2014) TRNSYS software was used to perform a comparative performance analysis of a stand-alone PV-battery-fuel cell HES with different power management strategies and sizing approaches. In (Cano et al., 2014) using Simulink toolbox in MATLAB software, the optimal sizing of stand-alone PV/WT/FC HES is carried out using several methodologies . In (Marchenko and Solomin, 2017) presented a research on a green power supply system in the area of Baikal Lake using photovoltaic-WT-batteries-hydrogen for electric and hydrogen energy production and storage. In (Mukherjee et al., 2017) the techno-economic, environmental, and safety assessment of PV-WT-hydrogen-fuel cell vehicles HES powered community micro-grids is carried out using mixed integer linear programing. In (Tebibel and Medjebour, 2018) presented a comparative performance analysis of grid-connected PV hydrogen production using water, methanol and hybrid sulphur electrolysis processes. In (Zhang et al., 2019) performed a size optimization of a stand-alone PV-WT-hydrogen HES using a hybrid search optimization algorithm and weather forecasting. In (Ghenai et al., 2018) the techno-economic analysis of an off grid PV-Fuel cell HRSE is performed for residential community. In (Duman and Güler, 2018b) HOMER software was used to carry out the techno-economic analysis of PV-WT-fuel cell an off-grid HES with different occupied households situations.

From literature, rooftop solar PV energy potential is mostly investigated on a community or city scale. In addition, the integration of spatial analysis and energy potential assessment with size optimization of rooftop PV based HES has not been examined. In addition, there is little discussion of the hybrid hydrogen-battery storage system and it has often been applied to off-grid areas. In this work, an integrated approach is developed for the optimal design of a rooftop grid-connected solar PV with hybrid hydrogen-battery storage system at an educational building (University campus) in urban area. Educational buildings, because have large roof area, the peak load is accrued in daytime, when the sun is available. The main contributions of this work are: 1) to identify feasible zones and installations for rooftop PV system, and 2) to find optimal sizing of the suggested HES.

6.2. Methodology

A GIS-Multi Objective PSO (GIS-MOPSO) method is developed for optimal design of rooftop solar PV with hybrid hydrogen-battery storage system to electrify a grid-connected University building in Ouargla, Algeria. In order to achieve the aims of the study, the following methodologies are followed. First, a map of the building (from Google-Earth) is exported, separately, to ArcGIS to perform spatial analysis, and to sketch up software to create a 3D model of the building. Based on the developed 3D model, Ecotect software is used to evaluate shading effects and sun light hours at each rooftop's zone for a one-year simulation. Hence, identifying the best zones for installing PV panels, selection of the best PV system's installation based on technical and spatial criteria, and finding the optimal sizing of the proposed HES are carried out next. Fig.60 shows the flowchart of the proposed method.

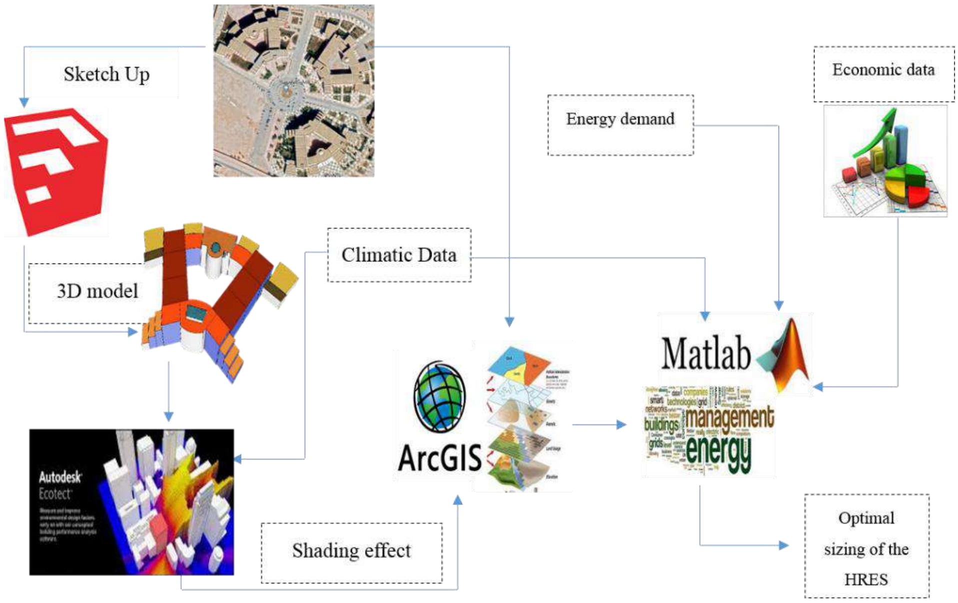

Figure 60. Flowshart of the applied method.

6.2.1. Building description and climatic data

The studied educational building, located in a hot dry climate, has a total roof area of 18209 m², and has an energy demand of 1485 MWh/year. Fig.61 shows a map of the building and its load profile (as supplied by energy provider Sonelgas). Meteonorm 7 software was used to collect the required climatic data for the building. Fig.62 gives the daily global radiation and hourly ambient temperature at Ouargla.

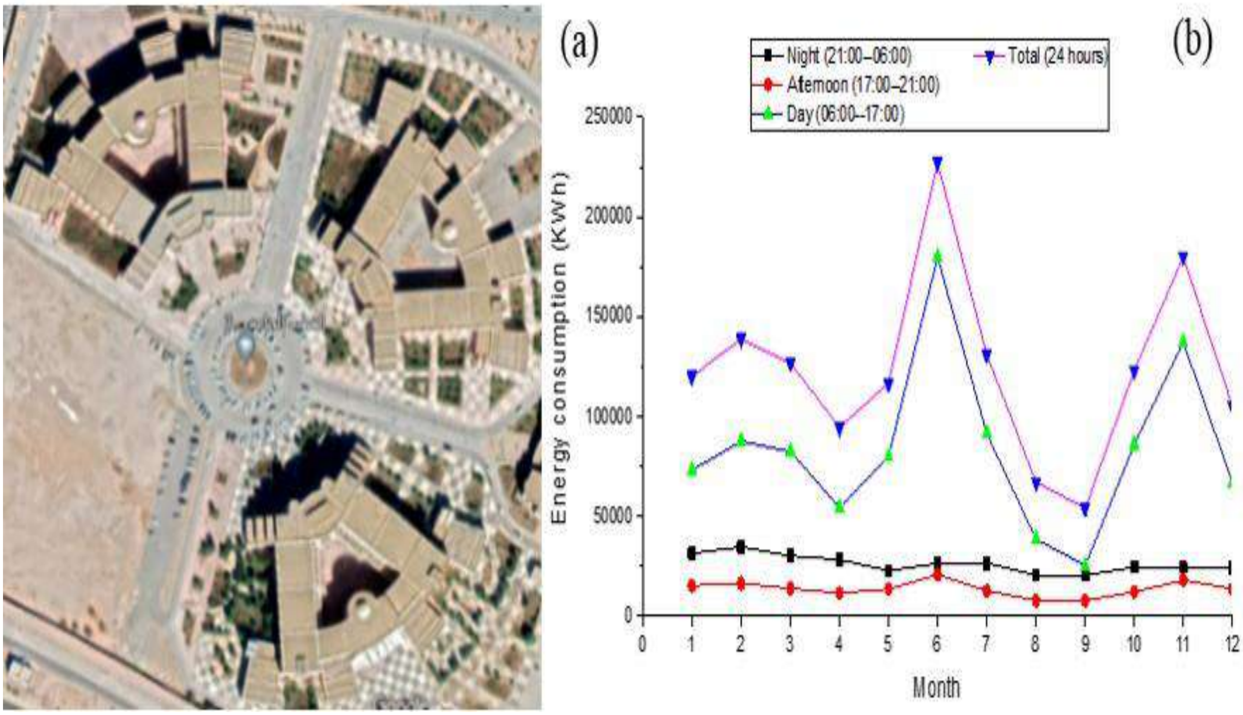

Figure 61. Building description: (a) map of the campus building, (b) yearly energy load profile.

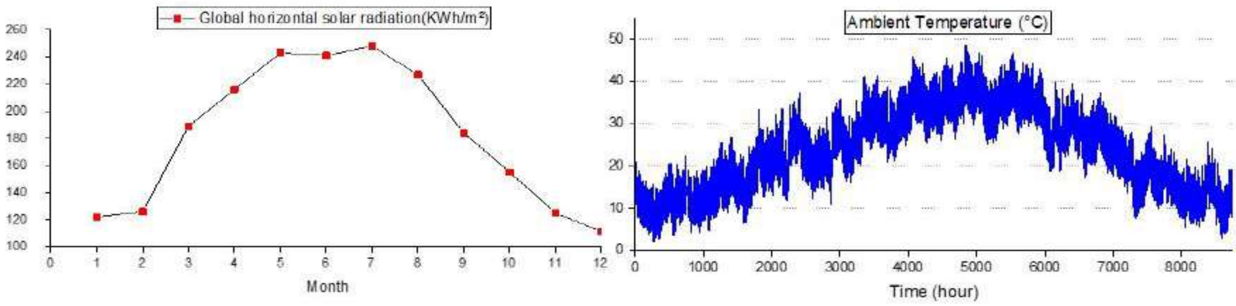

Figure 62. Climatic data at Ouargla, Algeria.

6.2.2. HES components

The investigated system is a hybrid energy system includes photovoltaic (PV) installed on the roof of a grid connected University building, and incorporated battery and hydrogen energy system (That includes Electrolyzer, fuel cell and storage tank). Fig.63 shows the schematic of the studied HES. The description of the HES's components are presented in the following subsections. However, the mathematical modelling of the components are provided in the second chapter

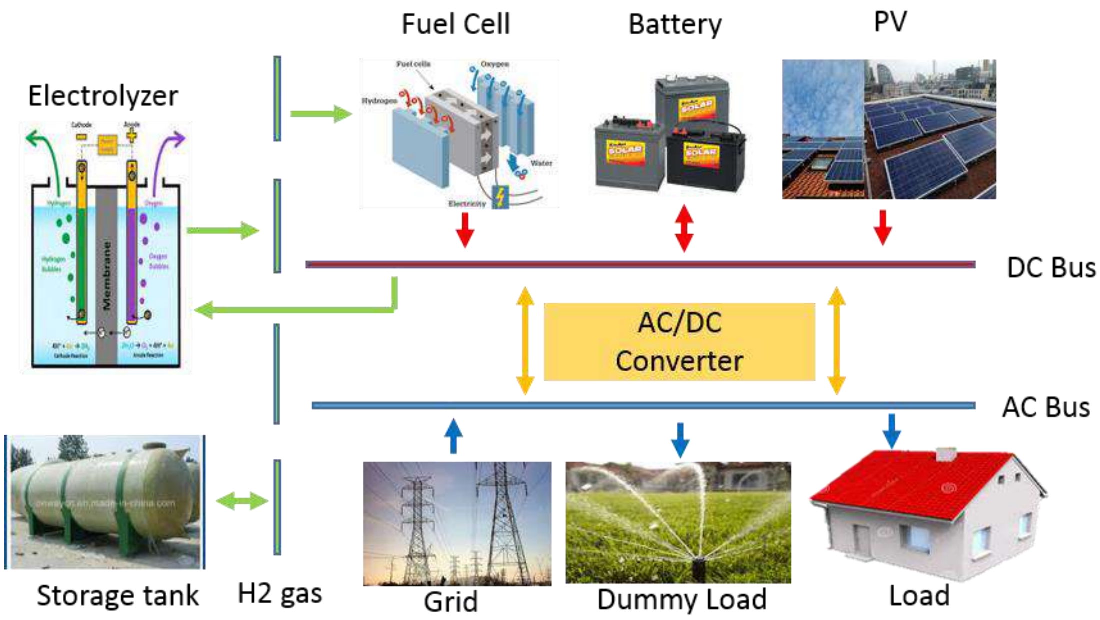

Figure 63. Climatic data at Ouargla, Algeria.

6.2.2.1. Solar photovoltaic (PV)

Rooftop Solar PV system was proposed in this work.

6.2.2.2. Battery storage (BS)

Batteries are used to store excess electricity from PV panels only in working days (from 15 September until first July.

6.2.2.3. Hydrogen storage

This system includes three parts are the Electrolyzer (Ele), hydrogen storage tank (ST), and Fuel cell (FC). A simplified FC and Ele models are used in this study. However, we assume that the FC and Ele work at a following operation point, which depends on generated and energy demand at time step simulation (t). Similarly, the size of the hydrogen storage tanks (ST) needs a deep analysis inclusive the Ele, FC, total energy generated and energy demand requirements. In this work, Ele is only operated in vacancy periods, hence, if the generated energy Pg (t) $\geq$ Energy demand El(t), then Ele is operated to produce hydrogen gas and fill ST. The efficiency of Electrolyzer and FC are 90% and 50%, respectively (Samy et al., 2019a).

6.2.2.4. Grid.

When the PV system and storage devices are not sufficient to supply the load, the grid is used to supply the deficit power. In Algeria, the purchase price of electricity (EPR) without subsidies is 0.13 $/kWh. The rest of stored hydrogen at the end of the academic year will be sold. The sell rate of hydrogen (HSR) gas is set at 3.3 $/kg (0.08 $/kWh) (Negrou et al., 2010), similar to the sell rate of hydrogen gas produced by conventional procedures.

6.2.2.5. Converter.

As the HES included DC and AC buses, a power converter was used to convert electricity between them.

6.2.3. Assessment of rooftop solar energy potential

Solar potential represents the theoretical maximum amount of PV that can be deployed on the rooftop of buildings, which depends on different factors (Kurdgelashvili et al., 2016). There have been many factors that influencing the rooftop photovoltaic potential. For example, the non-uniform irradiance on PV modules due to partial shading (Tanesab et al., 2018)(Lydon et al., 2017). Shading, which reduces significantly the output of PV system (Shukla et al., 2016), commonly results of neighbour obstacles, the difference of height between buildings and the inter rows shading. Further, the building orientation has an important effect on PV production and on the shading distribution. In addition, the ambient temperature has a significant effect on the power output of the PV panels, which depend on PV panel technology. Besides, wind speed is also an important factor that can be used for refreshing PV panels to increase its output in hot dry climates. Wind speed intensity depends directly on the height of the building. Further, the inclination of PV panels has an important effect on PV panel productivity. In addition, selecting adequate PV technology must be considered. Compared to mono-crystalline as a base of minimum required modules area, polycrystalline technology plant requires an additional area of 8.39%, thin-film cadmium telluride (CdTe) plant needs an extra area of 19.33% (Hamza et al., 2017). In this study, the assessment of rooftop solar energy potential consists of three major steps:

6.2.3.1. Evaluation of sunlight hours and shading effect

Ecotect software, which is primarily intended as conceptual design tool for NZEB (Koutra et al., 2018), is used to evaluate sunlight hours (i.e. number of hours when the zone exposed to the sun) and exposer ratio (i.e. percentage of maximum exposed area to the total area) of the building roof's zones for the whole year. Ecotect based on the created 3D model of building (by Sketch up software), solar radiation data and geographical information of the building location. In addition, inter rows shading effect is taken into account. Therefore, the minimum distance to avoid inter-rows shading is assumed for all the suggested configurations of the PV system.

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6.2.3.2. Identifying optimal rooftop zones

Geographic information system software plays a key role in future analyses; it enables us to monitor, evaluate and view the spatial distribution of all types of geographically referenced data (Rahmouni et al., 2016). ArcGIS software (V. 10.2) was used to select the best rooftop zones to install PV panels considering five evaluating criteria. Tab.32 provides the description and weights of the five investigated criteria. After creating the raster maps of the five criteria, and based on their weights, a multi criteria decision-making (MCDM) calculation is performed to classify and select suitable areas and zones using raster calculation toolbox on ArcGIS. Multi-criteria analysis is mostly used to solve problems where several conflicting criteria or objectives are considered (Sadiq et al., 2019).

Table 32. Summary of evaluating criteria and their definition and weights.

Criteria	Definition	Weight (%)
Exposer Ratio	Is the ratio of the area exposed to the sun per the entire area of the zone	30
Sun light hours	Is the number of hours when the zone is exposed to sun light	30
Shape Factor	Is the shape of the zone, and suitability to install PV panels	20
Available Area	Is the area available on the zone and can be used	15
Wind speed intensity	Wind speed is needed to refreshing PV panels. This factor is function of zone's height.	5

6.2.3.3. Selecting the best PV system installation

To select the best PV system installation, many factors are considered such as PV panels' technology (including thin film of First-Solar (FS) and crystalline modules of Trina-Solar (TS)), inclination angle, and available area for the obtained optimal zones. Three inclination angles are considered: 17°, 47°, and 32°; these represent the optimum tilt angles at the studied location for summer period, winter period, and yearly average, respectively. The maximum capacity of the best rooftop PV installation is used as a constrained in the size optimization.

6.2.4. Multi objective optimization

Multi-objective optimization problem could be defined as optimizing multi-purpose goals while meeting all constraints by identifying the variables of the decision (Wang et al., 2019). In this work, the multi objective problem consists of three objectives are the cost of energy, loss of power supply probability (LPSP) and renewable usage (RU). The decision variables include size of PV panels, battery bank, Electrolyzer, storage tank and fuel cell. The size of PV system depends on available area, the obtained optimal zones, and the selected PV system installation (results of section 2.2). The size optimization problem is solved by multi objective PSO.

6.2.5. Objective functions modelling

Cost of energy (COE). This parameter is widely used to evaluate the economic feasibility of HES. COE can be calculated using Eq. 39-45 (Maleki, 2018)(Das and Zaman, 2019)(Padrón et al., 2019)(Gharibi and Askarzadeh, 2019). The techno-economic feasibility of HES is evaluated by comparing the cost of energy of the studied HES with the real energy purchase rate of electricity. This rate is similar to feed in tariffs MW scale PV plants.

$$COE(\$/KWh) = \frac{C_{A\_cap} + C_{A\_O\&M} + C_{A\_rep} + C_{Grid} - C_{H2}}{E_{served}} \quad (39)$$

$$C_{A\_cap}(\$) = (P_{Npv} \cdot C_{PV} + Eb_{max} \cdot C_{BS} + P_{Cnv} \cdot C_{Cnv} + P_{FC} \cdot C_{FC} + P_{Ele} \cdot C_{Ele} + ST_{max} \cdot C_{ST}).\text{CRF} \quad (40)$$

$$C_{A\_O\&M}(\$) = 0.02 \times C_{A\_cap} \times \sum_{k=1}^{T} \frac{1}{(1+j)^k} \quad (41)$$

$$C_{A\_rep}(\$) = \left(Eb_{max} \times C_{BS} \times \sum_{k=10}^{T} \frac{1}{(1+j)^k} + P_{Cnv} \times C_{Cnv} \times \sum_{k=15}^{T} \frac{1}{(1+j)^k} + FC \times C_{FC} \times \sum_{k=10}^{T} \frac{1}{(1+j)^k} \right) \times CRF \quad (42)$$

$$\text{CRF} = \frac{i(1+i)^T}{(1+i)^T - 1} \quad (43)$$

$$C_{\text{Grid}} = E\text{PR} \times E_{Grid} \quad (44)$$

$$C_{\text{H2}} = H\text{SR} \times E_{H2} \quad (45)$$

Where EGrid and EH2 are the energy purchased from the grid and the amount of sold hydrogen respectively. CGrid and CH2 are the cost of energy purchased from the grid and the cost of sold hydrogen. CRF is the capacity recovery factor. T and i are the project lifetime and the real interest rate. CPV, CBS, CCnv, CFC, CEle, and CST are the capital cost of PV, BS, converter, FC, Electrolyzer, and ST respectively. CA_cap, CA_O&M and CA_rep are the annualized capital, operation and maintenance and replacement cost, respectively. PNpv, PCnv, PFC and PEle are the rated capacity of PV, converter, FC and Electrolyzer, respectively.

Loss of power supply probability (LPSP). Is considered an indicator of HES's reliability. LPSP represents the ratio of the annual energy that the HRSE failed to meet the demand by the annual required demand of the building. So that, this function must be minimized to increase the system reliability. LPSP is assessed based on Eq. 46.

$$LPSP(\%) = \frac{\sum_0^T E_l(t) - P_{pv}(t) - P_{grid}(t) - (Eb(t-1) - Eb_{min}) - FC_{avail}}{\sum_0^T E_l(t)} \quad (46)$$

The techno-economic feasibility of HES is evaluated by comparing the cost of energy of the studied HES with the real unit cost of electricity from the grid in Algeria which is 0.15 \$/KWh. This rate is similar to feed in tariffs MW scale PV plants.

Renewable usage (RU). This factor represents the share of renewable sources on supply of load demand. RU is calculated using Eq. 47. As RU factor is a function that must be maximized, in the optimization, only the second part of RU equation is defined to be minimized instead.

$$RU(\%) = 1 - \frac{E_{Grid}}{E_{Grid} + E_{pv}} \quad (47)$$

Where EGrid and Epv are the annual energy purchased from the grid and the PV, respectively.

The technical economic parameters for the HES' components that used in this work are summarized in Tab.33 (Mandal et al., 2018a)(Fodhil et al., 2019) (Jafari et al., 2019)(Guzmán et al., 2018) (Zhao et al., 2018)(Han et al., 2018).

Table 33. Technical economic parameters for the HES' components.

Generation source	Parameters	Specification
Solar PV	Capital cost ($/kW)	1300
	O&M cost (% of Capital cost)	2
	Temperature coefficient of power (%/°C)	-0.0041
	Life time (Year)	20
Electrolyzer	Capital cost ($/kW)	1500
	O&M cost (% of Capital cost)	2
	Life time (Year)	20
Fuel Cell	Capital cost ($/kW)	2500
	Replacement cost ($/kW)	888
	O&M cost (% of Capital cost)	2%
	Life time (year)	10
Storage tank	Capital cost ($/kWh)	30
	O&M cost (% of Capital cost)	2
	Life time (year)	20
Battery	Capital/replacement cost ($/kW)	155
	O&M cost (% of Capital cost)	2
	DOD (%)	90
	Discharge efficiency	95%
	Charge efficiency	100%
	Life time (Year)	10
Converter	Capital/ Replacement cost ($/kW)	625
	Efficiency (%)	95
	Life time (Year)	15
Economic parameters	Project life time (Year)	20
	i (interest rate) (%)	8.25

6.2.6. Energy management strategy

The energy management (EM) strategy applied in this work has two modes:

Mode 1. The surplus electricity from PV panels is used to charge batteries or produce hydrogen gas. The selected storage option depends on the time of operation. In the summer vacation (from

10 July to 10 September), surplus electricity is converted to hydrogen. Out of this period, surplus electricity is used to charge batteries.

Mode 2. When the PV panels are unable to meet the required load demand, then batteries and/or fuel cells are used to supply the shortage. If there is further shortage, the grid will provide the rest of the demand. Loss of power supply is evaluated if the complete hybrid system fails to meet the load.

6.2.7. Particle swarm optimization

As previous works, PSO algorithm was used to find the optimal sizing of the investigated HES. The parameters of the PSO algorithm used in this work are taken from (Ghorbani et al., 2018).

6.2.8. MATLAB simulation of the HES

Simulations are carried out in MATLAB software. First, the mathematical modelling equations for objective functions and HES's components are developed. Furthermore, the management strategy and PSO algorithm are implemented. Thus, climatic data (temperature and solar radiation) and energy load demand of the case study building are defined for one entire year (8760 hours). In addition, technical-economic parameters of the HES' components are also introduced to start the calculation. Within the project lifetime of 20 years, the optimization must proceed until the maximal iteration value is reached. At each time step (hour), for over 8760 hours of the year, and during the project lifetime, the energy balance between supply sources and electrical load is assessed to make best decisions of component's operation. Hence, the total annualized cost including cost of investment, replacement, operation and maintenance of HES' components, the cost of energy purchased from the grid and the cost of hydrogen sold, are evaluated. Finally, Based on defined objectives and constraints, the optimal size of the HES is determined.

6.3. Results and discussion

Based on the created raster maps of the five evaluating criteria and their weights, a MCDM analysis for area classification within the building is carried out and the results are presented in Fig.64. Results clearly show three categories of areas, with the optimal zones (of area 10633 m^2) representing more than half of the total area of the building. Because of high influence of shading and other factors on the performance of PV panels as well as on the cost of PV system, only the optimal zone area is selected for installing PV panels. Therefore, the maximum capacity of rooftop PV depends on the available area from this optimal zone. This information will be used in following subsection to select best PV system installation.

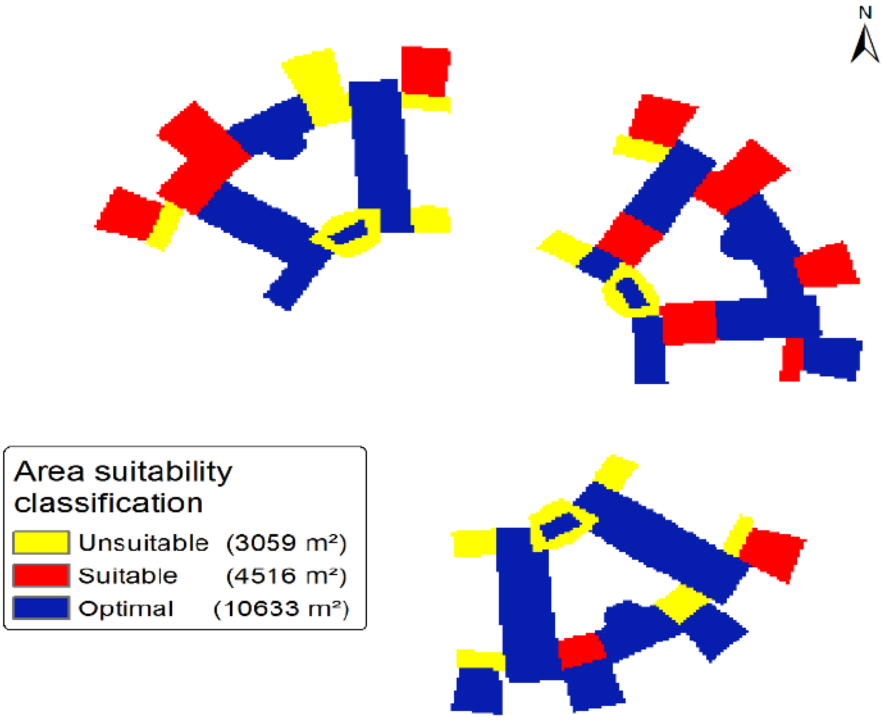

Figure 64. Area suitability for installing PV panels on three buildings of the campus (from ArcGIS).

6.3.1. Selecting the best PV system installation

Based on the results of area suitability, and as mentioned, only the optimal zone area is considered for installing PV panels. This information is used to determine the allowable capacity of PV system at the optimal zone area of the roof. In this study, different configurations are compared to select the best one based on their total electricity produced by exploiting the total area of the optimal zone. Three inclination angles with two different technology of PV modules, gives six possible configurations. In Tab.34 the results of the six investigated configurations and their ranking are provided.

Table 34. Ranking of PV system installations.

Configuration	Required area per KW	Maximum allowable PV capacity (optimal zone) (KW)	PV output per KW (KWh/year)	PV total power (optimal zone) (MWh/year)	Rank
TS_17°	8,12	1310	1781	2333.11	1
FS_17°	9,04	1176	1804	2121.50	2
TS_32°	9,5	1119	1800	2014.20	3
TS_47°	10,22	1040	1743	1812.72	4
FS_32°	10,83	982	1828	1795.10	5
FS_47°	11,67	912	1759	1604.21	6

From results, multi crystalline PV panels at 17° inclination represent the optimal installation for the case study building. This is because it provides the largest yearly electricity production by exploiting the entire area of the optimal zone. We can see that with considering the effect of inter-rows shading (must be avoided), the required area for installing 1 kWp is changed, and therefore, the output power of the PV system is affected. Comparing results to other results that obtained without considering the effect of inter-rows shading, PV panels at 32° (optimum inclination at Ouargla) presents the best option. Therefore, it is recommended to take 17° as the optimal inclination angle for Ouargla. With taking into account inter-rows shading effect, multi-crystalline PV modules present better results than thin film modules for the three inclinations. Therefore, we encourage using multi-crystalline PV modules in hot dry climate. In this work, only the first option in the ranking is the one that will be selected for the simulation of optimal sizing of the proposed HES. This information is an important input for any size optimization of HES incorporating rooftop PV system. Because, it will determine the maximum capacity of PV that cannot be exceeded.

6.3.2. Optimal sizing of the HES

Multi crystalline PV panels at inclination angle of 17° are selected for further optimization. Results of optimal sizing of the studied HES are presented in Tab.35.

Table 35. Result of optimal sizing of the HES.

Component	PV (kW)	BS (kWh)	EL (kW)	ST (kWh)	FC (kW)	LPSP (%)	COE ($/kWh)	RU (%)
Size	1310	866	300	2601	80	0.45	0.225	99.9

The obtained HES configuration from optimal sizing has a renewable usage of 99.9 %, COE of 0.22 $/kWh with high reliability (less LPSP). Despite the COE being higher than the current price of purchase rate of electricity, the optimized HES is more environmentally attractive. In addition, this final HES configuration produces electricity and hydrogen gas, which could more attractive for future cities, where hydrogen as fuel will be needed as the electricity to supply electric vehicles. In addition, this HES can create many jobs. Furthermore, with the continuous decrease of the price of PV panels and hydrogen storage components, the proposed HES will be more cost effective than using conventional sources. The findings of this work are significant, and can help policy makers to make best decision for future energy systems. By applying assuming the large number of educational buildings in Algeria, high benefits can be achieved. Therefore, it will contribute on converting existing building toward sustainable green buildings. The proposed method could not be applied to only building scale, but could be extended to city scale in the future, where other criteria and factors are introduced to obtain accurate results.

6.4. Conclusions

In this work, a rooftop PV/battery/hydrogen grid-connected HES is optimally designed using a combined GIS and MOPSO method. Results show that the use of standard multi crystalline PV panels at an inclination angle of 17° is the most suitable configuration for the studied building. Moreover, PV/battery/Electrolyzer/storage tank/fuel cell is found to be the optimal configuration, with 99% of renewable energy usage, and COE of 0.22 $/kWh. The results have emphasized the efficiency of the proposed method in solving complex energy problems, which relates to HES integration on buildings in urban area. The proposed method could not applied to only building scale, but could be extend to city scale in the future, where other criteria and factors are introduced to obtain results that are more accurate.

Chapter 7.
Conclusion

7. Conclusion

For the aim of limiting the increase of energy consumption and reducing greenhouse gas emissions in building sector, PEBs constitute a key solution nowadays. The net zero/plus energy building (NZEB) has been paid attention to internationally through last decade. Making buildings very energy efficient might be a step toward reaching the NZEB balance but alone it is not sufficient. Integrating the renewable energy systems, hence, is an important step toward achieving NZEB balance as a target. There have been many works carried out on the achievement of NZEB for different regions; however, implementing such buildings according to Algerian territory is not investigated yet. In light of this, pathways to reach plus energy goal in existing and new buildings have been discussed in this study. The aim of this thesis was to develop a methodology for optimal design a multi sources (hybrid) energy system. Besides, it aims to assist designers to select the suitable design options of energy efficiency and renewable energy sources for achieving zero (plus) energy buildings in different climates and geographic locations of Algeria. The investigated aspects include the selections of appropriate strategies of energy efficiency measures and renewable sources to fulfil plus energy balance under different climate of the country (original publication and conference paper I); Decision making and optimization of multi sources energy systems (original publication and conference paper II); The techno-economic viability of integrating hydrogen into building sector (conference paper II). This thesis is paying more attention to design optimization of HESs including finding the optimal configurations, component's sizing, and energy management between different components. The entire work was performed using simulation approach, using both software tools and optimization algorithms and combining different technics of optimization and decision-making.

From the obtained results during the achievement of this thesis, many conclusions can be outlined. Increasing the energy performance of the building (using insulation, efficient appliances and HVAC technologies) has a large effect not only on energy demand, but also on reducing the size of energy supply system. Besides, DSM techniques such as shifting the desired temperature of cooling and heating can reduce significantly the energy consumption of the building. The energy management strategies in all design stage (at early design step and during the operation of energy generating system is crucial to provide appropriately the configurations and capacities of energy supply sources and ensure the load demand of buildings at all the period of operation. HES's feasibility from technical, economic, environmental and social aspect has been demonstrated at wide area of the country (Algeria). We can also notice that the Sahara of the country that represents more than 80 % of the national territory, has a big potential for achieving plus energy targets. On

the other hand, optimal design of HES cannot be ensured without using advanced design optimization technics such as PSO for solving sizing problems, ArcGIS software and AHP for MCDM analysis for spatial and non-spatial entities. Nowadays, advanced control systems, which are based on multi agent system architecture, must be implemented to ensure the best operation and interaction between all building's parts in a smart and intelligence way.

Finally, this thesis shows that solar-based HESs could be a promising integrated energy system in Algeria achieving the PEB. The upcoming research works and policy makers have to take the outcomes of this thesis into consideration for implementing high-energy performance buildings in Algeria. The outcomes of this work are significant and can help researchers and policy makers to make best decisions and provide accurate acts about HES design, integration, and investment. However, some limitations are shown, specifically that related to data collection, availability and accuracy. Therefore, we recommend doing experimental studies in the future to obtain more and accurate data. However, other aspects should be investigated in the future works to bring enough information about the influences of implementing the PEB socially, economically, and environmentally. Some of the main aspects that could be further investigated are public acceptance and interaction between different types of buildings; it means studying the possibility of achieving plus energy balance at city or community scale instead of single building scale.

Appendices

Appendix A List of conferences and original publications

Pathways to plus-energy buildings in Algeria: design optimization method based on GIS and multi-criteria decision-making BS **Charafeddine Mokhtara** , Belkhir Negrou , Noureddine Settou , Abderrahmane Energy Procedia 162, 171-180 14 2019.

Integrated supply–demand energy management for optimal design of off-grid hybrid renewable energy systems for residential electrification in arid climates **C Mokhtara**, B Negrou, A Bouferrouk, Y Yao, N Settou, M Ramadan Energy Conversion and Management 221, 113192 7 2020.

GIS-Based Method for Future Prospect of Energy Supply in Algerian Road Transport Sector Using Solar Roads Technology B Settou, N Settou, A Gouareh, B Negrou, **C Mokhtara**, D Messaoudi Energy Procedia 162, 221-230 4 2019.

Decision-making and optimal design of off-grid hybrid renewable energy system for electrification of mobile buildings in Algeria: case study of drilling camps in Adrar **C Mokhtara**, B Negrou, N Settou, A Gouareh, B Settou, MA Chetouane Algerian Journal of Environmental Science and Technology 6 (2) 3 2020.

Suitable Sites for Wind Hydrogen Production Based on GIS-MCDM Method in Algeria D Messaoudi, N Settou, B Negrou, B Settou, **C Mokhtara**, CM Amine Advances in Renewable Hydrogen and Other Sustainable Energy Carriers, 405-412 1 2020.

A high-resolution geographic information system-analytical hierarchy process-based method for solar PV power plant site selection: a case study Algeria B Settou, N Settou, A Gouareh, B Negrou, **C Mokhtara**, D Messaoudi Clean Technologies and Environmental Policy, 1-16 2020.

Design optimization of grid-connected PV-Hydrogen for energy prosumers considering sector-coupling paradigm: Case study of a university building in Algeria **C Mokhtara**, B Negrou, N Settou, A Bouferrouk, Y Yao International Journal of Hydrogen Energy 2020.

A GIS-MOPSO integrated method for optimal design of grid-connected HRES for educational buildings **C Mokhtara**, B Negrou, N Settou, A Bouferrouk, Y Yao, D Messaoudi Advances in Renewable Hydrogen and Other Sustainable Energy Carriers, 371-378.

Charafeddine Mokhtara, Belkhir Negrou, Noureddine Settou, Belkhir Settou, Mohamed Mahmoud Samy, Design Optimization of Off-grid Hybrid Renewable Energy Systems Considering the Effects of Building Energy Performance and Climate Change: Case Study of Algeria, Energy,2020,https://doi.org/10.1016/j.energy.2020.119605.

Appendix B List of papers under review

Techno-economic optimisation of diesel-PV-Wind-Battery Hybrid Energy System for off-grid residences electrification considering the effects of building efficiency and climate change in Algeria. Energy.

Optimal design of grid-connected rooftop PV systems: Short review and development of a new approach for education buildings in arid climates of Algeria. Renewable and Sustainable Energy Reviews.

Appendix C List of used software

	Software	Information
1	MATLAB	is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks.
2	HOMER Pro	is the global standard for optimizing microgrid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. Originally developed at the National Renewable Energy Laboratory, and enhanced and distributed by HOMER Energy.
3	TRNSYS	is an extremely flexible graphically based software environment used to simulate the behavior of transient systems.
4	ENERGY PLUS	is a whole building energy simulation program that engineers, architects, and researchers use to model both energy consumption—for heating, cooling, ventilation, lighting and plug and process loads—and water use in buildings.
5	DESIGN BUILDER	is a state-of-the-art software tool for checking building environmental performance including energy, carbon, lighting, comfort and cost performance. Developed to simplify the process of building simulation, DesignBuilder allows you to rapidly compare the function and performance of building designs and deliver results on time and on budget.
6	SKETCH UP	is a 3D modeling computer program for a wide range of drawing applications such as architectural, interior design, landscape architecture, civil and mechanical engineering, film and video game design.
7	ARCGIS 10.2	is a geographic information system for working with maps and geographic information maintained by the Environmental Systems Research Institute.
8	ECOTECT	Autodesk Ecotect Analysis is an environmental analysis tool that allows designers to simulate building performance from the earliest stages of conceptual design. It combines analysis functions with an interactive display that presents analytical results directly within the context of the building model.
9	VOS VIEWER	is a software tool for constructing and visualizing Bibliometric networks.
10	EXCEL	is the industry leading spreadsheet program, a powerful data visualization and analysis tool.

Appendix D Particle Swarm Optimization algorithm pseudo code

For each particle
    Initialize particle
End For
Do
    For each particle
Calculate fitness value
If the fitness value is better than the best fitness value P_{best} in history
    Set current value as the new P_{best}
End
Choose the particle with the best fitness value of all the particles the G_{best}
    For each particle
    Calculate particle velocity according to the following equation

$$V_{i,d} = \omega \times V_{i,d} + C_1 \times R_1 \times (P_{best,i,d} - X_{i,d}) + C_2 \times R_2 \times (G_{best,i,d} - X_{i,d})$$

    Update particle position according to the following equation

$$X_{i,d} = X_{i,d} + V_{i,d}$$

End
While maximum iterations or minimum error criteria is not attained.

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