Impact of rural housing energy performance improvement on the energy balance in the North-West of Algeria

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A B S T R A C T

Forty-two percent (42\%) of Algerian primary energy was consumed by the building sector and it is still in expansion, due to mainly on an exceptional growth of population and urbanism. In order to reach the increase demand of housing and to keep the rural areas' inhabitants in their lands, the Algerian state has launched a huge plan of rural housing construction without taking into account the energy performance level which is too bad. The main objective of this work is to analyze the energy performance of rural housing built in the district of Chlef for the three construction programs, besides study their impact on the overall energy balance in the district of Chlef. There are two ways to improve the energy performance of a typical rural house. First, a passive one through the integration of a set of efficiency measures to reduce the need for heating and air conditioning. The efficiency measures include the adequate orientation of the house, insulation of the envelope house, efficient glazing and increased windows size with the use of shading device in summer.

Second, an active one using solar PV to supply the house with electricity. The results show that at the end of the last construction's program, more than 219 GWh of electricity and 26,508 t of butane gas could be saved annually at the energy balance level of the district. The annual cost savings associated to these energy savings was estimated at 1281,933$ for butane gas and at 5110,431$ for electricity.

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1. Introduction

Building construction industry is one of the most consuming energy sectors, thus contributing significantly to the greenhouse effect and climate change, and has a serious environmental impact. Worldwide, buildings are responsible for approximately 40\% of annual total energy consumption. In Algeria, buildings, with about 35\% in the residential sector and 6\% in the tertiary sector, use approximately 42\% of total energy consumption [1]. The reasons that led to the increase in energy demand are: (a) substantial increase of population and housing, (b) low prices of conventional energy, (c) increase number of electrical equipment in each house, (d) use of non-economic electrical equipment such as incandescent lamps and cheap air conditioners, (e) absence of awareness and lack of culture on the energy control, (f) growing desire of people to comfort.

The Algerian thermal regulation of residential buildings was released in 1997. In the framework of this thermal regulation, three Regulatory Technical Document were developed (DTR).

- The DTR.C3-2 which establishes the rules for calculating of winter heat losses for residential buildings [2].
- The DTR.C3-4 includes the rules for calculating of the summer heat input for residential buildings [3].
- The 3-31 DTR.C deals with the natural ventilation of residential premises [4]. The implementation of this regulation should allow a saving of 20 to 30\% on energy consumption for heating homes.

Algeria must establish its development based on other types of energy and try to control its energy consumption by implementing an appropriate energy efficiency policy. For this reason, the Algerian State, has adopted a Renewable Energy and Energy Efficiency Program, published in 2011, including an ambitious energy efficiency program particularly in the residential sector [5]. Proposed measures to achieve energy efficiency in this sector include the introduction of thermal insulation of buildings, which will reduce energy consumption related to home heating and cooling by about 40\% [6]. Thus, a pilot project of 600 houses with high energy

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performance (HEP), as demonstrative operation, was launched. It incorporates the principle of energy conservation in the design and construction of buildings. The promotion and development of renewable energies including solar, enshrined in the Law on Renewable Energy 2004 [7]. By 2030, the Renewable Energy and Energy Efficiency Program expected to reach a 40% share of solar and wind energy in the balance of the national electricity [5]. The choice to use renewable energy is strengthened by its geographical location. Indeed, Algeria holds one of the largest solar potential in the world. Sunshine duration in almost all the country exceeds 2000 h annually and can reach 3900 h (highlands and Sahara). The energy received daily on a horizontal surface of 1 m² is about 5 kWh on most territory of the country (1700 kWh/m²/year at North and 2263 kWh/m²/year in the South [8].

During the last few years, the Algerian authorities have made development of rural housing one of their priorities. Since 2005, Algeria has launched a programme for the construction of one million housing units. Nearly half of this programme (450,000 unit) is devoted to housing in rural areas in order to keep rural populations in place and to encourage their return from urban areas [9]. The construction of a rural house, benefited by a state subsidy (SS) of 7000$, aimed to encourage families to build a self-construction with a decent house in rural environment.

However, the construction of these houses whose level of energy performance is very bad, surely leads to a significant increase in energy consumption, since the government has built them without taking into account the climatic conditions and the required thermal performance level.

The main objective of this paper is to analyze the impact of energy efficiency and solar PV integration on the overall energy balance in rural housing. In addition an economic analysis was performed. These actions will help decision-makers to use renewable energy in the building sector and implement policy packages which deliver a deep path of energy consumption reductions and associated CO₂ emissions mitigation from buildings.

2. Energy situation in the district of Chlef

2.1. Geographical location

The district of Chlef is located in the Northwestern region of Algeria (see Fig. 1). It is 208 km far from the capital Algiers, at latitude 36°13’, longitude of 1.20° and an altitude of 133 m. It extends over an area of 4791 km² and a population of around one million inhabitants with a density of 194 inhabitants/km². It occupies a strategic place due to its geographical location. It is characterized by a Mediterranean climate: sub-humid in the North and continental in the South, cold in winter and hot in summer.

2.2. Energy situation

Electricity and natural gas are the most common energy sources used by the households in the region. The electricity is used for lighting, household appliances running and space cooling, while natural gas is used for cooking, space heating and production of sanitary hot water. In the zones where houses are not connected

![Fig. 1. Geographical situation of the district of Chlef.](image-url)
to natural gas, especially those in rural areas, the gas supply is provided by butane gas cylinders.

Previously, rural inhabitants used the wood and its derivatives for cooking and heating. But in recent years, the development of the road network and the availability of butane gas cylinders decreased the use of wood.

The number of subscribers connected to the low voltage (LV) electricity grid and low pressure (LP) natural gas are continually increasing from year to year, as shown in Fig. 2. These data are provided by the “Société Nationale de Distribution d’Electricité et du Gaz” (Sonelgaz) of the district of Chlef. According to the assessment made in 2011 by the Department of Energy and Mines, the subscribers number connected to the low voltage network (LV) is 78,562 subscribers representing a coverage rate of 94.56%. The rate of the district is near the national average rate which is around 95%. For natural gas, the current rate has increased from 26% in 2004 to 36.03% in 20. But, the rate is one of the lowest in Algeria. This increase of the subscriber’s number is mainly due to connection of new buildings to the electricity grid and gas, which will surely lead to new consumption scenario.

In Fig. 3 are represented the evolution of the overall electricity consumption in the residential sector, of the district of Chlef. It is noticed that the electric energy demand is growing sharply from one year to another. An increase of approximately 30% is recorded from 2006 to 2011 due mainly to the increase in housing stock, estimated at 189,708 units at the end of 2011. This trend of increase was experienced in recent years.

The evolution of butane gas consumption shows that the demand on the butane gas is decreasing significantly from 2006 to 2009 (Fig. 4). This evolution is due to an increase in the number of subscribers to the natural gas network, as shown in Fig. 2.

3. Integration of energy efficiency and solar energy in rural housing

3.1. Rural housing program

In order to meet the greater housing needs, a social housing policy has been set up by the Algerian state. Accordingly, successive different programs for building houses have been implemented with regard to the level of income and the living conditions of the people:

- Rural: State subsidy (SS = 7000$) to help local people to start building a new house in rural areas.
- LSL (Logement Social Locatif, Social Rented Housing): housing built by the state, intended to disadvantaged social groups, without houses. These are multi-family units (apartments) that are occupied at an extremely low rent.
- LSP (Logement Social Participatif, Participatory Social Housing): housing built by the state, addressed to middle-income peoples. Access to this type of housing is made according to a financial package that takes into account a personal contribution, an enhanced credit and a direct frontal support.

According to the direction of housing and public facilities of the district of Chlef, the rural housing program has practically tripled in the last ten years, rising from 7350 to 23,700 rural house for the program 2010–2014, as shown in Fig. 5. From Table 1, it can be seen that rural housing had the lion’s share of the construction programs.
compared to others programs. The construction plan of rural housing (2010 to 2014) has experienced greater increase compared with the one of (1999 to 2004).

This program generates a positive impact on the stability plan, living conditions improvement of the rural areas population and the eradication of precarious housing. Except the town of Chlef, all the other municipalities, 34 in number, have been hit by this program for obvious reasons. Indeed, according to official data, rural areas are home of 50% of the population, whose house is characterized for a large part by precarious constructions where living conditions are deplorable. The majority of houses are scattered, whereas the rest is concentrated around the towns of the municipalities.

3.2. Methodology

In this paper, in order to improve the energy performance of rural housing in the district of Chlef, we proceeded to the selection of a reference type housing which groups all the characteristics of the rural built in this region. These characteristics concern the number of rooms, construction materials, the number of occupiers per house, available electrical equipment and the electrical consumption profile. A detailed model about the reference house has been implemented in TRNSYS and the yearly simulations have been performed using the time step for one hour. Weather data files of Chlef district is input in the model.

The energy performances of the reference house are improved first in a passive manner, through the integration of a set of energy efficiency measures (EEM). Then in an active manner, by using low consumption lamps and efficient appliances, and the recourse to photovoltaic energy to meet the electrical needs of the house. The simulation of the PV system for the reference house has been done separately with Homer software. An analysis economic is made to accurately evaluate the investment cost, the annual cost savings and the return on investment due to the energy performance improvement of the house under study. The investment cost represents the additional cost that the Algerian state will added to the state subsidy (SS) to build an efficient rural house. Finally, the overall energy savings and cost savings owed to the integration of energy efficiency and photovoltaic energy in rural housing, built during the various construction programs, is established.

3.3. Meteorological data

The values of the average temperature and solar radiation on a horizontal plan and tilted 35° are shown, respectively, in Figs. 6 and 7. The data for air temperature are provided by the meteorological station of Chlef. Based on data from the hourly global irradiation on horizontal surface, we can see that the Chlef region has a higher average annual daily to 4.61 kW h/m²/day. It can be noticed that the winter has less solar potential whose average daily monthly global radiation varies between 2 kW h/m²/day and 3 kW h/m²/day. Solar radiation becomes very important between March and October when the average daily monthly global radiation varies from 5 kW h/m²/day to 7 kW h/m²/day. The average monthly temperature varies between 10.5 °C in January and 30.5 °C in July.

3.4. Energy efficiency performance

3.4.1. Efficiency using passive method

Energy efficiency measures are top research subjects all over the world [10]. It refers to the reduction of energy consumption without causing a decrease in the level of comfort and service quality in buildings [11]. The goal of energy efficiency, therefore, is to produce the same goods or services, but using the lowest energy possible. Jaber and Ajib [12] have demonstrated that the application of energy efficiency measures at the design stage of the home under the Mediterranean climatic conditions can provide thermal comfort to the occupants by unless prices. The results show that about 27.59% of the annual energy consumption can be saved by choosing optimal orientation, window sizes and use of sun protection during hot season, in addition to the insulation of walls and roof by 0.13 m and 0.20 m, respectively. Nathan et al. [13] analyzed the effect of a set of measures energy efficiency for residential houses in a semi-arid climate. The energy efficiency measures include insulation panels for exterior walls, control of natural light (daylight), increase of windows surfaces, glazing effective, and various combinations of these. This model has determined that the energy consumption is reduced by 6.1% when several energy efficiency measures are combined. Daniele et al. [14] studied the interaction between various
measures of energy efficiency and thermal comfort in residential buildings in Salamanca (Mexico) using a detailed simulation and optimization procedures. The results show that a combination of efficient appliances, increased levels of roof and wall insulation, heating system water efficient is necessary to save about 52% of the annual energy for new homes. One of the most effective ways to reduce heat transmission rate and energy consumption for space cooling and heating is the use of an appropriate thermal insulation in the building envelope. Jinghua et al. [15] used an eQUEST simulation to study the effect of the thickness and the position of building façade insulation on the total energy demand, among other things. By using a combined optimization strategy for insulation, window/wall ratio, glazing and shading system, they achieved a reduction of up to 25.92% in the total heating and cooling demand. However, after a certain insulation thickness threshold was surpassed, the energy reduction continued, but at a significantly lower rate.

3.4.1.1. Reference house description. It was intended to build rural houses with tiles (with pitched roof) but people prefer flat-roof houses made of concrete, since they offer them alternatives for parts under roof. For this purpose, we have proposed a typical representative rural house with a flat roof, as shown in Fig. 8. This type of housing is the most widely built in district of Chlef with 80 m² floor area. The house has a simple rectangular layout with floor dimensions of 10 × 8 m and the long axis of the house running east–west while it height is about 3 m. The interior of the house consist of a living room, two bedrooms, a kitchen, a bathroom and a toilet and occupied by an average of four people per habitat. The floor plan for the reference house is shown in Fig. 9.

This house is connected to the electricity grid, but the gas supply is provided by butane gas cylinders. Since the house is locating in a rural area where district heating is not available, a mobile heating system operating with propane gas or butane gas is used.

Fig. 8. (a) Typical rural houses in Chlef with tilted roof (b) Typical rural houses in Chlef with flat roof.

Fig. 9. Typical rural house plan with a living area of 80 m².
for space heating (see Fig. 10). During the warmer months, no air conditioning is used, in addition to natural night ventilation; inhabitants use mechanical ventilation such as ceiling fans for cooling.

Construction properties for the house are listed in Table 2. In the majority of housings in this district, the construction materials are also very similar, the roof is in heavy concrete and slabs, the wall in hollow clay brick, the floor is in cement. Façades containing windows are oriented towards the south and north, as shown in Table 3. The windows are all clear, single pane glazing with a wood frame. It was assumed that four people, each contributing 115 W (75 W sensible and 40 W latent) to the internal gains, would occupy the house during hours from 5:00 pm to 8:00 am, and one person is present from 8:00 am to 5:00 pm. Fridays and Saturdays, four persons presence is assumed throughout the day. The total internal gains were calculated from a load profile of typical household electrical loads and occupancy to be 3 W/m² of floor area averaged over a 24 h period. The temperature set points for the zone were set to 20–26 °C from 7:00 am to 10:00 pm and during sleeping hours a wider thermal comfort range of 18–26 °C was implemented as a lower temperature can be tolerated in bedrooms.

TRNSYS software, version 16.01.0003 [16], is chosen to simulate the annual energy balance of the reference house (heating and cooling energy needs).

The thermal balance of the house can be written in the following form:

\[ Q_{IS} + Q_{IG} + Q_V + Q_{inf} + Q_{aux} = c_p \frac{dT}{dt} \equiv 0 \]  

(1)

where \( Q_{IS} \) is the heat flow exchanged, by convection, between the surfaces of the internal environment and the internal air, \( Q_{inf} \) and \( Q_V \) is the heat flow concerning infiltrations and ventilation, respectively. \( Q_{IG} \) is the convective heat flow from the external heat sources to the indoor environment, \( Q_{aux} \) is the convective heat flow supplied (heating energy need \( E_{Nh} \)) to or subtracted (cooling energy need \( E_{Ne} \)) from the internal air by the technical system, \( t \) is the internal air temperature, \( t \) is time, \( c_p \) is the heat capacity of the internal air which is considered negligible.

The heat flux associated to air infiltration through of the house envelope and openings (doors and windows), between the inside and outside of the house at each step time, are calculated by CON- TAM and provided to TRNSYS.

Most infiltration air mass flow models are based on the empirical relationship between the flow and the pressure difference across a crack or opening in the house envelope:

\[ q = (\Delta P)^y \]

(3)

The air mass flow rate, \( q \) [kg/s], is a simple function of the pressure drop, \( \Delta P \) [Pa], across the opening. Theoretically, the value of the flow exponent should lie between 0.5 and 1.0. Large openings are characterized by values very close to 0.5, while values near 0.65 have been found for small crack-like openings [17]. The pressure drop is proportional to the temperature difference between the zone and outdoor air and the wind velocity.

3.4.1.2. Energy efficiency actions. In this analysis, in order to reduce the heating and cooling needs and improve consequently the energy efficiency of the reference house, a parametric study is conducted to determine the optimum energy efficiency measures (EEM). The energy need of the house is taken as the criteria for the optimal EEM. The effect of this optimum EEM is examined, individually and in combination, as shown in Table 4. These energy efficiency measures include:

- Optimal orientation of the house: As the reference house presents a rectangular form, two orientations of house are considered in this analysis. First, the house is oriented on the East/West axis with longest walls facing south and north. Second, the house is oriented on the North/South axis with longest walls facing East and West. Note that windows are oriented with longest walls of house, as shown in Fig. 9.

Table 2
Different walls characteristics of the reference house.

<table>
<thead>
<tr>
<th>Construction</th>
<th>Matériel</th>
<th>Value of ( U ) (W m⁻² K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior wall</td>
<td>Cement plaster (2.5 cm) hollow brick (15 cm) plaster coating (2.5 cm)</td>
<td>1.77</td>
</tr>
<tr>
<td>Interior wall</td>
<td>Cement plaster (1.5 cm) hollow brick (10 cm) plaster coating (1.5 cm)</td>
<td>2.16</td>
</tr>
<tr>
<td>Roof</td>
<td>heavy concrete (10 cm) slabs (15 cm) plaster coating (1.5 cm)</td>
<td>2.55</td>
</tr>
<tr>
<td>Floor</td>
<td>heavy concrete (5 cm) mortar (4 cm) tiling (2 cm)</td>
<td>3.46</td>
</tr>
<tr>
<td>Window</td>
<td>single glazing</td>
<td>5.74</td>
</tr>
</tbody>
</table>

Table 3
Design parameter of the reference house.

<table>
<thead>
<tr>
<th></th>
<th>Surface (m²)</th>
<th>Windows percentage in façade</th>
</tr>
</thead>
<tbody>
<tr>
<td>North façade</td>
<td>22.4</td>
<td>12% (3.36 m²)</td>
</tr>
<tr>
<td>South façade</td>
<td>22.4</td>
<td>12% (3.36 m²)</td>
</tr>
<tr>
<td>West façade</td>
<td>28</td>
<td>0%</td>
</tr>
<tr>
<td>East façade</td>
<td>28</td>
<td>0%</td>
</tr>
</tbody>
</table>
- Optimal thermal insulation thickness: In order to determine an optimum insulation thickness, the annual heating and cooling requirement for the reference house is estimated for different thermal insulation thickness (from 0.02 to 0.20 m) of external walls and roof. The thermal insulation used is the expanded polystyrene (1.4 W/m K).

- Glazing type: The glazing type is a parameter to be considered in order to reduce heating and cooling requirements. For this reason, single glazing (5.47 W/m K) is replaced by double glazing (1.4 W/m K). Interaction between glazing type and thermal insulation is also investigated.

- Optimal windows size: the windows size of the reference house represents only 12% of the façade facing south. This minimizes direct solar gain and daylight through windows of the house. Different windows sizes (from 10 to 90%), with the use of external shading device in summer, are studied to determine an optimum windows size. The minimum windows size is 10% from the façade area in order to reach human comfort.

3.4.2. Efficiency using active method

Solar energy is anticipated to play a major role in electricity generation in Algeria especially solar photovoltaic. There are two types of the photovoltaic systems, stand-alone PV system and grid-connected system. In a PV grid-connected system, the capital cost is less because batteries are not needed for this system. Al-Salaymeh et al. [18] studies the feasibility of utilizing photovoltaic systems in a standard residential apartment in Amman city in Jordan. The component design and cost of PV system required to supply required energy was calculated and the payback period for the suggested stand-alone PV system was estimated in a constant inflation rate in electricity price similar to that of interest rate. The results show that the calculated payback period was high in a stand-alone system, to decrease payback period a grid-connected PV system is suggested. Li et al. [19] presents a methodology to accurately evaluate the economic viability of a domestic solar PV system on a case-by-case basis. The methodology utilizes the software program HOMER for the energy and economic analyses. Utilizing this methodology, a realistic economic analysis of eight sample domestic solar PV systems available in Ireland is presented. Based on the predictions, the domestic solar PV system is not economically viable under current conditions in Ireland. Domestic solar PV systems still do not look promising even if better financial support is given.

McHenry [20] discusses finding from technical simulations and economic models of 1 kWp and 3 kWp grid-connected photovoltaic systems supplying a rural home electricity load in parallel with the electricity network in Western Australia. The results show that 1 kWp and 3 kWp PV systems produced the equivalent of 27.9% and 59.9% of the total electricity consumed in the home, respectively. The results suggest also that current market prices generate a negative NPV (a net private loss), even with the current government subsidies, which lead to higher home electricity costs than conventional network electricity use.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Baseline (construction characteristics described in Table 2)</td>
</tr>
<tr>
<td>2</td>
<td>Orientation (east/west axis)</td>
</tr>
<tr>
<td>3</td>
<td>Increasing of windows size</td>
</tr>
<tr>
<td>4</td>
<td>Use of efficient glazing (1.4 m2·K−1)</td>
</tr>
<tr>
<td>5</td>
<td>Thermal insulation of wall and roof</td>
</tr>
<tr>
<td>6</td>
<td>Combination: insulation of exterior walls and roof with use of efficient glazing and increasing of windows size with use of shading device</td>
</tr>
</tbody>
</table>

3.4.2.1. Electrical consumption profile. Rural houses are characterized by their average level of electrical equipments. Generally, the energy source for space heating and for sanitary hot water (DHW) production is gas, which is available and less expensive in the region. Cooling is absent due to the high cost of air conditioners. Consequently, electricity consumption in the house provides only for the services of lighting, refrigeration and general power (e.g. dishwasher, washing machine, computers, telecommunications etc.).

Before being able to calculate the energy production of our PV system, we need to establish reference electrical consumption for an individual family located in rural area based on the power consumption of a rural households sample in different areas of the district, and the use of electrical equipment by the inhabitants. According to data provided by Sonelgaz of Chlef District, the annual electricity consumption of selected homes is given as a sample in Table 5. We can notice that the rural houses in the region have a very similar annual electrical consumption which varies from 1300 kWh and 1400 kWh. Based on this electrical consumption, we propose an annual profile established from conventional electrical equipments identified, their conditions of use and their annual consumption, see Table 6.

The average annual electricity load is calculated using the following equation:

$$
\text{load} = \sum_{i=1}^{n} P_i \times N_i \times f_i
$$

where:

- \( P \) is the power of equipment (e.g. refrigerator, television . . .),
- \( N_i \) is the number of equipment and \( f \) is the usage frequency of the equipment. \( n \) indicates the total number of equipment (in our case 8 equipments). Using data in Table 6, the average yearly electrical consumption \( E_{Cy} \) is 1991 kWh. The average daily electrical consumption \( E_{Cd} \) is given by the following equation:

$$
E_{Cd} = \frac{E_{Cy}}{365}
$$

It can be noted that for a single family household where electricity is used only for lighting and electrical appliances, the average daily electrical consumption of 5.45 is very high. This is mainly due to the use of inefficient electrical equipments which consumes a lot of energy.

To design an efficient PV system with the less cost of investing in house, it is important to use an efficient electrical equipments. Thus, a second annual profile is estimated by replacing incandescent lamps, which are commonly used by Algerian homes, with low consumption lamps and conventional appliances by other efficient. From Table 6, we can detect that the use of efficient electrical equipment helps to reduce the annual electrical needs of the reference house from 1991 kWh to 1350 kWh, with a reduction of 47.91%.

After defining the annual consumption profile, we perform hourly domestic electrical load profile for light and appliances, which are shown in Fig. 11. The daily electric load is 3.69 kWh. We observe consumption peaks in the morning between 6 h and 8 h and in the evening between 19 h and 21 h in agreement with
what can be seen on Algerian territory. This situation occurs when several appliances are running at the same time such as lighting.

3.4.2.2. The PV system. The PV system would produce electrical energy to satisfy needs for electrical energy of the house. The house uses the utility power grid for storage-delivering energy to the grid when the PV system produces more energy than the home uses and draws from the grid when the PV system produces less energy than the house needs. The scheme of a grid-connected PV system chosen in this study is shown in Fig. 12. It is comprised of a PV array, an inverter, a meter to measure the energy exported to the grid and the energy imported from the grid. The array slope is set to 35° in accordance with local latitude (36.13N) and can be installed on the flat roof or beside the house, far from the sunscreens. PV module parameters are listed in Table 7. This PV module is available in Chef market. New solar energy Omniksol-1.0k-TL inverter is used to convert DC current produced by the PV panels into alternating current (AC).

The simulation of a grid-connected PV system was undertaken using HOMER, version 2.68 beta [21]. The power produced by the PV system is calculated using the following formula

\[ P_{pv} = P_{max} F_{pv} \left( \frac{G}{G_{STC}} \right) \left( 1 + \alpha (T_c - T_{c,STC}) \right) \]  

where \( P_{max} \) is the peak power output (kW), \( F_{pv} \) is the derating factor, \( G \) is the solar radiation incident on the PV modules in the current hour (kW/m²), \( G_{STC} \) is the incident radiation at standard test conditions (1 kW/m²), \( \alpha \) is the temperature coefficient of power (%/°C), \( T_c \) is the PV cell temperature in the current hour (°C), and \( T_{c,STC} \) is the PV cell temperature under standard test conditions (25°C). Each term is described below.

In order to design a PV system according to the electricity load required (2.1 kWh/day) for the reference house, we have studied the energy performance of different PV array sizes (from 0.25 to 1.25 kWp). As shown in Fig. 13, a PV array of 1.0 kWp may

Fig. 11. Daily home electricity consumption profile.

Fig. 12. Grid-connected PV system.

### Table 6

<table>
<thead>
<tr>
<th>Device type</th>
<th>Power (W)</th>
<th>Number</th>
<th>Usage frequency</th>
<th>Average annual consumption (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refrigerator</td>
<td>120 1.35 kWh/cycle</td>
<td>1</td>
<td>Continuously</td>
<td>416 312</td>
</tr>
<tr>
<td>Washing machine</td>
<td>40 0.94 kWh/cycle</td>
<td>1</td>
<td>2 cycles/week</td>
<td>227 236</td>
</tr>
<tr>
<td>Television</td>
<td>120 5h/day</td>
<td>1</td>
<td>5h/day</td>
<td>247 234</td>
</tr>
<tr>
<td>Sat. receiver</td>
<td>300 30h/day</td>
<td>1</td>
<td>1h/day</td>
<td>109 105</td>
</tr>
<tr>
<td>Ironing amenities</td>
<td>75 6h/day</td>
<td>1</td>
<td>5h/day</td>
<td>823 350</td>
</tr>
<tr>
<td>Lighting</td>
<td>120 1h/day</td>
<td>1</td>
<td>4h/day</td>
<td>72 27</td>
</tr>
<tr>
<td>Computer</td>
<td>75 6h/day</td>
<td>4</td>
<td>(60 days)</td>
<td>1991 1350</td>
</tr>
</tbody>
</table>

### Table 7

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum power (W)</td>
<td>250</td>
</tr>
<tr>
<td>Module efficiency (%)</td>
<td>15.37</td>
</tr>
<tr>
<td>Nominal operating cell temperature (°C)</td>
<td>45.3</td>
</tr>
<tr>
<td>Open circuit voltage (V)</td>
<td>37.70</td>
</tr>
<tr>
<td>Short circuit current (A)</td>
<td>8.69</td>
</tr>
<tr>
<td>Maximum power current (A)</td>
<td>8.22</td>
</tr>
<tr>
<td>Maximum power voltage (V)</td>
<td>36.43</td>
</tr>
</tbody>
</table>
produce more than the annual electrical consumption of the reference house (1350 kWh). As a result, a 1.0 kWp PV system is selected for analysis in this study. The designed PV array is composed of four PV panels, each panel produces 30.34 V and 250 Wp (8.22 A). PV panels are connected in series to gives required input voltage of inverter (80 V). The single PV panel cost is 276.46$, the total cost of the four panels is 110,584$. The inverter cost is 434.77$ and the protection box is 84$. Fig. 14 shows components of the PV system which includes PV solar panels, Omnikol-1.0k-TL inverter and a protection box.

3.5. Results and discussions

3.5.1. Impact of energy efficiency actions

3.5.1.1. Effect of house orientation. The optimal house orientation increases the quantity of daylight and reduces the energy demand for artificial light. Fig. 15 shows that the total energy needed to provide comfort throughout the year is about 12,438 kWh when the house is oriented on a North/South axis and about 12,065 kWh when the house is oriented on an East/West axis. The greatest energy saving was obtained when the rectangular house is oriented on an East/West axis with the longest walls facing south and north. The simple fact of house orientation on an East/West axis in the design step, with the longest side facing south can save 2.99% of energy. It can be found that buildings with a small ground plan were less sensitive to changes in orientation.

3.5.1.2. Effect of windows size and shading device. The effect of windows size on heating need is estimated for different windows size from the total façade area. Fig. 16 shows that for the south façade, increasing windows size from 10% to 40% decreases annual heating requirement from 8569 to 8260 kWh. This is due mainly to the large amount of useful solar heat gains obtained through south facing windows. However, beyond this size (50% to 90%), heating needs of south face tend to increase with the increase of window size. This can be attributed to the fact that the increase of solar heat gain with large window areas is offset by increased heat losses with large windows due to their relatively low insulation. For the north façade, heating requirement of the house increases from 8569 to 9527 kWh with an increasing windows size from (10% to 90%).

As can be seen in Fig. 17, for both façades (north and south) annual cooling needs increases (from 3551 to 5317 kWh for south façade and from 3551 to 4511 kWh for north façade) with an increasing windows area (from 10% to 90%). However, thanks to external shading device, the increasing of cooling needs result in the increasing of windows size of the southern façade can be avoided. Since, shading device plays an important role in modulating heat gain of the house and blocking out unwanted radiant heat gain [22]. As a result, the optimum windows size is 10% for North façade and 40% South façade. Increasing the windows size of the southern façade by 40% (11.2 m²) compared to the originally windows size (12%) with the use of external shading device in summer provides significant energy savings by reducing the total energy needs of 5.40%.

It is noticed also that in addition to gain maximum benefit from solar radiation in heating season, increased window area facing south enhances a house natural lighting especially in rural area where sunscreens are absent. While, the minimum windows size on north façade (10%) minimizes heat loss by conduction in heating season. However, it represents a good way to bring in daylight and avoid solar heat gains by improving night cooling in cooling season.

3.5.1.3. Effect of thermal insulation. In order to determine an optimum insulation thickness, the annual heating and cooling needs for the reference house is estimated for different thermal insulation thickness for walls and roof. As can be seen from the results shown in Fig. 18, the increase in the thickness of the thermal insulation leads to a significant reduction in the energy need of house. The annual energy need diminishes (from 12,090 kWh to 5384 kWh)
as the insulation level increases (from 0.02 m to 0.2 m). A reduction of 49.40% in annual energy need is recorded when increasing the thermal insulation thickness of only (0.08 m). However, beyond this thickness, the impact on annual energy need strongly attenuates with a reduction of about 6%, for an increase of the insulation thickness of 0.08 to 0.2 m. Consequently, the effectiveness of increasing the insulation as a method for reducing energy need is effective only up to a certain point, after which a massive increase in insulation continues to produce a reduction in the heating demand, but at a lower rate. In our case study, the optimum insulation thickness is 0.08 m for both walls and roof.

3.5.1.4. Effect of glazing type. In this section, an analysis of the impact of the glazing type on the house energy needs is presented. The interaction between the glazing type and insulation level is also illustrated through the simulation of two configurations. The simulation results of the case studies are presented in Table 8.

For the reference house, the impact of double glazing windows on the annual energy needs is low. The total annual energy needs decrease (from 12,065 kWh to 11485 kWh); a reduction of only 4.8% is achieved. While, in the case of an insulated house, the impact is significant. The annual energy needs are decreased (from 6118 kWh to 5326 kWh), with a reduction of 12.94%.

3.5.1.5. Effect of the combination. The individual performance of any of these energy efficiency measures can be considerably different when used in combination with others. So far, the optimum energy efficiency measures to minimize the requirements of energy have been identified. Fig. 19 shows the energy savings achieved by these optimum energy efficiency measures (EEM) individually and in combination. The orientation of the house on an East/West axis with longest walls facing south and north reduces the annual energy need of 2.99%. The increase of the existing window area of the south façade, measured as a percentage of total wall area, to 40% leads to a reduction of 5.40% in annual energy need. The U value for external walls is improved from 1.77 W/m² K to 0.38 W/m² K and the U value for roof from 2.55 W/m² K to 0.4 W/m² K resulting in annual energy need reduction of 49.40%. This makes the thermal insulation the best measure of energy efficiency. The improvement of the U value for glazing from 5.74 W/m² K to 1.4 W/m² K leads to a further energy need reduction of 12.94%. Compared with reference house design, the energy saving in energy with optimum EEM is about 63.51% reduction of the original annual energy need (from $EN_{1,1} = 12,065$ kW h/y to $EN_{2,1} = 4402$ kW h/y). There is a reduction in annual heating energy need from $EN_{h,1} = 8514$ kW h/y to $EN_{h,2} = 3641$ kW h/y (57.23%) and a reduction in annual cooling energy need from $EN_{c,1} = 3551$ kW h/y to $EN_{c,2} = 382$ kW h/y (89.24%).

![Fig. 16. Annual heating energy at different windows sizes.](image)

![Fig. 17. Annual cooling energy at different windows sizes.](image)

![Fig. 18. Energy saving at different insulation thickness for ceiling and walls.](image)

![Fig. 19. Annual energy reduction rate.](image)
3.5.1.6. Thermal comfort. Thermal comfort has been evaluated, basing on the computed hourly indoor temperatures. A temperature frequency plot of the resulting indoor temperatures of the house with and without applying EEM is presented in Fig. 20. The thermal comfort range is between 20 °C and 26 °C. There is a clearly difference between these two cases. The large spread of temperatures in the case without EEM illustrates the higher energy need to maintain the house within the thermal comfort range. In this case, the number of hours outside the thermal comfort range is significantly higher. As shown in Table 9, the indoor temperatures are above 26 °C for 1877 h (21.42%) of the year and below 20 °C for 3640 h (31.89%) of the year. In the case with EEM, the indoor temperatures are above 26 °C for only 217 h (0.24%) of the year. Indeed, the indoor temperature for this house does not exceed 28 °C in summer. Overheating period is very limited essentially thanks to night ventilation. Tantasavasdi [23] have shown that in addition to natural night ventilation, a ceiling fan can be an interesting solution to achieve a comfortable indoor environment in warm time. Since, the ceiling fan increases the indoor air velocity. In winter, it was found that comfortable indoor temperatures were more difficult to achieve with the integration of EEM. In fact, the indoor temperatures are below 20 °C for 2858 h (25.04%) of the year.

3.5.2. Contribution of photovoltaic energy

The annual electrical simulations results for a 1.0 kWp PV system are given in Fig. 21. The total electricity consumption in the home from all sources “AC primary load”, supplied in parallel from the inverter and the network is EC = 1347 kWh and the total annual kWh exported to the electricity network per annum which occurs when the PV inverter generates excess electricity relative to the home electricity demand “grid sales” is ES = 1229 kWh. The total annual kWh imported from the electricity network per annum which occurs when the PV inverter generates less electricity relative to the home electricity demand “grid purchases” is EP = 989 kWh and the total annual kWh produced by the PV system “PV array” is EPV = 1764 kWh. The PV system produced the equivalent of 64% of the total electricity consumed in the home. The annual electricity purchased from the grid represents 36% of the total electricity consumption in the home.

The monthly electrical simulation results for the 1.0 kWp PV system are shown in Fig. 22. As the calculation of the power output specifically takes into account the effect of temperature on a solar PV module into account; the solar PV becomes less efficient as its temperature increases. Consequently, the maximal production of the PV system is 105 kWh in January and the minimal production is 71 kWh in June. However, the monthly electricity imported from the grid, when the sun is not available, varies from 41 kWh to 48 kWh.

The monthly net electricity imported from the grid “Net purchases” is calculated by subtracting the electricity exported to the grid “energy sold” from the electricity imported from the grid “energy purchased”. As shown in Fig. 23, we can note that the monthly net electricity purchased from the grid is negative.

<p>| Table 9 |
| Indoor thermal comfort in the RH with and without EEM. |</p>
<table>
<thead>
<tr>
<th>Temperature range</th>
<th>RH without EEM (%)</th>
<th>RH with EEM (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual hours in 20–26 °C</td>
<td>35.39</td>
<td>54.31</td>
</tr>
<tr>
<td>Annual hours under 20 °C</td>
<td>31.89</td>
<td>25.04</td>
</tr>
<tr>
<td>Annual hours above 26 °C</td>
<td>21.42</td>
<td>0.24</td>
</tr>
<tr>
<td>Annual hours above 28 °C</td>
<td>11.42</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Fig. 20. Frequency of indoor temperatures without and with EEM.

Fig. 21. Electrical simulation results.

Fig. 22. Monthly average electrical produced by the grid and PV system.

Fig. 23. Monthly net electricity purchases from the grid.
during all the year, since the monthly electricity fed to the grid is higher than the electricity purchased from grid with a maximum in January (∼30 kWh) and a minimum in June (∼1 kWh).

The daily electrical simulation results for the 1.0 kWp PV system for two days (a sunny and a cloudy day) are shown in Figs. 24 and 25. The presented results are consumed electricity, the purchased electricity, the generated PV electricity, and the PV electricity exported to the electricity grid for each one hour of the day. It is noted that the PV system can still produce electricity on cloudy days, but not as much as on a sunny day. Fig. 24 presents results for a sunny day, that the PV-origin electricity between 6:00 am and 8:00 am does not cover the energy consumption, as the sun did not generate any electrical energy. The PV electricity starts to be generated from 8:00 am to 19:00 pm. When the electricity is generated from the sun, it easily covers the house energy consumption. The excess electricity produced by the PV system, relative to the home electricity demand, is exported to the electricity network. After 19:00 pm the energy consumption is not covered as the PV electricity is not generated. Then, all electricity is purchased from the electricity grid. Fig. 25 shows results for a cloudy day that the electricity generated by the PV system cannot cover the energy consumption between 8:00 am and 19:00 pm. In this case (cloudy day), the energy consumption is entirely or partially purchased from the electricity grid.

In conclusion, the PV system may entirely cover consumption of electrical energy in the house using the grid electricity as storage to overcome parts of day without solar energy. In addition, it is clear that part of the day when several appliances such as lighting starts to operate at the same time is critical part of the day for the electricity grid as there is the highest electricity demand and no solar electricity is available.

**4. Economic analysis**

In order to get information about the profitability of EEM and PV system on rural housing, an economic analysis was made. In this direction, we investigated yearly revenue, investment cost and return on investment due to the installation of a grid connected PV system and EEM in rural housing of Chef district. In the analysis, the time value of money, the effective interest rate or rising energy prices, or the replacement cost where not considered. The life cycle of the PV system components is estimated to be 25 years and thermal insulation of the house envelope 35 years. To compile the most accurate and realistic prices for the case study house, every effort was made to get up-to-date pricing from local vendor for the buildings materials and solar components [24].

**4.1. Yearly income**

The yearly income for the case of the existing rural house in Chef district when the thermal insulation and the PV system are additionally installed was calculated using data from Table 10. The total yearly income by house is given as

\[ Y_l = Y_{el} + Y_g \]  

(7)

The yearly income due to butane gas saving is given as

\[ Y_g = C_g \times E_{g} \]  

(8)

where \( C_g \) stands for the price of gas (1.11 DZA/kWh). \( E_{g} \) represents the energy saving due to the space heating need reduction (difference between the yearly energy required for space heating before \( E_{Sh,1} = 8514 \) kWh) and after \( E_{Sh,2} = 3641 \) kWh (installing PV system and EEM).

\[ E_{Sh} = E_{Sh,1} - E_{Sh,2} \]  

(9)

The yearly income due to electricity saving is given as

\[ Y_{elec} = C_{el} \times E_{elec} \]  

(10)

where \( C_{el} \) stands for the price of electricity purchased from the electricity grid assumed to be 4.179 DZA/kWh €/kWh. \( E_{elec} \) represents the electrical energy saving (difference between the yearly electrical energy need of the house before and after installing PV system and EEM).

\[ E_{elec} = (E_{P1} + E_{Sc,1}) - (E_{P2} - E + E_{Sc,2}) \]  

(11)

where \( E_{P1} = 1431 \) kWh represents the yearly electricity purchased from electricity grid when the PV system is not installed (RH without PV system). \( E_{Sc,1} = 3169 \) kWh is the yearly electricity need for space cooling when the EEM is not installed (RH without EEM). \( E_{P2} = 527 \) kWh is the yearly electricity purchased from electricity grid when the PV system is installed (RH with PV system). \( E = 1229 \) kWh is the PV-origin electricity sold to the electricity grid. \( E_{Sc,2} = 382 \) kWh is the yearly electricity need for space cooling when the EEM is installed (RH with EEM).

**Table 10: Heating, cooling and electrical gain.**

<table>
<thead>
<tr>
<th></th>
<th>Heating needs (kWh)</th>
<th>Cooling needs (kWh)</th>
<th>Electrical needs (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH without EEM and PV system</td>
<td>8514</td>
<td>3551</td>
<td>1991</td>
</tr>
<tr>
<td>RH with EEM</td>
<td>3641</td>
<td>382</td>
<td></td>
</tr>
<tr>
<td>RH with EEE</td>
<td>–</td>
<td>–</td>
<td>1350</td>
</tr>
<tr>
<td>RH with EEE and PV system</td>
<td>–</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Energy saving (kWh)</td>
<td>4873</td>
<td>3169</td>
<td>1991</td>
</tr>
</tbody>
</table>

**Fig. 24.** Hourly electrical simulation results of a sunny day.

**Fig. 25.** Hourly electrical simulation results of a cloudy day.
4.2. Investment cost

The initial investment cost includes the cost of the grid connected PV system and the cost due to integrating EEM in the house envelope (cost of thermal insulation and double glazing window) as given by the following equation:

\[ IC = IC_{PV} + IC_{EEM} \]  

The cost of the grid connected PV system \( IC_{PV} \) includes the cost of the PV array, the inverter and the protection box. The costs for mounting the PV system and the inverter are assumed to be 10% of the investment cost for the PV system. Hence,

\[ IC_{PV} = 1.1 \times (P_{ar} \times C_{ar} + P_{inv} \times C_{inv} + C_{pg}) \]  

where \( P_{ar} = 1.0 \text{ kWp} \) represents the array rated power, \( C_{ar} = 1.1 \text{$/Wp} \) represents the average price of the array per unit of its rated power and \( C_{inv} = 0.43 \text{$/Wp} \) represents the average price for the inverter per the unit of the rated power. \( P_{inv} = 1.0 \text{ kWp} \) represents the inverter rated power. The protection box cost is \( C_{pg} = 845 \text{$.} \) The cost of installation is assumed to be 10% of the total investment costs for integration of EEM. Hence,

\[ IC_{EEM} = 1.1 \times (S_{ins} \times C_{ins} + S_{w} \times C_{w}) \]  

where \( S_{ins} = 168.8 \text{ m}^2 \) represents the total area of the house envelope without windows area, \( C_{ins} = 4.50 \text{$/m}^2 \) represents the cost of thermal insulation per \text{m}^2, \( S_{w} = 12 \text{ m}^2 \) represents the total windows area of the house and \( C_{w} = 290 \text{$/m}^2 \) represents the cost of windows glazing per \text{m}^2.

4.3. Return on investment

The return on investment is defined as the initial investment cost divided by the annual cost savings due to the installation of EEM and PV system.

\[ ROI = \frac{IC}{VI} \]  

Fig. 26 represents the investment cost in EEM and PV system and their corresponding cost savings (yearly income).

The investment cost in energy efficiency measures is higher, it was estimated about 4664$. This is due mainly to the high cost of double glazing (290$/m²) compared to the thermal insulation material (4.5$/m²). However, the annual cost saving is 186.525 and return on investment is estimated to 25 years, far less than the assumed life cycle of 35 years. Compared to the cost investment in EEM, the cost investment in a grid PV system is lower (1980$), but for limited annual cost saving abilities (83.20$) result in a return on investment (24 years) that is only a little lower than its guaranteed life cycle of 25 years. When both investments in EEM and PV system are considered, the capital cost is about 6643$ with a yearly income of 269.72$. The return investment is about 24 years. Thus, the investment in EEM and PV system can be paid back during their service periods.

It can be concluded that, the calculated return on investment in all cases is not too high, therefore, the utilization of grid connected PV system and thermal insulation in Chlef district is economically feasible.

5. Rural housing energy efficiency impact on energy balance of the district

After evaluating the annual energy savings and annual cost savings due to the energy performance improvement of the reference house, let us estimate the impact of rural housing energy efficiency improvement on energy balance of the Chlef district.

The electrical energy gain at the end of each program, depending on realization rate can be calculated by the following equation:

\[ E_{G_{elec},i} = E_{S_{elec}} \times \left\{ \frac{r_i}{100} \times (H_i + S_{i-1}) + R_{i-1} \right\}, \quad i = 1, 2, 3 \]  

Hence, the cost savings at the end of each program are given by the following equation:

\[ C_{S_{elec},i} = C_{elec} \times E_{G_{elec},i}, \quad i = 1, 2, 3 \]  

The number of butane gas cylinder of 13 kg saved at the end of the three programs (knowing that the energy capacity of a cylinder of 13 kg is 179 kWh), depending on realization rate can be calculated by the following equation:

\[ E_{G_{g},i} = \frac{1}{179} \times E_{G_{g}} \times \left\{ \frac{r_i}{100} \times (H_i + S_{i-1}) + R_{i-1} \right\}, \quad i = 1, 2, 3 \]  

Hence, the cost savings at the end of each program is given by the following equation:

\[ C_{cost,i} = C_{g} \times E_{G_{g},i}, \quad i = 1, 2, 3 \]  

where \( i \) represents the program number (\( i = 1 \) for 199/2004, \( i = 2 \) for 2005/2009 and \( i = 3 \) for 2010/2014). \( R \) is the number of houses built during the previous program (\( R_0 = 0 \)). \( S \) is the number of houses unrealized in the previous program (\( S_0 = 0 \)). \( H \) is the total number of houses in current program. \( r \) is the realization rate (ratio of the number of homes achieved and the total number of houses in current program).

Table 11 summarizes the realization rate of various programs of housing construction in Chlef. It is assumed that all the different houses programmed during the various programs will be achieved at the end of the 2009/2014 period.

Energy gains which are due to improved energy performance of houses carried out during the various construction programs are given in Table 12. We note that the energy savings are proportional to the number of homes built. At the end of the program 1999/2004 the energy savings are estimated at 31.85 GW h of electricity and 296435 cylinders butane gas and at the end of the program 2005/2009 reaches more than 99.87 GW h of electricity and 929,535 cylinders butane gas. As energy gains of the first and second program adds the third program (2010–2014), the energy saved at the end of the last program would be considerable, more than 219.10 GW h of electricity and 2039,125 of cylinders butane gas. In addition, at the end of the last program, the annual cost savings associated to these energy savings was estimated about 1281,933$ for butane gas and about 5110,431$ for electricity.

In order to highlight the impact of energy performance improvement of homes built at the end of each construction program on the
Table 11
Realization rate of the various programs of construction.

<table>
<thead>
<tr>
<th>No. of program</th>
<th>Period</th>
<th>Number of homes programmed</th>
<th>Realization rate (%)</th>
<th>Rest</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1999/2004</td>
<td>7350</td>
<td>94.21</td>
<td>426</td>
</tr>
<tr>
<td>2</td>
<td>2005/2009</td>
<td>18,994</td>
<td>73.96</td>
<td>4938</td>
</tr>
<tr>
<td>3</td>
<td>2010/2014</td>
<td>23,700</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 12
Energy savings and cost savings for different programs of construction.

<table>
<thead>
<tr>
<th>No. of program</th>
<th>Period</th>
<th>Electricity consumption GWh/year</th>
<th>$/year</th>
<th>Gas butane consumption (cylinder/y)</th>
<th>$/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1999/2004</td>
<td>31.85</td>
<td>1584,880.5</td>
<td>296,435 (3853.65)</td>
<td>393,561.5</td>
</tr>
<tr>
<td>2</td>
<td>2005/2009</td>
<td>99.87</td>
<td>4095,676.22</td>
<td>929,535 (12,083.9)</td>
<td>1027,385.46</td>
</tr>
<tr>
<td>3</td>
<td>2010/2014</td>
<td>219.10</td>
<td>5110,431</td>
<td>2039,125 (26,508.63)</td>
<td>1281,933</td>
</tr>
</tbody>
</table>

Fig. 27. Rate of electrical energy saved in 2006, 2010 and 2015.

Fig. 28. Rate the amount of butane gas saved in 2006, 2010 and 2015.

energy balance of the district, we calculated the rate of energy saved for a few years, as shown in Figs. 27 and 28. Energy consumption (electricity and butane gas) of the year 2015 is estimated according to the evolution of the energy of the district. The energy performance improvement of rural housing can save 3.70% of electricity and 6.37% of butane gas consumed in 2006, 7.64% electricity and more than 22.81% of butane gas in 2010 and 12.17% electricity and 53.01% butane gas in 2015.

6. Conclusions

In this paper, the impact of the integration of energy efficiency measures and PV energy in rural housing in Chlef on the energy balance of the district is analyzed. To achieve this goal, a typical rural house was chosen as a reference house and their energy performance is improved. The result indicates that the annual heating and cooling needs and electrical consumption of the reference house was very higher. The energy performance of this house is improved. In one hand, the integration energy efficiency measures using passive method allowed to a reduction of 63.5% of energy needs with a minimum of comfort for the reference house. In this case, as the space cooling need was reduced of 89%, the use of air conditioning in summer is not necessary and in winter time; the space heating needs is reduced by 57.23%. In other hand, through an active manner, the use of grid-connected PV system allowed the production of electrical energy to feed appliances and lighting. Thus, with an important solar potential which the region holds, the electricity production from solar PV, can contribute up to 72% of the annual electricity consumption.

The investment cost due to these energy performance improvements was estimated about 6644$. Therefore, the Algerian government will increase the State Subsidy for building an efficient rural house from 7000$ to 13644$.

Finally, results analysis show that rural electrification of houses using solar PV and improving energy efficiency can generate significant energy savings at the level of the energy balance of the region. We can note that if the energy performance of all 23,700 rural houses, carried out during various construction programs were improved, more than 219 GWh and 26,508 t of butane gas can be saved annually. In addition, the annual cost savings associated to these energy savings was estimated at 1281,933$ for butane gas and at 5110,431$ for electricity.

These energy savings make the residential sector more energy efficient: In one hand, to reduce the problems of electricity cuts, which are frequent in the region in summer due to the use of air conditioners for cooling, and on other hand, limiting the shortage of butane gas which is highly consumed in winter to cope with the cold.

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