Contribution in reducing energy consumption of telecom shelter

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Abstract— This paper presents different modes of power supply for base transceiver stations (BTS) situated in South-eastern Algeria, mainly at neighboring of Ouargla province. In order to reduce energy consumption, passive cooling techniques are being increasingly proposed as alternative systems. They are profitable in terms of cost, energy requirement and carbon dioxide emission, so, passive cooling system for BTS is examined. There are many cooling techniques, in the present study; solar chimney with earth-air heat exchanger (EAHE) is introduced. During the whole year, Shelter audit energy has been examined using Trynsis 16 software. Then, CFD code (Fluent 6.3) is used to predict thermal performance for chimney and underground pipe. This simulation shows that increasing inlet flow causes significant cooling improvement which indicates that some shelters can be designed without conventional air conditioning. In order to extend the analysis on wide area, three cooling modes are examined. The first is insured by mono-bloc air conditioning supplied by diesel driven generator where energy consumption is calculated from energy bills. In the second mode, cooling energy evaluation is based on degree-days method and the net transceiver consumption is added. For the last approach, according to station type, photovoltaic (PV) system, EAHE and solar chimney are introduced. The obtained results show significant energy consumption fall due essentially to cooling energy decrease. Indeed, during all year, pylon station operating needs small capacity of PV panel. In addition, prospection study with trend and voluntary models indicates that investment payback is relatively short.

Keywords— phone station, Earth-air heat exchanger, solar chimney, photovoltaic, energy cost.

I. INTRODUCTION

Mobile phone operators seek to extend their markets in remote areas and provide better services. So, they must solve the problem of electricity supply in cost-effective way [1]. In these areas, the diesel generator supply has become a much less viable solution due to its high operating cost and low system efficiency [2]. Also, this stations registry a lot of failures which induce significant network disturbances, so they need an alternative power supply.

E.M. Nfah et al. [3] examined photovoltaic hybrid systems for energy supply of 33 base transceiver stations of MTN Cameroon. The energy costs showed that the annual operational times of the diesel generator were in the range 3–356 h/year with renewable energy fractions in the range 0.89–1.00. The PV array sizes evaluated for the 22 stations were found to be the range 2.4–10.8 kWp corresponding to daily energy demands in the range 7.31–31.79 kWh.

Kusakana et al. [4] investigated the possibility of using hybrid Photovoltaic-Wind renewable systems as primary sources of energy to supply mobile telephone base stations in the rural regions of the Democratic Republic of Congo. For the case of Kabinda for example, the hybrid system (composed of two 7.5 kW wind generators, 10 kW PV array, 7.5 kW inverter, and 82 batteries) has an initial capital cost of $119,250, a Net Present Cost of $196,975, an operation cost of $3109 and a cost of energy produced of 0.372 $/kWh.

L. Han et al. [5] studied an integrated air conditioner with thermosyphon (IACT) as an efficient cooling device for mobile phone base stations in China, combining vapor compression refrigeration with a thermosyphon. The comparison with the traditional air conditioner shows that the IACT saves 19.1% -28.2% more energy and in hotter regions has a larger energy saving amount but a smaller energy saving rate. The thermosyphon mode works effectively when the mean monthly temperature is 5.4 °C-24.5 °C. The monthly smaller energy saving of IACT in the stations of Beijing and Guangzhou is 12.2%-48.6% and 12.1%-45.2% respectively. By the same techniques, A. S. Sundarm et al. [1] developed two-phase closed thermosyphon to cool shelters. The enclosure temperature is maintained at an average of 37.67 ◦C and the maximum reaches 38.70 ◦C. It is seen that phase change material temperature increases above its melting level (29◦C) during the period 11.00 a.m. to 5.00 p.m. This is due to the storage capacity of this material is insufficient to take all the heat loads of the day during the month of May.

B. Dokkar et al. [6] proposed photovoltaic-hydrogen power system for mobile phone station. This base transceiver station (BTS) is located in neighboring Ouargla city (in the south of Algeria). The power system includes a photovoltaic (PV) field, water electrolyzer and two PEM fuel cells. The high number of photovoltaic modules (80 modules of 300W) and PEM fuel cells equipments lead to increase the investment cost. So, the installation needs introducing low load cooling system and using cheaper energy assistance equipments.

In traditional Iranian building, a passive cooling technique is used in desert hot regions. It consists of vertical wind-catcher and underground water canal [7]-[8]. This system is very

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interesting for adjusting the inside temperature and keeping it constant, but, the main disadvantage of this system is that its performance depends on wind strength. In green building, a common used technique remedies the inconvenient of natural and forced convection systems. It is composed of solar chimney and EAHE which is characterized by its simplicity and high removed heat rate [9]-[10]-[11]. In addition, it has low electricity consumption, so it is very convenient in remote area where photovoltaic is used to provide shelter [12].

This work presents a comparison of BTS energy consumption for three cooling methods. For the first, the station is equipped by a mono-bloc air conditioning where energy consumption is evaluated by using energy bills. In the second method, cooling energy evaluation is based on degree-days principle. But, for the last approach, the cooling of pylon stations is insured by EAHE with solar chimney and the stations are supplied by photovoltaic fields.

II. Base transceiver station

A. *Station description*

Base Transceiver Station (BTS) connects between mobile phone and the subsystem network. The transceiver station is composed of metallic shelter and antennas support (see Fig. 1). The shelter contains the electronic equipments, dry storage batteries, power supply cupboard and mono-bloc air conditioner (Mega Hussoto HP 8V). The standalone stations are supplied by 15 kW fuel power generators. During the day, the electricity is consumed in different ways: mono-bloc air-conditioner consumes at full load 2.28 kW (alternative current) or at low load (fans by direct current) 10 A x 48 V, transceiver electronic equipments (including AC-DC inversion) operate on the interval 10-40 A x 48 V and batteries charging at 20 A x 48 V (including AC-DC inversion).

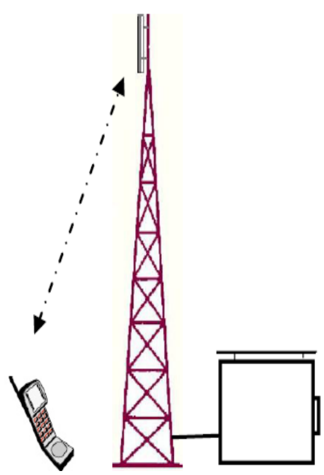

Fig.1: Base transceiver station.

B. *Shelter characteristics*

The shelter door side is oriented exactly toward the south. On the top, the roof is protected by a supplementary metallic plate which is separated from the roof by air strip 0.010 m thick. For pylon station, the shelter is installed on the ground by means of reinforced concrete slab. The details of shelter dimensions are presented on figure 2.

The sandwich shelter wall consists of polyurethane insulation layer (80 mm) in the middle and covered by two steel plates (5 mm). The wall is painted on both sides in clear coating (1 mm). The roof consists of inner steel plate (5 mm), polyurethane insulation (50 mm), exterior steel plate (5 mm) and the wall is painted on both sides with clear coating (1 mm). Each material is characterized by its thermal conduction coefficient (λ): steel plate (λ = 51.8 W/m.K), polyurethane insulation (λ = 0.032 W/m.K) and coating (λ = 0.032 W/m.K).

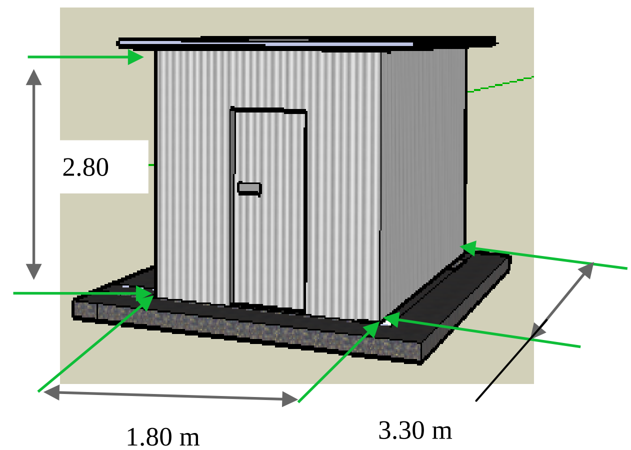

Fig. 2: Schematic of shelter

C. *Different types of stations*

Generally, in Algeria, BTS station used by mobile phone operators is characterized by its implantation mode and its power supply system [6]:

- Mode of implantation **:**
  - Pylon: the station is constructed on the ground.
  - Rooftop: the station is constructed on the Roof of building.
- Power supply system **:**
  - Electricity grid.
  - Diesel driven generator : for standalone station

In 2013, the statistics of Moblis phone operator concerning different BTS stations located in east-southern Algeria shows 953 stations. Pylon constructions present 65 %, among these pylons 33 % are supplied by diesel driven generator.

In order to simplify the classification, the different stations are renamed as follow: Pylon-grid as the station built on ground and powered by electricity grid and pylon-diesel for that supplied by diesel driven generator. Rooftop as the station built on building and powered by electricity grid.

D. *BTS repartition in the region*

The investigation is carried out on BTS stations situated within the following provinces: Ouargla, Biskra, Laghouat, Ghardaia, El-Oued, Illizi, Tamanrasset. Figure 3 shows Algeria and these seven provinces painted with yellow color. By treating the statistics in Arcgis software, figure 4 shows that the density of station (BTS per km^2) is high in the north.

That is due to population concentration factor, so, toward the south the density decrease and more stations are standalone.

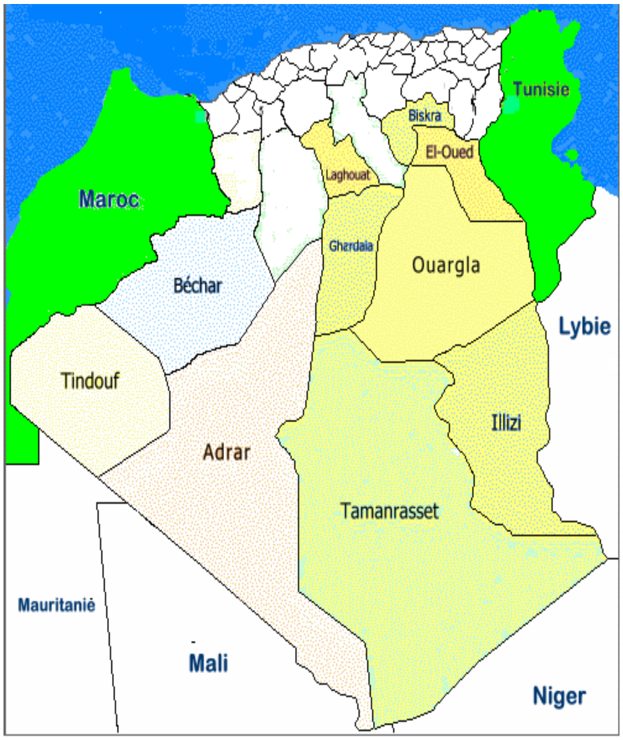

Fig. 3: Region of east-southern Algeria

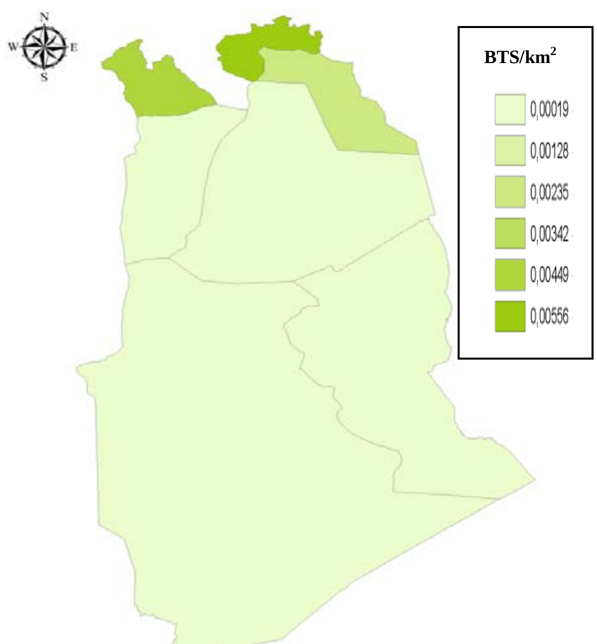

Fig. 4: BTS density in east-southern provinces

E. Energy consumption of stations

Figure 5 shows the statistical cost of energy consumption for the three types of stations. The energy consumption is low for pylon stations compared to rooftop stations because the latter are located in densely populated areas with high call loads and much cooling needs. In addition, pylon-diesel stations registry long time break down. In general, consumption is high because the cooling system operates throughout all the year and in particular during the summer, it takes more than 70% of energy consumption, so, it requires the search for new systems to reduce this load.

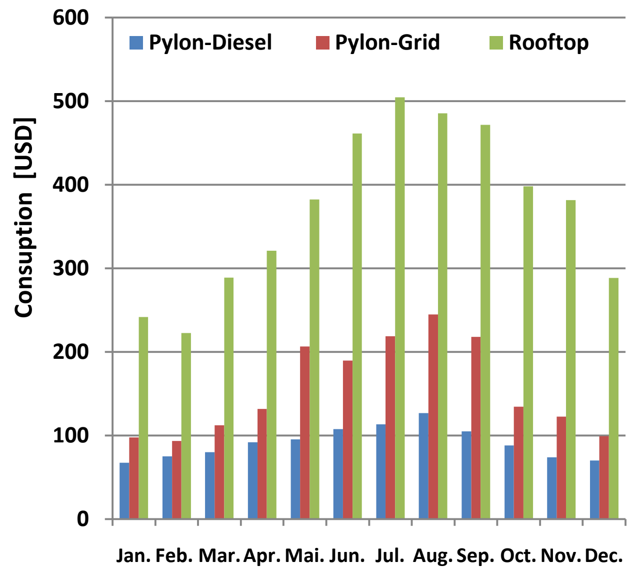

Fig. 5: Energy consumption by type of station

F. Shelter energy audit

Energy balance simulation is carried out using Trnsys 16 software. For validating the results, shelter without internal gain is used. Shelter indoor temperature is plotted during the day of June 30th 2013. Also, for the same day the indoor temperatures are measured using digital thermometer. Figure 6 shows a good agreement between simulation curve and experimental data.

Then, the shelter with internal gain and without cooling system is simulated; shelter indoor temperature curves along the year are obtained. The temperature data of lateral walls and zone show that the worst case occurs in the day of 21/07/2013. The high indoor temperature reaches 83 °C which is taken as boundary conditions on the lateral walls.

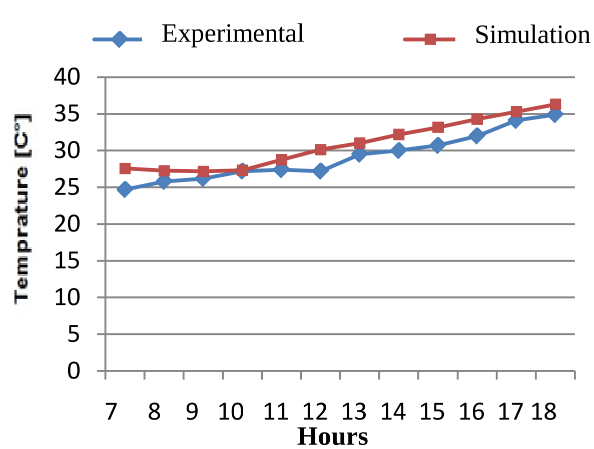

Fig. 6: Shelter indoor temperatures in the day 30/06/2013.

III. Alternative Power Systems

A. System description

The system consists of photovoltaic panels to provide the station during sunshine hours. At night and weak sunning periods, rooftop and pylon-grid stations are supplied by grid electricity, but, for standalone stations, dry batteries ensure the electricity supply. For pylon stations, the passive cooling system is consists of earth-air heat exchanger combined with slopped solar chimney connected on the shelter roof.

B. Passive cooling mode

Figure 7 shows the passive cooling system, it consists of an underground pipe situated at 1.5 m as minimal depth. A solar chimney connected to the shelter roof on the south side with latitude angle (31^{o}). In base case, the length of solar chimney is 1m with high equal to 0.35 m as adopted by Z. Akchiche [13].
During year's hot period, air with ambient temperature goes through underground pipe. The air is cooled by earth absorption effect. Furthermore, cold air goes into the shelter across its north side and push hot air toward shelter roof. By buoyancy effect, solar chimney accelerates hot air to escape out.

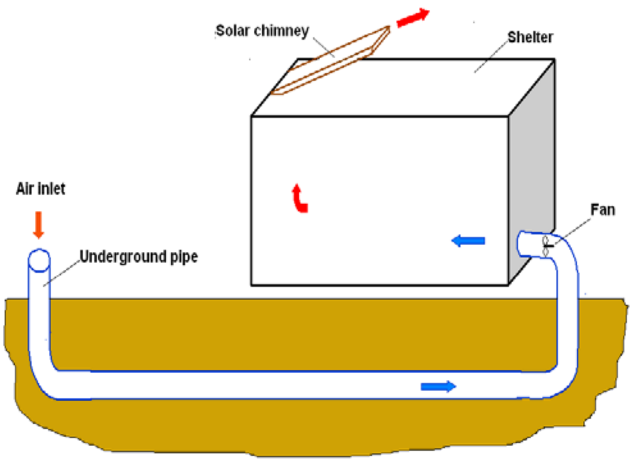

Fig. 7: Passive cooling system

C. Governing equation

Heat transfer and air flow are due to natural and forced convection together. In this work, laminar regime, Newtonian fluid and neglected viscous dissipation are considered. In bi-dimensional computational domain, the phenomenon is governed by the conservation equations expressed as follows [14]:

- Mass balance

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho U_i) = 0 \qquad (1)$$

- Momentum equation

$$\rho \frac{\partial U_j}{\partial t} + U_J \rho \frac{\partial U_j}{\partial x_i} = -\frac{\partial p}{\partial x_j} + \mu \left[\frac{\partial^2 U_j}{\partial x_i^2} \right] + \rho g \qquad (2)$$

- Energy equation

$$\frac{\partial T}{\partial t} + U_i \rho \frac{\partial T}{\partial x_i} = \frac{1}{\rho} \frac{\lambda}{c_p} \left[\frac{\partial^2 T}{\partial x_i^2} \right] \qquad (3)$$

With: ρ density (kg/m^3), μ cinematic viscosity (kg/m.s), c_p calorific capacity (J/$kg.K$), λ thermal conductivity J/m^2.
Natural convection effect is considered in the momentum equation by varying the density expressed according to thermodynamic reference state (density ρ_0 and temperature T_0) by the Boussinesq approximation as follows:

$$\rho = \rho_0 [1 - \beta (T - T_0)] \qquad (4)$$

With β is the isobaric expansion coefficient of the fluid:

$$\beta = -\frac{1}{\rho} + (\frac{\partial \rho}{\partial T})_{p=cst} \qquad (5)$$

In this work, the detailed of the flow inside the underground pipe isn't addressed, but it is limited to take only the pipe outlet flow data as shelter inlet condition. So, the values of velocity and temperature are chosen as shelter inlet boundary conditions. More details for EAHE model and dimensions optimization are given by G. Vlad et al. [15].

D. Numerical procedures

For the passive cooling system, the governing equations are solved by using CFD code (Fluent 6.3). For meshing the computational domain, GAMBIT software is used. Figure 8 shows meshes cover the shelter and the solar chimney. In order to improve the simulation, the meshes at shelter inlet, along solar chimney and at all borders proximity are refined. The shelter meshes consists of (240 × 225) and the chimney as (120 × 60). Drichlet boundary conditions are adopted for indoor walls and roof. But, at shelter bottom, internal gain of electronic devices is assumed as heat flux.
Coupling betweens velocity field and pressure is insured by the SIMPLE algorithm developed by P. Suhas [16]. For convergence, residual error is fixed at 10^{-6}.

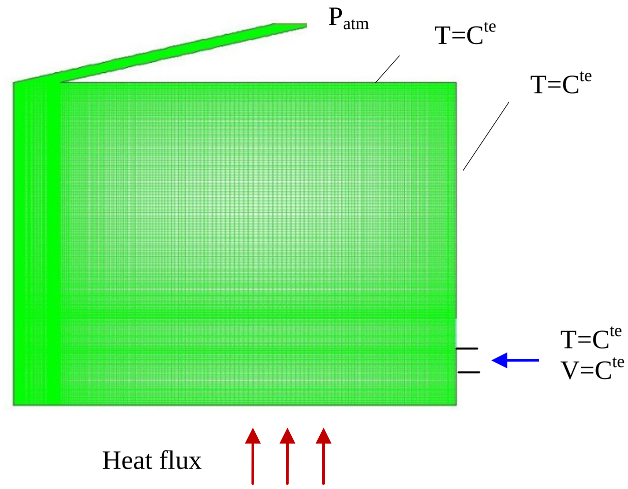

Fig. 8: Meshes in the computational domain

E. Effect of EAEH and solar chimney

Fluent software is used to plot shelter indoor temperature and velocity contours. Without EAHE, the initial indoor temperature remains high. By ventilating cold air from underground pipe, the temperature decreases progressively. Figure 9 shows that the temperature in the zone records a significant fall. Inlet flow temperature at 15°C and the variation of shelter opening high and inlet velocity improves the cooling. So, the effect of the flow rate increases by the simultaneous rise in the velocity (V) and the open space (OS) at shelter inlet. Until reaching V=0.1 m/s and OS=0.4 m, the obtained temperature in the middle of the shelter does not exceed 29 °C.

For dynamic field, figure 10 shows velocity contours, a clear increase is recorded on the velocity at the whole zone. It reaches a maximum value of 0.14 m/s in the shelter and 0.46 m/s in the chimney. So, the flow remains in laminar interval.

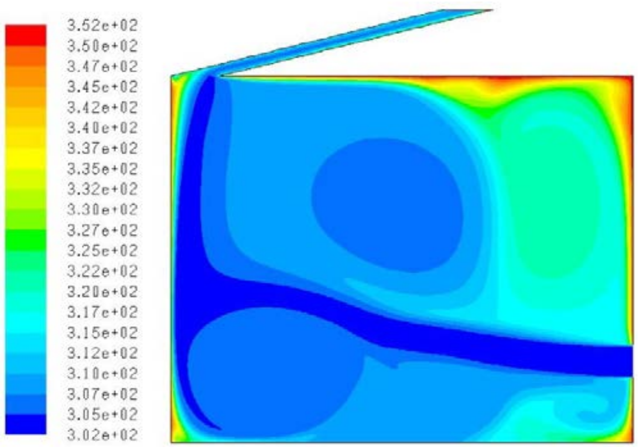

Fig. 9: Temperature contours for shelter with EAHE, V=0.1 m/s, OS=0.4 m

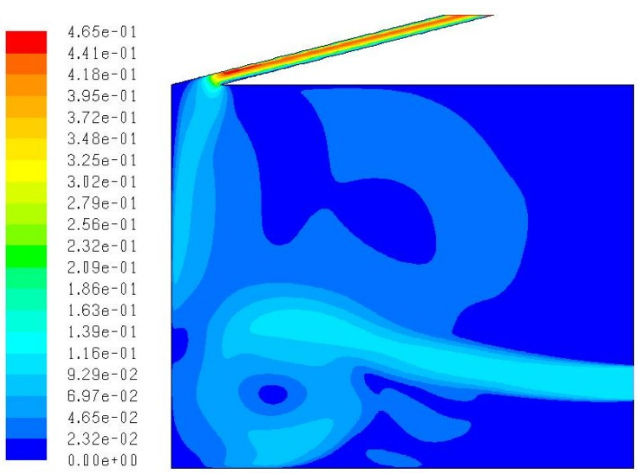

Fig. 10: Velocity contours for shelter with EAHE, V=0.1 m/s, OS=0.4 m

IV. Modes of Energy Consumption

A. First mode

For grid connected stations, we take the consumption billed by Sonelgaz (Algerian company of electricity and gas). But, for standalone stations, the calculation is based on the volume of diesel consumption (L) in liters and we get the energy consumption in kWh as follows:

$$E_{diesel}=PCI * L * \eta \qquad (6)$$

Where PCI is lower heating capacity (35 000 kJ/L) and η is diesel generator efficiency (20-25%) [2].

B. Second mode

Generally, energy consumption of electronic equipments and their cooling needs are determined according to time and charge level during the day. But, in order to simplify the estimation, the hypothesis that pylon-grid station has the half telephonic load of rooftop station and pylon-diesel station has the half telephonic load of pylon-grid station is considered.

For heat transfers through the walls and the roof, the degree-days method is used to estimate the energy consumption of air conditioning equipment. This case is limited to the shelter cooling, where the heat transfer across the outer wall per unit area is [17]:

$$q = U\,(T_b - T_e) \qquad (7)$$

Where U is global heat transfer coefficient, T_b is base temperature.

T_e is air-sol temperature which takes into account solar radiation effect on external ambient temperature. It is expressed as follow [18]:

$$T_e = T_0 + \frac{aI_T}{h_0} - \frac{\varepsilon\Delta R}{h_0} \qquad (8)$$

Where T_0 is outdoor ambient temperature, I_T and a denote total solar radiation and absorptivity of outdoor wall surface. The term $\varepsilon\Delta R/h_0$ is the correction factor, it is assumed at 4 °C for horizontal surfaces and 0 °C for vertical surfaces [18]. The coefficient h_0 presents the combined heat transfer of outdoor surface; generally, it is fixed at 17 W/m^2K. In summer period, for clear colors, the ratio (a/h_0) is equal to 0.026 m^2K/W [19].

The annual heat gain is expressed per surface unity by the relation [17]:

$$q_A = 24\, DD\, U \qquad (9)$$

Where DD presents degree-days values for the shelter cooling.

The annual energy need is determined by dividing the annual heat gain by system cooling efficiency (COP).

$$E_A = 24 * DD * U / COP \qquad (10)$$

The conductance U of the wall which contains an insulation layer is given by:

$$U = 1/(R_i + R_w + R_{ins} + R_e) \qquad (11)$$

Where R_i and R_o are respectively air thermal resistance inside and outside films, R_w is total material thermal resistance of the sandwich wall without insulation, and R_{ins} is thermal resistance of insulation layer, which is expressed by:

$$R_{ins} = x/\lambda \quad (12)$$

Where x and λ are the thickness and thermal conduction coefficient of the insulation material.
The base temperature is T_b = 25 ^{0}C which presents comfort temperature specified by the equipments manufacturer including the battery [14]. The cooling system efficiency is COP = 2.5. Then, calculating the energy densities and multiplying the result by the wall surfaces, the electricity needs for cooling the empty shelter is obtained.

In addition, the ratio of released heat from electronic equipments is specified by Huawei manufacturer [20]. We note that specific energy consumption of electronic equipments and their released heat E_B are determined according to time and charge level during the day. Operating details are given in reference B. Dokkar et al. [6]. The corresponding instantaneous cooling power for equipments is expressed by the following equation:

$$E_{CB} = \frac{E_B}{COP} \quad (13)$$

C. *Third mode*

In this mode, it is assumed that rooftop stations can operate with one split air conditioner of 18000 Btu during the winter and with two split air conditioners of 18000 Btu each one during the summer. But, pylon stations are cooled by passive system and only the exhaust fan consumes energy (5 A x 12 V) and works continuously throughout the year. Noting that with the passive system a minimum temperature of 29 °C is reached, so, it requires the use of batteries that can withstand this temperature. The specific consumption of electronic equipment is taken as the previous mode.

D. *Results and discussions*

Figure 11 shows that the first mode has the highest consumption that is caused by the use of mono-bloc air conditioner which is considered very oversized for cooling the shelter. But, the second mode shows that the cooling with split air conditioners is very undersized especially during the summer. For against, the second mode gives more accurate energy needs results.

In figure 12, the same previous remarks for the first mode are noted, and despite the use of split air conditioners with lower power, the second mode remains relatively high. But, the use of passive cooling gives a good appreciation in the third mode.

Figure 13 shows that the first mode is the worst one, it is generally caused by high diesel consumption which is due to additional electricity supplied to the room of the guardian for isolate stations. For the second mode, the curve is significantly higher during the summer period by the fact that a high consumption of active cooling. So, the third mode is the most favorable to rationalize energy consumption.

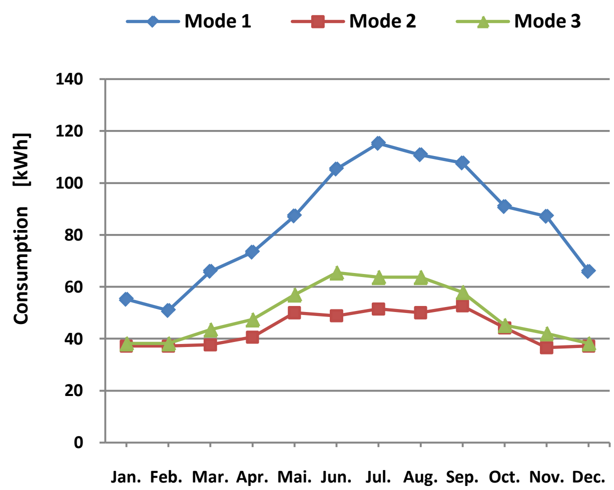

Fig. 11: Consumption of rooftop station

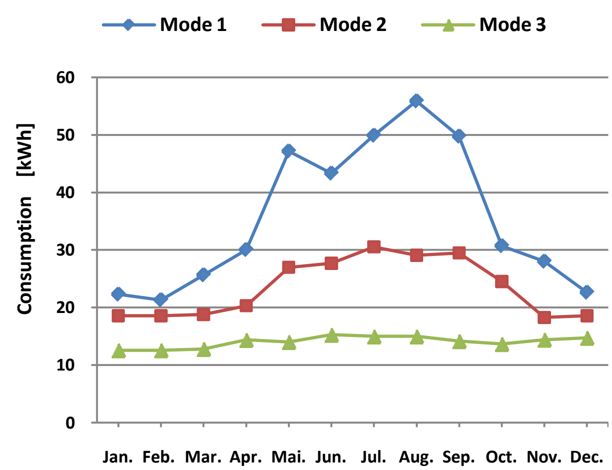

Fig. 12: Consumption of pylon-grid station

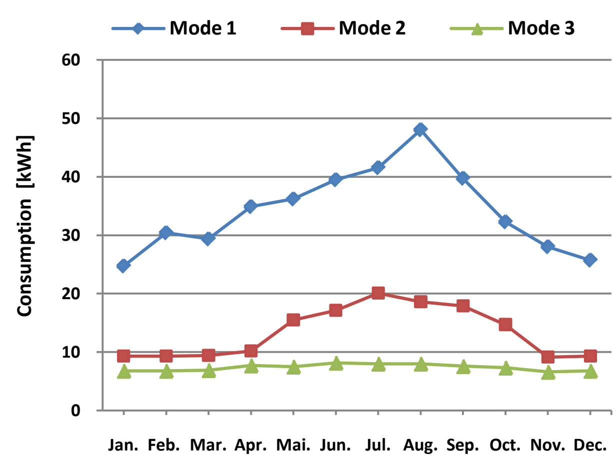

Fig. 13: Consumption of pylon-diesel station

V. ECONOMIC ANALYSES

A. Peak power and number of modules

By knowing the optimal daily incident radiation on PV modules surfaces, the generator peak power P_{cc} is expressed as follows [6]:

$$P_{cc} = \frac{G}{F_m[1-\gamma(Tmoy-Tr)]\,\overline{H}_{cp}(\beta)} \cdot \frac{E_m}{\eta_{ond}} \quad (14)$$

G: Standard solar radiation (1000 W/m²).
$\overline{H}_{cp}(\beta)$: Daily solar radiation on modules surface at titled angle β [Wh/m^2]
F_m: Connecting factor, generally we use MPPT with factor equal to 0.9.
γ: Cells temperature coefficient (between 0,004 and 0,005 /°C for silicon modules).
T_{moy} : Average temperature during sunshine, T_r: Reference temperature (25 °C).
η_{ond} : Inverter efficiency for only alternative current equipments (we take η_{ond}= 0.95).
E_m: Electrity needs for operating equipments.

The number of modules N_m is calculated by the following relation:

$$N_m = \frac{P_{cc}}{P_{cm}} \quad (15)$$

Where: P_{cm} is the PV module pick power (we choose P_{cm}=200 W).

We calculate the number of modules for each month, and for the operating along the year we take the maximum number

B. Capacity and number of Batteries

For standalone station, the batteries storage capacity C_{acc} [Ah] varies according to night load E_M [Wh]. It is expressed by the following relation [21]:

$$C_{acc} = \frac{E_M * Aut}{V_{acc} * \eta_{acc} * DM} \quad (16)$$

V_{acc}: Battery nominal potential, we choose 12 V.
DM: Batteries discharge ratio, between 20-80 %.
η_{acc}: Battery efficiency, in practice is considered as constant (85%).
Aut: Station autonomy days (taken equal to 1 day).
The number of battery N_{bat} is calculated by the following equation [21]:

$$N_{bat} = \frac{C_{acc}}{C_{bat}} \quad (17)$$

C_{bat}: Battery storage capacity, we choose 100 Ah.

From the results, we get the maximum number of batteries to ensure the operating during the year.

C. Cost of PV systems

Noting, for all economic analysis, the costs are given in Algerian Dinar (1 \$= 100 DZD) and the year 2015 is considered as a reference of estimation starting. For PV prices, the Algerian Company "Condor" proposes the unit price (without taxes) of 200 W solar modules at 19000 DZD (190 \$), with warranty of 25 years [22]. Considering assembly and installation costs, the price of PV module is set to 230 \$. So, the PV panel costs by station type are as follows:

Cost of PV panels = unit price *modules quantity * stations number

For rooftop stations, inverter price index is based on a measure of inverters output power which reaches \$ 0.711 per continuous watt [23], and adding others fees (customs, transport) at 40%. The inverters have an average of 10 years as lifetime, so, for an operating period of 25 years, 25/2.5 of inverters costs are progressively added. The inverters will be:

Cost of inverters = Price index * Output power *(140%)* stations number

For standalone stations, the commonly used batteries have an average price index at \$ 0.215/watt hour [23], and adding others fees (customs, transport) at 40%. Dry batteries have an average of 5 years as lifetime. So, for an operating period of 25 years, 25/5 of batteries costs are progressively added. The batteries cost by type of station will be:

Cost of batteries = (Price index) * (required energy [W.h])*(140%) * stations number

Additional costs (wiring, fuses, switches, controllers, maintenance) are added progressively. These costs are estimated at (1000 \$), so, the additional costs by type of station will be:

Additional costs = (1000 \$) *stations number

D. Cost of solar chimney and EAHE

From the industry of structural steel buildings, the solar chimney cost is estimated. This cost with maintenance fees is about 90 \$. For both types of pylons stations, the cost of solar chimney will be:

Cost of solar chimneys = (90 \$) * stations number.

The cost of installing Earth-air heat exchanger including the costs of pipe, ventilator, construction works and maintenance are estimated at 250 \$. So the cost of the investment for the two types of pylons stations is estimated as follows:

Cost of the Earth-air heat exchanger = (250 \$) * stations number

E. Investment payback

In Figure 14 and 15, for both approaches, the cost of grid connection is not taken into account. The evaluation of trend model is based on the cumulative of annual electricity consumption from the grid. While voluntary model takes into account electricity grid supply during the night and the initial cost of renewable energy systems, then, maintenance fees of these systems are gradually added. Obtained results show that Investment paybacks reach 7 years for rooftop stations and 6 years for pylon-grid.

In Figure 16, the trend model is based on the initial cost of diesel generator, cumulative average of annual fuel consumption and maintenance fees of diesel generator. For voluntary model, it is evaluated by including the initial cost of PV system, batteries, solar chimney and the Earth-air heat exchanger. Then, maintenance fees of this system are gradually added. Obtained results show that investment payback is 05 years for pylon-diesel stations.

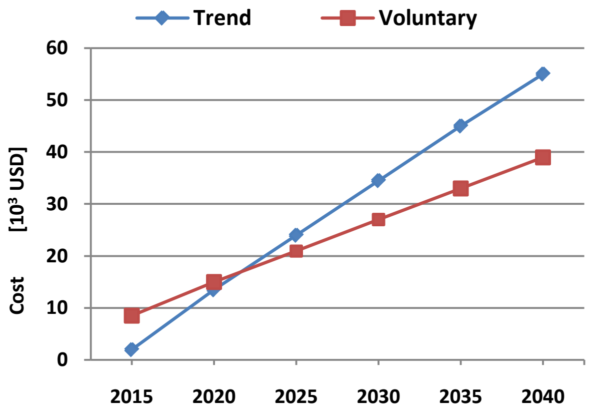

Fig. 14: Costs for rooftop BTS

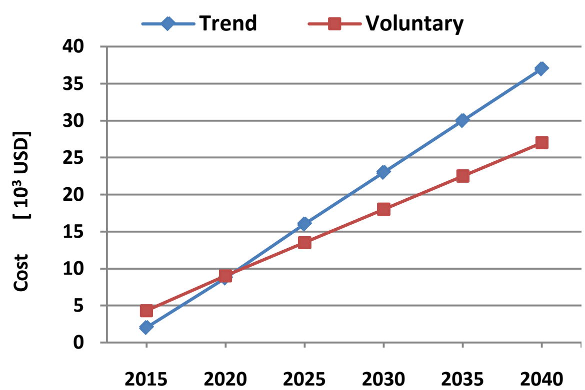

Fig. 15: Costs for pylon-grid BTS

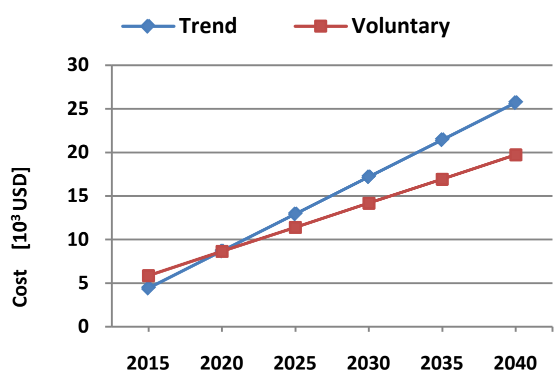

Fig. 16: Costs for pylon-diesel BTS

VI. Conclusion

The passive cooling system (solar chimney and EAHE) is viable and reliable for shelters installed in Algerian desert. It requires less power; therefore it is highly efficient system for remote areas where there isn't electricity grid. Particularly, its application on pylon-diesel stations removes some difficult problems such as fuel logistics and maintenance of diesel generator. In addition, it is low cost cooling system and eco-friendly, the temperature in the middle of the shelter does not exceed 29 °C. So, it is possible to design shelters without conventional air conditioning.

The passive cooling system is simple, but unfortunately, it can't be applied on rooftop stations. While its application on two types of pylon stations, particularly during the hot period helps to reduce energy consumption at about 70%.

The rationalization of energy consumption is translated by an economic and prospective study which shows that conventional supply (grid and diesel generator) causes a large financial charge in medium and long term. But, for the supply based largely on the use of renewable energies causes a significant drop in energy bills. Thus, the financial gain on consumption can be deployed on the extension of the phone network and it contributes in increasing company competitiveness. In addition, the payback for the installation of renewable systems is relatively low for all stations, mainly, for the pylon-diesel station it reaches only 05 years..

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