Solar mixed thermal and photovoltaic installation for an infantile educational-sanitary lodging in Senkata-El Alto (BOLIVIA)

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Abstract.

The paper describes an international cooperation project for depressed zones. The aim of the project is to supply electricity and hot water in a refuge for around 150 children in El Alto (Bolivia) with solar energy.

Key words

Photovoltaic energy. Thermal energy. International cooperation.

1. Introduction

It is a fact that much of the world's population doesn't have access to basic services like electricity or hot water. In this case renewable energies are a real alternative to conventional energies, an also the possibility of overcoming the obstacles of this kind of energies.

The performed project is an actuation on a refuge which gives service to 150 children of the lodging and their familiar environment that approaches 1000 persons. Parallel there has been carried out an occupational workshop of renewable energies for the teen population.

Fig. 1 – The lodging

The refuge is placed in El Alto place (Bolivia). The actuation place is Senkata's neighborhood, placed to 4200 m of height, to 30 kilometers of La Paz and with one of the climates more end of the planet. This lodging does not have any covers of their basic needs for the daily life. The development of this project is based in achieving a supply of electric power, since the infrastructures of electrical networks in the zone are very precarious and to realize a contribution of warm sanitary water to improve the hygienic - sanitary conditions of the population of the zone. For this motive we have carried out a study of the solar radiation of the zone with the aim to install a photovoltaic and thermal system to correct the above mentioned lacks. Bolivia has a high solar radiation as well as a large number of sunshine hours per day due to climatic and geographical conditions. These factors made of this zone a suitable place for a photovoltaic and thermal installation.

The project has been developed in the frame of international cooperation and includes local government (Dirección Xeral de Cooperación da Xunta de Galizia[1]), university (Universidade de Santiago de Compostela[2]) and diverse companies of the sector. Likewise there constitutes a pioneering experience realized by students of the Master in Renewable Energies[3] as post-graduation project.

2. Design of the installation

A) Preliminary study.

For the proper design of the facility is necessary a study of the location. It is also necessary to study climatology and consumption of energy in the building.

1) Location

The lodging is situated en El Alto, close to La Paz in Bolivia. Its geographic data are as follows:

TABLE I. – Geographical data

Longitude	68º 12' W
Latitude	16º 30' S
Altitude	4000 m

2) Climatologically data

For the development of the project we use as climatologically data "daily global horizontal irradiation" and "temperature". These data were obtained from the NASA[4].

TABLE II. – Climatologically data

MONTH	Daily global horizontal irradiation (Kwh/m2)	Temperature (ºC)
January	6,2	10,5
February	6,3	10,1
March	6,0	9,74
April	5,8	8,61
May	5,5	7,08
June	5,2	5,97
July	5,3	5,72
August	5,7	7,18
September	6,5	8,58
October	6,8	10
November	7,1	10,7
December	6,8	10,7
Annual	6,1	

3) Consumption of the building.

For the study of energy consumption of the building is necessary to distinguish between electricity consumption and the consumption of hot water.

TABLE III. – Electric consumption of the building

Element	Number of elements	Power (W)	Daily use(hours)	Wh/day
Bulbs	40	18	2	1440
PC's	3	210	6	3780
Fridge	2	600	6	7200
TV DVD	1	75	0,15	11,25
Heat pump	1	60	12	720
Extractor hood	1	200	0,2	40
Others	1	300	1	300
Standby	1	2	24	48
TOTAL				13539,25

To calculate the consumption of hot water in the building we assumed the use of about 40 showers a day, with about 20 liters per shower.

It is also necessary to estimate a percentage of monthly occupation. In January the building is practically inoperative due to the period of holidays. It is also important the temperature of the water for each month

TABLE IV. – Hot water consumption

MONTH	% OCUPATION	MONTHLY COMSUMPTION (m3)	WATER TEMPERATURE (ºC)
January	10	2	10
February	100	22	10
March	100	25	10
April	100	24	6
May	100	25	6
June	100	24	6
July	100	25	6
August	100	25	6
September	100	24	6
October	100	25	10
November	100	24	10
December	75	19	10

B. Design of installation

Whatever installation you have got, the first step is to know what inclination is the optimum for the panels. Reading the technical conditions article of IDAE[5], the optimum inclination to be sure that annual needs are supplied, is given by latitude minus 10º, so the chosen inclination will be around 6º.

Now it should be planning both installations separately.

1) Photovoltaic installation.

To do this design, we will follow a method written in the technical conditions article of IDAE.

Firstly, calculate the lighting factor *FI*:

$$FI = 1 - \left[1,2 \bullet 10^{-4} \bullet \left(\beta - \beta_{opt} \right)^2 + 3,5 \bullet 10^{-5} \alpha^2 \right] \quad \text{to } 15º < \beta < 90º \quad (1)$$

$$FI = 1 - \left[1,2 \bullet 10^{-4} \bullet \left(\beta - \beta_{opt} \right)^2 \right] \quad \text{to } \beta \leq 15º$$

Where β is the real inclination of panel, β_{opt} is the optimum inclination, and α is the azimuth of panel.

Secondly, it should be calculated the shadow factor. To get it, it´s necessary a pattern of shadows with a right table. However, there aren´t any shadow in the place where the panels will be located. So, by this way the value of the shadow factor is 1.

The next step is to get a correction for the level inclination of horizontal irradiation. It is needed the "correction factor by inclination", K. In this case, the inclination has got a negligible number, so K is equal to 1.

Finally, the irradiation that panels will get is shown by:

$$G_{dm}(\alpha,\beta) = G_{dm}(0) \cdot K \cdot FI \cdot FS \qquad (2)$$

Where $G_{dm}(0)$ is horizontal global irradiation y $G_{dm}(\alpha,\beta)$ is corrected global irradiation.

In this table, results are shown:

TABLE IV. – Corrected diary Irradiation.

MONTH	DIARY HORIZONTAL IRRADIATION (Kwh/m^2)	K	DIARY CORRECTED INCLINATED IRRADIATION (Kwh/m^2)
January	6,2	0,93	5,79
February	6,3	0,97	6,05
March	6,0	1,02	6,10
April	5,8	1,1	6,33
May	5,5	1,18	6,53
June	5,2	1,23	6,39
July	5,3	1,21	6,37
August	5,7	1,14	6,48
September	6,5	1,06	6,86
October	6,8	0,99	6,72
November	7,1	0,93	6,59
December	6,8	0,91	6,16
ANUAL	6,09		6,36

The next math expression allows calculate the minimum power to install:

$$P_{mp} = \frac{E_D \cdot G_{CEM}}{G_{dm}(\alpha,\beta) \cdot PR} \qquad (3)$$

Where:

G_{CEM}=1kW/m^2
E_D in kWh/day
PR is performance ratio, which bear in mind energy loss that happen in installation owing to different systems. So its value is PR≈0,7 for a isolated system with electronic inverter; and PR≈0,6 for isolated system with electronic inverter+battery (our case).

Having all this, our minimum power to install will be 3,54 kW.

We chose panels with a peak power of 175Wp. By this way, we should install 20 panels and this implies 3500 Wp.

To make the sizing of accumulation system we have to consider the place has got a high radiation levels that means 1,5 days of autonomy should be enough. We use the following expression to get the size of accumulation system:

$$C = \frac{A \cdot L_D}{PD_{max} \cdot \eta_{inv} \cdot \eta_{rb}} \qquad (4)$$

Where:

-C: nominal capacity of accumulator in Ah
-A: autonomy of system in days, 1,5 days.
-PD_{max}: Maximum depth of discharge, 0,7.
-μ_{inv}: yield of electronic inverter 0,85.
-μ_{rb}: energy yield of system 0,81. Accumalator+regulator
-L_D: daily average requirement of load in Ah, 282,07Ah.

We need a capacity of 877Ah. We decided to make an oversizing of accumulation system to make up for the loss of load by time. Chosen batteries have got a capacity of 150 Ah for a working voltage of 12V. The used matrix was this:
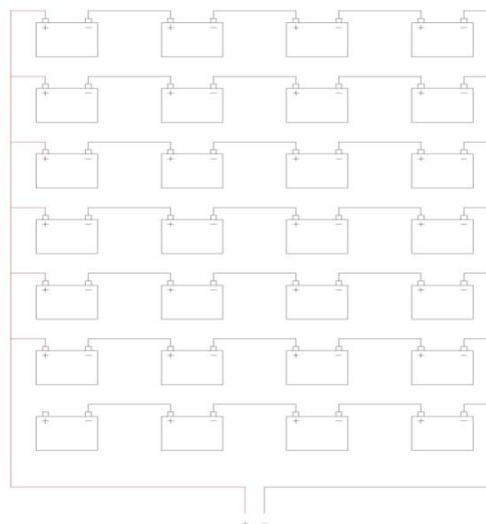

Fig. 2. Accumulation Matrix.

So, our accumulation system is characterized by 1050Ah and 48V.

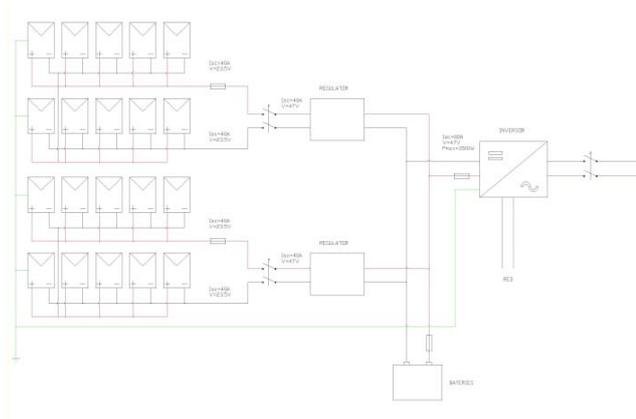Following it is showed the used diagram of installation:

Fig. 3. Photovoltaic diagram.

As we can see in the diagram, we use two regulators and only one electric inverter.

To make the sizing of the wiring we use the next expression:

$$S = \frac{\rho_{Cu} \bullet 200 \bullet L \bullet P}{\%_e \bullet V^2} \qquad (5)$$

Where:

ρ_{Cu}= Copper conductivity, ρ_{Cu}=0,017Ωmm^2/m
L= Wire length (m)
P= Maximum power for the wire (W)
$\%_e$= Allowed Percentage of voltage drop in wire:
   $\%_e$=1,5 direct current
   $\%_e$=0,5 alternating current
V=Working voltage (V)

2) Thermal Installation.

The first step in the design of the installation is the sizing of thermal collection system. To do this we use the f-Chart method, which is based on the calculation of the number *f*, which is the ratio of useful energy captured and the heating load each month, and can be calculated as follows:

$$f = 1{,}029 D_1 - 0{,}065 D_2 - 0{,}245 D_1^2 + 0{,}0018 D_2^2 + 0{,}0215 D_1^3 \quad (6)$$

For this, we must follow these steps:

-Heating load study for warm water. This gives us the quantity of heat necessary each month:

$$Q_a = C_e C N \left(t_{ac} - t_r \right) \qquad (7)$$

Where:

Q_a=Monthly heating load for warm water (J/month)
C_e=Specific heat. For water 4187 J/(kg°C)
C= Daily hot water consumption (l/day)
t_{ac}=Temperature of hot water accumulation (°C)

t_r=Water temperature of the net (°C)
N=Number of days per month

-Calculation of the parameter D1. This parameter indicates the relationship between energy absorbed by the panel and the total monthly load:

D_1=Absorbed energy by the panel/Monthly thermal load

The energy absorbed by the panel is given by:

$$E_a = S_C F_r^{'}(\tau\alpha) R_1 N \qquad (8)$$

Where:

S_C=Capture surface (m^2)
R_1= Monthly average daily radiation incident on the surface of catchment area per unit of area (kJ/m^2)
N=Number of days per month
$F_r^{'}(\tau\alpha)$= Adimensional factor given by:

$$F_r^{'}(\tau\alpha) = F_r(\tau\alpha)_n \left[(\tau\alpha)/(\tau\alpha)_n \right] \left(F_r^{'} / F_r \right) \quad (9)$$

Where:

$F_r(\tau\alpha)_n$=Optical efficiency factor of the panel
$(\tau\alpha)/(\tau\alpha)_n$=Angle of incidence modificator. It usually takes as a constant: 0,96 (simple transparent surface) o 0,94 (double transparent surface).
F'_r/F_r= Correction factor of the entire panel-heat exchanger. It is advisable a value 0,95.

-Calculation of the parameter D_2. This parameter indicates the relationship between the loss of energy in the panel and the monthly load.

D_2= Energy lost by the collector / monthly heat load

Energy lost by the collector is calculated as follows:

$$E_p = S_c \bullet F_r^{'} U_L \bullet \left(100 - t_a \right) \bullet \Delta t \bullet K_1 \bullet K_2 \qquad (10)$$

Where:

S_c=Collector surface.
$F'_r U_L$=$F_r U_L (F'_r / F_r)$

Where:

$F_r U_L$=Overall loss coefficient of the collector.
t_a= Monthly average temperature of the environment
Δt= Period of time considered in seconds.
K_1= Correction factor for storage, is calculated as:

$$K_1 = \left[\text{kg accumulation}/(75 S_c) \right]^{-0{,}25} \qquad (11)$$

$37{,}5 < (\text{kg accumulation}) / (\text{m}^2 \text{ collector}) < 300$

K_2=Correction factor, it relates minimum temperature of hot water, net water and monthly average of the environment as follows:

$$K_2 = 11,6 + 1,18t_{ac} + 3,86t_r - 2,32t_a / (100 - t_a) \quad (12)$$

Where:

      t_{ac}=Minimum temperature of hot water
      t_r=Temperature of net water
      t_a=Monthly average temperature of environment

With this method, we estimate the number *f* for each month. We will vary the number of panels to find the minimum number of panels that gives us greater annual coverage. We must consider, for security reasons, do not reach f ≥ 1 in more than three consecutive months. For our installation, this is achieved using 6 collectors and a volume of 1000 liters of accumulation.

TABLE VI. – Factor *f*

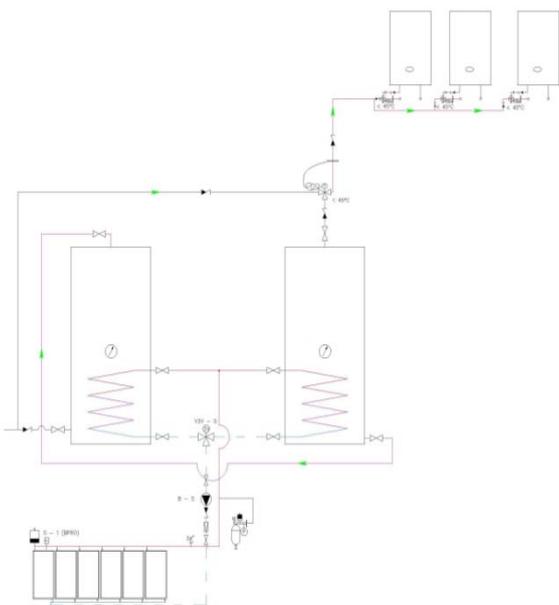| MONTH	f
January	1,0000
February	0,8594
March	0,8736
April	0,8631
May	0,8828
June	0,8636
July	0,8638
August	0,8779
September	0,9157
October	0,9378
November	0,9235
December	1,0000

The chosen scheme is as follows:

Fig. 4. Thermal Scheme.

For dimensioning the size of the pipe, we assumed a length for the primary installation of 24 meters. Since the loss of load must be less than 40 mm ca per meter of pipe, through appropriate abacus, we get a diameter of 22mm.
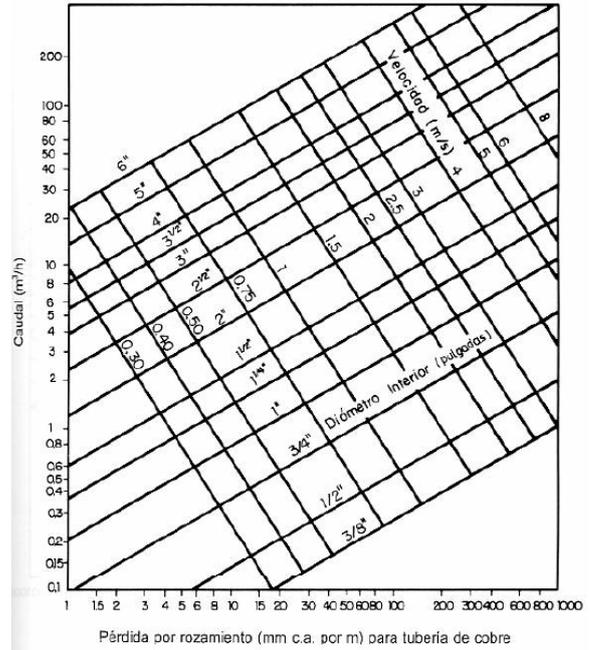

Fig. 5. Abacus for the calculation of the load loss for cooper pipe

We must also install an appropriate expansion tank. To do this we use the following calculations:

$$V_t = V \cdot C_e \cdot C_p \quad (13)$$

Where:

      V_t=Total volume of expansion tank (l)
      V=Total volume of working fluid in the circuit (l)
      C_e=Expansion coefficient of the fluid. In a mixing water+antifreeze, its value is C_e=0,07
      C_p=Pressure coefficient. It is given by:

$$C_p = \frac{P_{max} + 1}{P_{max} - P_{min}} \quad (14)$$

Where:

      P_{max}=Maximum pressure of operation admissible in the expansion tank (bar). It is calculated as follows:

$$P_{max} = P_{VS} - 0,3bar \quad (15)$$

      P_{min}=Minimum pressure of the expansion (bar).

$$P_{min} = 0,5bar + P_{est} \quad (16)$$

Where:

P_{est}=Static Pressure.

$$P_{est} = h(m) \cdot 0,1 bar / m \qquad (17)$$

 Finally, we decided to oversize the expansion tank for security and because in December and January (summer months) the center has a low occupancy, and this can produce an overheating of the installation. In figure 4 the expected results are shown.
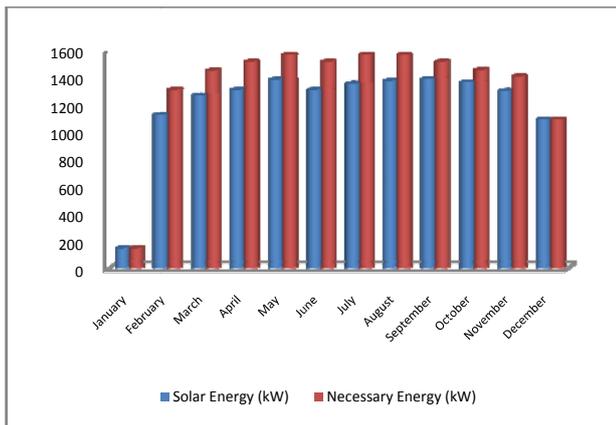

Fig. 6. Expected results in energetic saving.

3. Conclusion

The presented project allowed to supply a center for disadvantaged children with warm water and led to a reduction in electricity consumption. The cost savings that this involves, will allow the center an improvement in the budget of the institution in which teaching materials are concerned.

This project constitutes an example that how renewable energies are an alternative to conventional energy in areas to which these can hardly arrive to. While the price of such facilities may be too high for these areas, international collaborative projects involve a good way to overcome these obstacles.

The project has been executed by the authors as final Project for the Master in Renewable Energies and will be protocolized for futures actuations.

References

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