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THEORETICAL BEHAVIOR OF A SMART SOLAR KIOSK FOR STUDENT USE

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Abstract: In the following work, the sizing of a solar kiosk and the theoretical analysis of the energy behavior under the ambient temperature conditions of San Francisco de Campeche in the summer season and outside of summer at different irradiance values are carried out. The purpose is to determine if, despite the losses, the energy needs of the students are met. The power losses were estimated through the temperature increase of the module using two models proposed in the literature, that of Mattei et al. and the Markvart in conjunction with the maximum power temperature coefficient of the module. The temperature data used corresponds to an interval of 30 °C to 40 °C of the average maximum average temperatures of the period 2015-2018 predominant in the entity. The proposed arrangement consists of energy storage via a battery, as well as the remaining components for grid-independent use. The results show that the loss of power and energy in the arrangement for both seasons is insignificant and the energy needs are satisfied with the proposed design, so it is concluded that it is viable to make the investment.
Keywords: storage, solar, kiosk, temperature and autonomous.

INTRODUCTION

As part of the students' activities, in Higher Education Institutions, electrical installations are used for academic and recreational purposes, mainly with the use of cellular devices, tablets and laptops. This can represent a significant consumption of energy for miscellaneous equipment, since on average the institutions of the State of Campeche have increased their enrollment from 28,388 in 2020 to 29,520 in 2023 (INEGI, 2023) and each student uses an average of 6 hours on their mobile or other similar devices (Gutiérrez-Rentería, Santana-Villegas, & Pérez-Ayala, 2017).

The case of the Faculty of Engineering of the Autonomous University of Campeche does not go unnoticed, since it is common for students to keep their devices connected and thus increase electricity billing costs.

Given this, the sizing of a kiosk model that uses solar energy through modules and that has the required elements so that students can charge their devices while carrying out their activities is proposed. Furthermore, it is necessary to estimate the energy generation in real conditions with a warm subhumid climate and thereby define whether the installation is appropriate.

It is intended that once the resources are authorized, they will be installed in the common areas of the faculty and allow the storage of energy for use during hours of low or no radiation.

In the operational part, the results show that, despite the losses, the arrangement supplies the necessary energy to satisfy energy uses; while, according to the survey carried out, the lack of spaces for academic or recreational activities is evident, which is why it is concluded that it is viable to make the investment.

ENERGY USES

Through a survey, the uses of energy in lighting were classified, considering a 20 W LED lamp and 1500 lumens/m2 and miscellaneous, which includes a contact, two laptops and a modem, for a total of 175 W. The hours The average usage time is 4 to 6 hours/ day and only the modem has a time of 8 hours/ day. As shown in graph 1, Significant Energy Use is due to the operation of miscellaneous equipment.

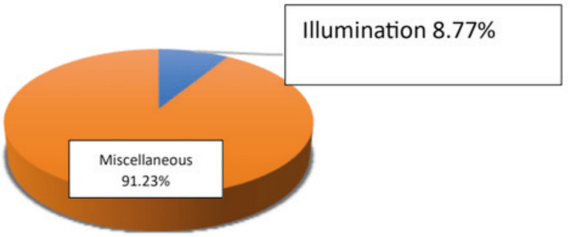

Figure 2.1: Estimated energy uses for the smart kiosk (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

SIZING

In the case of an autonomous photovoltaic system, the starting point is an analysis of the electrical equipment that will make up the kiosk, as shown in table 3.1.

Equipment	Power W	Wh/day
Luminary	20	100
Laptop	60	360
Contact	80	320
Modem	15	120
Total	175	900

Table 3.1: Proposed equipment for the kiosk (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

The energy storage equipment, whose capacity is determined by equation 3.1:

$$Ah_{bank} = \frac{Required\ energy}{Bank\ Voltage\ (\%DOD)} \tag{3.1}$$

The energy required refers to 900 Wh/day, the bank voltage will be 12 V, and a recommended depth of discharge (DoD) of 50% (DGS, 2008). So the capacity is 150 Ah.

In this case, an AGM battery is proposed because it is maintenance-free.

Considering that the total power of the system increases suddenly due to the connection of other elements by the students, the capacity of the inverter is determined to a margin of 80%, using equation 3.2.

$$Ability = \frac{175}{0.8} = 218\ W \tag{3.2}$$

Commercially, a 250 W at 12 V inverter is required, with a minimum input voltage of 10.5 V. The type of wave will be modified sine wave due to the capacity and type of equipment to be powered.

Regarding photovoltaic power, the required energy must be satisfied and the array losses must be considered by oversizing the system by 30%, as seen in equation 3.3:

$$P_{FV} = \frac{(900\frac{Wh}{dia})\ (1.3)}{5.2\ HSP} = 225\ Wp \tag{3.3}$$

Using modules of 36 cells at 150 Wp, results in an arrangement of 2 modules connected in series, whose electrical characteristics are shown in table 3.2:

Peak power	300 Wp
LID	3%
Maximum power voltage	36.8 V
Maximum power current	8.1 A
Open circuit voltage	45.0 V
open circuit current	8.7 A
Temperature coefficient	-0.31 %/°C

Table 3.2: Electrical parameters of the arrangement (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

The proposed controller is an mppt model, which must satisfy the following characteristics:

- Support a power of 300 Wp
- Support a charging current of up to 25 A
- Withstand an open circuit voltage of 45 V.

Figure 3.2: shows the general sizing diagram and the designed prototype.

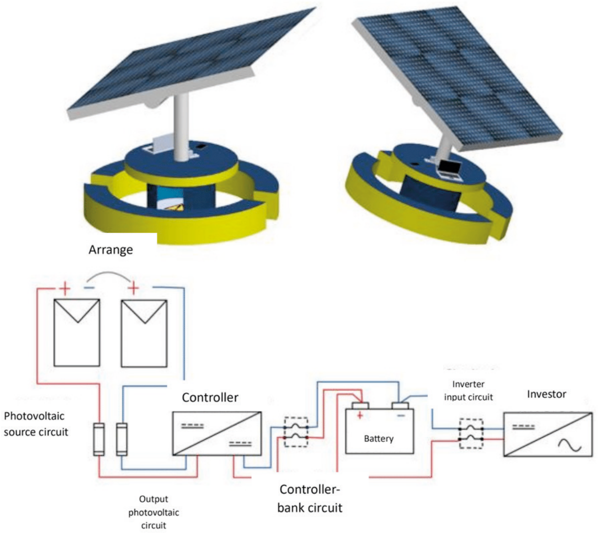

Figura 3.2: Solar kiosk proposal to implement (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

ENVIRONMENTAL OPERATING CONDITIONS

The predominant average temperatures in San Francisco de Campeche are variable for the summer season and outside of summer, but they are located in the intervals indicated in table 4.1.

Summer season	≥35 °C T_{half} <40 °C
Non-summer season	≥30 °C T_{half}<35 °C

Table 4.1: Prevailing temperatures (Own elaboration with CONAGUA open data)

The data was obtained through an analysis of the period 2015-2020 and is summarized in figures 4.1 and 4.2. For each month, the presence of the corresponding temperature interval is shown as a percentage.

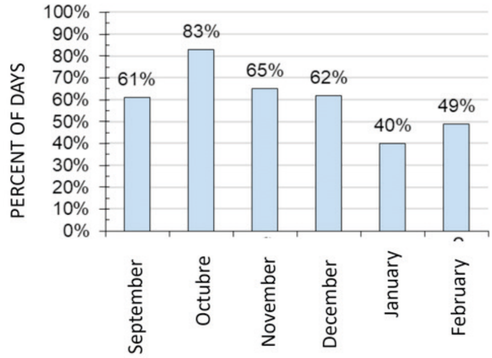

Figure 4.1: Percentage of days/month with temperatures ≥ 30 °C and < 35 °C (Tec Acevedo, Huchin Miss, Demesa López, & Ovando Sierra, 2021)

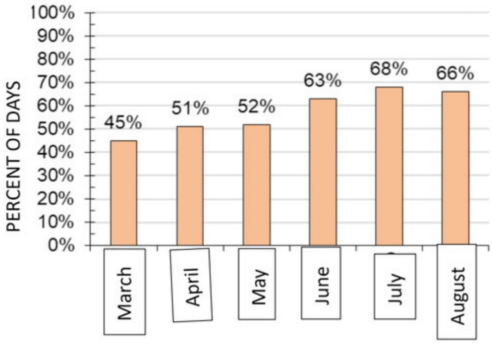

Figure 4.2: Percentage of days/month with temperatures ≥ 35 °C and < 40 °C (Tec Acevedo, Huchin Miss, Demesa López, & Ovando Sierra, 2021)

ENERGY BEHAVIOR

The average temperatures reached at the site will affect the power and energy generated by the array, when they exceed 25 °C, so that losses may be up to 0.4-0.5%/°C (Goetzberger & U.Hoffmann, 2005) may cause the proposed arrangement to not satisfy the energy requirements.

The evaluation of losses consider two theoretical models used in the literature. The first Standard model, called the nominal operating temperature of the cell, does not consider the wind speed, but takes into account the ambient temperature and the incident irradiance in the plane of the module (Markvart, 2000) as shown in equation 5.1.

$$T_c = T_a + \frac{I}{I_{NOCT}}\left(T_{NOCT} - T_{a,NOCT}\right) \quad (5.1)$$

Where:

T_a = Room temperature

I = Incident irradiance

I_{NOCT} = 800 W/m^2

T_{NOCT} = Module temperature 45°C

$T_{a,\,NOCT}$ = 20°C ambient temperature

The second model estimates the operating temperature of the cell considering the wind speed, the heat exchange coefficient, the module efficiency, the maximum power temperature coefficient, transmittance, absorbance, ambient temperature and irradiance (Mattei, Notton, Cristofari, Muselli, & Poggi, 2006) as shown in equation 5.2

$$T_c = \frac{U_{PV}(v) * T_a + I[\tau\alpha - \eta_{STC}(1 - \beta_{STC} T_{STC})]}{U_{PV}(v) + \beta_{STC} * \eta_{STC} * I} \quad (5.2)$$

Where:

$U_{PV}(v) = 26.6 + 2.3\,v$ is the heat exchange coefficient

T_a = Average ambient temperature

I = Incident irradiance

$\tau\alpha = 0.81$ is the transmittance times absorbance

η_{STC} = Efficiency under STC conditions

$\beta_{STC} = 0.41°\%/C$ is the maximum power temperature coefficient

= 25°C is the temperature under STC conditions

In order to compare both methods, the average temperature data of the temperature intervals proposed in table 4.1 were used, while the average wind speed for the non-summer and summer seasons was 4.07 m/s and 3.85 m/s respectively. (NASA, 2023). The irradiance values evaluated were from 1000 to 600 W/m^2.

The results obtained for the operating temperature of the module are shown in table 5.1

1000 W/m2		800 W/m^2		600 W/m^2	
Markvart	Mattei *et al*	Markvart	Mattei *et al*	Markvart	Mattei *et al*
61	48	55	44	49	41
62	49	56	45	50	42
63	50	57	46	51	43
64	51	58	47	52	44
65	52	59	48	53	45
66	53	60	49	54	46
67	54	61	50	55	47
68	55	62	51	56	48
69	56	63	52	57	49
70	57	64	53	58	50

Table 5.1: Module temperatures for irradiance from 1000 to 600W/m^2 *(Own elaboration)*

As it can be seen, there are module temperature increases greater than 60 °C with the Markvart model in summer, despite only considering the average temperature as the main variable. The evaluation using the Mattei et al model is more conservative, since temperatures of up to 57 °C are reached for the same season and irradiance value.

Given this, it was decided to estimate the energy behavior of the arrangement from the second model, since it considers the influence of environmental, optical, and mechanical variables involved in the heat transfer to the module, the peak power results generated are shown in table 5.2.

1000 W/m2	
T_{module}	Wp
48	136
49	135
50	134
51	134
52	133
53	132
54	132
55	131
56	131
57	130

Table 5: Peak power for different module temperatures considering the Mattei et al model. *(Own elaboration)*

For comparison purposes, the PVSyst software was used to contrast the results obtained. To do this, the data from table 3.2 was entered into the software, dimensions, type of technology, cells in series and parallel, temperature loss coefficients, among others.

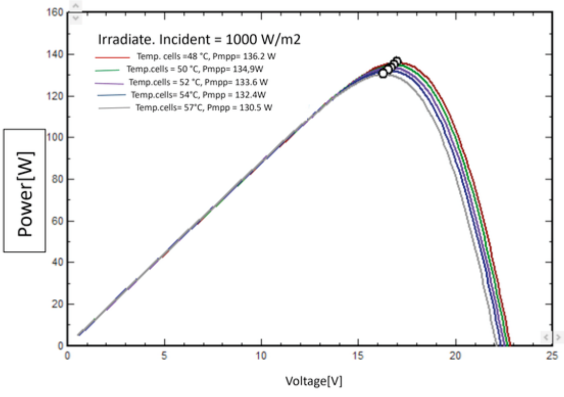

Figure 5.1: Power generated for irradiance of 1000 W/m2 at different temperatures (In-house elaboration with PVsyst)

As it was shown in figure 5.1, the powers generated at different temperatures are similar to those calculated by the software.

Figure 5.2 shows the useful power estimated by the software, under different irradiance conditions. In it, it is observed that for an irradiance of 400 W/m², the power generated will not be enough, as shown in figure 5.4.

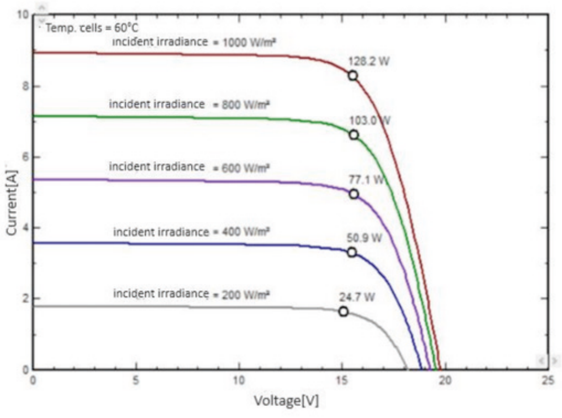

Figure 5.2: Useful power for different irradiances at 60 °C (In-house elaboration with PVsyst)

Regarding energy generation, the proposed arrangement satisfies the daily requirement even with a critical value in December of 1,127 Wh/day, which is greater than the 900 Wh/day required. In addition, there are energy surpluses in the range of 20-39% depending on the month, which will be used for energy storage and which together will allow the battery to be charged 100% in an average of 5 days, as shown in the figure. graph 5.3.

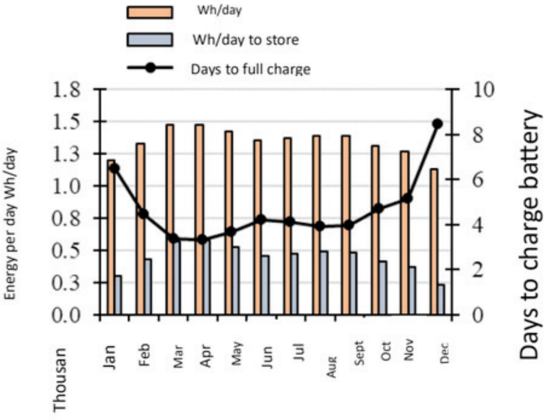

Figure 5.3: Power generation of the proposed arrangement at 1000 W/m2 (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

Considering a decrease in irradiance to 400 W/m², the energy behavior will be as shown in graph 5.4. The energy generated is 544 Wh/day, so the daily requirement is not satisfied; all the energy generated is for the exclusive use of the equipment to be powered and consequently the battery will not be charged.

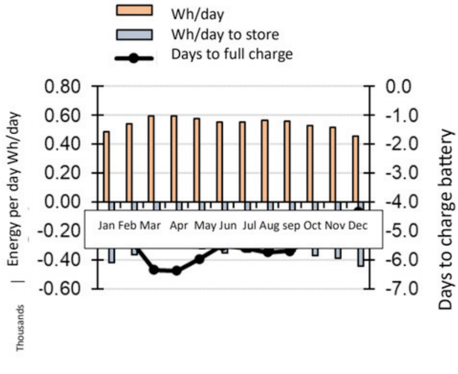

Figure 5.4. Power generation of the proposed arrangement at 400 W/m² (Huchin Miss, Escalante Notario, López, Coyopol, & Romano Trujillo, 2023)

CONCLUSIONS

From the results obtained in the case study, it is concluded that:

1. The Markvart model overestimates the module temperature by up to 13°C, so power losses are not realistic for the project needs.
2. The model proposed by Mattei et al. improves the predictive behavior of the module temperature by considering electrical, mechanical and environmental variables and, in addition, the results obtained coincide with those simulated in PVSyst.
3. In the critical months of lower solar resources (January and December), the system will reach full charge in one week, as long as 20% of the energy generated by the modules is available.
4. In the months with the greatest solar resource (March and April), the system will reach full charge in three days, provided that 39% of the energy generated by the modules is available.
5. The amount of energy to be stored in the battery will depend on energy availability. For example, in the summer months, the average availability is 500 Wh/month, assuming the energy required at the kiosk is 23 kWh/month. However, if the power required at the kiosk is lower, the availability of battery storage will increase.
6. It is advisable to design new spaces in the faculty focused on the development of academic and recreational activities, to reduce the lack of spaces indicated by students by up to 10 to 15%.

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