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The Impact of Roof Coating and Solar PV System in the Tropical Region of Ghana

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Authors' contributions

This work was carried out in collaboration among all authors. Authors WO, WA and SAM conceived the idea, designed the study, conducted literature review, handled the methodology and data gathering. Author JAA managed the validation of the model, and performed the analysis. Authors WA and JAA performed editing activities and wrote the first and final drafts of the manuscript. All authors read and approved the manuscript before submitting to the journal.

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ABSTRACT

Adding PV module to roof has impacts on building`s electricity energy consumption. The aim of this paper is to assess the energy consumption performance of buildings by integrating solar Photovoltaic (PV) system into buildings with roof coating. An experiment was conducted to verify the efficient outcome of PV module using a building from the Anaji area of Takoradi in the Western region of Ghana. A framework energy model was proposed to analyse the integrated contribution of coating and PV performance using PVSOL. The temperature of the coated roof surfaces underneath the PV panels were significantly lower than that of the exposed roof in the daytime. The

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system integrated energy efficiency for flat and tilted overhead PV roofs are 63.35 % and 62.73 %, respectively. Using the mean absolute percentage error (MAPE) performance criterion, the monthly energy savings for coated roofs with solar PV is 28.86 kW or GH¢ 340.21; while the monthly energy savings for coated roofs without PV is 25.91 kW or GH¢ 303.00. Overall, the proposed integrated coated roof with PV outperforms the coated roof without PV. Validating the model, the mean relative errors (MRE) were all below 10%, while the accuracy of Power-Added Efficiency (PAE) were all beyond 95%. Thus, the proposed integrated roof coating and solar PV model for optimizing energy consumption is reliable.

Keywords: Financial savings; roof coating; solar photovoltaic module; energy consumption; field test; heat transfer.

1. INTRODUCTION

As long as mankind has been around there have been a need for shelter and protection from sunlight, rain and wind [1]. Throughout history, roofs have been made from available resources. In the past, the early people used roof thatching for their houses and that tradition runs down to this generation. These early shelters provided good resistance against rain and sunlight which has great effect of reducing heat in rooms [2].

In this modern era, this tradition has been reduced greatly due to the adoption of aluminum sheet roofing, slate roofing, metal roofing, shingle roofing and among others, which mostly culminates to heat absorption and increased electricity energy demand that results in high energy consumption [3]. "Heat gains and heat losses through building surfaces are the main factors that determine the building`s cooling and heating loads. One of the effective ways to reduce heat absorption in a room is by applying white roof" [4, 5]. Research indicates that on sunny day, the black roofs absorb the light whiles white roofs reflect it back into the atmosphere [6]. White roof can help to reduce building temperature, saving huge amount of energy and money spent on air conditioning [7]. It is a common practice in warmer part of the world and would forever be in existence, but it is not too common in Ghana. This has led to high demand of electricity and tariffs in common Ghanaian household as a result of buying electrical gadget to extinguish the accumulated heat in rooms [8]. The role of low sunlight reflectivity in abnormally higher electrical energy consumption has been established in research, where projected energy consumption rose to 1167 kWh per year [9]. Because reflectivity factor can reduce surface roof temperature and building cooling loads, it aids in reducing radiative heat flux to the atmosphere. Another property of the roof surface that must be considered is thermal emissivity, which affects the heating and cooling energy use of buildings. Emissivity is a positive correlate of radiative heat transfer from the roof to the sky [10], indicating that roofs with high emissivity are desirable in areas with high sun/heat intensity. Hence, a combination of both reflectance and emissivity are useful in reducing roofing temperature [11].

Africa is particularly noted for its world sunshine records. Ghana in the sub-Saharan also experience higher amount of sunlight which requires more units of electrical energy to reduce temperatures absorbed into rooms by buildings. This creates a high demand for electrical energy to compete with the demand of the same for industrial use. The frequent power fluctuation or outages (dumsor) makes the demand for electrical energy for both domestic and industrial purposes unsatisfied leading to domestic accidents, deaths and low industry productivity. Nonetheless, the heat produced is itself useful for the production of electrical energy to fight these high temperatures in buildings. There is an average of 2377 hours of sunlight per year with an average of 6:30 am to 6:10 pm of sunlight per day, indicating that solar photovoltaic modules can work effectively to generate electricity for the people of Ghana. Unfortunately, thermal production constitutes the major source of electrical energy in Ghana, with the traditional hydro-electric constituting only about 30%. The thermal sources are dominantly powered by fossil fuels which have devastating implications on environmental safety and sustainability [12] as well as higher electric energy production cost and its far-reaching impact on electricity tariffs [13]. In addition to the recent ubiquitous trend to save energy through smart homes [14], the global crusade to embrace green environment and circular economy practices [12,15] as part of the sustainable development goal is gaining popularity. There is therefore, the need to adopt an integrated renewable or a sustainable source of energy country-wide in Ghana. The favourable performances of coated roofs and solar energy on electric energy consumption has been overemphasized, which suggests that their integrated effects will outperform their separate performances. However, the said integrated role of coated roofs and solar PV module has not been covered in the literature. Therefore, we propose in this paper, a combination of coated roofs and solar PV system. The objective is to numerically assess the impact of an integrated roof coating and Solar PV System in the tropical region of Ghana. This will help to evaluate the capability of the proposed system in reducing the energy consumption as well as maintain sustainable energy and environment. The paper derives its contribution to knowledge by integrating the solar PV system into the roof coating of buildings. The PV system also known as solar power system, is an electric power system designed to supply usable solar power by means of photovoltaics. Solar is a renewable power source of energy which supports the 'green' ideology to sustainability in terms of environmental safety and tariff reduction. Coated roofs also have higher reflectivity and thermal emissivity. Thus, the propose system serve more than one purpose, by integrating the roles of both coated roofs and solar PV module. This system functions whether rainy or shinny thus reducing its limitations.

2. MATERIALS AND METHODS

Generally, in assessing the performance of the proposed integrated system of coated roofs and solar PV system, the buildings at Takoradi Technical University of Ghana were used to describe heat transfer associated with the roofs considered. A comparison between numerical results and field data was implemented. The energy budget of the building was inspected. It is estimated to spread the existing knowledge of effective exploitation of the solar energy and to deliver a reference for the joint application of roof coating and PV modules.

2.1 Performance Analysis and Strategy

"The building used in this study is located at Takoradi (Anaji) with accessible roof. Experiment was carried out from July to August, 2022. Several 260 W polycrystalline PV panels were installed on the rooftop in forms of flat and tilted overhead, with 20 cm of the height between flat PV panels, and roof with 30° south inclination angle of tilted overhead PV array" [16]. "PVSOL was used to describe heat transfer associated with the roofs considered. Both coated roof with solar PV were investigated and temperature distributions over the roofs were analyzed. The temperatures of the measuring points were measured by four channel CENTER309 thermocouple and the Button DS1922L" [9]. "Wind speed and solar radiation were measured by the solar power generation test recorder. Schematic diagram of experimental apparatus and distribution of measuring points is shown in Fig. 1" [17].

2.2 Theoretical Modelling Framework

"Roof solar PV system are electricity generated distribution options which help to meet a building's energy need, or provide electricity within an existing distribution network. This can be used to meet the building own energy consumption requirement or in certain situations, feed back into electrical grid" [18]. "The orientation of the PV panel depends on the type of the roof. Actually, proper installation of the solar panel can avoid excessive wear on the roof caused by weather-related factors" [19]. "Furthermore, in fixing the solar panels on the roof, the angle of the roof should be considered, and the roof angles close to the latitude of the site are expected. In addition, as the roof faces south to the greatest extent, adequate amount of sunlight will be captured. The dimensions of the roofs of the two-building considered are shown in Fig. 2 with roof parameters listed in Table 1" [20].

2.3 Theoretical Assumption

"A roof exposed to the solar radiation in the center of the three modes of heat transfer: conduction, convection, and radiation. When there is heat between two bodies, a temperature gradient heat travels from the hotter to the colder; thus, the difference tends to instinctiv ely resolve" [21]. "Significantly, transfers between two bodies implement three distinct processes concurrently or not: conduction, convection, and radiation. The heat absorption and reflection are encountered as the solar radiation reaches the surface of the roof. However, some parts of the heat are reflected while others are absorbed by the building. The cool roof, roof insulation, and the radiation barrier are basic strategies in curbing heat transfer in the building industry" [22].

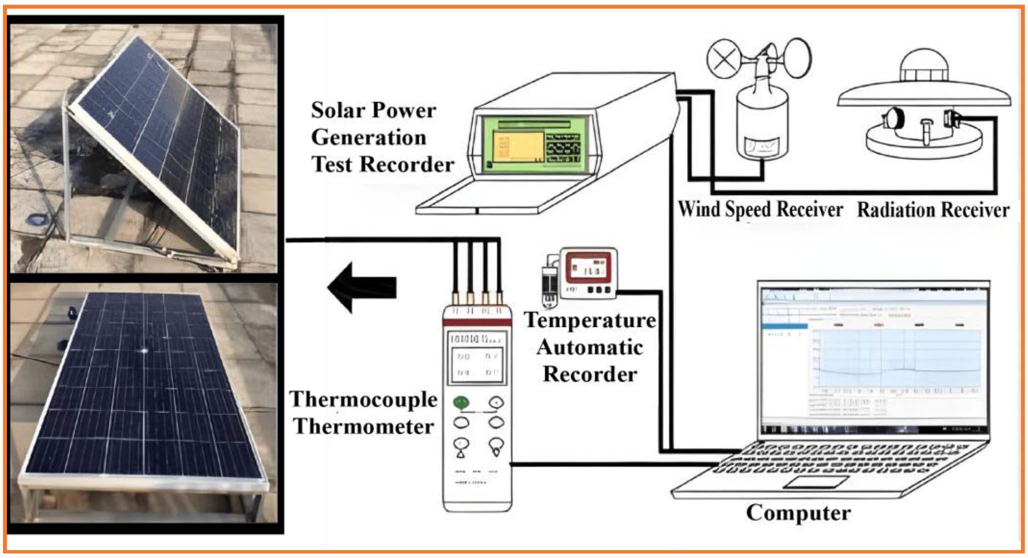

Fig. 1. Schematic diagram of the experimental apparatus

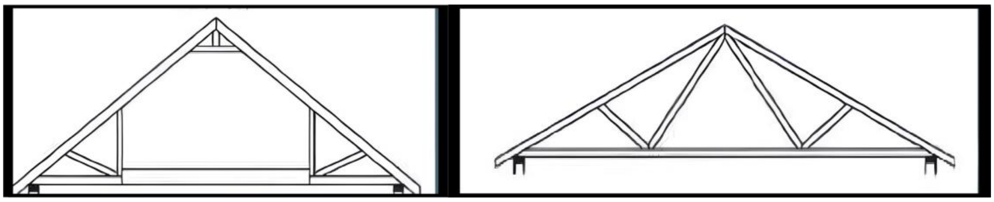

Fig. 2. Schematic view of the roof structure

Table 1. Roof dimension

Description	Coated roof	Uncoated roof
Length	84.2 m	46.3 m
Width	9.2 m	9.2 m
Height	1.2 m	1.2 m
Angle	60^0	60^0

"Moreover, the mechanisms of the heat transfer (convection and radiation) occurring in building's roof are shown schematically in Fig. 3. In any given house, it can be assumed that the size of the roof is sufficiently large to have a one-dimensional net heat flow. With this assumption, the net heat flow that crosses the external surface of the roof is the same conductive heat flow that goes through the concrete slab, and it is the same heat flow between the slab and the air inside the house. The magnitudes of the heat flow by convection and by radiation are difficult (but not impossible) to measure" [23]. "However, heat conduction through the concrete slab can be easily calculated if the temperatures of the exterior and the interior surfaces, along with the thermal conductivity and the thickness of the concrete slab are known. This study defines Te as the external air temperature, Ti as the internal air temperature, Tse as the external surface temperature of the probe, and Tsi as the internal surface temperature of the probe, he and hi correspond to the convection heat transfer coefficients that occur in the exterior and interior sides of the probe" (Fig. 3) [24,18].

2.4 Software Simulation and Result Analysis

PVSOL software was utilized for the simulation purpose. The parameters taken for simulation are tabulated in Table 2. By utilizing these parameters, rigorous simulation is carried out and a monthly profile is obtained from the software. However, the software showed quite a promising result in terms of energy production on coated roof and PV which is depicted in Fig. 4. The annual yield was 82,076 kWh, 83,038 kWh, and 80,401 kWh in PVSOL, respectively. It is observed that the maximum yield was obtained during March due to high global horizontal irradiation. However, the lowest yield was experienced during June when the irradiation was low due to cloudy sky and rain.

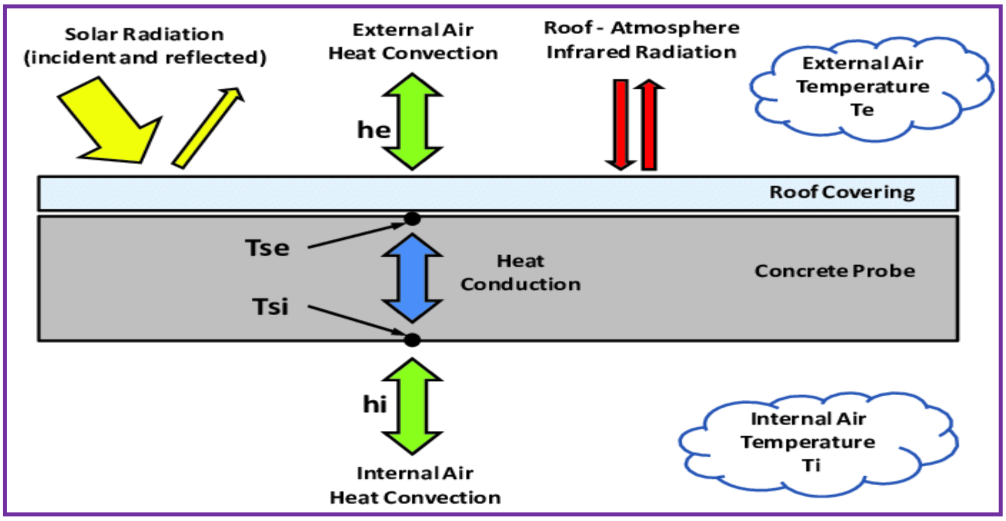

Fig. 3. Heat transfer mechanism in building roof

Table 2. Simulation parameters

Parameters	Panel rating	No. of panels	Total generator output	Tilt	Azimuth	No. of inverters	Mounting surface
Values	340 W	174	59.16 kW	24 °	180 °	11	2 m

Financial Analysis		Tech. Quality of the PV System	
Internal Rate of Return (IRR)	5.79%	PV Generator Energy (AC grid)	28,028 kwh/Year
Total Payment from Utity	3,246.54 $/Year	Spec. Annual Yield	1,111.75 kWh/kWp
Accrued Cash Flow (Cash Balance)	21,555.59 $	Performance Ratio (PR)	62.9 %

System integraton			
Erergy from Grid	12 kwh/Year	Grid Feed-in	28,028 kwh/Year

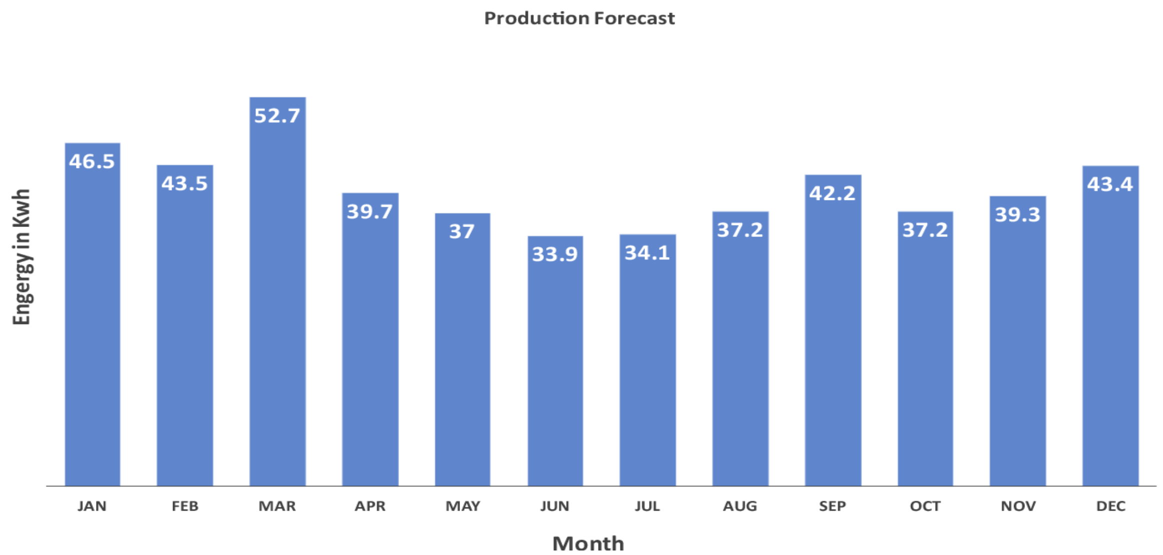

Fig. 4. Monthly PV energy generated profile using PVSOL software

2.4.1 Model of a BIPV house

The house considered for this model has an area of 94.4 m^2. The dimensions of the house are length: 11.7 m, width: 7.2 m, and height: 7.3 m. Table 3 lists the overall heat-transfer coefficients for the building envelope. The entire house was defined as one thermal area, that is, one air-conditioned area conditioning was on. Fig. 5 shows the BIPV house model without coating.

2.4.2 Building without PV Panels

Building Not Exposed to Sunlight: For simplicity, the house with PV panels is referred to as the "BIPV house," and the house without PV panels is referred to as the "regular house." Fig. 6 shows the temperature measurement points on the south-facing roof of the regular house when it was not exposed to sunlight [20].

Table 3. Overall heat-transfer coefficients for the BIPV house

Structure	Main materials (from outside to inside)	Overall heat-transfer coefficient K (W/(m2 ·K))
Exterior walls	Concrete panel Fiberglass insulation Dry wall.	0.8
Roof	Concrete panel Plastic benzoic (XPS) board Dry wall	0.5
Floor	Wooden floor Fiberglass insulation Wooden floor	1.0
Windows	6 clear + 12 argon (Ar) + 6 Low-EGlass-fiber reinforced polyurethane (GRPU) door and window profile	2.3
Door	Solid wood	2.0

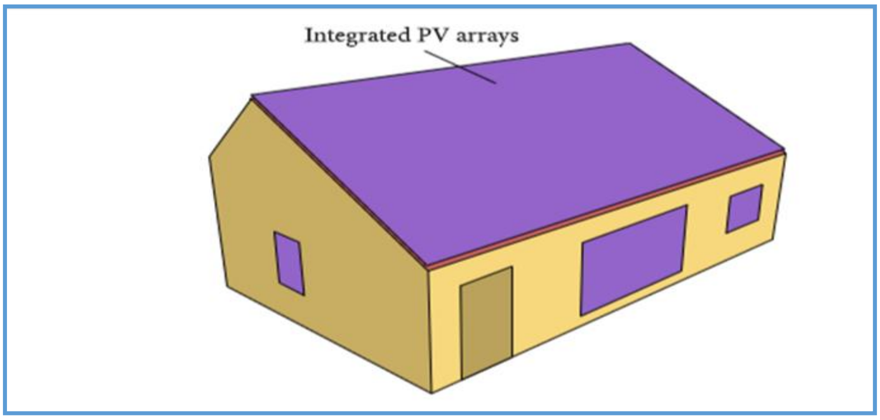

Fig. 5. Model of the BIPV house [18]

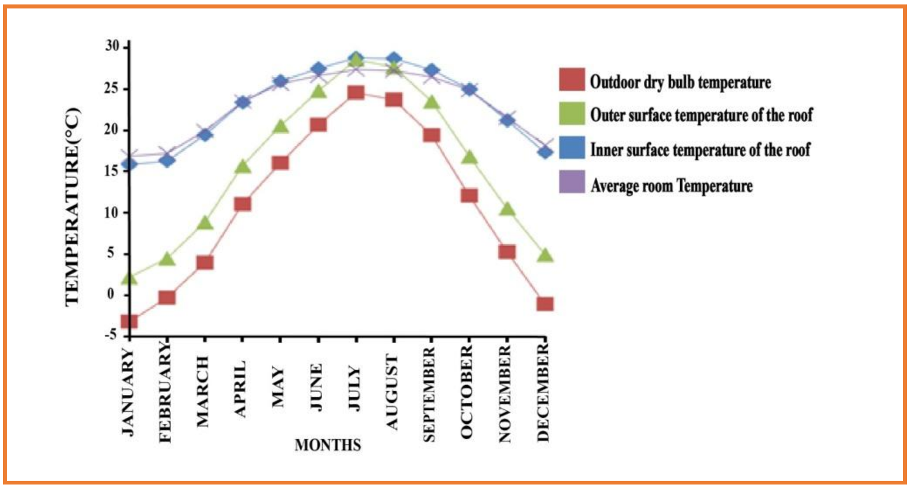

Fig. 6. Simulated inner and outer surface temperatures for the regular house not exposed to sunlight [25]

Building Exposed to Sunlight: Fig. 7 shows the simulation results. When the regular house was exposed to sunlight, the outer surface temperature of the south-facing gable roof, measurement point 1 in Fig. 7 (a), was always higher than the outdoor dry-bulb temperature, measurement point 3 in Fig. 7 (a). Also, the outer surface temperature, measurement point 1 in Fig. 7 (b) was considerably higher than the outdoor dry-bulb temperature, measurement point 3 in Fig. 7 (b), when the south-facing gable roof of the regular house was exposed to solar radiation during the daytime. However, the outer surface temperature was lower than the outdoor dry-bulb temperature during the night. The simulated results were in agreement with the actual situations. PV sole module was used for the design.

2.5 Performance Effect of Solar PV

"The Installation of the solar PV system on roof top might offer more benefits to buildings. Meanwhile, some roof area is shaded by the solar PV system components and the temperature input to the roof surface can be further decreased. More importantly, a power source is thereby provided to reduce the energy consumption in the building. It was reported that the output electricity was dependent on the strategies of utilizing the solar radiation" [6].

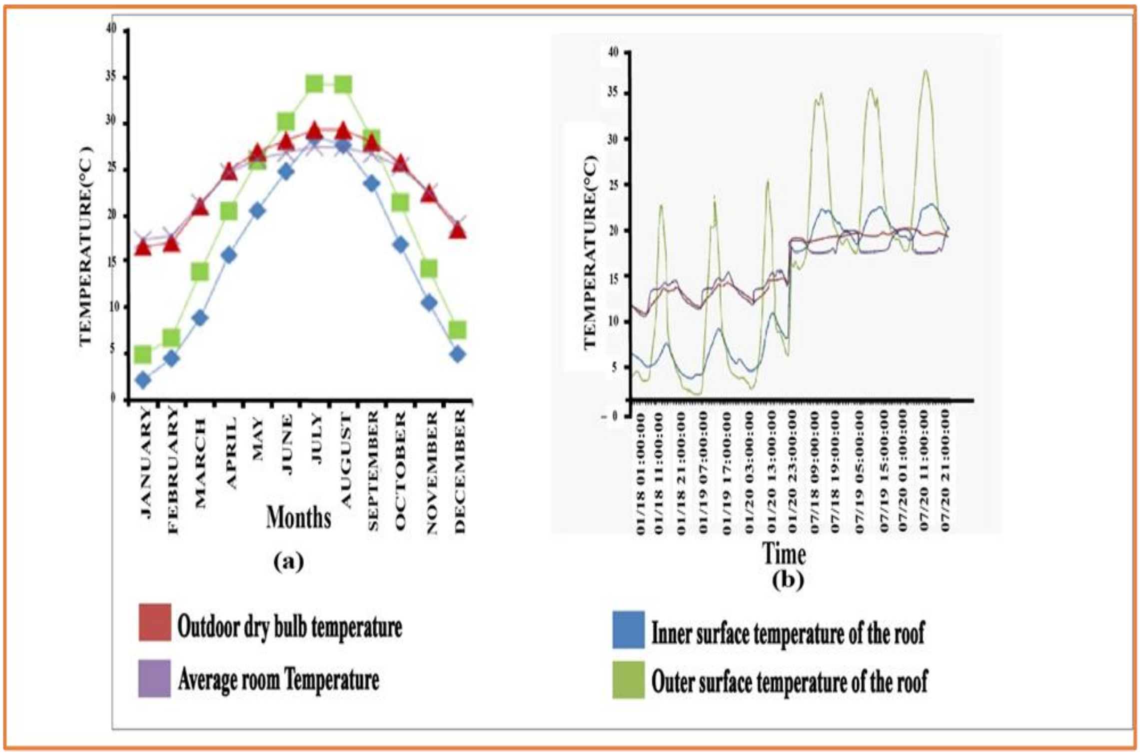

Fig. 7. Simulated inner and outer surface temperatures for the regular house exposed to sunlight

2.6 Mathematical Model Formulation

For roof added PV module, TZ (τ) could be represented as

$$TZ_{PV}(\tau) = T_a(\tau) + \frac{a_t I_{SD}(\tau)}{h_t(\tau)} \quad (1)$$

Because of coating effect, only part of diffuse radiation projects on roof, which is obtained by $I_{SDI} = I_{D\tau} \times VF$, where view factors $VF = \left[\text{COS}B\tau - \text{COS}(Bp + Br)\right]/2$. The radiation heat exchange between PV back sheet and roof cannot be ignored, which is represented by $Q_{bt} = \varepsilon_{br}\sigma\left(Tb^2 - T\tau_{PV}\right)$, where $\varepsilon_{br} = 1/\left(1/\varepsilon b + 1/X_{br} - 2\right)$ and $X_{br} = 1 - \sin Bp/2 - \sin\left(Bp/2\right)$.

According to electrical performance model described by [19] at SNL, empirical relationships with coefficients of the temperature on the rear surface of the panel was predicted as

$$T_b(\tau) = T_a + I_T \times \exp(a + BV) \quad (2)$$

where empirical coefficient a and b, were assigned to –3.562 and –0.0786 respectively. It was assumed that the heat transfer through the roof is one-dimensional unsteady heat-conduction. The indoor space was characterized by a specified internal temperature T_I. "Applying PVSOL, the temperature of roof with and without PV could be obtained. For performing design cooling load calculation, radiant time series method was used. Periodic response factors (PRF) instead of conduction transfer function was conducted to calculate conduction heat gains. Then all heat gains were split into radiative and convective portions, for roof, which account for 0.84 and 0.16 respectively" [6]. Once PRFs and sol-air temperatures are known, hourly conduction heat gains q_θ and the cooling and heating load Q_θ of the roof could be directly calculated, which were shown as illustrated below.

$$q_\theta = \left(\sum_{j=0}^{23} Y_j tz\theta - t_j \sum_{j=0}^{23} Y_j\right) \quad (3)$$

$$Q_\theta = Q_{r\theta} + Q_{c\theta} = 0.84\sum_{j=0}^{23} rj\left(q\theta - j\Delta r\right) + 0.16q\theta \quad (4)$$

Here, Y_j is periodic response coefficient for 24 hours $tz\theta - t_j$ represents the sol-air temperature j hours ago; the value of time interval $\Delta\tau$ was set to 1 h; $r_1, r_2, r_3, \ldots, r_{23}$ are radiant time factors and $q\theta - j\Delta r$ stands for conduction heat gains j hours ago. Other parameter which can influence cooling load are specified. Radiant time factors were achieved from the PRF-RTF Generator [26].

2.6.1 Integrated energy efficiency model

"Integrated contribution of PV roof was divided into two parts: coating benefit and power generation benefit. To study coating benefit, the percentage reduction of heating or cooling load through roof between PV covered roof ($Q_{n\theta}$) and exposed roof ($Q_{PV\theta}$) was determined. The power output from PV module was converted into a heating or cooling energy according to a certain COP, which value is 5.5 for conventional air-conditioning system" [16]. The integrated energy-saving effect is compared with conventional roof to instruct air-conditioning system design, operation and maintenance. This requires the use of the system comprehensive energy efficiency model, which is given by

$$\eta = \frac{Q_t + EPV}{I_t} = \frac{\sum_{\theta=0}^{23}(Q\theta - QPV\theta) + \sum_{\theta=0}^{23} PV\theta \times COP}{I_t} \quad (5)$$

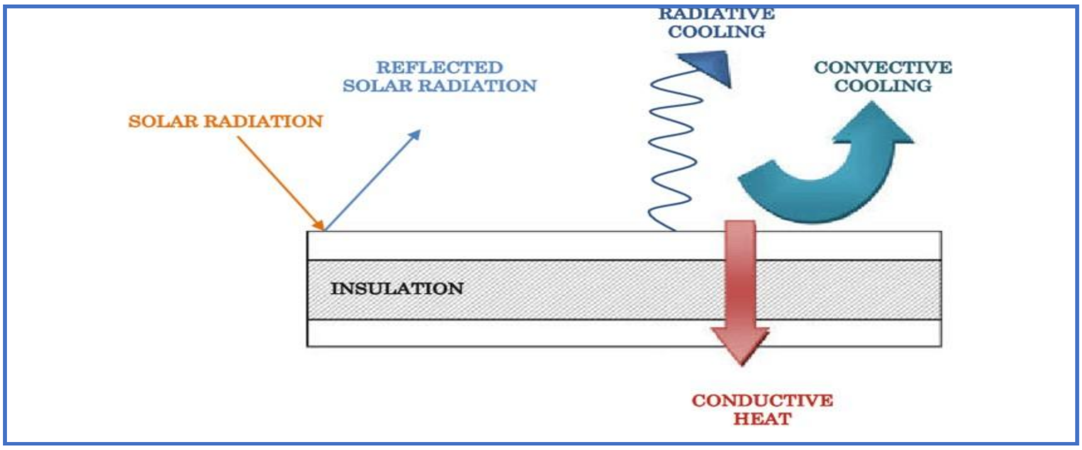

Fig. 8. Energy balance of a roofing system

2.7 Energy Balance of a Roofing System

Fig. 8 shows energy balance of a roofing system that describes how solar radiation and reflection affect the roof of a building. Sun radiation is partially reflected back to the atmosphere while the rest is absorbed by the roof and other parts of the building. Roof material and coating determine to a large extent the absorption rate of the roof; and both the coated and uncoated roofs were made of aluminum [18].

3. RESULTS AND DISCUSSION

3.1 Effect of Coating on the Temperature of Roof's Exterior Surface

"Temperatures of roof's exterior surfaces in different forms of Building Applied Photovoltaics (BAPV) are shown in Fig. 9 (b). In the daytime, due to shading, the surface temperatures of roof under PV were lower than that of exposed roof, especially tilted overhead PV roof, for the reason that the roof under the solar panels is heated by longwave radiation from the panel underside and diffuse radiation from the sky (which is small given the small tilt angle), the sum of which is less than the solar irradiance to the exposed roof" [27]. "At night, roof without PV will be cooled through longwave radiation. Installing PV module can play an insulation role in the roof under that. Therefore, the surface temperatures of roof under PV were higher than that of conventional roof, which was obvious to flat overhead PV roof as established in" [18]. PV sole was used to designed this model.

3.2 Effect of Coating on the Cooling and Heating Load through Roofs

"The effect of PV module coating on the cooling and heating load through roofs is shown in Fig. 10, with measuring line. Comparing with conventional roof, heat gain and cooling load of PV roof have greatly attenuated while heating load has increased slightly. Fluctuation amplitude was relatively smooth" [10]. "Specifically, the peak value of heat gain through flat and tilted overhead PV roof has reduced by 67.1% and 59%, respectively. Among the three, the peak cooling load and the total daily load of the flat overhead PV roof have decreased by 72.2% and 77.4% respectively while that of the tilted overhead PV roof reduced by 61.5% and 69.4%, respectively" [28, 29]. Added photovoltaic panels also changes the thermal storage capacity of the roof as shown in [10]. The peak value of cooling load of the PV roof was delayed by 2 hours while the peak value of heating load was delayed by about 1 hour.

Irradiance on horizontal plane compare with tilted open area (Fig. 11).

Parameter to be considered when designing and utilizing photovoltaic system is the solar irradiance. Consequently, the commonest input parameters of solar photovoltaic system are the solar irradiance, the wind speed and the ambient environment temperature. Normally before installing a PV module, both horizontal plane and the tilted plane should be considered in order to get the maximum potential solar

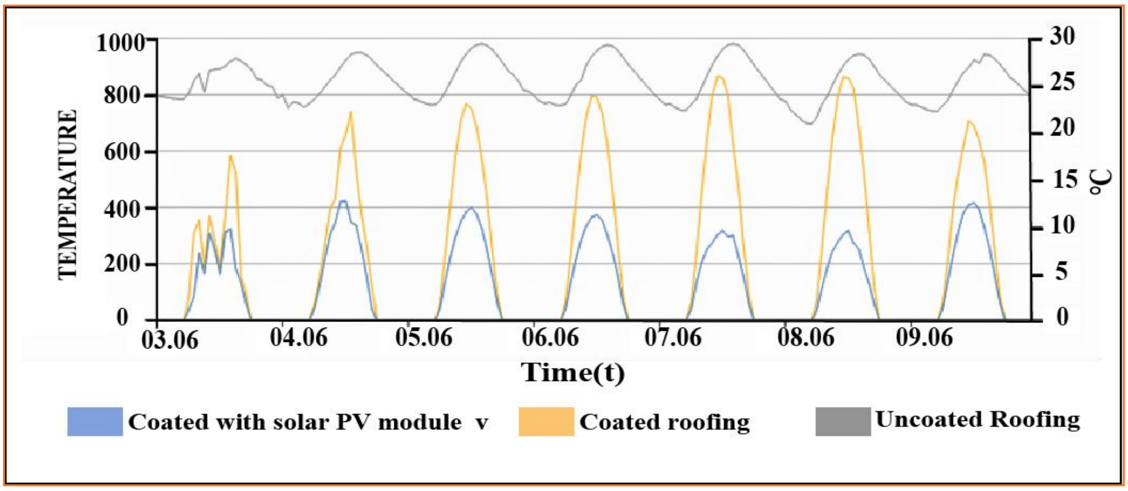

Fig. 9. (a) Temperature under coated with solar PV module (b) Temperature under coated roofing (c) Temperature under Uncoated roofing system

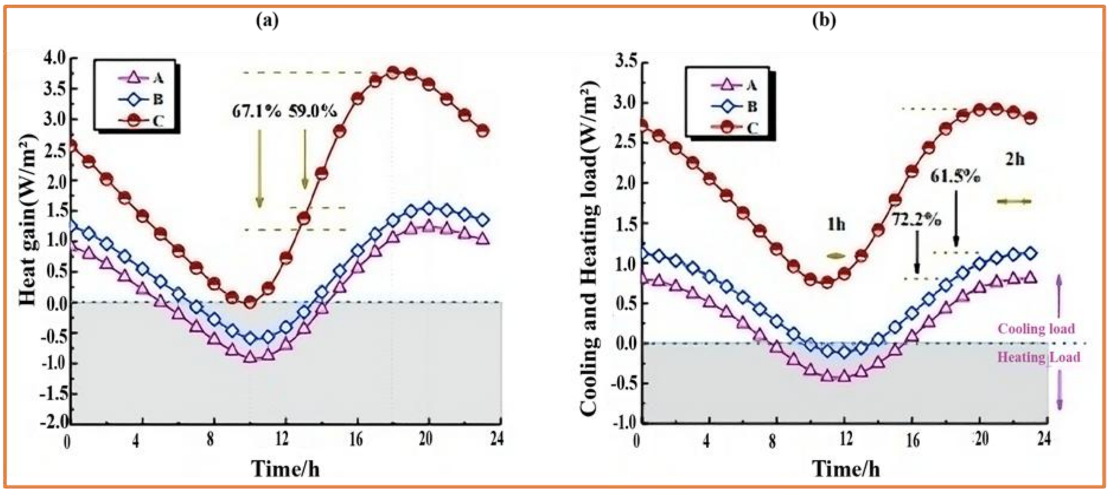

Fig. 10. Comparisons of heat gain and cooling and heating load through roofs (A – flat overhead, B – tilted overhead, C – conventional roof)

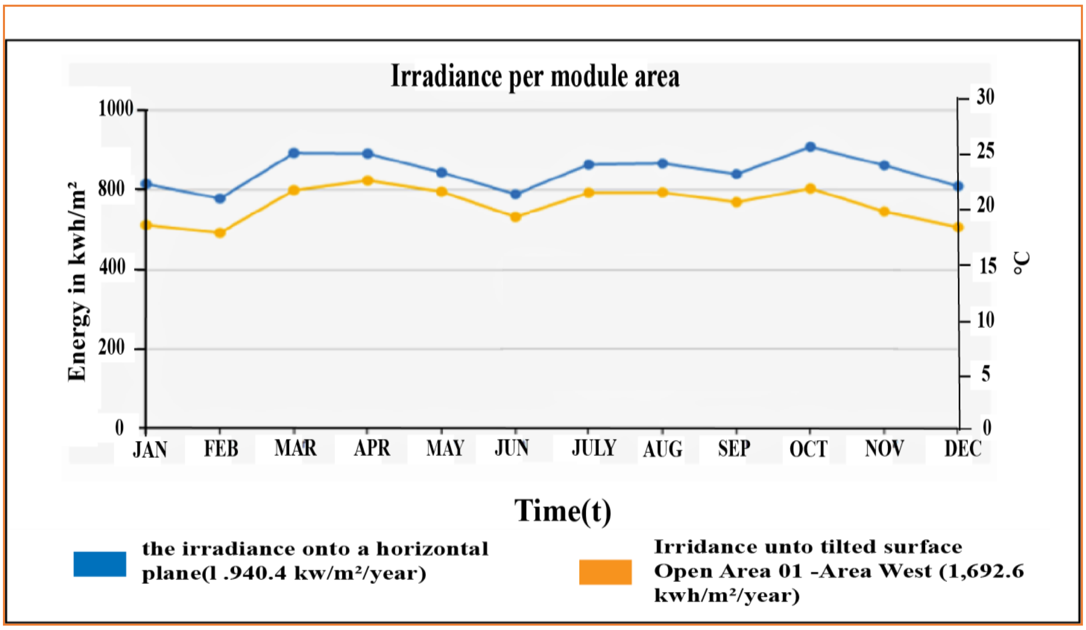

Fig. 11. Comparison of irradiance on horizontal plane to tilted surface

energy. The simulated result below shows that, the irradiance on horizontal plane has a high energy production as compare to the irradiance on a tilted open area.

3.3 Economics and Financial Impact of Roof Coating

Many roof coatings are “cool,” meaning they reflect solar energy instead of absorbing it. As cited in [9], the end result of roof coating are as follows: reduced energy bills by decreasing air conditioning needs, improved indoor comfort for spaces that are not conditioned, decreased roof temperature, which may extend roof service life, solar-reflective roofs can reduce cooling energy demand by 10-40%.” From Fig. 12, the results clearly show that roof coatings applied in a building could help in reducing energy consumption for cooling (kWh) and peak demand (kW) in individual residence.

The Tables 4 and 5 refer to the financial comparison of building in Anaji’s previous bill to current bill when solar PV was installed and the energy produced monthly.

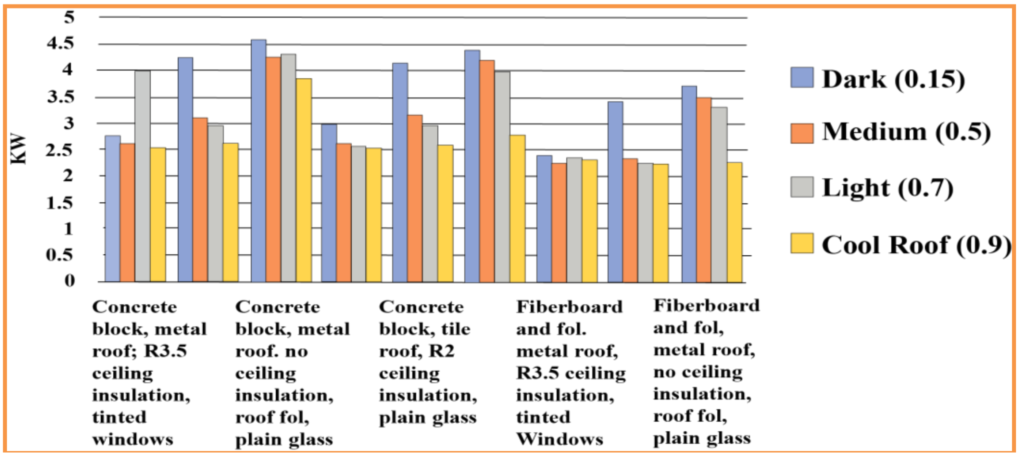

Fig. 12. Simulated peak demand (kw) for variations of the building at Takoradi (Anaji)

Table 4. Monthly data accumulated

Month	Previous Bill with Uncoated Roof (GH¢)	Current Bill with Coated Roof (GH¢)	Current Bill with Integrated Coated Roof and PV (GH¢)
January	860.00	455.00	396.20
February	790.00	427.00	407.30
March	940.00	549.00	481.20
April	820.00	383.00	334.70
May	800.00	329.00	311.00
June	680.00	421.00	383.70
July	720.00	419.00	382.10
August	790.00	557.00	528.50
September	810.00	476.00	464.70
October	840.00	686.00	593.70
November	830.00	542.00	514.40
December	870.00	476.00	454.00

Table 5. Monthly energy accumulated

Month	Energy Produce (kW) with coated roof	Energy Produce (kW) with Integrated Coated and PV	Energy Produce (kW) Previously with Uncoated roof
January	46.5	40.5	87.9
February	43.5	41.5	80.5
March	52.7	46.2	90.1
April	39.7	34.7	62.4
May	37	35.0	90.1
June	33.9	30.9	54.7
July	34.1	31.1	58.5
August	37.2	37.2	52.7
September	42.4	41.4	72.1
October	37.2	32.2	45.2
November	39.3	37.3	60.2
December	43.4	41.4	78.5

The different form of PV roofs, the deviations between air layer temperatures and ambient air temperature were less than 10%. Therefore, model hypothesis was basically proved. By solving the established model using PVSOL, temperatures of coated roofs with and without PV were obtained. The calculated values well agreed with the experimental data. From the calculation, the mean relative errors (MRE) were all below 10%; and the accuracy of Power-Added Efficiency (PAE) were all beyond 95% throughout the measuring period. On account of this, the proposed thermal model of PV roofs can be considered reliable. In terms of electricity bills and energy consumption, mean average percentage errors (MAPE) as applied in [15,30,31] was used as performance metric. For the electricity bills, the MAPE for coated roof with and without PV are approximately 46.07% and 41.31% respectively. The values imply that on average, the electricity bills for coated roof with PV deviates from the bills of uncoated roofs by approximately 46%, while the bills for the coated roofs without PV deviates from that of the uncoated roofs by 41% approximately. Thus, for the coated roofs with PV, monthly electricity bills are reduced by 46% (GH¢ 340.21), and a monthly reduction by 41% (GH¢ 303) in the case of the coated roofs without PV. The energy consumption was associated with a MAPE of about 47.26% for coated roofs with PV, and a MAPE of 44.71% for coated roofs without PV, indicating that the coated roofs with PV saves energy by approximately 47% (28.86 kW) on average while on average, the coated roof without PV achieves energy savings by 45% (25.91 kW) approximately. The proposed integrated coated roof with PV module outperforms the coated roof without PV module by approximately 5% in terms of electricity bills and 2% in respect of energy consumption.

4. CONCLUSION

The impact of roof coating and solar photovoltaic was performed based on one particular building at in the Anaji area of Takoradi. Coating and photovoltaics are two key benefits of roof added photovoltaics. Analyzing integrated contributions of the two has a vital implication for predicting the electrical energy consumption of buildings. In this paper, a comparison of the performances of coated roofs with and without solar PV module was made. The roof surfaces underneath the PV panels, especially under tilted PV panel, were coated, therefore, the temperature was significantly lower than that of the exposed roof in the daytime. At night, the roof surfaces under the solar panels remained warmer, due to the reduction in radiative cooling to sky, especially for flat overhead PV roof. Heat gain and cooling load of roofs under PV panels attenuated significantly while heating load increased slightly with a smoother fluctuation. Added PV panels also changed the thermal storage capacity of the roof. Considering total benefits of coating and power generation, system integrated energy efficiency for flat and tilted overhead PV roofs are 63.35 % and 62.73 %, respectively. The monthly energy savings associated with coated roofs with solar PV module is 28.86 kW or a monthly savings of GH¢ 340.21 (GH¢ 4, 082.52 annually) on electricity bill; while the monthly energy savings for coated roofs without PV is 25.91 kW or a monthly savings of GH¢ 303 (GH¢ 3,636.00) on electricity bill. Thus, overall, the proposed integrated coated roof with PV module outperforms the coated roof without PV module by approximately 5% in terms of electricity bills and 2% in respect of energy consumption. Reliability of the proposed integrated coated roofs with solar PV system was assessed. Inferring from the computations, the mean relative errors (MRE) were all less than 10%. In addition, the accuracies measured by the Power-Added Efficiency (PAE) were all above 95% throughout the measuring period. Based on these values of MRE and PAE, the reliability of the proposed thermal model of coated roofs integrated with PV modules has been established. This integrated coated roofs with PV module therefore, outperforms existing coated roofs without PV systems. This plays a twin role as a sustainable and cost-effective/efficient source of energy; and as a key strategy to achieving sustainable environment through the principle of greening.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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