

(ORIGINAL RESEARCH ARTICLE)

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

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 system integrated energy efficiency for flat and tilted overhead PV roofs were 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 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 etc., 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 be in existence for as long as there is white wash, but it is not too common in Ghana. This has led to high demand of electricity and tariffs on common Ghanaian household as a result of buying electrical gadget to extinguish the heat accumulated in a room [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

37 that must be considered is thermal emissivity, which affects the heating and cooling energy
38 use of buildings. Emissivity is a positive correlate of radiative heat transfer from the roof to
39 the sky [10], indicating that roofs with high emissivity are desirable in areas with high
40 sun/heat intensity. Hence, a combination of both reflectance and emissivity are useful in
41 reducing roofing temperature [11].

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

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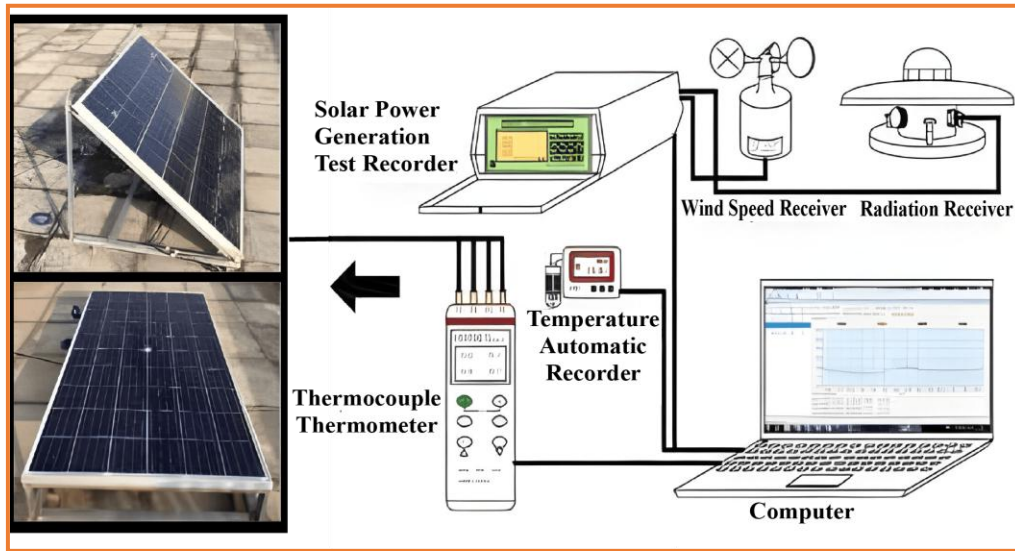
77 **2. MATERIAL AND METHODS**

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

86 **2.1 Performance Analysis and Strategy**

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



96 experimental apparatus and distribution of measuring points is shown in Figure 1 [17].

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98 **Fig. 1. Schematic diagram of the experimental apparatus**

99 **2.2 Theoretical Modelling Framework**

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

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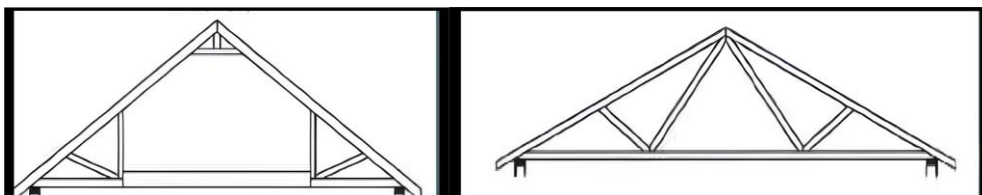
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Fig. 2.



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Schematic view of the roof structure

Table 1. Roof dimension

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

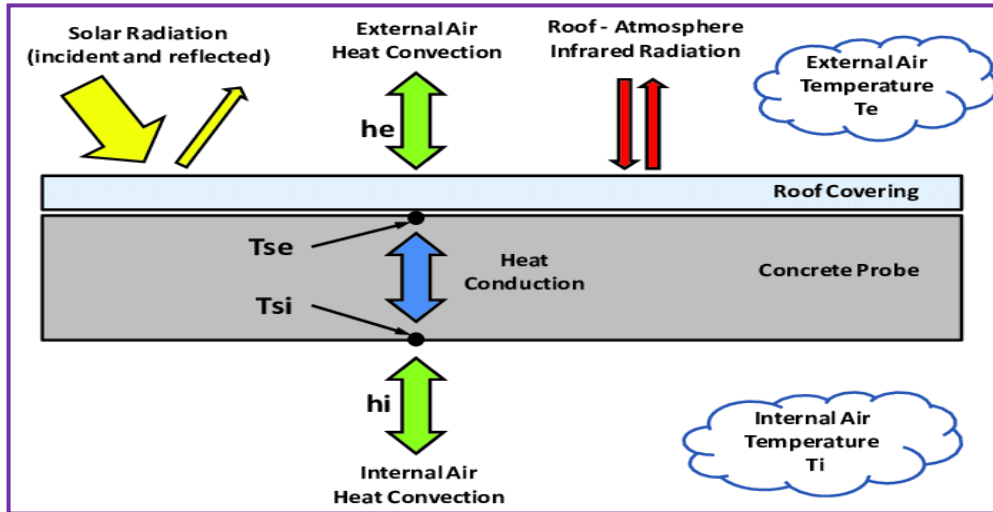
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2.3 Theoretical Assumption

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

129 Furthermore, the heats transfer mechanisms (convection and radiation) occurring in
130 building's roof are shown schematically in Figure 3. In any given house, it can be assumed
131 that the size of the roof is sufficiently large to have a one-dimensional net heat flow. With
132 this assumption, the net heat flow that crosses the external surface of the roof is the same
133 conductive heat flow that goes through the concrete slab, and it is the same heat flow
134 between the slab and the air inside the house. The magnitudes of the heat flow by
135 convection and by radiation are difficult (but not impossible) to measure [23]. However,
136 heat conduction through the concrete slab can be easily calculated if the temperatures of
137 the exterior and the interior surfaces, along with the thermal conductivity and the thickness of
138 the concrete slab are known. This study defines T_e as the external air temperature, T_i as
139 the internal air temperature, T_{se} as the external surface temperature of the probe, and T_{si}
140 as the internal surface temperature of the probe, h_e and h_i correspond to the convection
141 heat transfer coefficients that occur in the exterior and interior sides of the probe (Figure 3)
142 [18].

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Fig. 3 Heat transfer mechanism in building roof

158 **2.4 Software Simulation and Result Analysis**

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

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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

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Financial Analysis

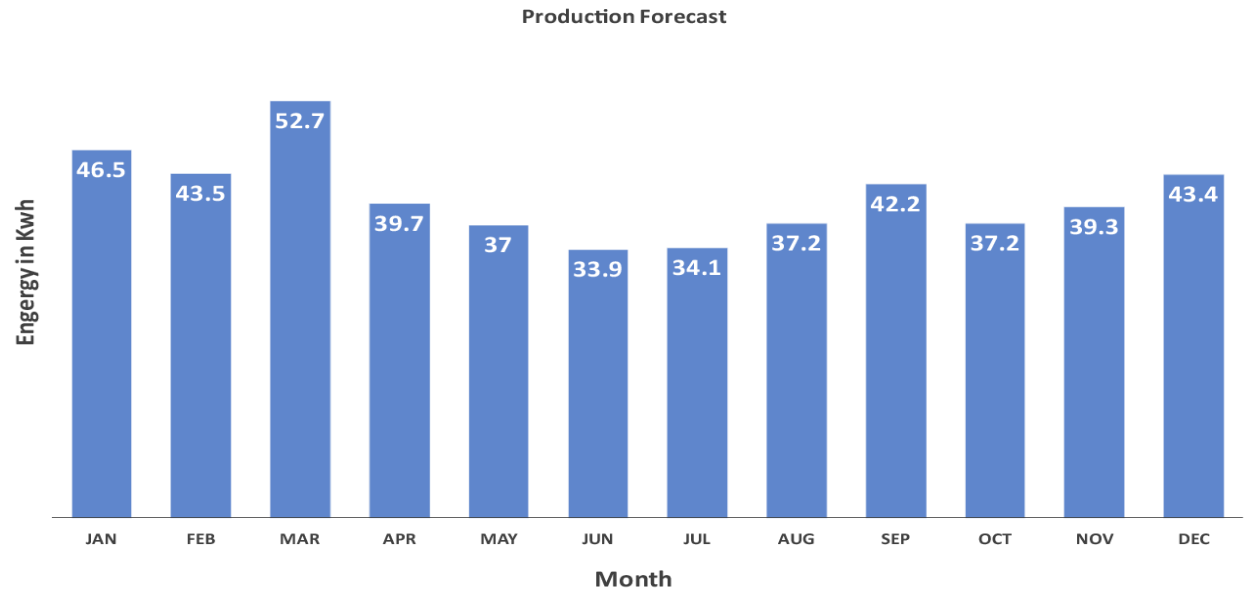
Internal Rate of Return (IRR)	5.79%
Total Payment from Utility	3,246.54 \$/Year
Accrued Cash Flow (Cash Balance)	21,555.59 \$

Tech. Quality of the PV System

PV Generator Energy (AC grid)	28,028 kwh/Year
Spec. Annual Yield	1,111.75 kWh/kWp
Performance Ratio (PR)	62.9 %

System integraton

Energy from Grid	12 kwh/Year	Grid Feed-in	28,028 kwh/Year
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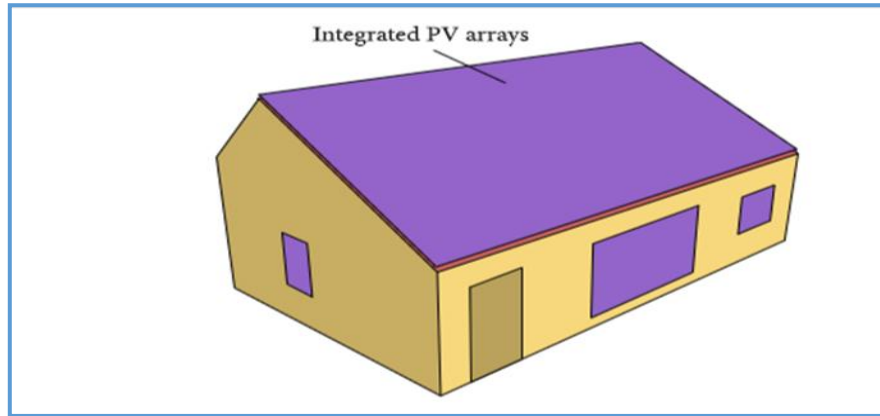
Fig. 4. Monthly PV energy generated profile using PVSOL software

176 2.4.1 Model of a BIPV house

177 The house considered for this model has an area of 94.4 m². The dimensions of the house
178 were length: 11.7 m, width: 7.2 m, and height: 7.3 m. Table 4 lists the overall heat-transfer
179 coefficients for the building envelope. The entire house was defined as one thermal area,
180 that is, one air-conditioned area conditioning was on. Figure 5 shows the BIPV house model
181 without coating.

182 **Table 4. Overall heat-transfer coefficients for the BIPV house**

Structure	Main materials (from outside to inside)	Overall heat-transfer coefficient K (W/(m ² ·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



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

186 **2.4.2 Building without PV Panels**

187 **Building not exposed to sunlight**

188 For simplicity, the house with PV panels is referred to as the “BIPV house,” and the house
 189 without PV panels is referred to as the “regular house.” Figure 6 shows the temperature
 190 measurement points on the south-facing roof of the regular house when it was not exposed
 191 to sunlight [20].

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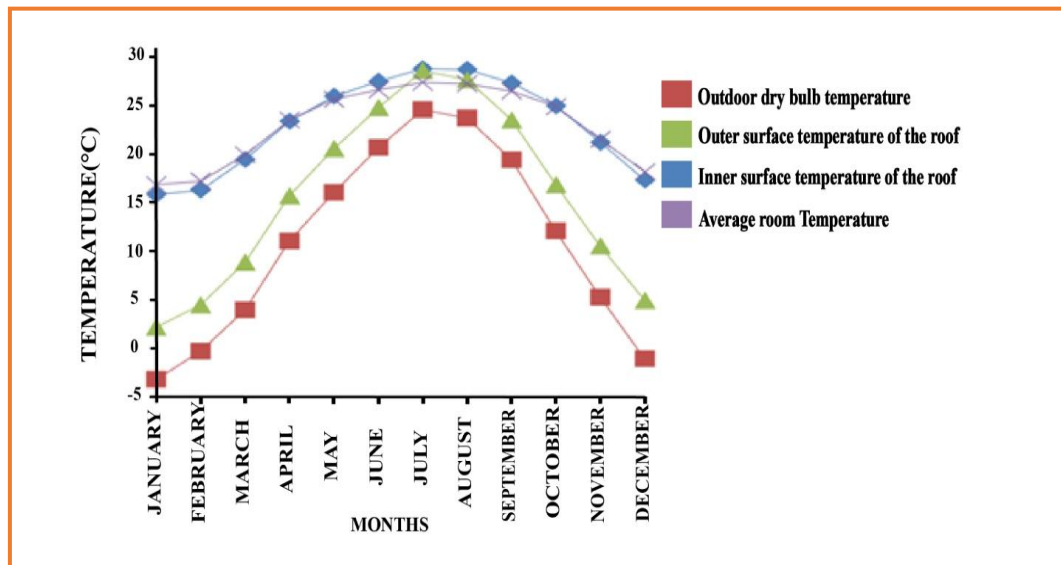
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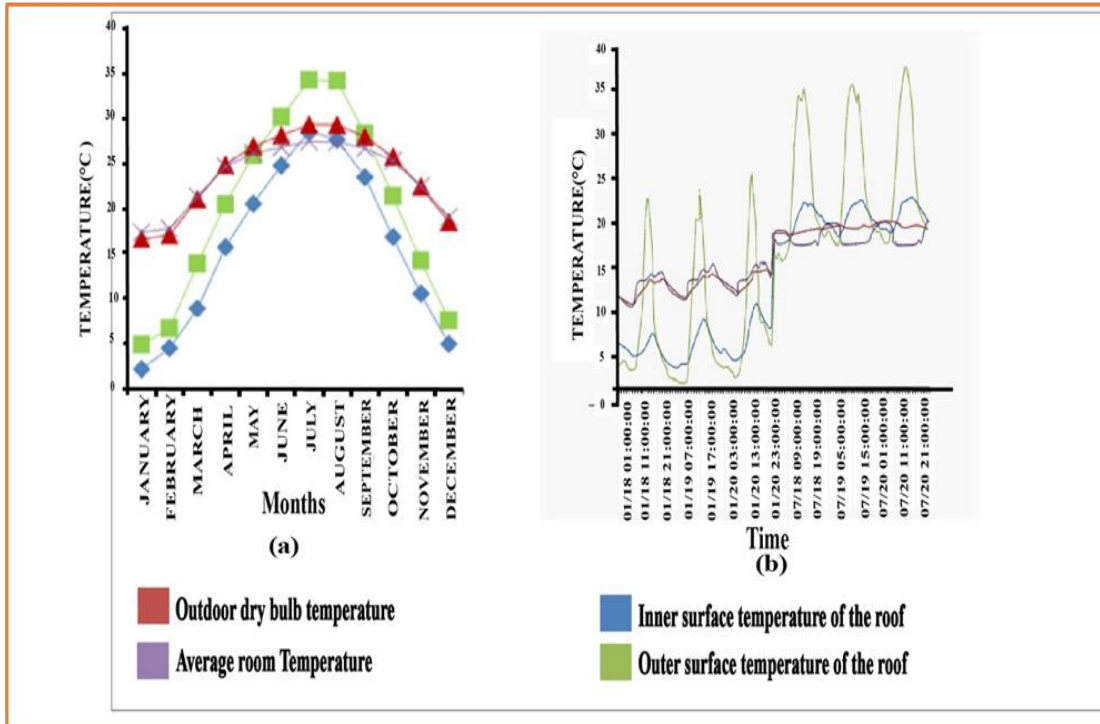
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204 **Fig. 6. Simulated inner and outer surface temperatures for the regular house not**
 205 **exposed to sunlight [25]**

206 **Building exposed to sunlight**

207 Figure 7 shows the simulation results. When the regular house was exposed to sunlight (The
208 outer surface temperature of the south-facing gable roof (measurement point 1 in Figure 7
209 (a) was always higher than the outdoor dry-bulb temperature (measurement point 3 in
210 Figure 7 (b) shows that the outer surface temperature (measurement point 1 in Figure 7)
211 was considerably higher than the outdoor dry-bulb temperature (measurement point 3 in
212 Figure 7) when the south-facing gable roof of the regular house was exposed to solar
213 radiation during the daytime. However, the outer surface temperature was lower than the
214 outdoor dry-bulb temperature during the night. The simulated results were in agreement with
215 the actual situations. PV sole module was used for the design.



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

220 **2.5 Performance Effect of Solar PV**

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

226 **2.6 Mathematical Model Formulation**

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

228
$$TZ_{PV}(\tau) = T_a(\tau) + \frac{a_t I_{SD}(\tau)}{h_t(\tau)} \quad (1)$$

229 Because of coating effect, only part of diffuse radiation projects on roof, which is obtained by
 230 $I_{SDI} = I_{Dr} \times VF$, where view factors $VF = [\cos B\tau - \cos(Bp + Br)]/2$. The radiation
 231 heat exchange between PV back sheet and roof cannot be ignored, which is represented by
 232 $Q_{bt} = \varepsilon_{br} \sigma (Tb^2 - T\tau_{PV})$, where $\varepsilon_{br} = 1/(1/\varepsilon b + 1/X_{br} - 2)$ and
 233 $X_{br} = 1 - \sin Bp/2 - \sin(Bp/2)$.

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

236
$$T_b(\tau) = T_a + I_r \times \exp(a + BV) \quad (2)$$

237 where empirical coefficient a b, were assigned to -3.562 and -0.0786 respectively. It was
 238 assumed that the heat transfer through the roof is one-dimensional unsteady heat-
 239 conduction. The indoor space was characterized by a specified internal temperature T_i .
 240 Through COMSOL solving, temperature of roof with and without PV could be obtained. For
 241 performing design cooling load calculation, radiant time series method was used. Periodic
 242 response factors (PRF) instead of conduction transfer function was conducted to calculate
 243 conduction heat gains. Then all heat gains were split into radiative and convective portions,
 244 for roof, which account for 0.84 and 0.16 respectively [6]. Once PRFs and sol-air
 245 temperatures, were known, hourly conduction heat gains $q\theta$ and the cooling and heating
 246 load Q_θ of the roof could be directly calculated, which were shown as illustrated below.

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

248
$$Q_\theta = Q_{\tau\theta} + Q_{c\theta} = 0.84 \sum_{j=0}^{23} r_j [(q\theta - j\Delta r)] + 0.16q\theta \quad (4)$$

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

254 2.6.1 Integrated energy efficiency model

255 Integrated contribution of PV roof was divided into two parts: coating benefit and power
 256 generation benefit. To study coating benefit was to determine the percentage reduction of
 257 heating or cooling load through roof between PV covered roof ($Q_{n\theta}$) and exposed roof
 258 ($Q_{PV\theta}$). The power output from PV module was converted into a heating or cooling energy
 259 according to a certain COP, which value is 5.5 for conventional air-conditioning system [16].
 260 In order to discuss the integrated energy-saving effect, facilitating to compare with
 261 conventional roof and instruct air-conditioning system design, operation and maintenance,
 262 system comprehensive energy efficiency model is

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

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2.7 Energy Balance of a Roofing System

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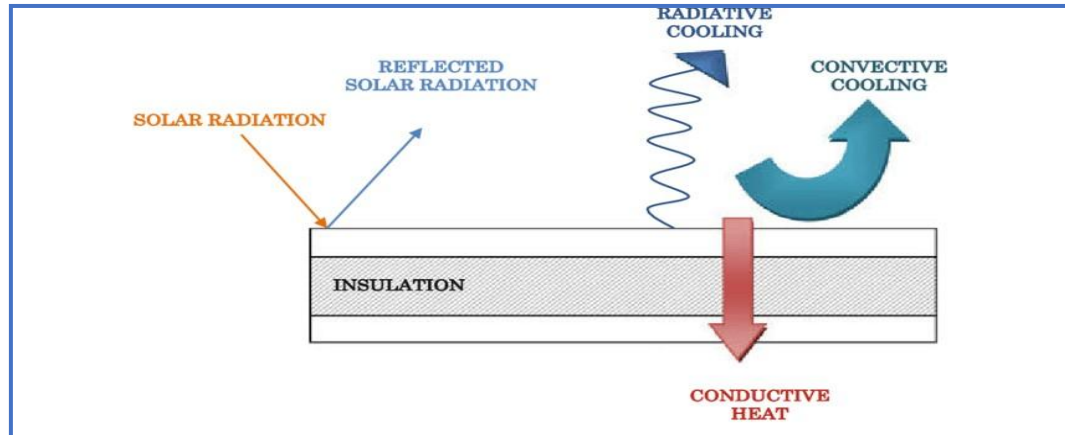
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Figure 8 shows energy balance of a roofing system that describe how solar radiation and reflection affect the roof of a building. Sun radiation is partially reflected back to the atmosphere while the rest is absorbed by the roof and other parts of 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].



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Fig. 8. Energy balance of a roofing system

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

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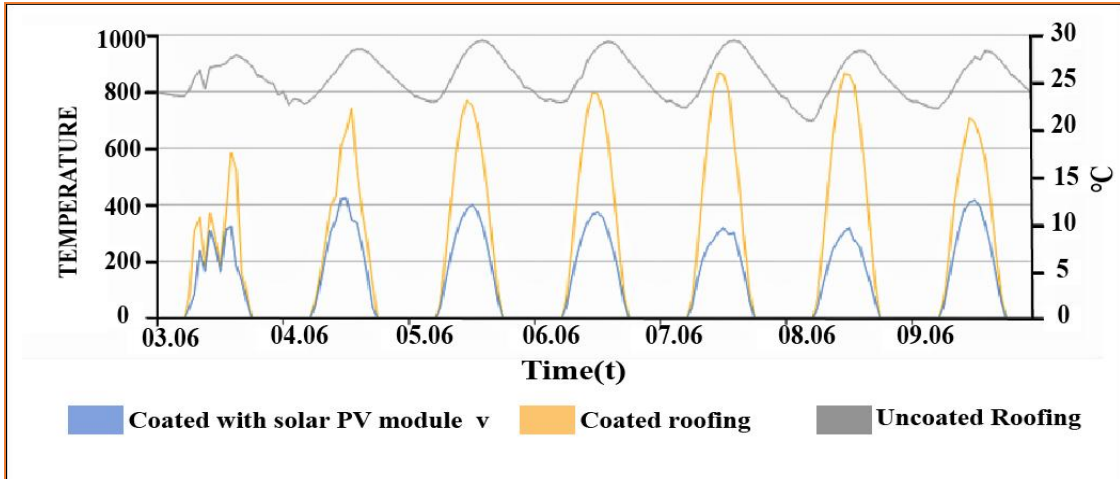
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Temperatures of roof's exterior surfaces in different forms of Building Applied Photovoltaics (BAPV) are shown in Figure 9 (b). In the daytime, due to shading, the surface temperatures of roof under PV were lower than that of exposed roof, especially 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. This confirms the results in [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.

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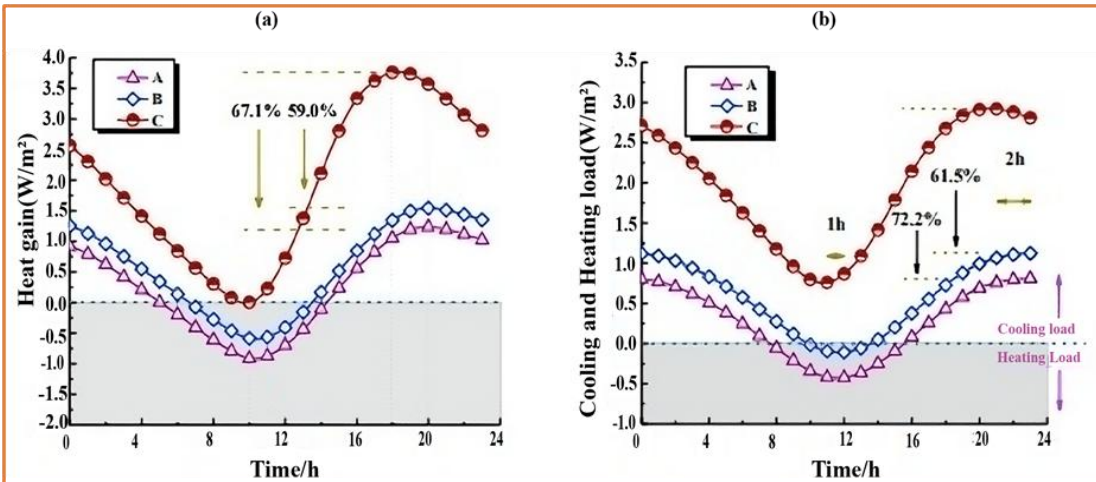
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293 Fig. 9. (a) Temperature under coated with solar PV module (b) Temperature under
 294 coated roofing (c) Temperature under Uncoated roofing system.

295 **3.2 Effect of Coating on the Cooling and Heating Load through Roofs**

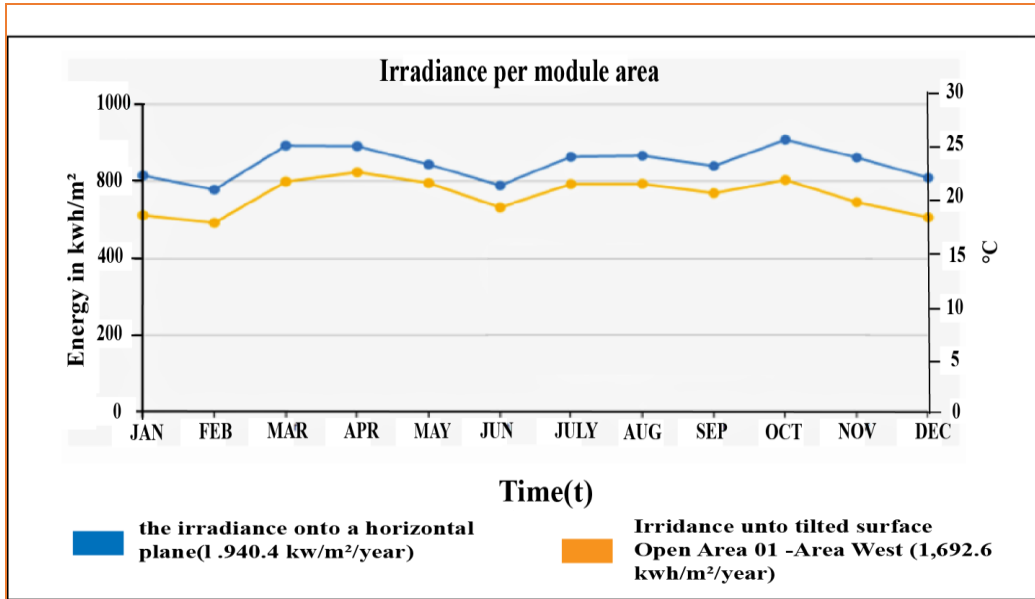
296 The effect of PV module coating on the cooling and heating load through roofs is shown in
 297 Figure 10, with measuring line. Comparing with conventional roof, heat gain and cooling
 298 load of PV roof were greatly attenuated while heating load increasing slightly. Fluctuation
 299 amplitude was relatively smooth, which confirms the result in [10]. Specifically, the peak
 300 value of heat gain through flat and tilted overhead PV roof were reduced by 67.1% and 59.0%,
 301 respectively. Among the three, the peak cooling load and the total daily load of the flat
 302 overhead PV roof were decreased by 72.2% and 77.4% respectively while that of the tilted
 303 overhead PV roof were reduced by 61.5% and 69.4%, respectively. Added photovoltaic
 304 panels also changes the thermal storage capacity of the roof as shown in [10]. The peak
 305 value of cooling load of the PV roof was delayed by 2 hours while the peak value of heating
 306 load was delayed by about 1 hour.



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308 Fig. 10. Comparisons of heat gain and cooling and heating load through roofs (A – flat
 309 overhead, B – tilted overhead, C – conventional roof) [28]

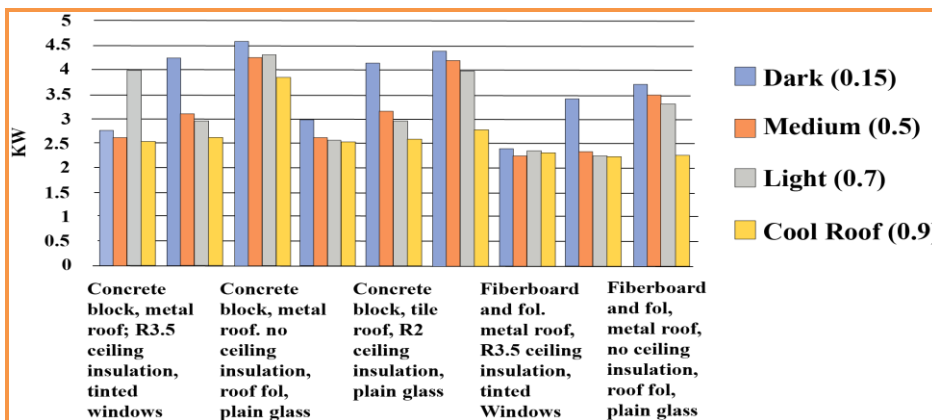
310 Irradiance on horizontal plane compare with tilted open area (Figure 11).
 311 Parameter to be considered when designing and utilizing photovoltaic system is to consider
 312 the solar irradiance. Consequently, the commonest input parameters of solar photovoltaic
 313 system are the solar irradiance, the wind speed and the ambient environment temperature.
 314 Normally before installing a PV module, both horizontal plane and the tilted plane should be
 315 considered in order to get the maximum potential solar energy. The simulated result below
 316 shows that, the irradiance on horizontal plane has a high energy production as compare to
 317 the irradiance on a tilted open area.



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

320 **3.2 Economics and Financial Impact of Roof Coating**

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



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

330 The table 5 and 6 refer to the financial comparison of building in Anaji's previous bill to
 331 current bill when solar PV was installed and the energy produced monthly.

332 **Table 5. 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

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Table 6. 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

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337 The different form of PV roofs, the deviations between air layer temperatures and ambient
 338 air temperature were less than 10%. Therefore, model hypothesis was basically proved. By
 339 solving the established model using PVSOL, temperatures of coated roofs with and without
 340 PV were obtained. The calculated values well agreed with the experimental data. From the
 341 calculation, the mean relative errors (MRE) were all below 10%; and the accuracy of Power-
 342 Added Efficiency (PAE) were all beyond 95% throughout the measuring period. On account
 343 of this, the proposed thermal model of PV roofs can be considered reliable. In terms of
 344 electricity bills and energy consumption, mean average percentage errors (MAPE) as applied in

345 [15, 29, 30] was used as performance metric. For the electricity bills, the MAPE for coated roof
346 with and without PV are approximately 46.07% and 41.31% respectively. The values imply that
347 on average, the electricity bills for coated roof with PV deviates from the bills of uncoated roofs
348 by approximately 46%, while the bills for the coated roofs without PV deviates from that of the
349 uncoated roofs by 41% approximately. Thus, for the coated roofs with PV, monthly electricity
350 bills are reduced by 46% (GH¢ 340.21), and a monthly reduction by 41% (GH¢ 303) in the case
351 of the coated roofs without PV. The energy consumption was associated with a MAPE of about
352 47.26% for coated roofs with PV, and a MAPE of 44.71% for coated roofs without PV, indicating
353 that the coated roofs with PV saves energy by approximately 47% (28.86 kW) on average while
354 on average, the coated roof without PV achieves energy savings by 45% (25.91 kW)
355 approximately. The proposed integrated coated roof with PV module outperforms the coated
356 roof without PV module by approximately 5% in terms of electricity bills and 2% in respect of
357 energy consumption.

358 359 **4. CONCLUSION**

360
361 The impact of roof coating and solar photovoltaic was performed based on one particular
362 building at in the Anaji area of Takoradi. Coating and photovoltaics are two key benefits of
363 roof added photovoltaics. Analyzing integrated contributions of the two has a vital
364 significance for the prediction of building consumption. In this paper, a comparison of the
365 performances of coated roofs with and without solar PV module was made. The roof
366 surfaces underneath the PV panels, especially under tilted PV panel, were coated,
367 therefore, the temperature was significantly lower than that of the exposed roof in the
368 daytime. At night, the roof surfaces under the solar panels remained warmer, due to the
369 reduction in radiative cooling to sky, especially for flat overhead PV roof. Heat gain and
370 cooling load of roofs under PV panels were attenuated significantly while heating load
371 increasing slightly with a smoother fluctuation. Added PV panels also changes the thermal
372 storage capacity of the roof. Considering total benefits of coating and power generation,
373 system integrated energy efficiency for flat and tilted overhead PV roofs were 63.35 % and
374 62.73 %, respectively. The monthly energy savings associated with coated roofs with solar PV
375 module is 28.86 kW or a monthly savings of GH¢ 340.21 (GH¢ 4, 082.52 annually) on
376 electricity bill; while the monthly energy savings for coated roofs without PV is 25.91 kW or a
377 monthly savings of GH¢ 303 (GH¢ 3,636.00) on electricity bill. Thus, overall, the proposed
378 integrated coated roof with PV module outperforms the coated roof without PV module by
379 approximately 5% in terms of electricity bills and 2% in respect of energy consumption.
380 Reliability of the proposed integrated coated roofs with solar PV system was assessed. Inferring
381 from the computations, the mean relative errors (MRE) were all less than 10%. In addition,
382 the accuracies measured by the Power-Added Efficiency (PAE) were all above 95%
383 throughout the measuring period. Based on these values of MRE and PAE, the reliability of
384 the proposed thermal model of coated roofs integrated with PV modules has been
385 established. This integrated coated roofs with PV module therefore, outperforms existing
386 coated roofs without PV systems. This plays a twin role as a sustainable and cost-
387 effective/efficient source of energy; and as a key strategy to achieving sustainable
388 environment through the principle of greening.

389 390 **COMPETING INTERESTS**

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392 Authors have declared that no competing interests exist

393 394 **AUTHORS' CONTRIBUTIONS**

395
396 Authors WP, WA and SAM conceived the idea, designed the study, conducted literature
397 review, handled the methodology and data gathering. Author JAA managed the validation of

398 the model, and performed the analysis. Authors WA and JAA performed editing activities
399 and wrote the first and final drafts of the manuscript. All authors read the final state of the
400 manuscript before submitting to the journal.

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