Analysing the Execution of a Building Unifying with Concentrating Photovoltaic System and Phase Change Materials

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Abstract

Building Unifying with Concentrating Photovoltaic (BUC-PV) systems are seamlessly incorporated into building envelopes, replacing traditional construction materials while offering benefits such as on-site electricity generation, enhanced radiant efficiency, and improved thermal management. This research introduces an innovative empirical assessment of Phase Change Materials (PCM) to enhance the efficiency of less-concentrated BUC-PV systems through heat transfer mechanisms. Unlike previous studies, which focused primarily on transient and spatial temperature analyses of PCM within constructed systems, this experiment examines the impact of paraffin-based PCM on the electrical energy output of the current setup. Addressing the limitations of the initial system, an advanced evaluation model is proposed and validated through controlled indoor experiments. Wax-based RT42 (paraffin) was used in a custom PCM enclosure. An indoor test was conducted using a steady irradiance of 950 W/m^2. Results demonstrated a 7.57% increase in electrical energy efficiency with the integration of PCM. Additionally, the BUC-PV–PCM system exhibited a mean module temperature reduction of 4°C compared to a PCM-less outdoor system. The experiment also revealed that PCM performance varied with irradiance flux density, showing an efficiency increase of 1.4% at 600 W/m^2, 5.0% at 700 W/m^2, and 7.0% at 950 W/m^2.

Keywords: Concentrating Photovoltaic, Phase Change Materials, RT42 Wax, Irradiance, Experimentation.

1. Introduction

BUC-PV systems are rapidly emerging in the solar industry, with an estimated growth of over 55% between 2011 and 2017 [1]. Applications include shading devices for windows, translucent glass exteriors, exterior siding, railing units, and rooftop systems [2].

Building-Incorporated Concentrating Photovoltaic (BUC-PV) systems focus solar flux using reflective elements such as curved mirrors or refractive concentrators like lenses. These design structures offer advantages over traditional Building-Integrated Photovoltaic (BIPV) systems with flat panels, such as improved efficiency, better floor space utilization, recyclability, and the use of low-toxicity materials in PV cell manufacturing [3]. Collectors with a minimal geometric concentration ratio (Cgo10 – Gadolinium – doped ceria) are often static, simplifying the system's design [4]. However, BUC-PV systems face challenges due to temperature increases, which result in reduced electrical efficiency and thermal overload. Therefore, lowering the temperature in the units is crucial and can be achieved through draft ventilation and external heat dissipators [5]. A decrease in PV unit efficiency due to temperature rises is primarily caused by a drop in the open-circuit voltage, which is related to the Number of Transfer Units (NTU) [6]. Silicon-based solar units convert less than 22% of solar irradiance into electrical energy, making them cost-effective [7]. Light particles that are not converted are dispersed as thermal energy within the cells. As solar irradiance peaks, the unused solar energy is almost uniformly redistributed within the thermal sink [8]. The efficiency of silicon cells decreases by approximately 0.5% for every degree increase in temperature [9]. Effective thermal management and maintaining uniformity across the module are essential to avoid hot spots, which can cause current imbalances and reduce overall system efficiency [10]. The current incorporation of PV and PCMs for thermal regulation offers a prospect to prolong its function into BUC-PV systems. Utilizing paraffin's could indifferently hold the heat level of BUC-PV in an optimal working parameter and compile the refused thermal energy for possible rejuvenation. PCMs function in designated temperature spans or sustain almost temperature in constant [11], using their Thermal energy of integers to shield contrary to variations of temperature [12]. They are implemented in heat control of systems to improve the effectiveness by incorporated with brickwork [13]. They are also engaged as heat storing units for purposes like solar distil [14]. PCMs in large-enclosed form could be incorporated into aerated exteriy within their air gaps to expedite natural lighting and space heating [15], alongwith less-energy and natural heat reduction of systems [16, 17]. They are also used as featherweight heat extorted overhead modules [18], incorporated as dynamic PCM with thermally better ventilations [19], improving heated water staked by segregation [20], and as pavers for building usages [21]. Furthermore, PCMs are used in floor provision A/C units with heat storage using coarse PCM [22], amid other uses. PCMs have been engaged for their heat capacity in A/C systems to ease the variations in everyday cooling loads. This has enhanced to incorporate PCMs with refrigeting unit, bringing about stoking of energy and improved control [23]. PCMs are classified into natural, artificial, and eutectic types, as shown in Fig. 1. The strategical benefits of PCMs in phase change energy storage units over apparent heat storing units, like hydro, include: little variations in temperature because of decreased temperature difference between loading and unloading thermodynamic cycles [24]. Although, limitations of utilising these structures comprise the verity that PCMs, in particularly natural ones, have less convective heat transfer. Besides, change of states like sublimation and evaporation are linked to the substantial Spatial shift [25]. Unlikeable parameters of the material transitions because of cycle process, state demixing, and below saturation cooling demanded thorough the research before effectuating PCMs [26]. Besides, the spillage of PCM in its dissolved phase poses functional limitations to their thriving practicality in different systems. insulating methods, like shape reinforcement attained by incorporating PCMs into aiding materials or insulating PCMs filled in shells, gives valuable remedies to PCM spillage problems. These SS-PCMs are segregated like composite's of PCMs and encapsulated PCMs [27]. HDPE substance, settled through interconnecting, is mostly employed as an aiding substance for Phase Change Materials because of its high strength of its framework. Potential alternatives to show less conventional heat transfer coefficient in Phase Change Materials contain: Enacting enhanced methods of heat transfer to improve the rate of loading and unloading. Integrated with peak convective heat capacity of materials into the PCM.

Conventionally, metal embeds utilised with paraffin comprise: Al in the guise of like gauze, powder, alumina foam, and gauze etc. Co (Copper) in the guise like suds and platters utilised as fins. SS (stainless steel) in the guise like fins and screens. C (Carbon) fiber in the guise like woven sheets and brushes [28]. Blend of PCMs with additives are known to exhibit enhanced heat transfer capacity. For situation, Analysis have illustrated heat transfer capacity enhanced with 13% (with fusing temperature Tm=41–43°C) and 25% (Tm=55–59°C) by included enlarged and shed graphite at a rate of 4% by mass. This improvement is ascribed to the heat conductive structure offer by the pore morphology of shed graphite [29]. In addition to the heat transfer capacities of blend of PCMs illustrated a direct correlation (with a coefficient of enhanced correlation r=0.997) to the mass fraction of the improved substance, like shed graphite in this scenario. An enhancement of 82 %, 137 %, 210 %, and 275 % in heat transfer capacity of the blend of PCM was perceived with percentage of fractions of mass of 3 %, 4 %, 8 %, and 11 %, respectively, then to unadorned paraffin [30]. The assortment of PCMs can be taken into contemplate the following standards based on their important properties like thermal, physical as well as eco-safety concerns. (a) Temperature at shift of state occurs drip under the spectrum of desire [26], (b) elevated phase change heat, heat capacity, and heat conductive capacity [31], (c) Less volumetric augmentation and less or negligible under cooling during congealing [32], (d) Innocuous, rustproof, flame resistance, inert, and unreactive. Assortment requirement may also contain aspects like feasibility of full or intermediate buffer, thermal parameters while solidifying and thawing, and credibility in recurring cycle [33]. The options of paraffin for peculiar BUC-PV systems must be relies on these criterial. focused approach and tier, obtainable intensity of radiation, configuration of the system, working heat level of cells made of silicon, restraint material, and layout. Moreover, loading / unloading ratios, heat interchange surface, and heat convective capacity of the heat transfer container material engage important responsibility [34]. Regardless of the substantial writings on BUC-PV systems, assessment work employed into PCM cooling applications hasn't been noted till date. Motive of the analysis was to construct an incorporated BUC-PV–PCM block, aiming on securing and heat for cooling on the BUC-PV side using PCM to improve the efficiency in electrical. In addition to, this research is to analytically assess and analogize the hike in efficiency of electrical attained by using the similar PCM at various solar radiance grades in a restraint enclosed surroundings. The analysis narrow on experiments the heat transfer restrictions given by a Natural PCM and its outcome of the block's effectiveness of electrical by atmospheric heat level limits (16–30°C) and RH between 26% and 38%. Solar radiance levels (4) were selected: 600, 700 and 950 W/m^2, included a wide spectrum to analyze the PCMs efficiency. Natural paraffin based PCMs were chosen for this research because of those properties like high phase change heat of fusion, low super cooling, chemical stability, lower vapor pressure and etc. In [35], the researcher's analysis of energy storing methods, explored the phase change heat storage mediums, including PCM. They division the PCMs into three different groups based on their promising levels on properties like fusing temperature (Tm), phase change heat (H) and number of C atoms. Assessment methods for selecting fusion temperature (Tm) and phase change heat (H), like DTA and DSC using aluminum oxide as the standard material. Besides, heat related properties of various PCM enclosed materials like Al, Co, amorphous materials, SS, etc., are summarized. Mathematical simulations of phase change heat storing systems, incorporating enthalpy formulation and working out the moving boundary, have been proposed and addressed using mathematical correlations by the control volume method innovated by Voller [36] and Patankar [37]. Huang et al. [38] deal the importance of the temperature control on enhancing the efficiency PV. At first, they analyzed 3 formations: (i) a lone flat plate system made of Al, (ii) PV with Paraffin model devoid of fins in inside, at last (iii) Photo Voltaic–PCM plan with internal ribs utilizing Paraffin (RT25). A 4.5 mm plate made of Al was used to made the PCM system with the design parameters of (L = 300 mm, W = 40 mm, H = 13 mm) and included two full-length fins with 30 mm wide.

Layout (iii) sustained the frontage temperature below 35°C for 90 minutes using lone PCM under 950 W/m^2 solar radiation (atmospheric temperature - 20°C), whereas it persisted under 33.5°C for 140 minutes with further PCM under 700 W/m^2 solar radiation. The incorporation of fins made of metals under the Paraffin enclosure also indicates vital progress in effectiveness in thermal. Further analysis done by the same, assessed the working of two kind of paraffin (RT 42 paraffin and Grade 40) in controlling temperature hike in PV Modules. They attained reduction in temperature of past 30°C utilizing RT25 with interior ribs. Quarter of points of systems were defined at 700 W/m^2 (atmospheric temperature 38°C), Such as: (i) Flat plate made of Al, (ii) Flat plate made of Al with 11 extended surfaces (fins), (iii) PV–Phase Change Materials module, and (iv) PV–Phase Change Materials module with 31 Al fins (within the PCM) utilizing RT42. The impact of fin properties on limiting temperature can be described follows: The various fin spacing in an upright alignment results that a spacing of 8 mm almost halves required fins than the first set spacing. In addition to, the 8 mm spacing supporting a higher amount of Paraffin while controlling the temperature below 29°C. The module with 4 mm, quickly fusion, directing to a quicker decline in frontage temperature because of their peak heat transfer ratio. The temperature variance between module with 12 mm and 4 mm fin spacing was only 1°C. The ideal design parameters under 8–12 spacing utilized lesser fin and maintained low heat level for prolonged time period. Within the five extended dimensions (27, 30, 33, 36, 40 mm), the last one executed better in controlling the PV front face at 30°C for the longest time of 2 hours. There was a direct relationship between width of the fin and the retention duration of temperature, other than for 30 mm and 33 mm, which describes effects. Three type strips such as Al matrix, Soft-Fe wire without coating matrix, and 36 mm straight fins. Within these, the last one produced the least temperature and quickest to phase change. The outcome, mathematical simulations, and study addressed in this segment limiting the importance of Phase Change Materials in cooling components made of electronic things and controlling the PV heat level. These outcomes guiding the way for furthermore implementation of Phase Change Materials in BUC-PV arrangements. This study presents the first empirical investigation of using Phase Change Material (PCM) for temperature regulation in BUC-PV systems, introducing a novel approach to improving solar panel efficiency. By integrating a PCM-based heat absorber, the research demonstrates significant temperature control, resulting in enhanced electrical efficiency and power output across varying levels of radiant flux. The findings highlight the potential of PCM to reduce overheating, improve energy storage, and extend the lifespan of photovoltaic modules, with applications in building-integrated photovoltaic systems and sustainable energy solutions. Additionally, the study offers an improved mathematical model for further optimization, contributing valuable insights into the thermal management of solar panels.

2. Design layout and fabrication of the Building-Incorporated Concentrating PV System with Phase Change Materials

2.1 Building unified CPV–PCM system

Fig. 2(a) shows the fabricated Building Unifying with Concentrating PV module, while Fig. 2(b) gives the information about the dimensional constraints of the unidirectional skewed combined parabolic accumulator with approval half-angles of 0° and 55°. The experimental model for the PCM heat accumulators were manufactured utilizing 12 mm thickness walls made of acrylic sheets, under the design parameters of 140×130×40 mm^3 inside and of 170×160×44 mm^3 outside.

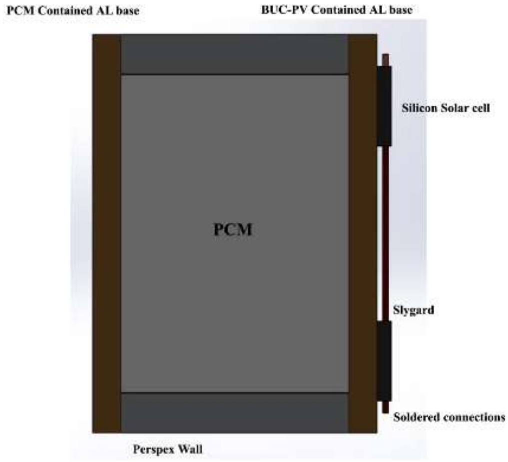


Figure 1. Profile view of fabricated BUC-PV PCM system.

The rear plate made of Al (0.06 cm thickness) of the Building Unified with Concentrating PV system works as the hood for the paraffin contained module, with additional plate with same thickness made of Al as its base. This layout is rooted on altered thermal correlations, as shown in Equations below. Based on the current offered writings, the balancing of energy for a Building unified with Concentrating PV – Phase Change Material system is described as follows:
T is smaller than mean T, the affiliation is given by

$$Al\ \Delta_t = A\ (h_1+h_2)\ (T_{pv,t} - T_{amb})\ \Delta_t + (T_{pv,t} - T_{pv,t})\ (\boldsymbol{\rho} C_p \Delta_a) \quad (1)$$

The phase shift for the energy balance

$$Al\ \Sigma\Delta_t = A\ (h_1+h_2)\ (T_m - T_{amb})\ (\Delta_t + H\Delta_a) \quad (2)$$

The presumptions are:

- Primary thermal balance between the Building Unifying with Concentrating PV and PCM
- Values of h1 and h2 are constant
- Apex and base heat-isolated limits of the module

These correlations present numerically varying for the following reasons:
Equation 2 is dimensionally inconsistent in its last instance, which could be evaluated by taking in to the account the concentration of Phase Change Material and exclude varying area (A) from the correlations.

$$L\ \Delta_t = (h_1 + h_2)\ (T_{pv,t} - T_{amb})\ \Delta_t + (T_{pv,t+}\Delta t - T_{pv,t})\ (\boldsymbol{\rho} C_p \Delta_a) \quad (3)$$

$$L\ \Sigma\Delta_t = (h_1 + h_2)\ (T_m - T_{amb})\ (\Delta_t + \boldsymbol{\rho} H \Delta_a) \quad (4)$$

This transfer of energy does not report for the efficiency of electrical transfer of the solar cell (typically under 20%), applying that all of the available solar radiation intensity is transferred into heat, with no effects on transfer of electrical energy taking place within the Building Unifying with Concentrating PV module. Another energy balance correlation for the Building Unifying with Concentrating PV system, taking in account it as an unsteady heat transfer instance in one dimensional space and summarizing for the dimensional parameters of the collector, could be noted as shown in Equations. (5) and (6). The term specifies the part of solar intensity that is not included to electricity, generall 0.8 of the accessible solar intensity. According to the presumptions presented above (i) to (vi), and also taking in the account such (iv) the Paraffin is unblendable, inert and uniform, (v) transfer of thermal deviations happens initially free convection and thermal conductivity, and (vi) losses in radiation and resistance in thermal balance between the Phase Change Materials and walls, and between Phase Change Materials and PV are ignored, the altered correlations are projected as follows:

$$I\ (1 - \eta_{elec})\ C_g \Delta_t = (h_1 + h_2)\ (T_{pv,t} - T_{amb})\ \Delta_t + (T_{pv,t+}\Delta t - T_{pv,t})\ (\boldsymbol{\rho} C_p \Delta_x) \quad (5)$$

$$I\,(1 - \eta_{elec})\,C_g\Sigma\Delta_t = (h_1 + h_2)\,(T_m - T_{amb})\,(\Delta_t + \boldsymbol{\rho} H\Delta_a) \tag{6}$$

These correlations work as the base for studies about thermal analysis in Building Unifying with Concentrating PV–PCM systems, using a three-dimensional analysis volume approach where heat flows right angle to the solar intensity. This method presumes ignorable transfer via the walls because of the very less heat transfer Capacity of Perspex (0.0001875 kW/mK).

2.2 *The fabrication approach and materials*

Concentrators with low concentration and a concentration factor (2.7) were fabricated diaphanous LC optics 200 transparent Urethane Resin, which is a mixed in a ratio of 10:9, as précised by [39], 6 Photon beam Striated Buried Contact clear silicon cells, each with proportions of 0.116×0.006 m^2, were fused sequentially in series with fine tin-plated copper foils. This segment was built on an Al rear panel to assure better heat conduction encased in Kapton Film to insulation for electrical. An insulator, Silicone Rubber (Sylgard 184), was drenched over the solar module compilation and allowing to set for a day at ambient temperature, forming a consistent layer. This technique assured better optical linking between the optics and the welded cell structure, working as a bond and a protective film against physical destruction. An added fine film of treated silicone addition to deterred peeling at increased heat. An Acrylic sheet (Perspex) was removed to create the barriers, and apertures were pierced. An Al plate was carved to the dimensions and adhered under the Acrylic barriers by adhesive binder (epoxy). Binder made of silica was utilized to bond the crest Al cover to the wall width. In addition to, the fastened walls were secured by the same binder to assure a hermetic bond between the faces and corners. Paraffin Rubitherm (RT42), with a fusing range of 37-44°C, was chosen as the Phase Change Materials for temperature control of the incorporated with BUC-PV module. Thermal parameters of the elements of the BUC-PV Phase Change Materials module are emphasized in Table 1.

Table 1. Thermal properties of elements of BUC-PV PCM system.

Element	Solar cell	Concentrator	Base plate	Heat Shield	Encapsulation	PCM
Substance	Si	Crystal Clears	Aluminium	Kaptons tape	Sylgards 184 Silicone	RT-42s
Density (kg/m^3)	2328	1025	2690	_	1119	_
Thermal Conductivity (W/mK)	152	_	212	_	0.32	0.19
Max. Operational Temp (°C)	_	_	_	180	_	90
Temperature range	_	_	_	_	45 to 200	4 to 72

2.3 *Research Approach*

The BUC-PV Phase Change Materials module was depicted at 0° from Horizontal illumination is achieved using Super Solar Simulators by the Wacon, which provide extremely aligned light. Figure 3 displays a layout diagram of the experimental apparatus along with locations of the chosen heat level focusing nodes. K-type Quartet temperature sensors were fastened to the backside of the BUC-PV system using Al adhesive tape to improve heat transfer and precise measurements of heat level. Another set of K-type quartet thermocouple was affixed to the internal surface of the Al base segment. These positions are selected to examine the fluctuations of heat level throughout the mid and edges of the system, investigating how temperatures are distributed beneath the plates.

I–V characteristics of the system were analyzed by the EKOMP-160i I–V Tracker equipment, while temperature measurements were simultaneously taken using the Keithley 2700 DMM Data Acquisition for collection and Data Logging System for tracking. Data were collected continuously over a period exceeding 2 hours, with readings taken at 5-minute intervals. The Test of 608-H1 hygrometer was used to monitor atmospheric temperature and relative humidity.

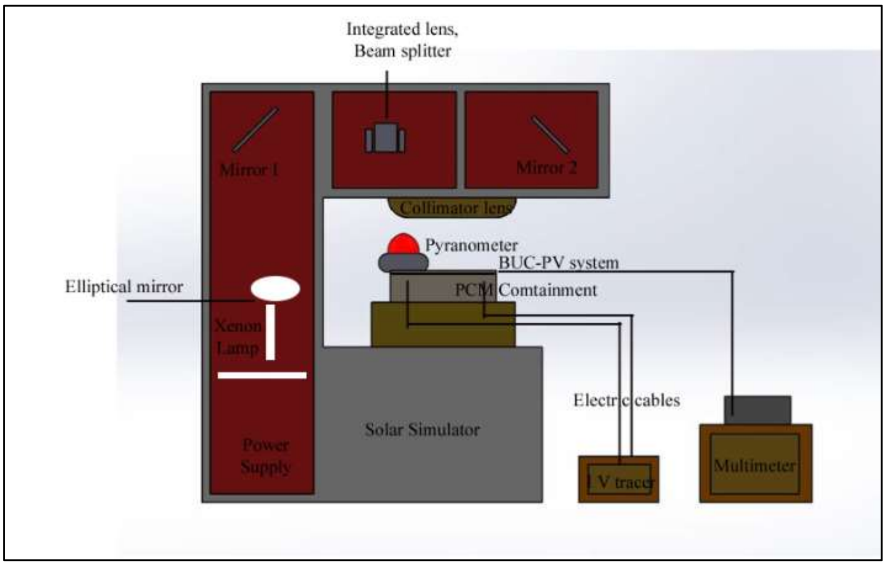


Figure 2. Experimental layout of BUC-PV PCM System.

3. Result and Discussions

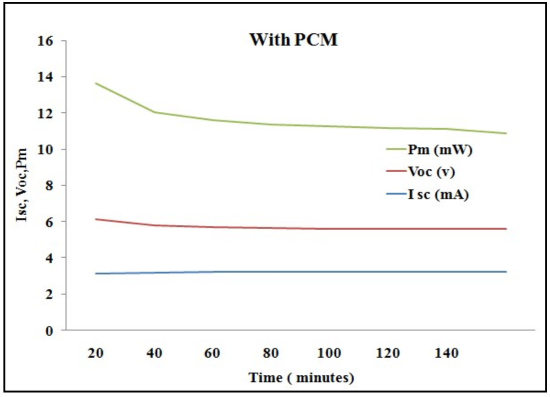
3.1 The E-properties of the system

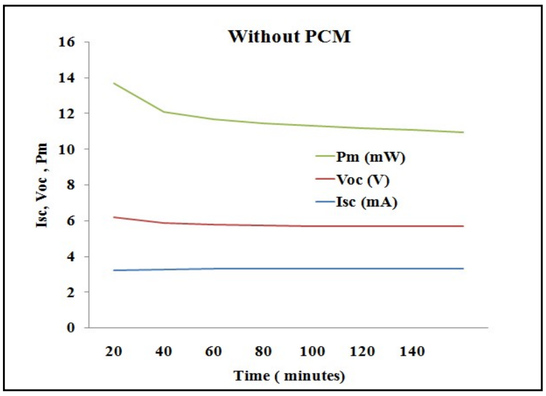
The surge current (ISC) and terminal voltage (V_{OC}) are crucial factors in the IV characteristics of a PV system. I_{SC} and V_{OC} both fluctuate in response to incident irradiance and module temperature; I_{SC} varies nearly proportionally with irradiance, whereas V_{OC} changes are minimal. On the other hand, V_{OC} decreases as module temperature rises, leading to a notable decrease in electrical power output, despite I_{SC} showing a modest increase [47]. Experimental evidence indicates that elevated module temperatures result in a decrease in the peak yield power (Pm) of the Al base system. The BUC-PV system with phase change material was exposed to solar simulation at 950 W/m^2 irradiance, positioned horizontally at 0°, for a duration of 1.45 hours. Figures 4(a)-(c) illustrate the I_{SC}, V_{OC}, and Pm curves gradually for the BUC-PV system, both with and without Paraffin. The incorporation of PCM led to higher V_{OC} and Pm because of the reciprocal relationship of heat level, when I_{SC} exhibited a relative decrease. At the outset of the analysis, the voltage enhancement in the BUC-PV phase change material system showed only a slight increase. This enhancement persistent to grow as the examine advanced, with an alike trend noted in the difference in PCM. The average V_{OC} was 2.49V without PCM, and it rose to 2.63V with Paraffin, marking a 6% rise.

Table 2. Analysis outcome of BUC-PV.

Description	Tc, Min	Tc max,	I_{SC}, min	I_{SC}, max	V_{OC}, min	V_{OC}, max	Pm, min	Pm, max
	(°C)	(°C)	(mA)	(mA)	(V)	(V)	(mW)	(mW)
Without PCM	15	55.23	320	328	2.5	3	520	743
With PCM	25	49	318.2	2.8	2.7	3.1	607.2	707
Change (%)	62	11.5	1	1.74	8.3	0.3	16.5	5.1

demonstrates that the minimum Pm output with paraffin was approximately 17% more than without Paraffin, thanks to the control over heat capacity provided by the Paraffin. Nevertheless, the peak Pm value was more for the PCM less scenario by 5%, possibly because of low atmospheric temperatures during startup. After 15 minutes of running the experiment, the Pm with PCM surpasses that without PCM. Like temperature variations, Pm exhibits a rapid decline within the initial 30 minutes with PCM (as opposed to 60 minutes without PCM), followed by stabilization. The duration could be influenced by the fusing heat level range of the Paraffin used in the examine. Following 70 minutes of running the experiment, Pm stabilized with minor fluctuations around 0.008 W for the remainder of the period with PCM. In the absence of paraffin, Pm stabilized at a period after 1.10 hours then subsequently declined more after 1.50 hours (refer to Figure 3). In summary, the mean Paraffin Less Pm was 0.582 W, whereas with Paraffin, it rose to 0.627 W, indicating a comparative effectiveness improved of 8%. This system achieved a full power conversion effectiveness of 6.5% without PCM cooling, which increased to 7% with the paraffin in the system. Figure 3 illustrates the comparison of percentage changes in Pm and Tc at 30-minute intervals, where negative values denote a decrease over time. Figure 3 illustrates the I-V system characterizations without Paraffin, while Figure 4 shows the I-V characteristics with PCM.





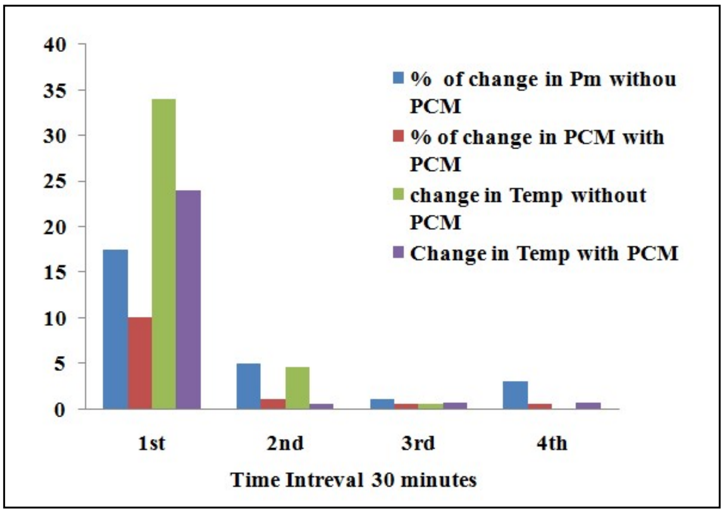


Figure 3. BUC-PV parameters comparison and its % of change with respect to Time.

3.2 Impact of divergent solar flux

The analysis explained in before portion was frequent for 120 minutes utilizing various layers of solar flux (600, 700, and 950 W/m^2) to estimate the effectiveness of phase change material usage comparative to attainable flux. The effect of raising flux potency on phase change material efficiency, V_{OC}, I_{SC}, and Pm are described in Fig. 4 sequentially. It should be recorded that the analysis was executed for a lesser period, thus correlation have been made beyond nearly 125 minutes. As predicted, maximum flux strength yielded in a raise in Pm. Nevertheless, this raises in Pm was not linear related to the raises in flux when utilizing phase change material, specifically at maximum strength. The corresponding raises (expressed as a %) in electric energy utilizing phase change material by the BUC-PV system was noted as 1.14% at 600 W/m^2, 4.21% at 700 W/m^2, and 6.82% at 950 W/m^2. It's remarkable that at 950 W/m^2, the roses the peak Pm with phase change material is nearly 1.2% less. This could be because of inadequate phase change material thickness or the fusion range of the phase change material. The exact mean correlations of peak power (Pm), surge current (I_{SC}), and terminal voltage (V_{OC}) with PCM and without PCM are described in Fig. 5(e)–(g). The fluctuation ranges in V_{OC} and I_{SC} were estimated as 1.5% (1.2%) at 600 W/m^2, 2.5% (0.6%) at 700 W/m^2, and 3.8% (3.7%) at 950 W/m^2. The outcomes represented this specific phase change material has an additional emphasized impact at moderate levels of flux and is below efficient at maximum levels. This could be assigned to the maximum fusion limit of the pcm, which equates to heat capacity formation in the BUC-PV plate at those maximum strengths.

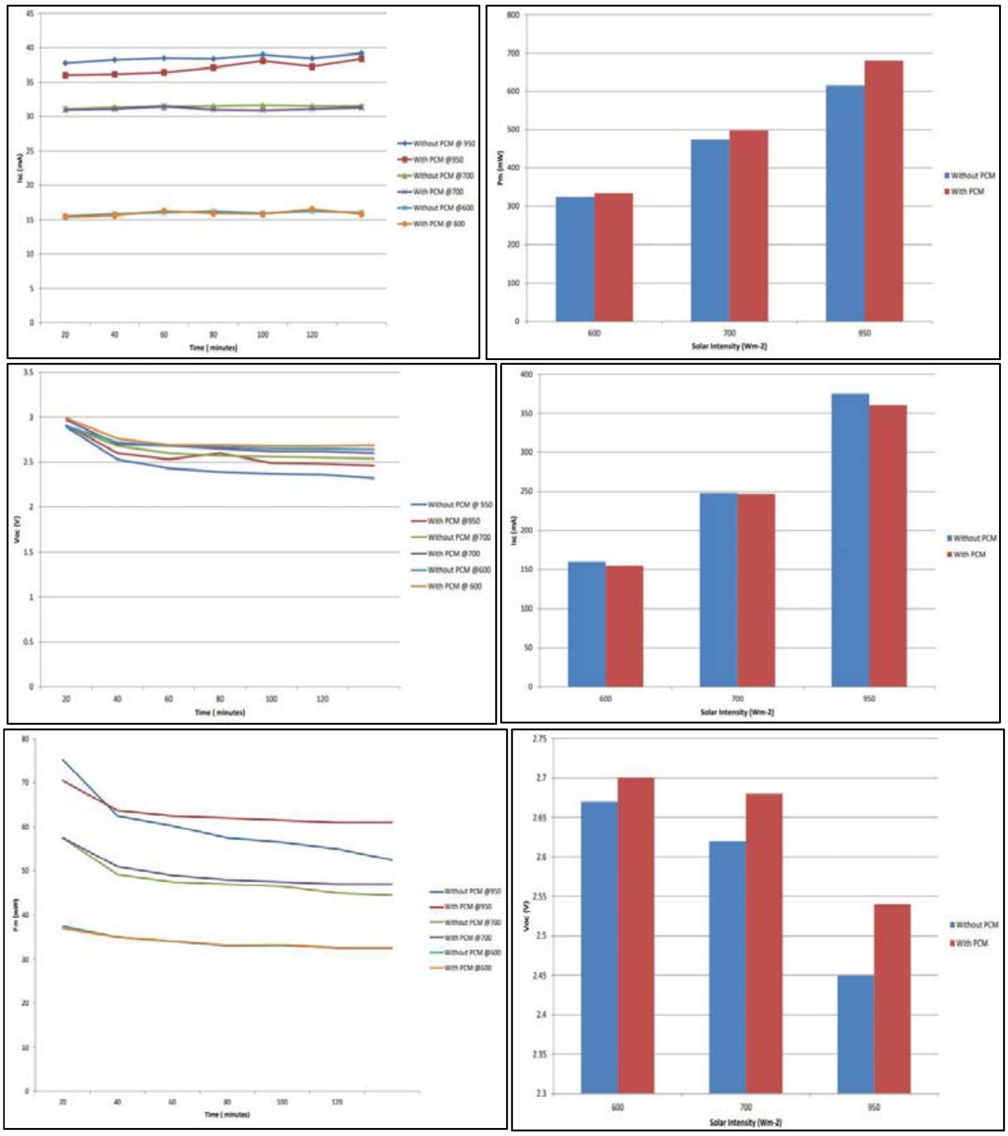


Figure 4. BUC-PV system: comparison of the Properties of I_{SC}, V_{OC}, Pm with respect Solar intensity for Elapsed time.

3.3 Temperature pattern

The middle temperature (Tc) of the BUC-PV segment noted at 5-minute periods is graphed in Figure 4. Contrasting mean Tc reached by the PCM less and the PCM arrangements, it was calculated that Phase Change Material usage decreased the mean heat level about 3.7°C in this period. The period of analysis impacts the heat level variation; functioning the analysis for extended period may balance the entire heat level with phase change material captivating all potential heat. The peak Tc attained was 2.9°C greater under Phase Change Material and 4.9°C greater Phase Change Material less contrasted to the mean Tc in each instance. An analogy of the variations in peak power (Pm) and Tc is shown in Figure 4 for each condition. In course of the first 30 minutes of functioning the replicator, the middle temperature raised by 32°C without PCM (23°C with PCM) from an atmospheric heat level of 16°C (25°C with PCM), outcome in an 18.4% energy loss (10.1% with PCM). Correspondingly, in the succeeding 30-minute period, Tc raised by

4.6°C without Phase Change Material (0.5°C under PCM), guide to conservation power of 4.7% (1.1% under PCM). Later 60 minutes, the heat level raise in each instance was limited. As shown in Table 2, utilizing Phase Change Material decreases the peak segment heat level, $T_{c,Max}$, by 11.5% contrasted to the non-PCM arrangement. The 63% raise in the lower heat level, $Tc_{,Min}$, with Phase Change Material utilization contrasted to the non-PCM arrangement is because of greater atmospheric heat levels at the initial state of the analysis. The fusion range of the Phase Change Material is 37–42°C, which is moderately below than the heat level at which the BUC-PV segment heat level balance (around 46.4°C) to the end of the 2-hour analysis. The base plate of the Phase Change Material restraint has been assembled utilizing aluminum to scale regardless the quantity of heat capacity (total PCM fusing) could be utilized for other restoration objectives, such as household water heating. This, in revolve, could additional enhance the entire arrangement capability by assisting to heat treatments accompanying electrical effectiveness enhancements. At present, it had been a peak heat level improvement of 4.8°C in the middle of base plate, by a mean heat level of 24.5°C. Executing experiments for extended periods may, however, enhance these figures. It may be finalized that utilizing Phase Change Material makes heat level difference more unvarying over time. The peak variations happen in the initial 30 minutes of the whole period, and subsequently, it is more stable than the non-Phase Change Material instance, with only modest deviations. Exceedingly uneven heat level circulation was also noticed within the segment without phase change material. Comparatively peak heat levels were registered under the segment middle, below towards the corners, and least in the corners, which could be imputed to corner impacts or reductions because of connection with the environments. This interior heat level slope may direction to regional heat peak focal points within the segment, outcome in effectiveness reductions and capability enduring deterioration in the overtime. The photovoltaic segment is fused in sequence, and the cell under the modest result constraints the entire result. Thus, regularity of heat level can implicitly assist to attaining greater entire electric power generation. It is gathered that the usage of Phase Change Material could also standardize the heat level throughout the BUC-PV segment, possibly influential to extended segment life. The constructed BUC-PV segment is distinctive and deviates from its earlier counterparts due to, rather than a glass rear-panel (for visual characteristics), an aluminum panel (for heat conduction) was utilized for removal of heat and attainable reclamation.

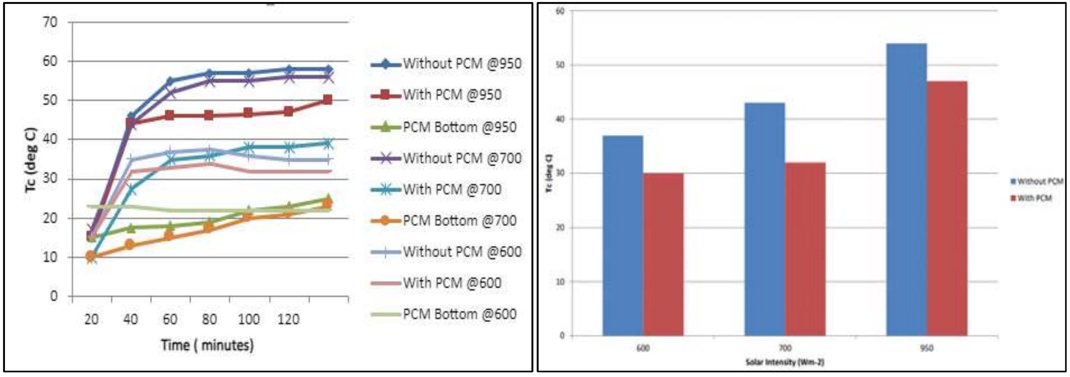


Figure 5. BUC-PV systems variation of Temperature with respect to Solar intensity

4. Conclusions

This paper empirically examines the practicality of utilizing Phase Change Material (PCM) for temperature regulation in BUC-PV systems, a concept that has not been previously reported. A PCM-based heat absorber was designed, developed, and integrated with an internally assembled BUC-PV module. The BUC-PV–PCM system was evaluated in an air-cooled setup, first without PCM and then with PCM. A natural phase change material (RT42) was employed to regulate the heat level of the aluminum backplate during the initial experiment. A consistent BUC-PV temperature of 46.5°C was achieved, which is moderately higher than the upper melting range of the PCM (38–43°C). An abrupt rise in temperature and a corresponding decline in peak output were observed during the first 30 minutes of the investigation. This initial analysis resulted in a relative electrical efficiency improvement of 7.7% and a relative VOC enhancement of 4.4% with PCM compared to the system without PCM. A typical thermal reduction of 3.8°C was observed at the center of the BUC-PV module integrated with PCM, compared to the PCM-less system. The assessment was conducted at different radiant flux levels (600, 700, and 950 W/m^2), with the relative improvement in electrical efficiency recorded as 1.15% at 600 W/m^2, 4.20% at 700 W/m^2, and 6.80% at 950 W/m^2. Previous research has largely focused on BIPV systems, emphasizing thermal behavior and the extent of melting within the PCM component. However, the current research provides a detailed analysis of the impact of paraffin-based cooling on the performance of BUC-PV systems, including outputs such as VOC, Pm, and ISC. At present, the theoretical mathematical model for the BUC-PV–PCM system presents the only improved method for developing such models. Future research could extend to longer durations to further examine the thermal properties of PCM. Investigating the heat level increase in the underlying plate of the PCM restraint could help determine whether the dissipated heat can be effectively used for recovery purposes. The experiment demonstrates that the use of PCM can significantly contribute to the thermal regulation of BUC-PV modules. Further advancements in this technology could benefit from considerations such as construction standards, financial assessments, and environmental impact evaluations.

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