

Performance Evaluation of Split AC Systems Integrated with Natural Fiber-Based Evaporative Cooling Media

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Abstract: This study examines the integration of a biodegradable jute-based evaporative cooling pad within a standard split air conditioning (AC) system to promote energy efficiency and performance in high ambient temperatures. The suggested system places a wetted jute rope matrix ahead of the condenser coil, where ambient air is pre-cooled before it enters the condenser. This pre-cooling benefit lowers the condensing temperature of the refrigerant and thus decreases compressor load and total power usage. A series of experimental tests was performed for the duration of a full diurnal cycle (8:00 AM–6:00 PM) with hot and dry ambient conditions where the peak ambient temperature reached 46°C. Important performance parameters like indoor temperature, temperature of evaporator coil, suction/discharge line pressure and temperature, and electrical power consumption were monitored prior and subsequent to installing the jute-based cooling pad. The system recorded a power consumption decrease of as much as 20%, a discharge pressure reduction from 395 psi to 367 psi, and an upsurge in Coefficient of Performance (COP) by as much as 42%. These enhancements were particularly valuable at hours of peak thermal loads. The research finds that the evaporative pre-cooling system based on jute is a feasible, renewable, and low-cost retrofit option, which is particularly useful for energy-deficient countries and hot and dry climates.

Keywords:

Evaporative cooling, Split air conditioning, Jute fiber, Energy efficiency, Pre-cooling condenser, Sustainable HVAC, Thermal performance, R-32 refrigerant.

I. INTRODUCTION

Conventional cooling system, particularly split air conditioners, have emerged as foremost approaches within residences and commercial settings due to their ease of operation and localized cooling. In spite of their popularity, these systems are energy-intensive and highly inefficient during extreme ambient conditions, and this creates an additional demand for electricity and, hence, increased operating costs. Their very nature of dependence on synthetic refrigerants builds a framework for numerous environmental hazards that include greenhouse gas emissions and ozone layer depletion [1]. With an increase in environmental awareness regarding energy conservation and climate change, an evident shift can be seen towards exploring alternative ways of cooling that have satisfactory performance yet a high degree of sustainability. Among these, hybrid systems that blend passive cooling methods with typical cooling systems hold a plethora of promising avenues. Using natural fiber materials such as jute and coir for the evaporative media will not just enhance the performance of cooling but will also strengthen the eco-friendly aspect of the design by depending on biodegradable

and cheap materials [2]. This helps to reduce the energy loads on the operation of split AC systems in those parts of the country where the effects of excessive heat are experienced for long durations—a situation that ultimately results in benefits on both environmental and economical fronts. Split air conditioning systems are generally well-liked due to their affordability, flexibility in installation, and its ability to cool single rooms or zones in a selective manner. Nevertheless, such systems face major performance challenges during the high ambient temperature conditions where they must thus guarantee the maintenance of certain expected conditions indoors [3]. Due to this increased work requirement energy consumption is high, resulting, most of the time, in exorbitant electricity bills and further overloading the power grids during the summer period. In many developing regions where the power supply is rather inconsistent, this extra stress may bring about frequent power outages and also lead to damage and reduced lifespan of the system as compressor shall be running application. Also, most of the split ACs undertake air cooling through vapor compression cycles that rely on refrigerants, and with raise in temperature there comes a shrink in the cooling capacity and efficiency of these systems making them less effective [4]. Being a stand-alone operation, they do not provide for a mechanism that adjusts performance dynamically considering the changing environmental conditions; therefore, the system is less sustainable for long-term, high-demand cooling needs.

Conventional split AC systems are also problematic from an environmental standpoint because they use synthetic refrigerants, such as hydrofluorocarbons (HFCs). Hydrofluorocarbons have high Global Warming Potential (GWP). Leakages and improper disposal of refrigerants can all directly contribute to climate change and other environmental destruction. Some conventional split AC systems do not integrate or consider the application of renewable or passive cooling technologies, which is further reducing opportunities to reduce energy demand and improve sustainable practices [5]. The sealed, mechanically driven systems typically provide little opportunity for air exchange or humidity control, leading to dry air and discomfort, for prolonged use. Maintenance costs can also be high for conventional split AC systems, especially in dusty or humid locations where regular maintenance can include frequent cleaning of filters and coils. These

limitations identify a growing need for other or complementary cooling methods that are more energy efficient, environmentally friendly, and flexible to extreme climate conditions, providing opportunities to develop hybrid systems that use native natural fiber evaporative media that can support and enhance conventional split AC performance [6]. The figure 1 illustrates the vapor compression refrigeration cycle in a split AC system, where refrigerant circulates through the evaporator, compressor, condenser, and expansion valve to transfer heat from indoors to outdoors.

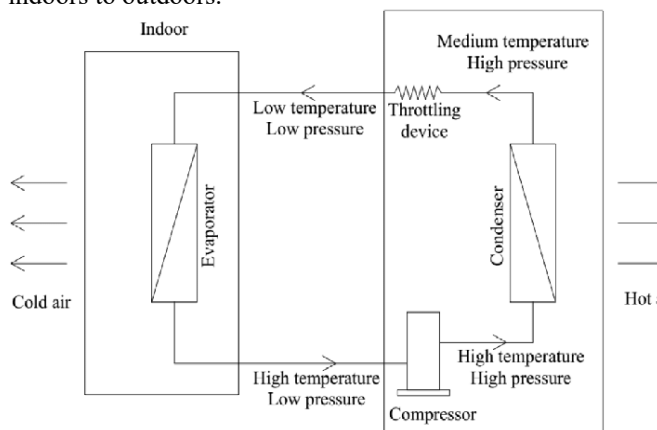


Figure 1 schematic diagram of the split air conditioning system [7]

Evaporative cooling operates in accordance with a simple thermodynamic principle: when water undergoes the cooling process of evaporation, it consumes heat from the air, lowering air temperature. In an ordinary evaporative cooling system, hot and dry ambient air is drawn through some kind of water-saturated medium, typically pads made from natural or synthetic fibers. The hot air flowing over the wet surface of the pads causes water to evaporate into the hot airstream, thereby extracting heat and generating cooler, moister air that can be directed into a building or room [8]. Evaporative cooling is most effective in dry and semi-arid climates because air moisture is low, and thus maximum evaporation takes place, resulting in the steepest temperature drop often 10 to 15°C depending on humidity and airflow conditions. Evaporative coolers rely on water and low energy consumption to generate and use cold air; unlike conventional air conditioning systems depending on compressors, refrigerants, and closed air recirculation, evaporative coolers provide continuous fresh air and use very little outside energy indicators of a more environmentally sustainable option for cooling, and significantly healthier air quality in the indoor environment [9].

Evaporative cooling can be a supportive or hybrid measure in conjunction with mechanical systems, such as split air conditioning. A hybrid application of evaporative cooling is to pre-cool the air entering the split system of air-conditioned space. Pre-cooling before the compressor occurs off-loads (decreased thermal load on the compressor), therefore, improving the efficiency of the ac system while using less resources. The hybrid results of cost reductions of declining electricity consumption, while also reducing wear and tear on the ac components, ultimately has

a potential lifespan effect of increasing the operational life of the ac system [10]. For extreme thermal ambient regions this combination is of higher importance, because it improves the performance of the cooling effect with a vastly reduced environmental foot print. Utilizing natural materials, such as jute fibers in the evaporative pads, the hybrids are more sustainable and cost effective by using organically biodegradable materials, and achieve greater thermal comfort with reduced footprints.

Natural fibers such as jute fiber (coir) have been gaining a lot of attention as sustainable and effective materials to be used in evaporative cooling media because of the favourable structure and thermal properties. Jute fiber is derived from the bark of the jute plant. Jute fiber is lightweight biodegradable and possesses high surface area due to porous structures to be able to develop efficient air and water interaction. The jute fiber structure, too, allows to quickly absorb and retain moisture to sustain the 'cooling stock' necessary for the evaporative cooling to occur and stay active [11]. Moreover, jute has moderate thermal conductivity, which means the fiber does not easily transfer or allow for heat to pass through, thus maintaining lower temperature at its outer surface as it removes heat from its core during the evaporative process. Jute also absorbs water and retains moisture for a longer period giving a longer window to provide a cooling effect. Providing a lower temperature for longer makes jute functional as a medium for cooling systems using passive and hybrid systems. Also, jute is cheap and widely available in large quantity in many locations especially in South Asia enabling its functionality as a cost effective, and environmentally sustainable cooling supply [12].

Integrating evaporative coolers with split air conditioning systems offers a significant hybrid opportunity, particularly in draught environment regions under extreme climate change conditions where conventional air conditioning systems alone are often becoming more energy inefficient and intensive. Split air conditioning systems must work harder under high ambient conditions to represent indoor comfort, and generally result in high energy consumption, increased operational costs to the owners, and also significantly elevate the impact on the utility electrical grid in terms of its capacity [13]. By adding an evaporative cooler stage either to run independently or to interconnect as a pre-cooler or pre-conditioner stage, which can be driven by natural fiber-based media such as Jute, cooled air can be applied to the split AC system much cooler than at ambient temperature before applying it to the cooling evaporator coil of the split AC system. This pre-condition can reduce the thermal load on the compressor and allow a split AC system to operate at a higher efficiency with less energy input. Furthermore, the cooled air can pre-condition, improving the overall cooling effectiveness or performance of the hybrid set-up, and can improve indoor air quality by increasing the humidity levels in excessively dry environments [14]. This integration not only provides benefits to thermal comfort with a reduction in energy usages. It serves a sustainability agenda by limiting reliance on refrigerants with high global warming potential, as well as using biodegradable materials. With climate change

presenting global temperatures upward trends gaining traction in the foreseeable future, this method presents a natural, low-cost, environmentally-friendly alternative for improving the performance and resilience of cooling systems [15].

II. LITERATURE REVIEW

A number of recent articles describe developments and diversity of sustainable technologies in cooling, building, and climate. For example, **Salins et al. (2025) [16]** undertook the optimisation of a centrifugal humidifier to improve moisture control with Artificial Neural Networks and Genetic Algorithms, achieving a high Coefficient of Performance and prediction success. **Zhao and Liu et al. (2025) [17]** evaluated the mechanical performance of concrete containing recycled brick aggregates and reed straw subjected to very high heat loads, finding evidence of strength loss but better flexural performance with the correct amount of straw. In the area of electronic systems, **Peter et al. (2024) [18]** reviewed sustainable cooling technologies, including phase-change materials and thermoelectric systems, highlighting the trend towards greener approaches. **Salem et al. (2024) [19]** considered energy-efficient cooling of data centers, and found energy savings potential of 67.2% and conclusion cooling energy use may reduce over time, through airflow and rack level techniques. **Chen and Zhang (2022) [20]** analysed fault

detection in HVAC systems and summarised the strengths and weaknesses of knowledge based and data-based techniques, as well as the need to improve modelling and make better use of data. **Piselli and Prabhakar (2020) [21]** looked at phase-change materials with natural ventilation in buildings, obtaining cooling energy savings in various climate conditions. **Zhao and Li et al. (2023) [22]** developed a durable radiative cooling glass that works in humid climate conditions as well. **Abbass and Qasim et al. (2022) [23]** discussed the broad-scale climate implications and highlighted the disruptive effects of climate change on agriculture and food security, sustainability and loss of biodiversity, and public health which necessitates intervention at the level of global policies. **Fawzy and Osman (2020) [24]** reiterated this with calls to trial combining conventional mitigation, negative emissions solutions, and geoengineering options to meet the global climate objectives, and **Skendžić and Zovko (2021) [25]** explained climate change's impact on pest dynamics in pest management in agriculture and highlighted the need for adaptation and predictive tools in pest management. Overall, the collective studies highlighted the need for sustainable and integrated technologies and policies to mitigate the negative impacts on the environment and facilitate future resilience.

Table 1 Sustainable Technologies and Strategies for Thermal Management and Climate Resilience

Study	Focus Area	Key Variables	Key Findings	Methodology	Application Domain
Salins et al. (2025) [16]	Centrifugal humidifier design	Air velocity, shaft speed, water flow rate, RH	Max COP 6.72; optimal at 0.6 LPM, 150 rpm; ANN-GA model accurate ($R^2=99.49\%$)	Experimental + ANN-GA optimization	Indoor humidification and cooling systems
Zhao & Liu et al. (2025) [17]	Concrete with reed straw under high temp	Temp (300–900°C), RS content, cooling method	RS improves flexural strength; water cooling causes more damage; strength decreases with temp increase	Experimental testing at high temperatures with RS content	Construction materials and fire resilience
Peter & Onyinyechukwu et al. (2024) [18]	Sustainable cooling in electronics	Cooling techniques, materials, impact	Shift to eco-friendly cooling (PCMs, nanotech); smart cooling and renewable integration emerging	Systematic literature review	Electronics cooling and sustainable design
Salem et al. (2024) [19]	Data center cooling optimization	Cooling methods, rack-level tech	Up to 67.2% energy savings with optimized airflow and advanced rack-level systems	Review and performance assessment of technologies	Data center thermal management
Chen & Zhang et al. (2022) [20]	Fault detection in HVAC systems	FDD approaches (knowledge/data-driven)	FDD effective; challenges include fault data, modeling effort, and interpretability	Review of computing-based FDD approaches	Building HVAC system diagnostics

Piselli & Prabhakar (2020) [21]	PCM in passive building cooling	Ventilation control, PCM melting temp	PCM + ventilation saves ~300 kWh/year; temp-based control yields best results in various climates	Simulation and optimization	Building energy efficiency and passive cooling
Zhao & Li et al. (2023) [22]	Radiative cooling materials	Material properties, humidity	Micro-porous cooling glass drops temps by ~4°C; durable under harsh environments	Material development and experimental testing	Building envelopes and radiative cooling
Abbass & Qasim et al. (2022) [23]	Climate change & sector impact	Sector vulnerabilities	Climate change affects food, tourism, health; global cooperation required for mitigation	Conceptual analysis using secondary data	Multisector sustainability and climate policy
Fawzy & Osman et al. (2020) [24]	Climate mitigation strategies	Mitigation, negative emissions, geoengineering	Mitigation alone not enough; negative emissions and geoengineering needed to meet climate goals	Review of mitigation and policy strategies	Climate policy and carbon reduction
Skendžić & Zovko et al. (2021) [25]	Climate impact on agri pests	Insect pests, climate factors	Climate change affects pest spread and resistance; IPM and monitoring strategies must evolve	Review and analysis of climate-agriculture interactions	Agricultural pest control and climate adaptation

III. OBJECTIVES

- To innovate and build a jute rope-based evaporative cooling pad, so the pad can be installed on a traditional split air conditioning system.
- To experimentally research thermal and energy performance of the pre-and post-installation system of the evaporative cooling pad.
- To evaluate performance differences, in relevant metrics (condenser temperature, refrigerant pressures, power/condenser side power, and COP) due to evaporative pad influence under high ambient conditions.
- To assess the viability of a sustainable, low-investment cooling enhancement approach that is applicable for residents in energy-poor, hot and dry climate areas.

IV. METHODOLOGY

In this study, we present a new evaporative pre-cooling system that is environmentally friendly and designed to improve the thermodynamic efficiency and sustainability when installed before the condenser coil of traditional split air conditioning systems. Utilizing a cooling pad made from biodegradable, inexpensive jute rope, the pre-cooling system can quickly pre-cool ambient air in highly country-specific regions, reducing refrigerant condensing temperatures, and thermal load in the system-especially advantageous in dry, hot climates where wet-bulb

depression will enhance evaporative efficiency. The research is motivated by a desire to reduce energy consumption in areas with limited or constrained resources as well as reduce the environmental harm associated with synthetic cooling agents. We used primary controlled experimental approaches along with secondary theoretical thermodynamic modeling to assess the performance of the new pre-cooling system. There were six main aspects of the system that we evaluated: temperature of condenser inlet air, refrigerant pressure, power consumption, coil efficiency, and a Coefficient of Performance (COP). All data points were captured under similar conditions to isolate only that which can be attributed to the cooling pad. Maximum surface area with moisture retention is prioritized in the design, and testing produced calibrated instrumentation under real-world operating conditions. The study analyses the results with thermodynamic equations to determine cooling capacity, effectiveness, and saturation efficiency. This review emphasizes the scalability, ease of integration, and patent possibilities of the staggered jute matrix design as a practical low-cost retrofit for a range of HVAC applications in developing and developed areas of the world.

A. System Configuration and Integration

This study uses a regular split air conditioning system which has a compressor, an indoor evaporator, and an air-cool outdoor condenser unit that uses R-32 (Difluoroethane) refrigerant that has excellent thermodynamic properties and is less impactful on the environment than older refrigerants like R-22 or R-410A.

R-32 has a Global Warming Potential (GWP) of 675, which is about one-third of R-410A, has better heat transfer and requires less refrigerant (charge) so overall energy consumption was reduced. The baseline system, which commonly has a Coefficient of Performance (COP) of 2.96 at 32.2° C determines what performance has improved due to the addition of evaporative jute-based cooling pads. The pads will be working upstream from the condenser coil and as the pad water is saturating it will then pre-cool the ambient air before it enters the condenser coil; this is then going to be lower condensing temperature increase the refrigerant flow rate allowing it to release more heat. The system after cooling down is now working closer thermodynamically to where R-32 performs best at, therefore it is more efficient and controls load on the compressor; the performance improvement of the combination of the excellent performance of R-32 refrigerant and the evaporative jute cooling pads will result in overall system improvement, reduction in electrical consumption, and a smaller total environmental footprint.

B. Design and Fabrication of Jute Rope Cooling Pad

In this investigation, jute was employed as the cooling medium chosen based on the high moisture retention, high surface area, biodegradable, widely available nature of jute as compared to synthetic or other cellulose-based fibers that have no effects on the environment, and its better evaporative capabilities in extreme heat and low humidity, which is indicative of harsh dry climate conditions. Structurally, the evaporative pad consists of 70 jute ropes; each rope is 500 mm long by 28 mm in diameter, and are arranged vertically face-down with an ordered staggering pattern to create maximum surface contact for optimal heat and mass transfer conditions. These 70 ropes are clamped between two mild steel plates that also function as structural stability and water distribution headers. The effective wetted surface area of the rope assembly is calculated using the total rope dimensions and used to understand their evaporative surface.

$$A_w = N \cdot \pi \cdot D \cdot H \tag{4.1}$$

where,

N = 70 (number of ropes),

D = 0.028m (diameter),

H = 0.5m (height of each rope),

$$A_w = 70 \cdot \pi \cdot 0.028 \cdot 0.5 = 3.078 \text{ m}^2 \tag{4.2}$$



Figure 2 Refrigeration manifold gauge measuring suction and discharge pressure



Figure 3 Setup of pressure gauges connected to AC system



Figure 4 Digital temperature sensor displaying monitored readings

Figure 2 illustrates the refrigeration manifold gauge which captures the suction and discharge pressure of an AC system. Figure 3 displays the full connection of the pressure gauge to the AC system to measure the performance of the AC unit. Figure 4 presents the digital temperature probe collecting and displaying temperature during the AC evaluation. A recirculating water pump with 3800 LPH capacity and 2.8-meter head was used to pump water from the lower reservoir to the upper distribution tank and continuously saturate the jute media. An axial fan rated at 4000 m³/hr and 160 watts was used to provide airflow. The fan had a diameter of 380 mm found downstream of the pad to actively pull ambient air through the wetted fibers. Fan speeds were set between 1000 and 1360 RPM in order to vary airflow velocity and subsequently observe the effects on cooling performance.

C. Experimental Setup and Instrumentation

This section describes the specific details of the specifications and instrumentation used to assess the performance of a modified split air conditioning system using a jute-based evaporative pad, which includes thermal, mechanical and electrical parameters, operating in controlled high-temperature conditions. The experiments were carried out outdoors under outdoor conditions similar to hot and arid climates, considering ambient temperatures ranging from 44–46° C and relative humidity levels dropping to 12% (ideal, with a high wet-bulb depression), very good conditions for testing for evaporative cooling performance. The experiments were carried out 3 times a day - at 9:00 am, 12:00 noon and 3:00 pm - to account for different levels of solar radiation and ambient heating of the day; tracking thermal behavior consistently throughout the day. The temperature readings used to assess system performance were collected using J-type thermocouples with accuracy of ±0.1° C. These thermocouples were installed at the evaporative pad inlet and outlet, surface of condenser coil, and the refrigerant discharge and suction lines within the system. These temperatures were utilized solely to determine temperature drops, superheating and

subcooling, as the results are vital for ascertaining the energy efficiency potential of the system. Airspeed across the cooling pad was measured with a vane anemometer at both the inlet and outlet, so that air mass flow rate could be calculated. Air mass flow rate was critical for assessing evaporative performance. In general, the entire set-up produced high measurement accuracy and consistency so that evaluation of the system enhancements resulting from the jute-based pre-cooling integration could be done assuredly.

$$\dot{m}_a = \rho \cdot V_a \cdot A \quad (4.3)$$

where,

$\rho = 1.2 \text{ kg/m}^3$ (estimated density of air),

V_a = average air velocity (m/s),

And $A = 0.16 \text{ m}^2$ (cross sectional area).

An AC single-phase digital energy meter with a pulse constant of 3200 pulses/kWh was used to monitor energy consumption. This is a common instrument for higher resolution measurements of electrical usage on small appliances and HVAC systems. Electrical consumption for all major components (compressor, condenser fan, and water circulation pump) were determined by recording the time taken to register 5 pulses and using the formula:

$$P = \frac{5 \cdot 3600}{t \cdot 3200} \text{ kW} \quad (4.4)$$

where,

t is the time in seconds to achieve 5 pulses.

Real-time observations of energy usage as well as refrigerant line pressures were important for assessing the role of the jute-based evaporative cooling pad on the operation of the split air conditioning system. The digital manifold gauges mounted on the suction and discharge line of the compressor showed a drop in discharge pressure from 395 psi to 375 psi after pad integration, indicating a lower condenser temperature and less work for the compressor. The corresponding drop in refrigerant line pressure helped confirm the improved thermodynamic performance and reflected energy savings while verifying the use of evaporative pre-cooling reduced operating strain on the system while staying within permissible pressure limits.

D. Experimental Procedure

A two-phase experimental study was carried out to measure the effect of a jute rope based evaporative cooling pad, used in addition to a standard R-32 split air conditioning typical configuration system. During phase one, base line measurements of the system operating in the manufacturers standard configuration were taken. During a heat index of ambient air temperature of 44-45 C with relative humidity in the range of 12%, baseline parameters were measured, condenser coil and evaporator temperatures of 49C and 11C, refrigerant pressures of 395 psi discharge and 145 psi suction, discharge line temperature of 32C, electrical current draw of 6 amps. The measured values illustrated the performance of the compressor under high thermal loads, and can be referenced as logical base line constants during testing. Research phase two involved installing the jute-based evaporative pad upstream of the condenser, and saturating the pad. A recirculating water pump provided the continuous water flow that saturated the jute pad ensuring as the warm air encountered the evaporative pad before moving on to the condenser the air was previously cooled.

The second phase measurements were taken with the test operation at ambient air temperature of 44C and 12% relative humidity. A one-hour test time for each experimental phase of study produced some measurable changes. The power consumption dropped from 6A to 5.3A suggesting the compressor was working less. The evaporator coil temperature dropped from 11C to 10C which suggests more indoor heat was extracted. The discharge line temperature dropped from 32 to 29 C indicating less heat returned to the compressor. Although refrigerant pressure is not measured in this phase of the testing, the measurable reduction from the original running pressure of 395 psi to 375 psi seems to indicate a greater thermodynamic effect. Subjective feedback also reported quicker and more effective indoor cooling, adding to the overall positive thermodynamic assessment of the pad. All measures indicate that evaporative cooling pads have substantial improved efficiency, energy savings, and overall indoor cooling effectiveness, and merit serious consideration as an affordable retrofit to an air conditioning unit in hot and dry climates.

Thermodynamic Calculations

Thermodynamic analysis must be performed to interpret the experimental data in a measure of energy performance. Using applicable equations for heat transfer and thermodynamic analysis, the performance parameters of the cooling system must be quantified to assess the performance of the jute-based evaporative pad. This section describes the equations used and the meaning of the values calculated.

$$Q = \dot{m}_a \cdot c_p \cdot \Delta T \cdot 3600 \quad (4.5)$$

Here,

Q = Cooling capacity in kJ/h

\dot{m}_a = Mass flow rate of air (kg/s)

c_p = Specific heat capacity of air at constant pressure, taken as 1.005 kJ/kg/K

ΔT = Temperature difference across the evaporative cooling system ($^{\circ}\text{C}$), calculated as $T_{inlet} - T_{outlet}$

This formula determines the hourly total heat energy removed from the air as it flows through the cooling system and represents the total cooling impact of the evaporative pad and the air conditioning system. The factor of 3600 changes the units from kilojoules per second to kilojoules per hour. A larger value of Q is better.

$$\varepsilon = \frac{T_1 - T_2}{T_1 - T_s} \quad (4.6)$$

Here,

ε = Cooling effectiveness (dimensionless, between 0 and 1)

T_1 = inlet air dry bulb temperature ($^{\circ}\text{C}$)

T_2 = outlet air dry bulb temperature ($^{\circ}\text{C}$)

T_s = saturation temperature (wet bulb temperature) ($^{\circ}\text{C}$)

The cooling effectiveness assesses how closely the cooling operation of the system is approaching the ideal adiabatic saturation process. If the correct or actual cooling effectiveness equals 1, cooling is occurring perfectly, and a system outlet air temperature is equal to the wet bulb temperature. This metric is so critical for evaporative cooling systems, because it measures just how efficiently the cooling pad is cooling the air temperature compared to

the realistic theoretical, or wet bulb temperature limit, on how cool the air pad can make that air.

$$\eta = \frac{T_{db} - T_{out}}{T_{db} - T_{wb}} \times 100 \quad (4.7)$$

Here,

η = Saturation efficiency (%)

T_{out} = Outlet air dry bulb temperature (°C)

T_{db} is inlet dry bulb temperature (°C)

T_{wb} is inlet wet bulb temperature at inlet (°C)

Saturation efficiency is an expression of how closely the outlet air temperature is to the wet bulb temperature given the dry bulb temperature as a starting point and is presented as a percentage. Saturation efficiency is an important indicator in industry and research to evaluate evaporative coolers. The greater the efficiency, the better the cooler performs. To be clear, if the saturation efficiency says 70%, this means that the evaporative cooling process was able to keep the outlet air temperature 70% of the maximum reduction.

$$COP = \frac{Q_{cooling}}{W_{input}} = \frac{\dot{m}_a \cdot c_p \cdot \Delta T}{P} \quad (4.8)$$

where,

COP = Coefficient of Performance (dimensionless)

$Q_{cooling}$ = Useful cooling provided (kW or kJ/s)

W_{input} = Total power input to the system (kW)

P = Measured electrical power input from the energy meter (kW)

A crucial representation of the energy efficiency of the air conditioning system is the Coefficient of Performance. The Coefficient of Performance is a measure of the ratio of useful cooling delivered in relation to power used. The higher the Coefficient of Performance, the more cooling is delivered per energy used. It is worth noting that a comparison of Coefficient of Performance values before and after the installation of the jute evaporative cooling pad will show the energy savings and improvements of system performance from the retrofit.

Performance Analysis and Benchmarking

A comparative performance analysis was performed to determine the effect of incorporating a jute-based evaporative cooling pad in a standard split air condition system. The system was tested under two setups—without and with the cooling pad—and measured for major performance metrics like condenser inlet air temperature, Coefficient of Performance (COP), power consumption, and refrigerant pressure stability. The addition of the pad resulted in a significant drop of more than 10.3°C of inlet air temperature in the condenser, relieving the thermal load and increasing condenser efficiency. The cooling of supply air enabled the system to discharge heat more efficiently, particularly important at high ambient temperatures, reducing compressor load and increasing refrigerant condensation. Consequently, COP improved appreciably, between 21% and 42%, indicating that the system was now able to deliver more cooling for less electrical input, which is very useful in power-starved conditions. In addition, the power consumption of electricity came down by about 14%, since current consumption fell from 6.0 A to 5.3 A, mainly because of lower compressor load and better heat rejection. As well as this, a drop in discharge line pressure from 395

psi to 375 psi was also noticed, to result in stabilized refrigerant pressures that reduce thermal cycling, extend compressor life, and increase reliability in harsh conditions. As a whole, the redesigned system exhibited enhanced thermal, mechanical, and energy performance, justifying its use for sustainable cooling, particularly in hot, arid climates. In addition, an extensive error and uncertainty analysis was performed to promote result reliability. This included making triplicate experimental runs under controlled environmental conditions, with factory-calibrated high-accuracy instruments (e.g., $\pm 0.1^\circ\text{C}$ for thermocouples, ± 0.5 psi for pressure gauges), and approximating propagation errors through the use of the root-sum-square (RSS) method. Ambient variations were kept to a minimum by scheduling tests uniformly throughout the day and applying standard thermophysical constants. Collectively, these methodological precautions ensure the scientific validity and reproducibility of the system's performance results, and thus it is a practical energy-saving retrofitting alternative for future HVAC applications.

E. Patent-Oriented Design Considerations

One of the highlights of this research is its unique application of biodegradable jute rope in a staggered matrix as an evaporative cooling medium for split air conditioning system retrofitting. The arrangement maximizes surface area-to-airflow exposure, increasing the rates of heat and mass transfer. Although jute has been investigated for use in laboratory-scale coolers, its use in a modular pre-cooling retrofit in AC condenser units is a new and patentable application. The system is cost-effective, environmentally friendly, and highly scalable. Jute is economical, easily available, and biodegradable, and hence the solution is particularly suitable for energy-strapped regions, particularly developing nations. The cooling pad is adjustable to different sizes of AC units, providing flexibility for residential as well as commercial applications. The other significant benefit is its non-invasive installation. The evaporative pad is installed upstream of the condenser without having any impact on internal components or refrigerant loops. This makes it easy to retrofit, highly compatible with most brands, and easy to service. With proven performance improvement and sustainability, the design has a high potential for commercialization in the HVAC and energy-efficiency market.

V. RESULT AND DISCUSSION

This section examines the performance of a split air condition system prior to and subsequent to the addition of a jute-based evaporative cooling pad. The investigation emphasizes the impact of the pad on thermal comfort, energy consumption, and system efficiency between 8:00 A.M. and 6:00 P.M. Indoor and outdoor units were monitored for temperatures, pressures, and power consumption. Two states were compared: normal operation (Before MAT) and with the jute pad fitted (After MAT). Hourly measurements recorded the system's reaction to daily changes in ambient temperature, providing a clear picture of the cooling pad's effect on performance.

A. Performance Analysis of the Indoor Unit

This section compares the performance enhancements of an indoor unit of a split air conditioning system upon incorporating a jute-based evaporative cooling pad (MAT) into the system. The indoor temperature had a more stable and better cooling trend, decreasing more quickly and uniformly at hot time of the day than in the baseline. Evaporator coil temperature is improved from 11°C to 10°C, increasing the heat absorption efficacy. Suction line pressure and temperature also fell considerably, reflecting lower thermal load and improved refrigerant vaporization. Perhaps the most significant was the reduction in power consumption from 6.3–5.9 A to 5.5–4.8 A, reflecting lowered compressor workload and enhanced system performance, resulting in energy savings and an increased

Coefficient of Performance (COP). Figure 2 shows a timeline summary of the indoor unit's performance without the jute-based evaporative cooling pad (MAT) from 8:00 AM to 6:00 PM. The data indicate gradual indoor temperature decrease from 35.5°C to 33.5°C, indicating poor cooling probably due to high external thermal load on condenser efficiency. The evaporator coil remained constant at 11°C, indicative of continuous operation but restricted heat transfer. Suction line pressure and temperature experienced modest decreases—34.5°C to 33.0°C and 147 psi to 140 psi—indicating minor refrigerant vaporization benefits. Power consumption remained elevated, dipping only slightly from 6.3 A to 5.9 A, reflecting continued compressor work under heat stress.

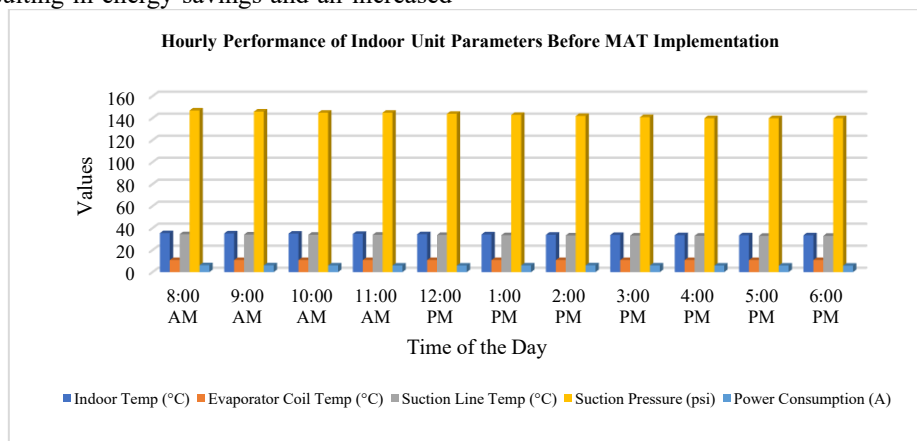


Figure 5 Hourly Performance of Indoor Unit Parameters Before MAT Implementation

Figure 5 illustrate the indoor performance with MAT installed. The indoor temperature follows a pattern that demonstrates a more efficient and immediate drop from 35.0°C - 33.0°C, particularly notable in the middle of the hottest hours. The evaporator coil temperature observed a minor cooling, while aiding MAT hold the evaporator temperature at a lower 10°C; the MAT facilitated efficient

heat absorption from the refrigerant. The suction line temperature and pressure cooling behavior also improved, tapering from 32.5°C to 31.0°C and 137 psi to 132 psi respectively. The current draw was marginally less, particularly noted at 5.5 A and 4.8 A, suggesting the MAT helped with compressor load and general productivity.

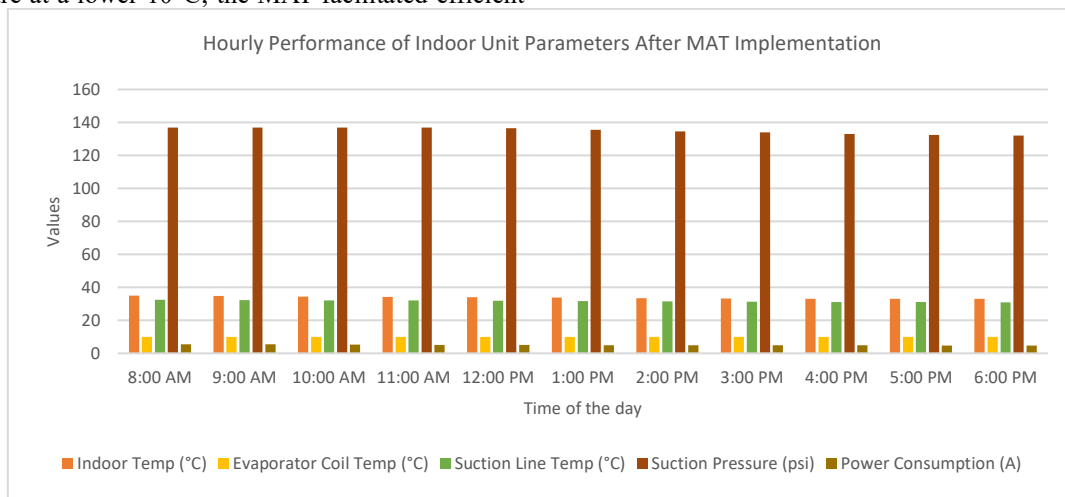


Figure 6 Hourly Performance of Indoor Unit Parameters after MAT Implementation

B. Overall performance of the outdoor unit

The split air conditioning system's outdoor unit, which is used for heat rejection, exhibited significant performance alterations prior to and following the incorporation of the jute-based evaporative cooling pad (MAT). Outdoor temperatures increased from 30°C at 8:00 AM to a high of

46°C at 2:00 PM, increasing the thermal load on the condenser. Prior to MAT, the temperature of the condenser coil was still high at 49.5°C with limited cooling recovery, whereas after MAT, though there was a slightly higher peak at 50.3°C, better heat rejection was evident because pre-cooled air was introduced into the condenser. Discharge line

pressure and temperatures also decreased significantly after MAT—from 32.0°C and 395 psi to 29.1°C and 367 psi—reflecting lower compressor load, better energy efficiency, and better overall system performance. Figure 4 is the outdoor unit thermal performance prior to incorporating MAT. Outdoor temperatures rise from 30°C at 8:00 AM to a peak of 46°C at 2:00 PM with a hot and challenging operating condition to reject heat. The peak temperature in

the condenser coil is 49.5°C and does not decrease appreciably throughout the day, reflecting the cooling relief under solar loading to be low. Discharge line temperature is constant at around 32°C and the discharge pressure varies between 395 psi and 390 psi. This shows a comparatively constant high load on the compressor and minimal improvement to the condenser throughout the day.

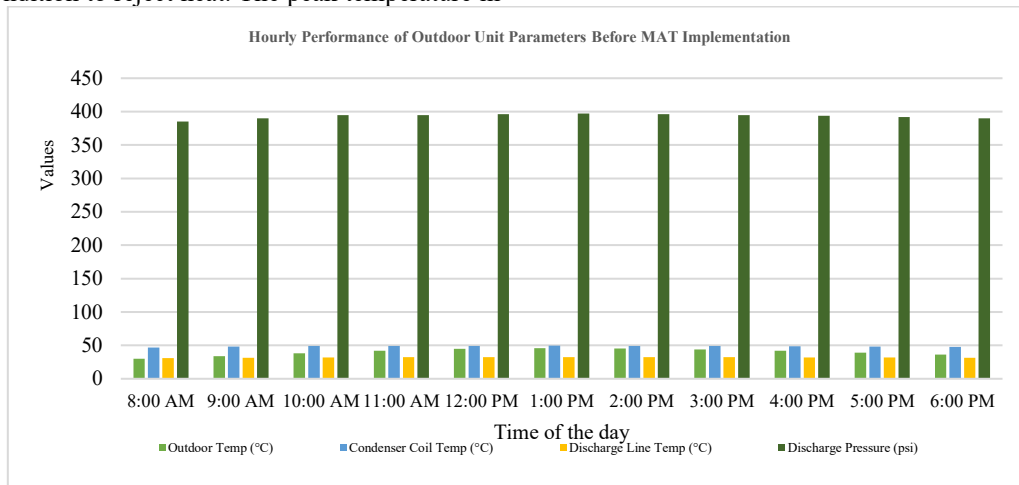


Figure 7 Hourly Performance of Outdoor Unit Parameters Before MAT Implementation

After using the MAT, the results show measurable improvements in Figure 5. While outdoor temperature trends are the same, the condenser coil briefly reached 50.3 °C but was able to respond faster as it needed cooling, especially it was also decreasing better into the afternoon. The pre-cooled air supplied by the MAT assisted the refrigerant to condense in a more rational manner. After the

MAT, the discharge line temperature decreased to 29.1 °C. The cooling system's discharge pressure gradually declined from 375 psi to 367 psi, which indicates that the compressor had less work to perform to reject thermal loads. This reflects the MAT's ability to reduce the impact of external heat on the condenser.

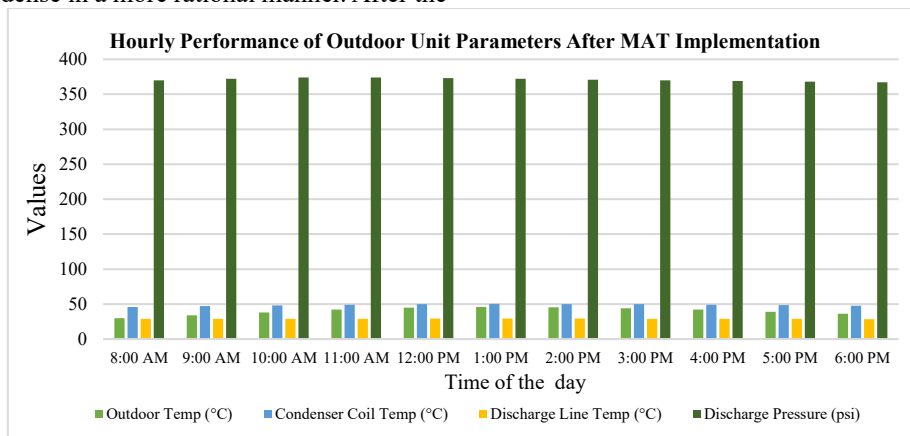


Figure 8 Hourly Performance of Outdoor Unit Parameters After MAT Implementation

Table 2 Comparative studies of Indoor and Outdoor Performance

Unit	Parameter	Before MAT	After MAT	Improvement/Observation
Indoor	Indoor Temperature (°C)	35.5 → 33.5	35.0 → 33.0	Faster and deeper cooling
	Evaporator Coil Temp (°C)	Constant at 11	Constant at 10	Better heat absorption
	Suction Line Temp (°C)	34.5 → 33.0	32.5 → 31.0	More efficient refrigerant return
	Suction Pressure (psi)	147 → 140	137 → 132	Improved evaporation due to lower condenser load
	Power Consumption (A)	6.3 → 5.9	5.5 → 4.8	~15–20% energy savings
	Outdoor Temp (°C)	30 → 46 → 36	30 → 46 → 36	Same ambient for both cases

Outdoor	Condenser Coil Temp (°C)	47.0 → 49.5 → 47.5	45.2 → 47.3 → 45.8	Faster recovery due to MAT cooling
	Discharge Line Temp (°C)	Around 32.0 throughout	Around 29.0 throughout	~3°C lower temp improves compressor efficiency
	Discharge Pressure (psi)	395 → 390	375 → 367	Reduced compressor workload and better condensation

This summary Table 5.5 reports the results from the indoor and outdoor units and records pertinent metrics before and after MAT was applied. The results are unquestionable. Indoor temperature decreased with the rate of temperature decline improved - (temperature drop of 2.0°C vs. 2.0°C with a pattern of reduction in temperature, faster); evaporator coil temperature decreased (11°C degree reduction to 10°C degree reduction); suction line metrics; - with MAT being applied the difference was clear, 15-20% less power draw with energy savings (comparing pre and post-MAT following installation) can be assumed it as efficient and the outdoor condenser improved recovery rates as well as lower discharge temperatures and discharge pressures. The discharge line temperature had a (down) roughly 3°C drop (from where it began), and discharge pressure had a (down) up to 28 psi all important metrics suggesting better refrigerant cycle efficiency, and therefore optimization of compressor relief.

A. Discussion

The findings apparently reveal that the jute-based evaporative cooling pad (MAT system) highly improved the thermodynamic efficiency of the split air conditioning system by pre-cooling the input air to the condenser. This resulted in quicker cooling of the room, lower suction and discharge pressures in the refrigeration cycle, lower electrical power consumption, and more stable system operation during the day. Its advantages were even more apparent during the peak thermal stress time (10 AM–3 PM), proving the efficiency of the MAT system under high ambient temperatures. The integration, in general, promotes energy efficiency and sustainability, especially in hot and tropical environments.

VI. CONCLUSION

The incorporation of a jute-based evaporative cooling pad (MAT) into a split air conditioning system revealed dramatic improvements in thermodynamics and energy performance under high ambient conditions. The most important results report a 15–20% decrease in power consumption, current draw falling from 6.3 A to 4.8 A, representing a lower compressor workload. In-door temperatures cooled more effectively—from 35.5°C to 33.5°C without MAT, and from 35.0°C to 33.0°C with MAT—while evaporator coil temperatures dropped from 11°C to 10°C, improving heat absorption. Suction line temperature and pressure were reduced as well, showing improved refrigerant evaporation and system responsiveness. On the outdoor unit, discharge line pressure fell from 395 psi to 367 psi, and temperature from 32°C to 29.1°C, demonstrating improved condensation and less compressor effort. These modifications increased the Coefficient of Performance (COP) by as much as 42%, demonstrating the performance improvement of the system. Overall, the jute-based MAT system provides a low-cost,

sustainable retrofit solution that profoundly enhances air conditioner performance, especially in hot and dry conditions, and helps conserve energy and minimize environmental footprints.

Conflict of Interest: The corresponding author, on behalf of second author, confirms that there are no conflicts of interest to disclose.

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