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Content

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Editorial

Advancing Research in Recent Technologies: Editorial of the First Issue

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Abstract-

This editorial gives an overview about our newly launched journal, named Advanced Technologies Journal of University of Benghazi. The editorial reports an introduction for the newly launched journal as a scholarly platform for cutting-edge contributions in advanced technologies. Vision and scope of the journal has been summarized with emphasis on its multidisciplinary nature, quality and academic ethics. It also outlines the five articles that have been published in this issue in terms of their significance and contributions and encourages researchers to submit their works for second issue of this year with the major aim of expanding the knowledge boundaries of advanced technologies. It finally concludes by setting the outlook for global research community for sustained and regular publishing across the scope covered in the journal.

Keywords: Advanced Technologies; Cutting-Edge Research; Inaugural Issue; Research Quality; Sustained Publishing.

1 - Introduction

It is our great pleasure to present the first issue of *Advanced Technologies Journal of University of Benghazi (ATJUOB)* published by the University of Benghazi and warmly welcoming readers, researchers, reviewers, editorial and advisory boards. With support and sponsorship of the University of Benghazi, ATJUOB has been launched that aims to publish original research relevant to advanced technologies. ATJUOB is an international open-access peer-reviewed journal that is currently fully free to submit and publish various types of articles in the field of advanced technologies. The multidisciplinary nature of this journal allows covering variety of science, engineering, and medicine disciplines that are recently used to interact with and/or feed advanced technology. The general target is to regularly publish high quality articles online to enrich readership and global scientific community with current contributions in the journal scope. The journal will target local and international indexing databases such as Scopus, google scholar, and DOAJ, and Directory of Open Access Libyan Journals (DOLJ). Confirming the fact that journal indexing is as important as being as open access. The journal has committed to open access policy, making authors' research more visible, accessible, and at the same time, rigorously peer reviewed with linguistic and scientific refining prior to publication. Internationally recognized editorial and advisory boards have been formed from different countries and institutes, considering diversity in nationalities, gender, and geographic locations of the institutes and Universities of the members of the boards. A robust submission system and website has been established with support of the University of Benghazi. In addition, the journal is supervised by another independent committee named the Scientific Journals Follow-Up Committee of the University of Benghazi who first nominated the editorial and advisory boards to issue the appointment decision by the University President. The next section presents the vision and scope of the journal.

2- Vision and Scope

The general vision is to establish and sustain a recognized and high-quality global forum for digital publishing of articles that have useful contributions to humanity and society. The specific vision is to preserve research with relevance to the rapid growth and evolution to advanced technologies and make it either free or very affordable to get and read. Advanced technologies have positive and negative impacts on human beings; therefore, the vision is not just to praise advanced technologies and show only their revolutionary positive effects on human beings, but may also prove their risks on humanity, such as health risks and social isolation. Thereby expanding the understanding of advanced technologies as tools, some of which have dual-edged nature. The journal covers many advanced forms of disciplines related to technology, but not limited to those mentioned here or in the journal website. Advances in engineering disciplines, which have cross-linking of three developed majors of mechanical, electrical, and computer engineering, such as: mechatronics engineering, system engineering, control engineering, neuro-engineering, communication engineering, robotics and smart systems, renewable energy engineering. Keeping Advances in computer science and information technology, which include: machine/deep learning, data science, big data analytics, quantum computing, internet of things (IoT), technology-health Interactions, technology-education Interactions. Thereby, creating a strong link among those fields to deliver robust solutions to recently used technologies.

3- Overview of the articles in the Issue

This issue presents five articles with different types and focuses. The first one is an *invited paper*, under the category of (Perspective article), authored by Prof. Paulo Ribeiro, an IEEE Life Fellow from Federal University of Itajubá, Itajubá, Minas Gerais, Brazil. The article presents a philosophical system engineering perspective on energy storage in electrical grids, that has influenced today's shape and characteristics of modern power systems. The second article is a systematic review paper about airlines IT audit challenges and success factors, authored by Ms. Shahed Al Tamimi et al. from IT Department, Community College of Qatar (CCQ), Doha, Qatar, and contributed to the security, compliance, and optimum operation of aviation's IT systems, which include air-ground communication, navigation aids, aeronautical surveillance, and system-wide information management. The third article authored by Dr. Doha Jdeed and Mr. Mohamed Aldiry from Tartus University, Syria, where it is categorized as the type of (Original Research Article) and reports an important scientific investigation into an emerging phenomenon affecting photovoltaic solar energy systems in the coastal areas of Tartous, Syria, namely the formation of white spots on solar cells, linking it to quantitative measurements of solar panel performance, which helps energy auditors in initial energy audits (Walk-Through

Energy Audits). The fourth article, authored by Dr. Amenh Yousif et al. from University of Benghazi and contributed as original article within the scope of Health-Technology interactions. The article shows the effect of digital games on children's health and academic performance in Benghazi in 2025. The fifth article authored by Mawada Algaddari et al. from the University of Benghazi, which contributes in wireless communication scope through investigating the integration of Intelligent Reflecting Surface (IRS) technology into Terahertz (THz) wireless communication systems to enhance transmission reliability and coverage. The next section presents the conclusion and the way forward.

4- The Way Forward

The future outlook is to strengthen the requirements of the journal by remaining committed with rigorous peer-review process and open access policy for quality and accessibility of research. We welcome more contributions from researchers worldwide and shall start targeting local and international indexing.

5- Conclusion

In conclusion, this issue has been shown as a significant milestone for ATJUOB with considerable contributions that reflect diversity, usefulness, informative, and significance of some contemporary achievements and issues in advanced technologies. Our sincere thanks to authors, reviewers, editorial board, advisory board, and the scientific journals follow-up committee of University of Benghazi whose significant effort that made the launch of this journal and issue possible.

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Advanced Technologies Journal of University of Benghazi (ATJOUB)

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Perspective Article – System Engineering

A Philosophical Systems Engineering Perspective of Energy Storage for Electric Grids

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Abstract-

Energy storage has become an essential enabler of resilience, stability, and flexibility in today's electric grids. While standardized by some nominal measures, such as power capacity, energy density, and cost, the advanced storage technologies paved the way for wider requirements of system engineering that goes beyond their technical performance. This paper introduces a philosophical system engineering perspective of energy storage, viewing it as an approach of shaping time within complex power system architectures rather than simply storing energy. Relying on practical experience from large-scale military and utility applications, the analysis emphasizes lifecycle, integration, interoperability, degradation, and end-of-life management as major determiners of storage value. It is stated that no single storage technology can address the diverse requirements of the energy transition. Instead, future electric grids must rely on carefully engineered portfolios of complementary storage technologies, designed using systems engineering principles. The paper concludes that the primary challenge of energy storage is architectural rather than technological, requiring grids to be designed with temporal intelligence to balance immediacy, reliability, resilience, and long-term sustainability.

Keywords: Philosophical perspective; System Engineering; Energy Storage; Flywheels; Batteries.

1 - Introduction

Energy storage has long fascinated me, not only as an engineer who has worked with military and utility applications (with superconducting magnetic energy storage (SMES), Flywheels, and Batteries), but also as someone intrigued by its deeper meaning within the electric grid .

Storage sits at the intersection of physics, technology, and philosophy: it is where potential becomes purpose, where time itself becomes a resource to be shaped, delayed, or released.

From a practical short-term standpoint, energy storage has evolved from simple peak shaving and shifting to an essential enabler of grid flexibility, supporting stability, inertial response, renewable generation smoothing, and a wide range of ancillary services.

In transmission stages, it improves security and reliability, whereas in distribution systems, it supports resilience, congestion management, and hosting capacities of renewable resources.

Beyond its technical functions, a system engineering change exists, to recognize the energy storage not only as standalone source, but also as a dynamically active component within a complex ecosystem of electric grids. Its true value rooted from lifecycle thinking, design, integration, operation, degradation, and eventual repurpose. Only through this integrated view, the genuine contributions of energy storage to sustainability and grid integrity can be appreciated.

Advanced technologies such as High Temperature Superconducting Magnetic Energy Storage, Advanced Flywheels, Batteries, Liquid Air, Pumped Hydro, and the like, have to be assessed from a system engineering perspective. Figure 1 demonstrates a SE model development perspective [1].

In future, I hope to explore these layers, from technology families (electrochemical, mechanical, electromagnetic) to their philosophical and intrinsic implications, looking forward how storage connects the physical and temporal power systems' dimensions.

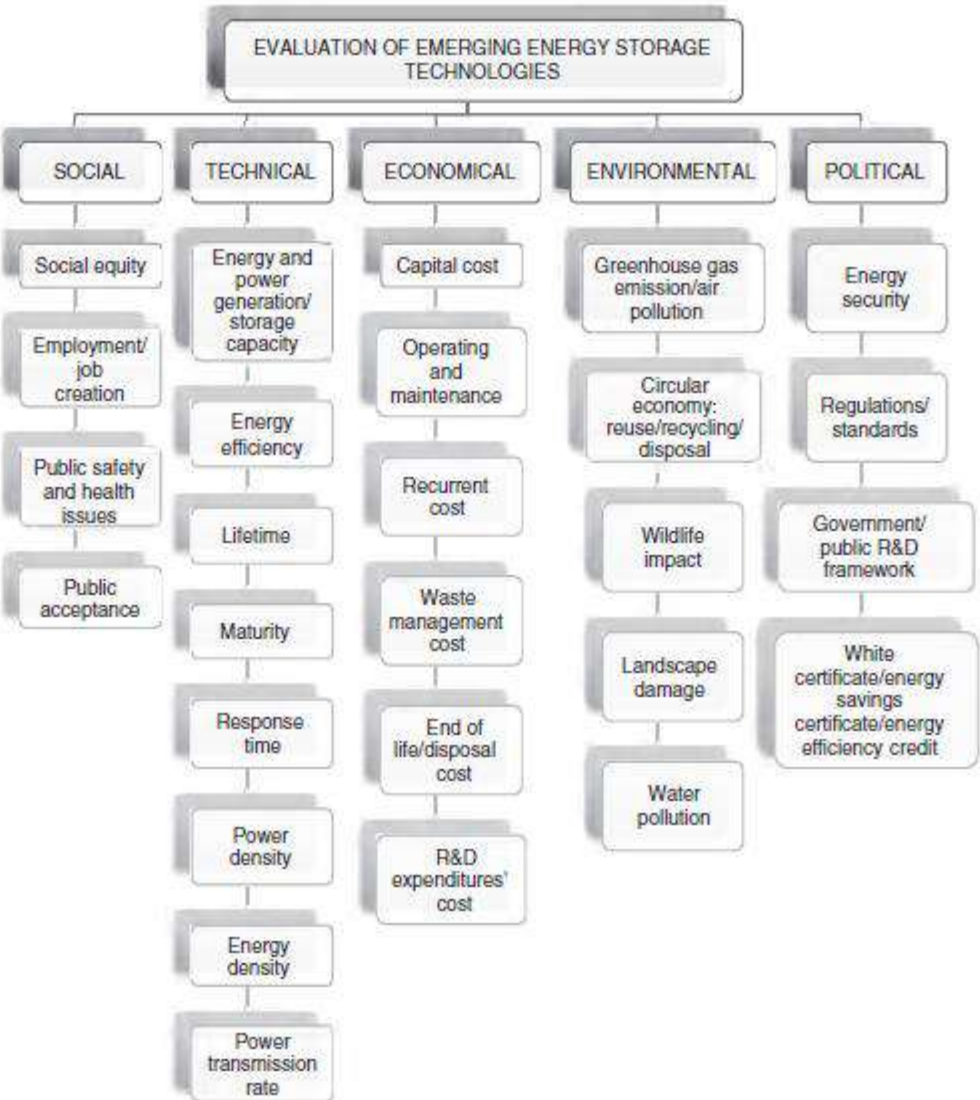

Fig. 1- Model Development Perspectives [1].

Energy storage keeps challenges in order to rethink what it means to design for time per se. In an age where immediacy predominates, storage includes patience, the engineering of delay as an action of wisdom. By system engineering discipline, storage can be perceived, not only as equipment, but also as balance discipline between present requirement and future needs, between transient event and surviving resilience.

The next sections discuss how such a perspective can illuminate both our grids and our thinking about energy, time, and purpose [2-10].

2 - A Philosophical Perspective of Energy Storage: Flywheels

Although these is a considerable development in the many ways of energy storage systems, flywheels stand salient for their elegant simplicity, where energy is neither held on chemistry nor in magnetism, but in motion itself. Through converting electrical energy into rotational kinetic energy, they feature instantaneous responses, higher efficiency, and virtually unlimited cycling capability.

In advanced processes, such as ship propulsion and electromagnetic launchers, flywheels offer mechanical inertia that can be harnessed for precision control and bridging physical and temporal power delivery dimensions.

One of the most complex projects I worked on was the Electromagnetic Aircraft Launch System (EMALS) for naval aircraft. My role was quite specific: to define the interface between the ship's prime power source (and the power quality impact) and the energy storage system based on a bank of flywheels. This was the project in which I learned a great deal of systems engineering that ensured proper performance, safety, and interoperability .

There is a special satisfaction in moving from the Preliminary Design Reviews to system testing, watching ideas become hardware and equations turn into motion. Yet it is also humbling to realize that your contribution is only one small part of a much larger symphony, one that succeeds only because others, across different subsystems, have performed their roles with the same precision, and because every interface has functioned as intended, ensuring seamless interoperability throughout the entire system.

As I look at the challenges of the electric grid of the future, I see flywheels as one of the technologies capable of making a profound difference. The EMALS, now operating on the USS Gerald R. Ford, delivers hundreds of megawatts within a few seconds through a linear induction motor to launch a single aircraft, a striking demonstration of controlled, high-power bursts .(*)

This same principle, scaled and adapted, could serve electric networks to provide short, powerful injections of energy that can help stabilize frequency and voltage during critical transitions.

In many ways, the story of energy storage with flywheels mirrors the story of the grid itself, both are about controlling momentum, storing potential, and releasing it at the right time.

3 - Batteries: From Burden to Backbone?

For much of modern electrical engineering history, batteries were considered as the Achilles' heel of power systems - fragile, expensive, short-lived, and unreliable. They powered flashlights, radios, and early portable electronics, but few people imagined they would one day support electric grids.

In just a few decades, batteries have undergone a deep diversion, not only in chemistry and performance, but also in meaning. Once a peripheral technology, they now rest at the core of debates on decarbonization, system resilience, renewables, mobility, autonomy, and geopolitical supply chains. What was once a constraint has become a strategic cooperator.

(*) According to the manufacturer General Atomics Electromagnetic Systems, the EMALS aboard Gerald R. Ford "successfully performed as designed" during the ship's Full Ship

Shock Trials in mid-2021. The system successfully achieved and exceeded the Navy's target of 8,000 launches and recoveries.

Nowadays, batteries are being used to participate in frequency stability, assist share of renewables, handle disturbances, shift load, electrify transport, and enable fully digitalized control of power systems. But their rise also reveals a deeper truth, energy storage is not only about containing electrons, it is about shaping time as well. Batteries do not store energy as much as they decide when energy is the highest priority.

A landmark in battery storage history was the 10 MW / 40 MWh Chino project by Southern California Edison, commissioned in 1988 as part of an EPRI demonstration. Regarded as the first truly utility-scale battery energy storage systems (BESS), it proved that batteries could operate at grid level and helped lay the groundwork for today's large-scale storage formation. I personally later applied its interface topology when defining the coupling (Power Conditioning System) for the BWXT 30 MW / 60 seconds SMES project in 1996.

Afterward, BESS deployment has been rapidly accelerated. In Southern California alone, installations have exceeded 12 GW, while global installed capacity now exceeds 45 GW. What began as experimental demonstrations has evolved into a fundamental component of modern grid infrastructure. This surge highlights not just the progress of battery technology but the growing urgency to tackle challenges in control, integration, lifecycle management, and system interoperability.

From a systems engineering perspective, the value of a battery cannot be measured by energy and power density or cost per kWh alone. It must be understood through lifecycle thinking, extraction of minerals, manufacturing, integration, monitoring, safety, degradation, second life, recycling, and repurposing. A battery is only as useful as the ecosystem it belongs to. That is why batteries must also be examined in contrast to other time-shifting technologies: flywheels, pumped hydro, compressed air, hydrogen-based systems, and superconducting magnetic energy storage (SMES). Each stores time in different physical states, motion, magnetism, gravity, chemistry, or pressure. Each answers a different question about power, duration, and response. (For a summary of commercially available battery technologies - see below Table.1).

Tabl 1: Battery Technologies Compariosn

Battery Type	Chemistry / Variant	Typical Application	Key Advantages	Main Limitations
Lithium-ion (Li-ion)	LFP, NMC, NCA, LMO, LTO	EVs, grid storage, consumer electronics	High energy density, high round-trip efficiency, fast response	Thermal runaway risk, aging, cost of materials
Lead-Acid	Flooded, AGM, Gel	Backup power, UPS, telecom, small storage	Low cost, mature tech, recyclable	Low energy density, shorter cycle life
Sodium-Sulfur (NaS)	Molten salt	Grid-scale storage, peak shaving	Long discharge duration, high energy density	High operating temperature (~300 °C), safety concerns
Sodium-Nickel-Chloride (Zebra)	Molten salt	Transport, off-grid	Good safety, high operating temperature tolerance	Needs heat, slower response
Nickel-Cadmium (NiCd)	Alkaline	Aviation, industrial backup	Long life, wide temperature range	Cadmium toxicity, memory effect
Nickel-Metal Hydride (NiMH)	Alkaline	Hybrid vehicles, portable devices	Safer than Li-ion, good cycle life	Lower energy density, self-discharge
Flow Batteries	Vanadium Redox, Zn-Br, Fe-Cr	Long-duration grid storage	Decoupled power & energy, deep cycling	Lower power density, higher CapEx
Zinc-Air / Metal-Air	Rechargeable or primary	Remote power, emerging grid tech	Very high theoretical energy density	Limited cycle life (rechargeable versions still developing)

4- The Challenges Ahead

Despite extraordinary progress, the future of battery technology faces several unresolved systemic challenges:

- Material constraints
- End-of-life management
- Safety and urban deployment
- Standardization and interoperability
- Grid integration at scale
- Chemistry vs. architecture

5- Conclusion

Batteries alone will not solve the energy transition. Their success depends on how wisely they are embedded within system architectures that respect physical limits, application-specific roles, lifecycle constraints, and, above all, the engineering of time. Treated separately, batteries risk becoming yet further technological burden; understood systemically, they become powerful instruments of balance and flexibility. This system engineering perspective clearly stated that energy storage must be re-evaluated, not merely by its nominal values, such as power ratings, cost, and energy density, but also by how it reacts with network ecosystem, variability in generation, power system dynamics, control strategies, degradation mechanism, safety provisions, and terminal tracks.

The energy transition of energy thus requires pluralism rather than exclusiveness. Batteries must coexist and cooperate with other time-shifting technologies, flywheels, pumped hydro, SMES, compressed air, hydrogen, each storing energy in different physical states and answering different temporal questions of the grid.

Ultimately, the true challenge is not technological but architectural. The energy transition demands that we design grids not just for capacity and efficiency, but for temporal intelligence, the ability to decide when energy matters most. Systems engineering provides the discipline to see storage not as equipment, but as an integral element in shaping resilient, sustainable, and meaningful power systems for the long term.

Author's short bio: Paulo F. Ribeiro received the B.S.E.E. degree from the Federal University of Pernambuco, Recife, Brazil, and the Ph.D. degree from the University of Manchester, Manchester, UK. He was a Research Fellow with the NASA Glenn Research Center, Cleveland, USA, Electric Power Research Institute (EPRI), Palo Alto, USA, and Erskine Fellow with the University of Canterbury, Christchurch, New Zealand, and with the Brazilian Institute of Electric Energy (INERGE), Brazil. He is a Life Fellow of IEEE. He is a Full Professor with the Federal University of Itajubá, Itajubá, Minas Gerais, Brazil.

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Advanced Technologies Journal of University of Benghazi (ATJOUB)

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Review Article – Information Technology

Towards Airlines IT Audit Challenges & Success Factors: A Systematic Review

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Abstract-

Examining the field of Information Technology (IT) audit in the airline industry, the methodical investigation seeks to uncover elements contributing to success as well as obstacles. The importance of this study stems from the crucial role of IT systems in ensuring efficiency, safety, and customer satisfaction in the rapidly expanding aviation industry. The study begins with a brief overview of IT auditing in the aviation business, revealing details about audit methods and kinds. Given the critical role that IT systems play in aiding airline operations, a thorough examination of their audit processes becomes necessary. The systematic review encompasses a comprehensive examination of 61 prior articles, offering an in-depth look at the current state of knowledge on this topic. The following sections describe the research methods employed in conducting the systematic review, including the methodology and criteria used for selecting and interpreting the literature. This sets the stage for the findings to be presented and thoroughly discussed. Throughout this process, a special emphasis is placed on explaining the obstacles encountered during IT audits in the aviation industry and identifying the key elements that contribute to their effectiveness. In addition to providing a comprehensive review of the current literature, the study offers valuable insights into the challenges that IT audits face in the aviation industry, as well as the key success factors required to overcome these issues. The results synthesis aims to inspire future research topics and provide practical applications for IT audit experts working in the ever-changing and technologically complex aviation sector. This systematic evaluation, therefore, provides a comprehensive reference for knowledge, addressing and improving IT audit processes in airline operations.

Keywords: Information technology; IT systems, IT infrastructure; IT Audit, Airline IT Audit; Success factors; Airline industry.

1 - Introduction

The growth of the airline sector has grown as well as dramatically changed over the years, thanks to technological innovations that have reshaped how airlines operate. However, all aspects of airline operations seamlessly integrate IT systems. Whereas the airline industry relies increasingly on sophisticated IT infrastructures to promote efficiency and competitiveness, the demand for rigorous IT audit processes is vital to ensure the integrity, security, and compliance of these systems grows. Furthermore, the evaluation method of this systematic review delves into the sensitive relationship within an airline's IT system infrastructure and the auditing systems that ensure its operations. The aim of this systematic study is to provide a comprehensive understanding of the current environment of IT audit within the airline industry, emphasizing key concerns and opportunities that impact IT audit within the airline sector. Nowadays, in a dynamic aviation business, IT is critical to allowing flawless operations, ensuring passenger happiness, and preserving regulatory compliance. The complexity and interconnection of airline IT systems need a comprehensive and methodical examination to assure their effectiveness, security, and compliance with industry standards. This is a situation where IT audits come into action. The auditing process plays a crucial role in identifying human errors and system weaknesses through monitoring and verification, as well as employing the audit process. Where audit tasks include identifying the target or existing problem and proposing solutions to mitigate its escalation. Nevertheless, as the market economic climate evolves, legal systems progress, and the audit atmosphere grows more complicated, audit risks have grown in significance [1].

1.1- IT Audit

Recently, the IT audits have played a vital role in the aviation industry to ensure and examine the effectiveness of IT systems security and legality. Therefore, the key areas focus on how to assess the protection of sensitive data and ensure data integrity and availability, as well as confirm and meet compliance with industry standards established by the International Air Transport Association (IATA). Thus, IT audits can include disaster recovery and continuity of operations plans, where IT risk management, technical infrastructure examinations, and security and performance assessments of independent IT service providers are performed. Within this context, IT audits contribute to the resilience and adaptability of airline IT systems, leading to boosted security services and dependability in air transport operations. Also, IT audits evaluate the performance of IT procedures and processes to ensure integrity, security, and regulatory compliance of data. Furthermore, it is conducted in various nations throughout the globe to evaluate the IT infrastructure and operations of organizations such as government agencies, enterprises, and healthcare facilities. The goal is to identify possible risks, vulnerabilities, and opportunities for enhancement of IT systems to improve security as a whole and efficiency during operation. [2] IT audits [3] are used in civil aviation to review and evaluate the efficacy, security, and dependability of IT systems and infrastructure. Moreover, the study contributes to the security, compliance, and optimum operation of aviation's IT systems, which include air-ground communication, navigation aids, aeronautical surveillance, and system-wide information management. An IT audit may also help uncover possible vulnerabilities, analyze cybersecurity risks, and apply suitable risk mitigation measures. Figure 1 illustrates an audit process in general that is used in various sectors.

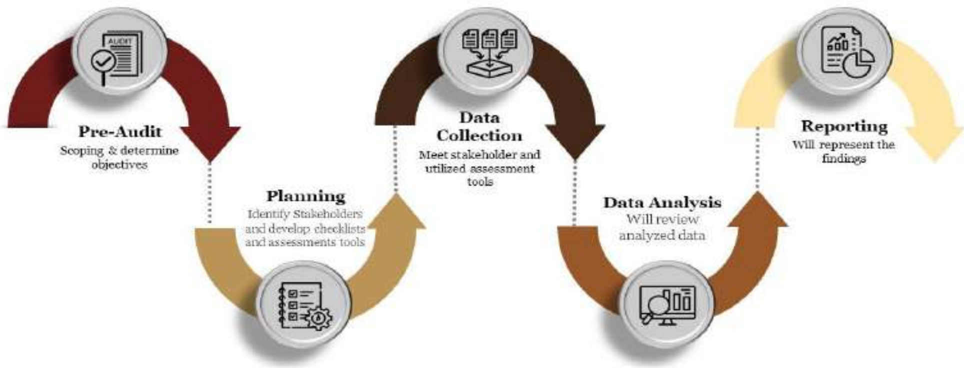

***Figure 1**: Generic IT Audit Process.*

For most instances, Figure 1 describes the generic IT audit process involved in conducting an IT audit:

i. **Pre-audit:** As part of the pre-audit process, audit planning is usually conducted. This involves determining the audit strategy and assigning resources to carry it out. Before moving on to data collection, analysis, and reporting, this step establishes the framework for the audit.
ii. **Planning:** An audit entails settling on an audit plan and distributing resources to carry it out.
iii. **Collecting Data:** Interviews, observations, and pertinent document gathering are examples of manual sampling methods used to get the necessary data.
iv. **Data Analysis:** To evaluate the process's efficiency and compliance, the obtained data samples are examined.
v. **Reporting:** The results of the analytics audit are shared with the public.

1.2- Types of Audits

There are two types of IT audits: internal and external. Internal IT auditing in the airline business entails analyzing and guaranteeing efficacy and effectiveness while including security within the airline's information technology systems and infrastructure. This audit is conducted internally via an airline's own IT auditing group or department to ensure regulatory compliance, identify possible risks, and enhance IT governance. It focuses on data security, network infrastructure, system stability, and adherence to industry standards. The internal IT audit is intended to improve the airline's IT processes. reduce possible risks and protect critical passengers. and operational data. [2] The paper discusses the use of internal and external audits. Internal audits are conducted through the Internal Audit Service (IAS). The Internal Audit and Assurance division coordinates external audits. The work detailed in the publication focuses on adapting FOMS to operate in the presence of partial information. [4]. Table 1 illustrates the key difference between internal audit and external audit. Also, Figure 2 provides an overall description of the overall review process subsection.

Figure 2: *Overview of Review Process.*

Table 1: *Audit Types Comparison.*

Aspect	Internal Audit	External Audit
Scope of Work	Organizational operations	Fiscal Functional Records
Focus	Enhancement to protect organization value	Faire representation for finical statement
Risk Range	Board	Narrow
Primary Audience	Board and Executive Management	Inventors and public interests
Employment	Depends on internal employees	Depending on third party
Qualification	Not Mandatory	Mandatory
Licensing	No	Yes

Figure 3 outlines the organized systematic review study flow. Therefore, the current systematic review study is for airlines IT audit concerns to explore the challenges and success factors. Moreover, the study inspiration and contribution are organized as follows: the study begins with introducing the IT audit process and kinds (internal and external) within Section 1, followed by a literature study and analysis of 61 previous studies involving IT audits in the aviation industry during Section 2, whereas previous studies are in chronological order and summarized. Following that, the study methods for this systematic review are identified via Section 3. The findings and analysis section addresses the research question within Section 4. Finally, the conclusion and future work are provided in Section 5. Therefore, a list of the abbreviation table that displays keyword abbreviations is mentioned in Appendix A.

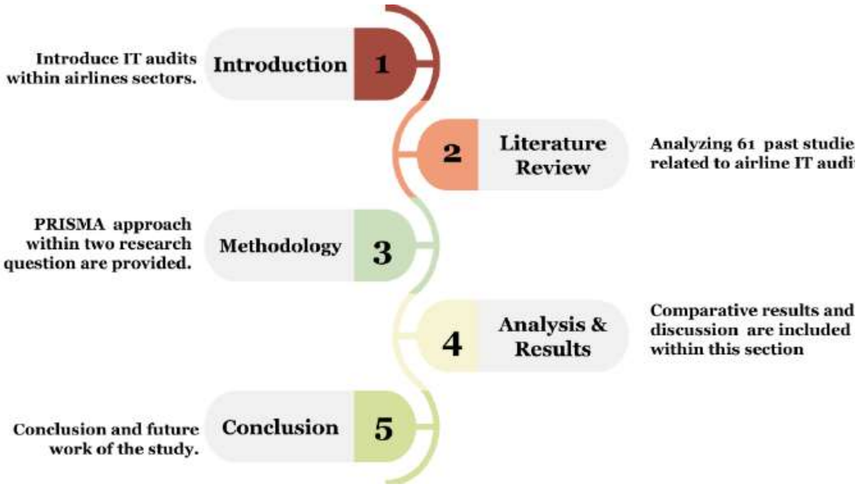

Figure 3*: Overview of Proposed Research.*

2- Literature Review

To begin with the literature review section, the study examines 61 previous studies of research published between 2015 and 2025, ordered in chronological order. However, Table 2 provides an overall summary of the contributions and limitations of various past studies. Therefore, this section is categorized as follows:

2.1 Audit, Risk Management, and Cybersecurity Frameworks in the Aviation Sector

The global growth of technology impacts the increase of cyberattacks and cyber risks that surface. However, relevant research examined the airline IT audit to understand what frameworks, contributions, and limitations were employed, where the authors of the study [3] described Fly Africa's effective implementation of Information Technology Risk Management (ITRM) utilizing the RITM 23 method. This strategy, which encompassed standards such as COSO ERM, ISO 31000, and COBIT 5, provided a complete and simple approach to ITRM. The deployment procedure comprised both ITRM protocols and IT risk governance mechanisms. Although the report in [5] shows the preliminary planning work completed through the Nebraska Auditor of Public Accounts in response to the concerns raised regarding the American Rescue Plan Act funds provided to Airlines Next LLC, a virtual airline based at Lincoln's municipal airport. While the article [6] provides an overview of APA’s concerns as well as potential remedies. The study objective is to educate stakeholders and the broader public about the APA's findings and to advocate for corrective action to address the problems raised. Thus, the research [7] examines the implications of the COVID-19 pandemic on representations in passenger airline financial accounts using International Financial Reporting Standards (IFRS) and US Generally Accepted Accounting Principles (GAAP). Furthermore, it contrasts the transparency practices and standards of these two accounting systems. Moreover, private ownership, low-cost airlines, increasing trade ties, and technical improvements have all contributed to the aviation industry's exponential rise [8]. Therefore, Qatar Airways has employed techniques that include purchasing interests with different airlines, expanding into new areas, and supporting activities to accelerate its worldwide growth. Due to [9], the authors give a threat categorization study based on the STRIDE model, emphasizing the need for suitable systems and infrastructure for maintaining airworthiness. Likewise, the purpose of using IT audits inside [10] is critical in the context of controlling safety risks in aviation maintenance outsourcing since cyber risk presents a severe danger to safety. Furthermore, IT audits assist in the security of information technology resources, examination records, and qualification papers, all of which are utilized to assess if MROs follow requirements.

2.2 Practical Limitations of Existing Approaches

Recently, various practical methods have become popular, especially those based on the multi-level framework from [11] created by Frambach and Schillewaert in 2022, which look at various issues related to airline partnerships and airport-led transfer programs in the industry. Furthermore, Etihad Airways' [12] requirement for internal audit capabilities is motivated by the significance of delivering guarantee services in a wide variety of business sectors, which has grown increasingly crucial. Internal audit functions are critical in establishing trust and credibility, improving the validity of information, procedures, and reports, and giving assurance to a broad variety of stakeholders. Moreover, the internal audit operations may contribute value by conducting business process improvement audits, risk management evaluations, and fraud detection. Additionally, the research [13] considers the use of internal audits, especially internal algorithmic audits, in order to guarantee that AI systems fulfill ethical norms and standards. This research paper proposes an internal audit framework for AI systems, especially the SMACTR framework. Thus, by evaluating a huge dataset of passenger evaluations [14], the research helps to better understand consumer satisfaction and feedback in the aviation sector. It employs the use of semantic network analysis as well as regression analysis to determine the elements that influence customer happiness and recommendation. The results provide insights into building long-term plans in the airline sector and emphasize the relevance of consumer input to corporate success. The report also underlines the importance of understanding internet reviews and their ramifications for the airline business. Therefore, the study [15] emphasizes the evolution of airline ownership and control compliance with US legislation rather than IT systems or infrastructure. According to the study [16], they examine the implementation of a modernizing IT risk universe framework to satisfy the new needs in the IT audit plan for the aviation sector. This approach is suggested to address the risks that come with digital transformation. The research helps to identify the needs and prospects for upgrading the IT risk universe in IT audit methods, especially in the framework of digital transformation. It offers a framework for dealing with the rising complexity of IT risk categories. Also, within [17], the research was done to analyze the degree of compliance with an airworthiness criterion in Myanmar's aviation industry. Furthermore, the report illustrated the airlines' existing airworthiness preparation and recommended modifications to training programs. In addition, the research [18] helps to clarify the function of internal auditors in ensuring regulatory compliance and safety in aviation maintenance, as well as the use of the Becker Model to analyze the benefit, cost, and likelihood of illegal activity in this context.

2.3 Research Gaps & Limitations

This subsection examines the limitations and research gaps based on analyzing the previous studies. However, the approach for performing airport security audits, which is shown in [19], underlines the need to hire external auditors who are experienced in assessing airport management and organization. Therefore, the research in [20] focuses on airlines' susceptibility to being appropriately qualified and having specialist knowledge of the sector being audited. The research also examines the method of auditing civil airport security and protection, and it advises using external auditors to ensure impartiality and objectivity in cyberattacks and the possible implications. It outlines examples of system failures at United Airlines and Alaska Airlines, resulting in flight interruptions and revenue losses. Numerous cyber risks, including DDoS assaults, viruses, and data breaches discussed in [21], emphasize the need for robust cybersecurity procedures, frameworks, and guidelines. It also discusses the misuse of passenger information and the associated liability for airlines. While it does not explicitly state contributions, the research emphasizes the importance of cybersecurity within the airline sector and briefly touches on limits, such as persistent cyber threats and the impact of social networking sites on airline operations. Table.2 summarized the analysis of the past studies.

Table 2: *Analysis of Past Studies.*

Ref.	Year	Type	Frameworks	Contribution	Limitation
[3]	2023	Case Study	ISO 31000 & COSO ERM.	The RITM 23 methodologies approach is utilized in this study to look at the implementation of a proposed ITRM system throughout an African airline.	Lack of a complete End-to-End technique for ITRM. This problem is significant because it suggests that the research does not effectively integrate or account for the interconnectedness of numerous risk management systems as well as the resulting cumulative effect on the firm.
[6]	2023	Audit Report	Audit Process	They attempted to improve the authority's processes and practices, notably those related to finance and contract regulations.	Report on the constraints of IT audit techniques, as they may not reveal all potential shortcomings in policies or procedures.
[7]	2021	Financial Research Study	IFRS & US GAAP, & GOST R ISO 19011.	Examines implications of COVID-19 on passenger airline financial reports and gives info on the openness and quality of business reporting and the auditors' replies in their reports. Also, it revealed the existence of tax breaks and continued issues.	Reported that the research sample of 24 statements of income is limited and should not be used to extrapolate larger groups. Also, they acknowledge the significant difference in the complexity of disclosures linked to the effect of the epidemic to the chosen sample of statements.
[9]	2021	Review Paper	NIST Framework. ISO 27001	It examines the significance of cybersecurity in aviation, prospective dangers, including DDOS attacks, and how cybercrime affects air transportation.	Lack of awareness Complexity of systems Insider threats Limited resources
[10]	2020	Review Paper	SWOT Framework.	Provide info on worldwide aviation maintenance outsourcing, its risk factors, and safety concerns. It also gives insights into outsourcing, global trends of aviation outsourcing, and the regulatory procedures taken by FAA agencies.	The constraints and limits of IT auditing in the context of maintenance for aviation outsourcing might encompass the requirement for real-time data access, capabilities for data analysis and interpretation, and data-driven decision-making.
[12]	2020	Review Study	Framework based on service quality; they suggest.	Proposing a framework for evaluating the perceived value added by internal audit functions based on insights from literature on internal auditing and service quality disciplines. It also conducts a thematic analysis of published profiles of various organizations' internal audit functions to identify recurring value-adding attributes.	The research contributes by presenting a methodology for assessing the perceived value contributed by internal audit functions, according to findings from the literature on internal auditing and quality of service professions. It further performs a topical evaluation of published profiles of different firms' internal audit functions to identify recurrent value-added characteristics.
[13]	2020	Research Study	SMACTR framework	Underlines the significance of conducting internal audits on AI systems to guarantee ethical and responsible growth. The suggested SMACTR framework intends to guide realistic deployments of internal audits for AI systems by identifying failure mechanisms, prioritizing risks, and generating problem-solving strategies.	While the paper does not go into depth on the contributions and limits of IT audits, it does emphasize the need for internal algorithmic audits within the overall picture of artificial intelligence development.

Table 2: *Continued.*

[15]	2019	Report	U.S. Government Accountability Office (GAO)	This report adds to our knowledge of the difficulties and issues regarding foreign ownership throughout the US aviation sector.	As a result, it provides essential stakeholder viewpoints, but it may fall short of delivering a thorough and complete study of the possible effects of changing foreign ownership regulations on the US aviation sector.
[17]	2018	Thesis	ICAO & EASA	The contribution may be deduced from the evaluation of compliance with the airworthiness criteria in Myanmar's aviation sector.	Constraints can involve data collecting limits, number of samples, or other issues influencing the study's breadth and generalizability.
[19]	2016	Research Study	PDCA	Use external auditors who have sufficient expertise to ensure impartiality and objectivity while assessing airport security, show a methodology to perform airport security audits: administrative, technological, & physical factors, recommend using checklists to cover all processes, operations, duties, and functions throughout the audit & emphasizes the need to plan corrective measures for recognized faults.	The report does not dive into case studies or illustrations of how the proposed approach is used in practical problems with airport security audits. It fails to tackle any possible issues or barriers that may occur throughout the suggested framework's implementation process. The report fails to provide a full analysis of the costs or resource requirements for performing airport security audits utilizing the specified methodology.
[20]	2015	Research Study	ISO 27001, CIS Controls, & NIST	Airline technology and systems were found to have weaknesses. The need to safeguard passenger information was again stressed.	There is a dearth of data pertaining to individual cyberattacks. Moreover, details regarding the veracity of certain assertions are lacking.
[21]	2022	Systematic Review	Audit Process	Provides info on security vulnerabilities, risks, and possible surfaces in the civil aviation business. The findings depend on an assessment of reported occurrences and recommended security solutions.	The study emphasizes the difficulties in obtaining accurate and complete information on aviation events owing to the industry's sensitive nature as well as the overwhelming majority being owned by government entities.

3- Methodology

The methodology section provides a detailed overview of the review approach utilized in the study.

1.1 Review Planning

The review planning method for this systematic review is detailed in this section. This review's planning phase included the creation of the study questions, the development of an approach to searching, and the design of study selection criteria. The goal of describing the review strategy is to assure openness, replicability, and thoroughness.

1.1.1 Research Question

The following study questions were developed with the goal of performing a quantitative examination of the research literature in science, investigating the possible application of process mining in conventional auditing, and investigating the problems associated with process mining-based audits:

RQ1: What are the key challenges associated with utilizing the audit process within airline companies?

RQ2: What are the success factors of IT audits within airline companies?

1.1.2 Review Procedure

The review methodology was created by constructing search strings, choosing appropriate databases to perform the search, and defining the criteria for both inclusion and exclusion. Each of these subsections is discussed in further depth below.

1.1.2.1 Search String

Numerous trial investigations into literature were undertaken prior to developing the best search phrase. Nevertheless, the query that followed was chosen for its capacity to provide the most pertinent search results. (Audit OR auditing) AND (IT Audit OR “information technology audit”) AND (Airlines IT Audit OR Aviation IT Audit) The localized rendition of the preceding query for searching was used for each of the specified literature indexing databases.

1.1.2.2 Databases to Search

The literature search for this review was conducted using various online resources that index scholarly literature, including:

- ScienceDirect
- IEEE Explore
- ACM Digital Library
- Springer Link
- Google scholar
- ProQuest
- ResearchGate
- Elsevier

- Other various Journals.

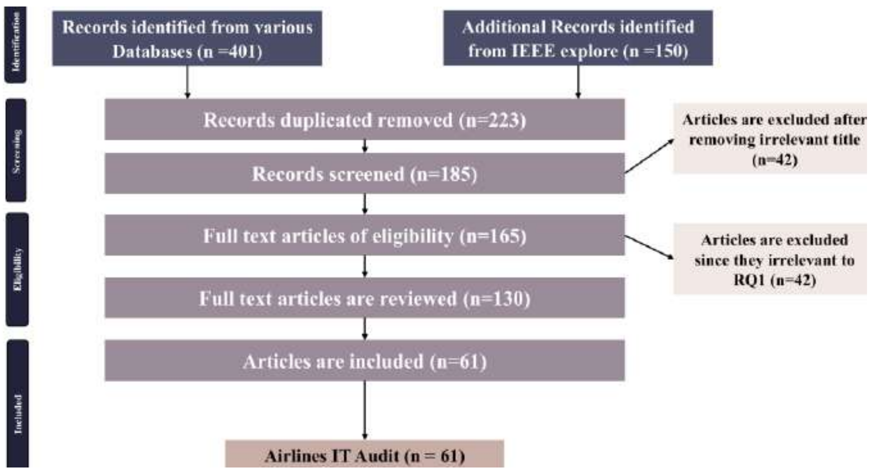

Figure 4: *PRISMA Diagram for Systematic Review.*

1.2 Report Conducting

Regarding this phase, the review plan created in the previous stage is executed. Where the search for databases and the results obtained are done. Therefore, a title-based duplication approach is utilized to remove identical papers from several databases. The publications were screened according to inclusion and exclusion criteria, comprising titles and abstracts. After passing the previous screening phases, the articles underwent full-text screening. Answers from chosen articles were recorded on an Excel sheet.

1.2.1 Data Collection and Analysis

The data regarding the overall study question was gathered using a Microsoft Excel form, which also aided in the quantitative analysis for the information that was collected. The last phase in the review process was to report on the results, which will be discussed in the next section.

1.3 Reporting and Findings

In this phase, the review results are reported. Our methodology for this systematic review is based on the PRISMA declaration. Figure 4 is a high-level overview of the piece of literature selection process, showing the steps taken and the articles included or excluded depending on the approach employed. Listed below is a breakdown of the following steps that make up the procedure: To fulfill the study's concerns, sixty research papers were considered appropriate. Figure 5 depicts the distribution of research by year, whereas Figure 6 shows the distribution by publication type. Figure 5 shows that the frequency of publications has been on the rise throughout the years, but it has been on the downturn as of late. Figure 6 shows that there was no significant difference in the distribution of the studies included across journal articles and those published at conferences. The number of articles presented at conferences was somewhat lower than that in journals. The results section that follows will discuss the findings that are pertinent to each study topic.

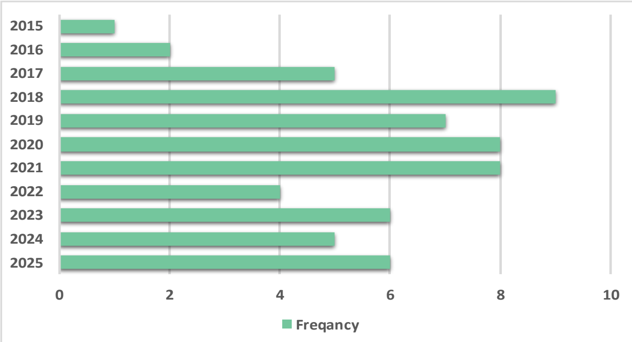

Figure 5: *Yearly Publication Distribution.*

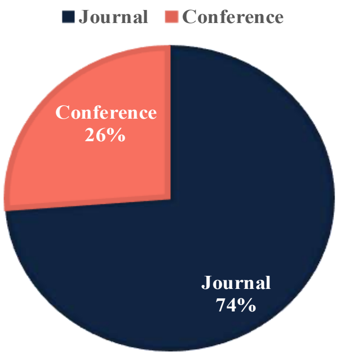

Figure 6: *Distribution of Publication Types.*

4- Analysis and Results

The results of the review are detailed here. The research questions established during the review planning phase served as a guide for the analysis and structuring of the findings. At the outset, the section provides a detailed presentation of the results pertaining to each study topic, backed up by appropriate data, tables, and figures. Investigators and those working in the area may greatly benefit from the insights provided by this section, which offers a comprehensive look at the pros and cons of employing process mining for business process audits. Focusing on the efficacy of organizational procedures and applied business principles, the internal audit process seeks to guarantee the fulfillment of both internal and external requirements. It is widespread practice for an organization's internal auditors to conduct audits inside the company [22, 23]. Conversely, external audits are conducted by independent auditors who verify compliance with external regulations. In cases where the airline may also choose to hire an outside firm to conduct an IT audit in order to ensure that its systems are secure, up to code, and operating according to industry standards, The efficacy of the airline's information technology controls may be evaluated, and opportunities for improvement can be identified with the help of external auditors who provide specialized knowledge and an outside viewpoint. [24]. Their recommendation that airlines employ internal and external audits to protect themselves against cyberattacks is due [25]. Although external audits deliver an unbiased assessment of security measures, internal audits aid in evaluating risks inside the business. The thorough evaluation of security measures and the identification and correction of any vulnerabilities are both aided by this two-pronged strategy. Furthermore, [26], they utilize audits from both within and outside the company. When it comes to customs hazards, internal audits are used to analyze and target all the data that can manifest, while organizations such as the ICAO and the IATA do external audits for assessing security precautions and monitoring. To find patterns in the use of process mining techniques in distinct kinds of audits, studies were classified according to the audit type. Research dispersion according to Figure 6. Categories of publications distributed. Figure 7 displays the audit type. The items that relate to each kind of audit are listed in Table 3. These findings suggest that academics have paid greater consideration to internal audits than external audits, or both. A more positive outcome with process mining-based audits seems to be internal audits, according to the research that is currently accessible. Additionally, Table 1 provides a concise comparison using both internal and external audits.

Table 3: Articles Using Internal and External IT Audits.

Internal IT audit	[2],[5],[11],[12],[13],[16],[18],[27],[28],[36],[39],[40],[41],[44], [49], [50],[52],[53],[56],[57],[58]
External IT audit	[6],[7],[15],[19][23],[25],[38],[48],[51],[60].
Both	[1],[3],[4],[8],[9], [24],[29],[30],[31],[35],[43],[54],[55],[59],[61].

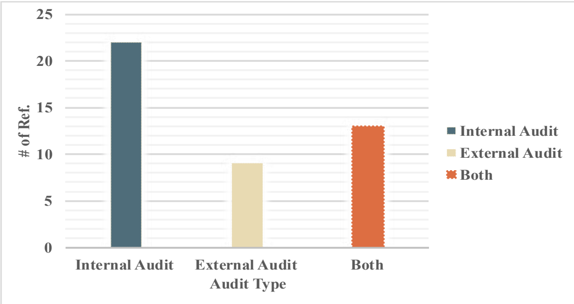

Figure 7: Distribution of Publications by Type of Audit.

Figure 8 represents an overall airline distribution within a worldwide range where the past studies related to these airlines are case studies, review studies, reports, and surveys.

4.1 **RQ1:** What are the key challenges associated with utilizing the audit process within airline companies?

Regarding the research question, this subsection begins to answer the research question; therefore, the key challenges are associated with utilizing IT audits in airline companies. Further, the successful factors for IT audits within airline companies. To guarantee that firms' IT implementations are secure, auditors conduct.

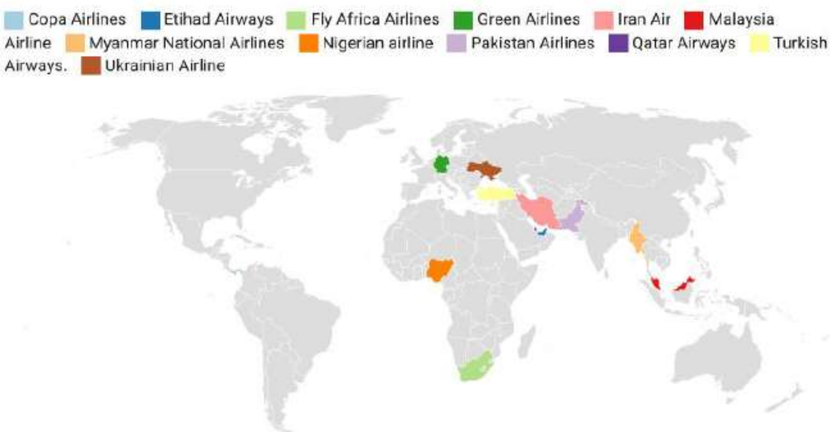

Figure 8: Airlines Distribution Over Worldwide.

IT audits. They also noted that there are several advantages to doing an IT audit inside airlines, including reduced expenses, safer data storage, and a better overall experience for customers in [32]. They are conducted to guarantee the efficacy, efficiency, and security of IT systems and procedures. The growing importance of IT and the consequences of fast technological development highlight the need for regular IT audits in today's organizations. [33] In addition, vulnerability assessment and innovative security technology are necessities in the aviation business due to the importance of security [34]. An evaluation and proposal for a vulnerability assessment methodology targeting aviation cyber-physical systems (ACPS) have been made. Nevertheless, [35], authors underline the necessity of the internal auditor's role in providing objective assurance, as well as advising in analyzing and monitoring the firm's ERM implementation. The study additionally highlights the need for a robust internal audit role in ensuring that risk management and governance systems are in place. There are numerous key challenges for IT audits within the airline industry. Where Table 4 provides a general key challenge for an IT audit within an airline company with a description and frequency, frequency refers to the number of repeated challenges within past studies. To begin with [36], there is an imbalance in the coordination of policies and objectives between different management systems, which may reduce efficiency. Although, due to the study [37], the key challenges for airlines in IT audits include ensuring cybersecurity in aviation, addressing cybersecurity threats and risks, and managing the security of air traffic control systems. In [23, 38], difficulties in identifying and reporting key audit matters include determining the most important concept and emphasizing specific aspects of the audited entity. The review of audit reports from transportation companies shows that the most mentioned critical issues are how revenue is recognized, the loss of value in receivables, and planning for major repairs of leased aircraft, which is important and critical. This report may have been stolen or leaked to reveal the airline's plans, which attackers could exploit to cause financial harm or damage the airline's reputation. This instance simplifies the scenario of exploiting and stealing information to cause damage to the airline company. More about key challenges, while [39] examines the problems of IT audits, highlighting the need for frequent audits to check the security of data and communication networks. It emphasizes the significance of international standards and guidelines in the design and implementation of information security systems. The paper also discusses the difficulty and time of acquiring audit material, in addition to the need for a precise audit methodology and schedule. It also underlines the importance of this audit report for discovering current flaws and strengthening the security systems. Within [40], they mentioned mobile device security for managing the security of mobile devices used by airline staff for operational and administrative purposes. Also, cloud security addresses security concerns related to the use of cloud-based infrastructure for airline operations and data storage. Figure 9 illustrates key challenges over frequency, where the top three highest frequency challenges are complex IT systems, data security, and privacy concerns, and ensuring regulatory compliance.

***Table 4**: General Airlines IT Audit Key Challenges.*

Key Challenge	Description	Frequency
Complexity of IT Systems	Airlines operate complex IT systems that handle reservations, flight operations, maintenance, and customer service, posing challenges in auditing these systems effectively.	18
Insider threats	Insider knowledge within the aviation industry can lead to potential security breaches.	1
Data Security and Privacy concern	Ensuring the security and privacy of passenger and operational data is crucial, and auditing IT systems for compliance with data protection regulations is a significant challenge.	17
Ensuring Regulatory Compliance	Airlines must comply with various industry regulations and standards, making it challenging to ensure that IT systems align with these requirements. Ensuring compliance with industry regulations and standards such as ICAO, FAA, and EASA.	19
Integration of Legacy Systems	Various airlines still use legacy IT systems, and auditing the integration of these systems with modern technologies presents a challenge.	5
Training and Expertise	Continually training and development of staff to counter the latest threats to cybersecurity is a challenge.	2
Resource Constraints	Lack of resources can hinder the implementation of effective IT audits.	1
Cybersecurity Risks	Airlines face challenges in safeguarding their IT systems from cyberattacks, making it crucial to address cybersecurity risks in IT audits. Also, it is sensitive to passenger data and flight operations.	12
Budget Limitations	Limited funds allocated to IT audit budgets can be a significant challenge.	2
Integration of New Technologies	Incorporating modern technologies such as AI, IoT, and blockchain into existing systems while ensuring security and compliance is a challenge.	7
Disaster Recovery and Business Continuity	Planning for and mitigating the impact of IT system failures or disruptions on airline operations.	3

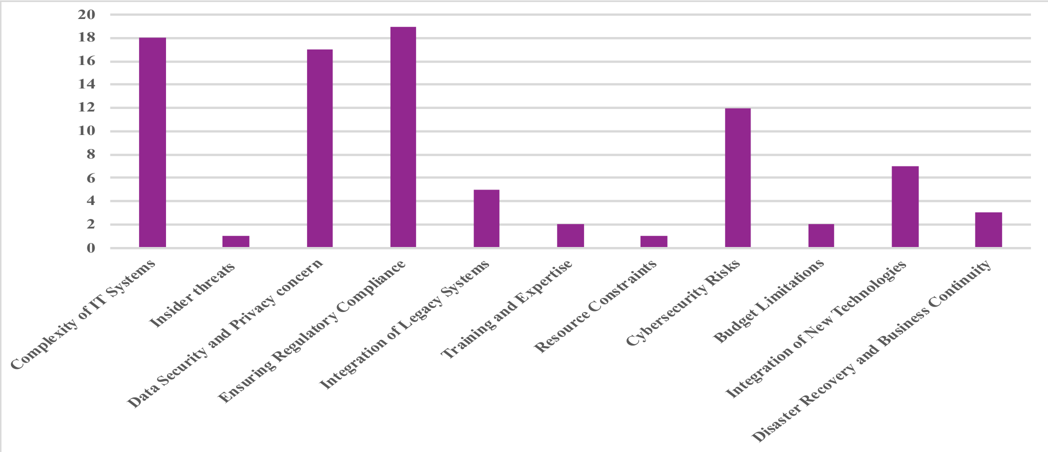

Figure 9: *Key Challenges Distribution.*

4.2 RQ2: What are the success factors of IT audits within airline companies?

This subsection represents and briefly discusses the success factors for airline IT audits. However, Table 5 provides a detailed overview of success factors for IT audits within airline companies. Where is the list of success factors, descriptions, and frequency of repeated studies due to various past studies. Furthermore, these success factors aim to mitigate risks and enhance the quality of airline IT audit work. Within [41], they focus on FOSA, which is an internal safety audit system.

Table 5: *Overall Airlines IT Audit Success Factors.*

Success Factors	Description	Frequency
Compliance with Data Protection Laws	Ensuring adherence to data protection and privacy regulations.	3
Cybersecurity Measures	Implementing robust cybersecurity protocols to protect against cyber threats.	11
Continuous Monitoring	Implementing continuous monitoring tools and processes enables proactive identification and response to IT risks	8
Collaboration with IT and Business Units	Effective collaboration between IT, audit, and business units to ensure alignment with strategic objectives and risk management.	9
Risk-Based Approach	Focusing on high-impact IT risks and vulnerabilities allows for more effective audits and risk management within the airline industry.	12
Talent and Expertise	Having skilled IT auditors with expertise in aviation technology and regulations is essential for successful audits in airline companies.	9
Alignment with Industry Standards & Best practices	Alignment with Industry Standards: Successful IT audits align with industry-specific standards and best practices, such as those outlined by aviation regulatory bodies and IT governance frameworks.	11
Adaptability to Change	Given the dynamic nature of the airline industry, successful IT audits are adaptable to changes in technology, regulations, and operational processes.	6
Regular Training and Awareness	Ensuring that airline staff are well-trained in IT security and compliance.	5
Data Encryption and Privacy Measures	Implementing encryption and privacy measures to protect sensitive data and ensure compliance with data protection regulations.	2

It is designed to collect, store, and analyze data related to human behavior during normal flight operations to proactively identify and address safety risks. Therefore, the audit system discussed in the document is an internal audit. Moreover, as mentioned in work [37], success factors involve implementing adaptive security solutions, conducting real-world penetration testing, and developing advanced security approaches for tactical and strategic operations. Additionally, incorporating consumption-focused indicators for resource efficiency and reliability in the aviation industry is crucial. Furthermore, via the study [42], the authors define success indicators for an airline IT audit as evaluating the effectiveness of IT systems in improving operational effectiveness, guaranteeing data security and privacy compliance, determining the integration of IT systems via business processes, and discovering ways to build innovations in technology to enhance consumer satisfaction and streamline operations. Moreover, the audit should assess the IT infrastructure's capacity to help achieve the airline's development and expansion objectives, as well as its resistance to cyberattacks and interruptions. While in [38], the authors discuss the adoption of industry best practices and standards for IT governance and compliance, such as COBIT and ITIL frameworks. Also, they mentioned a robust collaboration between IT, operations, and compliance teams to align IT strategies with business objectives. Moreover, within [43, 44], they suggest regular training and awareness programs for employees on IT security and compliance. In addition, the utilization of advanced IT audit tools and technologies for comprehensive monitoring and analysis, as well as keeping updated with technological advancements to address emerging threats. The authors [2] focus on the LOSA methodology, which is a proactive safety management tool used in high-risk industries such as aviation. LOSA is an internal audit methodology that involves the collection of de-identified, non-punitive quantitative and qualitative work performance data by trained LOSA observers. Table 6 provides a summary related to IT audits of airlines. key challenges and success factors. Furthermore, Figure 10 provides a key success factor distribution over frequency. Thus, the top three success factors are a risk-based approach, cybersecurity measurements, and alignment with industry standards and best practices. In the case of an airline, continuous monitoring means monitoring not only the usual IT systems but also, and more critically, the safety systems, flight operations, and the environments. This is unlike the usual IT environments, where continuous monitoring primarily means the monitoring of avionics systems, maintenance information systems, and the operations. Human-related issues also make the situation quite tricky, especially because the auditing and maintaining of the systems make way for human errors during the periods of maintenance and inspections.

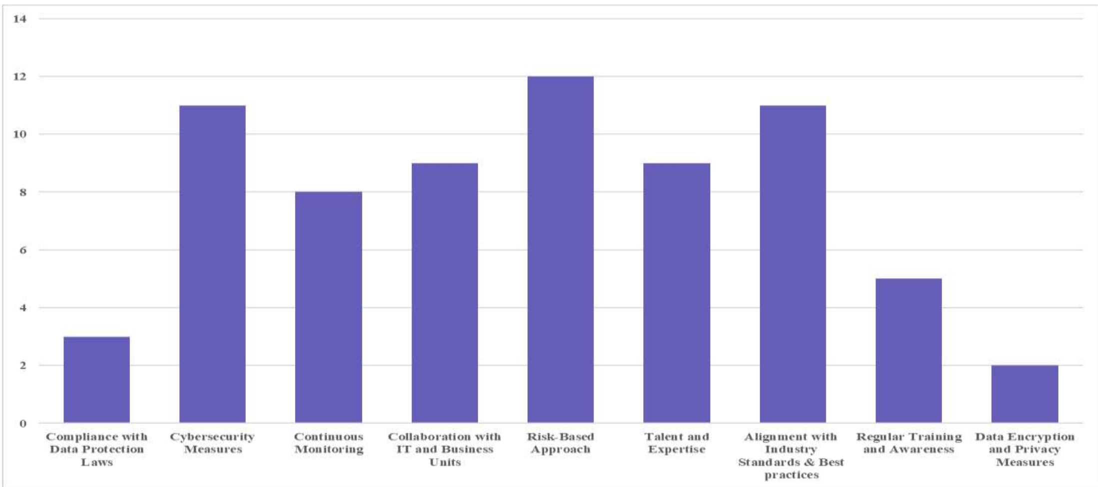

Figure 10: *Success Factor Distribution.*

In the case of the risk-based auditing system, the continuous monitoring and auditing of the systems in the context of an airline means the system focuses less on the application of universal audit controls and rather focuses on high-impact domains and sectors. Where security audit systems, operated through the context of flight operators, also face the issues of highlighting the importance of prioritization, especially through the context of risks, safety performance indicators, and regulatory findings. In the context of the strategic airline environment, where there are both micro and macro factors and issues, there is the need to have risks assessed through the application of an adaptive system.

Table 6: Overall Airlines Key Challenges & Success Factors IT Audit Comparison.

Ref.	Year	Key challenges	Success Factors
[45]	2023	The challenge includes resolving regulatory concerns, guaranteeing data security, and being current with technical developments.	It consists of employing innovative audit technologies and procedures, having auditors that are both informed and talented, and communicating effectively with stakeholders.
[36]	2023	The research found that aviation management systems lack consistency and uniformity, notably in policies, goals, and risk assessment. The lack of policy and objective coordination and various danger verification and risk assessment methodologies hinder efficiency and safety.	Success aspects include centralizing methods for reporting for disparate systems and identifying threats from several sources. To overcome these issues, the paper recommends extra global standards and aviation IMS research.
[46]	2022	• Regulatory Compliance: Adhering to federal aviation rules and industry norms. • Risk Management: Managing aviation's elevated level of hazards. • Technology Transfer Limitations: Exclusive information requirements for corporate operations restrict technology transfer. • Requires specific talents, abilities, and understanding for aviation industry space product manufacture.	• The process method is used to identify, monitor, and regulate the primary and supplementary activities within the company's operations. • Perform internal audits to assess quality management system aspects and assure compliance. • Strategic Planning: Strategic objectives and long-term planning guide resource use. • Continuous improvement: Adheres to full quality control to enhance goods, services, and production/rendering processes.
[47]	2021	• Cybersecurity risks such as securing communication systems which include ADS-B, RFID, as well as internet connection to prevent unwanted access and control. • Addressing vulnerabilities in GPS navigation and location validation mechanisms to avoid spoofing and hacking. • Encrypting data with AES and RSA for safe transfer and sensitive information protection. • Integrating Blockchain Technology for flight data encryption and tracking to maintain data integrity and security. • Public approval: Addressing the public's doubts and creating confidence in flying vehicle safety and security to win national airspace acceptability.	• Robust Cybersecurity Measures: Implementing fully autonomous flight with secure communication and navigation systems. • Compliance with Security Standards: Adhering to industry standards and regulations to ensure the safety and security of flying cars. • Government and Private Sector Collaboration: Collaboration between government and private companies to prioritize user safety and cybersecurity. • Long-Term Vision: Developing a holistic infrastructure to support secure cybersecurity operations for future flying cars. • Technological Innovation: Embracing advanced encryption methods and emerging technologies to address cybersecurity challenges effectively.

Table 6: Continued

[48]	2020	Remaining with quickly expanding technology, guaranteeing data security, and managing regulatory compliance.	Success criteria may include a professional and experienced IT audit team, outstanding interaction among stakeholders, and an ability to react to technological developments.
[49]	2018	The primary problems of IT auditing include keeping up with quickly expanding technology, ensuring regulatory and standard conformity, and managing cybersecurity concerns.	Success variables include experienced and knowledgeable IT auditors, good stakeholder communication, and alignment with business goals. Additionally, using technology and data insights may improve the efficacy of IT audits.
[33]	2018	• Risks associated with IT audit, which have a multi-dimensional and subjective concept, making it difficult to evaluate the impact of IT audit. • Lack of academic research on IT audits, leading to limited theoretical support for IT audit practices. • Complexity of modern organizational environments, which makes IT audit more complex and challenging.	• Adequacy and operation of the IT function within the organization. • Components such as the audit team, audit process and methodology, client control, technical competence of IT audit personnel, social people skills of IT audit personnel, client organizational environment, and IT audit targets.
[18]	2017	IT audits face significant problems such as keeping up with quickly changing technology, assuring regulatory and standard compliance, and managing cybersecurity concerns.	Success variables include knowledgeable and skilled IT auditors, good stakeholder engagement, and consistency with business goals.
[50]	2016	Certain obstacles may develop in meeting and maintaining Green Airlines' sustainable development objectives.	• Environmental Management System (EMS) Implementation • Sustainable Environmental Assessment • Corporate Environmental Management Practices • Greening Initiatives such as flight planning, greening on board, and ground operations. • Third-party Consultancy Evaluation based on environmental standards and practices.
[51]	2025	• Lack of uniform global standards for aviation monitoring and revision. • Data fragmentation in international regulatory bodies. • Difficulty monitoring real -time monitoring across different sectors. • Integration challenges between different technology systems and inheritance infrastructure.	• Implementing of integrated technical framework for monitoring and auditing. • Use of automated matching tools and data reconciliation techniques. • Adoption AI-driven analysis for adjusting cross-border regulations. • Stronger cooperation between international aviation authorities.
[52]	2025	• Limited awareness and understanding of insider threats in the aviation sector. • Override security while ignoring internal vulnerabilities. • Inadequate training, reporting mechanisms, and sharing of threat telecommunications. • Lack of organizational complacency and continuous risk assessment.	• Promoting a culture of security awareness across all aviation personnel. • Integrating behavioral analytics and insider risk detection systems. • Continuous training and education on insider threat indicators. • Collaboration between industry stakeholders and security agencies for better threat mitigation.

The aim of the research was to investigate the literature on concern for cybersecurity [54], focusing on risk, compliance, and regulatory adjustment. The study showed that digital integration, legacy systems, and outdated software made aviation systems more susceptible. Whereas control frameworks, real-time threat detection, and cross-industry collaboration improve cyber resistance and regulatory compliance. In addition, a blockchain-driven aviation cybersecurity architecture in [55] aims to secure airlines and airport information systems. According to studies, Blockchain reduces the risk of computers through decentralized trust, unchanging records, and smart contract-based authentication. This technology-driven strategy improves openness, traceability, and operational confidence in the aviation ecosystem. However, a hybrid Aczel–Alsina and Grey DEMATEL-ISM model is used to establish a causal link between industrial aviation transitional barriers [56]. Their results show that a lack of digital infrastructure, lack of competence, and significant adaptation costs prevent industrial aviation standardization. According to the report, strategy and innovation are the keys to seamless transformation. In [57], strategic security management in airlines is investigated using CPI-driven observation for continuous improvement. According to research, quantitative security indicators improve performance dashboards' security management system visibility, accountability, and decision-making. This shows that data-driven internal audits are crucial for security experience. Aviation Cybersecurity Organizational Preparedness was investigated using a technology assessment methodology. Within [58], a Secure E-payment system found deficiencies in risk management, personnel expertise, and technology adoption. The research found that training, leadership engagement, and political texture improve maturity and compliance preparedness. Even [59] used DEMATEL-QSFS to prioritize aviation cybersecurity measures by assessing mutual addiction in criteria for cyber preparedness. Risk beliefs, infrastructure Resilience, and enforcement of policy affect the cybersecurity performance according to their model. Evidence-based cybersecurity resource allocation is supported by outcomes. A classification of aircraft hackers and types of attacks is presented in [60]. The report categorizes attackers by motivation, from online criminals and hacktivists to state-sponsored groups, and describes their techniques, including phishing, injection of malware, and system penetration. It advocates better external threat monitoring and information exchange to defend cyberspace aviation. The research concludes with a comprehensive framework for combining IT audit approaches with automation technologies [61].

5- Conclusion and Future Work

Several airlines have regulatory issues, as well as concerns about privacy and risk management. Ensuring compliance, the complicated nature of IT systems, and other challenges. Success elements include incorporating novel audit technologies and methodologies, attracting qualified and knowledgeable auditors, and successfully connecting stakeholders. A comprehensive review of IT audits carried out in the aviation sector reveals the primary obstacles and success factors involved with this vital activity. The study highlights the importance of IT audits within the airline sector, emphasizing the challenges and success factors faced by airlines. Furthermore, it emphasizes the need for regulatory compliance, data security, and risk management for airlines. In contrast, success variables include the utilization of innovative audit technology and the presence of qualified auditors, along with successful stakeholder involvement. This in-depth analysis offers significant insights that may help educate and drive the creation of efforts to improve IT audit procedures in the aviation sector. However, developing a comprehensive framework in the future for airline IT auditing that incorporates best practices, regulatory requirements, and emerging technologies, aimed at enhancing the overall effectiveness and efficiency of IT audits in the aviation sector.

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Appendix

***Table 7**: List of Abbreviations.*

Abbreviation	Description
IFRS	International Financial Reporting Standards.
GAAP	Generally Accepted Accounting Principles.
ITRM	Information Technology Risk Management.
ISO	International Organization for Standardization.
NIST	National Institute of Standards and Technology.
COBET	Control Objectives for Information and Related Technology.
SWOT	Strengths, Weaknesses, Opportunities, and Threats.
DDoS	Distributed Denial of Service.
LOSA	Line Operations Safety Audit.
FOMS	Flight Operations Management Systems.
UIA	Ukraine International Airlines.
EASA	European Aviation Safety Agency.
ICAO	International Civil Aviation Organization.
ACPS	Aviation Cyber-Physical Systems.
IT audit	Information Technology Audit.
FOMS	Flying Operations Management Systems.
IATA	International Air Transport Association.
ERM	Enterprise Risk Management.

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Photovoltaic solar cells white Spot Phenomenon in high humidity Coastal: Environmental Factors and Performance Implications

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Abstract-

This paper presets a "cell spotting" phenomenon that was noticed on the rooftop PV systems along the coast in Tartous, Syria, during the summer, mainly in the early morning and late evening hours under specific environmental conditions. This phenomenon appeared as white spots on the photovoltaic cells. Repeated periodic measurements were taken over four months during the summer, revealing a strong correlation between the appearance of these spots and high humidity levels (above 50%), high temperatures, low direct solar radiation, and dust accumulation. Infrared images were taken of the studied panels during the study period in order to show the temperature deference between the cells with white spots and the other cells in the same panel, and the deference was about 2°C. After cleaning the cleaning the panels, the phenomenon was disappeared. Also, when the sunlight is not direct on the PV panel surface, the phenomenon does not appear. Practical measurements of temperature, humidity, and solar radiation monitoring revealed a strong correlation between the presence of this phenomenon and high humidity, temperature, dust accumulation, and indirect solar radiation on the surface of the panels. It was concluded that this phenomenon is a transient effect caused by a dust and moisture interaction, a condensation related process and appears as a white layer on the outer surface of the panel above the effected cells.

Keywords: PV Cell spots, dust effects, potential degradation, humidity effects, shading effects, hot spots, mismatch cells.

1 - Introduction

Solar Photovoltaic (PV) panels have become an unavoidable advanced technology in modern electrical grids due to economic viability for consumers and environmental aspects. However, the interaction of PV panels with natural surrounding factors like humidity, temperature, dust, and pollution leads to significant impact on their efficiency and radiation that reaches the panels. Regular or scheduled inspection of PV panels may not be carried out due to accessibility challenges, limited maintenance resources, and budget limits. However, some visual observations in walk-through energy audits would have initial concerns about performance degradation. In order to deduce such preliminary visual indicators, a visual observation should be conducted with concurrent electricity and meteorological data in order to deduce a reliable correlation. Rooftop PV systems along the coastal strip of Tartus, Syria, on the eastern Mediterranean coast, were monitored. A spotting phenomenon was observed on the cells, appearing during the morning and before sunset, when solar radiation is indirect on the panel surface and humidity levels are generally high. This phenomenon appears as white spots covering the entire cell surface and may appear on multiple cells within the same panel. These spots create shading effects on the affected cells and may extend to several adjacent or isolated cells within the same panel, as well as across different panels within the same photovoltaic solar energy system, and cause the temperature to be increased. This temperature increase persists as long as the environmental conditions favorable to this phenomenon remain. Conversely, the spots disappear, and the cells return to their normal temperature once these conditions or environmental factors change.

While existing research primarily addresses phenomena like hotspots, the specific white spot phenomenon observed here exhibits distinct characteristics. Hot spots are localized regions of elevated temperature resulting from shading, cell defects, or connection failures, which accelerate material degradation [1] [2]. These hot spots often occur when partially shaded cells operate in reverse bias, producing excessive heat that can reach temperatures above 130°C, leading to irreversible damage.[3]

Measurements have shown that this phenomenon is closely linked to high temperature and humidity, dust accumulation, and indirect solar radiation. Therefore, it differs from shading caused by other factors such as internal defects. Numerous studies have indicated that environmental factors, such as high humidity, high temperature, and low solar radiation, affect the physical and chemical properties of photovoltaic cell surfaces, promoting phenomena such as discoloration, dirt accumulation, and thermal anomalies [4][5]. For example, condensation under high humidity conditions can lead to crystallization or surface changes that appear visually as white spots, sometimes accompanied by localized temperature increases [6] [7].

Multiple studies have demonstrated that cleaning reduces temperature differentials and diminishes the extent of discoloration, underscoring the importance of maintenance in mitigating environmental effects [8].

Furthermore, the interaction between moisture, dust, and solar radiation can induce complex phenomena, including changes in optical properties and surface charge distributions, which can explain the irregular shapes and spreading of white patches, often extending beyond cell boundaries under high humidity levels (>50–75%). The greatest impact occurs in warm coastal areas where salt and dust deposits may accumulate on the panel surfaces, leading to faster panel deterioration, especially at high humidity levels [9] [10], this necessitates regular monitoring and specialized management to maintain a longer service life [10] [11].

Hot spots in PV modules are common phenomena that significantly affect their performance and durability. These localized high-temperature areas result from temporary shading, permanent defects, cell failures, or damage to interconnection lines [1] [2]. In cases of temporary shading, such as bird droppings, the affected area may revert to normal once the shading is removed; however, if the incident lasts for a long period or in prolonged shading, the hot spot may become permanent, and can lead to permanent hot spots, causing irreversible damage to the cells or the entire module .[3]

In the case of shaded cells hotspots, the hotspots occur when shaded cells produce less power compared with other series-connected PV cells and operate in reverse mode, causing current to flow through the shaded cells from unshaded cells. Hot spot cells consume power instead of producing it, leading to temperature increases —temperatures can reach 130°C or higher—exceeding the operational limits of the cells and potentially causing material degradation, mechanical stress, and fire hazards, and can cause up to 6% power reduction .[4]

The severity of the temperature increase is approximately linearly related to the length of the series-connected string of cells, with longer strings tending to produce higher temperatures [5]. The IEC 61215-2:2021 standard includes a hot-spot endurance test to evaluate the ability of modules to withstand partial shading conditions, with temperature adjustments based on actual operating conditions, especially for residential systems exposed to frequent shading from structures or trees [6]. Studies have shown that hotspots can form at lower temperatures depending on cell quality and string configuration, and accelerated aging tests or modified testing protocols can predict the durability of modules under real shading scenarios, optimize test conditions, and reduce testing time while maintaining reliability .[2]

When dust and dirt accumulate on the surface of photovoltaic cells, less solar radiation reaches them, and the trapped heat causes a rise in temperature, leading to the cells turning white or lighter shades [12]. High levels of humidity that form during the early morning and sunset periods lead to water condensation on the surface of cells, and in the presence of dust and salts, white spots may form.

In summary, while prior research provides insights into hotspots and environmental degradation, the specific white spot phenomenon linked to humidity, dust, and temperature observed in coastal environments such as Tartous warrants further investigation. The findings suggest that high humidity and temperature, combined with dust accumulation, are key factors influencing the appearance and spread of these white discolorations, which are reversible with cleaning and direct sunlight.

This study analyzed the factors related to this phenomenon and identified the upper and lower values of the factors that must be present together for this phenomenon to occur, in addition to studying its effect on exposed solar panels in terms of temperature.

Based on measurements and observations, it was determined that this phenomenon is related to multiple factors that must coexist for it to manifest. The humidity level must exceed 50% where the phenomenon did not appear on dry days, when the humidity was lower than 50%. Additionally, there should be no direct solar irradiance incident on the panel surface. Dust accumulation also plays a role, along with more than 5 kWh of shortwave solar energy, particularly during the morning and evening periods before sunset. The appearance of this phenomenon is often accompanied by a solar azimuth angle (20°-35°), dew point (17°-21°), and temperature (25°-28°) during the morning hours, and solar azimuth (0°-10°), dew point (18°-21°), and temperature (24°-27°) during the evening hours. The results showed that the ultra-violet and atmospheric pressure had no role in the phenomenon. This phenomenon caused white spots on cells, causing temperature differences (above 2°C) between colored cells with white spots and other cells in the same panel. The rest of paper is organized as follows: section.2 presents the paper methodology, section.3 discusses the study results, section.4 reports the conclusion of the paper, section.5 states implications and recommendations.

2- Methodology and Materials

This section describes Study area: Syria, Tartous, Corniche

Cases studied: Off-grid rooftop photovoltaic solar systems of varying capacities using different panel types from different manufacturers, none of which are typically cleaned of dust.

Monitoring period: This phenomenon was tracked over four months during the summer season (June to September).

This phenomenon was monitored, and weather parameters were measured for four months during the summer, and temperature measurements of the cells within these panels were also recorded during the monitoring period.

Photographs and infrared thermography were taken of these systems. The temperatures within these panels for the colored and uncolored cells were compared. An IR thermometer/HYTIS TS550 and Fluke TiS Thermal Imaging Scanner/TIS-9HZ were used.

Weather data, including temperature, humidity, dew point, ultraviolet (UV) radiation, and shortwave solar energy, were also obtained from the weather Spark. Com (which records weather parameters at nearby locations such as Hmeimim Airport in Latakia) and weather.com.

Weather data were recorded, and photos and IR images were taken of the studied PV systems over several days for a period of four months, in both the morning and afternoon periods, to identify the conditions that cause this phenomenon. The results of the measurements for each case are displayed with the corresponding photos for each measurement day.

Table 1 shows the measurement sequences, sunrise and sunset timing, and temperature of each measuring day during the monitoring months.

Table 1: measurement days information

m-seq	Measurement date	Sunrise time (am)	Temperature at sunrise	Sunset time (pm)	Temperature at sunset C°
1 in June	9/6/2025	05:23	25	07:49	26
2 in June	13-15/6/2025	05:33	26	07:51	30
1 in August	9/8/2025	05:52	27	07:31	29
1 in September	4/9/2025	06:15	27	06:52	28
2 in September	13/9/2025	06:19	27	06:46	29
3 in September	20/9/2025	06:23	27	06:36	27
4 in September	26/9/2025	06:28	25	06:29	28

The Studied rooftop PV solar systems:

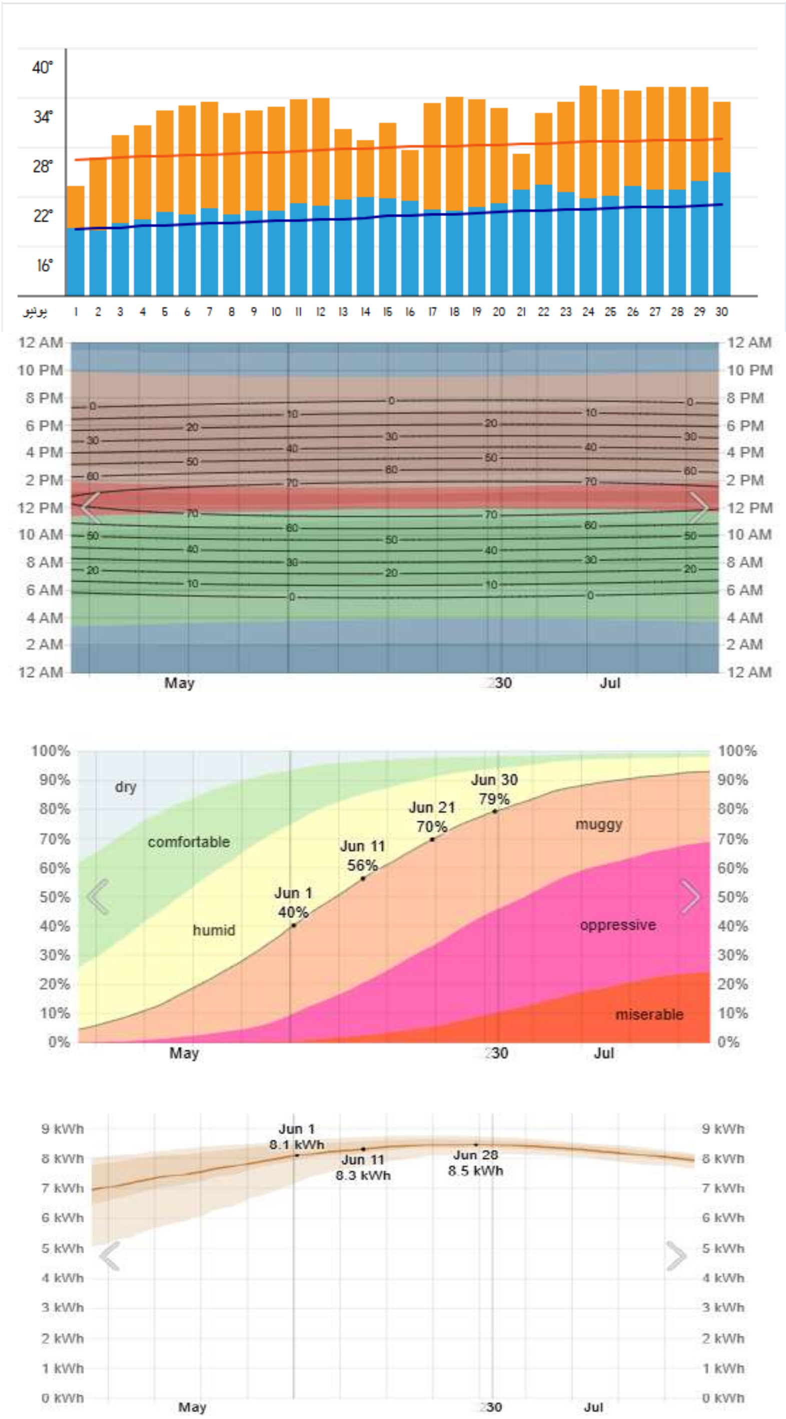
1-1.665 kW PV solar system: consists of three panels: panel orientation: south 170°, panel tilt 60°, module operating age: 2 year, LR5-72HPH-555M, 555 W, 6 × 24 half cells, V_{mp}=42.10 V, I_{mp}=13.19 A, V_{oc}=49.95 V, I_{sc}=14.04 A.

2-2.220 kW PV solar system: Consists of four panels: panel orientation: south 170°, panel tilt 60°, module operating age: 1 year, LR5-72HPH-555M, 555 W, 6 × 24 half cells, V_{mp}=42.10 V, I_{mp}=13.19 A, V_{oc}=49.95 V, I_{sc}=14.04 A.

3. Results and discussion:

3.1. June measurements:

Weather data were first obtained in June, as shown in Figure (1-a), Figure (1-b), Figure (1-c), (1-d), showing the minimum and maximum temperatures, azimuth and angle of the sun, humidity, and average shortwave temperatures during June, respectively.



(a)

(b)

(c)

(d)

Figure 1: a-Temperature, b-solar elevation & azimuth, c-humidity, d-Average daily incident shortwave solar energy in June, Tartus, Syria

As shown in Table 1, the measurement days were the 9th, 13th, and 15th of August, and returning to Figure (1), we conclude that the values of temperature, azimuth, humidity, and quantity of shear waves corresponding to the measurement days were as shown in Table 2.

Table 2: Temperature, solar elevation & azimuth, humidity and Average daily incident shortwave solar energy for measurement dates in June

date	Temperature C°	Solar elevation & azimuth (sunrise duration)	Solar elevation & azimuth (sunset duration)	Humitidy %	Average daily incident shortwave solar energy
6/6/2025	32°	20°-30°	0°-10°	≈50°	8kWh
13-15/6/2025	31°	20°-30°	0°-10°	≈60°	5.5kWh

3.1.1. Measurement number 1:

Day 9/6/2025: A sunny, high-humidity day, the1.665 kW PV solar system:

Images of the studied PV systems showed the spread of this phenomenon during the morning and evening periods. Figure (2-a) shows an image of the panels during the afternoon period before sunset, and the phenomenon of some half-cells turning white is clearly visible.

Temperature measurements were performed on the half-cells during this period. Figure (2-b) shows the same panels after two days, and an increase in the number of white cells can be noted. Figure (2-c) shows the measured temperatures of the colored cells in panel 3, where an equivalent matrix for the cell positions was formed, and the measured temperatures of the equivalent cells were determined on this matrix.

The temperatures in the colored cells were approximately two degrees higher than those in the surrounding uncolored cells.

a

b

6	5	4	3	2	1	[3]
						1
						2
						3
26.8	26.7					4
28	25.7	25.7	25.7	26		5
28	26.3	25.4	26	27.5	26	6
26.8		25.2	25.2	27.5	26	7
				27.7	26	8
				25.4		9
						10
						11
						12
24.7						1
24.7	24.7	25.4	24.9	26.3	24.5	2
24.7						3
						4
						5
						6
						7
						8
						9
						10
						11
						12

6	5	4	3	2	1	[3]
						1
						2
27						3
27						4
29	27					5
29	27	29				6
						7
						8
						9
						10
27						11
27	27	27	27	27	27	12
29	28	27	26	26		1
28	28	28	29	26		2
28	28	27	27			3
26	26	29	27			4
		28	27			5
						6
						7
						8
						9
						10
						11
						12

c

Figure 2: a-The phenomenon of coloring on the studyed PV solar panels, b-panel number 3, c- temperature matrix of panel 3.

Figure (3) shows the phenomenon on other nearby rooftop PV systems under the same weather conditions, and this phenomenon was observed to be widespread on them, whether they were half-cell or full-cell panels.

Figure 3: The phenomenon on other nearby rooftop PV systems

3.1.2. Measurement number 2:

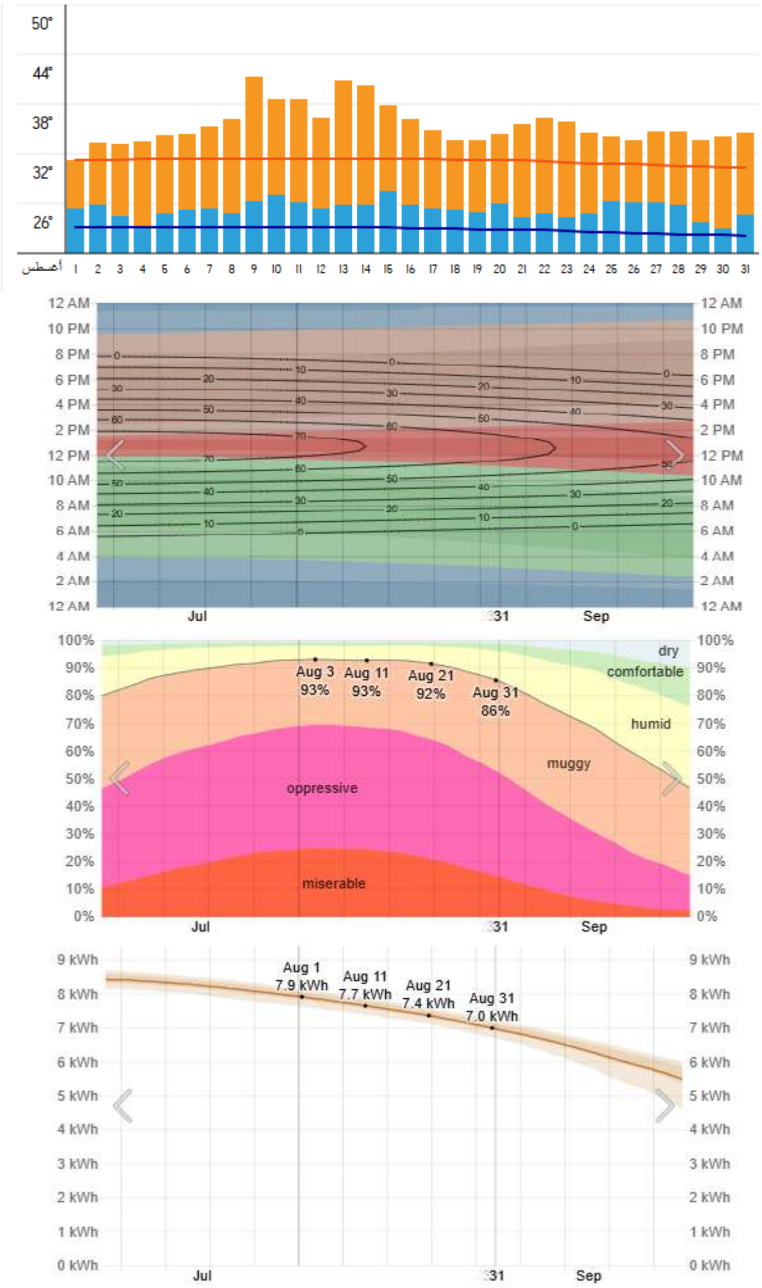
Day 13/6/2025: A sunny, high-humidity day, the1.665 kW PV solar system:

The images taken of the studied PV solar system on this day showed that this phenomenon was more widespread and present in a greater number of half-cells during the morning and evening periods. Figure (4,a) shows an image of the panels in the afternoon, just before sunset, clearly demonstrating the increased prevalence of the discoloration phenomenon across a larger number of half-cells. Returning to the temperature readings of the half-cells in Figure (2, c) which had been stained, an increase in temperature was observed since the previous measurement. Temperature measurements were taken on the cells during this period, and the results showed a temperature difference of approximately two degrees Celsius between the colored and uncolored cells.

Figure 4: The studied PV solar system at the second measurement number2

3.2. August measurement:

Figure (5) shows the temperature, solar elevation and azimuth, humidity, and average daily incident shortwave solar energy data in August.



(a)

(b)

(c)

(d)

Figure 5: a-Temperature, b-solar elevation & azimuth, c- humidity, d- Average daily incident shortwave solar energy dates in August, Tartus, Syria

3.2.1. Measurement number 1:

Day 9/8/2025: A sunny day with very high humidity

From Table 1, the measurement day was the 9th of August, and returning to Figure (5), we conclude that the values of temperature, azimuth, humidity, and quantity of shear waves corresponding to the measurement day are as shown in Table 3.

Table 3: Temperature, solar elevation & azimuth, humidity and Average daily incident shortwave solar energy for measurement date in August

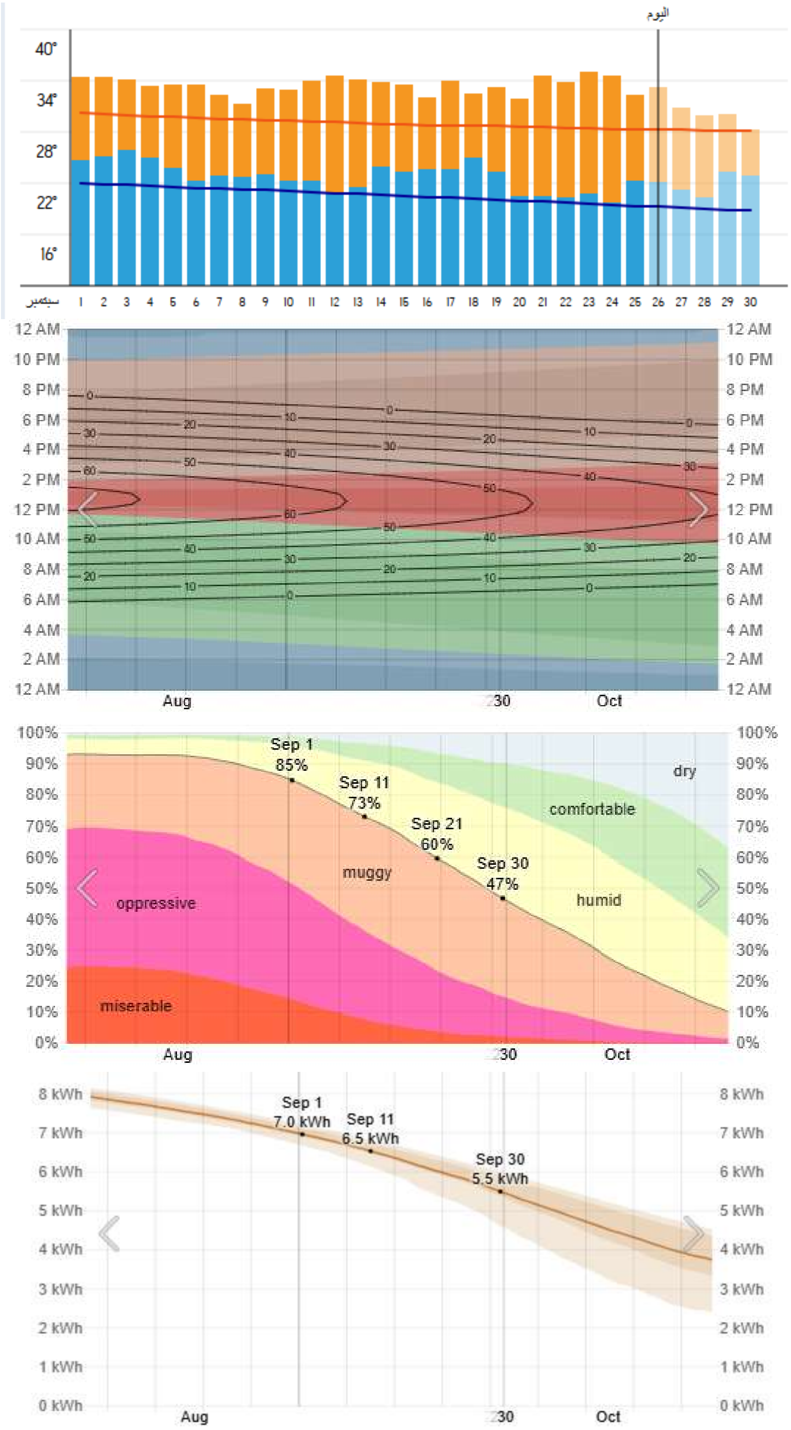
date	Temperature C°	Solar elevation & azimuth (sunrise duration)	Solar elevation & azimuth (sunrise duration)	Humidity %	Average daily incident shortwave solar energy
9/8/2025	45°	25°-35°	0°-10°	≈50°	8kWh

The average humidity was very high on 9/8/2025, and the temperature was over 45 °C. As shown in Figure (6), the phenomenon of white discoloration of the cells has spread and exceeded the geometric boundaries of the cell shape as a result of the significant increase in temperatures coinciding with the increase in humidity. Therefore, the cells have indistinct edges close to a curved shape instead of the rectangular shape that perfectly matches the cell shape.

Figure 6: a nearby PV solar systems at 9/8/2025

3.3. September measurements:

Figure (7), shows the temperature, solar elevation & azimuth, humidity and average daily incident shortwave solar energy dates in September.



(a)

(b)

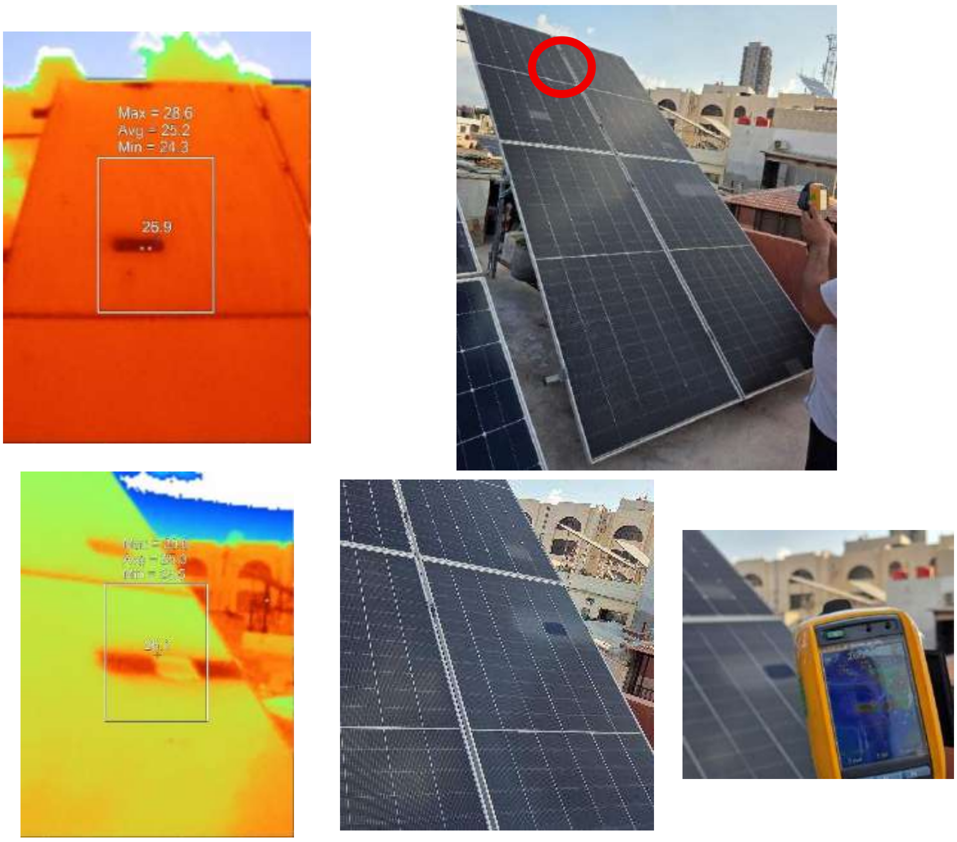
(c)

(d)

Figure 7: a-Temperature, b-solar elevation & azimuth, c- humidity, d- Average daily incident shortwave solar energy dates in September, Tartus, Syria

3.3.1 Measurement number 1:

Day 9/9/2025: A sunny, high humidity day, the 2.220kW PV solar system: Figure (8) shows the 2.22kW PV solar system at the morning duration in 9/9/2025. It could be noted in Figure (8, a) the high temperature of the colored cell in the Infra-Red photo. It is about two degrees higher than the uncolored cells. To ensure the strong connection between the coloring phenomenon and the dust that cover the panel, we have cleaned on cell as showing in Figure (8, b). It is very clear that the cleaned cell has a lower temperature than the uncleaned nearby cells.

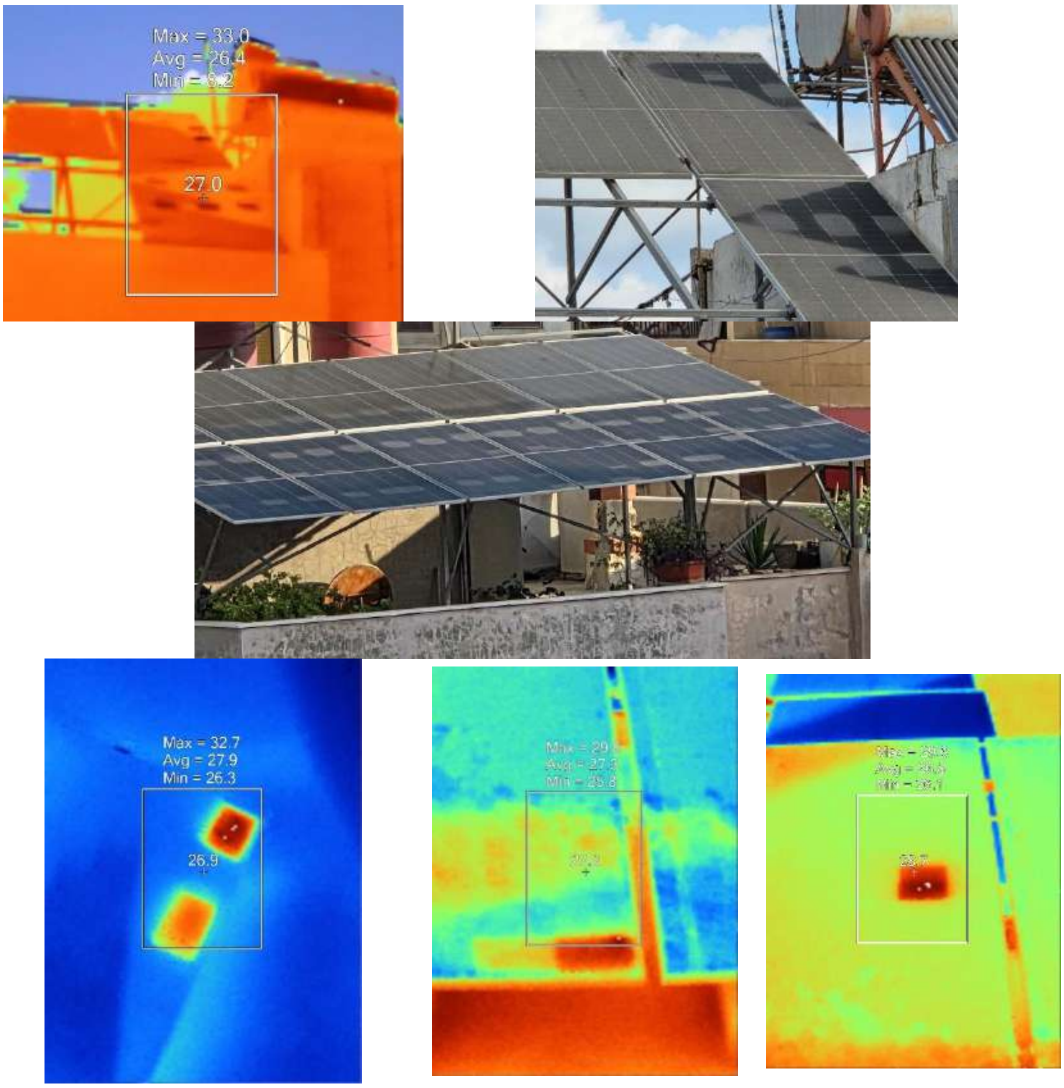


(a)

(b)

Figure 8 (a,b): The 2.220kW PV solar system in 9/9/2025

Figure (9), shows other nearby rooftop PV solar systems at the same high temperature and humidity measuring day, in morning duration. We could note from Figure (9, a) the temperature differences between the colored and uncolored cells, while figure (9, b) shows another rooftop PV soar system with the large scale of the phenomenon on the panels. In Figure (9, c), IR photos of several rooftop PV system were displayed.



(a)

(b)

(c)

Figure 9 (a,b,c): Different nearby rooftop PV solar systems in 9/9/2025

3.3.1. Measurement number 2:

Day 13/9/2025: A sunny, high humidity day, the 1.665 kW PV solar system:

Back to 1.665 kW PV system in 13/9/2025, we noted the increasing in the number of colored cells, as showed in Figure (10, a). We have cleaned the panel number 3, in order to clear the effect of dust in this phenomenon. Figure (10, b) shows the temperature matrix of panels number 1 and 2.

a

6	5	4	3	2	1	[2]
						1
						2
						3
28.2	27.9	27.9	27.9		27.9	4
28.8	27.9	27.9	27.9	28.5	27.9	5
28.1	27.9	27.9	27.9	27.9	28.4	6
						7
						8
						9
						10
						11
						12
						1
						2
						3
						4
						5
						6
						7
						8
						9
						10
27.8	28.8	27.8	27.8	27.8	28.5	11
27.8	28.9	28.9	28.9	28.8	29.3	12

6	5	4	3	2	1	[1]
						1
	28.5	29				2
	28.1	28.1	28	29.1	27.9	3
28.7	28	27.9	28	28.2	27.9	4
28.5						5
						6
						7
						8
						9
						10
						11
						12
						1
						2
						3
						4
						5
						6
						7
						8
						9
28.5	28.7	28.1	28	28	28	10
30.3	29.5	29.7	29.3	29.2	29.2	11
30.4	29.8	30.4	29.3	30.4	29.9	12

b

Figure 10 (a,b) The 1.665 kW PV solar system in 13/9/2025

The weather parameters (temperature, humidity, Dew point, Atmospheric pressure, Ultra-Violet (UV)) were recorded in 13/9/2025 measuring day at the morning and afternoon durations. The recording was taken while the phenomenon was appearing on the panels. It was noticed that the phenomenon was disappeared when the sunlight was directly fallen on the panel's surfaces. Table 4, shows the weather records in 13/9/2025 during morning, while the phenomenon appeared. The coloring phenomenon was standing till 09:14 am, when the sunlight has become directly with the panel's surfaces.

Table 4: Weather records in 13/9/2025 during morning

Time (am)	UV	Atmospheric pressure (m bar)	Dew point ◦	Humidity %	Temperature C°	Notes
07:15	0	1011.8	18	73	24	Phenomenon started to appear
07:54	0	1011.8	19	69	25	phenomenon spread
08:04	1	1011.8	19	68	26	Phenomenon stared to disappear on the panels with direct sunlight on surfaces
08:14	1	1011.8	19	68	26	//
08:24	1	1011.8	19	67	26	//
08:34	1	1011.8	19	66	26	//
08:44	2	1011.8	19	65	27	//
08:54	2	1012.2	19	64	27	//
09:04	3	1012.2	19	63	27	//
09:14	3	1012.2	20	62	28	Sunlight was direct on all the PV panels, so the phenomenon was dis appeared

Table 5, shows the weather records in 13/9/2025 during afternoon, while the phenomenon was appearing.

Table 5: Weather records in 13/9/2025 during afternoon

Time (pm)	UV	Atmospheric pressure (m bar)	Dew point ◦	Humidity %	Temperature C°	Notes
06:15	0	1011.8	18	73	24	phenomenon started to appear
06:30	0	1011.8	19	69	25	phenomenon spread
06:35	1	1011.8	19	68	26	phenomenon stared to disappear in some PV systems
06:40	1	1011.8	19	68	26	It is sunset, no longer sunlight, so the phenomenon was disappeared

The sunset duration is shorter than the sunrise duration, so the phenomenon last for a longer time in the morning.

3.3.3. Measurement number 3:

Day 20/9/2025: A sunny, low humidity (dry) day:

It was a sunny dry day in 20/9/2025, where the humidity was lower than 35%. It has been noted that the phenomenon did not appear.

Table 5, shows the weather parameters in 20/9/2025 in the morning duration.

3.3.4. Measurement number 4:

Day 23/9/2025: A sunny, low humidity (dry) day:

For the next few dry days, the phenomenon did not appear.

Table 6: shows the weather parameter in 23/9/2025, in the morning, where the phenomenon did not appear.

Table 6: Weather records in 20/9/2025 during the morning

Time (am)	UV	Atmospheric pressure (m bar)	Dew point ◦	Humidity %	Temperature C°	Notes
07:15	0	1012.2	8	35	25	Phenomenon did not appear
07:30	0	1012.2	8	35	25	//
07:45	0	1012.2	9	35	25	//
08:00	1	1012.2	9	35	26	//
08:15	1	1012.2	9	35	26	//
08:30	2	1012.5	9	34	26	//
08:45	2	1012.5	9	34	26	//
09:00	2	1012.5	9	33	27	//
09:15	3	1012.5	9	32	27	//

3.3.5. Measurement number 5:

Day 24/9/2025: A sunny, high humidity day:

The phenomenon reappeared.

Table 7: shows the weather parameter in 24/9/2025, in the morning and the afternoon, where the phenomenon started to appear.

Table 7: Weather records in 23/9/2025 during the morning

Time (am)	UV	Atmospheric pressure (m bar)	Dew point ◦	Humidity %	Temperature C◦	Notes
08:30	2	1011.2	17	40	28	Phenomenon did not appear

When the humidity was 50% and above, the phenomenon was appeared.

3.3.6. Measurement number 6:

Day 25/9/2025: A sunny, high humidity day:

Table 8: shows the weather parameter in 24/9/2025, in the morning, where the phenomenon started to appear.

Table 8: Weather records in 24/9/2025 during the morning and the afternoon

Time	UV	Atmospheric pressure (m bar)	Dew point ◦	Humidity %	Temperature C◦	Notes
07:30 am	0	1011.8	16	56	25	Phenomenon appeared
07:45 am	0	1012.2	17	58	26	//
08:00 am	1	1012.2	17	59	27	//
06:15 pm	0	1009.8	21	68	27	//
06:30 pm	0	1009.8	21	69	27	//

From Table 7, we could console that the humidity is not the only condition for this phenomenon appearing, the fallen sunlight on the panel surfaces is another condition. In 26/9/2025, it was a very high humidity day (more than 77%), so the phenomenon spread and exceeded the geometric boundaries of the cells. The temperature was 26◦, the dew point was 22 °. When the humidity is more than 75%, the phenomenon spread and exceeded the geometric boundaries of the cells.

4 .Conclusions

This study addresses the phenomenon of white spots that appear on the surfaces of PV cells in rooftop solar systems in the coastal strip of Tartous city under specific environmental conditions. This phenomenon was studied over a period of four months during the summer season with practical measurements. Based on measurements and observations, it has been determined that this phenomenon is related to multiple factors that must coexist for it to manifest.

The results demonstrate a clear correlation between the appearance of the white spotting phenomenon and environmental parameters, notably high humidity levels and elevated temperatures (>45°C). The absence of direct solar radiation during the morning and pre-sunset periods, when the solar radiation strikes the panels at a lower angle, is a primary factor in the occurrence of this phenomenon. Direct solar radiation on the panel surface prevents its appearance. Furthermore, it was found that this phenomenon must be accompanied by high humidity levels, exceeding 50%, as the humidity was below 50% despite the presence of solar radiation.When the humidity is more than 75%, the phenomenon spread and exceeded the geometric boundaries of the cells. In dry days with low humidity (less th50%), the phenomenon does not appear

.This phenomenon exhibits a dynamic time pattern, as it has been observed that the duration of this phenomenon during the morning period is longer as long as there is a decrease in the intensity of solar radiation, and it disappears as the intensity of radiation increases with the progress of the day and the angle of its fall on the surface of the panels changes, in addition to the evaporation of the condensed moisture on the surface of the panels.

It was also observed that this phenomenon is reversible, fading with direct exposure to sunlight and cleaning of the panel surfaces. When high humidity and high temperature conditions combine, white spots may spread beyond the geometric boundaries of individual cells, taking on irregular and curved shapes instead of a precise rectangular form. This suggests that condensation of moisture and accumulation of heat contribute to the spread of this phenomenon.

The emergence of the phenomenon is related to with more than 5kWh of the shortwave solar energy, particularly during the morning and evening periods before sunset, and also related to the solar azimuth (20°-35°), the dew point (17°-21°) and the temperature (25°-28°) during the morning hours and solar azimuth (0°-10°), dew point (18°-21°) and temperature (24°-27°) during the evening hours.

Elevated temperatures in cells affected by spotting indicate the presence of greenhouse heat, possibly due to dust accumulation, which acts as an insulating layer preventing heat exchange and causing localized heating. This aligns with prior studies emphasizing dust as a critical factor in thermal degradation and performance loss in PV cells.

Infrared thermography revealed that affected within white spots cells tend to have temperatures approximately 2°C higher than the surrounding uncolored cells. The results showed that the Ultraviolet and the atmospheric pressure have no role in the phenomenon. There can be an interaction. Dust particles, humidity, and solar radiation can influence surface charge distributions on solar panels. For instance, dust particles can become electrostatically charged, and humidity can facilitate charge accumulation or redistribution on the surface. These electrostatic effects might influence phenomena like dirt adhesion or localized electric fields, which can, in turn, affect the cell's performance or surface appearance. However, the primary visual changes (such as whitening) are more directly linked to physical and chemical alterations rather than charge accumulation alone, unless there's a specific electrostatic discharge or corrosion process involved.

5 .Implications and Recommendations

The study results indicate that the white spot phenomenon is caused by complex interactions between high humidity levels, temperature, dust accumulation, and solar radiation conditions. Its reversibility means that regular cleaning and maintenance can mitigate its negative effects, such as the increased temperature of affected cells.

However, it is necessary to conduct a study of the electrical parameters of the exposed panels, and a potential induced degradation in PV modules due to this phenomenon when lasting for a long time.

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The Digital Playground: Impact of Electronic Games on the Health, Behavior, and Academic Performance of Children in Benghazi, Libya in 2025

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Abstract-

Advanced digital technologies, despite their many benefits, have raised growing concerns about adverse effects on children's physical health, mental well-being, and social development. Electronic games are one of the most widely used and potentially harmful forms of digital entertainment. This study aimed to assess the potential adverse effects of excessive electronic gaming on children's physical health, social behavior, sleep patterns, and academic performance in Benghazi, Libya. A cross-sectional study was conducted among 653 parents and relatives (aunts/uncles) of children aged 3-15 years. Data were collected using a Google Form questionnaire that covered demographics, gaming habits, parental control measures, observed effects on health, behavior, and schoolwork, as well as device types, internet connectivity, and technical protection measures. The majority of children played action or adventure games (58.2%) and fighting games (42.4%). About (34.6%) played games for more than 4 hours a day. Many parents admit that their children had health problems, like eye strain (30.9%), trouble sleeping (31.2%), and neck or back pain (14.5%). When it came to social behavior, 31.1% of parents noticed their child was more easily irritated or aggressive. The most common problems were homework delay (32.0%) and losing interest in studying (38.7%). It is recommended that that parents need more guidance on how to strike a healthier balance with technology for their children.

Keywords: Electronic games; children; academic performance; sleep disorders; behavioral problems; IT-related factors; device usage, internet connectivity; and parental digital literacy.

1. Introduction

The rapid integration of advanced digital technologies into the daily lives of children and adolescents has raised substantial concerns among parents, educators, and healthcare professionals. While these technologies offer many benefits, including access to information and opportunities for social connection, their excessive and unregulated use has been associated with a range of health and behavioral problems[1]. In the 21st century, electronic games have become much easier to access and much more popular among children and adolescents. What used to be a rare hobby is now a major way to have fun, offering exciting virtual worlds, chances to connect with others, and mental challenges. But at the same time, this digital change has sparked a worldwide debate among parents, teachers, and doctors about the potential harms of excessive gaming. Concerns include physical problems like eye strain, muscle and back pain, and weight gain, as well as mental health issues such as aggression, feeling lonely, and internet gaming disorder [2,3].

Furthermore, the displacement of time spent on homework and sleep has led to growing worries about a negative impact on academic performance [4]. While some studies do show benefits in certain skills, such as problem-solving and strategic thinking [5], the majority of evidence points to significant risks, particularly when gaming is uncontrolled and excessive. In the Libyan context, as in many other societies, children's access to smartphones, tablets, and computers has increased dramatically, often without adequate parental guidance or digital literacy. A recent study emphasized that while parents may have some awareness of gaming's psychosocial impacts, their knowledge of specific risks and effective mitigation strategies remains significantly lacking [6]. This study contributes through evaluating the effects of electronic games on children's physical health, social behavior, sleep quality, and academic performance in Benghazi, Libya, with an additional focus on information technology-related factors, including device usage, internet connectivity, and technical protection measures. The next section explains the basic methods for data collection and interpretation.

2. Methods

2.1. Study Design and Setting

This was a cross-sectional, descriptive study conducted in Benghazi, Libya, over three months from the first of January to March 31, 2025. Data were collected via a structured online questionnaire.

2.2. Participants and Sampling

A convenience sampling method was employed. The survey link was shared through personal networks, such as friends, family, and coworkers. The target group was adult parents, aunts, uncles, and teachers who were the main caregivers or spent a lot of time each day with a child between the ages of 3 and 15. The survey link was distributed to 1,000 individuals; 653 completed the questionnaire (response rate 65.3%).

2.3. Data Collection Instrument

The questionnaire consisted of multiple sections:

1. **Demographics:** Caregiver's relation to the child, child's age, number of children in family, parents' education.
2. **Gaming Habits:** Average daily playtime, preferred game types, usual play location.
3. **Health and Behavioral Impact:** Presence of physical symptoms (e.g., eye strain, headaches), changes in sleep, physical activity,

and social behavior.

4. **Academic Impact:** Effect on study motivation, homework completion, concentration, and perceived relationship between playtime and grades.

5. **Parental Intervention:** Protective measures taken (e.g., parental controls, time limits), knowledge of technical protections, and occurrence of online risks (e.g., cyberbullying, inappropriate content).

6. **Information Technology Factors:** Device types used for gaming, internet connectivity status, parental control software utilization, and technical knowledge self-assessment.

2.4. Data Analysis

The data were entered and analyzed using SPSS 27. Descriptive statistics (frequencies and percentages) were used to describe the sample characteristics and summarize the key results.

2.5. Ethical Approval

All participants provided electronic consent before completing the questionnaire. The purpose of the study, the voluntary nature of participation, the anonymity of responses, and the right to withdraw at any time without consequence were clearly explained to all participants. All data were stored securely and accessed only by the principal investigator for research purposes.

3. Results

3.1. Demographic Profile of Child and Caregiver

- **Caregiver's Relation:** Mothers were the primary respondents (50.4%), followed by aunts/uncles (37.4%), and siblings/teachers (12.2%).

- **Child's Age:** A total of 653 children were included in the study. The largest age group was children under 5 years (46.6%), followed by children aged 5–8 years (39.4%). Smaller groups included children aged 9–12 years (8.5%) and children aged 13–15 years (5.5%).
- **Parental Education:** Over half (56.0%) of parents held a Bachelor's degree, while (15.6%) had postgraduate degrees.

3.2. Gaming Habits and Environment

- **Daily Playtime:** A significant proportion of children (34.6%) played for more than 4 hours each day. Another (26.9%) played for 3–4 hours. The remaining children played for less time: (23.1%) played for 1–2 hours, and (15.3%) played for less than 1 hour.
- **Preferred Game Types.** Children can choose more than one preferred type: Action/Adventure (58.2%) and Fighting (42.4%) games were the most popular. Puzzle/strategy games were less common (21.9%).
- **Play Location:** Children predominantly played "anywhere in the home" (53.3%) or in their own room (22.8%). Additionally, (23.9%) played at a friend's house.

3.3. Impact on Physical Health

As shown in Table 1, a substantial number of caregivers reported adverse physical symptoms in their children.

Table 1. Reported Physical Health Symptoms in Children

Symptom	Frequency (n)	Percentage (%)
No observed symptoms	278	**42.6**
Eye strain/redness	202	**30.9**
Sleep disturbances (insomnia, broken sleep)	204	**31.2**
Neck or back pain	95	**14.5**
Weight loss	88	**13.5**
Headaches	70	**10.7**
Wrist/finger pain	41	**6.3**
Weight gain	**30**	**4.6**

3.4. Impact on Sleep and Physical Activity

- **Sleep:** Nearly half of the parents and caregivers (47.5%) reported that gaming disrupts their child's sleep.
- **Physical Activity: (**39.8%, n=260) noted a decrease in physical activity associated with gaming.

3.5. Impact on Social Behavior

- **Negative Changes: (**31.1%, n=203) observed that the child became more irritable and aggressive. 16.5% (n=108) noted increased social isolation and withdrawal.
- **Positive Changes:** In contrast, (21.6%, n=141) noticed an improvement in some social skills (e.g., teamwork).

3.6. Impact on Academic Performance

- Moderate Negative Impact:(26.8%, n=175)
- Significant Negative Impact: (16.8%, n=110)

- No notable effect: (39.8%, n=260)
- Positive Impact: (9.8%, n=64)

Specific academic challenges reported included:

- **Homework delay/neglect:** (32.0%, n=209).
- **Loss of study motivation: (**38.7%, n=253) stated motivation had decreased to some extent.
- **Correlation with grades:** 41.0% (n=268) of parents believed there is a direct relationship: "The more the playtime, the lower the grades."

3.7. Parental Protection and Awareness

- **Protective Measures:** About (44.4%) used parental control applications and (45.3%) set time limits. However, (15.6%) said that they did not take any specific security precautions.
- **Knowledge Level:** About (33.8%) rated their knowledge level as “high.” A combined (41.8%) rated their knowledge as “Limited” or “Non-existent.”
- **Online Risks**: About (27.6%) said their child had encountered inappropriate content (violence, explicit language). Reported were also cyberbullying and attempted information theft.

3.8. Information Technology (IT) Perspective: Digital Infrastructure, Device Usage, and Technical Protection Gaps

From an information technology standpoint, this study reveals critical insights into the digital ecosystem within which children engage with electronic games.

3.8.1. Device Types and Gaming Platforms

As shown in **Table 2**, smartphones were the most commonly used device for electronic gaming among children (67.8%), followed by tablets (45.2%) and laptops/computers (28.4%). Dedicated gaming consoles were used by only (18.6%) of children.

Table.2 Device Types Used for Electronic Gaming

Device Type	Frequency (n)	Percentage (%)
Smartphone	443	**67.8**
Tablet (e.g., iPad, Android tablet)	295	**45.2**
Laptop or desktop computer	186	**28.4**
Dedicated gaming console (PlayStation, Xbox, Nintendo)	121	**18.6**
Handheld gaming device (e.g., Nintendo Switch, PSP)	**54**	**8.3**

"Multiple responses allowed; percentages sum to more than 100%."

3.8.1 Internet Connectivity and Online Gaming Exposure

Table 3 demonstrates that the majority of children (73.2%) played games that required an active internet connection. Only (26.8%) played exclusively offline games.

Table.3 Internet Connectivity During Gaming

Connectivity Status	Frequency (n)	Percentage (%)
Games require an internet connection (online games)	478	**73.2**
Games played offline only	**175**	**26.8**

Among children playing online games, (41.2%) played multiplayer games involving interaction with unknown individuals, while (32.0%) played games limited to known friends or family members.

3.8.3 Parental Control Software and Technical Protection Measures

Table 4 details the types of technical protection measures implemented by parents. Only (28.6%) had configured privacy settings within the games themselves, and (15.6%) applied no technical protection measures whatsoever.

Table.4 Technical Protection Measures Implemented

Protection Measure	Frequency (n)	Percentage (%)
Reviewing games before download (age rating verification)	312	**47.8**
Time limits set via router or device settings	296	**45.3**
Parental control applications (e.g., Google Family Link, Qustodio)	290	**44.4**
Privacy and security settings within games/platforms	187	**28.6**
No specific technical measures applied	**102**	**15.6**

3.8.4 Parental Technical Knowledge and Digital Literacy

Table 5 presents caregivers' self-rated knowledge of technical protection measures. Only one-third (33.8%) rated their knowledge as "high".

Table.5 Self-Rated Knowledge of Technical Protection Measures

Knowledge Level	Frequency (n)	Percentage (%)
High (apply several measures and understand basics of digital safety)	221	**33.8**
Moderate (have some knowledge and apply basic measures)	258	**39.5**
Limited (little knowledge, applies only simple measures)	98	**15.0**
Non-existent (know nothing about these measures)	21	3.2
No response	55	8.4

3.8.5 Online Risks and Cyber Threats Encountered

Table 6 summarizes the online risks that children encountered during gaming. Exposure to inappropriate content was the most frequently reported risk (27.6%).

Table.6 Online Risks Encountered by Children During Gaming

Online Risk	Frequency (n)	Percentage (%)
Exposure to inappropriate content (violence, explicit language, sexual content)	180	**27.6**
Cyberbullying from other players	81	**12.4**
Communication with strangers or suspicious individuals	76	**11.6**
Attempted information theft or phishing	58	**8.9**
No known risks encountered	358	**54.8**
Unable to confirm/don't know	**87**	**13.3**

3.8.6Association Between Technical Knowledge and Protective Action

Table 7 demonstrates the Association between parents' self-rated technical knowledge and the implementation of protective measures.

Table.7 Association Between Parental Technical Knowledge and Use of Parental Control Apps

Knowledge Level	Used Parental Control Apps (%)	Did Not Use Parental Control Apps (%)
High (n=221)	82.4	**17.6**
Moderate (n=258)	48.1	**51.9**
Limited/non-existent (n=119)	**23.5**	**76.5**

Chi square test: χ^2 = 119.7, df = 2, $p < 0.001$

There is a statistically significant association between technical knowledge and the use of parental control apps.

4. Discussion

This cross-sectional study, conducted among 653 caregivers in Benghazi, Libya, provides critical, real-world evidence of the pervasive negative impact of excessive electronic gaming on children's health, behavior, and academic performance. Furthermore, the IT-focused analysis reveals substantial gaps in parental digital literacy and technical protection measures. Our findings are remarkably consistent with a growing international consensus that uncontrolled screen media use poses a significant risk to child development.

4.1. Playtime and Academic Harm

One of the most significant findings of our study is the perceived association between playtime and academic decline. Over a third (34.6%) of children played for more than 4 hours daily, and 41.0% of parents believed that increased playtime directly led to lower grades. This aligns powerfully with the meta-analysis by Adelantado-Renau et al. [4], which concluded that higher levels of screen media use, including video games, are consistently associated with poorer academic performance. Firstly, excessive gaming time affects

essential academic activities. Our results support this, as 32.0% of parents reported homework delay or neglect, and 38.7% noted a loss of study motivation. This is directly supported by Islam, Biswas, & Khanam [7], who found that excessive internet use and game-play significantly reduced study time and homework completion.

Secondly, prolonged gaming executive functions like sustained attention and concentration. Cardoso-Leite et al. [8] demonstrated that heavy media use was associated with poorer attentional control, a prerequisite for academic learning. The report by Sachit, Salloum, & Jawad [9] further corroborates our findings, showing a direct negative correlation between daily video game duration and grade point average.

4.2. Behavioral and Psychosocial Consequences

The behavioral impact reported in our study is substantial. Nearly one-third (31.1%) of caregivers observed increased irritability and aggression, and 16.5% noted social withdrawal. Lérida-Ayala et al. [3] found a clear association between excessive internet and video game use and the development of behavioral disorders in children and teenagers, including conduct problems and emotional symptoms. Furthermore, Lobel et al. [10] demonstrated that higher levels of video gaming predicted an increase in psychosocial problems over time. Our finding of increased social isolation is particularly concerning, as it suggests that for some children, the digital world may be replacing critical real-world social interactions. Tse et al. [11] recently reported that "binge gaming" was significantly associated with poorer mental health and social outcomes. A study from Iraq by Ibrahim, Ghanim, & Alkhaderjameel [12] found results nearly identical to ours, suggesting that these challenges transcend cultural boundaries.

4.3. Physical Health and Sleep Disruption

The present study shows that nearly one-third of parents reported eye strain (30.9%) and sleep disturbances (31.2%). This is thoroughly reviewed by Alanko, who summarized that excessive screen time is associated with poor sleep quality, musculoskeletal pain, and reduced physical activity [2]. The mechanism for sleep disruption is two-fold: blue light from screens suppresses melatonin, and cognitive arousal from gameplay delays sleep onset [13]. Hastings et al. similarly found that young children's

video/computer
game use was associated with poorer sleep quality and more behavioral problems [14]. Our finding that 39.8% of parents noted a decrease in physical activity is a major public health concern. While active video games (exergames) have shown some benefits in a meta-analysis by Gao et al. [15], our data suggest that the vast majority of children are playing sedentary action or fighting games. The reported neck, back, and wrist pain (14.5% and 6.3% respectively) are evidence of poor ergonomics and repetitive strain.

4.4. The Information Technology Perspective: Digital Ecosystem and Protection Gaps

From an IT perspective, our study reveals several critical findings that have direct implications for child online safety.

Mobile-First Gaming Ecosystem: The dominance of smartphones (67.8%) and tablets (45.2%) as gaming devices reflects global trends toward mobile gaming [16]. This is particularly relevant in the Libyan context, where mobile devices are more accessible and affordable than dedicated gaming consoles. However, mobile platforms often have weaker default privacy settings and expose children to in-app purchases, targeted advertisements, and social features that can facilitate contact with strangers.

High Online Exposure: The finding that 73.2% of children play online games is alarming. Online gaming environments expose children to cyber-risks, including inappropriate content (27.6%), cyberbullying (12.4%), and communication with strangers (11.6%). These findings align with Al-Qudimat et al. [6], who reported that parents significantly underestimated their children's exposure to online risks. The fact that 41.2% of children playing online games interacted with unknown individuals represents a major child protection concern.

Significant Technical Knowledge Gap: Only 33.8% of parents rated their technical knowledge as "High," while 18.2% had limited or no knowledge of digital protection measures. This knowledge gap is consistent with findings from Al-Qudimat et al. [6] and represents a critical vulnerability. Parents cannot protect their children from online risks if they do not understand the technological environment in which those risks occur.

Underutilization of Privacy Controls: Despite the availability of privacy and security settings within games and platforms, only 28.6% of parents configured these controls. This represents a major missed opportunity, as platform-level privacy settings (e.g., disabling chat functions, restricting friend requests, setting content filters) are among the most effective technical protection measures available.

Knowledge-Action Gap: In the current study, among parents with "good" technical knowledge, 82.4% used parental control applications, compared to only 23.5% among those with limited or no knowledge. This finding suggests that targeted digital literacy interventions would have a direct, measurable impact on child online safety. It is important to acknowledge that the literature is not enormous. Some studies, such as the meta-analysis by David et al. [5], have shown that "serious games" designed for education or health promotion can be effective tools for promoting positive behavioral change. Similarly, Kovess-Masfety et al. [17] found that moderate gaming was associated with higher prosocial skills in a large European sample. Our data partially reflects this, as 21.6% of parents reported improved social skills (e.g., teamwork) from gaming. However, the overwhelmingly negative findings in our study, and in studies like Anjum et al. [18] and Tse et al. [11], suggest a clear threshold effect. The problem is not the game itself, but the loss of control—the transition from recreational play to problematic, excessive use. Our data, showing that over 60% of children play 3 or more hours daily, strongly suggests that many in our sample have crossed this threshold into the danger zone. The present study found that 15.6% of parents don't use any online safety tools at all, which is a high and worrying number because children face real risks online. It could be that these parents have less education or a lower income than others. Lou et al. (2024) found that higher parental education levels were positively associated with more active parental mediation [19].

Our results show a strange difference: 54.8% of parents said there are no online risks, but 27.6% said their child saw bad content online. This probably means many parents don't really know what their children do online, not that there are no real dangers. Studies show that parents often know less about their children's online problems than they think Dědková & Smahel, 2020 [20].

4.6. Limitations

Our study has some weaknesses that we need to be honest about. We collected all information at one point in time (cross-sectional). That means we cannot say that one thing causes another – only that things are related.

We relied on what parents told us. Parents may not remember everything perfectly (recall bias), and their answers depend on their own opinions. We did not pick a random sample. We simply asked whoever was available (convenience sampling). So, our results may not apply to all families everywhere. Because of this, we should not call our group of parents "diverse." It is better to say they were reasonably varied.

46.6% of the children in our study were under 5 years old. Some of our questions were about homework, study motivation, and school performance. These questions do not really fit preschool children. This may have introduced bias into our results. Parents rated their own technical knowledge. But what a parent thinks they know about technology may not match their actual digital skills. So, this measure is not very accurate.

5. Conclusion

The digital playground gives children fun and some good things, but it can also bring dangers to their health, happiness, and school work in Benghazi, Libya. Playing too much without any rules is linked to body pain, not sleeping enough, more anger, and doing badly in school. From an IT view, most children use mobile phones, they go online a lot, many parents do not know much about technology, and safety tools are not used often. These are problems that need to be fixed.

The most common health problems we saw were eye strain, sleep trouble, and neck pain. Most children who play action games act more aggressively and lose interest in school. Also, parents often do not watch their children enough, and they do not know much about the digital safety tools that could help protect their children. This study shows that parents need more help to find a healthier way to use technology, to learn more about online safety, and to get their children to do other physical and social activities.

The following recommendations can be beneficial:

1. For Parents:

- Establish and enforce firm rules: Limit daily playtime to 1-2 hours on school days.
- Prioritize location: Keep gaming devices in common family areas, not children's bedrooms.
- Activate technical protections: Configure parental controls on devices (Google Family Link, Apple Screen Time), enable privacy settings within games, and use content filtering.
- Act as a guide for your child. Look up games first using trusted rating systems such as ESRB, PEGI, or Common-Sense Media.

These will tell you if a game is appropriate for your child's age.

- Model balance: Engage children in sports, outdoor play, reading, and family activities.

2. For IT Professionals and Educators:

- Develop and deliver accessible digital literacy training programs for parents, focusing on practical skills: configuring parental controls, understanding privacy settings, and recognizing online risks.
- Create simplified, Arabic-language guides for common parental control tools on smartphones and tablets.
- Integrate digital citizenship and online safety education into school curricula.

3. For Policymakers and Technology Companies:

- Mandate clearer, age-appropriate privacy and safety defaults on devices and gaming platforms.
- Develop government-sponsored public awareness campaigns on safe online gaming for children.
- Support research into effective digital parenting interventions in the Libyan context.

4. For Future Research:

- Conduct longitudinal studies to establish causality.
- Investigate the specific impact of different game genres and online interaction types.
- Develop and test digital literacy intervention programs for parents.

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Intelligent Reflecting Surface-Empowered Terahertz Wireless Communications

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Abstract

This article investigates the integration of Intelligent Reflecting Surface (IRS) technology into Terahertz (THz) wireless communication systems to enhance transmission reliability and coverage. Although THz communications can support ultra-high data rates and massive network capacity, they are highly susceptible to severe path loss, molecular absorption, and blockage effects, which significantly restrict transmission distance and link stability. To overcome these limitations, an IRS is deployed to intelligently reconfigure the wireless propagation environment by reflecting and steering THz signals toward the receiver, particularly when the direct link is obstructed. The study analyzes the impact of IRS-assisted THz communications on system coverage and overall performance. The results demonstrate that the incorporation of IRS technology substantially enhances system capacity, coverage, and communication reliability. Furthermore, the findings highlight that efficient IRS configuration and system design are essential for realizing the full potential of THz communications in next-generation wireless networks.

Keywords: Intelligent Reflecting Surface (IRS); Terahertz (THz) Communications; Coverage Enhancement; Communication Reliability; Wireless Networks; System Capacity.

1. Introduction

Over the past decades, wireless systems have evolved significantly from early technologies to advanced cellular networks, leading to substantial improvements in data rates, coverage, and communication reliability. With the emergence of sixth-generation (6G) networks, research attention has shifted toward high-frequency bands, particularly the terahertz (THz) spectrum, due to its extremely wide bandwidth and its ability to support ultra-high-speed communication services [1]. THz communication systems can deliver data rates in the order of terabits per second (Tbps), making them suitable for advanced applications such as ultra-high-definition video streaming, holographic communication, immersive technologies, and smart connected systems [1]. Despite these advantages, THz systems face significant challenges, especially in indoor environments. The high carrier frequency leads to severe propagation losses, while molecular absorption and sensitivity to obstacles further degrade signal quality. These issues are particularly critical in non-line-of-sight (NLoS) scenarios, where the direct path between the transmitter and receiver is blocked, resulting in weak and unstable received signals and limiting the overall reliability of the communication system [1] [2]. From a standardization perspective, ETSI has initiated efforts to define technical foundations for THz communication systems, including use cases, deployment scenarios, and strict performance requirements such as multi-Tbps data rates and sub-millisecond latency [1]. In addition, several studies have investigated THz wireless channel modeling and measurement techniques. These include frequency-domain-based methods and time-domain sliding correlation [2]. Environmental effects such as fog, rain, and atmospheric absorption significantly impact THz communication performance. Results in [3], showed that frequency, visibility, and rainfall rate strongly influence attenuation, while temperature and particle distribution have less impact, these effects degrade link quality and require accurate channel modeling [3]. Furthermore, the study in [4] explained that molecular absorption, scattering, and turbulence not only degrade performance but also increase vulnerability to eavesdropping, requiring more robust system designs [4].

In addition, IRS technology is described as a passive surface capable of controlling phase and amplitude of signals to achieve directional beamforming, signal enhancement, and interference mitigation, making it a key enabler for future wireless networks. IRS-assisted THz communication has been investigated to overcome the limitations in THz communications. In [5] IRS has been used to enhance coverage by intelligently reconfiguring the propagation environment using passive reflecting elements, enabling signal direction control and performance improvement [5]. The authors in [6], presented a survey on intelligent surfaces, highlighting their integration with THz systems, including architecture, operation, and channel modeling approaches [6]. In [7] IRS-assisted THz systems have been studied with a focus on beamforming, beam steering, and practical implementation strategies. This work showed that joint active and passive beamforming improves communication quality and reduces blockage effects in THz networks [7]. In [8]-[10] IRS-assisted communication systems are analyzed under far-field and near-field conditions. The results in these works showed that increasing IRS size improves the communications quality and enhances coverage performance, making it an effective technique for THz systems. Finally, IRS assisted THz systems introduce advanced coverage capabilities. However, system performance is affected by inter-user interference, beam misalignment, fog, and quantization errors, which significantly impact capacity and reliability [10].

Accordingly, this work investigates IRS-assisted THz communication systems under realistic channel conditions, aiming to enhance coverage and mitigate severe propagation losses. The study provides a comprehensive performance evaluation considering environmental effects and system configurations to improve the reliability of future wireless networks. The study aims to analyze the impact of propagation challenges, including path loss and molecular absorption, and to evaluate the IRS deployment in effectively mitigating these impairments. In addition, the work seeks to assess overall system performance under realistic conditions and explore suitable approaches to enhance communication reliability in future wireless networks.

2. System model

We consider a THz communication system where a base station (BS) equipped with N antennas transmits data to a user with the assistance of an IRS equipped with M elements. Due to severe path loss and molecular absorption in the THz frequency bands, the direct BS–user link may be weak or even blocked. To mitigate this, an IRS is deployed to enhance signal propagation by intelligently reflecting incident signals. The overall system model is illustrated in Fig1.

The IRS consists of M passive reflecting elements, each able to adjust the phase of incoming signals. By configuring these phase shifts, the IRS coherently combines reflected signals to enhance the received signal strength at the user. Communication mainly depends on the cascaded base station BS-IRS and IRS-user links, with the direct BS-user link considered depending on propagation conditions. Path loss, atmospheric absorption, and additive noise affect the quality of the received signal. The IRS enhances communication performance by compensating channel impairments and improving signal quality at the receiver. Furthermore, the channels are modeled using Rician fading to account for both Line-of-Sight and Non-Line-of-Sight propagation conditions.

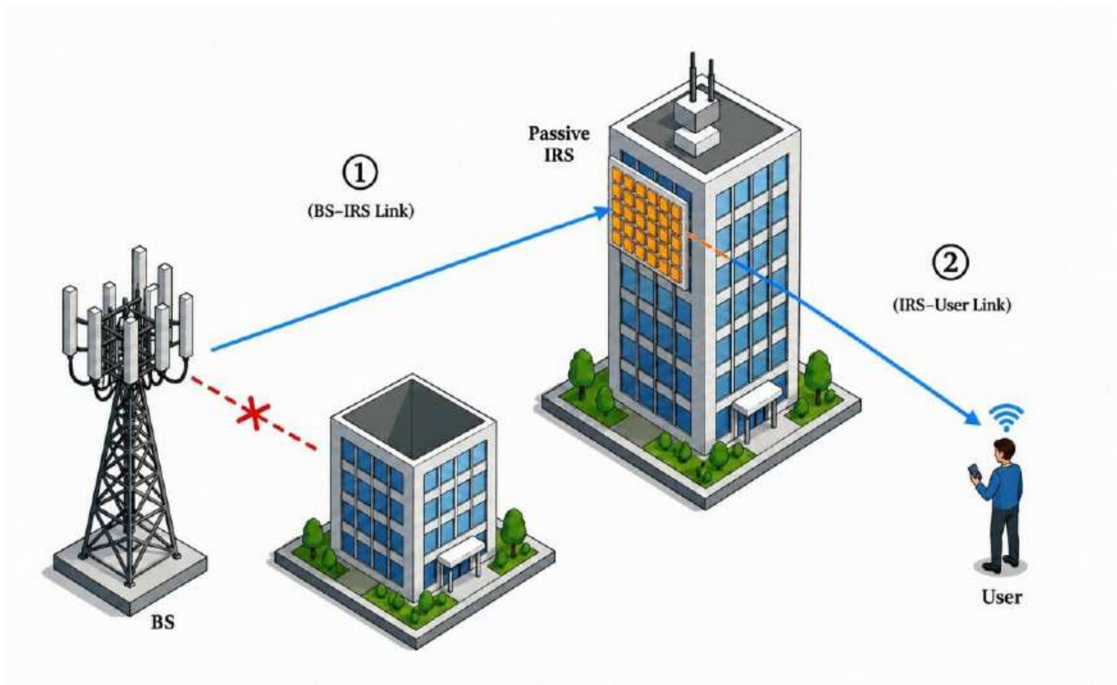

Fig.1 IRS-assisted THz system.

2.1 THz Channel model

a) Path Loss and Molecular Absorption

In THz wireless communication, signal attenuation is significantly influenced by both free space path loss and molecular absorption. The latter is primarily caused by atmospheric particles such as water vapor and oxygen, which absorb THz energy during propagation. channel coefficient for path loss and molecular absorption, h_r, captures these effects and is mathematically expressed as follows:

$$h_r = \sqrt{\frac{G_{Bs}G_r}{64\pi^3}\frac{c}{f d_{BS} d_r}} exp\left(-\frac{k_\alpha(f)(d_{BS}+d_r)}{2}\right) \quad (1)$$

where G_{Bs} and G_r denote the antenna gains of the BS and the IRS–user link, respectively; f is the carrier frequency and c is the speed of light; and d_{BS} and d_r represent the distances between the BS and the IRS and between the IRS and the user, respectively. Moreover, $k_\alpha(f)$ it is the frequency-dependent molecular absorption coefficient. The frequency-dependent molecular absorption coefficient $k_\alpha(f)$ quantifies the signal attenuation caused by atmospheric molecules. It varies with frequency and atmospheric composition and plays a key role in modeling THz propagation loss and is given by.

$$k_\alpha(f) = \frac{\alpha_1(\rho)}{\alpha_2(\rho)+(\frac{f}{100c}-C_1)^2} + \frac{\alpha_3(\rho)}{\alpha_4(\rho)+(\frac{f}{100c}-C_2)^2} + \varrho_1 f^3 + \varrho_2 f^2 + \varrho_3 f + \varrho_4 \quad (2)$$

Where $\alpha_1(\rho) = 0.2205\rho(0.1303\rho + 0.0294)$, $\alpha_2(\rho) = (0.4093\rho + 0.0925)^2$, $\alpha_3(\rho) = 2.014\rho(0.1702\rho + 0.0303)$, $\alpha_4(\rho) = (0.537\rho + 0.0956)^2$, $C_1 = 10.835\ cm^{-1}$, $C_2 = 12.664\ cm^{-1}$, $\varrho_1 = 5.54 \times 10^{-37} Hz^{-3}$,

$\varrho_2 = -3.94 \times 10^{-25} Hz^{-2}$, $\varrho_3 = 9.06 \times 10^{-14} Hz^{-1}$, $\varrho_4 = -6.36 \times 10^{-3}$, and ρ is the volume mixing ratio of the water vapor. After modeling the THz channel coefficient and the molecular absorption effect, the parameter ρ, which represents the water vapor concentration in the propagation environment, is introduced and is expressed as

$$\rho = \phi \mathrm{H} \left(\frac{0.06116}{\varrho} + \frac{2.1148}{10^7} \right) \exp \left(\frac{17.502T}{240.97 + T} \right) \quad (3)$$

where ϕ, H , ϱ and T denote the relative humidity, atmospheric pressure, and temperature, respectively.

b) Misalignment Fading Coefficients

In THz systems, highly directional beams are vulnerable to pointing errors caused by thermal expansion, vibrations, or mechanical misalignment. These errors lead to fluctuations in the received signal power, commonly referred to as misalignment fading. To model this phenomenon, a probability density function (PDF) is used to characterize the random variations in the received power fraction due to beam misalignment. The misalignment fading coefficient is expressed as follows,

$$f_{h_{p,m}}(X) = \xi_m A_m^{-\xi m} x^{\xi m-1} \quad , \quad 0 \leq x \leq A_m \quad (4)$$

With

$$A_m = \left[erf\left(\sqrt{\frac{\pi}{2}} \frac{a_r}{\omega\, d_{BS}} \right) \right]^2 \quad (5)$$

where $\xi_m = \frac{w^2{}_m}{4\sigma^2{}_m}$ denotes the ratio between the equivalent beamwidth and the pointing error displacement severity. $\sigma^2{}_m$ represents the variance of the pointing error displacement. while A_m represents the fraction of power collected by the receiver under perfect alignment conditions . Furthermore, $w^2{}_m$ and X_m are given as follows:

$$w^2{}_m = \frac{w^2{}_{d_{BS}} \operatorname{erf}(X_m)\sqrt{\pi}}{2X_m \exp(-X^2{}_m)}, \quad X_m = \sqrt{\frac{\pi}{2}} \frac{a_r}{w_{d_{BS}}} \quad (6)$$

c) Random Foggy Conditions

In order to incorporate the effect of random foggy conditions on the terahertz wireless channel, an additional attenuation term is introduced. This attenuation arises due to reduced visibility caused by fog particles, which results in signal degradation along the propagation path. Assuming spatially uniform fog distribution, the total fog-induced loss is modeled as an exponential decay function, dependent on the combined distance between the base station and the receiver. The corresponding channel attenuation due to fog is expressed as follows:

$$h_{f,m} = \exp\left(-\frac{\beta\,(d_{BS}+d_r)}{4343}\right) \quad (7)$$

Where β denotes different fog conditions, ranging from light to dense fog.

3. Signal Model

We can write the received signal at the user as:

$$\mathrm{y} = \zeta g^H \Theta \mathrm{H} \mathrm{w} x + n \quad (8)$$

Where H denotes the small-scale fading channel matrix between the BS and IRS, while g^H represents the Hermitian transpose of the channel vector between the IRS and the user, $\zeta = h_r\, f_{h_{p,m}}\, h_{f,m}$ and Θ represents the IRS reflection matrix that controls the phase shifts of the reflecting elements. The precoding vector w is designed using Maximum Ratio Transmission (MRT). The transmitted symbol x denotes the information-bearing signal, while n represents the additive white Gaussian noise (AWGN).

The received signal propagates through the cascaded BS-IRS-user channel, where the IRS optimizes its phase shifts to enhance signal propagation and improve the received signal quality.

The received signal to noise ratio (SNR) can be written as,

$$\gamma = \frac{p|\zeta g \Theta H w|^2}{\sigma^2} \quad (9)$$

And the rate at the user in (bits/s) can be written as

$$R = B\log_2(1+\gamma) \quad (10)$$

where B is the Band-width.

3.1 IRS Phase Shift Design

The phase shifts should be designed to maximize the received signal power in IRS-assisted THz systems. Therefore, the optimal phase shifts are selected to maximize the rate at the user. we can formulate the optimization problem as

$$\max_{\Theta} R \quad (11)$$

Assuming perfect channel state information (CSI) , in this work for simplicity we select the phase shifts to achieve coherent combining at the user. Therefore, the phase shift at k-th element is designed as

$$\Theta_k = \exp(j[\arg(h_k) - \arg(g_k)] \ (12)$$

This phase adjustment aligns the cascaded channel phases, enabling constructive interference and thereby enhancing the received signal strength.

4. Results

This section presents the simulation results of the IRS-assisted THz communication system. The analysis assesses the impact of multiple transmit antennas on signal strength, diversity, and overall system capacity. Furthermore, it examines the effects of environmental factors such as molecular absorption, fog attenuation, and the IRS-user distance on system performance, offering insights into system behavior under practical conditions.

The simulation parameters are summarized as follows: The carrier frequency and bandwidth are both set to **1 THz**. The Rician K-factor is fixed at **9 dB**. The transmit power, $\boldsymbol{Pt}$ varies from **0 to 10 W** to evaluate its impact on the capacity performance of the proposed IRS-assisted THz communication system. The number of IRS elements is set to **M = 32**, and the number of transmit antennas is **N = 4**. Noise Variance $\boldsymbol{\sigma^2} = \mathbf{10^{-7}}$W. The distance between the BS and the IRS is fixed at **10 m**, while the IRS-user distance varies as **2 m, 6 m, and 12 m**.

The comparison between IRS-assisted and conventional THz systems is illustrated in Fig.2 It is observed that the IRS-assisted system achieves significantly higher capacity, especially at higher transmit power, while the conventional system, without IRS remains limited due to obstacles.

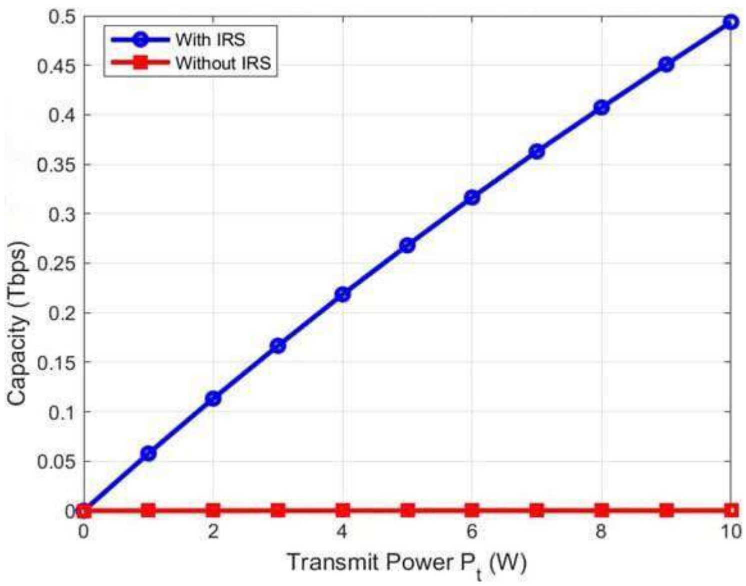

Fig.2 Capacity comparison with/without IRS.

Fig.3 illustrates the impact of molecular absorption and the transmit power on the system capacity. As we can notice from this result, the system capacity increases with transmit power, indicating that higher power improves SNR and enhances overall system performance. In addition, increasing the molecular absorption (a_l) reduces system capacity due to higher signal attenuation in the propagation medium.

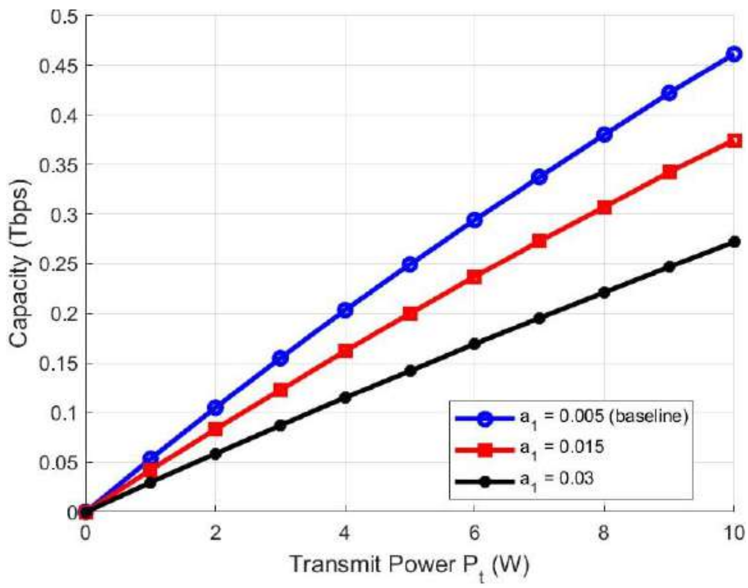

Fig.3 Impact of Molecular Absorption on Capacity.

Fig.4 examines the impact of fog attenuation factor on system capacity. Higher fog attenuation significantly degrades system capacity due to increased channel losses.

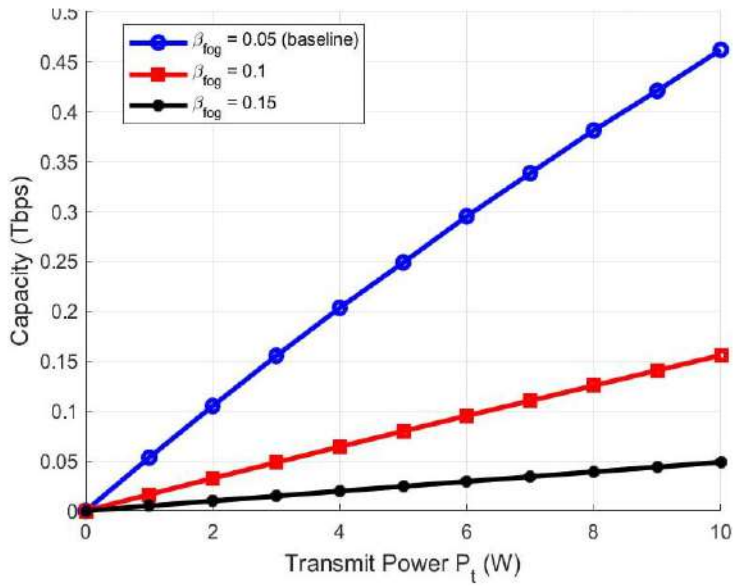

Fig.4 Impact of Fog Attenuation on Capacity

Fig.5 analyzes the impact of the IRS-to-user distance on system capacity. Reducing the IRS-to-user distance improves system capacity by minimizing propagation losses and enhancing the received signal strength.

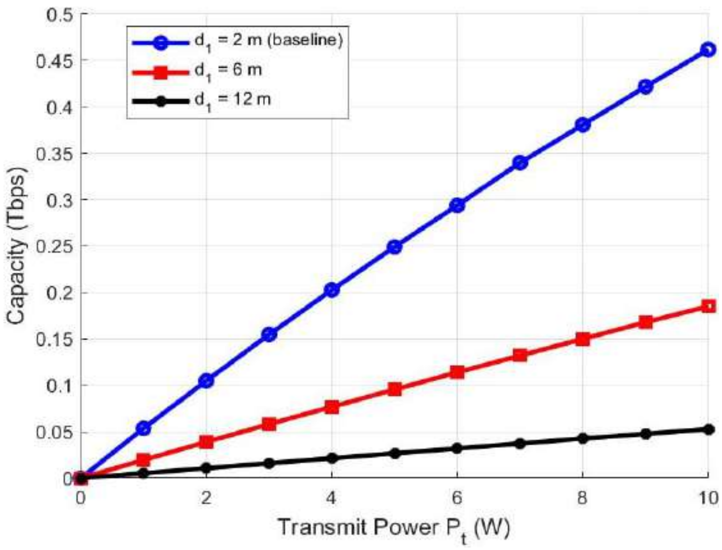

Fig.5 Impact of IRS-to-User Distance on System Capacity

The effect of IRS phase shift variation on system capacity is illustrated in Fig.6. The optimal phase shifts have better performance than the random ones. Thus, IRS phase shifts should be designed to maximize the THz system performance.

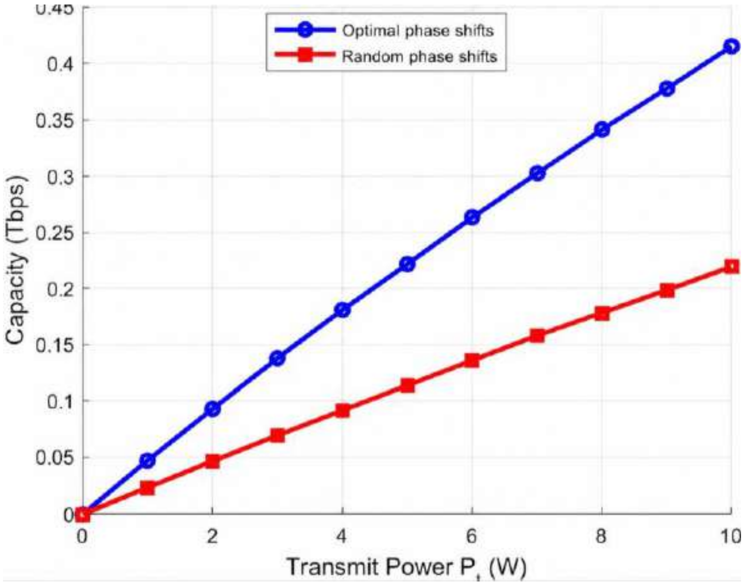

Fig.6 **Impact of IRS Phase Shift Variation on System Capacity.**

5. Conclusion

This article investigated the performance of an IRS-assisted THz communication system through extensive simulations, focusing on environmental impacts, IRS-to-user distances, and phase shift designs. The results demonstrate that the IRS significantly enhances THz communication performance by improving signal propagation in obstructed environments by up to 0.5Tpbs. The IRS provides spatial diversity and beamforming gains, leading to a marked improvement in achievable capacity. Additionally, channel impairments such as molecular absorption, fog attenuation, and increased IRS-to-user distance were found to degrade system capacity due to higher propagation losses, whereas lower attenuation conditions improved spectral efficiency and overall performance.

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