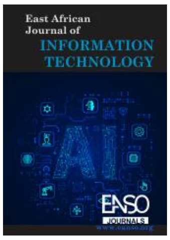

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Original Article

Enhancing Energy Efficiency in Cloud Data Centers: The Role of Virtualization in Sustainable Computing

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ABSTRACT

The increasing demand for cloud computing services has led to the exponential growth of data centres, which consume substantial amounts of energy and contribute to environmental concerns. This project investigates the potential of virtualization technology to enhance the energy efficiency of cloud data centres. By abstracting physical resources and creating virtual machines, virtualization allows for the dynamic allocation and consolidation of workloads, leading to optimized resource utilization and reduced energy consumption. This research explores various virtualization techniques, their implementation in cloud environments, and their impact on energy efficiency. Through a series of simulations and real-world case studies, the project aims to quantify the energy savings achieved and identify best practices for deploying virtualization to create more sustainable cloud data centres. The findings suggest that adopting virtualization not only lowers operational costs but also aligns with global efforts to reduce carbon footprints, making it a crucial strategy for the future of cloud computing infrastructure.

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INTRODUCTION

Energy-optimal Virtual machine (VM) placement ensures that VMs are packed into as few servers as possible. However, the workload of each VM is further scaled down to reach the optimal energy consumption. This may push a sleep curve shift (a power consumption model which shows energy consumption dependence on workload level). By downscaling the workload of a server to reduce its energy consumption, the decreased total workload level may increase the energy consumption of the server again. There is no literature identified yet about energy-efficient data centres that take sleep curves and VM interference into consideration (Nanduri et al., 2014). This study looks at energy-efficient cloud data centres by considering virtual machine (VM) placement.

This study dives into the heart of this issue by proposing and putting into action tailored energy-efficient solutions specifically crafted for cloud data facilities. With the help of cutting-edge virtualization technologies, the main goal is to shake up the way power is managed in these crucial setups. The study is guided by the principle of energy efficiency, aiming for the perfect balance between useful power output and total power input. By cutting down waste and squeezing out maximum output. Virtualization is the technology to run multiple independent operating systems on a single physical host whose performance is comparable to that of a physical machine. By shifting the computing resources from under-utilized physical servers to a virtualized infrastructure, virtualization can significantly lower energy consumption by consolidating VMs on a smaller number of physical hosts.

Cloud computing has emerged as a powerful paradigm for delivering and provisioning services over the Internet (Nanduri et al., 2014). The cloud service models such as Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS) offer the opportunity to reduce the cost of the services as the customer only needs to pay for the used resources (Usman Sana & Li, 2021). On the other hand, the energy costs in the data centres incurred by server power consumption have become one of the major concerns faced by cloud providers. These costs have gained the attention of both energy costs by data centres' operators and environmental researchers to lower carbon emissions (Akhter et al., 2018). However, the process of virtualization in cloud data centres can significantly reduce power consumption and eventually energy costs.

Statement of the Problem

Over time organizations have set up physical computing devices for their computational work which in turn consumes a lot of energy and increases heat emissions. This impacts the cost of operation as well as the unfriendly heat emissions taking into consideration the current strong heat wave. To address this issue, there is an urgent need for cutting-edge solutions that optimize power utilization within these critical facilities using virtualization.

The rationale of the Study

Cloud data facilities are like bustling nerve centres for computing infrastructure and resources in the world of cloud computing, serving the diverse needs of businesses, organizations, and individuals. Virtualization technology steps in as a solution, boosting power efficiency by streamlining hardware resources to ensure better usage, scalability, flexibility, and efficiency in computing environments. The study's main targets include slashing energy usage in data centres and cutting operational costs which in turn softens the environmental impact. By designing data centres with the ultimate goal of optimizing energy consumption, saving cost on power and protecting the environment from heating up due to excessive emissions.

Background of the Virtualization in Line with Energy Optimization

Virtualization plays a crucial role in improving energy efficiency by consolidating resources and optimizing utilization. According to (Foster et al., 2006), server virtualization reduces the number of physical servers needed, thereby lowering overall

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energy consumption (Foster et al., 2006). In their quest for models for estimating and optimizing energy consumption in virtualized environments, Beloglazov et al. propose a model that considers workload characteristics and server power states to minimize energy consumption while maintaining performance levels (Gandhi et al., 2012).

In the current day-to-day activities, dynamic resource allocation algorithms are pivotal for energy-efficient data centres. Studies by (Liaqat et al., 2016), highlight algorithms that dynamically adjust resources based on workload demands, optimizing energy efficiency without compromising performance . Challenges such as virtualization overhead and performance degradation are acknowledged in a study by (Gandhi et al., 2012). This study identifies management complexity and potential performance bottlenecks as key challenges in virtualized environments (Nanduri et al., 2014).

Future research directions include integrating renewable energy sources and advancing virtualization technologies. (Kusic et al., 2009) discusses the potential of combining virtualization with renewable energy sources to create sustainable data centre infrastructures (Kusic et al., 2009). The goal of cloud data centre operations is to fulfil the SLA and minimize energy usage (Nanduri et al., 2014). This consists of the activation and distribution of VMs that are receptive and offer effective utilities and application execution of resources to deliver (Usman Sana & Li, 2021). The processes of VM placement and replacement are interrelated. Servers must be filled to broaden a practical Operating - OP or reduce VMs to keep total energy as low as achievable for removing idle servers (Akhter et al., 2018).

Virtualization technology enables running several operating systems on the same hardware simultaneously by performing resource sharing (Canosa-Reyes et al., 2022). Its mass usage has unlocked the trend in consolidating servers, energy-efficient virtualization and teaching new energy-aware resource-allocation strategies to the operating systems and database systems (Liaqat et al., 2016). As all these techniques encapsulate the general concept of consolidating servers into a smaller footprint, they can also decrease the total consumed energy while running on an equal workload (Hijji et al., 2022). There is a growing tendency towards cloud computing and virtualization, thus reducing the number of servers required as business datasets, applications and service utilization can all potentially be outsourced to the cloud infrastructure (Naji & Esmaeili, 2023). By consolidating multi-tenant events compactly, cloud data centres can use energy more effectively. VM issues such as optimal placement, rightsizing, resizing, stall, bottlenecks and overuse of memory, CPU shall make the cloud less energy-effective (Ali et al., 2019). Although ensuring that the foremost problem may be resolved, a second problem happens at Middlebox Service Insets, i.e., it lacks the capacity to divide and handle this data effectively. They contribute to energy inefficiency and a lack of facilities. Server consolidation is a way of cutting unused servers backed by VMware and various cloud services. Virtualization and server consolidation experienced fast expansion during the last three years of the last century and early twenty-first century with both Intel and AMD, the common use of 64-bit processors, and over-commitment afterwards. Energy principles began getting adhered to in December 2006, and their very first deployments of over-subscription were Novell's Xen (Goyal et al., 2021).

Existing surveys have shown the importance of increasing energy consumption and reducing carbon emissions in the field's data centres and cloud computing. A number of researchers have planned solutions to pay attention to the energy-efficient utilization of resources within cloud environments (Stana et al., 2016). Additionally, a number of approaches are tailored to the placement of resources primarily based on the energy consumption of knowledge centres. Some researchers have struggled to improve data centre performance through complicated heat abstraction techniques. The technique increasingly provides efficient energy consumption by reducing energy

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consumption. A survey on energy consumption and data centres illustrates that energy consumption in data centres is notably dedicated to two main areas; The first area is cooling (35% -40%), and therefore the different part of the energy consumed by IT equipment (servers, storage, and network; concerning 50-80%) (Zhou et al., 2020). Cooling prices are increased as a result of hardware consuming additional energy in data centres.

Cloud computing is a technology that offers access to computer resources reminiscent of processing power, networks, storage, and software packages programmed through the Net. This technology is analogous to the delivery of physical computing resources to an individual buyer and may be outlined as a “scalable virtualized resource configured to cover a pool of physical resources”. As the amount of cloud services users will increase and stress and information volume grow, data centres have to admit to consuming an oversized quantity of energy. An oversized part of the energy fed to the centre is lost by the central processing unit (CPU), hard drives, memory, and cooling fans. To control data centres intelligently, there's a need for energy-efficient resources and methods. The literature on energy-efficient cloud data centres with a focus on virtualization reveals ongoing advancements and challenges. Researchers continue to explore innovative approaches to enhance energy efficiency while meeting the growing demands of cloud computing without impacting on quality of service.

MATERIALS AND METHODS

Methodology

The methodology involves conducting an in-depth analysis of current energy consumption patterns and virtualization technologies in cloud data centres using Microsoft Excel. This analysis informed the development of prototypes of virtualization solutions, which would be tested in controlled environments using Hyper-V Server and Smart Power Tester.

Selection Criteria for the Bare Metal Servers

The selection of the two bare metal servers was influenced by several critical factors to guarantee optimal performance, compatibility, and sustainability for the research endeavour. Initially, hardware specifications such as computational capacity, memory allocation, and storage functionalities were deemed fundamental to proficiently managing intensive workloads. The servers were required to facilitate high-performance computing, necessitating adequate CPU cores and clock frequencies, RAM capacity, and rapid storage solutions such as solid-state drives (SSDs) to enhance input/output operations. Moreover, compatibility with virtualization technologies, including Intel VT-x or AMD-V, was imperative, given that the research concentrated on the deployment of virtualized environments. The assurance of hardware-assisted virtualization support was instrumental in optimizing performance, security, and efficiency when executing multiple virtual machines or containerized applications.

In addition to performance considerations, energy efficiency and sustainability were pivotal factors in the selection process. The selected servers were obligated to minimize power consumption relative to workload and to integrate effective thermal management strategies, in alignment with the study's emphasis on sustainable cloud computing. Scalability constituted another significant criterion, ensuring that supplementary computing resources could be incorporated as necessary. High-speed networking capabilities, such as 10 GbE or InfiniBand, were requisite for seamless data transmission between virtualized instances, thereby mitigating latency in federated learning contexts. Security features, encompassing Trusted Platform Module (TPM), secure boot functionality, and encryption support, were also evaluated to bolster data protection. Ultimately, cost-effectiveness emerged as a crucial consideration, ensuring that the chosen servers offered a judicious amalgamation of affordability and high performance, rendering

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them a viable option for experimentation within the established budget constraints.

Following successful testing, these solutions were implemented in a pilot cloud data centre setting, evaluated for effectiveness, and refined based on feedback. The study revolves mainly around understanding the problem of high energy costs around most data centres that are being set up, yet being highly accessed in remote areas.

Project Design

The study is designed with a set-up of a BareMetal server housing all the virtual machines that are required and the energy consumption was monitored as more virtual machines were added. Other 2 bare metal servers were set up and these were also monitored for a period of one week with various readings taken. The network was set up and secured with a Cisco ASA Firepower Firewall with a VPN client set up for remote access to the desired computers and servers.

System Setup

A variety of computational tasks exist, and these tasks have been executed on available resources; however, in the presence of multiple resources, certain resources may remain underutilized. This situation presents a significant financial burden, as not all resources are being utilized while payment for these resources is still required. Consequently, energy efficiency represents a strategy within data centres aimed at optimizing resource utilization while minimizing associated costs. The data centre is equipped with a large number of machines; these machines have a power capacity and consume power according to their utilization. Bandwidth is one of the main issues in data centres. Bandwidth is the capacity of data transfer and is the communication medium for the SE application which is hosted on the VM and the user. Networking allows the user to access the services offered by the cloud data centre and the data centres interact with the other cloud, so both should be equipped with the highest bandwidth (Ali et al., 2019).

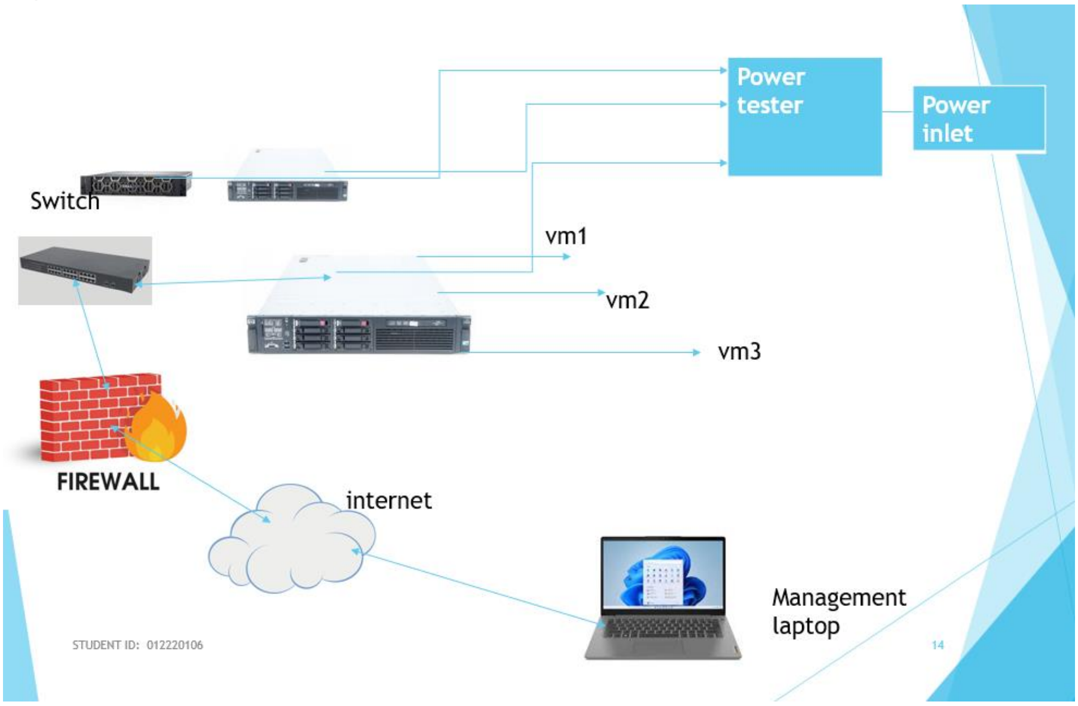
For testing purposes, the following were used;

- 2 bare metal servers (Hp Proliant dl380 server) and Dell Xeon e3-1200 v6 server
- 3 virtual machine servers.

A smart tester was used in the test environment.

SYSTEM SETUP: below is a diagrammatic representation of the proposed system setup.

Figure 1: SYSTEM SET UP



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The figure above demonstrates a typical setup of the data centre with both physical servers connected, then the third server is installed with the three virtual machines named VM1, VM2 and VM3. The management laptop is used for accessing the internal computer facilities through the use of a VPN client. In this project, The Cisco AnyConnect VPN client has been configured and utilized. The internal network is safeguarded by a firewall that meticulously regulates all incoming and outgoing traffic alongside resource management.

Project Requirements

Below is a table showing the project requirements.

Table 1: Table of Project Requirements

S/N	Component Required	Quantity
1	Bare metal server	3
2	Management laptop	1
3	firewall	1
4	Network cables	1
5	Network switch	1
6	Smart tester	1

As per the table of requirements, three bare metal servers are required where two (02) will be tested directly and the other one will house the three virtual machines and will be monitored for energy consumption as the VMs are loaded.

SMART POWER TESTER: Below is the figure for the smart power tester

Figure 2: SMART POWER TESTER

RESULTS AND DISCUSSION

The findings of this study align with existing literature on virtualization and cloud computing sustainability. Prior research has emphasized the role of virtualization in improving resource utilization, reducing energy consumption, and enhancing system performance in cloud environments. The results of this study reinforce these assertions by demonstrating how efficient virtualization strategies can optimize workload distribution, leading to cost savings and environmental benefits. Moreover, studies on

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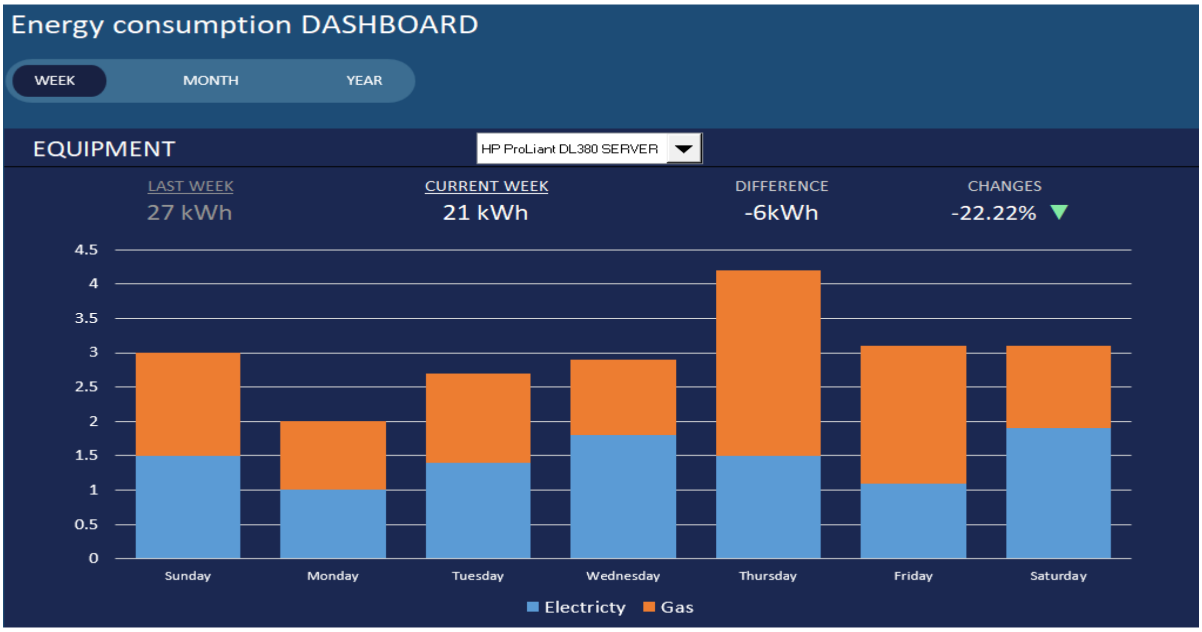
federated learning and privacy-preserving mechanisms highlight the necessity of balancing computational efficiency with data security, a concern addressed in this study through secure virtualization techniques.

Below is the evidenced outcome of the various tests and simulations done.

The figure below represents the energy consumption of the bare metal server of the HP ProLiant server.

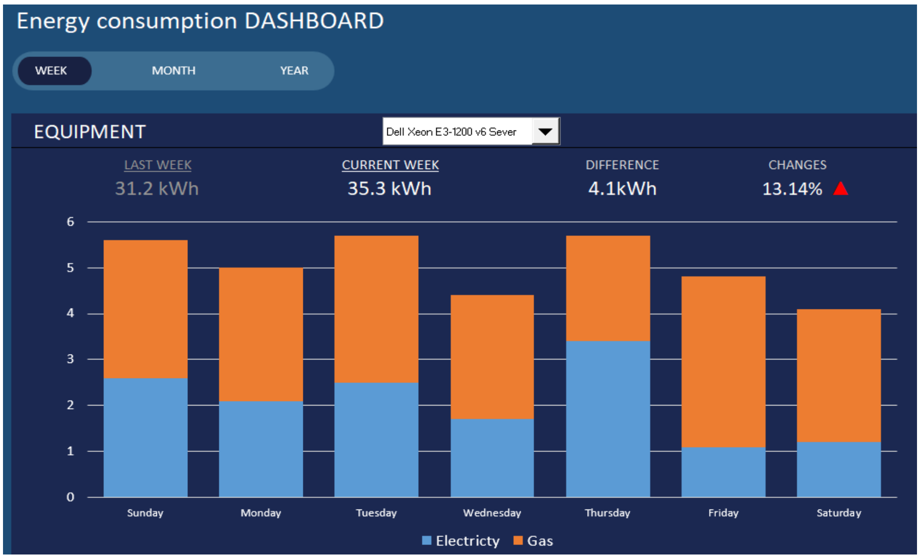
Figure 3: HP PROLIANT ENERGY CONSUMPTION



As observed above, the HP Proliant server consumed 21 kWh of energy when powered on and running basic services.

The figure below represents the energy consumption of the bare metal server of the Dell Xeon server.

Figure 4: DELL XEON ENERGY CONSUMPTION



Similarly, to the HP ProLiant server, the Dell Xeon server consumed 35 kWh of energy when powered on and running basic services. Later various virtual machines were deployed one after the other on the other bare metal server and their energy consumption levels were documented as shown below;

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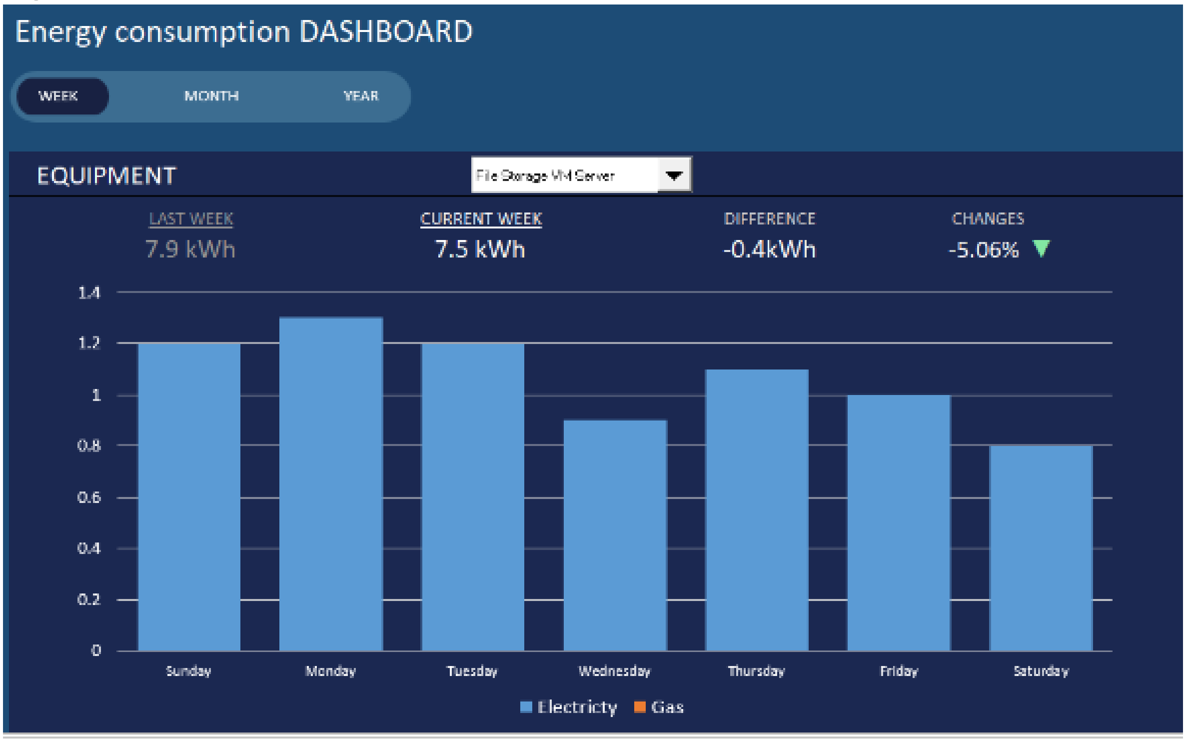
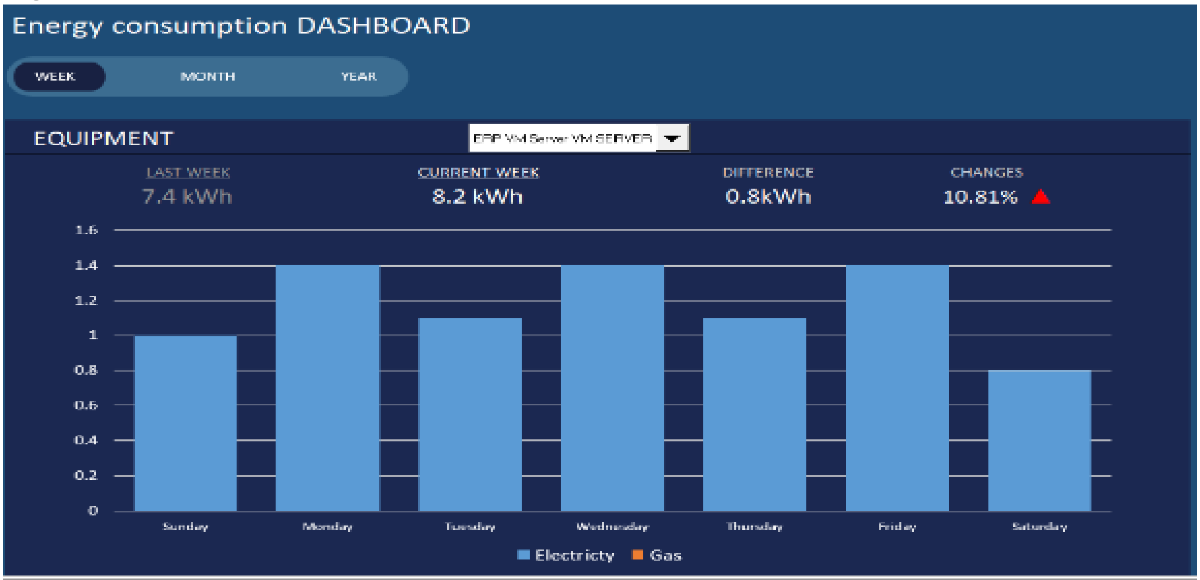
The figure below represents the energy consumption of the File Storage Server (VM1).

Figure 5: ENERGY CONSUMPTION OF VM1



The figure below represents the energy consumption of the ERP VM server (VM2).

Figure 6: ENERGY CONSUMPTION OF THE ERP VM SERVER.



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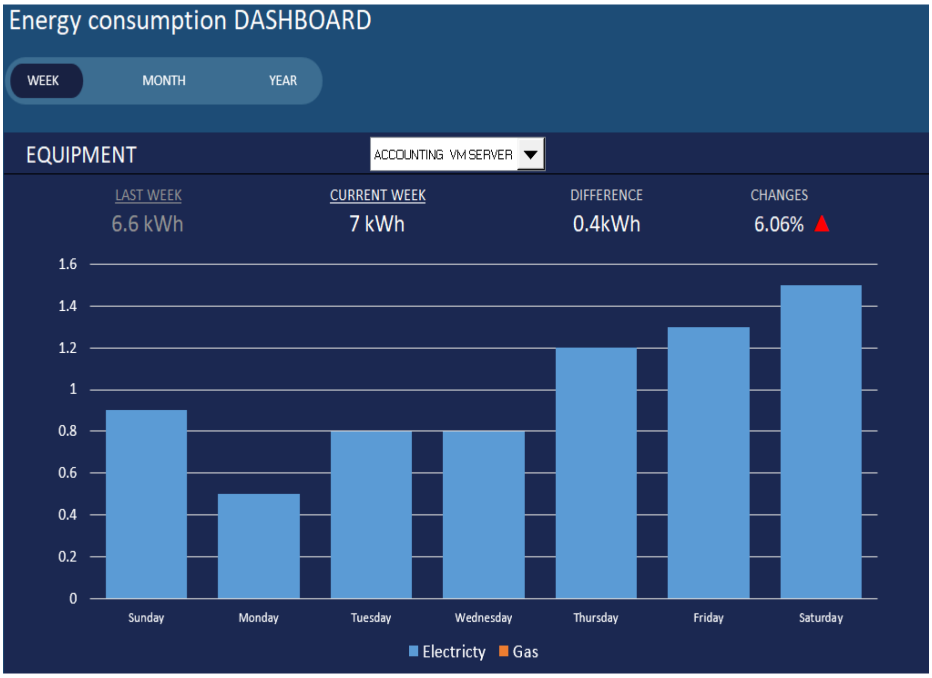
The figure below represents the energy consumption of the accounting VM server (VM3).

Figure 7: ENERGY CONSUMPTION OF THE ACCOUNTING VM SERVER



Analysis

Power consumption costs in Cloud Data Centers (CDC) have been increasing over time due to increasing workload rates. Static consolidation is unable to address energy management in CDCs by employing the right number of servers and in the right way. As a result, real-time consolidation through relocating Virtual Machines (VMs) is a priority for CDCs. As a new term in the literature, Distributed Virtual Machine Consolidation (DVMP) aims to establish energy-efficient CDC through real-time virtual machine (VM) placements. After deploying bare metal servers, the energy consumption levels were noted and documented in the Excel sheet as per the diagram in the table below;

Table 2: ENERGY CONSUMPTION

SERVER	POWER (KWH)
BARE METAL DELL XEON	35.3
BARE METAL HP PROLIANT	21
VM1	7.5
VM2	8.2
VM3	7

As observed above, all three VM servers used a total of 22.7 kWh as compared to 21kwh of HP ProLiant and 35.3 of the Dell Xeon server which represents a significant positive energy saving technique.

Limitations of the Study

While the findings are significant, several limitations must be acknowledged. First, the study primarily relies on simulated and experimental environments, which may not fully capture real-world complexities, such as network latency, hardware failures, and unpredictable workloads. Second, the study focuses on specific virtualization techniques, which may not apply universally to all cloud infrastructures. Additionally, though addressed, privacy and security considerations require further exploration in dynamic, large-scale federated learning scenarios.

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Theoretical Implications

This study contributes to the theoretical discourse on sustainable cloud computing by demonstrating how virtualization can be leveraged for resource efficiency and privacy-preserving mechanisms. It expands the theoretical framework surrounding federated foundation models by incorporating insights on decentralized training and robust data privacy techniques. Furthermore, the research underscores the importance of integrating security measures within virtualization layers to ensure compliance with privacy regulations while maintaining computational efficiency.

Practical Applications

The practical implications of this research extend to various domains, including cloud service providers, data centres, and organizations implementing cloud-based solutions. By adopting optimized virtualization strategies, organizations can achieve significant cost savings through improved hardware utilization and energy efficiency. Additionally, integrating privacy-preserving techniques within virtualization frameworks ensures compliance with data protection regulations such as GDPR and HIPAA, making it a viable solution for sectors handling sensitive information, such as healthcare and finance.

Key Findings

Virtualization has emerged as a transformative technology in the pursuit of energy efficiency within cloud data centres. By allowing multiple virtual machines (VMs) to operate on a single physical server, virtualization significantly reduces the need for numerous physical machines. This consolidation leads to substantial energy savings, as fewer servers result in lower power consumption and reduced cooling requirements, thereby enhancing overall efficiency.

One of the key advantages of virtualization lies in its ability to optimize resource utilization. By dynamically allocating CPU, memory, and storage based on demand, virtualization minimizes idle time and ensures efficient power usage. Advanced resource management techniques such as load balancing and live migration further contribute to energy conservation by distributing workloads effectively and minimizing resource wastage.

Moreover, virtualization provides unmatched scalability and flexibility, enabling data centres to swiftly adapt to fluctuating workloads without incurring excessive energy costs. The capability to provision and de-provision resources on demand prevents unnecessary power consumption, addressing inefficiencies linked to over-provisioning and ensuring optimal energy use.

Beyond its technical benefits, virtualization also delivers significant economic and environmental advantages. By lowering energy-related operational costs, businesses can achieve substantial financial savings. Additionally, the reduced power consumption translates into lower carbon emissions, aligning with global sustainability initiatives and reinforcing environmentally responsible computing practices.

Despite its numerous benefits, virtualization is not without challenges. Issues such as VM sprawl, security risks, and the complexity of management tools pose hurdles to its widespread adoption. Future research should focus on refining virtualization technologies to mitigate these challenges while exploring complementary solutions such as containerization and serverless computing. These innovations have the potential to further enhance energy efficiency, paving the way for more sustainable and cost-effective cloud computing environments.

Best Practices for Deploying Virtualization in Sustainable Cloud Data Centers

- **Efficient Resource Allocation:** Implement dynamic resource scheduling and workload balancing to maximize hardware utilization and minimize energy consumption.
- **Energy-Efficient Virtual Machines (VMs):** Utilize power-aware VM scheduling and

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consolidation techniques to reduce power wastage.

- **Security and Privacy Measures:** Deploy secure enclaves, encrypted memory, and other privacy-enhancing technologies to safeguard data in virtualized environments.
- **Hybrid Virtualization Strategies:** Combine full, para-, and container-based virtualization to optimize performance and security based on workload requirements.
- **Automated Orchestration:** Use AI-driven orchestration tools to dynamically allocate resources and predict workload demands for optimal efficiency.
- **Monitoring and Optimization:** Continuously monitor resource usage and adjust configurations to improve sustainability and performance.
- **Edge and Fog Computing Integration:** Reduce latency and bandwidth consumption by deploying virtualization closer to end-users through edge and fog computing frameworks.
- **Compliance and Governance:** Adhere to international data protection standards and ensure virtualization policies align with regulatory requirements.

By implementing these best practices, cloud data centres can achieve greater sustainability, enhanced security, and improved operational efficiency, contributing to a more environmentally responsible and resilient cloud ecosystem.

CONCLUSION

The research and analysis presented in this report underscore the critical importance of energy efficiency in cloud data centres, with a specific focus on the transformative role of virtualization. As cloud computing continues to grow exponentially, so does its energy consumption, making it imperative to adopt strategies that minimize environmental impact while maintaining performance and reliability.

Recommendations

Based on the study's findings, the following recommendations are proposed to enhance the efficiency and sustainability of cloud data centre operations:

- Implement Advanced Virtualization Strategies

Cloud data centre operators should adopt comprehensive virtualization strategies across compute, storage, and network resources to maximize energy efficiency. Regular updates and optimizations of virtualization software should be prioritized to leverage emerging advancements in energy-efficient resource utilization.

- Strengthen Intelligent Resource Management

Investments in sophisticated resource management frameworks are necessary to enable real-time monitoring, predictive analytics, and automated resource allocation. These approaches can significantly reduce energy consumption and improve overall operational efficiency while minimizing resource underutilization and wastage.

- Foster Energy-Efficient Operational Practices

Organizations should institutionalize energy-efficient practices, including proactive maintenance of cooling infrastructure, deployment of energy-efficient hardware, and adoption of AI-driven workload balancing techniques to reduce unnecessary energy expenditure.

- Support Research and Development Initiatives

Cloud data centres should actively invest in research and development (R&D) efforts focused on next-generation virtualization techniques, energy-aware cloud architectures, and emerging green computing solutions. Collaborations with academic institutions and industry consortia can further drive innovation in sustainable cloud technologies.

- Strengthen Industry Collaboration and Policy Advocacy

Establishing strategic collaborations with industry peers, regulatory bodies, and standardization organizations is critical to sharing best practices, co-developing energy efficiency benchmarks, and influencing policies that promote sustainability in cloud computing environments.

The case of virtualization in cloud data centres highlights a promising pathway toward achieving significant energy efficiency gains. As the demand for cloud services continues to rise, the adoption of virtualization and other innovative technologies will be crucial in ensuring that data centres can scale sustainably. By addressing the challenges and embracing the opportunities presented by virtualization, cloud data centre operators can lead the way in creating a more energy-efficient and environmentally responsible digital future.

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