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Exploring Contrastive Analysis for Energy Prediction in Cloud Data Centers: A Regresssive Approach

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Abstract- Data centers play a pivotal role in modern Internet and cloud computing systems, yet their escalating energy needs present formidable hurdles. Precise energy consumption forecasts are indispensable for optimizing resource allocation. Despite numerous methods proposed, a gap persists in rigorously tackling this issue. Existing approaches often falter in capturing the intricate and stochastic energy consumption patterns, necessitating more comprehensive methodologies. The suggested approach pioneers a novel method for predicting energy usage in cloud data centers, emphasizing the incorporation of random uncertainty. Recognizing this uncertainty is vital due to the variability inherent in factors impacting energy consumption, such as workload fluctuations and hardware failures. By employing regression distributions to model random uncertainty, the methodology aims to more effectively encapsulate the statistical characteristics of energy consumption compared to conventional deterministic models. Rather than furnishing deterministic forecasts, the methodology conceptualizes energy consumption predictions as random variables drawn from regression-derived distributions. This probabilistic paradigm acknowledges and quantifies the inherent uncertainty in energy consumption predictions. Moreover, it extends beyond individual data centers, providing probabilistic forecasts for diverse data center portfolios, accommodating varied configurations and workloads. The methodology introduces several pivotal methodological innovations to enhance prediction accuracy. It proposes a naive multiple linear regression model as a baseline for capturing fundamental relationships. Additionally, it presents a pioneering approach that combines quantile regression and empirical copulas to estimate joint distributions of random variables, capturing complex interdependencies among energy consumption variables. Finally, a weighted correction method, grounded in constrained quantile regression, is introduced to refine predictive distributions, further bolstering accuracy. In conclusion, the methodology addresses the critical challenge of energy consumption prediction in data c\e\nters by embracing the stochastic nature of energy usage. Through rigorous statistical modeling and innovative techniques, it represents a substantial advancement, fostering a nuanced comprehension of energy consumption dynamics and facilitating informed and efficient management strategies.

Keywords: Energy consumption prediction, data centers, random uncertainty, regression distribution, cloud data centers, linear regression, quantile regression.

I. INTRODUCTION

The Data centers serve as the backbone of the modern IT industry, facilitating the storage, processing, and dissemination of vast amounts of digital information. The exponential growth of cloud services, telecommunications, and other digital platforms has propelled the expansion of data centers worldwide. This growth is fueled by the increasing demand for computing resources from various sectors, including large-scale cloud services like Google and Facebook, telecommunication giants like British Telecom, and financial institutions. Consequently, data centers have evolved into largescale infrastructures housing thousands, and sometimes millions, of servers to meet these demands. However, this rapid expansion of data centers has raised concerns about their energy consumption and efficiency. The sheer scale of data center operations results in substantial energy usage, making them one of the largest consumers of electricity globally. This energy consumption has significant economic, environmental, and performance implications. Economically, data centers incur high operational costs due to their intensive energy usage. The energy bills associated with powering and cooling data centers can be substantial, often exceeding the costs of purchasing hardware. Additionally, the energy costs of operating data centers tend to increase over time, doubling every five years in some cases. Environmentally, the energy consumption of data centers contributes to carbon emissions and other environmental impacts. The substantial electricity usage of data centers results in significant carbon footprints, with data centers accounting for a notable portion of global electricity consumption. This has raised concerns about the environmental sustainability of data center operations. Furthermore, the performance impact of data center energy consumption cannot be overlooked. The heat generated by servers and other IT equipment must be effectively managed to prevent overheating, which can lead to hardware failures and performance degradation. Efficient cooling systems are essential to maintaining optimal operating conditions within data centers and mitigating the risk of equipment failures. To address these challenges, accurate prediction and proactive management of energy consumption and thermal dynamics are crucial. Predictive analytics and modeling techniques can help anticipate future energy needs and optimize resource allocation within data centers. Real-time monitoring and predictive modeling enable data center operators to make informed decisions about resource provisioning, workload scheduling, and cooling system optimization, thereby improving efficiency and sustainability.

In summary, data centers play a vital role in powering the digital economy, but their energy consumption and efficiency pose significant challenges. By leveraging predictive analytics and advanced modeling techniques, datacenter operators can optimize energy usage, reduce costs, and mitigate environmental impacts, ensuring the long-term sustainability of data center operations.

II. LITERATURE SURVEY

A Combinational Data Prediction Model for Data Transmission Reduction in Wireless Sensor Networks

1. Khushboo Jain, Arun Agarwal, Ajith Abraham - 2022

The paper highlights the significance of data prediction in WSNs to reduce redundant transfers and prolong network life. It classifies algorithms into backward and forward models, proposing the Combinational Data Prediction Model (CDPM). CDPM addresses delays and excessive data transmission through specific algorithms for SNs and BS, aiming for more efficient WSN operation. The paper cites Jain et al.'s CDPM work, focusing on minimizing data transmission and controlling delays in WSNs. It discusses model training using current data, reconstructing past values, and predicting future data. Techniques for real-world applications include creating step- by-step ideal models for SNs, enhancing feasibility and efficiency. The cited work offers valuable insights for optimizing data prediction models in WSNs.

2. Three-Way Ensemble Prediction for Workload in the Data Center - Rui Shi and Chunmao Jiang - 2022

The paper introduces a novel three-way ensemble prediction method for precise workload forecasting in data centers, taking into account workload volatility and enhancing predictions using simulated annealing. Through careful consideration of workload characteristics, the model allocation process is guided, resulting in significantly improved accuracy compared to traditional methods such as ARIMA, NN, and DMASVR-3WD. Emphasizing the efficacy of the three-way ensemble prediction (TWDRCPM) approach in heterogeneous data center environments, the paper demonstrates its superiority over existing methods and underscores its generality, scalability, and potential for diverse applications. Additionally, the paper outlines future research directions, including factors influencing data fluctuations and incorporating additional resource considerations, to further enhance predictive capabilities.

3. Learning in Energy Modeling: Application in Smart Buildings with Distributed Energy Generation- Seyed Azad Nabavi, Naser Hossein Motlagh, Martha Arbayani Zaidan, Alireza Aslani, Behnam Zakeri - 2021

The paper introduces DWT-LSTM, a method for precise building energy management, addressing 33% of global energy consumption and CO2 emissions. Integrating wavelet transformation and long short-term memory, it forecasts energy demand considering factors like electricity prices, renewables, and user priorities. Results show a 3.63-8.57% error range in hourly predictions and substantial reductions in energy imports, leading to an 87% electricity cost saving. Conventional methods struggle with the nonlinear complexity of building energy management with renewables. This paper introduces the DWT-LSTM method, leveraging weather and energy patterns for forecasting in Vancouver. The approach proves effective in addressing the weather-dependent nature of building energy management, offering a solution to the challenges posed by conventional methods.

4. A Virtual Machine Consolidation Algorithm Based on Ant Colony System and Extreme Learning Machine for Cloud Data Center - Fagui Liu, Zhenjiang Ma , Bin Wang and Weiwei Lin - 2020

The paper proposes ELM_MPACS for energy-efficient virtual machine consolidation, balancing energy efficiency and SLA violations. Results show superiority in reducing energy consumption, migration times, and SLA violations on CloudSim. Experimental results demonstrate its superiority in reducing energy consumption, migration times, and SLA violations on the Cloud Sim platform. The survey introduces ELM_MPACS for virtual machine consolidation using ELM and ACS. It accurately forecasts host states, reduces SLA violations, and showcases advancements on Cloud Sim. The algorithm proves effective in optimizing virtual machine migrations.

5. Provincial Energy Efficiency Prediction in China Based on Classification Method - Yufeng Guo , Qi Wang, Jie Wan, Donghui Yang, Jilai Yu and Kaiwen Zeng - 2019

This paper advances renewable energy in China by identifying key factors and predicting energy efficiency with high-accuracy models across 24 provinces. The results emphasize the need for provincial green energy policies and dedicated prediction institutions to coordinate traditional and renewable energy development strategically. This paper enhances China's energy efficiency via data mining, identifying six key factors and forecasting efficiency in six provinces with high-accuracy models. The study provides valuable insights for precise energy policy planning and implementation.

6. Predicting the Energy Consumption of Residential Buildings for Regional Electricity Supply- Side and Demand-Side Management - Huiling Cai, Shoupeng Shen, Qingcheng Lin, Xuefeng Li and Hui Xiao - 2019

This study optimizes SVM-based electricity consumption prediction using SMOTEENN sampling. Incorporating RF PCA SVD feature engineering and advanced PSO K-means clustering, the SVM model achieves 96.8% accuracy and 97.4% F-measure, highlighting its effectiveness in monthly predictions for rational power supply allocation in entire regions. This papers refers to imbalance classification in SVM-based residential electricity prediction, this study uses the SMOTEENN sampling algorithm, RF PCA SVD feature engineering, and improved PSO K-means clustering. Achieving heightened accuracy, the SVM model, compared to GBDT and BP, offers valuable insights for rational power supply allocation at a macro level.

7. SLA-Aware and Energy-Efficient VM Consolidation in Cloud Data Centers Using Robust Linear Regression Prediction Model - Lianpeng Li, Jian Dong, Decheng Zuo and Jin Wu – 2019

This paper introduces an innovative approach for energy-efficient virtual machine (VM) consolidation in data centers, achieving a balanced trade-off between energy savings and minimizing servicelevel agreement (SLA) violations through a novel VM placement strategy based on a robust simple linear regression prediction. The paper emphasizes the use of a robust simple linear regression prediction model to enhance VM consolidation in cloud data centers. By addressing over-prediction concerns through eight error calculation methods, the model significantly reduces SLA violations and improves energy efficiency, as validated through experiments with real-world and random workloads in the Cloud Sim simulator.

8. An Edge Computing Platform for Intelligent Operational Monitoring in Internet Data Centers - Congfeng Jiang , Yeliang Qiu , Honghao Gao , Tiantian Fan , Kangkang Li and Jian Wan – 2019

The paper introduces an edge computing platform designed for real-time operational monitoring in data centers, integrating wireless and built-in sensors to collect fine-grained data during operations. It emphasizes the growing popularity of data centers and the increasing costs tied to expanding computing capacity, highlighting the need for real- time monitoring to maintain hardware, meet SLAs, and optimize server uptime and energy efficiency. The proposed platform addresses these challenges by enabling proactive maintenance, swift issue detection, and efficient resource allocation. Leveraging edge computing principles, it processes data closer to the source, minimizing latency and enhancing data privacy and security. Overall, the platform offers a vital solution to optimize resource utilization, enhance hardware reliability, and drive energy efficiency in modern data centers.

9. Linear Power Modeling for Cloud Data Centers: Taxonomy, Locally Corrected Linear Regression, Simulation Framework and Evaluation - Leila Ismail and Eyad H. Abed - 2019

This paper proposes the LC-MLR power model to enhance energy efficiency in cloud data centers, introducing a unified evaluation framework and simulation setup. As cloud adoption rises, addressing power consumption becomes crucial, emphasizing the need for effective power models like LC-MLR for improved sustainability. The paper emphasizes the rapid adoption of cloud computing and its environmental impact. It proposes a new power model, LC-MLR, to address energy consumption challenges in cloud infrastructure.

10. Fine-Grained Energy Consumption Model of Servers Based on Task Characteristics in Cloud Data Center - Zhou Zhou , Jemal H. Abawajy , Fangmin Li , Zhigang Hu , Morshed U.Chowdhury , Abdulhameed Alelaiwi and Keqin Li – 2018

This paper presents an innovative energy consumption model tailored for cloud data centers, employing a combination of principal component analysis and regression techniques to attain remarkable prediction accuracy surpassing 95%. In contrast to conventional methods, the model integrates various components and application characteristics, emphasizing the importance of considering all relevant factors for enhanced predictive performance. Furthermore, the versatility of the proposed model extends to facilitating energy-saving algorithms deployment across different servers within data centers, showcasing its potential to significantly optimize energy efficiency and resource utilization in cloud computing environments.

III. COMPARISON ANALYSIS

S.No	Title	Author	Year	Work Done	Performance Analysis	Future Work	Drawbacks
1	A Combinational Data Prediction Model for Data Transmission Reduction in Wireless Sensor Networks	Khushboo Jain, Arun Agarwal, Ajith Abraham	2022	The paper introduces CDPM, a model for reducing data transmission and controlling delays in WSNs. It classifies algorithms into backward and forward models, addressing specific issues for SNs and BS.	Jain et al.'s CDPM demonstrates promising results in minimizing data transmission and predicting future trends. Real-world techniques, like ideal models for SNs, enhance feasibility and efficiency.	Future research may explore CDPM's performance in diverse WSN environments and evaluate scalability. Ongoing efforts could enhance predictive accuracy and adaptability to different scenarios.	CDPM's complexity in implementatio n and scalability limitations may hinder its adoption in large-scale WSNs. Further evaluation is needed to address potential sensitivity to environmental factors and network dynamics in real-world deployments.
2	Three-Way Ensemble Prediction for Workload in the Data Center	Rui Shi and Chunmao Jiang	2022	The paper introduces TWDRCPM, a novel method for workload forecasting in data centers, leveraging simulated annealing and workload characteristics to improve accuracy compared to traditional methods.	TWDRCPM demonstrates superior performance and scalability in heterogeneous data center environments, showcasing its potential for diverse applications in workload forecasting.	Future research aims to explore factors influencing data fluctuations and incorporate additional resource consideratio.	Potential drawbacks may include the complexity of implementatio n and the need for thorough evaluation in real-world deployments.
3	Learning in Energy Modeling: Application in Smart Buildings With Distributed Energy Generation	Seyed Azad Nabavi, Naser Hossein Motlagh, Martha Arbayani Zaidan, Alireza Aslani, Behnam Zakeri	2021	The paper presents DWT-LSTM, a method for precise building energy management integrating wavelet transformatio n and long short-term memory, addressing 33% of global energy consumption	The paper presents DWT- LSTM, a method for precise building energy management integrating wavelet transformation and long short- term memory, addressing 33% of global energy consumption and CO2 emissions.	Future research may enhance DWT-LSTM's scalability and generalizatio n across different locations while evaluating its long-term sustainability.	Drawbacks include implementatio n complexity and the need for extensive data preprocessing, alongside assessing real- world performance and adapt ability.

4	A Virtual Machine Consolidatio n Algorithm Based on Ant Colony System and Extreme Learning Machine for Cloud Data Center	Fagui Liu, Zhenjiang Ma, Bin Wang and Weiwei Lin	2020	The paper proposes ELM_MPACS for energy- efficient virtual machine consolidation, utilizing ELM and ACS. It accurately forecasts host states and reduces SLA violations, showcasing advancement s on the CloudSim platform.	Experimental results demonstrate the superiority of ELM_MPACS in reducing energy consumption, migration times, and SLA violations compared to existing methods, highlighting its effectiveness in optimizing virtual machine migrations.	Future research could focus on enhancing the scalability and generalizatio n of ELM_MPACS across diverse cloud environment.	Potential drawbacks may include the complexity of implementing ELM_MPACS and the need for extensive parameter tuning.
5	Provincial Energy Efficiency Prediction in China Based on Classification Method	Yufeng Guo , Qi Wang, Jie Wan, Donghui Yang, Jilai Yu and Kaiwen Zeng	2019	The paper advances renewable energy in China by identifying key factors and predicting energy efficiency across 24 provinces, utilizing data mining techniques.	Results showcase high accuracy models in predicting energy efficieny, underscoring the approach’s efficiency for informing precise energy policy planning and implementation.	Expanding analysis to more provinces and incorporating additional factors for enhanced predictive accuracy is crucial. Additionally, assessing long-term policy impacts and implementati on effectiveness is essential for sustainable energy development.	Challenges include integrating factors and accurately forecasting efficiency in dynamic environments, alongside ensuring stakeholder acceptance and ongoing policy effectiveness assessment.
6	Predicting the Energy Consumption of Residential Buildings for Regional Electricity Supply-Side and Demand- Side Management	Huiling Cai, Shoupeng Shen, Qingcheng Lin, Xuefeng Li and Hui Xiao	2019	The study optimizes SVM-based electricity consumption prediction using SMOTEENN sampling and advanced feature engineering techniques. It achieves high accuracy and F-measure, demonstrating effectiveness for rational power supply allocation in entire regions.	Results show the SVM model's superiority over GBDT and BP, highlighting its effectiveness in monthly predictions and offering valuable insights for macro-level power supply allocation.	Further research could refine the model with additional feature engineering and advanced algorithms, while considering temporal trends and external factors.	Scalability issues and interpretability challenges may arise, warranting careful consideration for generalizability to diverse datasets and geographical regions.

7	SLA-Aware and Energy- Efficient VM Consolidatio n in Cloud Data Centers Using Robust Linear Regression Prediction Model	Lianpeng Li, Jian Dong, Decheng Zuo and Jin Wu	2019	Scalability issues and interpretability challenges may arise, warranting careful consideration for generalizability to diverse datasets and geographical regions.	Experiments conducted with real-world and random workloads in the CloudSim simulator validate the effectiveness of the proposed approach, showing significant reductions in SLA violations and improvements in energy efficiency.	Future research could focus on enhancing the VM placement strategy and prediction model to address scalability and adaptability to dynamic workload environments.	Potential drawbacks include the complexity of implementing the proposed approach in large-scale data center environments and the need for further validation with diverse workload scenarios.
8	An Edge Computing Platform for Intelligent Operational Monitoring in Internet Data Centers	Congfeng Jiang , Yeliang Qiu , Honghao Gao , Tiantian Fan , Kangkang Li and Jian Wan	2019	The paper presents an edge computing platform for real-time monitoring in data centers, addressing the need for efficient resource management and energy optimization. It showcases the platform's ability to enable proactive maintenance, swift issue detection, and efficient resource allocation through experimental validation.	Experimental results demonstrate the platform's effectiveness in minimizing latency, enhancing data privacy, and improving resource utilization and hardware reliability. By leveraging edge computing principles, it achieves significant improvements in energy efficiency and operational effectiveness.	Future research could focus on scalability, adaptability to dynamic workloads, and integration with advanced technologies like AI for predictive maintenance. Additionally, addressing challenges related to implementati on complexity and sensor data reliability would be crucial for further development.	Challenges may include the complexity of implementatio n in large-scale data centers, interoperability concerns, and potential reliability issues with sensor data. Additionally, there could be increased management overhead associated with deploying and maintaining the platform.

9	Power Modeling for Cloud Data Centers: Taxonomy, Locally Corrected Linear Regression, Simulation Framework and Evaluation	Leila Ismail and Eyad H. Abed	2019	The paper introduces the LC-MLR power model to improve energy efficiency in cloud data centers and establishes a unified evaluation framework and simulation setup for its assessment. It highlights the significance of addressing power consumption in cloud environments, especially with the increasing adoption of cloud computing.	The LC-MLR power model demonstrates promising results in enhancing sustainability by effectively managing energy consumption in cloud infrastructure. Through rigorous evaluation and simulation, the model showcases its effectiveness in optimizing power usage and reducing environmental impact, contributing to the overall efficiency of cloud data centers.	Future research avenues could explore the scalability and applicability of the LC- MLR power model in larger and more diverse cloud environments. Additionally, efforts could focus on refining the model parameters and incorporating real-time data for more accurate power management strategies in dynamic cloud systems.	Challenges may include the complexity of implementing the LC-MLR power model in diverse cloud architectures and the need for comprehensive validation across various cloud platforms and workloads. Additionally, potential limitations in scalability and adaptability to evolving cloud technologies may need to be addressed in future iterations of the model.
10	Fine-Grained Energy Consumption Model of Servers Based on Task Characteristic s in Cloud Data Center	Zhou Zhou , Jemal H. Abawajy , Fangmin Li, Zhigang Hu , Morshed U.Chowdh ury, Abdulham eed Alelaiwi and Keqin Li	2018	The paper introduces an energy consumption model for cloud data centers, utilizing principal component analysis and regression techniques to achieve prediction accuracy exceeding 95%. It emphasizes the integration of diverse components, application characteristics to enhance predictive performance, highlighting the importance of considering all relevant factors in energy usage	The proposed model demonstrates exceptional prediction accuracy, surpassing 95% and outperforming conventional methods. By incorporating various components and application characteristics, it optimizes energy efficiency and resource utilization in cloud data centers, offering significant improvements in predictive performance and overall sustainabilit.	Future research could focus on further refining the model parameters and validation across diverse cloud environments to ensure its scalability and adaptability. Additionally, exploring advanced machine learning techniques and real-time data integration could enhance the model's predictive capabilities and support dynamic energy management strategies in evolving cloud infrastructures.	Challenges may include the complexity of implementing the model in large-scale cloud environments and the need for comprehensive validation across various workload scenarios. Additionally, potential limitations in scalability and adaptability to evolving cloud technologies may require further investigation and refinement.

Graphs

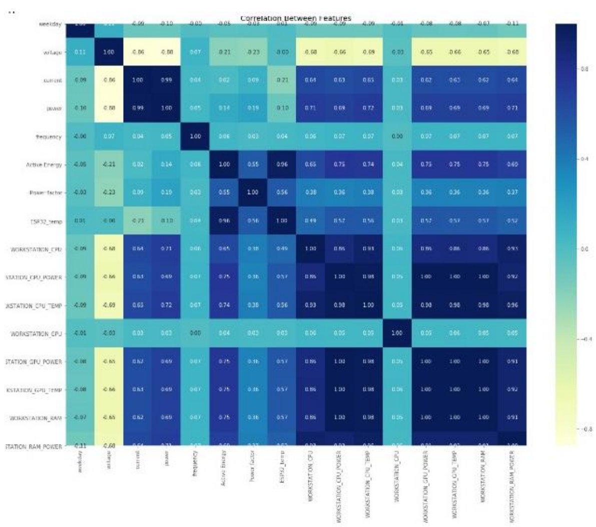

Fig 1: Correlation matrix

The heatmap plot illustrates the correlation between numerical features in the Data Frame df, with colors indicating the strength of correlation. Lighter colors represent stronger positive correlations, darker colors represent stronger negative correlations, and annotations display correlation values. The title "Correlation Between Features" summarizes the plot's content

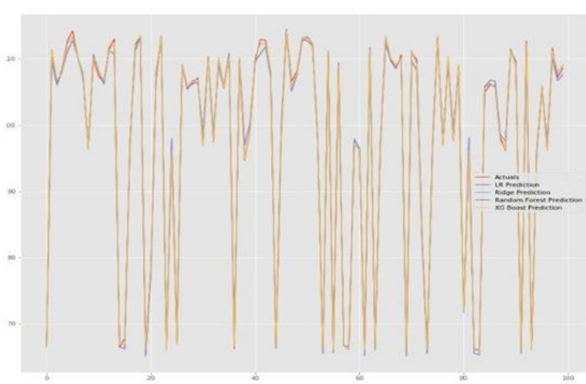

Fig 2: Trends/Patterns for the first 100 rows

The plot displays a line plot of the first 100 rows of data from the Data Frame results. Each row likely represents a data point, and each column represents a variable. The plot visualizes the trends or patterns of these variables over the initial 100 rows of the dataset. The specified figure size of 15 units wide and 13 units high adjusts the dimensions of the plot.

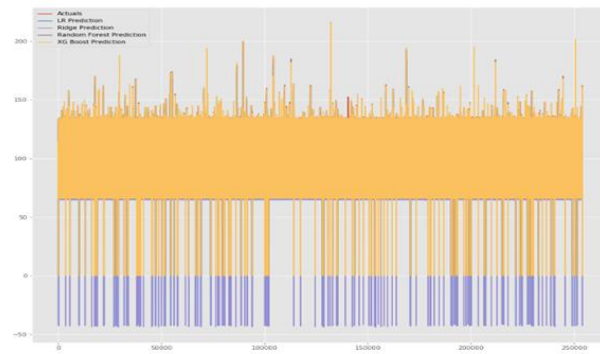

Fig 3: Trends / Patterns for all the variables

The plot visualizes the data in the Data Frame results, representing each column against the Data Frame's index. The line plot displays trends or patterns across all variables, and the specified figure size of 15 units wideand13 units high adjusts the plot's dimensions for better visibility

IV. FUTURE SCOPE

In our forthcoming research endeavors, we aspire to delve deeper into the realm of net-zero smart buildings, which represent a pivotal step towards achieving sustainable infrastructure and mitigating the environmental impact of urban development. These innovative structures leverage renewable energy sources and cutting-edge technologies to minimize their carbon footprint and energy consumption, thereby aligning with broader sustainability goals.

To propel this vision forward, our research will center on the integration of sophisticated deep learning methodologies with advanced optimization algorithms. By harnessing the predictive capabilities of deep learning models and the optimization prowess of algorithms such as the Sine Cosine Algorithm, Genetic Algorithm, and Wolf Pack Algorithm, we aim to develop robust frameworks for optimizing energy usage within smart buildings. These frameworks will not only enhance energy efficiency but also contribute to the realization of net-zero energy consumption targets.

Furthermore, our focus will extend beyond energy optimization to encompass the intricate challenges associated with load scheduling in smart buildings.

We recognize that effective load scheduling is crucial for balancing energy demand, maximizing utilization of renewable energy resources, and ensuring seamless operation of building systems. Through rigorous analysis and experimentation, we seek to devise innovative scheduling strategies that prioritize energy conservation while meeting the diverse needs of building occupants.

In addition to technical considerations, we place a strong emphasis on integrating user satisfaction metrics into our research framework. We acknowledge that the success of smart building technologies ultimately hinges on their acceptance and usability by occupants. By incorporating user feedback and preferences into our models, we strive to create environments that not only optimize energy usage but also enhance occupant comfort, productivity, and well-being.

Overall, our research endeavors represent a holistic approach to advancing the field of sustainable building design and operation By combining state-of-the-art technologies with user-centric principles, we aim to revolutionize the built environment, ushering in a new era of energy-efficient, environmentally friendly, and user-friendly smart buildings and also user - friendly smart houses or smart homes.

V. CONCLUSION

In our project, our primary goal was to develop accurate energy demand prediction models for data centers. The purpose of these models is to address multiple sustainable development objectives, including promoting affordable and clean energy, fostering innovation and infrastructure development, and facilitating climate action. By accurately predicting energy demand, we aimed to contribute to the creation of more sustainable and environmentally friendly energy systems. Specifically, our project focused on estimating the energy consumption of hosts within a data center environment. We recognized that existing approaches for temperature prediction in data centers were often inaccurate and computationally expensive. Therefore, we sought to develop a more precise and efficient method for energy estimation, particularly by leveraging data-driven techniques. To achieve this, we collected physical host-level data from a cloud data center, which included measurements of CPU and inlet airflow temperatures. Through our analysis, we observed significant thermal variations among hosts, highlighting the complexity of the energy estimation problem in data center environments. In response to these challenges, we explored various ensemble learning algorithms to develop our predictive models. Ensemble learning techniques are known for their ability to improve predictive accuracy by combining multiple models. By utilizing these algorithms, we aimed to capture the intricate relationships between energy consumption and temperature variations in data center hosts. Overall, our project was driven by the objective of creating accurate and efficient energy demand prediction models for data centers. Through our study, we aimed to contribute to the optimization of thermal management in data centers, ultimately reducing operational costs and increasing reliability in these critical infrastructures

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