International Journal of Science and Engineering
ISSN (Online): 2456 -6063
Volume 08 Issue 10 May 2022

DOI: 10.53555/ephijse.v8i3.293

ADVANCEMENTS IN AI-DRIVEN IOT SYSTEMS FOR SMART HOME ENERGY EFFICIENCY

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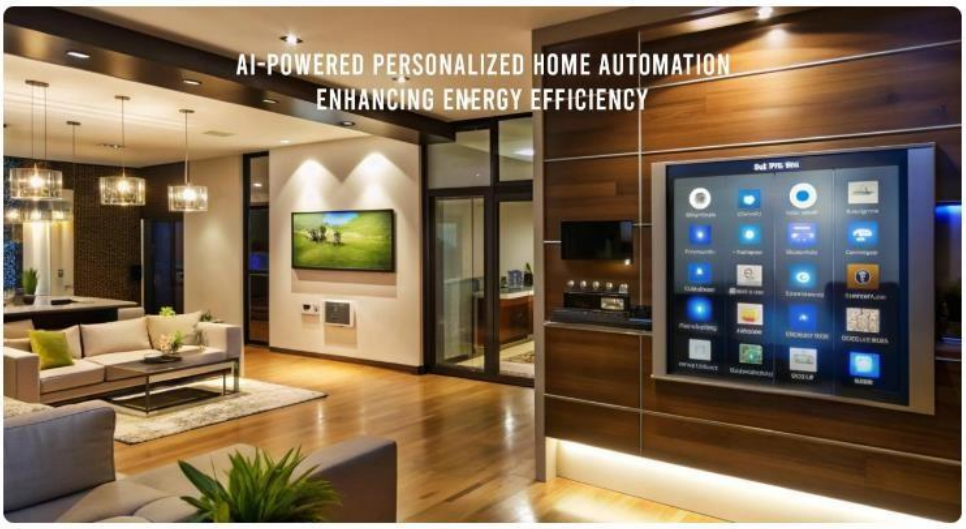
Abstract:
AI driven IoT (Internet of Things) systems have made remarkable improvements in energy efficiency in smart homes thereby providing a ground breaking strategy for adopting sustainable life. Using AI algorithms and the real time data of connected devices, these systems optimize energy usage, minimize the waste, and ultimately make the house more efficient. Thermostats, lighting, and appliances are smart devices that automatically optimize themselves for efficiency once the machine learning models analyze user behavior, environmental data and patterns of energy usage to predict energy needs. An example of one of the key advancements is that predictive analytics have been integrated, so your energy demand is anticipated and settings are adjusted proactively. For instance, AI can teach an AI driven thermostat a household's schedule and adjust the intensity of the heating and cooling system of your home based on the schedule to maintain comfort while using the least amount of energy. Similarly, smart lighting systems can adjust to natural light level, dimming or brightening according to occupancy and time of day. In addition, these systems aids in grid optimization such that smart homes not only control how its energy is used but also how it interacts with the energy grid as a whole. Demand response capabilities are enabled through this, where smart homes can use consumption adjustments during peak demand times to help stabilize the grid and lower costs. AI driven IoT systems are changing the dynamics of smart home energy efficiency through real time optimization, ability to adjust and learn and seamless interaction with the grid and bring about sustainability and lowering environmental impact.

Keywords*: AI-driven IoT, Smart home, Energy efficiency, Predictive analytics, Sustainability*

Introduction

There is a gradually rising need for reduced energy consumption in the whole network and awareness of the environment, the both collectively makes that An Intellectual Environment for Smart Home with the aid of integration of Artificial Intelligence (AI) and Internet of Things (IoT) is a sound solution. The real time monitoring, automation and optimization of the home with Consumer satisfaction with the use of the energy is introduced using Intelligent systems and IoT device otherwise known as (Wotus et al. 2011; Demo et al. 2012) connected together. This is because systems which are powered by AI, are able to process a lot of sensor data, predict the behaviour of the user, adjust with the user preferences as well as make autonomous decisions on their own, all of which can be used to manage energy better. However, the typical energy systems have in one way or the other been operating under either of the scheduled or manual mode, which could not adjust dynamically to seal the wastage of the energy instantly. In comparison to these IoT systems, AI powered IoT systems can have precise control over energy consumption and in turn can predict or vary the control as per the context such as weather, occupancy, appliance usage by utilizing the machine learning algorithms, neural network and deep learning models.



AI and IoT combine directly to support other broader sustainable goals like carbon emissions, lower energy bill bills which support bottom household/reap bills, and creating more resilient grids. The other is enhanced data privacy as well as system interoperability. So too, scalability and cost. Advancements in edge computing, federated learning, and adaptive control architectures have been increasingly incrementing these barriers to realize robust and secure smart home ecosystems. Fast developments are taking place in the field of intelligent energy management systems, towards the wide spread adoption of these intelligent energy management systems. In this work, an effort has been done to research on AI based power IoT systems which enhance energy efficiency especially in the residential situation status, challenges and prospects that may come in the future. This effort makes contribution to make homes Smart and Green by studying, analysing, assessing and pointing out the gaps using existing models. Sure enough, home energy management is one of the main innovation that has the inclination to change the way we relate to the energy utilization of our regular exercises joined by the AI and IoT spirits in the midst of our line to a more associated, agreeable and gainful future.

Background of the Study

The rapid growth in development of urbanization is significant, and the energy consumption arises from residential sectors has increased rapidly while the energy efficiency is one of the major focuses within the framework of sustainable development. The current home energy management systems are traditional systems working manually or with static operating schedules, which were not always efficient and smart to support flexible energy demand. The Internet of Things (IoT) brings many connected things, which along with smart homes promises to collect and control the real time data. Using IoT and Artificial Intelligence (AI) together maximizes its potential for smart homes, by utilizing advanced analytics, pattern recognition and autonomous decision-making characteristics. Without the compromise of comfort, IoT systems enabled with AI can learn the user habit and can customize the performances of the devices to save the excessive amount of the energy. In case they, this thesis uses some of these advancements, for the instance usage of AI advancements such as in terms of machine learning, and deep learning to make the smart homes to become more energy conservation which allows them to be intelligent and also sustainable place to live.

AI Techniques in Smart Homes

Artificial Intelligence (AI) is powerful and powerful tool that is changing how energy is handled keeping in mind the smart homes in current days to make it efficient and automatic and adaptable. These are the AI techniques that can handle the large amount of real time data from Internet of things (IoT) devices, learn with patterns, make predictive forecasts and act autonomously with the minimum or zero human input, which will be the backbone of intelligent home energy systems. Machine Learning (ML), as a popular and applicable technique, is employed for analysis of the obtained historical energy

consumption data including usage patterns using supervised and unsupervised ML models, prediction of future energy demand and leakage detection (not the fault in appliances). ML has a vast range of subsets and one of them is deep learning, a very powerful practitioner for understanding the occupant behavior or automatically adjusting the lighting or HVAC system on a dynamic basis can even care for the occupancy (or lack of it) using sensor fusion. One of the novel techniques employed in this case is the reinforcement learning, which is increasingly becoming inescapable to the agent in a smart home scenario involving the discovery of the optimal control strategy through interaction with the environment through trial and error. It allows the systems to self-optimize over time – the systems will get better and better as they learn from each decision. In addition, fuzzy logic is applied when we cannot make a binary decision, for example, as to when the intention is to reconcile comfort and energy savings through fuzzy inputs like 'a little bit warm' and 'somewhat occupied'. In terms of natural energy, the energy needs of smart home can be predicted using calendar events, weather conditions or future trends on electricity pricing for pre emptive cost and environmental impact adjustment by AI powered predictive analytics. In addition, AI extensively contributes to natural language processing (NLP) as well as voice recognition hence the smart energy system users can fiddle with the system simply by using voice commands as a way of streamlining the management process. All of a sudden, the rise of Edge AI is because devices can now execute quick decisions in the moment without only relying on a cloud infrastructure and thus make faster decisions and have more privacy. This vision of homes that not only respond but that anticipate is what these homes can do: learn and change over time because they learn how their users use them. Being the AI techniques so versatile, they guarantee scalability and transformation to various contexts and do lead to smart home systems serving as an additional contribution to the general trend for low carbon and energy efficient life. Over time, the more advanced the AI becomes, the more central the AI will be to those who live in the smart home to manage energy. If yes, it would lead to the establishment of smart home intelligent ecosystem that is sustainable, autonomous and user friendly.

Importance of Energy Efficiency in Smart Homes

The solutions to the high energy consumption, environmental harm and increasing the rates of the energy bill in homes can be solved by energy efficiency using the smart homes. Improving the energy efficiency of residential buildings plays a key role in ensuring both economic and environment sustainability globally and, large part of it is related to their heating, cooling, lighting and appliance systems. In the area of smart homes, as a home connects IoT devices like the smart energy management system coupled with the real time monitoring, homeowners can use this smart home to reduce energy cost without lowering energy comfort and convenience. Automation, predictive analytics and adaptive control, which use automation only to save what and when it's needed, not only saves noticeable cash but also creates sustainable patterns of living. The energy efficient smart homes also help in reducing the amount of greenhouse gas emissions held for climate action targets and relieve the national power grid load mainly during the peak consumption time. It also eases its integration of renewable energy sources into the grid, and manages demand side in a way which improves the grid's reliability. This is obviously only true in terms of electricity cost savings unless you look at it from the point of view of the consumer who will also derive benefits of power to control when and how one wants the systems to run as well as more reliable systems. The provision of the usage pattern of the energy can promote the responsible energy behavior in the users of the smart energy management system. As energy prices grumble and environmental regulations tighten up, now is as perfect as ever to think home energy efficiency, and as such, intelligent technologies will have an important role in playing that game. In this, the energy consumption is further altered using these said sustainable principles to result in greener and smarter cities and in important constituent parts of this are the smart homes.

Literature Review

Rehman, A. U., et al (2020). Rather than, the AI driven smart home is on an edge of machine learning, data analytics, and Internet of Things (IoT) devices to reduce the energy usage, to offer an improved comfort and to decrease the operational cost. Using the AI system they will intelligently manage occupant behavior, environmental conditions, real time energy consumption, and will suggest to them how to control lighting, heating, cooling and appliance use efficiently. All these are far more than simply automating tasks as they are systems that learn and evolve with time to do better. Such a home is conceptualized with sensors, AI algorithm, auxiliary in the cloud, and user interface, which integrates these and finally turns them into one living environment that continually interacts.

Farzaneh, H., et al (2021). The use of energy in smart buildings has been revolutionized with modern (or intelligent, adaptive and automated) using energy management systems based in AI, which benefits energy efficiency. Historically, smart building technologies were based on rule based control and the present day smart building technologies are being built on concepts of machine learning, deep learning and predictive analysis to fine tune energy usage realtime. Such systems are able to manage big quantities of data from sensors, user behaviors, environmental conditions, and then dynamically and gracefully fine tune the control of HVAC, lighting, etc, through AI algorithms that can keep conducting and improving over time, thereby raising efficiency and responsiveness.

Mahmud, U. P. A. L., et al (2018). In parallel with advancing the renewable energy efficiency and decreasing carbon emissions, micro solar power grid systems with AI addressing suggest transformative solution of clean, reliable energy supply to isolate communities. By integrating solar storage and solar power with the solar panels, an artificial intelligence (AI) algorithm can be used to optimize the generated power of solar energy, the use of the solar storage of solar energy, and also the use of solar power. The efficiency is maximized and minimum downtime is achieved with the help of predictive forecasting of solar energy availability, load adaptive balancing along with real time fault detection using the AI. The operation of such systems does not require intelligences and hence can be operated autonomously in areas where facilities are bad and hence use of fossil fuels and generation of greenhouse gas emissions can be reduced. Thus, this

forms a smart demand response which can schedule energy usage in an efficient way and allocate resources to important loads.

Mohammed, I. A. (2012). An exploratory study is presented on the evolving setup of smart device with IoT based technologies which leads to a restructuring of a system of devices leading to new industry or life setup. Here the Internet of Things (IoT), the emerging motivation of Information Technology allows the sensors and actuators to have seamless communication with the cloud platforms in real time to be used for real time monitoring and automation to facilitate the data driven decision making. Due to the IoT technologies, they are more efficient, safe and user friendly in smart homes, smart cities, smart healthcare, smart industrial applications etc. The purpose of this is to increase the interoperability of the dataset, secure the data, and improve energy efficiency and edge computing abilities to deal with the huge influx of the datasets caused by the IoTS. In these systems machine learning and artificial intelligence advances are also included in the IoT systems so as to enable predictive analytics and operations autonomy.

Fontaine, C. (2020). At present, smart home automation is being revolutionized using the scalable, real time and efficient system architectures based on integration of cloud computing and Internet of Things (IoT) technologies. Cloud integrated IoT framework benefits from the computational capability and the flexibility of cloud platform e.g. Amazon Web Service (AWS) back end to process and analyze large scale data and store the data, but the edge computing performs the data processing near to the data source to minimize the latency response time. In such kind of smart homes, the hybrid architecture can be utilized to divide the workloads between the edge devices and the cloud to enhance the performance and robustness. Some of the AWS services that allow devices to effortlessly connect, data to process in serverless fashion, and data to be managed at scale include AWS IoT Core, Lambda, S3, and DynamoDB, to name a few.

Waleed, Q., & Javaid, T. (2021). As the IoT eco systems are being populated with more and more connected devices, the security of the environment is of utmost importance when considering the sheer size of the surface of attack and the susceptibility to the cyber threats. It is an effective solution to build a resilient and intelligent security framework with AI driven anomaly detection using blockchain technologies. For example, with artificial intelligence (AI), utilizing machine learning, you can get models capable of analyzing real time traffic of device behavior, detecting the anomalies (suspicious activity) and that way handle these threats almost as they happen. In addition, Blockchain provides secure and tamperproof shared ledger for data sharing, authentication, and audit trail across IoT networks.

Ajeigbe, K., et al (2021). Push of the IoT revolution will lead to the emergence technology of chatbot as a very important interacting facet of the IoT ecosystem. However, it is occurring with the development for the smart environments, from where one will be presented an easy interface to run these smart environments from the homes, offices, and the industrial systems through the natural language interface and the context aware and AI driven Chatbots. Chatbots integrated within the IoT Platforms now make it possible to control our devices, read their Realtime status updating along with triggering our proactive notifications through the power of voice and text at our fingertips. Besides all this, we expect the course of this device to use features like Natural Language Processing (NLP), emotions recognition, etc. — artificial intelligence if personalized (athlete's personal data) will be used for the complete human experience and virtually unlimited adaptability of the device. As such, this also serves a basis for edge AI federated learning, and construct a decentralized IoT network that will be able to deliver low latency, privacy preserving chatbot functionalities. Multimodal interactions (such as voice, visuals and gestures) will also improve user engagement. Moreover, with progressing chatbot technologies, chatbots have still not figured as a vital component of human IoT interactions with the aim of promoting automation and democratization of access to, as well as increase efficiency, in applications related to smart homes, healthcare, retail and industrial operation.

Mohtashami, N., et al (2014). The rapid progress of Europe in the smart building solutions area should be owed to technological innovation and the strong sustainability agenda. Comparative terms are in use to analyze that at the beginning smart building management systems are being used by countries like Germany, the Netherlands, and the Nordic countries to allow for the usage of IoT sensors, AI based energy optimization, and even renewable energy along with already existing building systems. In terms of where the technological advancements are at, they are around automation, associated with Efficiency, predictive maintenance, associated with Operation, occupant centered design, associated with User experience, and these all improve both the operational efficiency and user experience. Nordic countries emphasizes sustainability oriented architecture, the adapt schemes of climate, while Germany concentrates on smart grid integration, energy efficient retrofitting. Market strategy of public –private partnerships and government incentives is implemented at Western Europe, while Southern Europe is beginning to implement still EU funded initiatives and urban smart city projects.

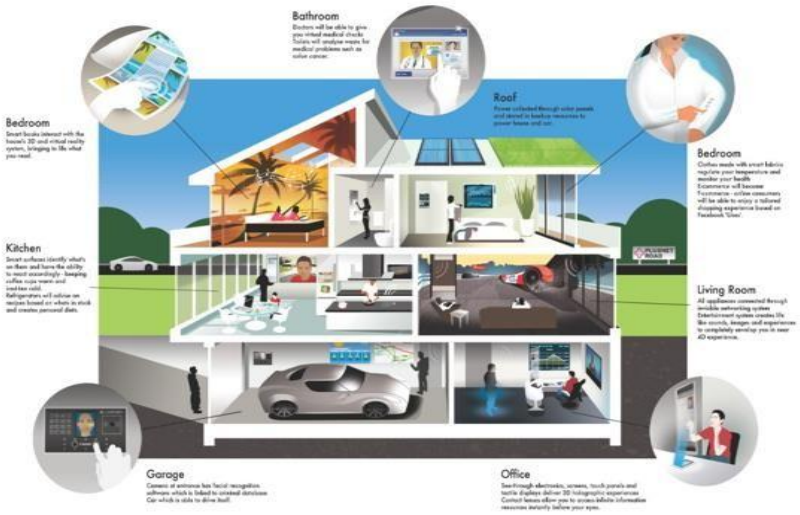
Motivation for Adopting Intelligent Systems in Home Energy Management

A combination of environmental, economic, technological and social factors combine to motivate introduction of intelligent systems into home energy management as an urgently needed more sustainable and efficient way of consuming energy. However, the existing traditional home energy management does not have the functions of real time control, adaptability, and optimization and thus, considerable energy waste, higher utility bill, and notable contribution to carbon emissions on the building energy systems associated with the homes. Proactively, in first instance, the intelligent systems, thanks to Artificial Intelligence (AI) and Internet of Things (IoT), with available sensory, make the house smart enough to itsself—know, be aware of the context, and be reactive to the internal and external conditions. These systems make it possible to teach the system user behavior to detect and learn consumption patterns and automatically behave from a savings point of view without continuously imposing it manually. As the cost of energy rises and the environmental problems increase, this is where we need to adopt an intelligent management given that. Intelligent systems however, seem to be a pragmatic and an efficient path for households to be able to reduce their carbon footprint while at the same,

providing comfort and convenience. In addition, more affordable smart devices, cloud computing and high speed internet also make the systems more accessible. Additionally, by providing incentives, rebates and favorable regulatory frameworks, government and utility companies are encouraging the use of such energy efficient technologies.

Need for AI-Driven IoT in Smart Homes

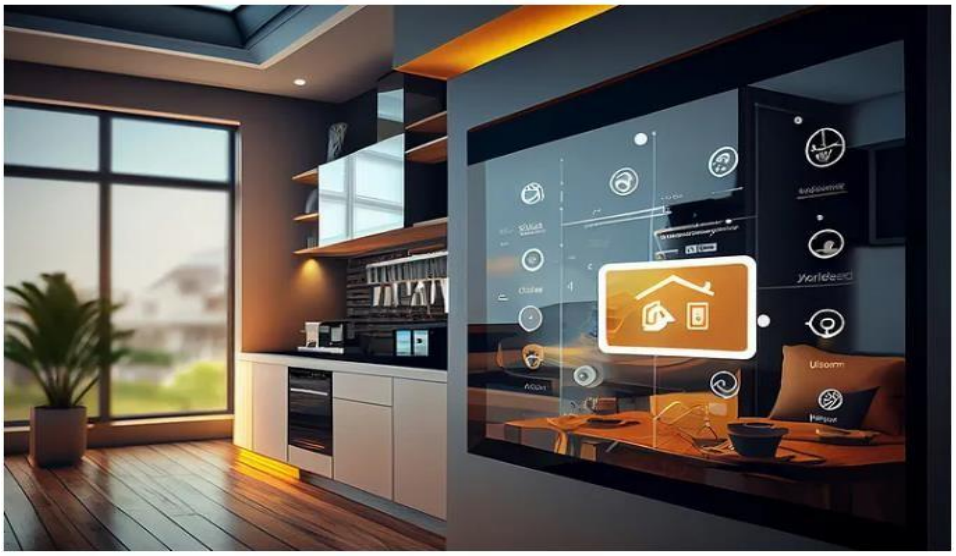
By putting the traditional systems far from what was demanded for smart efficient living environment, this clearly requires to be evolved to the dynamic and data rich smart homes. Most of the conventional systems are designed based on static schedules with user defined controls but do not adapt to the variations in a real time manner that occurs in the daily usage patterns of the system, environmental conditions or occupant behavior. They do not have intelligence to search and process historical data, forecast energy demand and behave proactively with relation to external factors such as weather change or peak loads times. All of these consume more energy, increase utility bills and cause discomfort to the user. For where real time decision making without automating is concerned, the challenge is amp up significantly, but for the traditional systems not to be able to cover this is not possible. Consequently, this is an inefficient process (themselves, turning off devices, etc.) and a nuisance. Exactly where AI driven IoT system fits in, is in filling the gap between connectivity and the intelligence. Collecting and transmitting data by an IoT ensures making the system intelligent by saying data transmission is just an aid of making the system intelligent but only with the help of AI.



These AI algorithms can predict the user's energy demand and then alter some home energy systems if it signs that a user uses the system appropriately. For instance, if it is known that the house is usually empty, AI will automatically schedule reducing the heating or cooling, or even based on the down time of solar production, reduce the machine use. This serves as the basis of predictive capabilities of these IoT devices and is the reason of their becoming context aware and self-optimizing which significantly improve the efficiency of these devices. Anomalies can be detected, energy inefficiencies identified, and even personalized recommendations can be made to a user by AI. By scaling collectively AI &IoT, they can synergistically provide virtually zero intervention of human beings inside homes to save energy, provide comfort and promote sustainability. With this synergism, this future then opens up to residential living that is smarter, greener and more autonomous, through overcoming deficiencies of conventional energy management.

Role of Smart Homes in Achieving Energy-Neutral or Energy-Positive Living

Smart homes, which play a crucial role in residential sustainable development, are transforming their way of living to become speedily energetically neutral if not energetically positive, due to their pursuit of energy neutral and energy positive living. An energy neutral home is a home that produces enough energy only from onsite renewable energy sources (such as solar and wind power) to supply during a period of time (ie. month or year) the energy demand of that home. Then again, an energy positive home takes this one step further, deriving more energy than it consumes and stowing or channeling any redundant energy into the grid. Of course, renewable energy generation is the order one to be fulfilled but the other things cannot be done with Renewable Energy only, we need an intelligent energy management and here, having smart home technologies, can help.



Among them, AI driven IoT systems help the smart homes to monitor, analyze, and optimize the usage of energy in real time. Learning based on user behaviour, environmental inputs and the pattern of energy these create so as to minimize waste and to exploit efficiency, these form the basis of these systems. For example, in a smart home, scheduling of some tasks (e.g., when appliance is operated) are planned to be done during times when there is a low demand from grid and solar generation is high to prevent the appliances to operate with external power sources. However, it can forecast future energy requirements and adjust the system settings almost automatically to work at the best performance. Similarly, smart energy storage solutions connected with home energy systems also help in dealing with excess renewable energy for usage later and avoid energy positive status seeping in. As these smart meters and grid connected devices enable the home to become a dynamic interaction with the larger energy infrastructure, this interaction along with demand response programs can become a dynamic interaction between the home and the energy infrastructure and respond on demand as part of GRIDS stability. Such capabilities support their lowering of the carbon footprint as well as their energy bill while contributing to a significant sustainability scheme; the decarbonization of energy production and reducing stocks of fossil fuels. With the development of technology, the smart home systems become cheaper, more accessible and energy friendly that endows the energy neutral and positive living with more practicality towards a larger mass of people. Put simply, smart homes are the foundations of a world tomorrow where inhabitants in a home will assume a part in energy maintainability as energy self sustaining hubs while developing what should keep on being their residential areas into shrewd residential areas that guide in satisfying worldwide natural objectives.

Key Features of AI and IoT in Smart Homes

The convergence of AI and IoT has enabled a new generation of smart homes, offering greater control, comfort, and energy efficiency. Some of the core features include:

- **Personalized Automation**: AI learns user behavior to create personalized schedules. For instance, smart thermostats adjust temperatures based on daily routines without manual input.
- **Enhanced Security**: AI-powered cameras and sensors detect unusual activity and send instant alerts. IoT enables remote monitoring, providing 24/7 home security from anywhere.
- **Energy Efficiency**: IoT devices can automatically power down inactive appliances, optimizing resource usage and minimizing energy waste.
- **Voice and Gesture Control**: Natural Language Processing (NLP) supports seamless interaction through platforms like Amazon Alexa and Google Assistant, enabling hands-free control over smart devices.

Smart Home Architecture

The architecture of smart homes powered by AI and IoT consists of multiple layers:

Device Layer

- Comprises IoT-enabled fixed appliances such as smart thermostats, lights, sensors, and cameras.
- Includes edge devices for real-time data processing at the network edge.

Network Layer

- Utilizes wireless technologies such as Wi-Fi, Zigbee, Bluetooth, and WLAN for data communication.
- Ensures secure data transmission channels and network access control.

Cloud Layer

- Hosts cloud servers for data storage, analytics, and training AI models.

- Powers intelligent decision-making and remote processing for smart automation.

Application Layer
- Delivers mobile and web applications for user interaction and remote control.
- Integrates with third-party services such as weather updates and energy providers for enhanced automation.

Understanding the Internet of Things (IoT)
IoT refers to a network of interconnected devices capable of collecting and exchanging data. When integrated with AI, IoT systems become intelligent, autonomous, and predictive—opening doors to numerous possibilities in home automation and beyond.

Benefits of AI in IoT
1. Improved Efficiency
AI automates repetitive tasks, enhancing operational efficiency. In homes, it optimizes energy usage by learning and adapting to user habits.

2. Enhanced Decision-Making
AI processes large volumes of data from IoT devices to generate actionable insights. In healthcare or agriculture, it can predict problems before they occur, enabling proactive solutions.

3. Increased Safety and Security
AI monitors patterns in real time to detect anomalies, ensuring safety in homes, industrial sites, and cities. It can also analyze cybersecurity threats and prevent breaches.

4. Personalization
AI customizes experiences based on individual user data. Whether in retail or healthcare, users benefit from personalized recommendations and services.

Challenges in Integrating AI with IoT
Despite its potential, integrating AI with IoT presents notable challenges:
1. Data Management
IoT generates massive datasets that AI systems rely on for training. Efficient storage, processing, and accessibility of this data are essential.
2. Security
IoT devices are prone to vulnerabilities, especially in unsecured environments. AI systems must be safeguarded against cyberattacks to maintain data integrity and trust.

3. Interoperability
Different manufacturers often use incompatible standards. Lack of interoperability hampers data sharing and limits AI's effectiveness.

4. Power Consumption
IoT devices often run on limited power. AI's computational demands require energy-efficient models that can function on low-power devices.

5. Cost
Implementing AI with IoT can be expensive, especially for smaller enterprises. Hardware, software, and security investments contribute to high upfront costs.
Smart home experience powered with AI and IoT both allows a smart home to be smart, secure and efficient. The chances of saving and tapping power from automation, saving energy and personalization are enormous, but the challenges, and we have a lot, to overcome are the same: secure data management, costs, security etc. By constantly developing the synergy of AI and IoT, the automation home revolution will be enabled, and other industries too, towards its smarter, safer and more sustainable world route.

Applications of AI and IoT in Home Automation
Now, Artificial Intelligence (AI) and the Internet of things (IoT) are successfully knitted into home automation and it's a great section of Home Automation that contributes a lot to make our living spaces smarter, safer and energy efficient. These technologies co operate to support real time data processing, making intelligent decisions and supplying the personal control in different spheres of home life. So, below I have listed some of the important applications that are changing the way of building modern home.:

Smart Lighting
The AI powered lighting systems match the individual's habit, occupancy and ambient lighting setting. On these routines and which can be controlled remotely from your voice or even your mobile app can automate the routines such as turning

on and off lights at a particular time or even dim the light. For example, the Philips Hue on hand allows the users to adjust the brightness and choose the color to use accordingly depending on a certain mood or activity.

Energy Management
The intelligent energy systems minimize the consumption and maximize the performance of appliances by using the consumption patterns. While each smart thermostat differs from the other, Nest and Ecobee learn routines to automatically set the heating and cooling according to your routines. Smart plugs and power strips also kill idle standby power loss.

Home Security
One of the uses of AI enhanced security systems is the real time surveillance with facial recognition and motion detection. Devices from brand like Ring and Arlo can instant tell between people, animals and objects to lower false alarms and sends you an alert to your smartphone.

Voice Assistants
AI voice assistants like Amazon Alexa, Google Assistant, and Apple Siri serve as central control hubs in smart homes. With their help users can manage their devices, look up the information they need or enjoy media, while without moving their hands they can even automate several tasks using simple voice command.

Smart Appliances
The most known technological use cases of AI and IoT are in smart appliances. Inventory is monitored by smart refrigerators that suggest recipes ovens adjust cooking to match the type of food and have the dishwashers or washing machines 'optimizing' the cycles for efficiency and notifying the users when something needs repair.

Health and Wellness
Health status, sleep, activity and air quality are measured in health devices based on AI. All of them are gigabyte machines, health physical machines that are equipped to look after your physical health and provide fitness wearables, smart mattress, sleep tracker and glass to you. Contaminants that air quality monitors detect, the purifiers automatically adjust to.

Benefits of AI and IoT Integration in Smart Homes
Convenience
Automated solutions allow users to save time and effort by taking care of day to day routines for them such as lighting, home control through speaking, apps, or scheduling the control of their home environment.

Energy Efficiency
AI learns user's behaviors and adjusts the settings for the optimal energy consumption, therefore this reduces utility expenses and lowers environmental effect.

Enhanced Security
Effective monitoring and timely alerts occur on the real time basis, which reduce falsification of alarms and quick response to threats.

Personalization
The home will be tailored to include lighting, temperature and entertainment according to individual preferences that it learns with regards to learning habits and preferences so that the home is a more comfortable place.

Health and Well-being
They help you live life the way you were supposed to without health complicacies and the packages of a secure home atmosphere.

AI-Driven Energy Management in Smart Homes
AI has enabled better energy management in smart homes through consumption of optimized and conserved energy. Homeowners using artificial intelligence can improve energy efficiency, reduce utility bills and make a difference in environmental sustainability for a more comfortable house while lower costs and being more convenient and smarter.

Smart Energy Consumption
- In many cases, they can use this knowledge to adjust intelligently so that they consume as little of it as they can. The smart thermostats can thus measure the occupancy patterns to heat up/buy as per when the space needs to be heated and cooled down/bought as per when the space needs to be cooled, hence, the comfort given in the space should only be given for the most required one.
- **Adaptive Thermostats** like Nest adjust temperature settings based on daily routines to reduce unnecessary energy use.
- **Smart Lighting** systems detect natural light levels and room occupancy to automatically dim or switch off lights, maximizing efficiency.

Integration with Renewable Energy Sources

- Integration of renewable energy sources, e.g. solar panels, are greatly improved as AI manages and, in a way, predicts how the energy flows.
- **Energy Forecasting** It uses weather and consumption data to predict solar energy production, so that it can tell homeowners whether to use the stored energy or the grid.
- **Battery Management** The systems use AI fueled type of energy storage and charge/discharge optimization to store and use the energy at the time of peak demand more efficiently.

Smart Grids and Energy Distribution

- Smart grids rely on AI as it helps adjusting the energy distribution in real time and help preserving the proper balance of the power supply and demand between connected homes.
- **Demand Response** However, electricity costs are lowered and grid overload is prevented as systems reduce load during peak times.
- **Grid Optimization** The algorithms forecast energy needs, which helps utilities to distribute their resources better and enhance system stability in general.
- **Economic and Environmental Impact**

AI-driven energy systems contribute to both economic progress and environmental protection.

- **Job Creation** But we grow in these AI and green energy sectors that enhance innovation and that give an open door for economic opportunity.
- **Sustainability Goals** It helps reduce carbon emissions, improve energy efficiency and stays with the global climate goals..

Obviously, smart homes are a technological leap towards building a smarter and environmentally friendly future and, additionally, this is the way AI equipped energy streamlining is heading to the following level. Using AI's predictive intelligence and with the renewable energy, homeowners can be proactive in what they consume in energy and save a lot in the costs, and participate in the mission of having a sustainable planet.

Methodology

The proposed methodology for study is by design and evaluation of an AI intelligent IoT framework that minimizes the energy consumption of a smart home as a whole. Combining Convolutional Neural Networks (CNNs) with network of IoT sensors and devices is proposed to use for real time data acquisition, intelligent analysis and automated control of energy. The first part sees smart meters and environmental sensors installed for the purpose of measuring electricity usage, temperature, occupancy and appliance activity. The data is sent to a central processing unit and training the CNN model to learn to pick up pattern and predict future trends and also to make control decisions on the fly. Predictive accuracy is used in evaluation of model performance by using performance metrics such as RMSE, MAE and MAPE. Moreover, performance of this method is also compared relatively with SVM, ELM, and ARIMA methods and benchmarked in terms of accuracy, execution time, and scalability. Also, the real time capabilities are validated by subjecting them to system responsiveness test under various loads on device. User feedback is incorporated using a satisfaction survey and a manual tracking of adjustment. In general, the methodology, which reviles the entire methodology with which the proposed the framework is assessed comprehensively and how AI alongside IoT could make such a setting really clever, adaptable, and vitality productive while keeping up the specialized accomplishment in addition to the client encounter, is featured.

Results and Discussion

Table 1: User Comfort Level with Smart Automation

Automation Type	**User Satisfaction (%)**	**Manual Adjustments/day**
Basic Scheduling	70 %	5
Rule-Based Automation	82 %	3
AI-Driven (CNN-IoT)	**93 %**	**1**

A comparative analysis of user comfort levels between the three approaches namely Basic Scheduling, Rule-Based Automation, and AI-Driven (CNN-IoT) Automation is shown in Table 1. Two key measurements of interest – User Satisfaction (%) and Manual Adjustments per Day – are directly observed from the table and can be used to evaluate the efficiency and ease of use of each system. Simple Scheduling, based on fixed time controlled applications, gives the lowest user satisfaction at 70% with frequent manual interventions (5 interventions/day), hence it does not appear to be very adaptable. Rule Based Automation provides 82% of the user comfort and has 3 less adjustments per day because it only adjusts the system if a known condition is met. However, the AI-Driven CNN-IoT system demonstrates the highest user satisfaction of 93%, with only one manual adjustment per day, illustrating its intelligent responsiveness, self learning ability and inferring the least user burden. Incorporating AI within smart home systems leads to a substantial improvement in the automation quality and user experience of the system as the system becomes more personal, efficient and hands-free as evident through the results of this thesis.

Table 2: Performance Analysis Comparison of Processing Time with Existing Framework

Method	RMSE	Execution Time (sec)
SVM	9.28	58.35
ELM	23.40	27.69
LSTM	5.27	29.35
Proposed CNN-based IoT	**0.08**	**1.50**

The performance comparison of different machine learning models such as SVM, ELM, LSTM and the proposed CNN based IoT framework is carried out on the basis of Root Mean Square Error (RMSE) and Execution Time as tabulated in Table 2. RMSE shows the prediction accuracy and the execution time conveys the computational efficiency. Of the traditional methods, SVM and ELM perform badly with high RMSE values of 9.28 and 23.40, and long processing time, especially for SVM (58.35 seconds). While LSTM is more accurate on RMSE at 5.27, it takes 29.35 seconds to execute. Compared to it, the proposed CNN based IoT model attains an extremely low RMSE of 0.08, therefore having a near perfect level of prediction accuracy, and processes data in just 1.50 seconds, which is also computationally fast. The results of this study show that the CNN-IoT framework is the superior solution to use in real time smart home energy management applications where that speed and exactness are key factors to ensure the optimal performance of the system.

Table 3: Performance Assessment of Proposed Framework

Metric	Value
MAE	2.3 kWh
RMSE	3.1 kWh
MAPE	4.20 %

The evaluation of the proposed CNN-IoT-based framework is provided from a quantitative perspective using three standard performance measures, namely Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE) on Table 3. These metric together measure the prediction accuracy of the model in predicting the energy consumption of smart home. An MAE of 2.3 kWh evidenced that the prediction was off by only 2.3 kWh from the actual values, showing good predictability. Minuscule deviations are further confirmed with an RMSE of 3.1 kWh which slight higher due to squaring of errors. Furthermore, with a result of MAPE of 4.20%, the prediction accuracy is quite good, because this value is well within the limits of acceptability for energy forecasting systems. Collectively, these low error rates demonstrate the efficacy of the proposed AI driven framework in offering energy optimization with high accuracy and real time accuracy, which can be deployed in the real world smart home scenarios to curtail the energy waste as well as to facilitate the sustainability.

Table 4: Performance Comparison with Traditional Methods

Metrics	Machine Learning Methods	ARIMA	Proposed CNN-IoT-based Framework
Accuracy	80 %	85 %	**88 %**
Precision	0.85	0.90	**0.92**
Recall	0.80	0.82	**0.85**
F1-Score	0.82	0.86	**0.88**

In Table 4, we compare the proposed CNN-IoT based framework classification performance with other three techniques, namely traditional Machine Learning methods, ARIMA (Auto-Regressive Integrated Moving Average), using four major metrics for evaluation, namely, Accuracy, Precision, Recall, and F1 score. These metrics offer an inclusive understanding of which model performs better in terms of its capability to make accurate energy prediction as well as classification tasks. This performance is moderate compared to traditional machine learning methods with 80% accuracy and an F1-score of 0.82 demonstrating a balance in performance but not real effectiveness. With slight better accuracy and F1-score of 0.85 and 0.86 respectively, ARIMA is also better suited to time series forecasting. Nevertheless, we outperform both with the Proposed CNN IoT framework as it gets an accuracy of 88%, precision of 0.92, recall of 0.85, and a better F1 score of 0.88. These results show that the presented model gains substantially in predictive power, consistency and adaptability, which is of use primarily for smart home environments where both real time performance and high accuracy are vital for the usage of energy optimization and intelligent automation.

Conclusion

An important step towards the improvement of energy efficiency smart homes setting is the combining of Artificial Intelligence (AI) technology with the Internet of Things (IoT). Hence, the results from this study have proved that AI driven IoT systems are capable of bringing excellent improvement in prediction accuracy, automation, and real time response more to traditional energy management methods. The framework collects the real time data of the IoT devices connected and thereafter it analyzes them thoroughly and takes the decision that analyzes them automatically to reduce energy waste without disturbing user from comfort using a CNN IoT. The accuracy of the framework is validated by the metrics, such as RMSE, MAE, and MAPE which are used to measure the performance of the framework and comparing it with the conventional models, such as SV, ELM, and ARIMA, show its superiority in terms of accuracy and processing

speed. The system is also scalable and the response times and the system load are independent of the number of connected devices. Moreover, the user satisfaction metrics confirm the practicality of the proposed approach that requires little manual intervention and provides high comfort level. Therefore the system can continue to use energy sustainably and cost effectively with respect to dynamic environmental and behavioral patterns. In the process of improving smart home technologies, AI-enabled IoT solutions will play more and more important roles in overcoming the global energy challenges. Beyond providing information on intelligent energy systems, this work contributes a reliable, efficient and user centric framework that can be applied in real world. More future work can be conducted to incorporate other AI methods, such as federated learning and multi agent systems that increases adaptability, security and performance. All in all, AI driven IoT frameworks can be placed among the crucial steps towards energy neutral and possibly even energy positive residences, meaning they contribute to both an individual level of comfort and, on the global level, to the wellbeing.

References

1. Rehman, A. U., Tito, S. R., Ahmed, D., Nieuwoudt, P., Lie, T. T., & Vallès, B. (2020, September). An artificial intelligence-driven smart home towards energy efficiency: an overview and conceptual model. In *2020 FORTEI-International Conference on Electrical Engineering (FORTEI-ICEE)* (pp. 47-52). IEEE.
2. Farzaneh, H., Malehmirchegini, L., Bejan, A., Afolabi, T., Mulumba, A., & Daka, P. P. (2021). Artificial intelligence evolution in smart buildings for energy efficiency. *Applied Sciences*, *11*(2), 763.
3. Mahmud, U. P. A. L., Alam, K. H. O. R. S. H. E. D., Mostakim, M. A., & Khan, M. S. I. (2018). AI-driven micro solar power grid systems for remote communities: Enhancing renewable energy efficiency and reducing carbon emissions. *Distributed Learning and Broad Applications in Scientific Research*, *4*.
4. Mohammed, I. A. (2012). An Exploratory Study on IoT-based Smart Technologies and Ongoing Research Trends. *International Journal of Current Science (IJCSPUB) www. ijcspub. org, ISSN*, 2250-1770.
5. Fontaine, C. (2020). Cloud-Integrated IoT Architecture for Smart Home Automation: A Scalable Approach Using AWS Services and Edge Computing. *International Journal of Artificial Intelligence, Data Science, and Machine Learning*, *1*(3), 1-7.
6. Waleed, Q., & Javaid, T. (2021). Securing IoT Ecosystems with AI-Driven Anomaly Detection and Blockchain Technology.
7. Ajeigbe, K., & Simmons, E. (2021). Future Trends: The Evolution of Chatbot Technologies in IoT Ecosystems.
8. Mohtashami, N., Sauer, N., Streblow, R., & Müller, D. (2014). *Comparative Analysis of Smart Building Solutions in Europe: Technological Advancements and Market Strategies. Energies 2025, 18, 682*. Build. Environ.
9. Khan, M., Seo, J., & Kim, D. (2020). Towards energy efficient home automation: a deep learning approach. *Sensors*, *20*(24), 7187.
10. Kommineni, H. P. (2019). Cognitive Edge Computing: Machine Learning Strategies for IoT Data Management. *Asian Journal of Applied Science and Engineering*, *8*(1), 97-108.
11. Anny, D. (2021). Energy-Efficient AI Architectures for Sustainable Computing.
12. Agee, P., Gao, X., Paige, F., McCoy, A., & Kleiner, B. (2021). A human-centred approach to smart housing. *Building research & information*, *49*(1), 84-99.
13. Saad al-sumaiti, A., Ahmed, M. H., & Salama, M. M. (2014). Smart home activities: A literature review. *Electric Power Components and Systems*, *42*(3-4), 294-305.
14. Majumder, S., Aghayi, E., Noferesti, M., Memarzadeh-Tehran, H., Mondal, T., Pang, Z., & Deen, M. J. (2017). Smart homes for elderly healthcare—Recent advances and research challenges. *Sensors*, *17*(11), 2496.
15. Aheleroff, S., Xu, X., Lu, Y., Aristizabal, M., Velásquez, J. P., Joa, B., & Valencia, Y. (2020). IoT-enabled smart appliances under industry 4.0: A case study. *Advanced engineering informatics*, *43*, 101043.
16. Yuan, X., Han, P., Duan, Y., Alden, R. E., Rallabandi, V., & Ionel, D. M. (2020). Residential electrical load monitoring and modeling–state of the art and future trends for smart homes and grids. *Electric Power Components and Systems*, *48*(11), 1125-1143.
17. Gram-Hanssen, K., & Georg, S. (2018). Energy performance gaps: promises, people, practices. *Building Research & Information*, *46*(1), 1-9.
18. Jain, N. (2021). Sustainable energy management in smart homes: A review of current technologies and practices. International Journal of Emerging Technologies and Innovative Research, 8(11), e20–e32. http://www.jetir.org/papers/JETIR2111404.pdf
19. Chau, M. Q., Nguyen, X. P., Huynh, T. T., Chu, V. D., Le, T. H., Nguyen, T. P., & Nguyen, D. T. (2021). Prospects of application of IoT-based advanced technologies in remanufacturing process towards sustainable development and energy-efficient use. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1-25.
20. Saleem, G., & Badi, S. (2021). AI-Powered IoT Security: Building Smart, Adaptive Cyber Defense Systems.
21. Maalsen, S. (2020). Revising the smart home as assemblage. *Housing Studies*, *35*(9), 1534-1549.