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Research Article

Secure Cloud Computing based Energy Analytics Framework in Construction of Residential Buildings

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ABSTRACT

The buildings are emanating a massive producer of data amidst being massive consumers of energy resources. Electrification of a region is seen as a breakthrough in fostering the economic development of the region. However, rapid urbanization has paved the way for the construction of huge buildings which is home to a large amount of population, which directly or indirectly contributes to energy consumption. Energy analytics is a form of energy conservation, especially in residential buildings, which is generally harnessed through cutting-edge computing technologies. This work proposed a comprehensive framework with five layers that collects data from the energy monitoring edge devices to build energy analytics by processing the data in the cloud platform. In addition to this, the framework uses a security score to monitor the illegitimate access of the cloud source by tracking the registered devices. This is a robust and generic framework that has the scope to include AI-based strategies that can be orchestrated in the cloud computing platform.

Keywords: Cloud Computing, Security Score, Residential Buildings, Household Appliances, Urbanization, Energy Analytics

INTRODUCTION

The construction of urban systems comprises many multi-level dynamic units that act as integral parts of the community. These units are responsible for the smooth functioning of society as they are governed by political frameworks [1]. The foundations of these interconnected units are efficiency, flexibility, and sustainability, which ensure the smooth operation of the urban environment. The population explosion fastens the pace of urbanization, which leads to the design, planning, and construction of smart cities with massive residential as well as commercial buildings [2]. Information and Communication Technologies (ICT) and contemporary computing techniques such as Cloud Computing (CC), Artificial Intelligence (AI), and the Internet of Things (IoT) have further accelerated the growth of urbanization [3]. It is evident that the constructions mostly rely upon energy and power sources. They form the pedestal on which modern life is built. Energy becomes a highly indispensable element for the smooth functioning of vital urban elements. The relationship between energy, urbanization, and population is shown in Figure 1. China, the most populous country in the world, shows an inclining trend in its GDP and Energy consumption, which is shown in Figure 1.

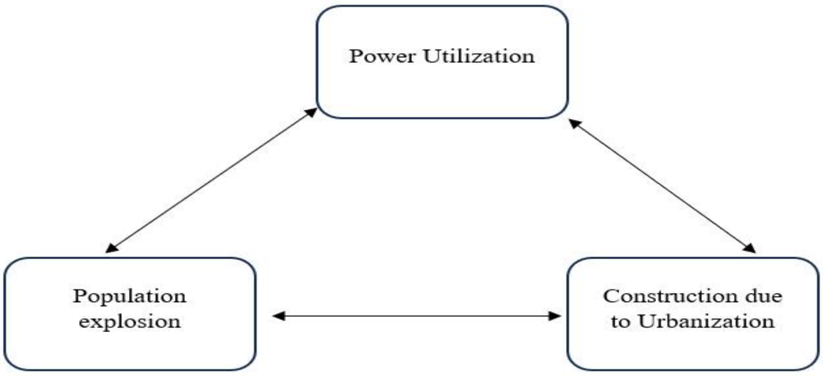

Figure 1. Triad Showing the Relation between Power, Urbanisation, and Population Explosion

The influence of specific types of energy resources, their availability, and utilization patterns is a subject of deeper analysis, especially in urban areas [4]. To ensure a balance between stability and energy efficiency, the world has transformed into a collective intelligent infrastructure, which led to the development of smart cities. Smart cities have a stable urban energy system that leverages an intelligent and smart technological framework [5]. The primary objective of this construction is energy savings that will be more productive, sustainable, and comfortable [6], [7].

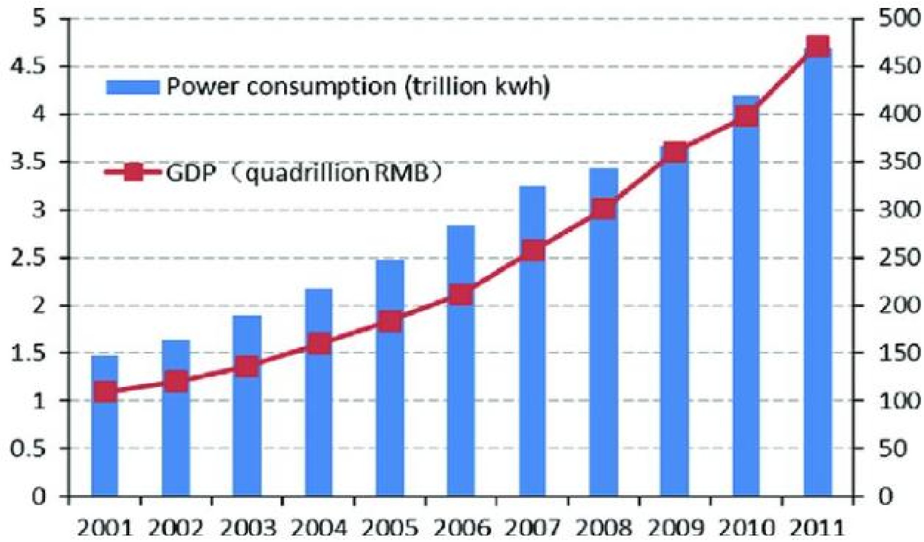

Figure 2. Growth in Power Consumption and GDP of China

LITERATURE REVIEW

The pivotal focus of smart cities depends on various factors, as shown in Figure 3. The rampant increase in urbanization, population, and internet-enabled devices has led to a tremendous demand for energy. Due to this fact, the cities, things, and even buildings are becoming receptors as well as generators of massive data, which is hard to tap, leverage, control, and analyze. The International Data Corporation (IDC) states that by the year 2025, the total amount of data generated will escalate to 175 ZB [8]. According to the European Union (EU), buildings account for nearly 40% of the total energy consumption. Hence, the construction sector must focus on enforcing effective climate policy that mitigates energy usage.

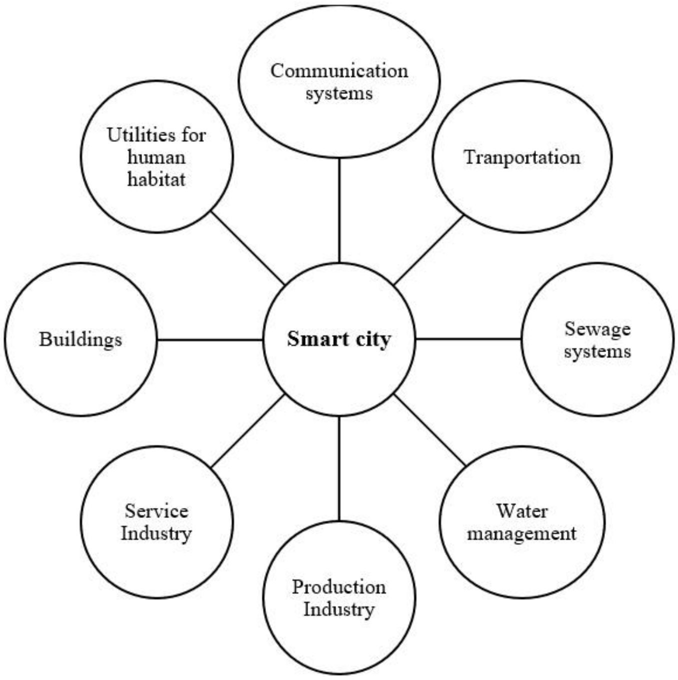

Figure 3. Focal Elements of Smart Cities

Energy consumption and energy monitoring in buildings are two major focal areas for fostering energy management in all types of buildings. In this perspective, technologies like CC and IoT emanate as an essential tools. However, leveraging these technologies poses numerous challenges like scalability, high acquisition costs, interoperability issues, etc [9]. The building sector is a major consumer of the produced energy, which is now undergoing a transition due to the new energy-saving policies implemented to promote low-energy consumption buildings known as net Zero-Energy Buildings (ZEB) [10]. ZEBs are designed in such a way that they consume as little energy as possible. It should also house a renewable source of energy that produces sufficient energy to meet the energy demands of the building. The International Energy Agency has published a report [11] that shows that digitizing buildings can cut energy use by 10% through real-time data, which fosters operational efficiency.

The energy performance in buildings relies on factors like exposure, insulation level, climate facilities performance, etc. To support the cause, the European Commission has delineated the Energy Performance of Buildings Directive (EPBD), which is a compilation of generic principles to augment the energy efficiency measures within residential as well as nonresidential buildings [12]. This enforces the implementation of energy performance certification for already existing buildings, thermal and insulation, space management, hot water heating, examination of heating and cooling devices, and ventilation, apart from legally imposing the performance requirements for the newly constructed and renovated buildings in alignment with the indoor climatic conditions [13]. Energy consumption by common utilities used in residential buildings is given in Figure 4. Though there is a 5increase in energy production, there is still a deficiency in the power supply.

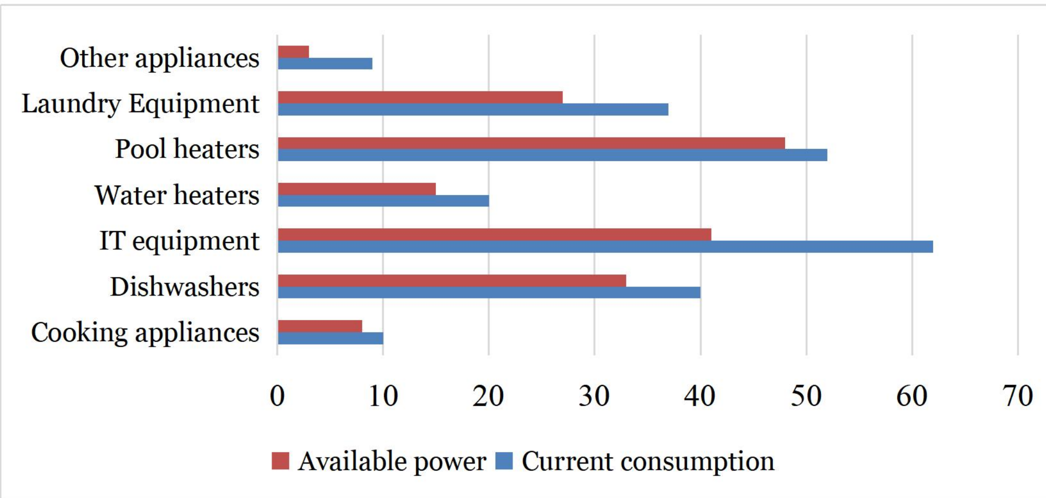

Figure 4. Energy Consumption by Various Residential Devices

The Buildings Value Chain (BVC) should integrate a comprehensive energy transition scheme to guarantee resilience as well as sustainability within the building's life cycle. The energy that is consumed by these buildings is generated locally. As buildings demand more energy, there is a need to adopt cutting-edge ICT to build smart landscapes [14]. They also generate large amounts of energy-related data, which are sourced from individual devices and may be in the range of thousands of TB [15], [16]. The next generation of building energy management systems has to process large voluminous amounts of heterogeneous data, which may be generated in real-time or maintained as historical data to derive useful information to aid in decision-making [17]. These trends are combined with energy analytics and CC, which act as catalysts in conceptualizing and realizing many innovative applications as well as energy-saving services for efficient energy management. It is now quintessential to devise an energy analytic framework for residential buildings by leveraging cutting-edge computing technologies.

Energy Efficiency in Residential Buildings

Energy-efficient buildings are the need of the hour. Investments in energy-efficient practices are much lesser when compared to capital investments for the supply side in the long run [18], [19]. Also, incorporating energy efficiency strategies has much lower lead times than the supply investments. Hence, by establishing energy efficiency targets for residential buildings, a great amount of power can be saved, which will be beneficial to the governments. Table 1 shows the average power consumed by various household appliances.

Table 1. Power Consumption Range of Various Household Appliances

Category	Appliance	Power Consumption Range (Watts)
Lighting	Incandescent lamps	60-100
	Fluorescent lamps	9-18
	Compact fluorescent	3-85
Kitchen Equipment	Cooker	450-1500
	Water dispenser	500-670
	Blender	250-700
	Refrigerator	225 (Average)
	Freezer	277-386
	Toaster	700-1300
	Coffee maker	700-1300
	Microwave oven	600-1550
	Electric kettle	800-3000
Laundry & Beauty	Washing Machine	200-460
	Hair dryer	800-2200
	Vacuum cleaner	700-2300
	Water heater	1500-5000
	Pressing machine	800-2400
Entertainment	Mobile phone	2-4
	Television	70-339
	Personal Computer	80-120
	Laptop	60-250
Cooling	Air conditioner	845-12,500
	Fan	47-140
	Room heater	1500 erage)

The reduction in energy consumption in residential buildings also helps in improving the QoS in the building. Figure 5 shows various energy-saving deployments in homes. The potential benefits of the energy minimization are enumerated below:

Reduced space heating, cooling, and water heating

Decreased electricity usage for lighting, domestic type, and office machinery

Lower maintenance

Enhanced comfort

Improvement in property value

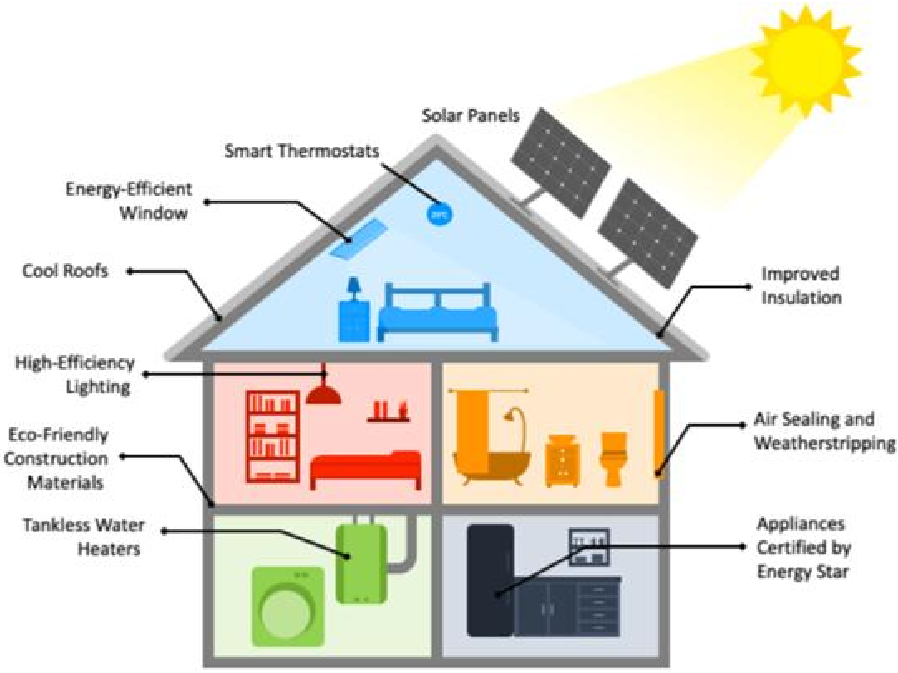

Figure 5. Energy Saving Options in Residential Buildings

Energy Analytics in Residential Buildings

Quantifying the energy usage and its savings through proper analytics will help to know the current status quo of the residential buildings. Implementation of energy-efficient strategies or systems facilitates the recording of various types of data from heterogeneous data sources. Figure 6 shows the major data that is commonly recorded in the context of energy consumption.

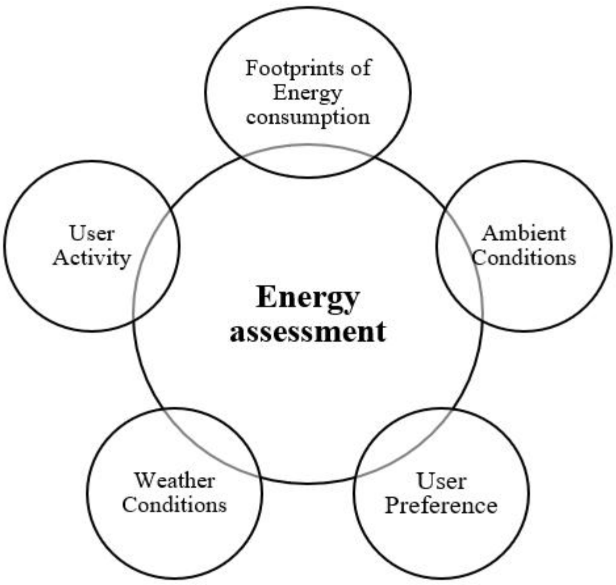

Figure 6. Energy Assessment and Analytics

The energy consumption footprints are aggregated wither from specific buildings either cumulatively or at the appliance level [20], [21], [22]. Also, the indoor ambiance plays a major role in lighting. This data that could be recorded from here includes temperature, CO2 emissions, humidity, and luminosity [23]. Outdoor weather is either collected from online sources or meteorological data to adopt proper energy-saving systems. The common forms of data recorded are humidity, temperature, wind speed, wind direction, solar radiation, etc. [24]. All the energy-saving schemes will become meaningless if the user activity is not regulated. Sensors are deployed to monitor physical activity like occupancy, switching on and off electrical appliances, adjusting the thermostat, windows openings, etc. [25], [26]. User preferences are also important driving factors in developing an effective energy-efficiency solution with user preferences, habits, and comfort. Figure 7 shows the energy usage in residential buildings in China according to [27] the Intergovernmental Panel on Climate Change (IPCC), 2007.

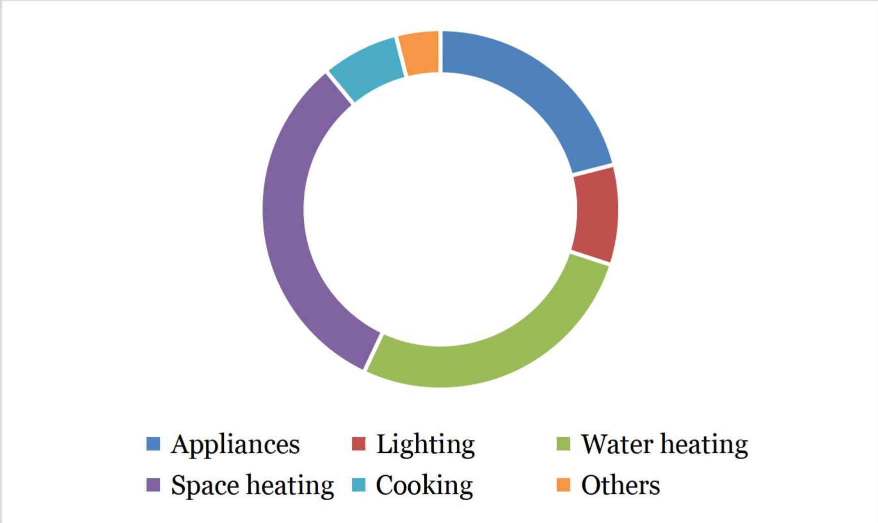

Figure 7. Energy Consumption by Major Activities in Residential Buildings of China

For providing energy analytics, it is important to design interactive interfaces, which are an essential part of the application ecosystem and help them to issue complex feature sets. To add to this, public cloud-based services can be leveraged [28]. The energy analytics comprises multiple layers with various functionalities as mentioned below:

Analysis: This renders the potential for detailed data analysis as well as visualization through case-to-case reasoning with automatic learning techniques.

Cloud Management: The storage and management service that isolates data either physically or virtually. Scalability is also a major concern for the growth of the infrastructure and resources.

Authentication: This is realized through proper authorization as well as distributed transactions.

Knowledge Base: As the social machine is formed, it permits the provisioning, supervision, and updating of technological resources.

Application Programming Interface: This helps realize that cloud services can be accessed through a web portal or browser.

This indicates there is a need for a secure, comprehensive framework that leverages cloud computing to foster energy analytics in all buildings. This work is a forerunner that proposes a secure framework that focuses on building energy analytics from the perspective of residential buildings.

This section briefs about some important research work that focuses on energy analytics and energy-saving strategies implemented in buildings. A novel energy efficiency system that deploys hybrid edge-cloud computing through a micro-moment approach is proposed by Himeur et al. [29]. The energy observations are clustered into different energy categories that indicate normal and excessive energy usage. As it is evident that CC fosters dynamic and active interactions between customers and providers, integrating energy efficiency by exploring the latest developments in constructing intelligent buildings through microgrids is studied [30].

Implementing low-cost, low-energy, but long-range IoT for real-time monitoring energy monitoring in buildings is done [31]. The Arduino MKR FOX 1200-based device was used along with Sigfox technology to deceit the leakages. This work uses open-source tools, which are easy to implement. A database of energy efficiency performance, which acts as a direct retrofit analysis resource for commercial buildings, is developed [32]. This is built by collecting the results from ten million EnergyPlus simulations, which use prototype models pertaining to the California region. This work analyses the energy savings as well as the financial payback.

The motivation behind the European Union's design of the Regulations for transforming existing cities into smart buildings is analyzed by proposing a smart building template [33]. This regulates the energy analytics of the technical systems by leveraging the IoT technology. This work minimizes the time consumption of the implementation of the energy-saving procedures. The segmentation of the point cloud of a residential building by analyzing the planar elements by isolating the planar clusters and façade break lines [34]. These are transformed into a 3D vector model. The integration between these factors and infrared thermography is also presented as a part of the work. The deployment of information technology-based solutions in building energy-saving schemes is reviewed [35]. An intelligent framework for efficient building energy monitoring, as well as an analysis system that relies on IoT, is proposed in this work.

A Cloud-Enabled BEMS for intelligent buildings that leverages CC to provide better energy management policies and schemes for energy utilization [36]. This is connected to the cloud to facilitate access to multiple advanced cloud-based services that foster energy management. This work also describes the limitations of the proposed framework. An energy-efficient model for residential buildings that relies on gradient descent optimization was proposed by Muhammad Shoukat Aslam [37]. This model predicts a building's heating-load conservation by considering the distribution of glazing area, wall, surface areas, density, elevation, etc. An architectural framework that is based on the principles for energy-efficient CC is presented [38]. The energy-aware allocation heuristics facilitate the data center to allocate resources to the client in a manner that improves energy efficiency without compromising the QoS. The results of the simulation show that this model has great potential as it leverages cost savings with good chances for the improvement of energy efficiency.

A novel energy-efficient fog-to-cloud architecture for the Internet of Medical Things is employed to optimize energy consumption in the healthcare sector [39]. The Bluetooth-enabled biosensors used in this architecture operate in two modes, namely sleep and awake. The architecture works in a periodic, sleep–awake, as well as continuous mode that regulates energy consumption. An instance of the energy-saving multi-agent system that yields results with completeness, as well as the feasibility of the energy-saving architecture, is analyzed [40]. The work also considers the building-related information agent mechanisms that aid energy-saving information processing as well as decision-making. The detailed result analysis shows that the system development and experiments produce better results.

The detailed literature review shows many works focus on the design, development, and deployment of CC-based energy-saving frameworks by leveraging other computing techniques. However, very limited works focus on developing a secure CC-based framework with effective energy analytics. The proposed framework concentrates on incorporating the analytics component in the residential buildings' energy efficiency strategy.

METHODOLOGY

Secure Cloud Computing-based Energy Analytic Framework for Residential Buildings

This section elaborates on the proposed framework that is developed for CC-based energy analytics for home appliances. The detailed activity in the process is mentioned in the flowchart as given in Figure 8.

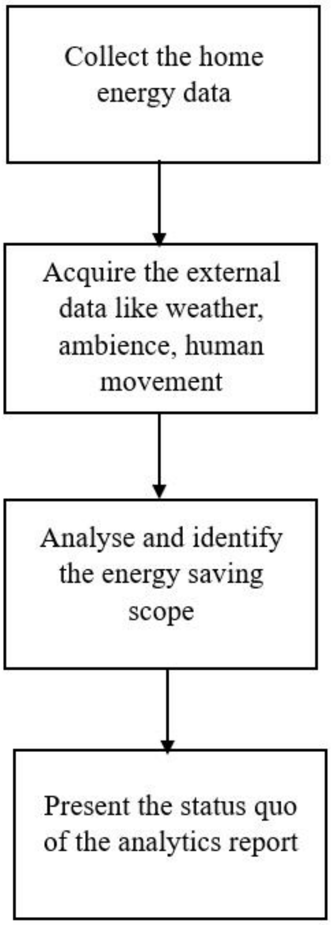

Figure 8. Actions in Energy Analytics at Residential Buildings

However, monitoring and assessing the electricity consumption at residential buildings is very tough as there are many devices manufactured by different brands that operate under different working conditions. This work considers a few energy indicators that try to best describe the energy landscape of the electricity demand. These indicators are very helpful in procrastinating future energy demands and are described in Table 2.

Table 2. Indicators for Energy Analytics

Indicator	Description
Equipment Usage	Aggregation of usage of household equipment
Usage-price Metric (UPM)	Total energy consumed by the household per month
Appliance Ownership	Score of the household appliance type owned by the people of a particular income class
Security Score	The measure of unauthorized access to the data.

Equipment Augie (EqU) is found by aggregating the end-use energy that is consumed by different household electrical appliances [41]. The amount of energy consumption is determined as the product of power rating (PR) as mentioned by the appliance k, its usage duration (T), and the count of the equipment owned (N) at a particular residential building. This is found on an average of 30 days. Equation 1 illustrates the expression for estimating the EU):

$$EqU = \sum_{i=1}^{k} (PR_k * T_k * N_k)/1000 \tag{1}$$

Another important energy analytics metric used is the usage price metric, which uses the reports derived from the monthly electricity expenditure along with the electricity price data. The consumption is measured in terms of KWh. The Usage Power Metric (UPM) is defined according to Equation 2.

$$UPM = \frac{Ex_i}{Price} \tag{2}$$

In this equation, the monthly household expenditure (Ex) of household i is measured against the mean electricity price. This value varies among various countries as the pricing scheme is not universal. This measure is transformed into monthly per capita figures that are estimated based on the assumption that the average household size is five. The next metric is the type of appliances that are possessed by the households based on their income. The association between the income and ownership of the equipment is approximated to the Gompertz curve [42]. The Appliance Ownership (AO) is estimated according to Equation 3.

$$AO(a, In) = AO_{max}(a)(1 - e^{-\alpha In})^{\beta} \quad (3)$$

The AO depends on the appliance used indicated by a and the income level signified by In. The term AOmax is the mean value of the appliance possessed by a group of people. The terms α and β are the coefficients which are estimated based on regression.

The security score of the proposed framework is estimated as the aggregation of access to the framework through internet connectivity by unauthorized or unregistered sensors. As these devices may also stream their data to the cloud, it is important to track their access. The Security Score (SS) is computed according to the Equation 4.

$$SS = \frac{\text{Frequency of data upload by unregistered devices}}{\text{Frequency of data upload}} \quad (4)$$

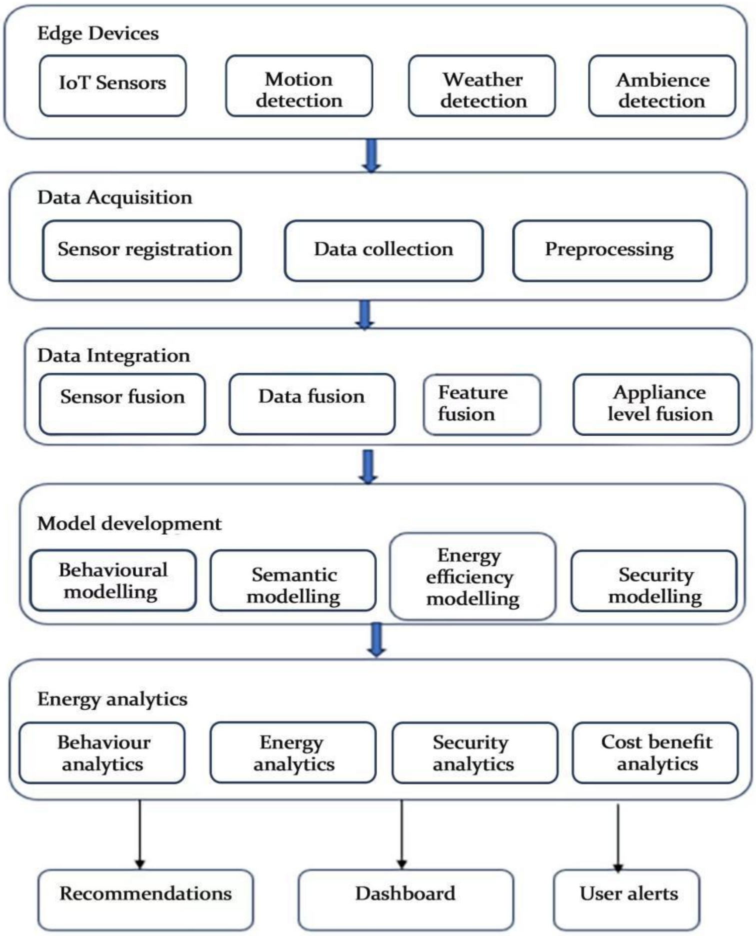

Figure 9. Proposed Secure Energy Analytic Framework

Figure 9 shows the holistic view of the proposed framework. The framework operates at five layers, namely edge devices, data acquisition, integration, modeling, and energy analytics. The functions of each individual layer are explained below:

Edge Devices: These are the devices that monitor the physical phenomena through sensors and other IoT devices. They track human as well as natural phenomena and send the data for further analytics.

Data Acquisition: This is a very important layer that performs functions like registration of appropriate sensors, collecting data from heterogeneous sensors, and preprocessing the acquired data. Sensor registration is one of the indicators used to assess the security component.

Data Integration: Combining data to form meaningful information with semantic insight is essential, especially while dealing with heterogeneous sensors [43]. Various kinds of fusion like data, feature, sensor, and appliance-level integration are done in this layer.

Model development: This layer focuses on creating behavioral models, semantic models, energy efficiency tracking models, and security models. These models are done in cloud layers, as these models can be reused and orchestrated.

Energy analytics: Energy analytics can be done in various flavors. A few common genres of measurement include user behavior analytics, energy analytics, security analytics, and cost-benefit analytics. This is done after the output of the models and is rendered to the users.

The output of the proposed framework can be informed to the users by providing recommendation systems, dashboards, or even alerts.

Within the Secure Cloud Computing Energy Analytic framework, AI technology plays a pivotal role in enhancing both energy efficiency and security in residential building construction. By integrating machine learning algorithms, the framework analyzes real-time data from IoT sensors to predict energy consumption patterns accurately. This predictive capability allows for the dynamic adjustment of energy usage, significantly reducing waste and optimizing operational efficiency. Moreover, AI-enhanced security protocols utilize anomaly detection techniques to identify and mitigate potential cybersecurity threats, safeguarding sensitive data. These AI applications not only exemplify the framework's advanced capabilities but also demonstrate its practical effectiveness in real-world scenarios, offering a seamless blend of theoretical innovation and tangible results.

RESULTS AND DISCUSSION

Rationale of Cloud computing in energy analytics of the proposed framework

The proposed model in Figure 8 has five major layers. Though most of the computations are done in the edge layer, the deployment of analytic models is done in the cloud platform. Energy analytics, user behavior analytics, and security analytics are done at the cloud layer as they are computed from the streaming data. Processing these heavy data at edge layers will impose a heavy computational load. Hence, by leveraging the cloud services by incorporating the analytics in the cloud layer will save time and computational overheads. Fig 10 shows the interactions between the cloud and the edge devices.

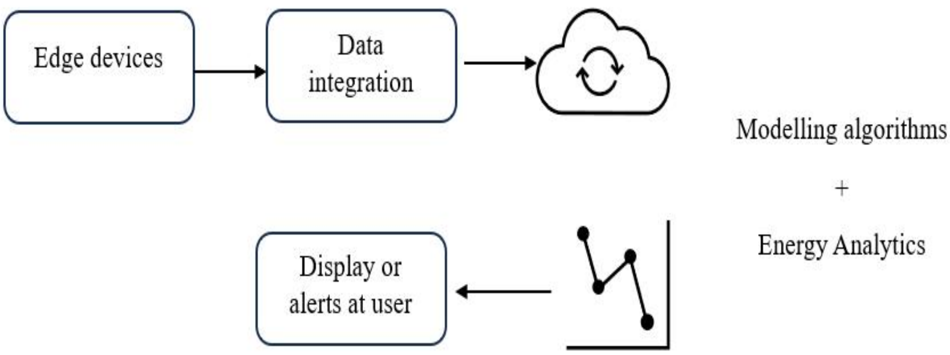

Figure 10. Interaction between Cloud and Energy Analytics

The cloud platform houses the algorithms or models that perform the analytics model based on the indicators mentioned in the previous section. The unique trait of this work is the inclusion of security analytics, which is assessed by monitoring the percentage of access by unauthorized devices or sensors. As mentioned in the previous section, any sensor installed in this framework must be registered. The unauthorized connection to the cloud by any particular device or sensor will not be condemned but notified to the owner, as the residential buildings house a huge population.

Thus, the proposed framework deploys cloud computing to perform energy analytics of residential buildings with a special inclusion of a security component . Through the analytics can be moved to the edge devices, it will be seamlessly difficult if the size of the building and its residents are huge in number.

In the detailed implementation case of the Secure Cloud computing-based Energy Analytics Framework in a residential building, the project involved a comprehensive application of IoT devices for real-time energy monitoring and data collection. The IoT setup recorded a significant amount of data, including daily energy consumption metrics of 5,000 kWh, temperature variations, and occupancy rates. Through cloud-based analytics, energy consumption was optimized, resulting in a 25% reduction in energy use and a 20% decrease in operational costs. Data security was enhanced with state-of-the-art encryption techniques, ensuring the integrity and confidentiality of sensitive information. This practical application not only validated the theoretical framework but also showcased its potential to improve energy efficiency and security in the construction sector.

CONCLUSION

The confined availability of fossil fuels and the campaign for sustainable development have facilitated the deployment of new technologies for achieving high efficiency in energy consumption through effective energy analytics. This research work focuses on employing CC as the primary means to attain energy efficiency in residential buildings. The detailed literature reveals that there is very limited work that concentrates on the energy analytics of the buildings. Hence, this work proposes a comprehensive framework with a layered architecture that provisions the usage of versatile devices and modes of operations in every layer. The data that is pulled from the edge devices pertaining to energy conservation is processed by the cloud using suitable models on the grounds of four major indicators. The results of the analytics are sent to the user, and the user can either use a recommender system, alerts, or even a designed dashboard for accessing the analytics. The framework also comprises a security component, which is leveraged through the security score that is estimated from the unregistered devices in the network. Thus, the proposed framework provides a holistic architecture for the specific algorithms and strategies to build upon, which focus on energy analytics. In the future, the framework can be implemented in real-time by harnessing the prowess of Machine learning or any other AI-based techniques.

ETHICAL DECLARATION

Conflict of interest: No declaration required. **Financing:** No reporting required. **Peer review:** Double anonymous peer review.

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