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# VIEWPOINT

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## Asset Management for Sustaining Built Facilities

# IoT Based Solutions for Centralized Management and Optimization of Building Systems



**Sudhir Nair**  
CEO  
NergyLive Solutions Pvt Ltd

## Abstract

The rapid evolution of the Internet of Things (IoT) has transformed the building management landscape by enabling real-time visibility, centralised control, and automated optimisation of critical systems such as HVAC, lighting, energy metering, security, and indoor air quality (IAQ). Traditional Building Management Systems (BMS) rely on proprietary protocols, limited interoperability, and static control logic, resulting in suboptimal energy utilisation and increased operational costs. This paper presents a scalable IoT-based framework for centralised management and optimisation of building systems. The work discusses system architecture, communication protocols, data acquisition strategy, cloud-based analytics, AI-driven optimisation, and cybersecurity requirements. A case study from a live deployment demonstrates improvements in energy efficiency, operational resilience, and occupant comfort.

## Introduction

Modern buildings consume 30-40% of global energy, with HVAC systems having the largest share. Conventional BMS platforms often suffer from limited interoperability, distributed siloed controls, high installation costs, and a lack of real-time optimisation.

IoT-enabled smart building solutions address these limitations by integrating sensors, controllers, gateways,

### User / Application Layer



- > Dashboards and mobile apps for monitoring and control
- > Supports setpoint changes, scheduling, overrides, and alerts
- > Provides automated reports and real-time notifications



### Cloud Platform Layer



- > Enables multi-building monitoring and centralized management
- > Uses digital twins for real-time device representation
- > Provides large-scale data storage and analytics
- > Executes advanced optimization logic via cloud rule engines
- > API integrations
- > Supports AI/ML-driven insights, predictive maintenance, HVAC optimization, energy baselining



### Gateway / Edge Layer



- > Bridges field devices and cloud platforms
- > Aggregates data and normalizes different protocols
- > Performs local edge processing
- > Maintains scheduling and logic during connectivity loss
- > Handles security: authentication, encryption, firewalling
- > Supports remote management and OTA firmware updates



### Sensor & Device Layer



- > Handles data acquisition and actuation
- > Environmental parameter sensors
- > Occupancy and motion sensors
- > Energy and power monitoring devices
- > Equipment controllers, thermostat, VFDs
- > Relays and actuators

Figure 1: Functional layers in IoT system architecture

and cloud analytics into a centralised platform. This enables rule-based automation, predictive algorithms, and remote operations, which together improve energy efficiency and comfort.

## System Architecture

A scalable IoT-based building and energy management system architecture is typically organised into four functional layers, each responsible for a distinct set of operations, from physical sensing to cloud intelligence and user interaction. This layered approach ensures interoperability, modularity, and ease of deployment across diverse building environments.

### 1. Sensor and Device Layer

The Sensor and Device Layer form the foundation of the IoT building ecosystem, consisting of all field-level devices responsible for monitoring environmental, electrical, and mechanical parameters and controlling building equipment. This layer functions primarily as the data acquisition and actuation layer, feeding real-time information to gateways and receiving control commands from supervisory systems. Common types of sensors and devices include:

- a) Environmental Sensors: temperature, relative humidity, pressure, CO<sub>2</sub>, VOCs, particulate matter, lighting level.
- b) Occupancy & Motion Sensors: PIR sensors, people counters, door contact sensors.
- c) Energy & Power Devices: single-phase and three-phase energy meters, power quality analysers, BTU meters.
- d) Flow Measurement Devices: Water flow meters, fuel flow meters, air flow measurement stations.
- e) Equipment Controllers: chiller/boiler controllers, AHU/FCU controllers, thermostats, lighting controllers, VFDs, actuators.

Devices in modern buildings use a mix of wired and wireless communication technologies. Most common protocols include BACnet, Modbus, MQTT, HTTPS, LoRaWAN, Zigbee.

### 2. Gateway/ Edge Layer

Gateways serve as the bridge between field devices and the cloud. They provide data aggregation, local intelligence, and secure communication pathways. Gateways collect raw telemetry from multiple field devices and normalise diverse protocol formats into standard IoT data models. This ensures interoperability between heterogeneous equipment from different vendors. A critical gateway function is converting traditional BMS/ industrial protocols into modern IoT communication standards. This enables cloud platforms to read data without directly handling low-level building protocols.

To reduce cloud dependency and ensure operational continuity, gateways perform limited local processing such as threshold-based event detection, preliminary fault detection, data smoothing and noise reduction, and local safety logic. In case of connectivity loss, gateways maintain essential logics and time-based scheduling. Gateways also handle device authentication and identity management, encrypted communication, local firewalling and over-the-air firmware updates.

### 3. Cloud Platform

Cloud platforms support portfolio-level visibility, enabling building owners and facility teams to monitor and optimise multiple buildings from a single interface.

The cloud layer ensures centralised intelligence, long-term storage, analytics, and multi-site management capabilities. Each connected device is represented as a digital twin, reflecting real-time operational status, telemetry, and control parameters. This allows the platform to manage devices at scale. Cloud services maintain time series databases capable of handling high-frequency sensor data. Processing pipelines enable trend analysis, anomaly detection, predictive modelling, and load profiling.

Cloud-based rule engine executes complex, multi-variable logic that may involve IAQ-based ventilation adjustments, energy demand limiting strategies, predictive scheduling of equipment

and cross system optimisation. Machine learning models can be trained on historical datasets to offer predictive maintenance, HVAC plant optimisation, energy baselining, and deviation alerts.

#### 4. User/ Application Layer

This layer is responsible for presenting information, enabling control, and supporting facility operations through intuitive interfaces. Users access real-time building data through web-based dashboards and mobile applications. Authorised users can remotely adjust temperature setpoints and other system parameters, modify equipment schedules, perform system overrides, configure alert thresholds, configure control logics, configure custom dashboards and reports, and acknowledge or act on alarms.

The application layer provides automated reporting such as Hourly/Daily/weekly/monthly energy consumption reports, IAQ compliance summaries, equipment uptime and performance reports and regulatory data logs.

Users receive real-time notifications via mobile push alerts, email and SMS. These alerts may be triggered by parameter deviations, equipment failures, energy anomalies, or IAQ breaches.

Open APIs allow integration with existing BMS systems, ERP platforms, maintenance management systems and third party analytics tools.

The four-layer IoT architecture creates a flexible and resilient framework for modern building automation. This structure ensures interoperability, real-time responsiveness, and future scalability, enabling buildings to move toward fully data-driven and autonomous operation.

### Communication Framework

Efficient and secure communication is a core requirement of IoT-based building and energy management systems. A robust communication framework ensures seamless interoperability between field devices, edge controllers, and cloud platforms, enabling real-time monitoring, analytics, and automation. The communication stack can be broadly categorised into field level protocols and

IoT/cloud protocols, each serving distinct roles within the system.

#### 1. Field Protocols

Field protocols enable reliable, deterministic communication between sensors, meters, actuators, and controllers in building systems.

Modbus is widely used in HVAC and energy management for its simplicity and vendor neutrality. Modbus RTU runs on RS485 for multi-drop field networks, while Modbus TCP uses Ethernet for faster, IP-based integration. BACnet is purpose built for building automation. BACnet MS/TP operates over RS485 and is common in HVAC controllers, while BACnet/IP runs on Ethernet. Its object based data model supports complex automation needs.

To integrate mixed legacy and modern equipment, IoT gateways normalise Modbus and BACnet data into standardised IoT formats, providing a unified semantic layer that simplifies analytics, automation, and cloud connectivity.

#### 2. Cloud/ IoT Protocols

IoT protocols enable communication between edge gateways, smart devices, and cloud platforms, supporting scalable, low bandwidth, and secure connectivity.

MQTT is the most widely used IoT protocol due to its lightweight publish/subscribe model. It supports low bandwidth usage, asynchronous messaging, topic based data routing, and QoS levels, making it ideal for real-time telemetry, alarms, and device-to-cloud communication in buildings. HTTPS/REST is commonly used for device provisioning, configuration, diagnostics, and bulk data transfer. While more resource intensive than MQTT, it offers strong security, broad compatibility, and ease of integration with enterprise systems.

IoT security is ensured through measures such as TLS encryption, certificate based authentication, secure boot and firmware signing, RBAC, and mutual TLS, protecting systems from unauthorised access and data interception. Together, field protocols and IoT protocols form a robust, scalable, and cloud-ready communication

foundation for modern building and energy management systems.

## Data Management and Analytics

Effective IoT-based building and energy management depends on robust data acquisition, storage, processing, and analytics to support real-time decisions, long term insights, and AI-driven optimisation.

### 1. Real-Time Data Acquisition

Sensors, meters, and controllers continuously send telemetry to edge gateways, typically at 5 to 60-second intervals based on parameter criticality. Gateways preprocess data through validation, filtering, compression, anomaly detection, and local buffering, and can trigger local alarms for immediate response during critical events or network outages.

### 2. Cloud Storage and Analytics

Processed data is ingested into cloud-based time series databases optimised for high volume, time-stamped data. These systems support fast trend analysis, scalable multi-site deployments, and cost efficient retention using high resolution recent data and aggregated historical data. Cloud platforms enable Fault Detection and Diagnostics (FDD) using rule-based and statistical models, enhanced by contextual data such as weather, tariffs, occupancy, and maintenance records.

### 3. AI/ML Optimisation

AI and ML models use historical and real-time data to optimise HVAC and energy systems, improve efficiency, predict faults, and support autonomous operation.

Together, edge processing, scalable cloud storage, and AI-driven analytics form an intelligent data pipeline that enables efficient, predictive, and smart building operations.

## Cyber Security Architecture

Security is fundamental to IoT-based building and energy management systems due to distributed devices, critical HVAC and energy operations, and cloud connectivity. A robust cybersecurity architecture protects devices,

networks, cloud infrastructure, and user access to ensure confidentiality, integrity, and availability.

### 1. End-to-End Encryption

All communications between devices, gateways, and cloud platforms should use industry standard encryption (TLS 1.2+ for MQTT/HTTPS, DTLS where applicable, and AES-256 at the device level). Sensitive data and credentials must also be encrypted at rest within gateways and cloud storage.

### 2. Network Segmentation (IT/OT Separation)

IT and OT (Operational Technology) systems should be isolated using dedicated VLANs or subnets, with gateways acting as controlled bridges. Firewalls enforce strict traffic rules, reducing attack surfaces.

### 3. Certificate Based Authentication

Each device and gateway must have a unique cryptographic identity using PKI and mutual TLS. User access is protected through MFA, RBAC, least privilege policies, and comprehensive activity logging.

### 4. Secure Firmware and Software Updates

Devices should support secure boot, signed firmware, and encrypted OTA updates with rollback, version control, and audit trails to safely patch vulnerabilities.

### 5. Continuous Monitoring and Vulnerability Management

Regular vulnerability scans, intrusion and anomaly detection, and centralised security logging enable proactive threat detection, incident response, and compliance reporting.

### 6. Physical Security and Incident Response

Physical protection of equipment, along with defined incident response, backup, and recovery procedures, ensures resilience and continuity of building operations.

Together, these measures create a secure, resilient IoT cybersecurity framework that safeguards modern building and energy management systems.

## Use Cases

IoT-based building and energy management systems support a wide range of applications across HVAC, energy, indoor air quality, and cold chain environments. By integrating high frequency sensing, edge computing, and cloud analytics, these systems enable real-time monitoring, control, alerts, optimisation, predictive maintenance, and improved operational transparency.

### 1. HVAC Optimisation

HVAC systems represent the largest energy consumers in commercial and industrial buildings. IoT-driven optimisation improves efficiency, enhances comfort, and reduces equipment wear.

**Chiller Plant Automation:** Chiller plants operate under highly dynamic load conditions. IoT systems optimise performance using real-time data from temperature sensors, pressure sensors, humidity sensors, flow meters, power meters, equipment controllers, occupancy sensors, and weather stations. Key capabilities include:

- **Dynamic Chilled Water Temperature Setpoint Adjustments:** Continuously optimises the chilled water temperature setpoint using real-time feedback from conditioned zones, prevailing weather conditions, occupancy data, and historical operating data. This enables the plant to operate at the highest feasible chilled water temperature without compromising zone conditions or occupant comfort. Operating at higher evaporator temperatures reduces compressor lift, improves the coefficient of performance (COP), and lowers overall energy consumption.
- **Automatic chiller sequencing:** Selecting the most efficient chiller based on real-time load, Coefficient of Performance (COP), and historical performance.
- **Pump and cooling tower VFD control:** Adjusting pump speeds and fan speeds to maintain optimal chilled water and condenser water conditions.

- **$\Delta T$  (temperature differential) optimisation:** Detecting low  $\Delta T$  syndrome and adjusting flows or setpoints to restore efficiency.
- **Automated start/stop schedules:** Based on occupancy or predicted cooling demand.

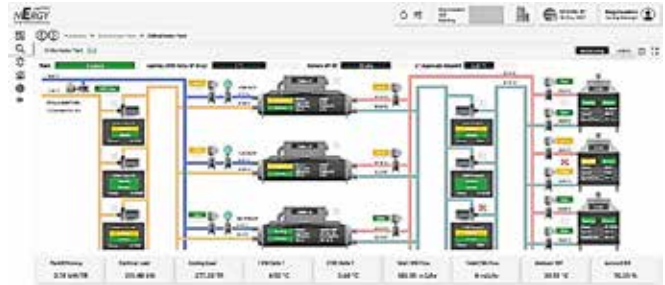


Figure 2: Cloud-based Monitoring & Control dashboard for a Chilled Water Plant

**AHU/ FCU Optimisation:** Air Handling Units (AHUs) and Fan Coil Units (FCUs) can significantly benefit from data-driven optimisation. Enhancements include:

- **Supply Air Temperature (SAT) reset:** Adjusting AHU SAT based on load, zone conditions, outdoor temperature, or occupancy trends.
- **VFD-based fan modulation:** Reducing fan energy while maintaining airflow and pressurisation requirements.
- **Fresh Air Control:** Using IAQ metrics (CO<sub>2</sub>, VOC) and occupancy data to determine optimal fresh air intake.
- **Adaptive cooling strategies:** Minimising reheating and preventing simultaneous cooling/heating events.



Figure 3: Cloud-based Monitoring and Control dashboard for an AHU

**Fault Detection for HVAC Components:** IoT systems continuously monitor equipment health and detect anomalies such as:

- Sensor drift or failure
- Valve misalignment or actuator failure
- Damper stuck positions
- Dirty or clogged filters
- Coil fouling
- Abnormal behaviour
- Inefficient operation
- Overheating, vibrations, and noise

Early detection reduces downtime and improves system reliability.

**2. Energy Management**

IoT-enabled energy management systems provide comprehensive visibility into real-time and historical energy usage across building assets.

**Real-Time Energy Dashboards:** Energy meters feed live data into dashboards for monitoring:

- Power consumption by equipment, floors, or zones
- Voltage, current, and power factor
- Phase imbalances
- Load distribution

Operators can quickly identify inefficiencies or abnormal patterns.

**Load Profiling:** Time series energy data allows:

- Hourly/Daily/weekly/monthly consumption pattern analysis
- Base load and peak load assessment
- Identification of operational inefficiencies
- Understanding peak load contributors

These insights form the basis for energy saving initiatives.

**Peak Demand Alerting:** IoT platforms monitor real-time demand and notify operators when consumption approaches utility peak thresholds. Actions may include:

- Automatically adjusting non-critical loads
- Automatically reducing HVAC intensity temporarily in selected zones based on criticality
- Staggering startup of large equipment

This helps avoid expensive demand charges.

**Energy Anomaly Detection:** Using rule-based or AI-driven algorithms, systems can detect:

- Sudden spikes in consumption
- Equipment running outside scheduled hours
- Energy leaks or losses
- Component degradation causing inefficiency
- Inefficient HVAC modes

Automated alerts support proactive intervention.

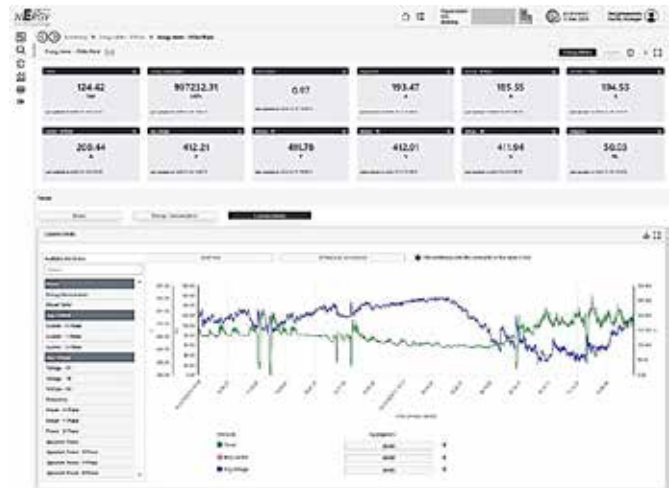


Figure 4: Cloud-based Energy Monitoring dashboard

**3. Indoor Air Quality (IAQ)**

Indoor Air Quality is critical for occupant health, comfort, regulatory compliance, and productivity. IoT-based IAQ management uses real-time sensing combined with automated ventilation controls.

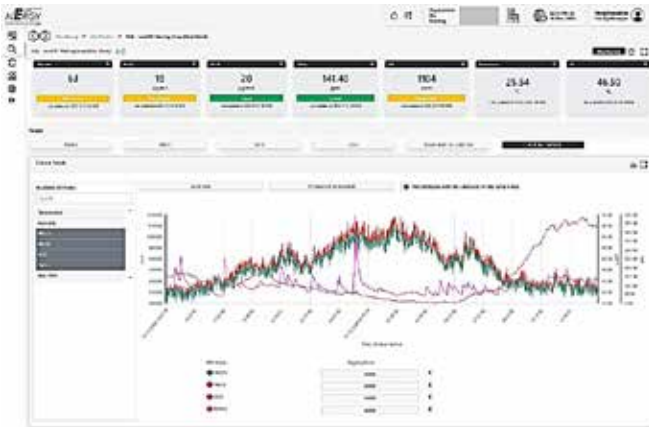


Figure 5: Cloud-based Indoor Air Quality (IAQ) dashboard

#### CO<sub>2</sub> Based Demand Controlled Ventilation:

CO<sub>2</sub> sensors measure occupancy driven air quality. When CO<sub>2</sub> concentrations exceed preset thresholds, the system can increase fresh air intake, adjust supply fan speed, and activate mechanical ventilation systems. When occupancy drops, ventilation is reduced to conserve energy.

#### PM<sub>2.5</sub>/ PM<sub>10</sub> Monitoring for Health

**Compliance:** Particulate matter sensors allow buildings to maintain compliance with health standards, particularly in hospitals, labs, and urban buildings. Actions may include:

- Automatically activating filtration stages
- Automatically adjusting damper positions when outdoor air quality is poor
- Triggering maintenance alerts for clogged filters
- Logging compliance for audits

**Predictive Filter Maintenance:** Differential pressure trends across filters enable predictive algorithms to estimate filter life. Operators receive notifications when filters approach clogging, allowing maintenance to be scheduled proactively rather than reactively.

#### 4. Cold Room and Healthcare Environments

Cold rooms and healthcare facilities require precise environmental monitoring to ensure product safety, regulatory compliance, and operational reliability.

#### Temperature and Humidity Excursion Alerts:

IoT-enabled temperature or temperature and RH

sensors continuously monitor cold rooms, freezers, incubators, and critical storage areas. Alerts are triggered when temperatures or RH exceed or fall below acceptable thresholds or change rapidly due to door openings or equipment failures. This prevents spoilage of perishable goods and pharmaceuticals.

**24×7 Remote Monitoring:** Continuous remote access to environmental conditions enables staff to:

- View live temperature/RH data
- Track performance of compressors and fans
- Detect abnormal door open durations
- Verify backup power status

This is especially crucial during off-hours.

**Compliance Reporting for Pharma, Healthcare & Food Processing Industries:** Regulated industries require detailed historical records of environmental parameters, and IoT systems automate these records to ensure traceability and facilitate audits.

The use cases presented illustrate how IoT-powered building and energy management systems deliver improvements in energy efficiency, HVAC reliability, IAQ quality, and compliance. By leveraging real-time data, automation, and analytics, buildings can achieve higher performance, lower operating costs, and improved occupant well-being across a wide range of environments.

### Technical Evaluation of Energy Savings Achieved Through Adaptive Control in a Chilled Water Plant

An IoT-enabled adaptive control strategy was deployed on a chilled water plant consisting of two 200 TR VFD screw chillers, variable speed CHW pumps, and fixed speed condenser pumps and cooling towers. Baseline operation maintained a static chilled water setpoint of 7 °C with primary pumps running at 85% speed. Under adaptive control, the system dynamically adjusted the chilled water temperature setpoints and chilled water pump speeds based on real-time zone conditions, weather data and history data while retaining automatic staging and sequencing.

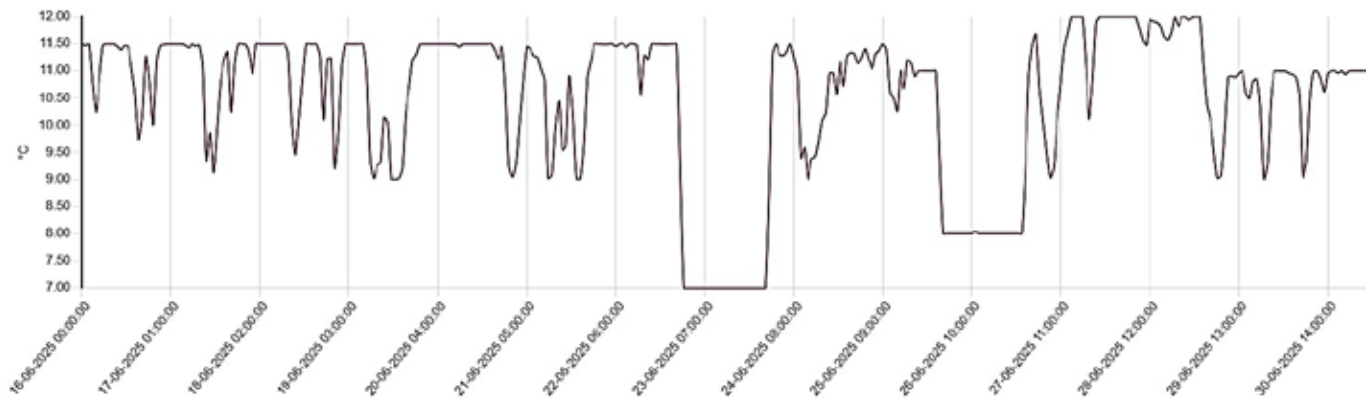


Figure 6: Chilled Water Temperature Setpoint trend with IoT-based Adaptive Controls enabled

A comparative analysis showed that **the adaptive control methodology delivered 15.07% overall energy reduction**. These findings highlight the effectiveness of data-driven, IoT-based supervisory optimisation in improving energy performance without compromising thermal comfort.

## Conclusion

IoT-based building and energy management systems offer a powerful pathway for centralised optimisation of HVAC, IAQ, energy, and other building services. By integrating modern sensing, edge analytics, and cloud intelligence, buildings can achieve significant energy savings, improved occupant comfort, and predictive operations.

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## Error

In the VIEWPOINT September 2025 edition, for the article 'When Pre-Determined Compensation ... The Site Access Dilemma', by Nippon Koei, the designation of one of the authors may please be read as 'Mr Rupesh Jain, General Manager, Metro/Railways' instead of 'Manager, Metro/Railways'. The error is regretted...Ed