slipstream

Smart building applications

Smart building application examples

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2024

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Learning Objectives

- Review smart building technology fundamentals
- Present several smart building application examples
- Discuss smart building project process and stakeholder roles
- Discuss smart building application challenges

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Outline

- Smart building technology fundamentals
- Smart building technology providers
- Example 1 – Natum
- Example 2 – InSite
- Example 3 - Kaizen
- Smart building project process and stakeholder roles
- Smart building application challenges
- Future trends

Smart Building Technology Fundamentals Review

Smart Building Characteristics and Elements

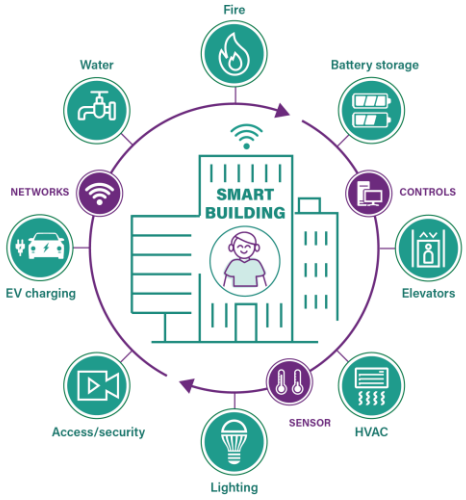
Characteristics

- Leverage interconnected devices, sensors, and automation/control systems
- Optimize its operations, enhance occupant comfort and safety, and other desired objectives

Elements

- Building systems
- Occupants
- Sensors
- Controls
- Networks

} makes a building "smart"!

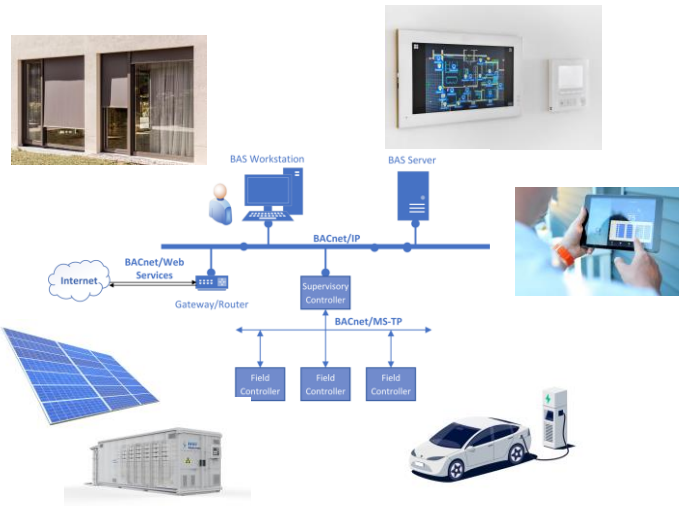


Refer to Video #1 Introduction to Smart Building Technologies

Smart Building Energy Systems and Individual Controls

Building Energy Systems

1) **Envelope**
2) **HVAC**
3) **Lighting**
4) Water
5) **Solar PV + battery energy storage**
6) **EV charging**
7) Other (elevator, fire, access/security)

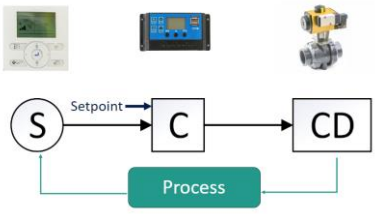


Refer to Video #2 - #6 Building Energy Systems

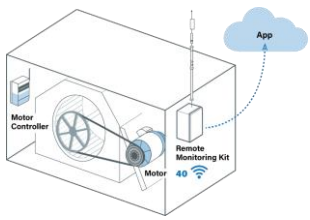
Sensors and IoT Devices

Sensors and IoT Devices

1) Sensors
2) IoT sensors
   - Sensors with internet connectivity
3) IoT devices
   - Controlled devices with internet connectivity and intelligence that may directly affect the building control process



Jefferson William CCO 1.0



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Refer to Video #7 - #8 Sensors and IoT Devices

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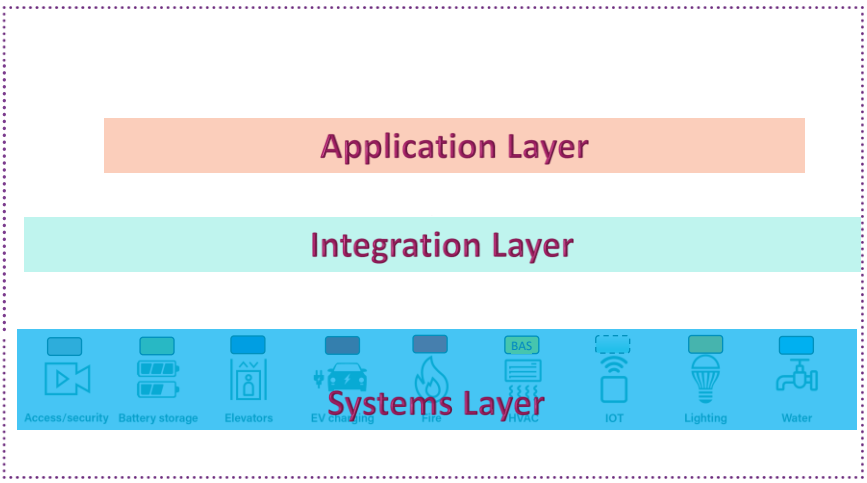
Smart Building Control Platform Architecture



Refer to Video #10 Smart Building Control Platform

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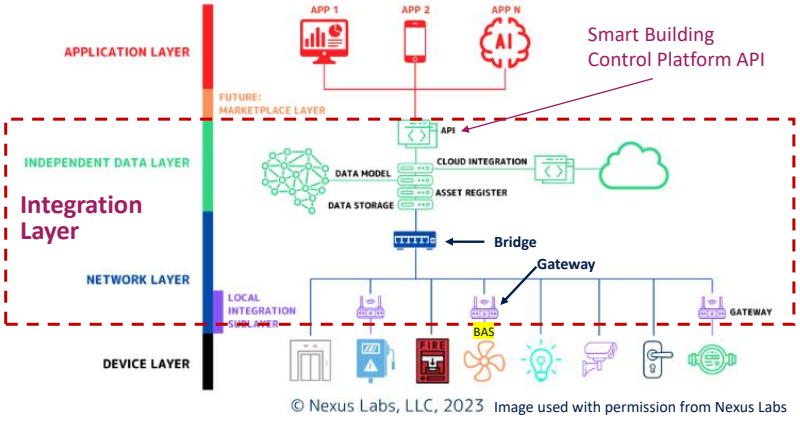
Network and Integration Layer

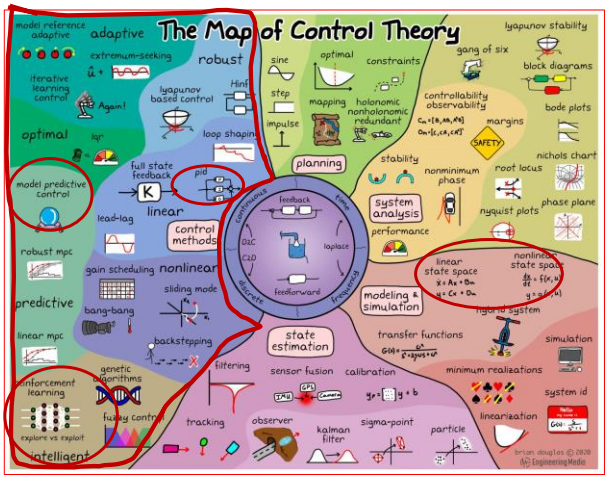
- Integrate various building control systems and IOT devices
- Two-way communication with external systems (e.g., utility automated demand response server)
- Independent data layer
- Data models (Haystack, Brick Schema, ASHRAE 223P)



Refer to Video #10 Smart Building Control Platform

Smart Building Control Methods

- P/PI/PID for single loop control
- HVAC control sequences - rule-base control (ASHRAE Guideline 36)
- Model-Predictive Control (MPC)
- Intelligent Control
  - Artificial Intelligence (AI)
  - Machine Learning (ML)
  - Neuron Network
  - Deep Learning



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Refer to Video #12 Smart Building Control Methods

Smart Building Technology Providers

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Smart Building Technology Providers

- Smart building technologies cover a wide range of topics, industries, and fields
- Building system control hardware and software
- Sensors and IoT devices

System / device layer

- Integration
  - Integration within building systems
  - Integration with external systems

Integration layer

- Smart building application software
  - AFDD
  - ASO
  - ADR & ADM
  - GEB and VPP
  - Advanced analytics and reporting
  - Space utilization
  - Many others

Application layer

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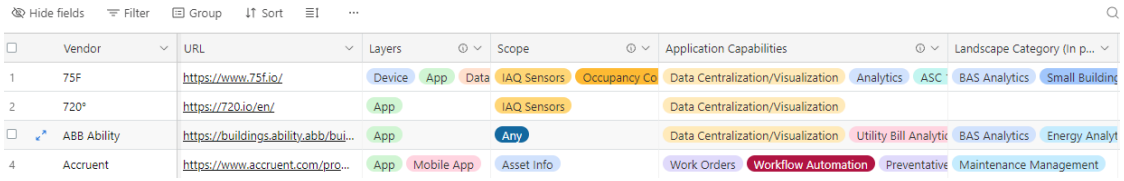
Smart Building Technology Marketplace

Nexus Labs

- An online smart building technology community – education, training.
- Learn and exchange smart building technology information
- Consists of learners, buyers, vendors, and other stakeholders
- Buyers' Guides for FDD, HVAC, IoT, Network Layer, Data Layer, Advanced Supervisory Control

Smart Building Technology Marketplace



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Example 1: Nantum

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Nantum

- A smart building control platform by Nantum AI (formerly Prescriptive Data)
- Building management and optimized HVAC, lighting, IAQ, shades, and glass control
- Portfolio-wide energy and carbon emissions management
- Automated demand response and peak load management
- Grid-interactive Efficient Buildings

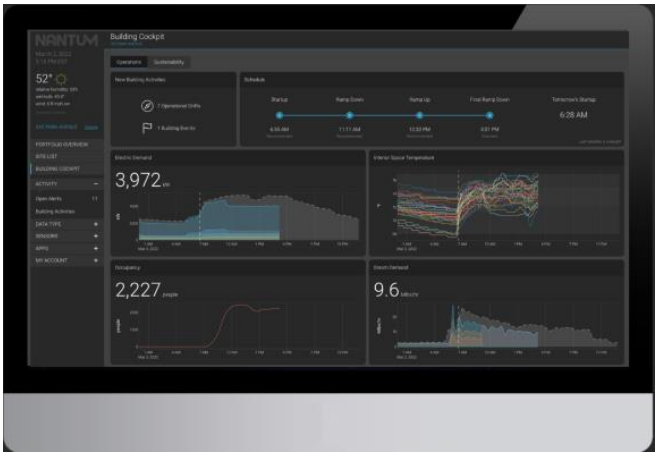

Image used by permission from Nantum AI

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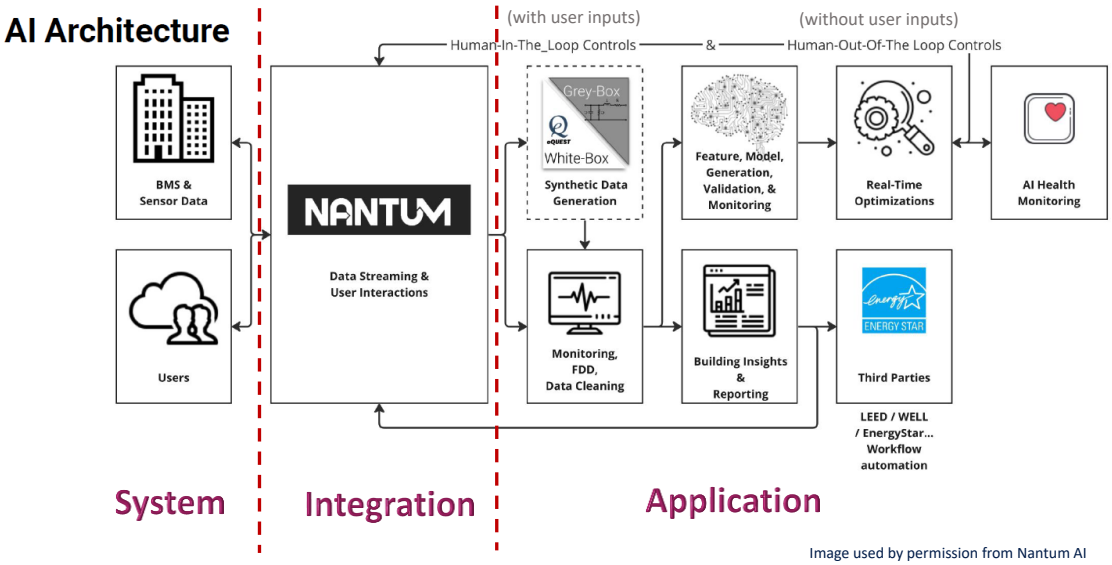
Nantum



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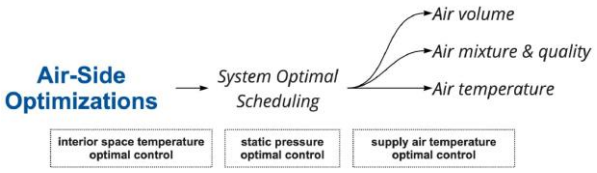
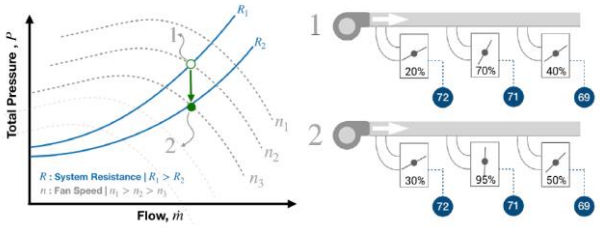
Nantum
EMIS with ASO



Uses machine learning for modeling the air-side system and model predictive control to plan and optimize the best control actions

- AHU fan power consumption optimization through setpoint changes
- Optimize AHU supply air static pressure and temperature and space temperature
- Coordinate among multiple AHUs



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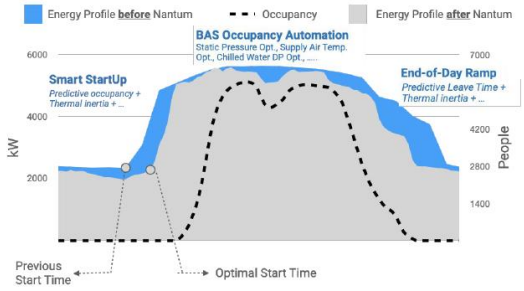
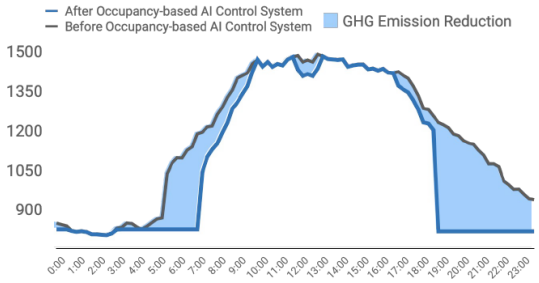
Nantum
EMIS with ASO





- Optimizes the buildings for startup, ramps, and shutdowns.
- Automatically controls the central plant HVAC or distributed HVAC based on real-time GHG intensity factors use various machine learning models for occupancy predictions, weather conditions, and indoor air quality.

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Nantum
EMIS with ASO

M&V

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY assessed the impact of an EMIS with ASO provided by Prescriptive Data at four testbeds representative of a range of GSA facility types and operating conditions.

RESULTS

How did the EMIS with ASO perform in M&V?

5-11%
WHOLE-BUILDING ENERGY SAVINGS[3]
from controlling AHU fan speeds based on weather and occupancy

95%
ACCURATE
PREDICTED DEMAND WAS WITHIN 5% OF MEASURED DEMAND[4]

VISIBILITY
INCREASED
WITH MULTIPLE DATA STREAMS[5]
INTEGRATED DASHBOARD REVEALED OPERATIONAL ISSUES[6]
POSITIVE USER ACCEPTANCE[7]

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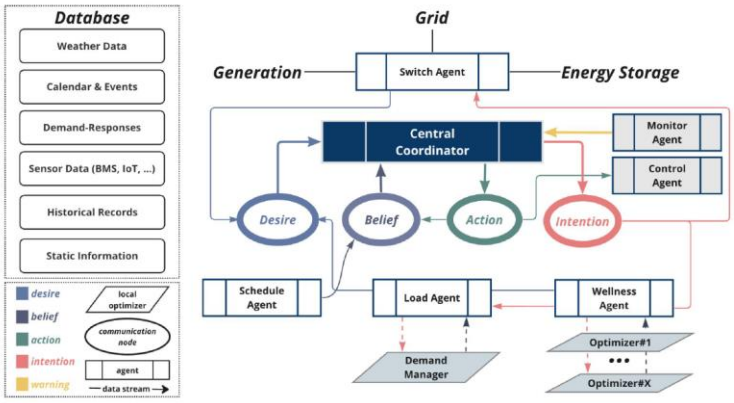
Nantum
Peak Load Management

- **Agent-based supervisory control and coordination**
- Building schedules, building peak load management, occupant wellness management are represented by local "agents"
- Central Coordinator agent coordinates multiple local agents' activities



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Nantum
Hierarchical Model Optimization

Types of Models

E-Radial Basis Model
LOESS XGboost
LSTM RNN
Gaussian Process
Exogenous Regressors ARIMA
CNN ARIMA
SVR NN
Logistic Regression

Our team has experience deploying specific model types (defines the high level formulation of the model) for different applications.

Types of Basis / Kernel Functions

$$K(x,y) = x \cdot y$$
$$K(x,y) = \tanh(ax.y + b)$$
$$K(x,y) = (1 + x \cdot y)^d$$
$$K(x,y) = a\left[\exp\left(\frac{\gamma}{||x-y||^2+\sigma^2}\right) - 1\right]$$
$$K(x,y) = \exp(-a||x-y||^2)$$
$$K(x,y) = \exp(-a||x-y||)$$

While most data scientists choose a models default configuration we modulate different kernels or basis functions in hidden layers of NNs.

Hyper-Parameter Values

$$\min_{u_{mk}} \{E_{med}, E_{max}\}$$
subject to
$$u_{mk}^{min} \leq u_{mk} \leq u_{mk}^{max}$$

- umk : vector of continuous variables (hyper-parameter value(s))
- Particle Swarm Optimization (PSO) is used to solve this multiobjective hyper-parameter optimization.

We dive further into each model by tuning/calibrating hyperparameters of each kernel to satisfy the overfitting/underfitting trade offs.

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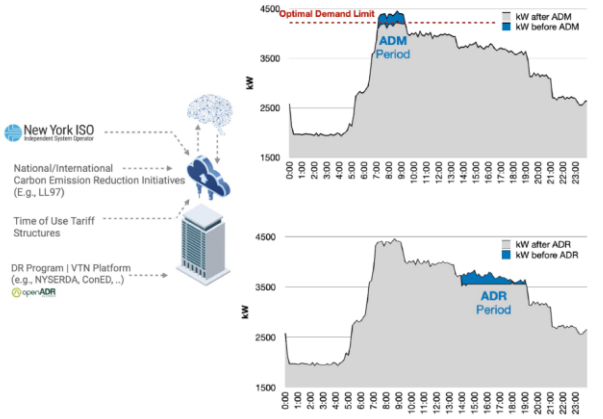
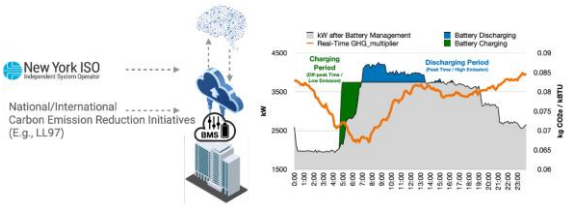
Nantum
ADM, ADR, DER Management





- ADM and ADR - use machine learning to adaptively predict the peak demand and set optimal demand limits
- DER Management – manage buildings with battery energy storage systems (BESS) to minimize GHG

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Example 2: InSite

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InSite

A Full-Stack Building Intelligence & Analytics Solution for utility consumption, cost savings, and CO2e reductions

Connect

Identify relevant data sources and establish data integration strategy

Collect

Gather data and ensure quality to establish a single source of truth

Describe

Develop data model to enable machine consumption and scalable analytics

Analyze

Utilize machine learning and human analytics to create actionable intelligence

Act

Mobilize to correct deficiencies and deploy optimizations

Image used by permission from InSite

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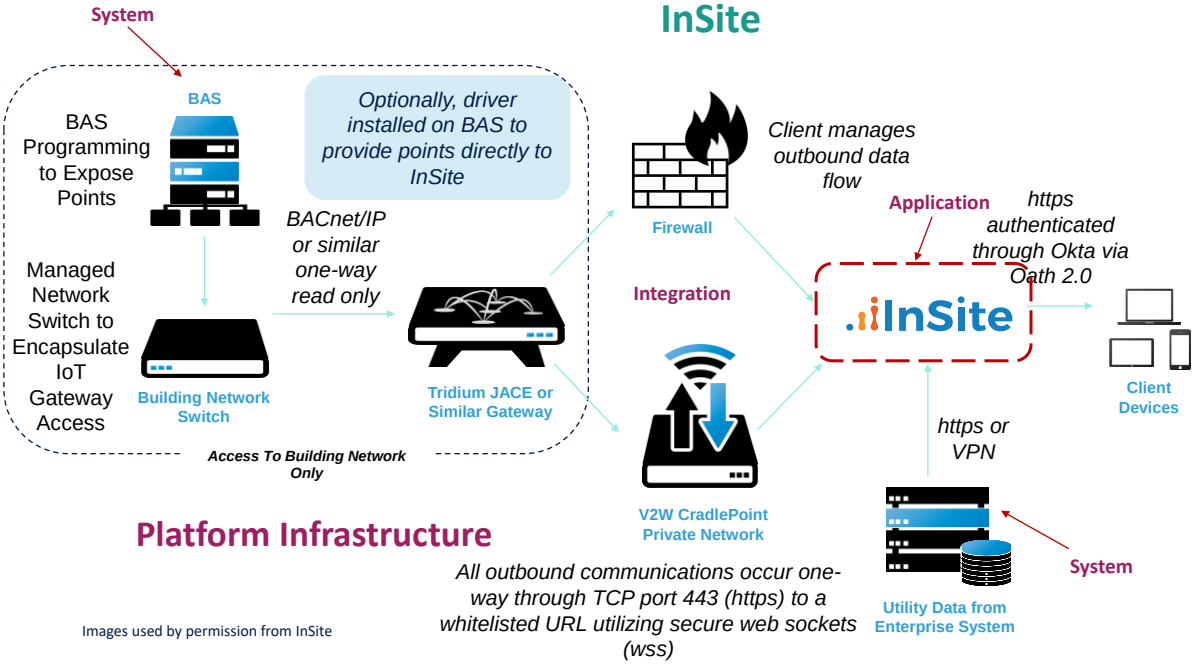

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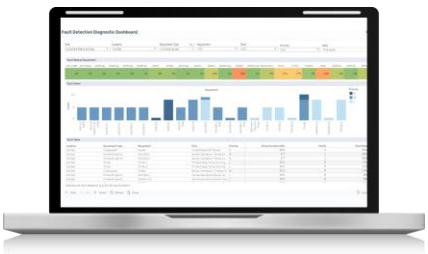
InSite

Algorithms

- Building systems data is continuously processed by a 'rules engine'
- Two types of rules:
  - **Fault detection rules** – detect deficiencies in system operation
  - **Rules for optimized operation** – alternative control scenarios that have a positive impact on IAQ, comfort, or energy consumption



1. Fault Dashboard

2. ECM Dashboard

Images used by permission from InSite

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InSite

Algorithms

- Generic rules library is applied to all datasets for common anomalies
- Custom rules for each dataset informed by
  1. Unique system and subsystem types
  2. Specific sequences of operations
- Advanced Diagnostics / Prognostics
  - Advanced rules that use machine learning to analyze extended histories and **predict equipment operation**
  - Equipment operation that outlies predicted operation flagged for investigation
  - Predict gradual operational shift or deviation that can be hard to identify with standard rules

Energy Prediction

Image used by permission from InSite

InSite

- A non-profit, integrated health-care delivery organization headquartered in Montgomery County, Maryland.
- Have multiple types of facility sites, complex systems, and varying levels of personnel interacting with facility data.

Services

- InSite **Full Platform Integration**
- **Energy Optimization**
- **Systems Optimization**
- **Health, Wellness, CSR**

Adventist HealthCare Case Study

Energy Conservation Measure (ECM)	Annual Savings*	kWh Savings*
Running CHP at High Utilization	$108,943.00	981,468
AHU Retro-commissioning	$70,769.00	637,559
Adjust Economizer Low Limits	$39,204.00	42,846 (Therms)
Analyzing Setpoints, Timers, and Sequence in Chillers	$20,691.00	209,000
Adjust Econ High Limit for AHU 1-2, 1-3, and 5-1	$12,318.00	124,426

*Numbers are calculated by the InSite Professional Engineers and then measured and verified by the Utility Rebate Program Engineers, before rebates are awarded.

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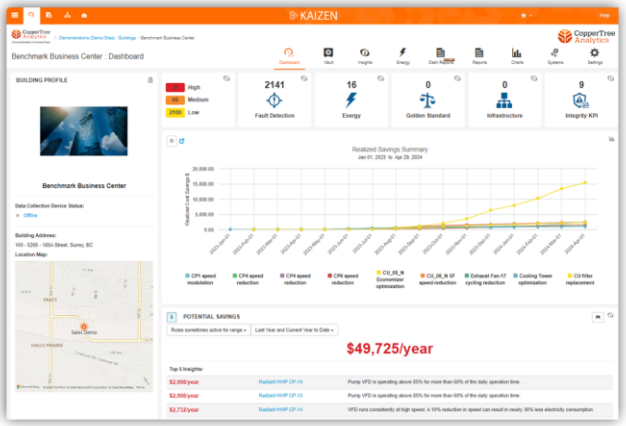
Example 3: Kaizen

Kaizen
CopperTree Analytics' Smart Building Solution

- Unified Energy Management and Information System (EMIS) platform
  - Fault Detection and Diagnostics (FDD)
  - Energy Information System (EIS)
  - Automated System Optimization (ASO)
  - Automated Commissioning (ACx)



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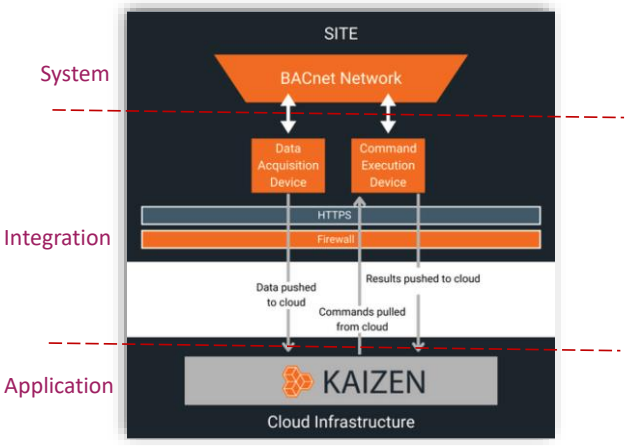
Refer to Video #9 Advanced Building Monitoring and Controls

Kaizen

Kaizen ASO and Kaisen ACx

- ASO: automated two-way interface optimization tool that elevates how Kaizen interacts with Building Automation Systems (BAS).
- ACx: automated commissioning process to systematically verify field devices associated with HVAC systems monitored and controlled by BAS platforms



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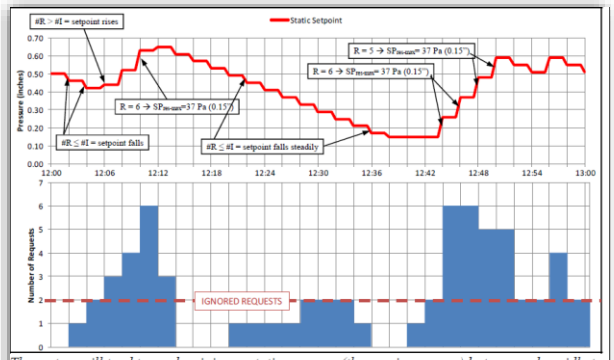
Refer to Video #9 Advanced Building Monitoring and Controls

Kaizen

Kaizen ASO: ASHRAE G36 Implementation

- Kaizen analyzes system performance to calculate the "Number of Requests" for each Plant/System.
- The BAS continuously receives these performance metrics from Kaizen to:
  - Adjust plant and AHU systems' supply static pressure and temperature setpoints.
  - Suppress rogue zones identified via statistical data.

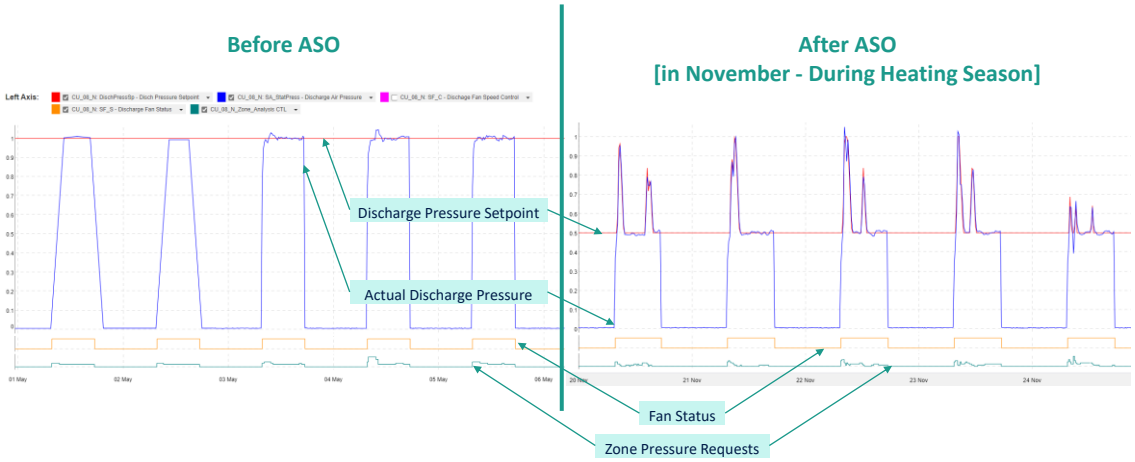


The system will tend towards minimum static pressure (thus saving energy) but respond rapidly to increasing demand from the terminal units. A cyclic pattern is characteristic of a robust Trim & Respond loop – the setpoint is not expected to remain static except at its minimum and maximum values. Note that this diagram was created for purposes of illustrating how requests are used to reset the setpoint and does not necessarily represent the expected behavior of an actual Trim & Respond loop, although the long, slow cycling of the setpoint value is typical of T&R control.

Used by permission from CopperTree Analytics

Kaizen

Kaizen ASO: Setpoint Reset Example



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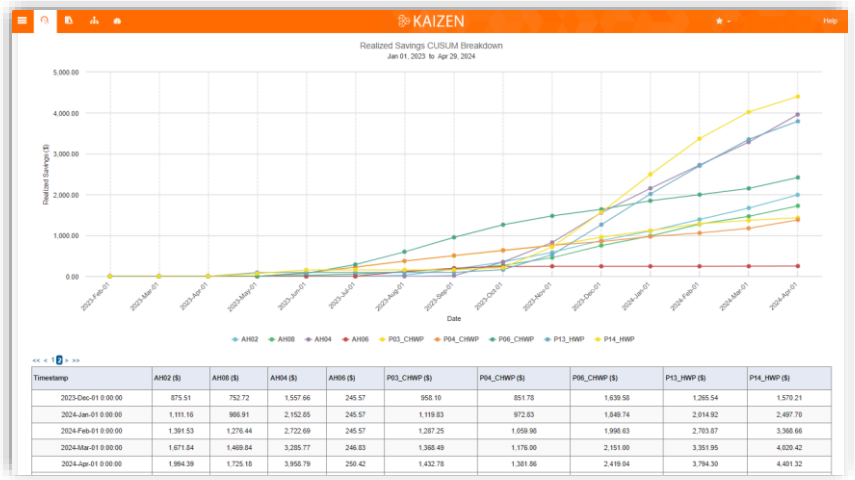
Kaizen

Kaizen ASO: Realized Savings Example



Timestamp	AH02 ($)	AH08 ($)	AH04 ($)	AH06 ($)	P03_CHWP ($)	P04_CHWP ($)	P06_CHWP ($)	P13_HWP ($)	P14_HWP ($)
2023-Dec-01 0:00:00	875.51	752.72	1,557.66	245.57	958.10	851.78	1,639.58	1,265.54	1,570.21
2024-Jan-01 0:00:00	1,111.16	986.91	2,152.85	245.57	1,119.83	972.83	1,849.74	2,014.92	2,497.70
2024-Feb-01 0:00:00	1,391.53	1,276.44	2,722.69	245.57	1,287.25	1,059.96	1,996.63	2,703.87	3,368.66
2024-Mar-01 0:00:00	1,671.84	1,469.84	3,285.77	246.83	1,368.49	1,176.00	2,151.00	3,351.95	4,020.42
2024-Apr-01 0:00:00	1,994.39	1,725.18	3,958.79	250.42	1,432.78	1,381.86	2,419.04	3,794.30	4,401.32

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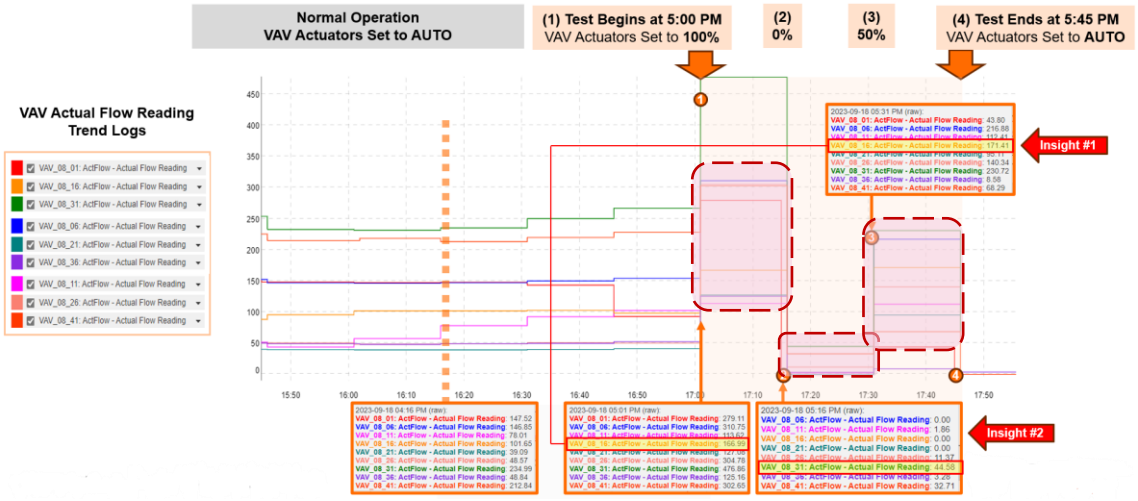
Kaizen

Kaizen ACx: Automated Verification Example



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Kaizen

Kaizen ACx: Automated Verification Example

Automated Commissioning (ACx) - Insights

Systems Commissioned: Terminal Units VAV_08_01 to VAV_08_45 served by CU_08_N

Insights generated from data collected between 2023-09-17 and 2023-09-23

Systems with triggered insights and summary of results.
Tests Performed:
- **Damper Feedback Mismatch**: Compares damper command and damper position feedback.
- **Damper Leakage**: Verifies airflow is less than 15% of the maximum airflow setpoint when the damper command is at 0%.
- **Damper Response**: Compares measurements at 50% and 100% damper commands.
- **Low Airflow**: Verifies airflow is higher than 85% of the maximum flow setpoint when the damper command is at 100%.

System Name	Insights Triggered	Tests	
VAV_08_16	1	low_airflow	Pass
		damper_feedback_mismatch	Pass
		damper_leakage	Pass
		damper_response	Exception: 171.408L/s measured when damper is at 50.0% which is higher than 166.991L/s measured when damper is at 100%.
VAV_08_31	1	low_airflow	Pass
		damper_feedback_mismatch	Pass
		damper_leakage	Exception: 44.578L/s measured when damper is at 0.0% and max. flow setpoint is 280.0L/s.
		damper_response	Pass

Insight #1

Insight #2

Used by permission from CopperTree Analytics

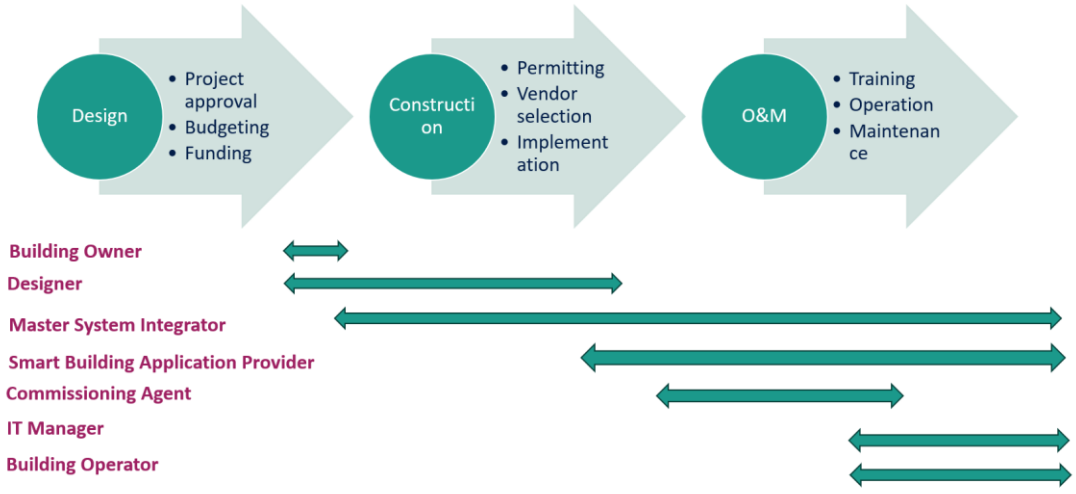
Other EMIS Case Studies

LBNL. 2020. Proving the Business Case for Building Analytics.

https://buildings.lbl.gov/publications/proving-business-case-building

Smart Building Project Process and Stakeholder Roles

Smart Building Project Implementation Process



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Who is Doing What?

Building Owner

- Decision maker
- (Need to be) Openminded. Accept change.
- Setup project goals and objectives

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Who is Doing What?

Designer

- Understand the value of smart building technologies and explain it to building owner
- Work with smart building solution providers and come up with smart building application strategies
- Integrate the vision into design, construction, and operation documents

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Who is Doing What?

Master System Integrator

- Connect building systems to enable data flow, storage, and intelligent analysis across multiple systems
- Can create custom APIs to interconnect different building technology systems
- Work with designer and IT manager in system integration design, and subsystems selection
- Has the technical and project management skills

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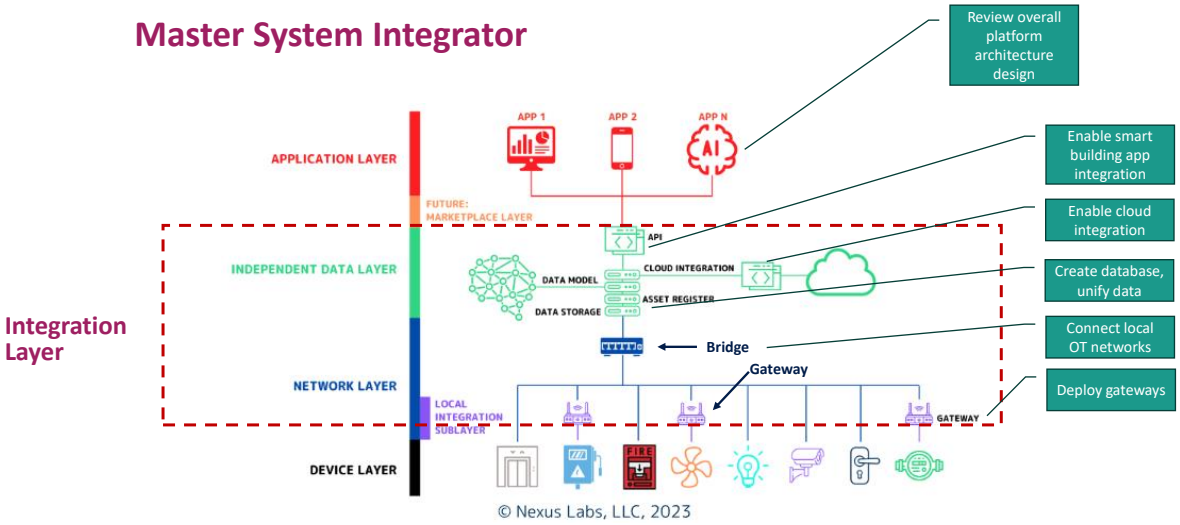
Who is Doing What?

Master System Integrator



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Who is Doing What?

Facility Management / Building Operator

- Mange contracts and assess overall usefulness of new technology
- Maintain relationship with internal IT department on cybersecurity and software patches/updates
- Need to learn the smart building technologies and the applications implemented
- Use the application effectively to receive maximum benefits

Who is Doing What?

Commissioning Agent

- Ensuring the interoperable interfaces are present and operating as specified
- Benefits from new data sources that reduce the effort for traditional commissioning tasks
- Validating the integrated applications function as specified
- Verifying core system functions are not compromised by new applications, and meet the original design intent

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Who is Doing What?

IT Manager

- May not be familiar with Operation Technology (OT) networks and protocols
- Maintain building network infrastructures (both IT and OT)
- Work with MSI in executing the system integration
  - Provides LAN addresses
  - Responsible for ensuring cybersecurity for the organization and policies

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Smart Building Application Challenges

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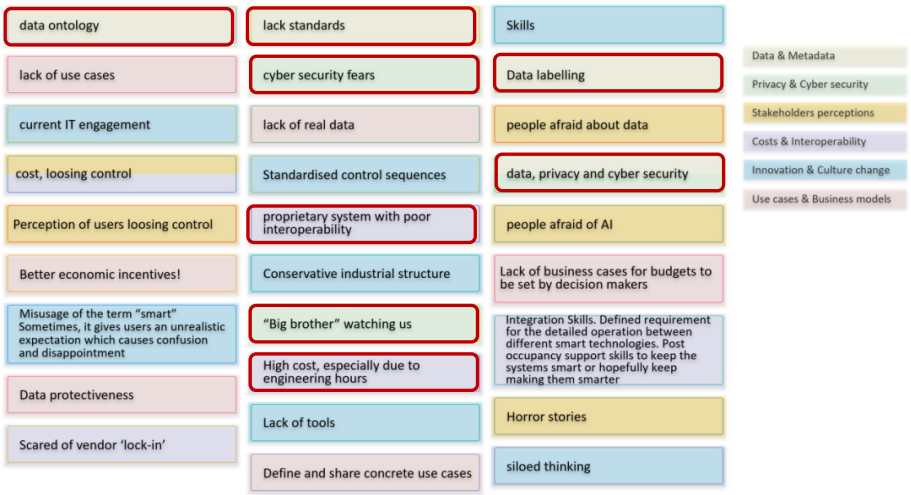
Barriers to Smart Building Application Implementations



Source: International Energy Agency. 2023. Data-Driven Smart Buildings: State-of-the-Art Review

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Barriers to Smart Building Application Implementations

- Involve many stakeholders
  - Building owner
  - Designer
  - Master system integrator
  - Smart building technology vendor
  - IT manager
  - Building operator
  - Utility provider
- Complex system architecture and control methods. Difficult for most people to understand
- Integration challenges:
  - IT vs. OT
  - Various communication protocols. Cybersecurity
- Lack of standardized building system data and data models
- Expertise to cover so many different technology areas
- Use cases, customer value proposition, and project cost effectiveness need be well-documented through third-party field validations

Future Trends

Future Trends

- Fully integrated building system components
  - Integrate all sensors, controllers, and controlled devices in various building systems
  - Shared data for smart building applications
- AI and ML applications in smart buildings
- Large Language Model (LLM) applications to reduce O&M cost
- Standardized data models for large-scale, low-cost smart building application implementations
- Adaptive and autonomous controls
  - Adapt to changing conditions in real-time – occupancy, weather, utility pricing, etc.
  - Self-tuning
  - Self-calibration
  - Autonomous control / generative autonomy?
- Edge computing
  - Decentralized control at the building system/ device level. Optimization and coordination at the supervisory level
- Smart communities and smart cities

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