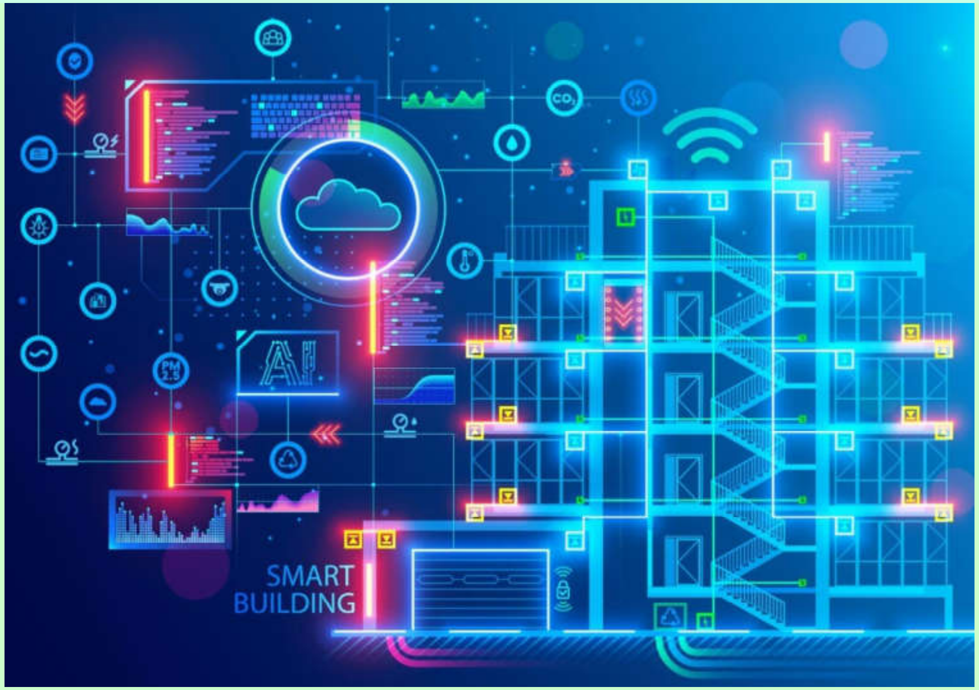
IDAT7219 Smart Building Technology

http://ibse.hk/IDAT7219/



Building Analytics

智能大廈科技

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Contents

Basic principles

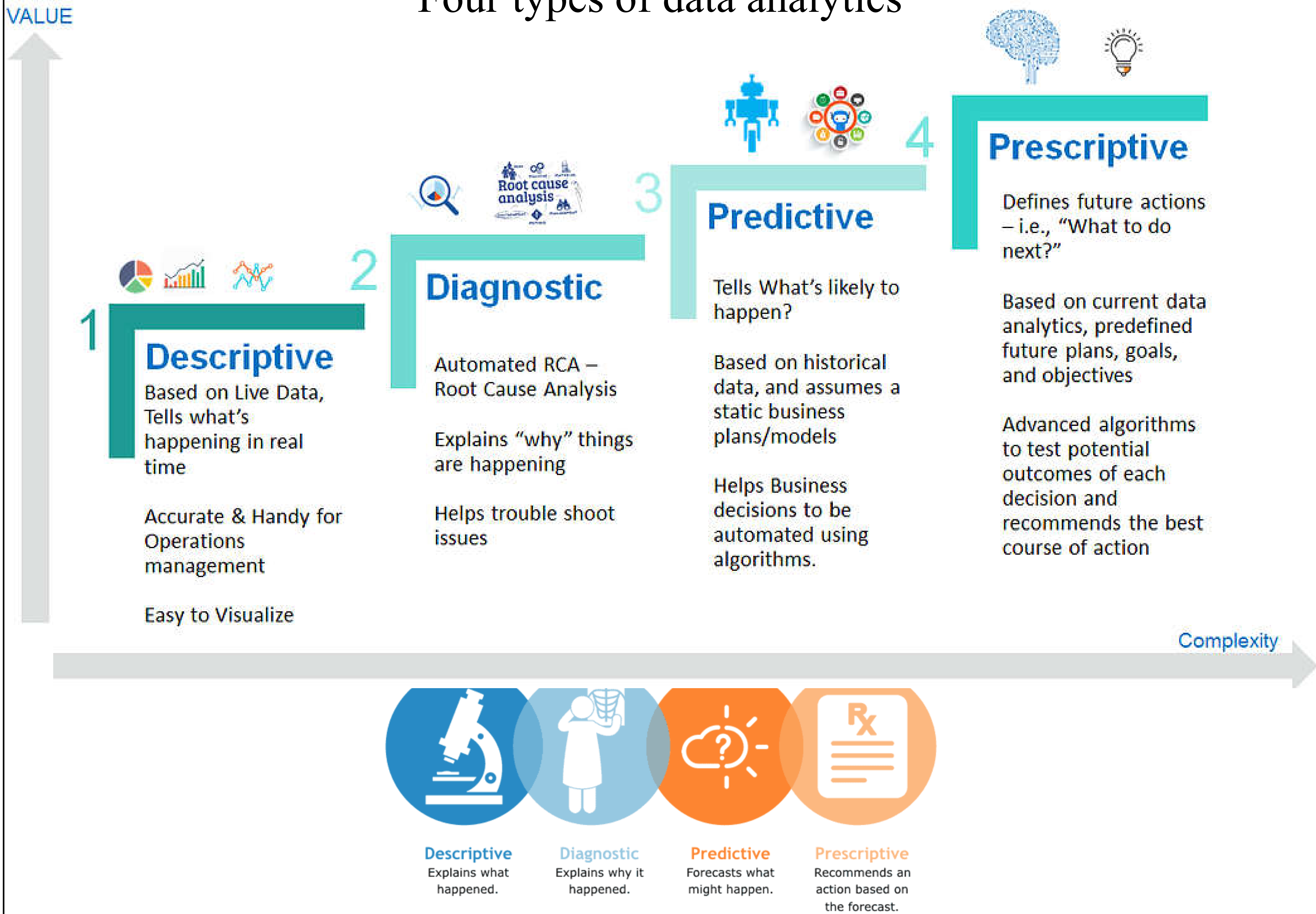
- Data analytics
  - The process of analyzing raw data using quantitative methods to find patterns & extract meaning to offer answers to crucial questions
  - Basic functions of data analytics:
    - 1. Gather hidden insights
    - 2. Reports generation
    - 3. Perform a technical or market analysis
    - 4. Enhance business requirements & customer experience

數據分析

Basic principles

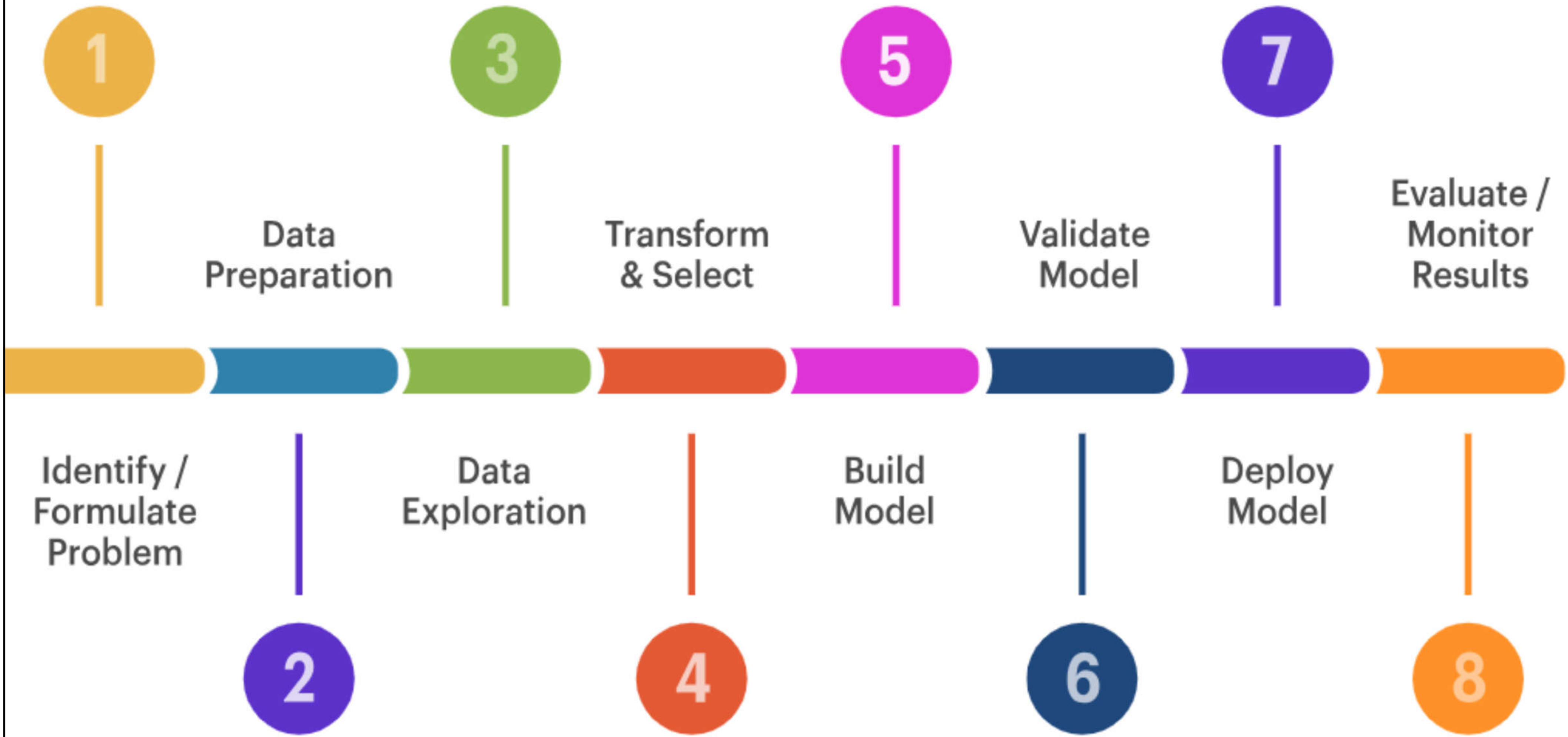
- Four types of data analytics:
  - 1. Descriptive Analytics (what happened?)
    - Examine past data & provide insights into patterns, trends & key metrics
  - 2. Diagnostic Analytics (why did it happen?)
    - Identify the root causes of a particular outcome
  - 3. Predictive Analytics (what is likely to happen in future): predict future events or outcomes
  - 4. Prescriptive Analytics (what is the best course of action to take?): to optimize outcomes

Four types of data analytics



(Source: https://medium.com/co-learning-lounge/types-of-data-analytics-descriptive-diagnostic-predictive-prescriptive-922654ce8f8f)

Predictive analytics process lifecycle

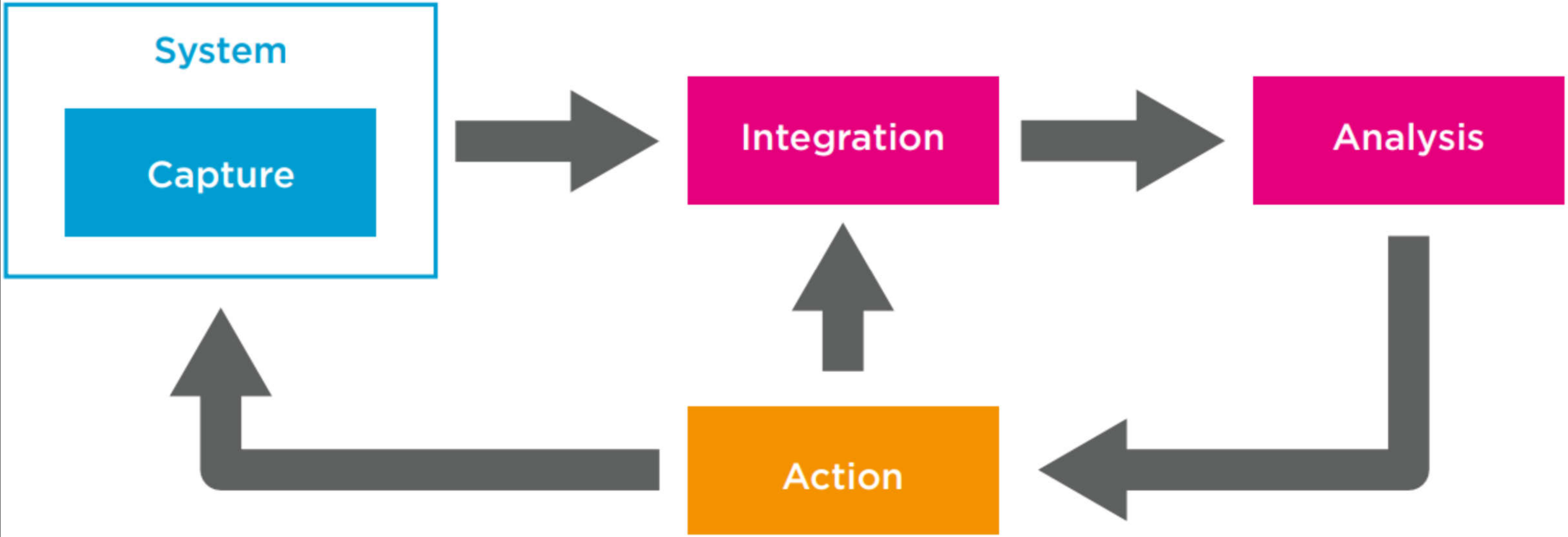


(Source: https://www.sigmadatasys.com/services/predictive-analytics-services/)

Basic principles

- Analytics solutions are beginning to shift the building systems to a more distributed platform with hybrid & predictive control based on multiple inputs & outputs
- Current methods focus mostly on energy management
- However, building data analytics can also provide cost savings through optimized O&M as well as improved occupant comfort

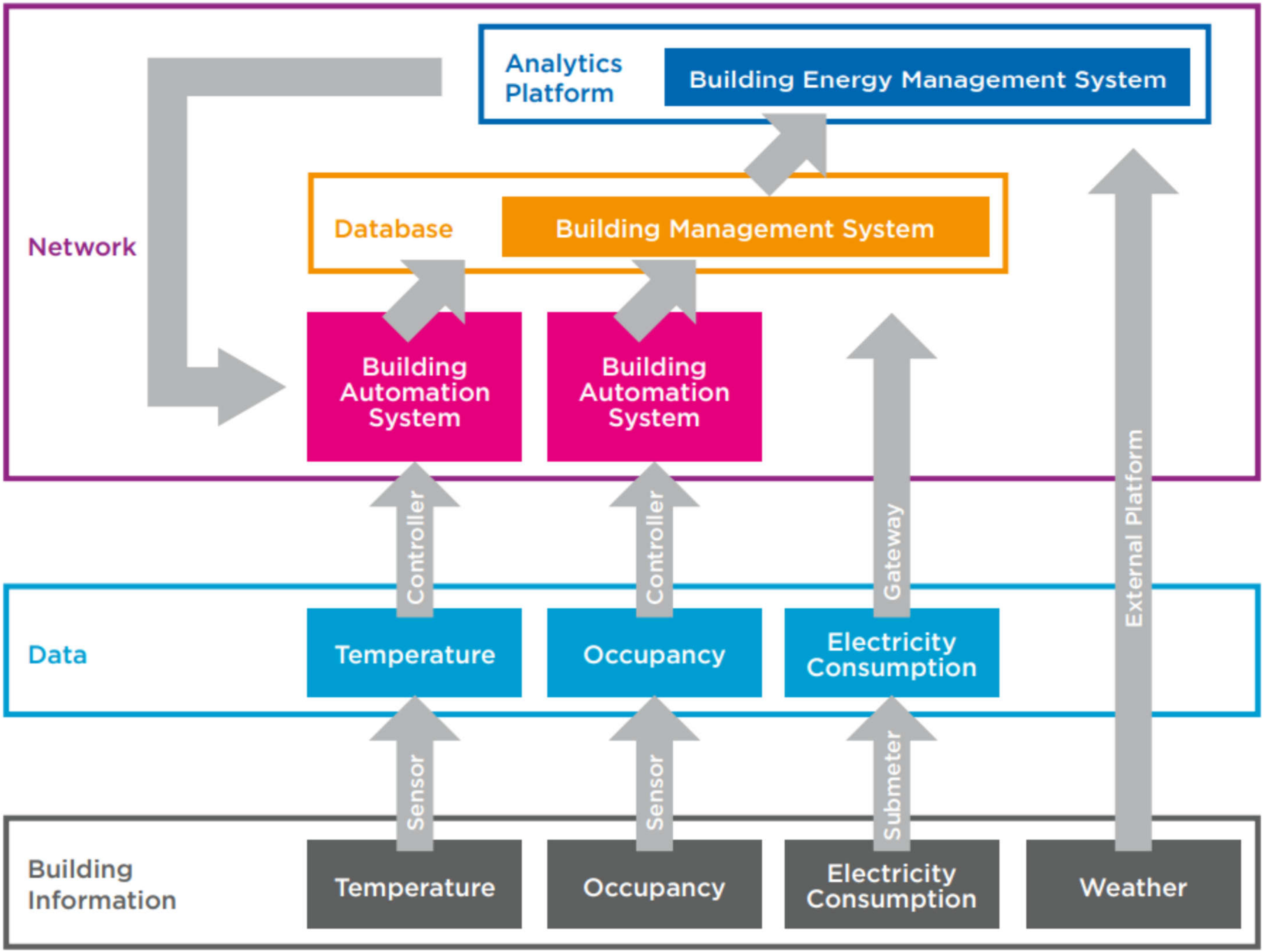
Basic concept of the analytics process
(using information technology tools to support decision making)



- Analytics includes the software layer & underlying algorithms that enable building owners, managers & operators to make more strategic decisions based on a more holistic insight into how their facilities are operating
- This process requires data from a system to be captured, analyzed & communicated in order to direct changes that meet specific business objectives
- It requires integration of data from several sources of information (from building systems or external)

(Source: Navigant Research)

Generic building data flow



(Source: Navigant Research)

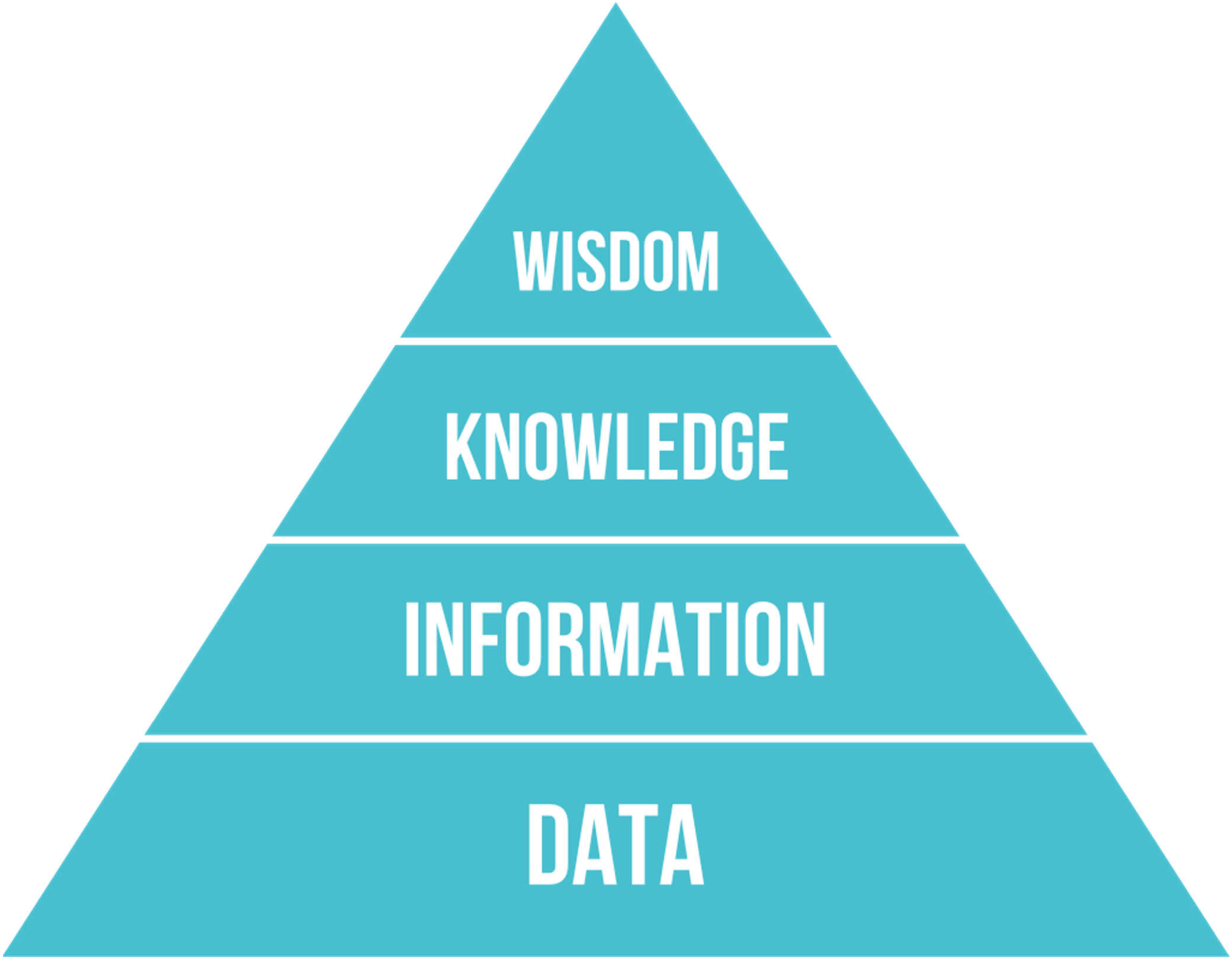
Basic principles

- Building data flow
  - Data capture starts with sensors (e.g. temperature, occupancy, air quality & energy consumption)
  - Integration of data stream through a building network or BAS/BMS
  - Data analysis occurs either on-premise on a local server or with a cloud-based service
  - Most analytics solutions compare with external data (e.g. weather, average building performance, building occupancy & space utilization)

Basic principles

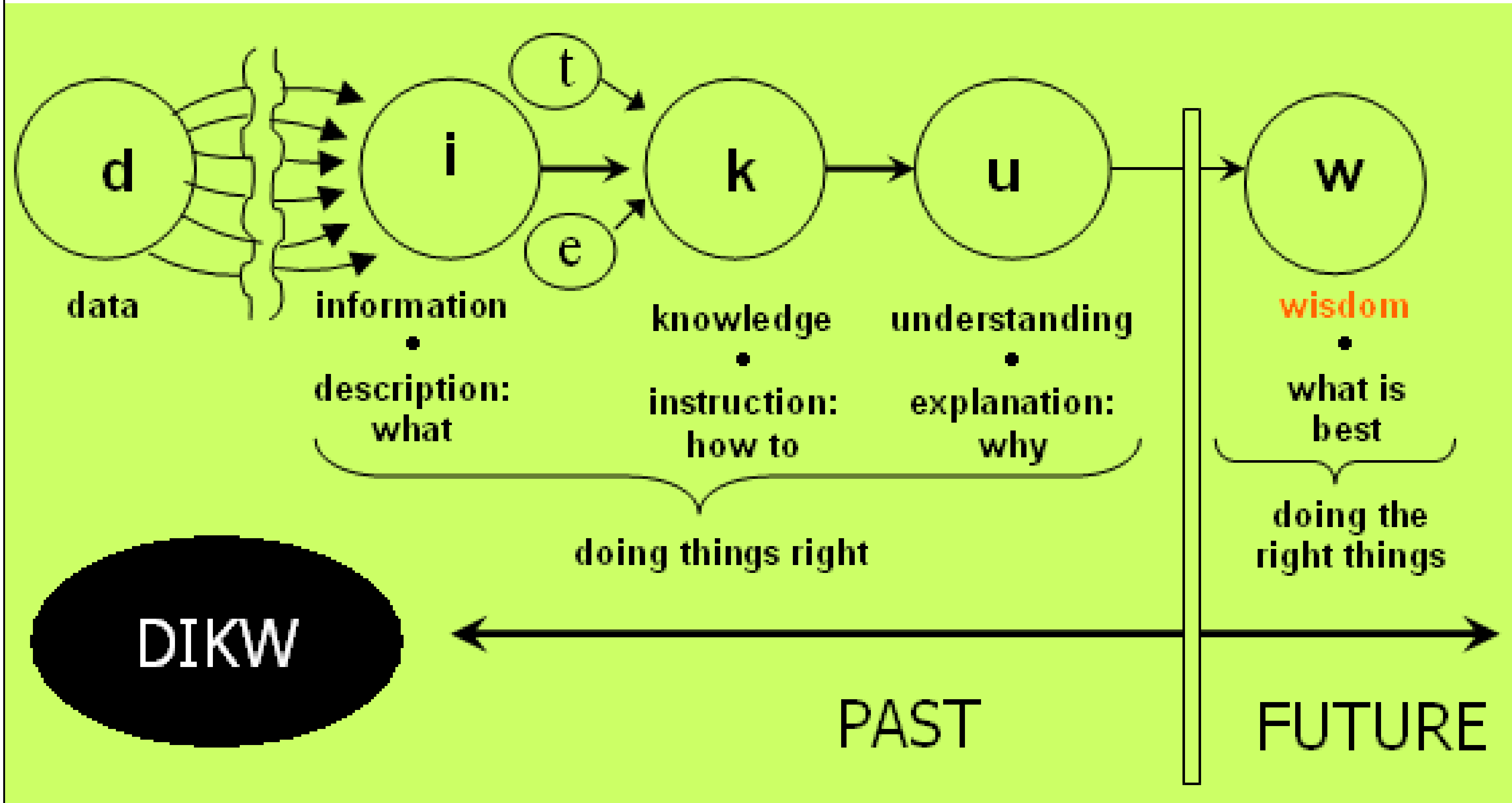
- Building data analytics can be viewed as the tool that gives business value to large data sets
  - Smart buildings generate a massive amount data
- On its own, big data, or any data for that matter, cannot actually solve any problem or do anything. It is only through the collection, integration & use of the data in analysis that value can be provided, turning data into information & ultimately knowledge/wisdom

The DIKW (data, information, knowledge, wisdom) pyramid

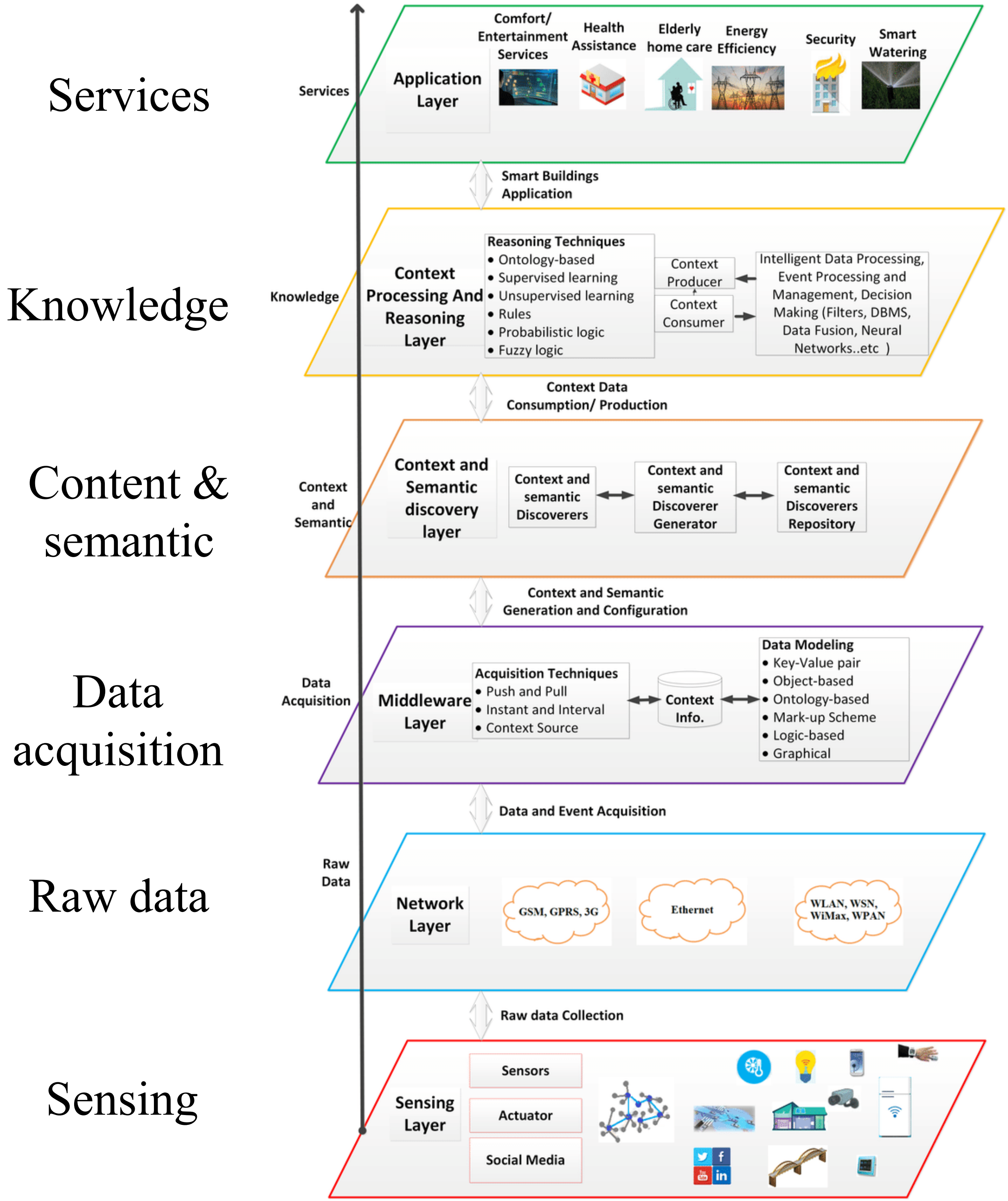


(Source: https://en.wikipedia.org/wiki/DIKW_pyramid)

A flow diagram of the DIKW (data, information, knowledge, wisdom) hierarchy



(Source: https://en.wikipedia.org/wiki/DIKW_pyramid)



Layers of the base IoT architecture that serves as the foundation for smart buildings

(Source: Qolomany B., Al-Fuqaha A., Gupta A., Benhaddou D., Alwajidi S., Qadir J. & Fong A. C., 2019. Leveraging machine learning and big data for smart buildings: a comprehensive survey, *IEEE Access*, 7: 90316-90356. https://doi.org/10.1109/ACCESS.2019.2926642)

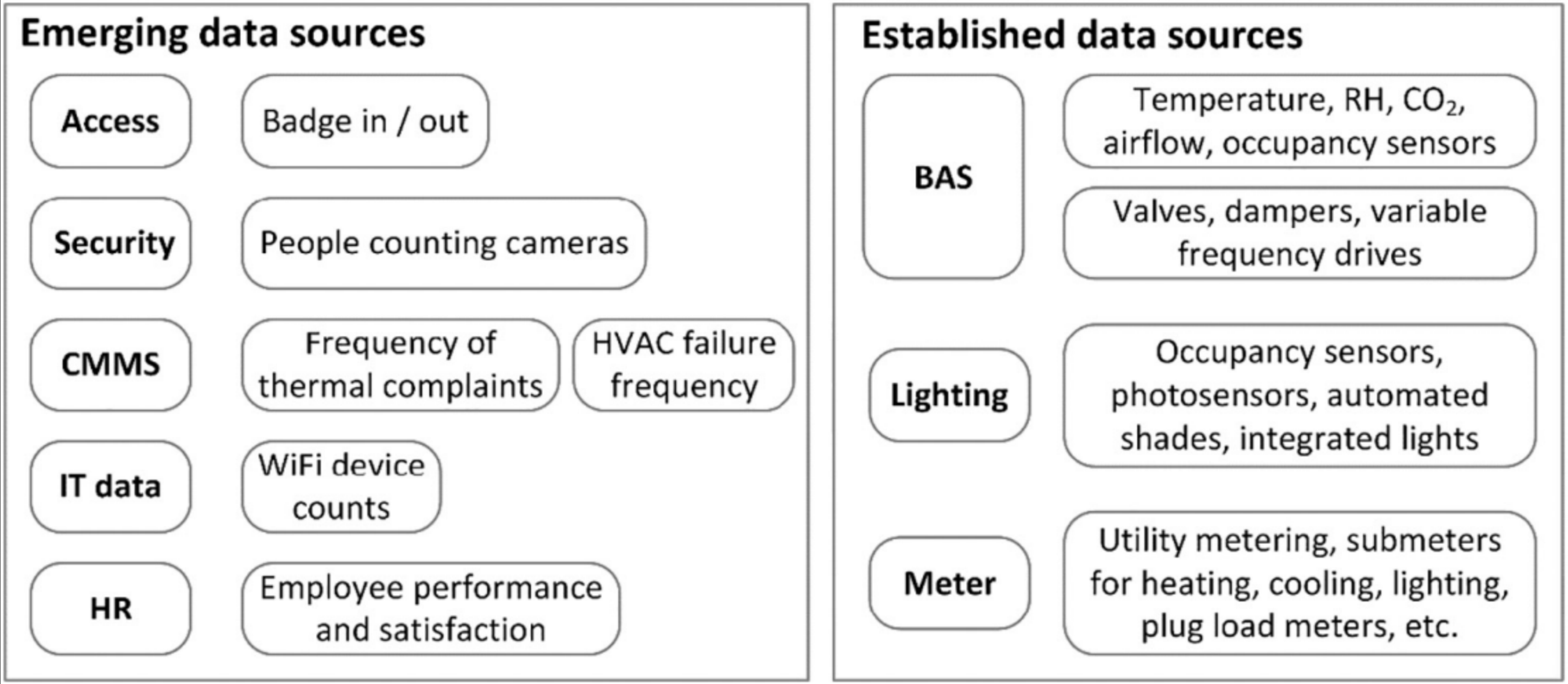
Building data analytics

- Data available from building systems:
  - Energy data from utility meters & other submeters
    - e.g. power (kW), current (A), frequency (Hz), voltage (V), power factor, total harmonic distortion (THD)
  - HVAC data from sensors
    - e.g. temperature, airflow, humidity, occupancy, equipment operation
  - Lighting data from photo-sensors
  - Security & access controls
- External data (e.g. weather, utility prices)

Building data analytics

- Types of dataset
  - Numerical data (continuous or discrete numbers)
  - Categorical data (categories or labels of data)
  - Text data (words & sentences)
  - Image data (e.g. from computer vision)
  - Audio data (sound waves, text-to-speech)
  - Video data (e.g. from CCTV camera)
  - Time-series data (at regular time intervals)

Established & emerging data sources in buildings useful for data analytics to improve building performance



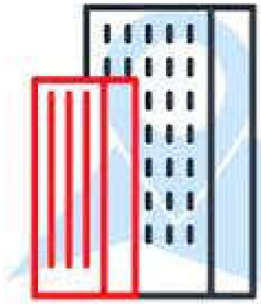
CMMS = computerized maintenance management systems
IT = information technology
HR = human resources
BAS = building automation system

(Source: Gunay H. B., Shen W. & Newsham G., 2019. Data analytics to improve building performance: A critical review, *Automation in Construction*, 97: 96-109. https://doi.org/10.1016/j.autcon.2018.10.020)

Building data analytics

- Data integration
  - Using building communication protocols (e.g. BACnet, LonWorks, KNX, DALI, Modbus)
  - Internet protocols & interoperability issues
  - Data volume, interval & communication speed
- Data monitoring & analytics solutions
  - Monitor equipment data & provide that data to remote expert engineering analysts to aggregate diagnostic results, track progress & consult with stakeholders to solve problems if needed

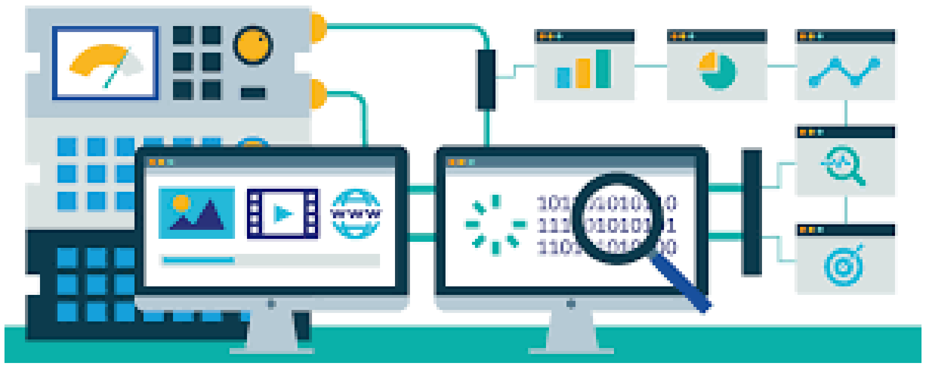
Building data analytics



- Big data analytics in smart buildings
  - The next generation in business & operational intelligence derived from the analysis of data integrated across multiple streams or sources for the purposes of overall system understanding, performance & optimization
  - Can provide new insight to key decision makers exploring opportunities for investment & operational management changes

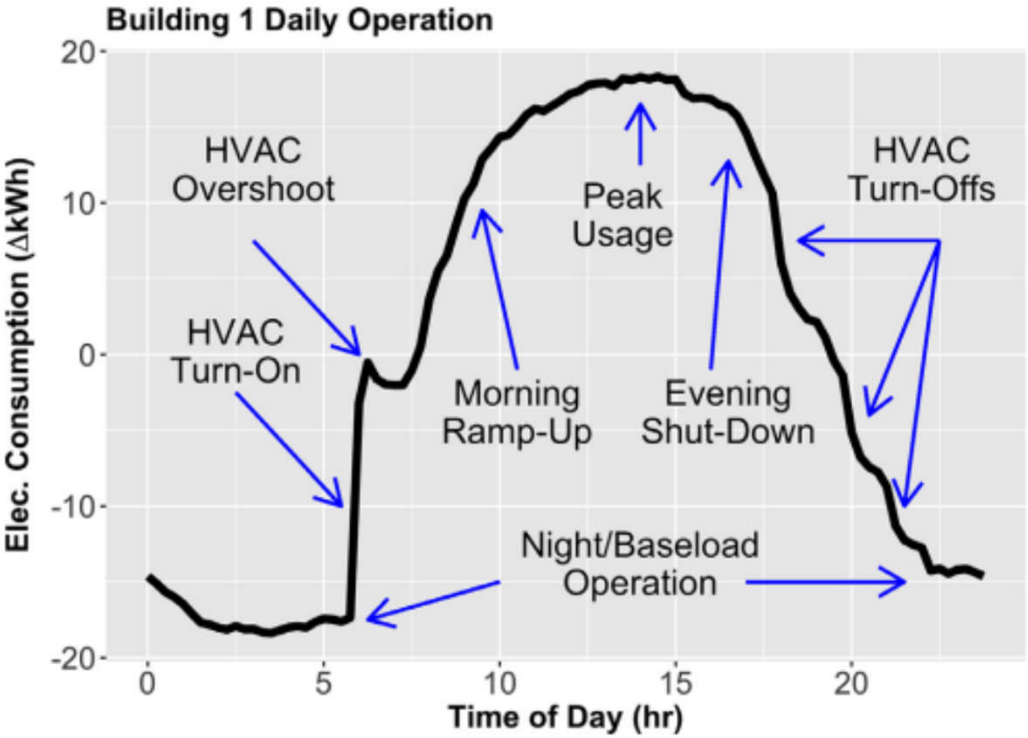
Business benefits of building analytics

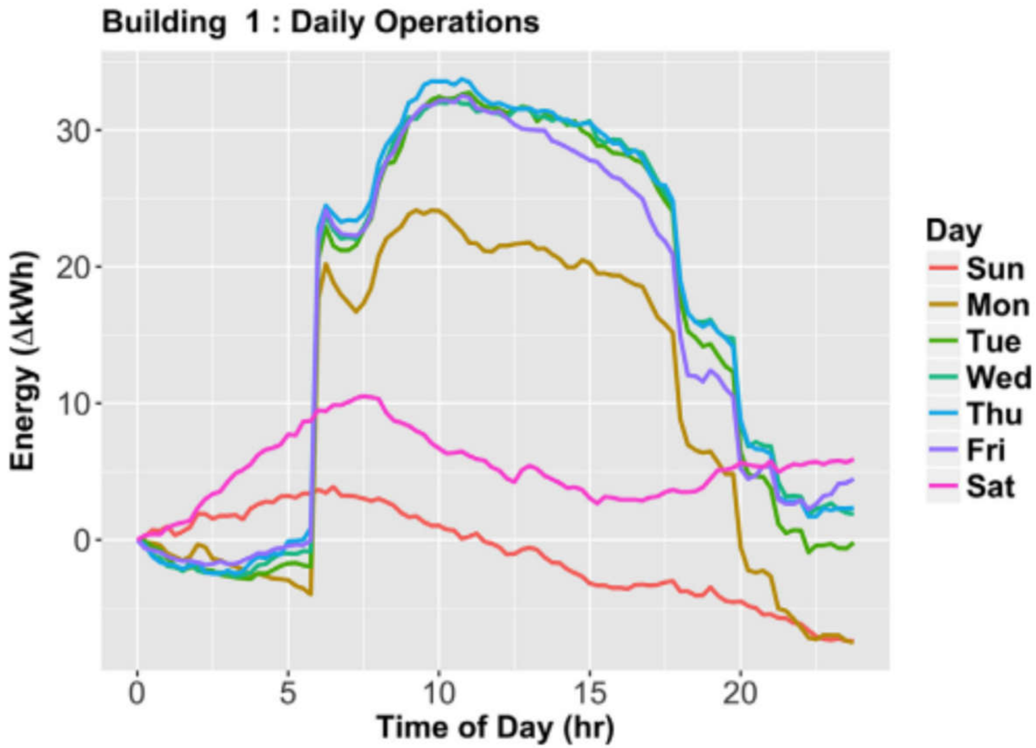
- Benchmark, assess & compare the performance of facilities
- Accurately forecast & budget utility consumption expenses
- Intelligently correlate parameters to investigate & explain events & incidents
- Strike the right balance between performance indicators without sacrificing one for another (e.g., occupant comfort vs. energy efficiency)
- Perform predictive maintenance to help avoid unexpected equipment failures
- Use analytics scores to gain quick insights on facility performance
- Introduce new features & functionalities leveraging building analytics



(Source: https://www.cognizant.com/us/en/glossary/building-analytics)

Identification of HVAC system operational characteristics for daily operations over various days of the week





(Source: Pickering E. M., Hossain M. A., French R. H. & Abramson A. R., 2018. Building electricity consumption: Data analytics of building operations with classical time series decomposition and case based subsetting, *Energy and Buildings*, 177: 184-196. https://doi.org/10.1016/j.enbuild.2018.07.056)

Building data analytics

- Typical building data analytics processes:
  - Establishing ground truth data (correct operation)
  - Data validation (ensure clean & error-free)
  - Fault detection & diagnosis (FDD)
  - Energy consumption prediction
  - Generation of maintenance schedules
  - Estimation of occupant comfort level
  - Building simulation & modelling

Building data analytics

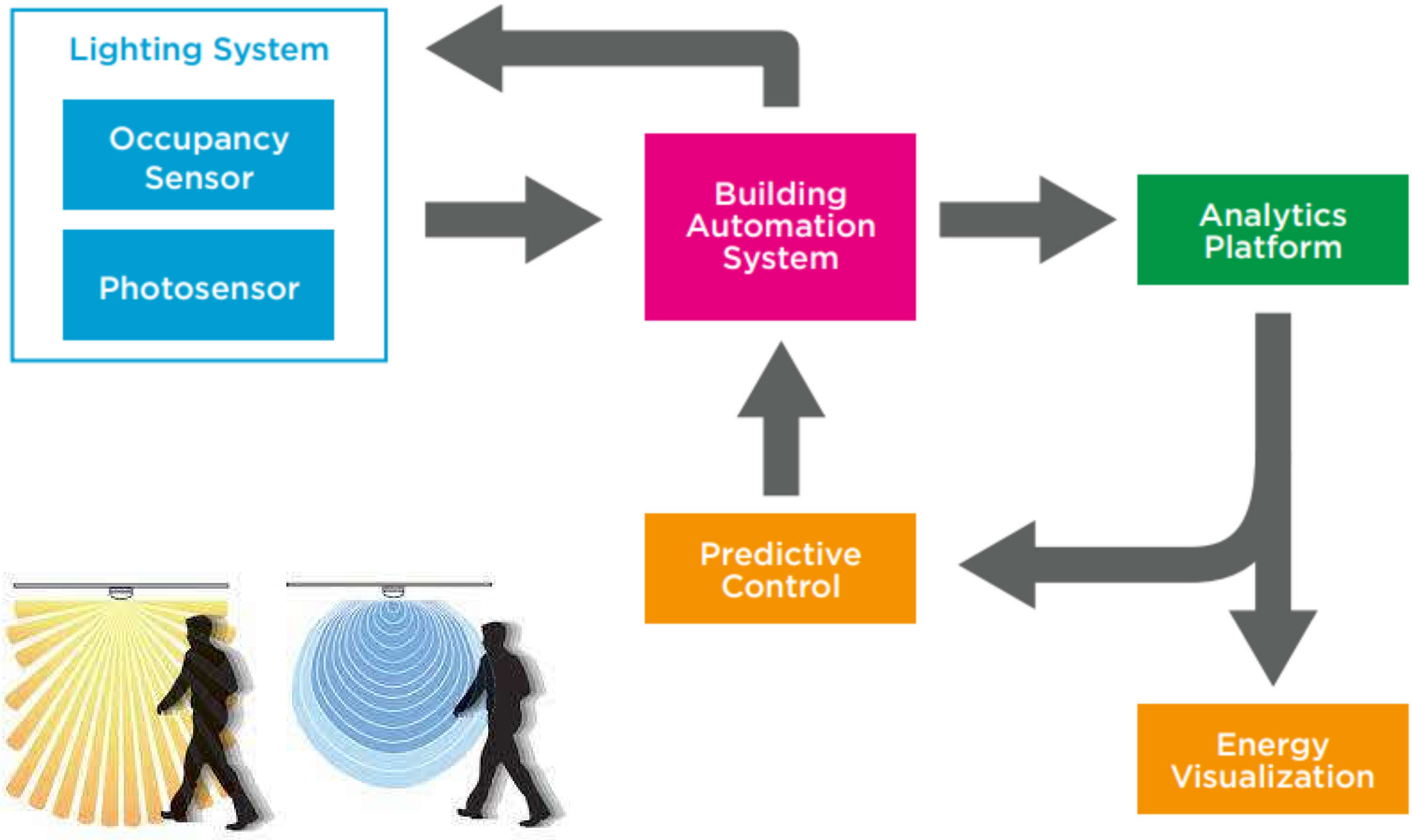
- Four main functions of building analytics:
  - 1. Visualization & reporting
    - Mapping, dashboards, periodic summaries
  - 2. Fault detection & diagnostics
    - Real-time analysis & alerts, performance analysis, historic benchmarking
  - 3. Predictive maintenance & continuous improvement
    - Capital planning, monitoring-based commissioning
  - 4. Optimization

Customer value propositions for building analytics

	Visualization and reporting	Fault Detection and Diagnosis	Predictive Maintenance and Continuous Improvement	Optimization
Key Benefits for the End User	• Economic metrics on efficiencies • Benchmarking • Customized data presentment	• OPEX savings • Prioritized fault management • Time-saving equipment management	• Capital planning • Efficient utilization of O&M human resources • Eliminate building drift	• Economic risk management • Sustainability / GHG improvements • Integrated energy and business strategies
Office / Enterprise	• Enhanced portfolio visibility for the C-suite	• Enhanced tenant comfort and retention	• Increased asset value of intelligent buildings	• CSR demonstration • Space utilization
Retail	• Comparative OPEX	• Customer comfort	• Reduced maintenance services costs	• Customer movement • Branding

(Source: Navigant Research)

Example of analytics process for lighting applications



(Source: Navigant Research)

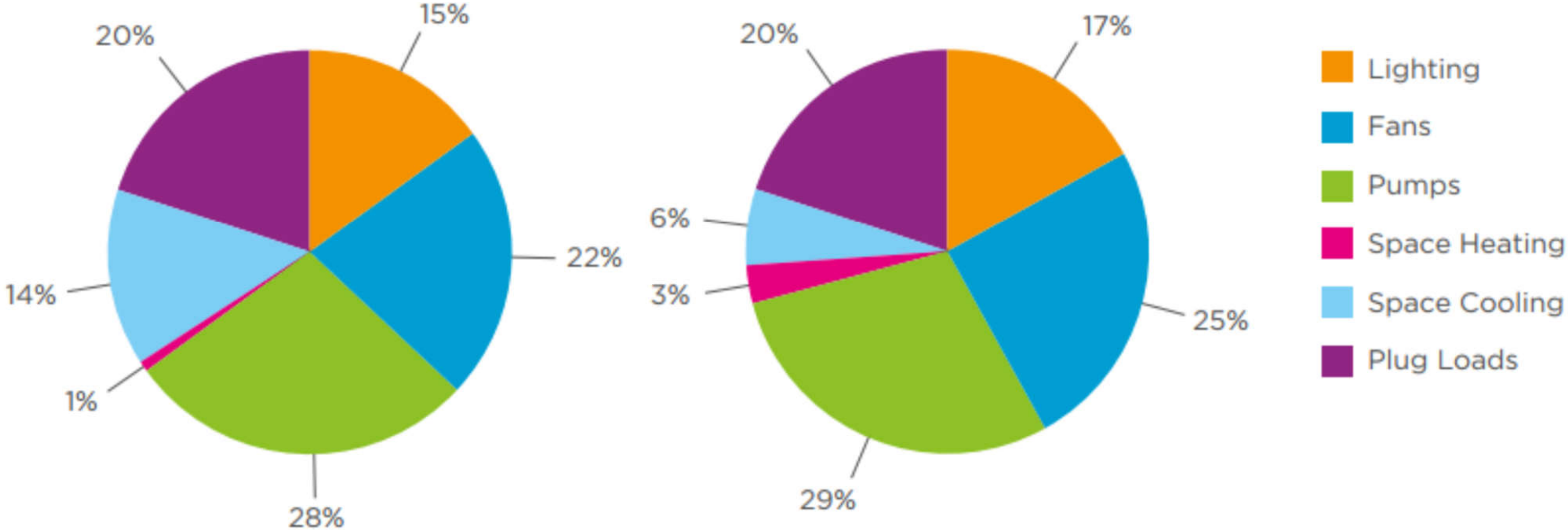
Example of hourly electrical demand heat map reporting

	SUN	MON	TUE	WED	THU	FRI	SAT	Hourly Avg
Midnight	137	159	160	155	137	142	145	148
1:00 AM	134	145	156	146	131	136	140	141
2:00 AM	131	139	143	140	134	129	138	136
3:00 AM	129	131	131	137	134	131	137	133
4:00 AM	125	127	134	138	133	128	140	132
5:00 AM	130	125	138	140	135	132	137	134
6:00 AM	129	132	142	141	133	131	137	135
7:00 AM	130	137	166	154	149	141	143	146
8:00 AM	151	175	192	171	165	154	151	166
9:00 AM	169	183	187	175	168	155	164	172
10:00 AM	165	181	190	176	172	166	162	173
11:00 AM	162	184	191	177	168	169	161	173
Noon	165	186	192	178	172	169	162	175

(Source: CABA, 2015. *Intelligent Buildings and Big Data*, Continental Automated Buildings Association (CABA). https://www.ashb.com/wp-content/uploads/2020/07/2015-CABA-Intelligent-Buildings-and-Big-Data-Full-Report.pdf)

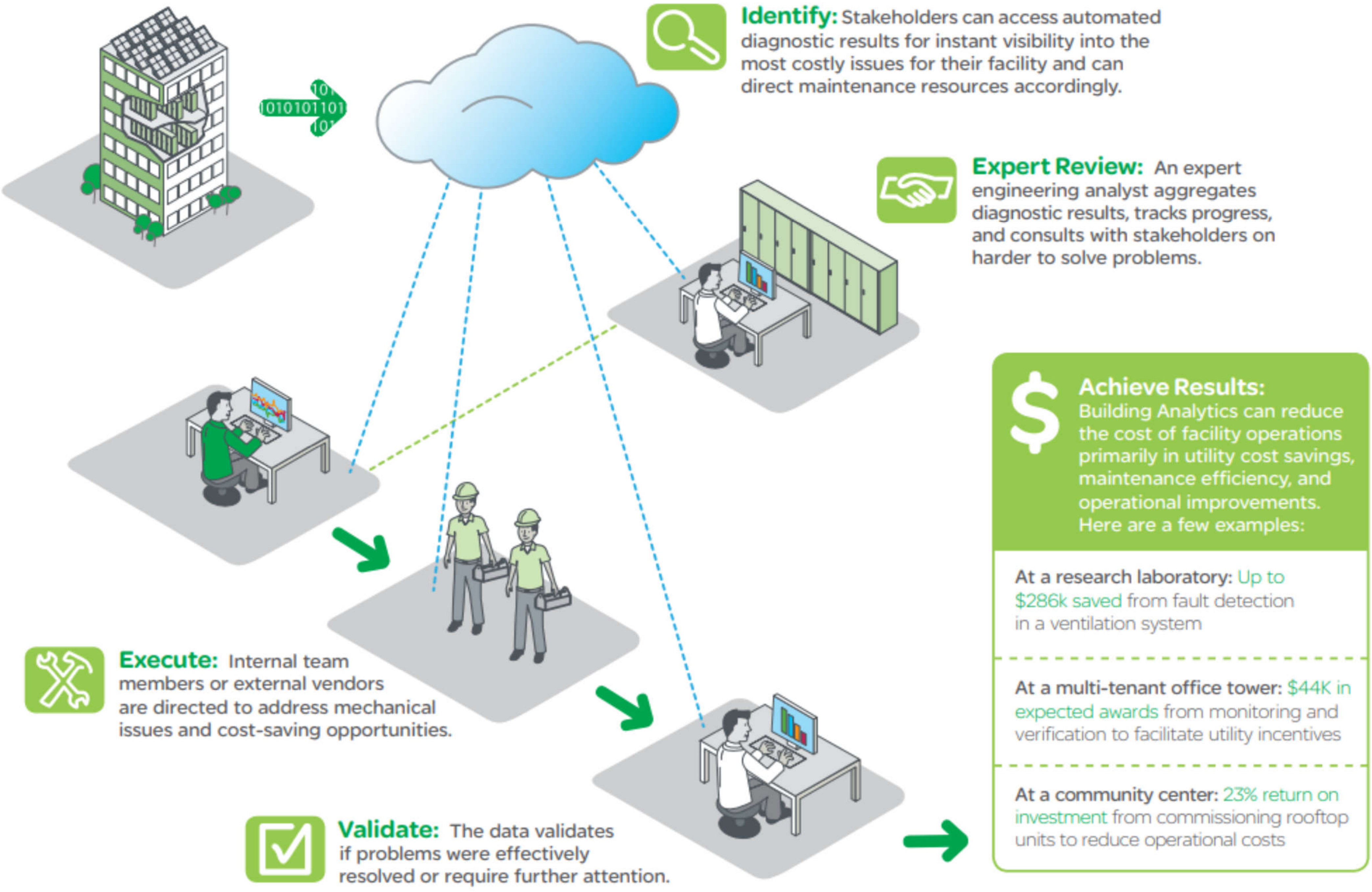
Example of energy use & load analysis summaries

	Reporting Period					Year to Date				
	Max Demand (kW)	Min Demand (kW)	Average Demand (kW)	Total (kWh)	Percent Total	Max Demand (kW)	Min Demand (kW)	Average Demand (kW)	Total (kWh)	Percent Total
Lighting	32.2	16.9	24.3	18,089	15%	36.3	13.3	25.0	141,075	16%
Fans	49.3	25.3	35.7	26.596	22%	61.0	23.1	38.1	214,917	25%
Pumps	56.3	10.6	45.2	33,670	28%	61.0	1.2	44.7	252,186	29%
Space Heating	18.2	0.0	1.2	917	1%	31.2	0.0	4.4	24,569	3%
Space Cooling	61.2	1.3	23.4	17,420	14%	61.2	0.7	8.9	49,914	6%
Plug Loads	58.7	0.0	32.8	24,441	20%	76.9	0.0	30.8	173,646	20%



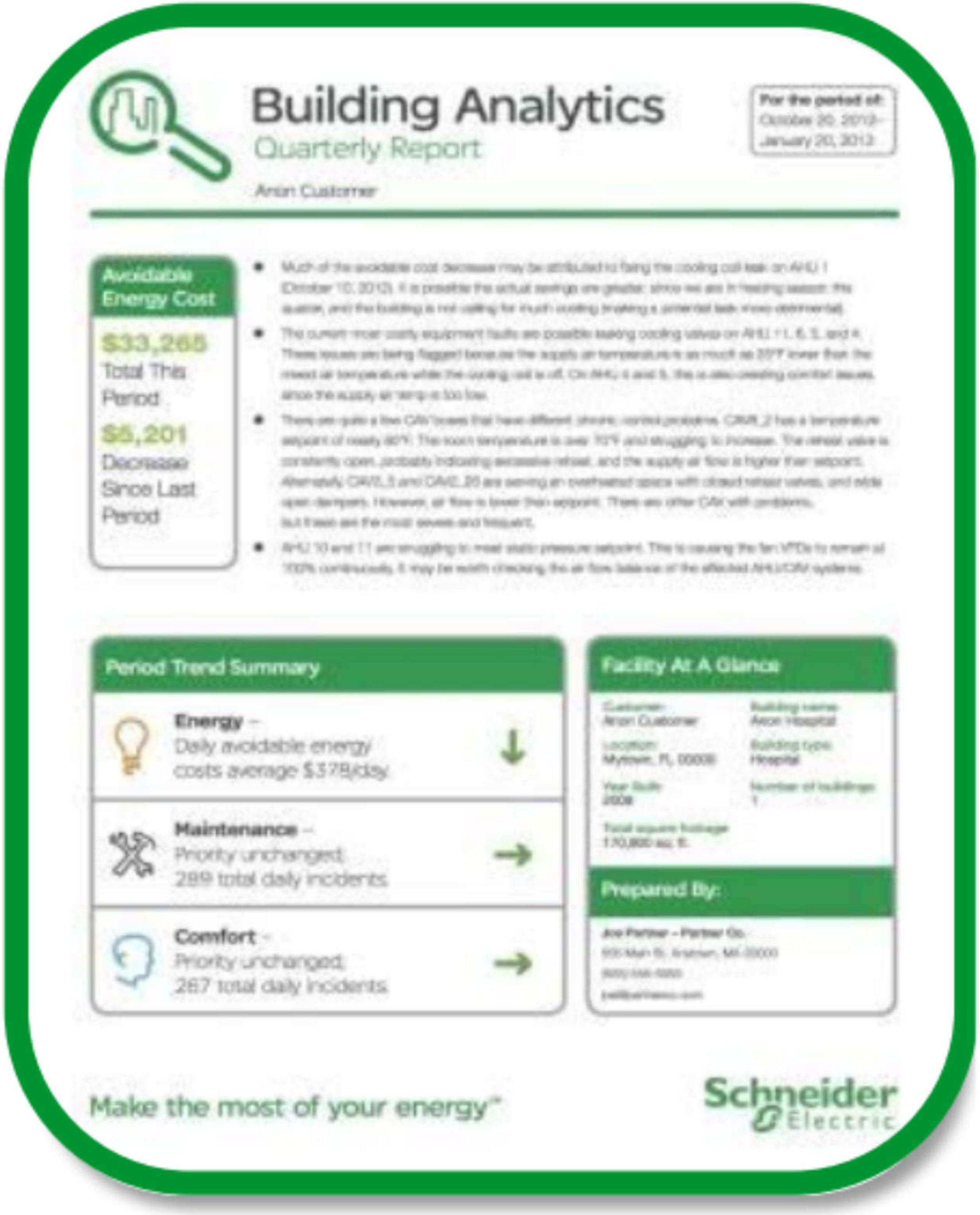
(Source: CABA, 2015. *Intelligent Buildings and Big Data*, Continental Automated Buildings Association (CABA). https://www.ashb.com/wp-content/uploads/2020/07/2015-CABA-Intelligent-Buildings-and-Big-Data-Full-Report.pdf)

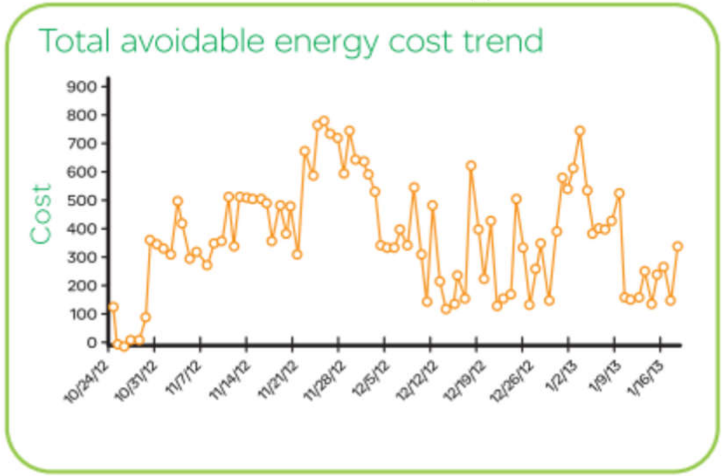
Cloud-based building analytics

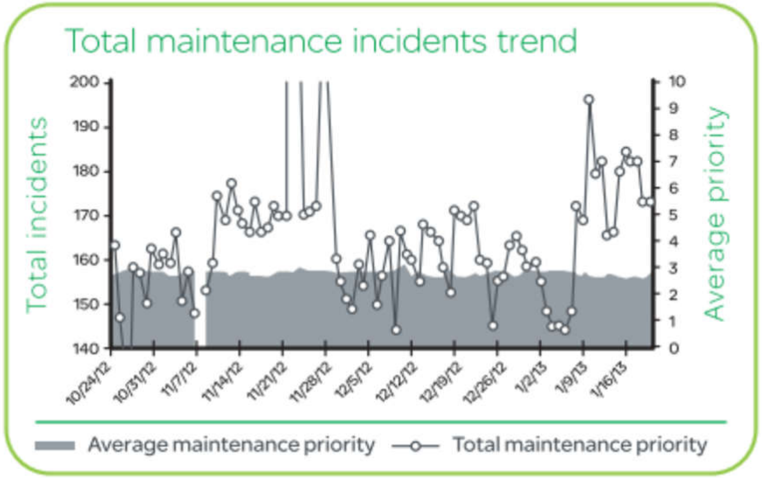


(Source: http://www.schneider-electric.com/)

Building analytics report & trend analysis over time to track performance

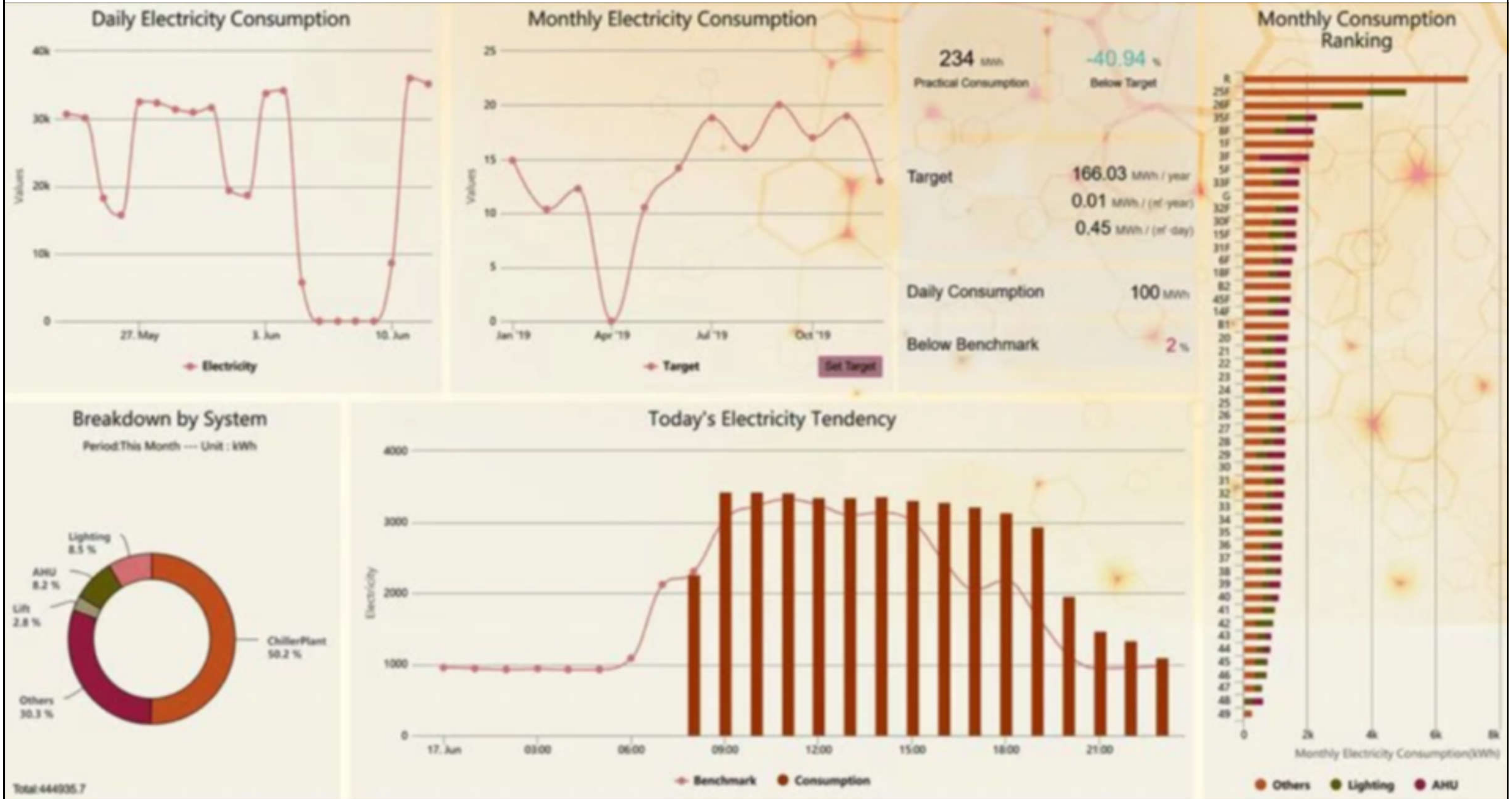






(Source: http://www.schneider-electric.com/)

Example of a dashboard for building data analytics

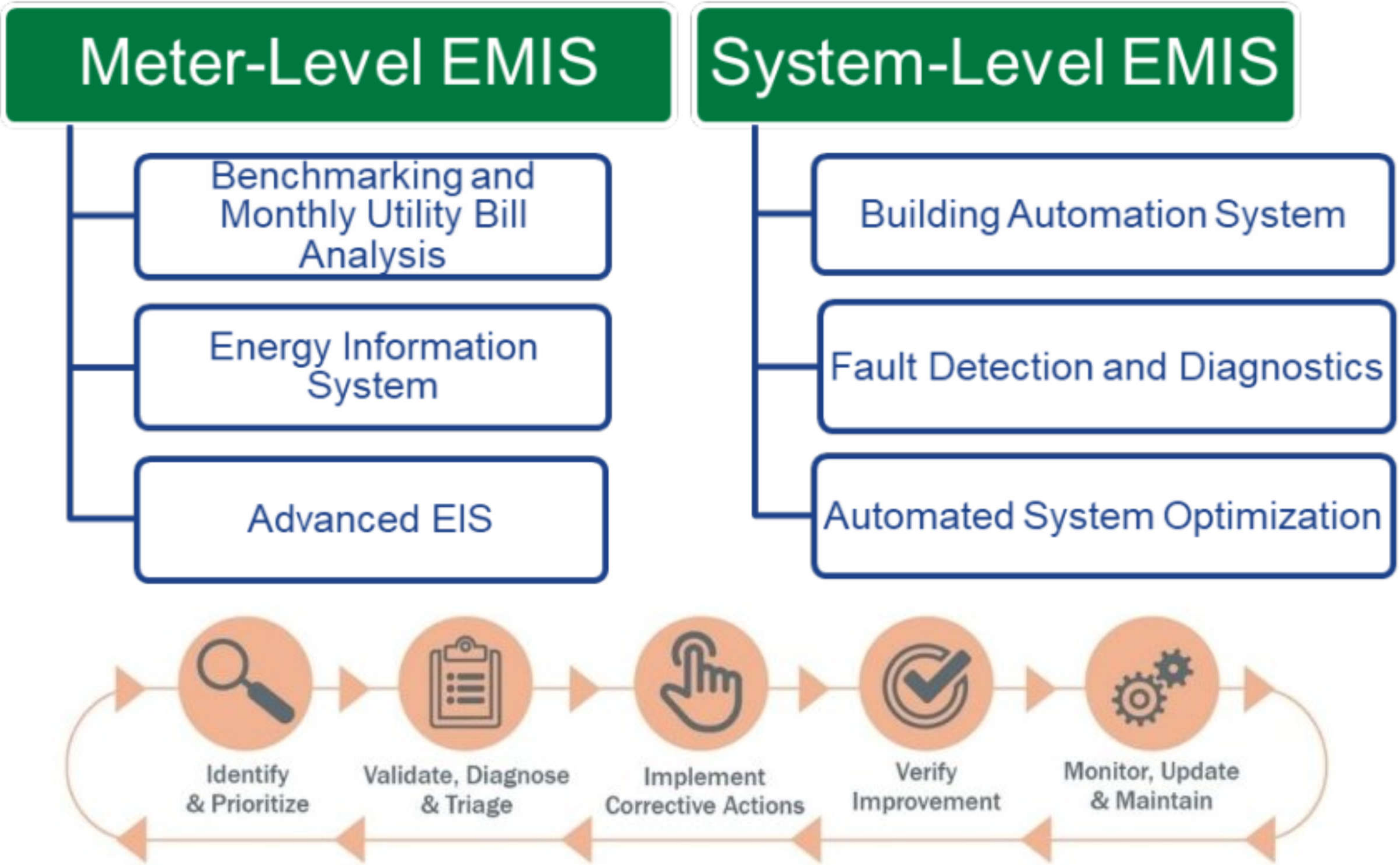


(Source: https://www.arup.com/services/digital/digital-asset-management)

Energy data analysis

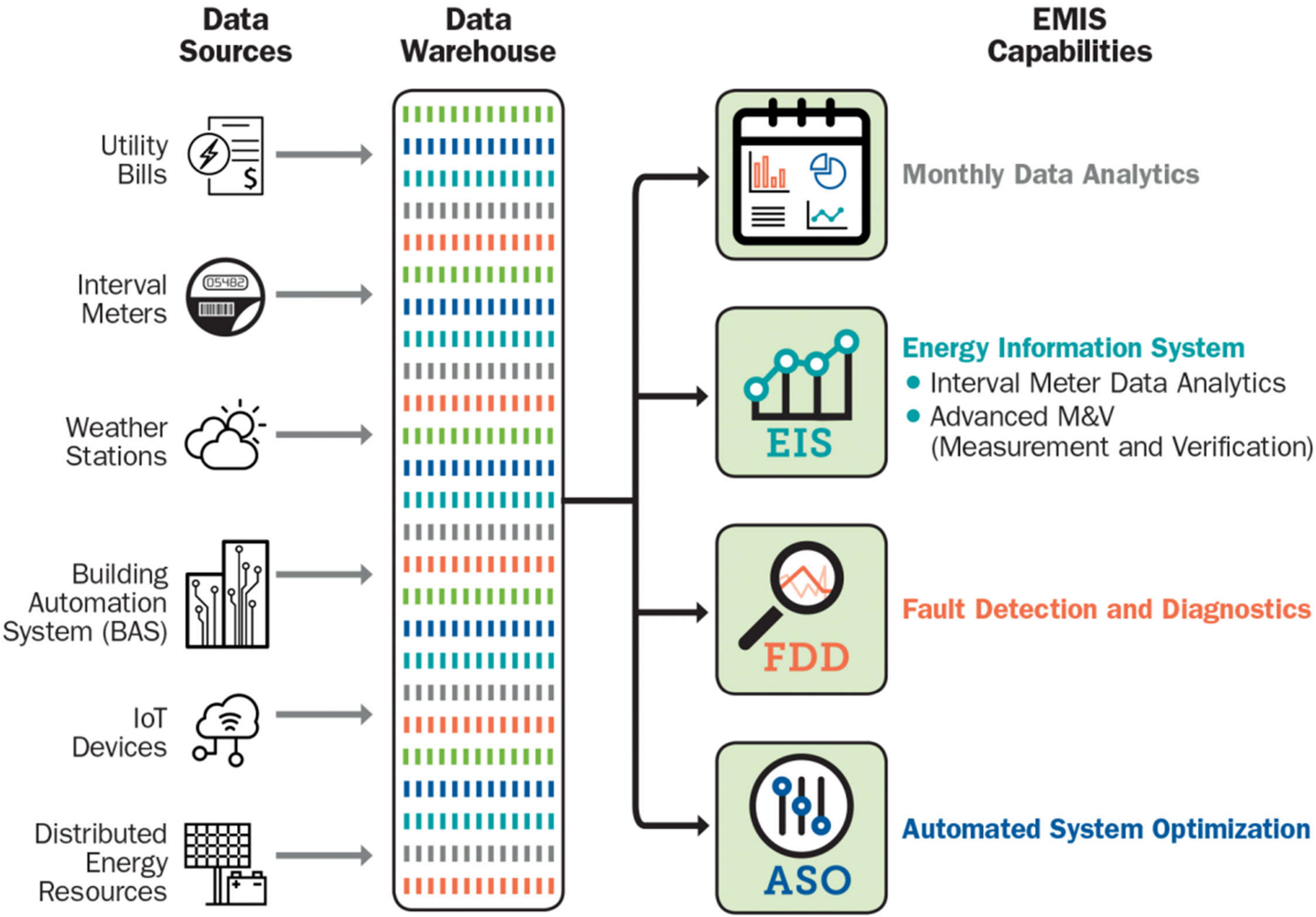
- Energy management & information systems (EMIS) are software that provide the needed analytical horsepower to building owners as they work to find meaning from data
  - Tools such as energy information systems (EIS), fault detection & diagnostics (FDD) systems, and automated system optimization (ASO) supplement the BAS to facilitate analysis & management of building performance

Energy management & information systems (EMIS) framework



(Source: Kramer H., Lin G., Granderson J., Curtin C., Crowe E. & Tang R., 2019. *Synthesis of Year Three Outcomes in the Smart Energy Analytics Campaign*, Building Technology and Urban Systems Division, Lawrence Berkeley National Laboratory. https://buildings.lbl.gov/sites/default/files/Smart%20Energy%20Analytics%20Campaign%20Year%203%20Report_LBNL_11.1.19.pdf)

Overview of an energy management & information system (EMIS)

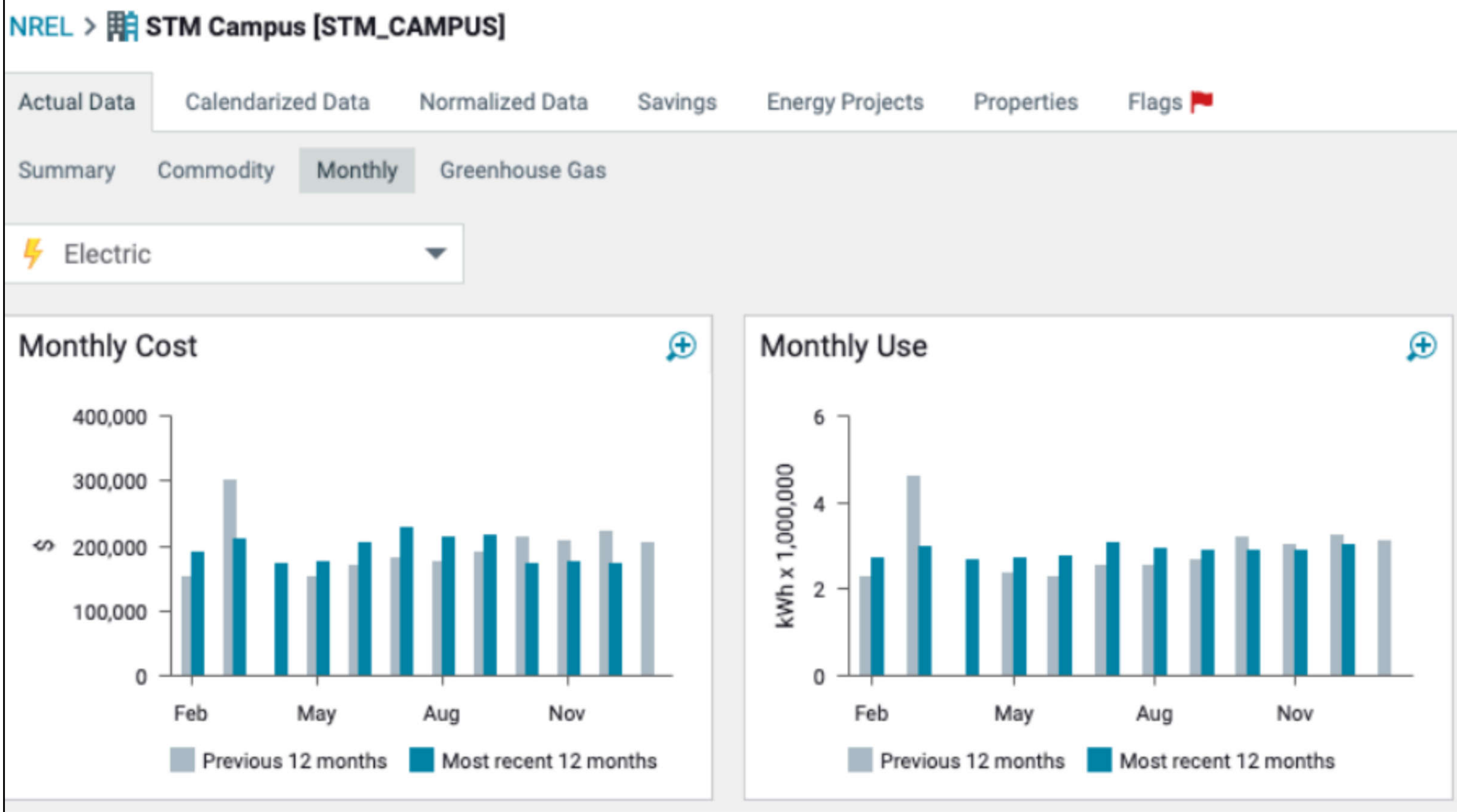


(Source: Kramer H., Lin G., Curtin C., Crowe E. & Granderson J., 2020. *Proving the Business Case for Building Analytics*, Lawrence Berkeley National Laboratory, Berkely, CA. https://doi.org/10.20357/B7G022)

Energy data analysis

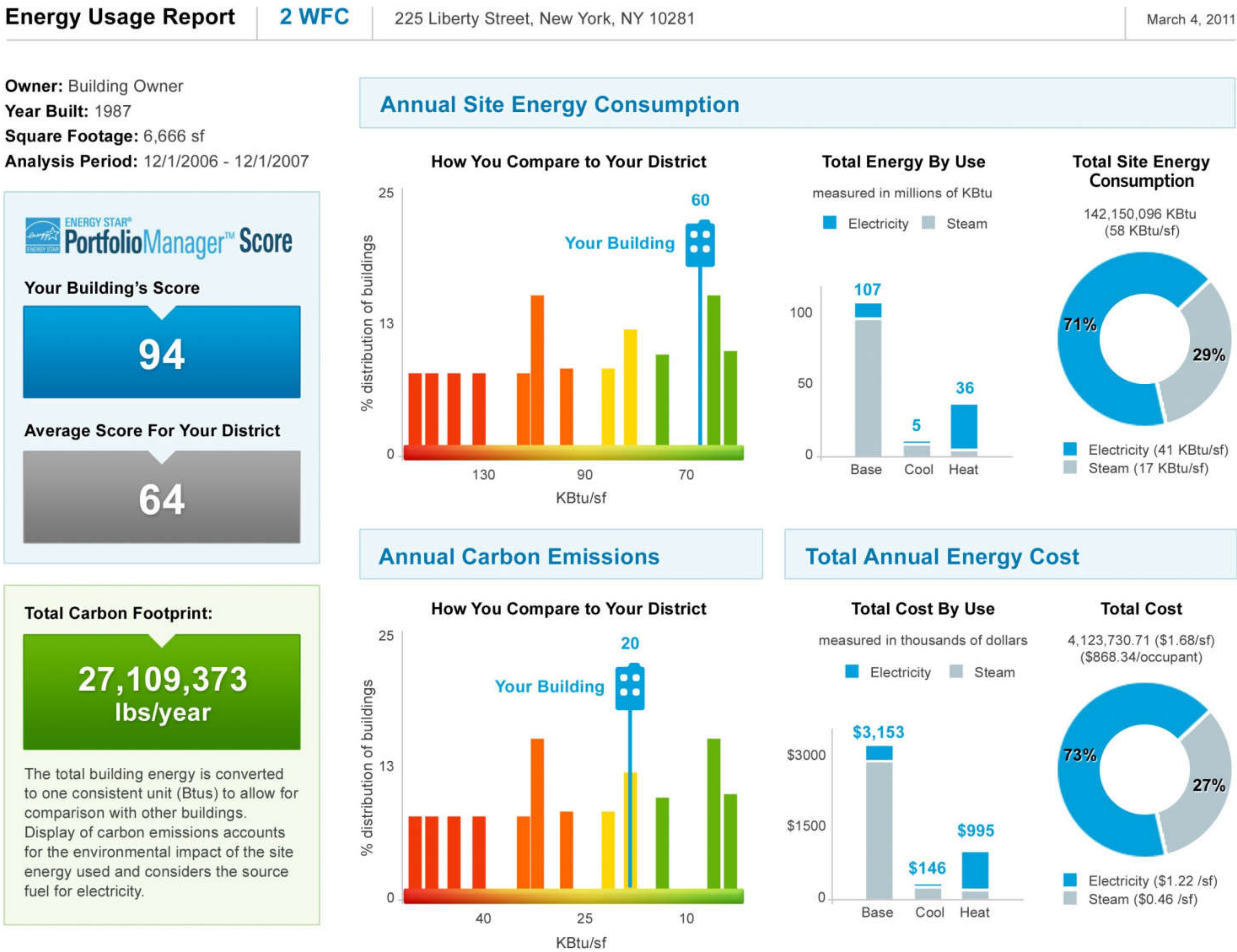
- Core capabilities of energy management & information systems (EMIS):
  - Centralize, normalize, visualize data
  - Utility bill management
  - Interval meter analytics
  - Measurement & verification (M&V)
  - Automatic fault detection & diagnostics (AFDD)
  - Supervisory control
  - Operation & maintenance (O&M) optimization

Example of EMIS usage & cost tracking



(Source: FEMP, 2021. *Energy Management Information Systems Technical Resources Report*, U.S. Department of Energy, Energy Efficiency Renewable Energy Office, Federal Energy Management Program (FEMP). https://www.energy.gov/sites/default/files/2021-09/emis-technical-resources.pdf)

Energy usage report & benchmarking of EnergyStar portfolio manager

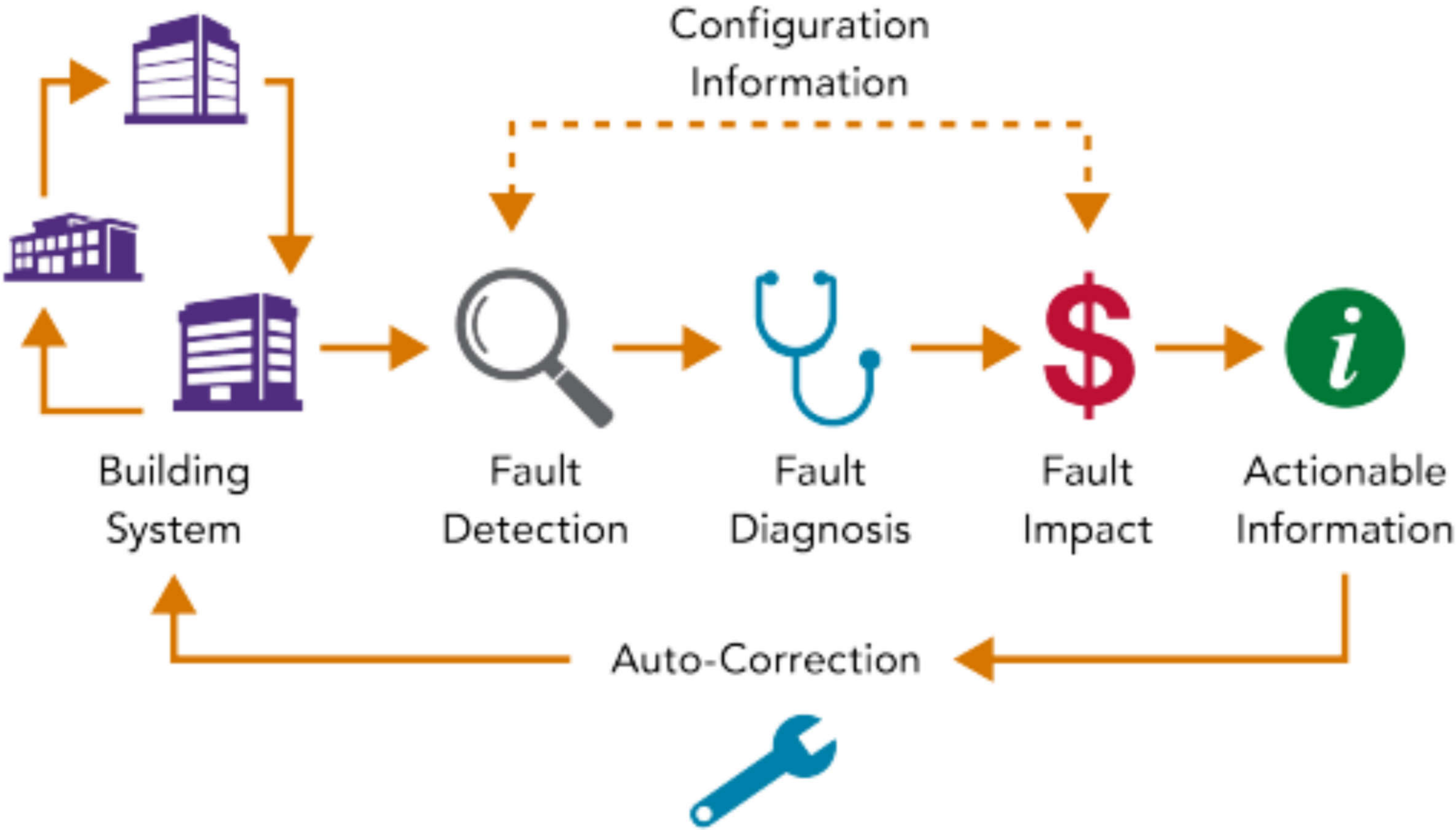


(Source: https://eepartnership.org/2020/02/step-3-track-energy-data-and-benchmark-performance/)

Dashboard of an energy manager service to manage workflow & assets, energy usage, utility billing, account auditing, capital forecasting & other administrative functions

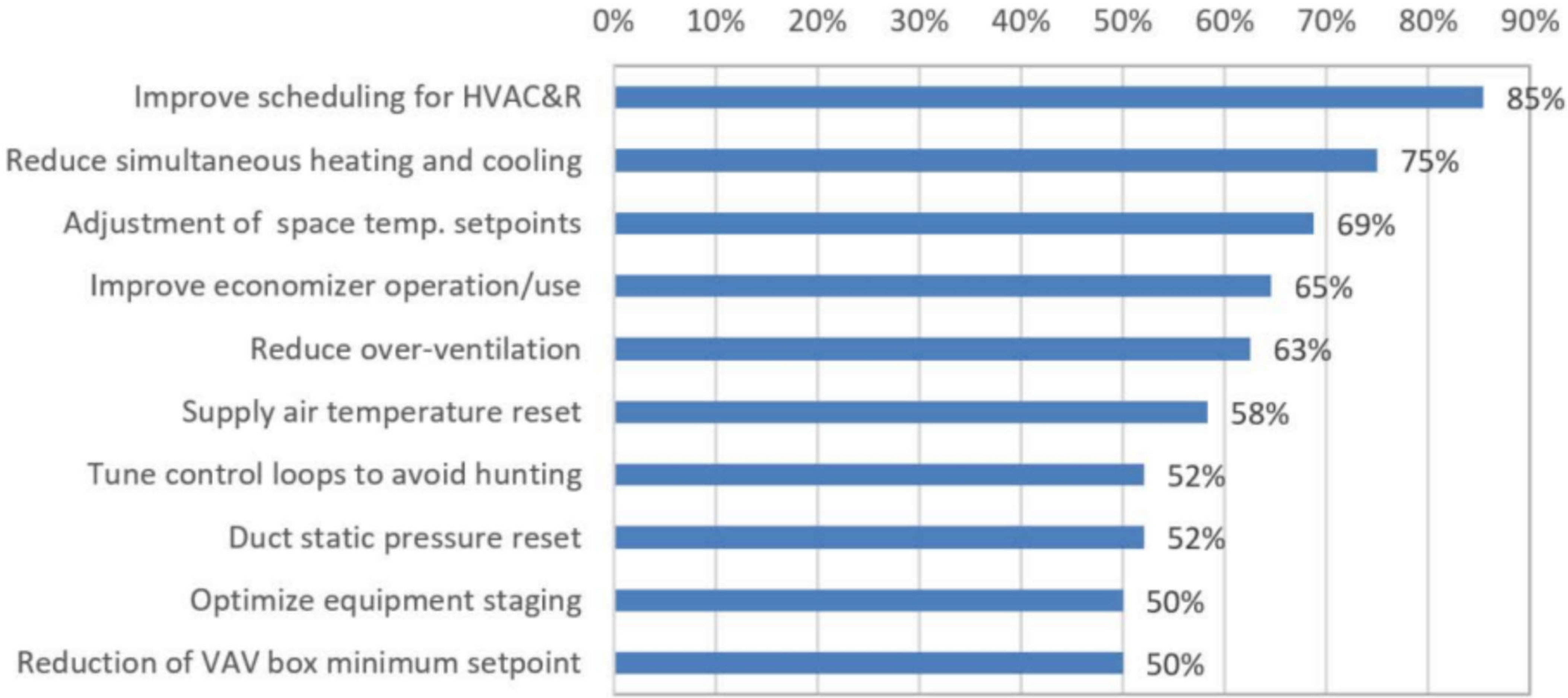
(Source: https://eepartnership.org/2020/02/step-3-track-energy-data-and-benchmark-performance/)

Basic concepts of automatic fault detection & diagnostics (AFDD)



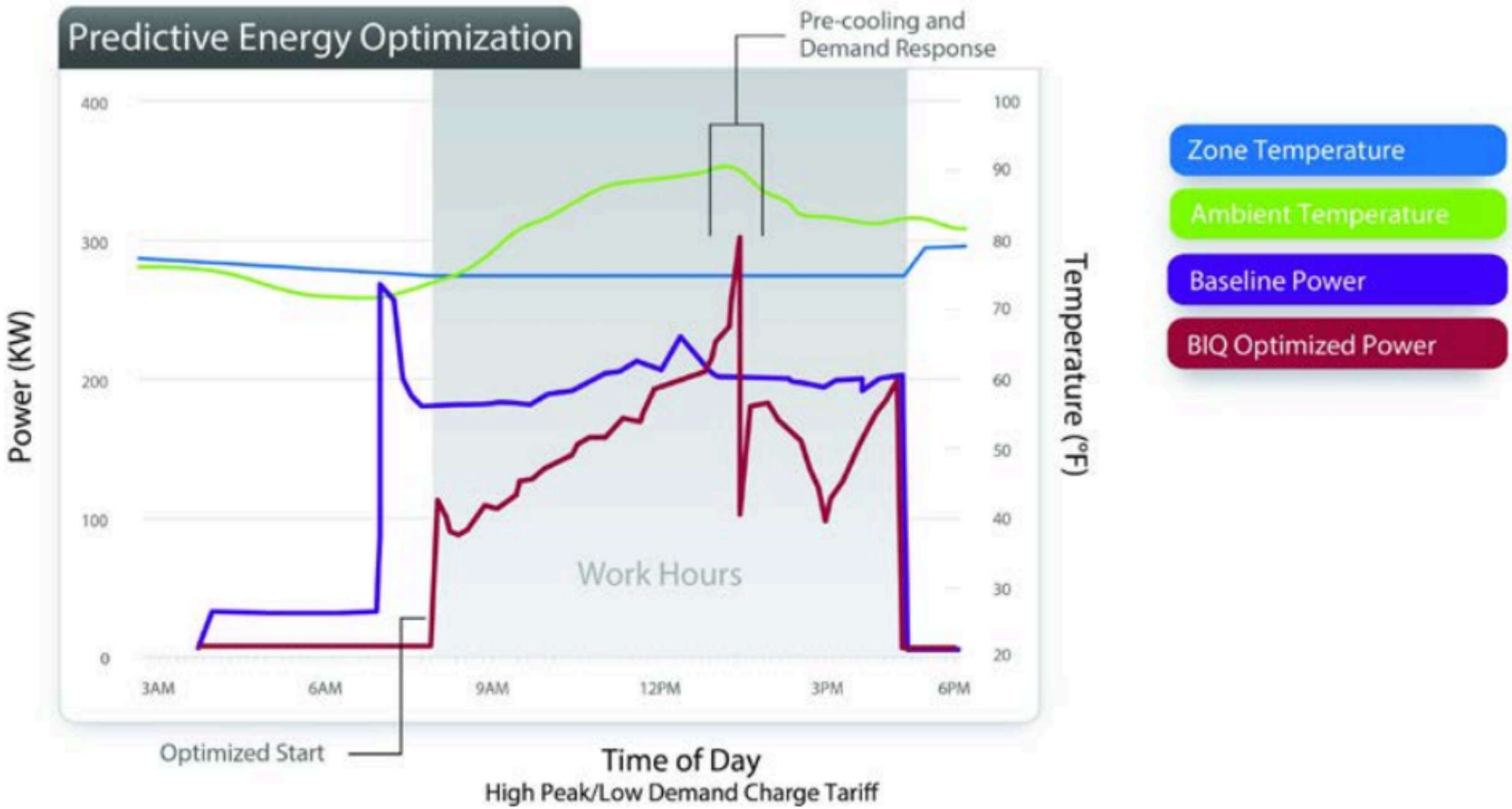
(Source: https://www.pnnl.gov/sites/default/files/media/file/EED_0073-Fault-Detection-flier.pdf)

Common measures identified & implemented through use of automatic fault detection & diagnostics (AFDD) technology



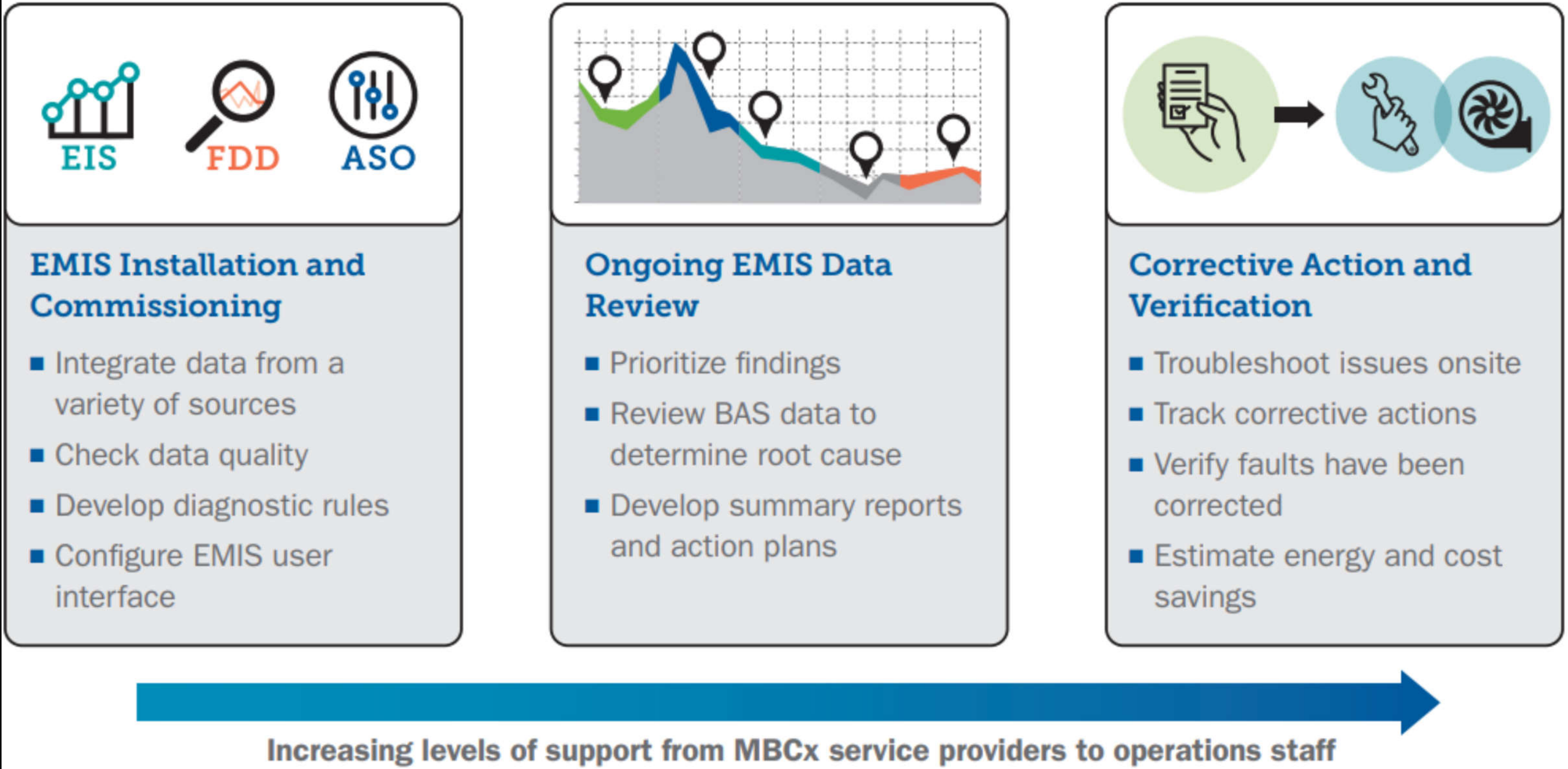
(Source: https://www.energy.gov/sites/default/files/2021-09/emis-technical-resources.pdf)

An example of automated system optimization (ASO) for optimized start of HVAC equipment using predictive energy optimization



(Source: https://www.energy.gov/sites/default/files/2021-09/emis-technical-resources.pdf)

Support options for the ongoing use of energy management & information system (EMIS)

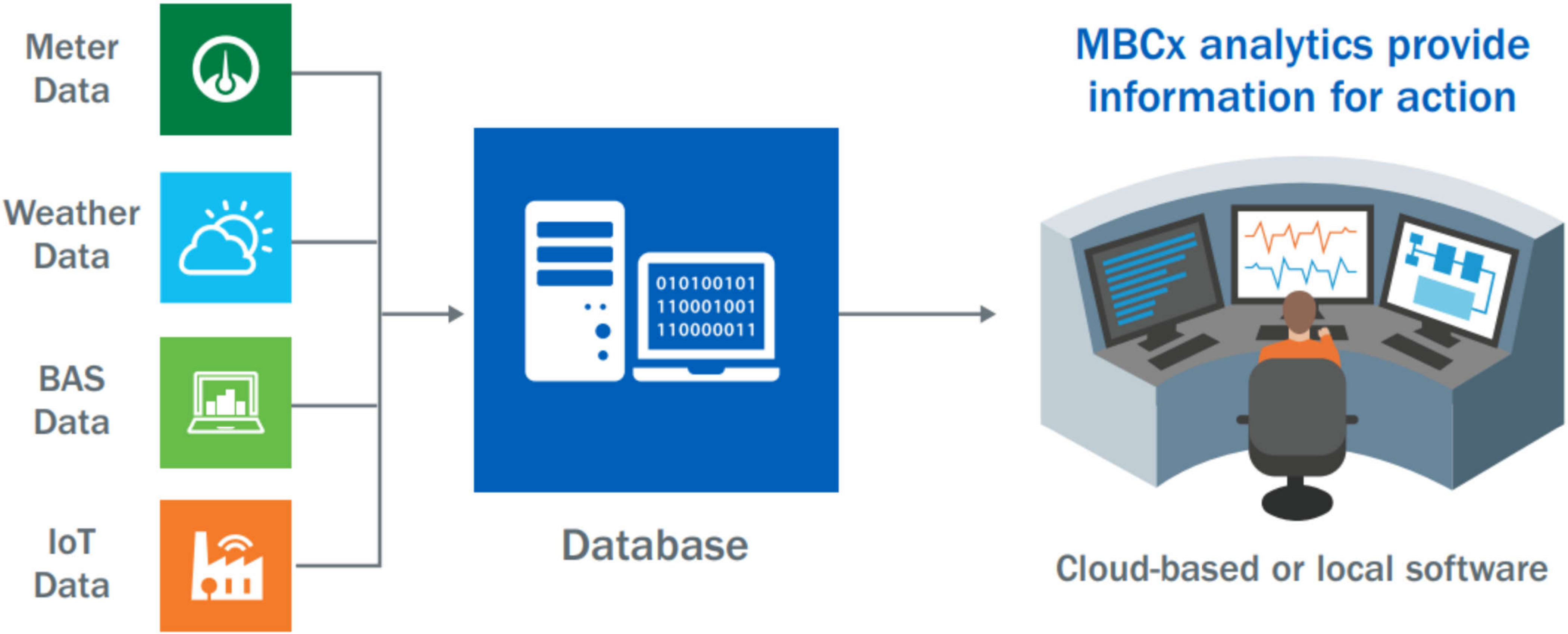


(Source: Kramer H., Lin G., Curtin C., Crowe E. & Granderson J., 2020. *Proving the Business Case for Building Analytics*, Lawrence Berkeley National Laboratory, Berkely, CA. https://doi.org/10.20357/B7G022)

Energy data analysis

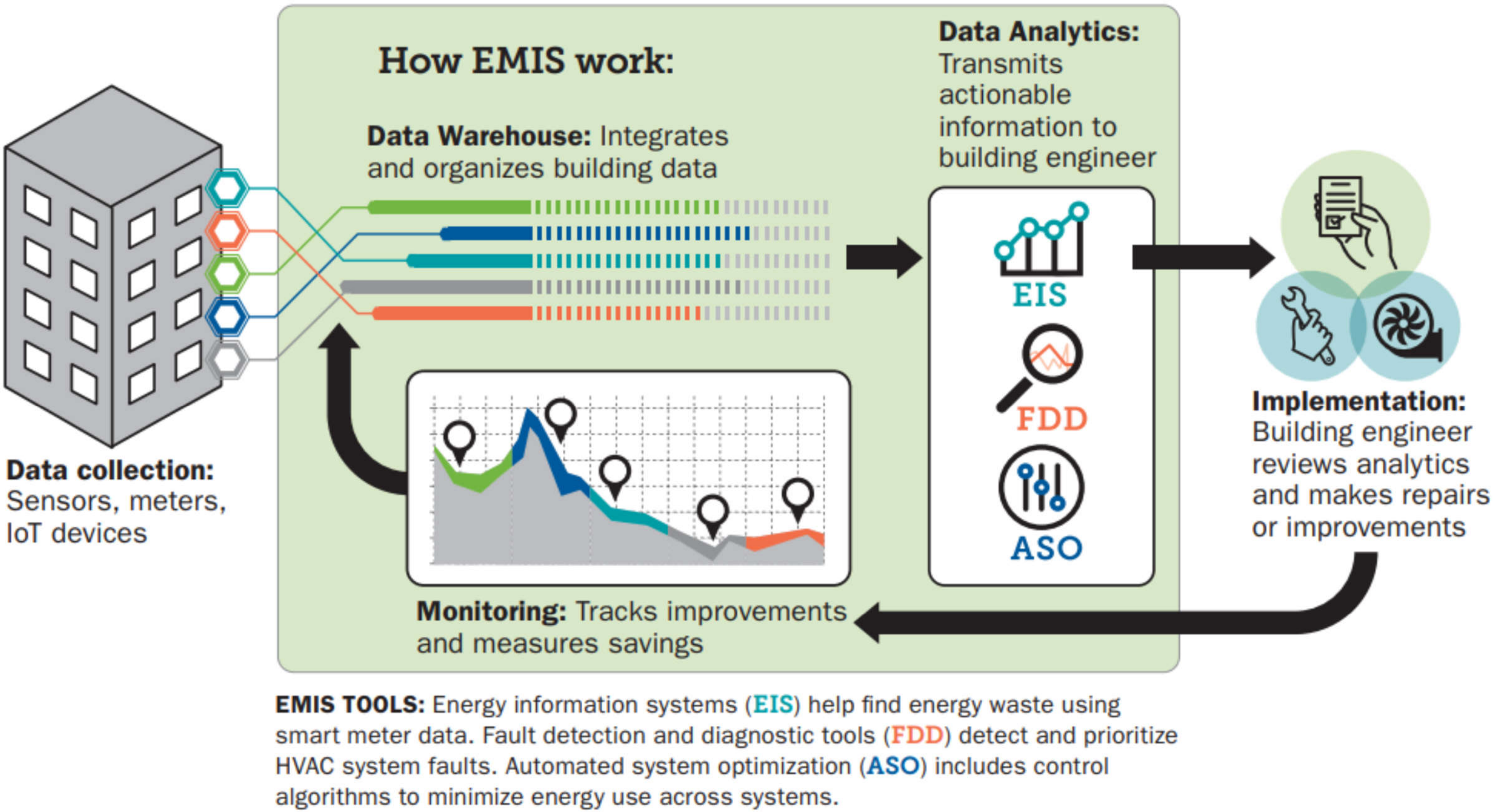
- Monitoring-based commissioning (MBCx)
  - A type of existing building commissioning (EBCx) applied to a building or energy system
  - A systematic process for investigating, analyzing, & optimizing the performance of building systems through the identification & implementation of low/no cost & capital-intensive facility improvement measures & ensuring their continued performance

Monitoring-based commissioning (MBCx) data flow, including metering, weather, building automation system (BAS) & internet-of-things (IoT) data



(Source: Best Practices for Enhancing Performance Contracts with Monitoring-Based Commissioning https://www.energy.gov/sites/default/files/2022-04/81742.pdf)

Monitoring-based commissioning (MBCx) process using an energy management information system (EMIS)

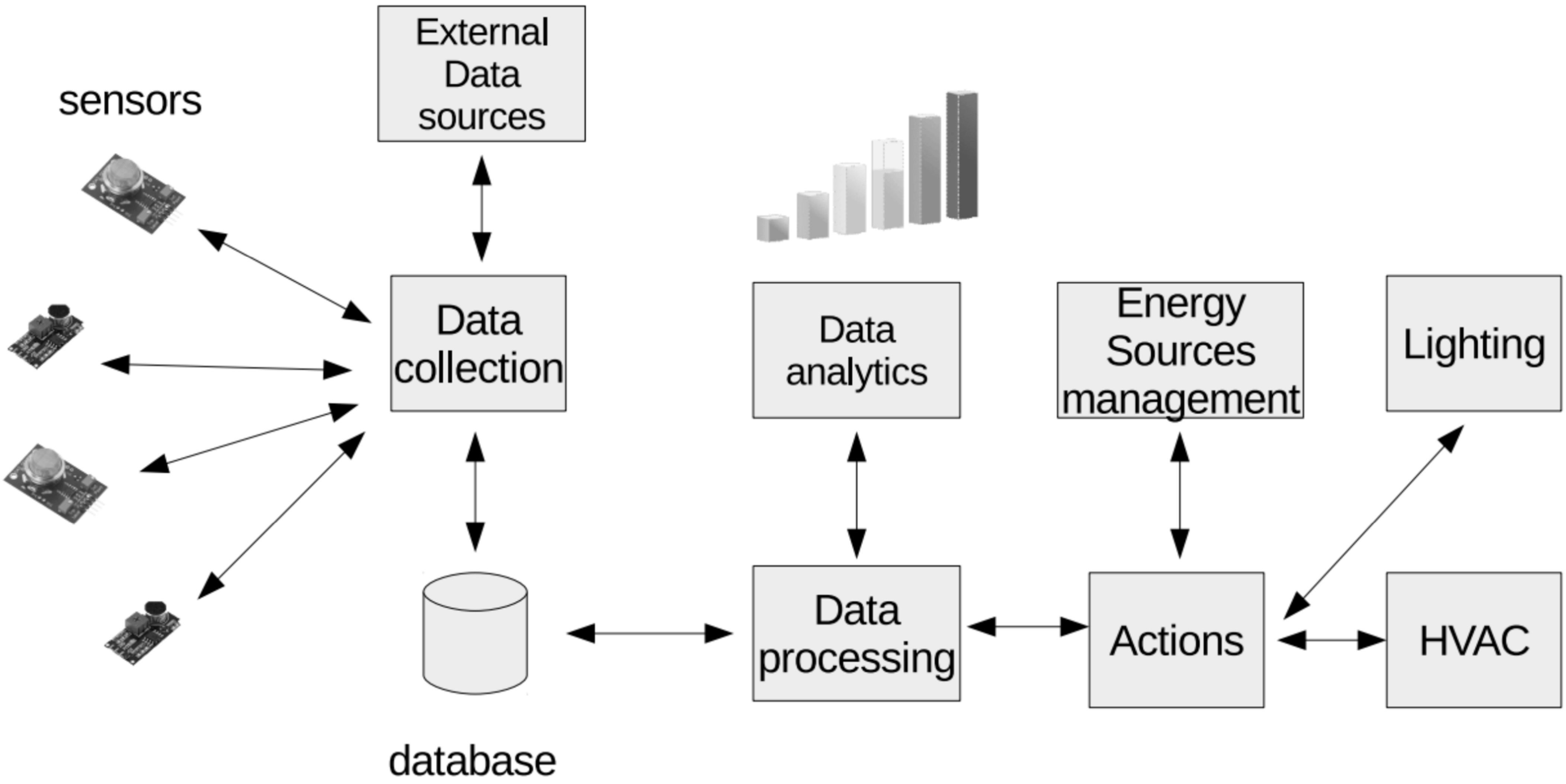


(Source: Kramer H., Lin G., Curtin C., Crowe E. & Granderson J., 2020. *Proving the Business Case for Building Analytics*, Lawrence Berkeley National Laboratory, Berkely, CA. https://doi.org/10.20357/B7G022)

Energy data analysis

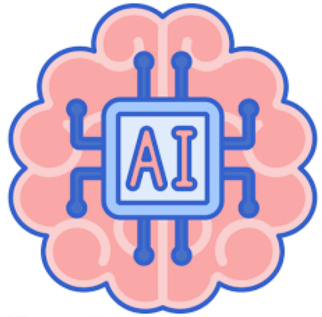
- Typical data analysis methods
  - 1. Energy savings
    - Interval data analysis, annual energy use analysis, short-term measurements & engineering calculations, building energy simulation & modelling
  - 2. Costs
    - Estimation of base costs, recurring costs, labour costs
  - 3. Cost-effectiveness
    - Costs & saving comparison, simply & discounted paybacks, return-on-investment (ROI), life-cycle cost

Example of the system architecture used to optimize energy consumption by using data analytics & high performance algorithms



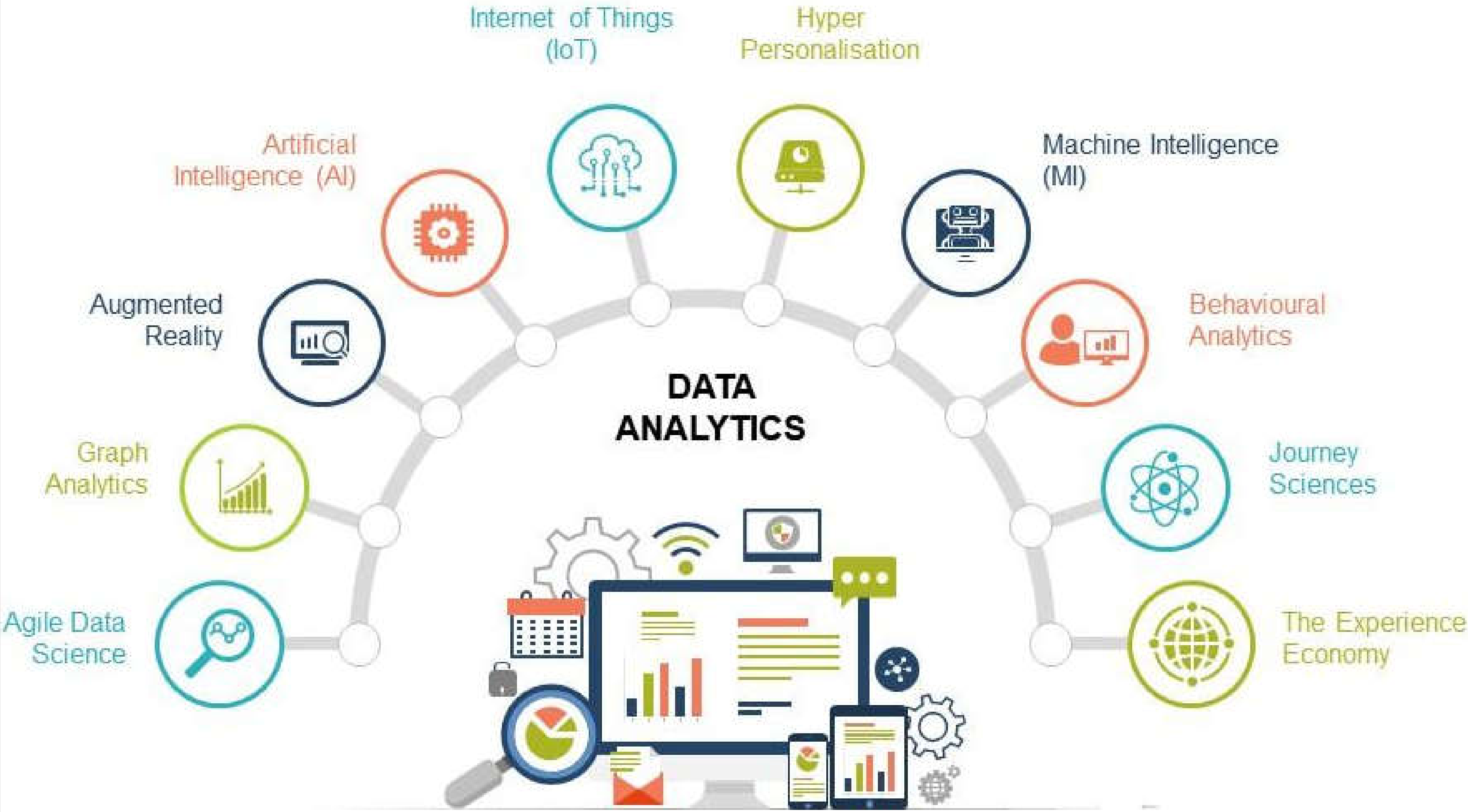
(Source: Benavente-Peces C., 2019. On the energy efficiency in the next generation of smart buildings—supporting technologies and techniques, *Energies*, 12 (22) 4399. https://doi.org/10.3390/en12224399)

Artificial intelligence (AI)



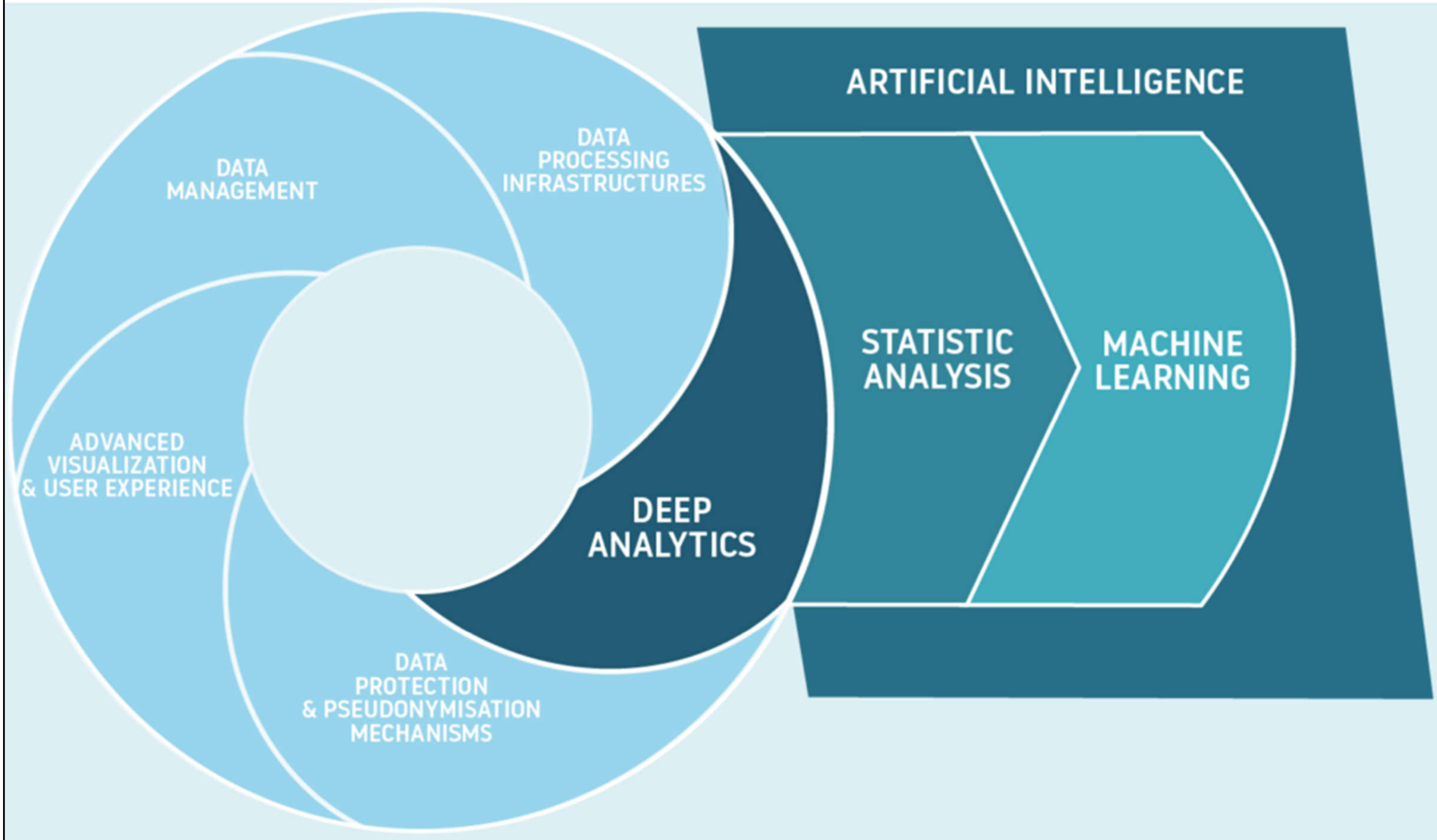
- From analytics to artificial intelligence (AI)
  - AI as a natural evolutionary outgrowth of analytics
  - Use of machine learning (ML) methods
    - e.g. optical character recognition (OCR) in document processing & adaptive algorithms in video games
  - The era of cognitive technologies
  - Extension of predictive & prescriptive analytics
  - Robotic process automation for digital tasks
  - Intelligence augmentation (IA) to assist humans

Data analytics & artificial intelligence



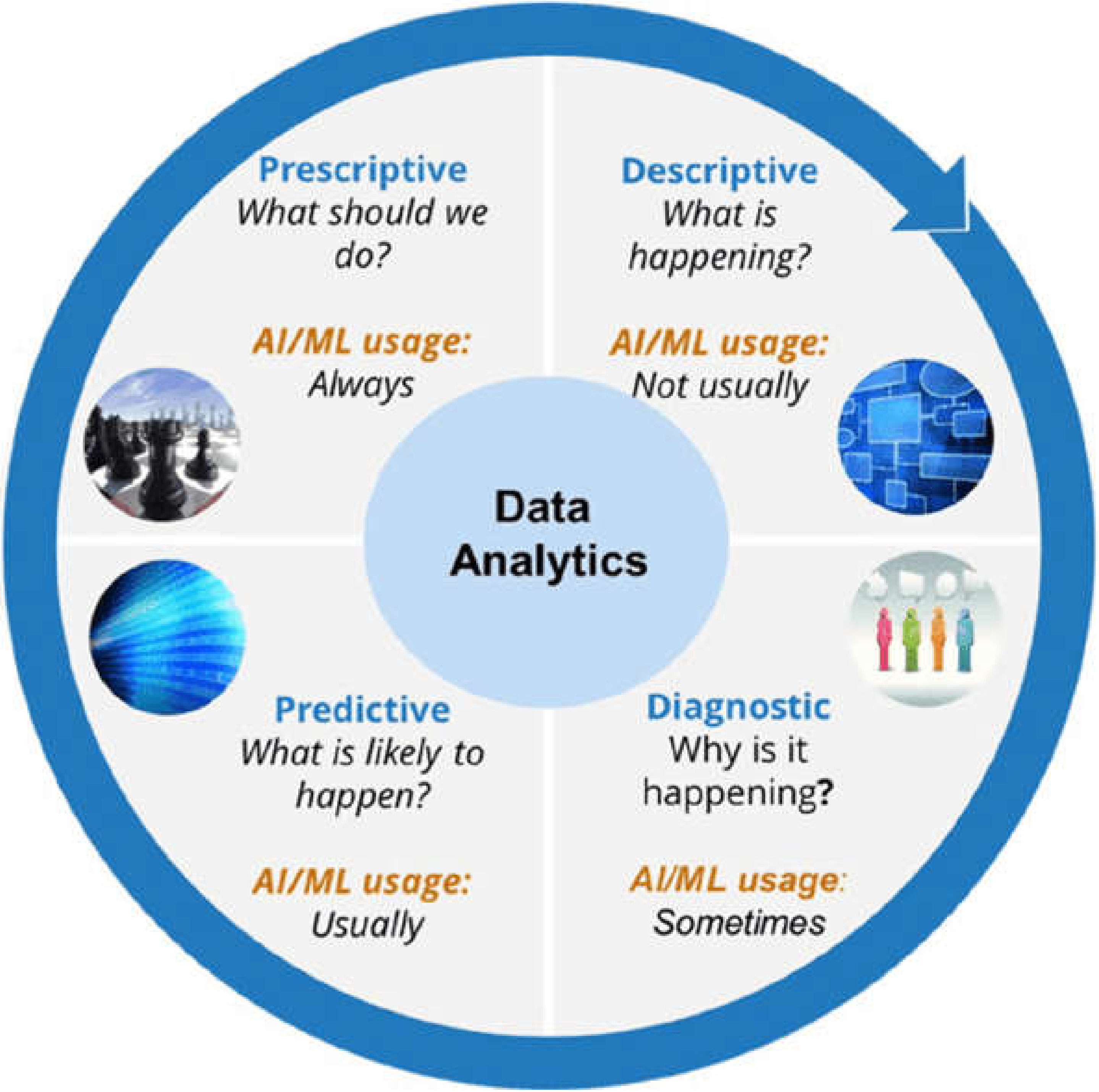
(Source: https://www.slideteam.net/data-and-analytics-artificial-intelligence-ppt-powerpoint-presentation-slides-icons.html)

Data science principles with deep analytics, artificial intelligence, machine learning & statistical analysis



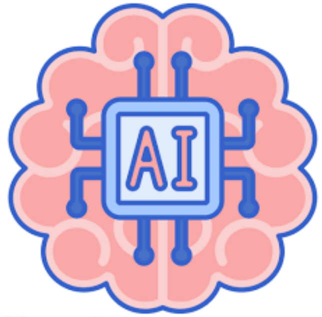
(Source: https://datascience.aero/artificial-intelligence-vs-data-science/)

Types of data analytics



(Source: https://ebrary.net/195875/engineering/unlock_true_power_data_analytics_with_artificial_intelligence)

Artificial intelligence (AI)

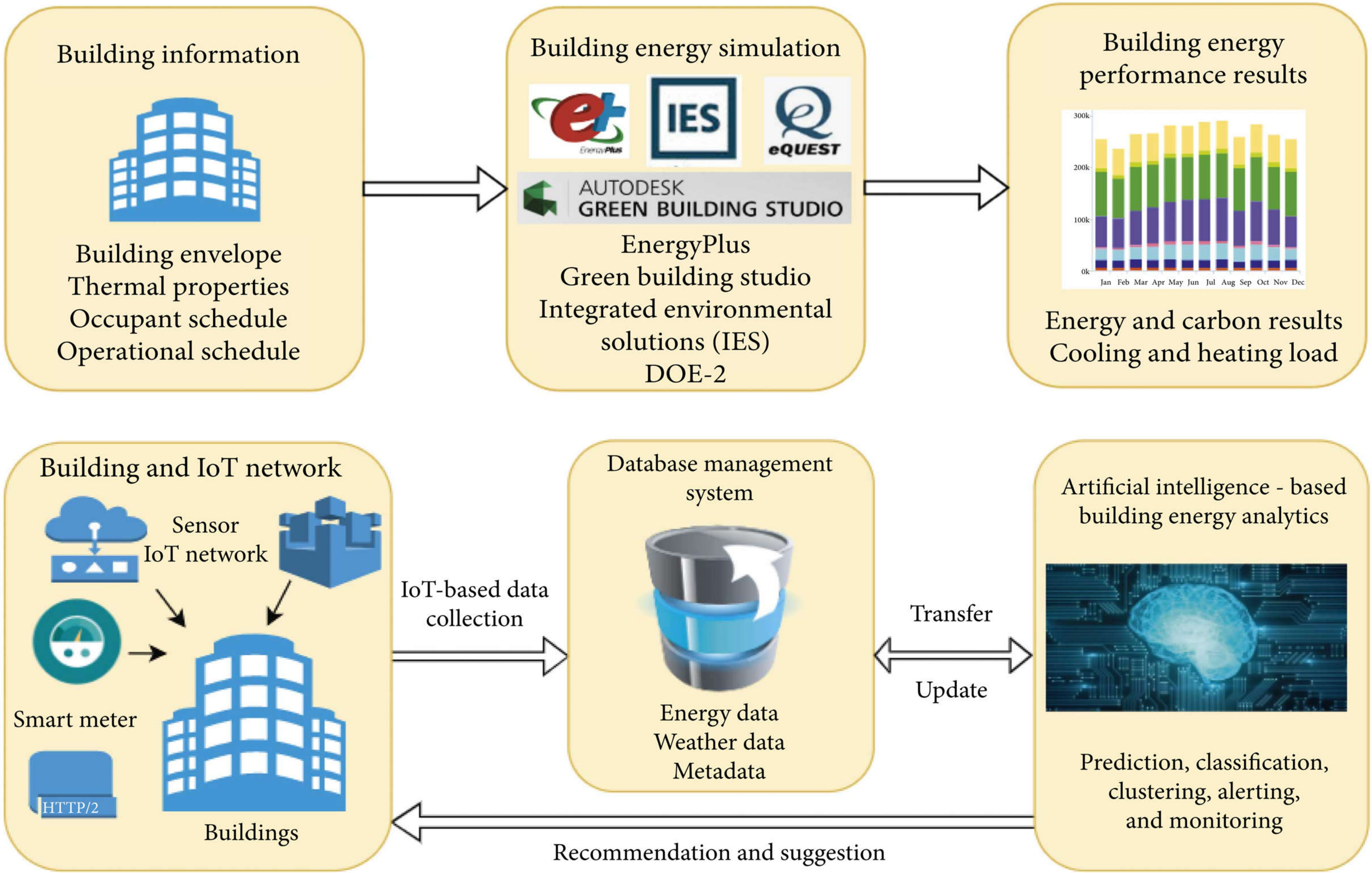


- Use AI to integrate the data from IoT devices & occupant behaviour to apply learning, optimize performance & improve efficiency
  - Provide insights about the operations, use & condition of everything from the building's infrastructure, physical environment, climate, water & energy usage, to an occupant's experience & satisfaction
  - Reduce costs through automation & optimization of operations

Data platform for monitoring, analysis & control of smart buildings using artificial intelligence (AI) tools

(Source: https://www.confluent.io/blog/smart-buildings-with-real-time-iot-analytics-using-confluent-at-aedifion/)

Artificial intelligence (AI)-based building energy analytics

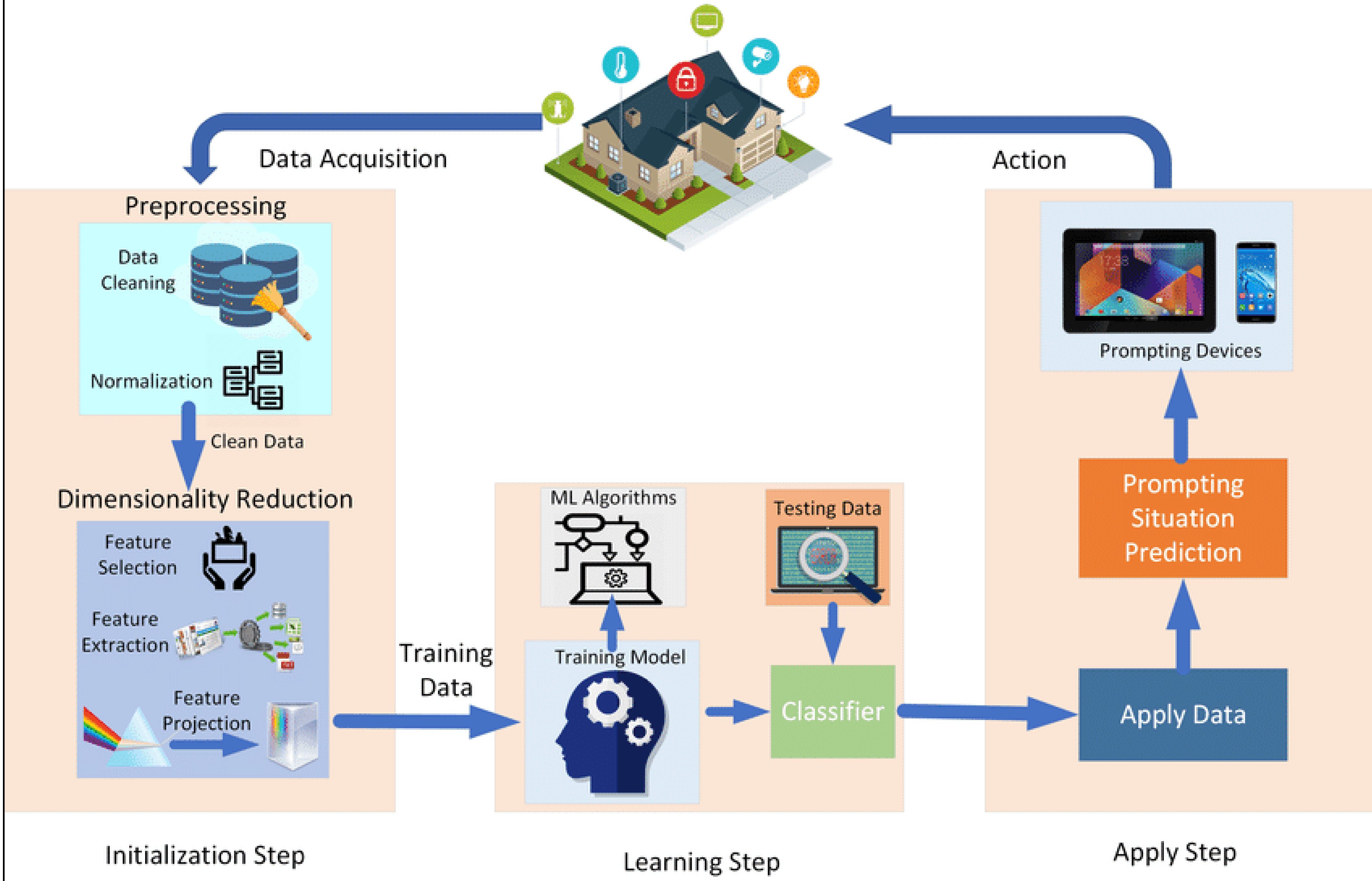


(Source: Truong N.-S., Ngo N.-T. & Pham A.-D., 2021. Forecasting time-series energy data in buildings using an additive artificial intelligence model for improving energy efficiency, *Computational Intelligence and Neuroscience*, 2021: 6028573. https://doi.org/10.1155/2021/6028573)

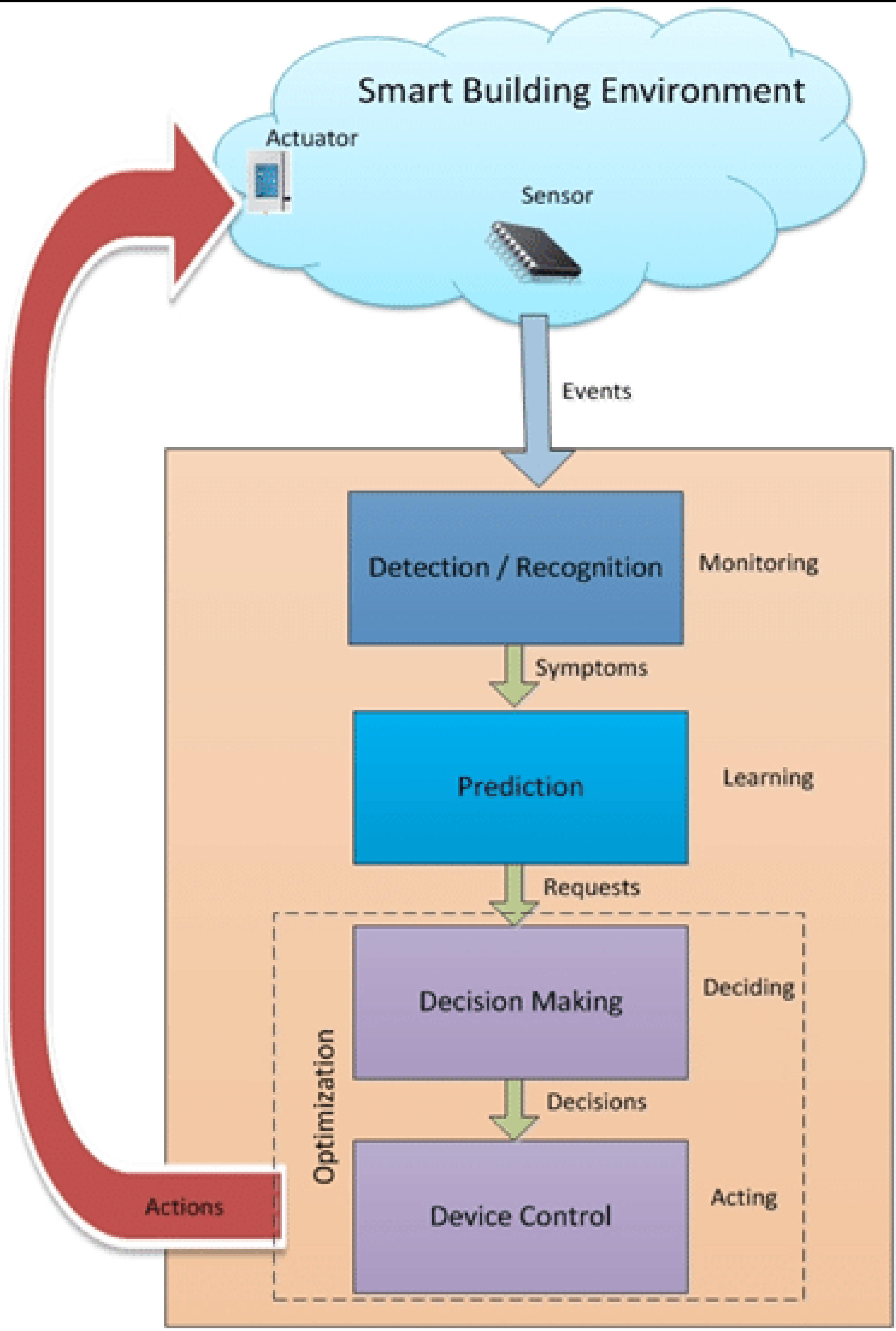
Artificial intelligence (AI)

- Basic machine learning (ML) is predictive analytics & it uses “supervised learning” to create a statistical model (e.g. linear regression) based on data for which the values of the outcome variable are known
- The resulting model is tested or trained with a validation dataset
- If the model can predict well, it is deployed to predict or classify new data (scoring process)

Machine learning (ML) tasks in smart building environment



(Source: Qolomany B., Al-Fuqaha A., Gupta A., Benhaddou D., Alwajidi S., Qadir J. & Fong A. C., 2019. Leveraging machine learning and big data for smart buildings: a comprehensive survey, *IEEE Access*, 7: 90316-90356. https://doi.org/10.1109/ACCESS.2019.2926642)

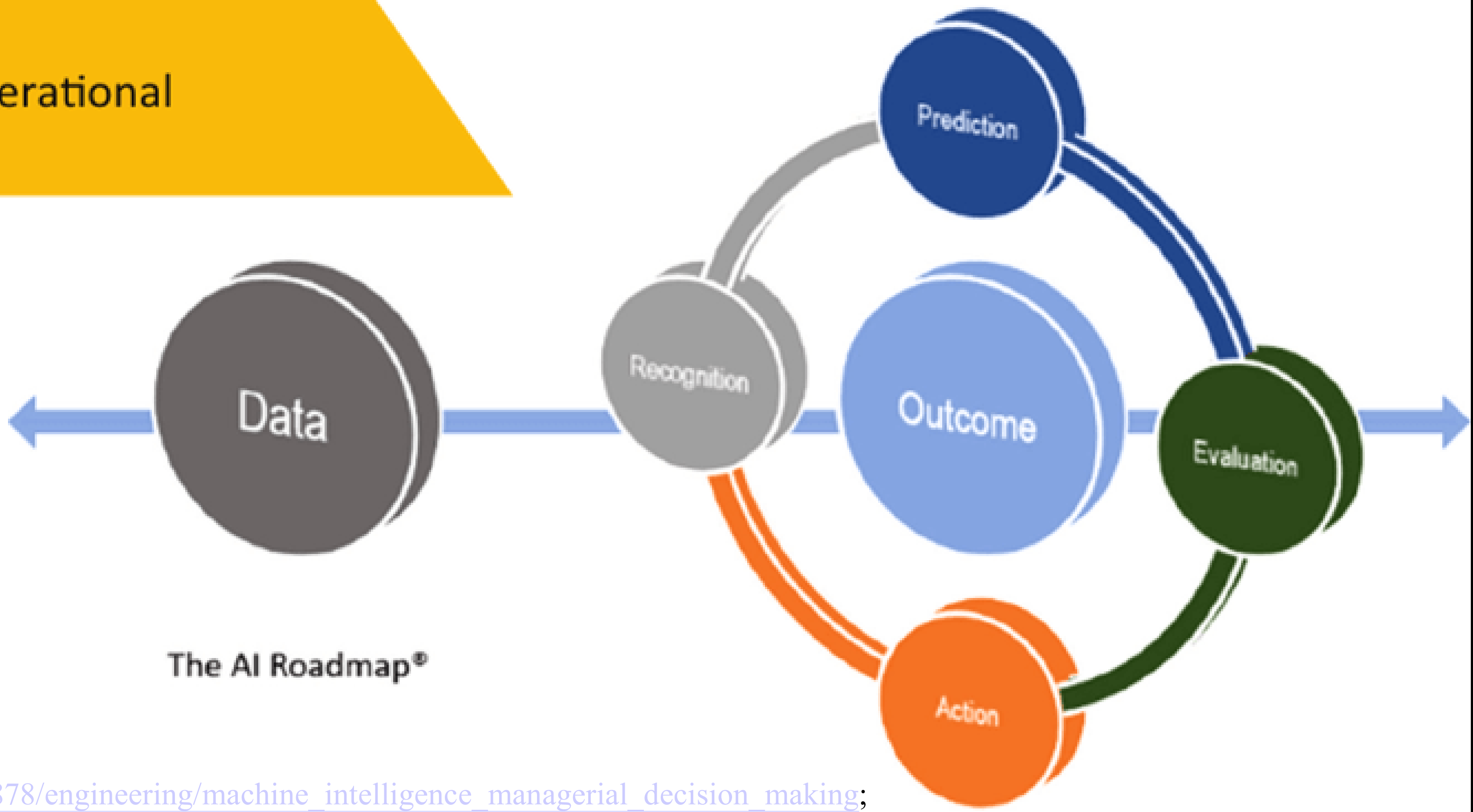


Steps involved in applying machine learning (ML) models in a smart building environment

(Source: Qolomany B., Al-Fuqaha A., Gupta A., Benhaddou D., Alwajidi S., Qadir J. & Fong A. C., 2019. Leveraging machine learning and big data for smart buildings: a comprehensive survey, *IEEE Access*, 7: 90316-90356. https://doi.org/10.1109/ACCESS.2019.2926642)

3 types of decisions (strategic, tactical & operational)

Decision-making process



(Source: https://ebrary.net/195878/engineering/machine_intelligence_managerial_decision_making; https://ebrary.net/195879/engineering/human_intelligence)

Cyber-security

- Smart buildings are highly reliant on networks of connected devices & systems, which means that they are vulnerable to cyberattacks
  - They can have serious consequences, for example
    - An attacker could take control of building systems e.g. HVAC, lighting, or access control, potentially causing physical harm or disruption
    - They could also steal sensitive data such as personal information, financial records, or intellectual property
  - Require strong security measures, ongoing monitoring & testing to address vulnerabilities

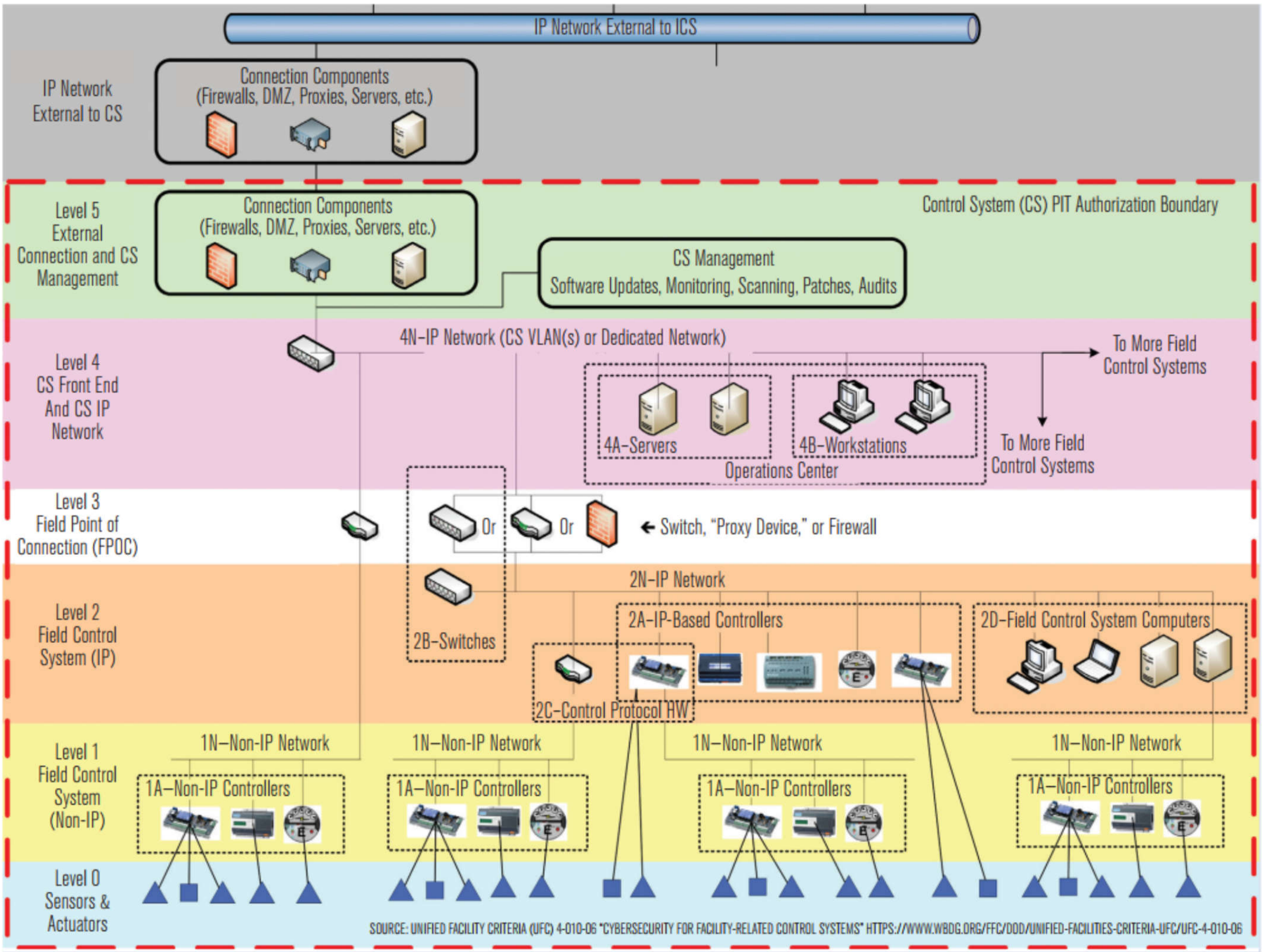
Cyber-security

- New challenges of smart building analytics
  - Security & privacy issues/concerns with potentially sensitive data or video images
  - Vulnerability of BAS networks (vs. hackers)
  - The need to transmit data to a third-party for monitoring & analysis, as well as storing data & making it available for future analysis
  - Security threat related to life safety
  - Cyber-security for smart buildings & networks

Protecting smart building technology from cyber threats

(Source: https://www.veridity.com/the-importance-of-protecting-smart-building-technology-from-cyber-threats/)

Cybersecurity for building automation systems



(Source: Shepard D., 2023. Cybersecurity project specs for building automation systems, *ASHRAE Journal*, 65 (11) 16-19.)

Cyber-security

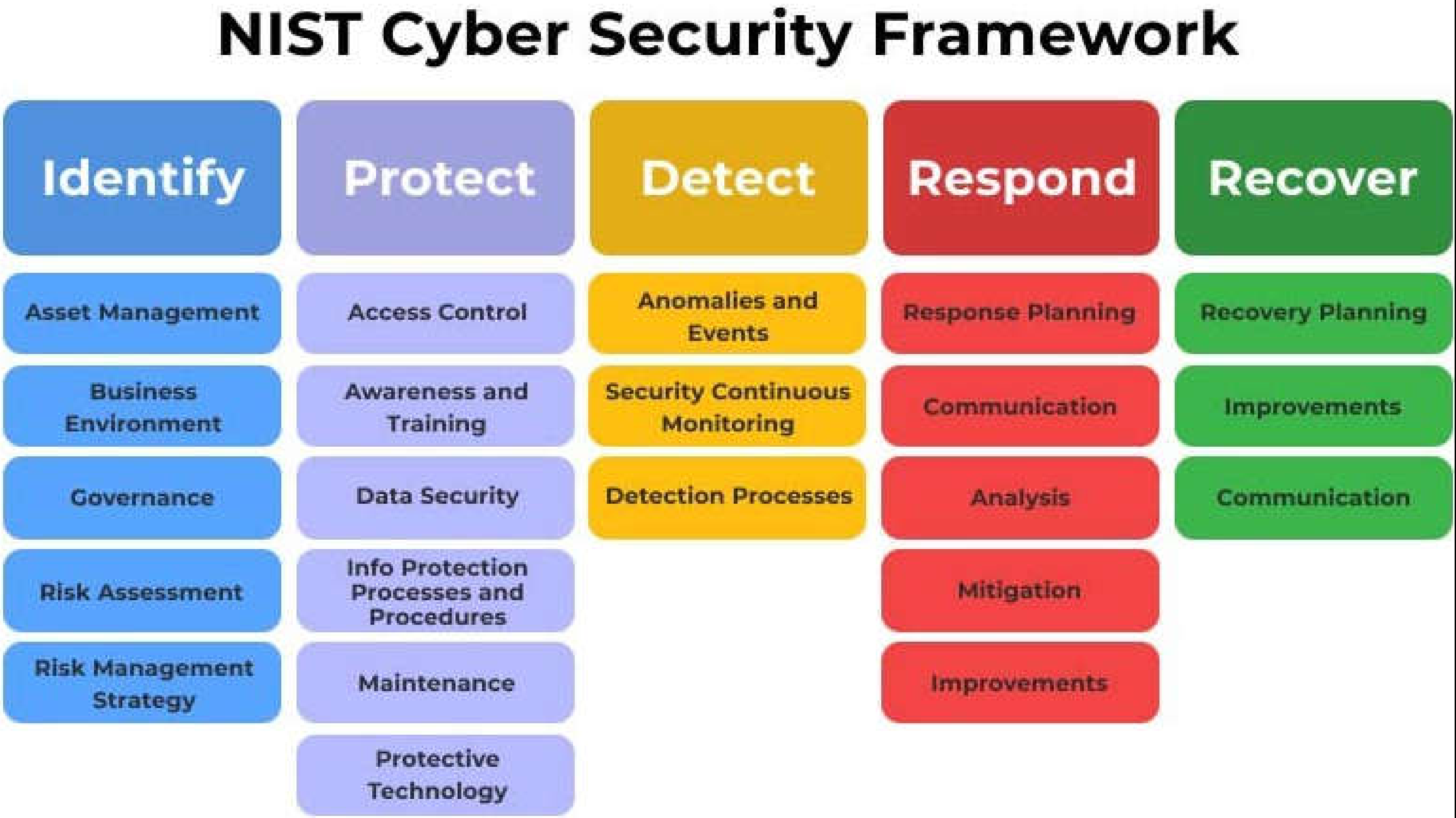
- Six key elements of cyber-security:
  - 1. Application security (web-based vulnerabilities)
  - 2. Information security (e.g. personal details, business records)
  - 3. Network security (protect against unauthorized access, modification or misuse)
  - 4. Disaster recovery & continuity planning
  - 5. Operational security (protect the functioning)
  - 6. End-user education (reduce human errors)

Cyber-security

- Strong security measures for smart buildings
  - Network security: firewalls to prevent unauthorized access & network segmentation to limit exposure
  - Software updates: Regular software updates & patches applied to address system vulnerabilities
  - Device-level security: Devices should be authenticated & communication should be encrypted to protect data
  - Physical security: Devices should be physically secured & access to them should be restricted to authorized personnel
  - Processes: Security processes should be documented & audited to make sure they are being followed

(Source: https://www.veridify.com/the-importance-of-protecting-smart-building-technology-from-cyber-threats/)

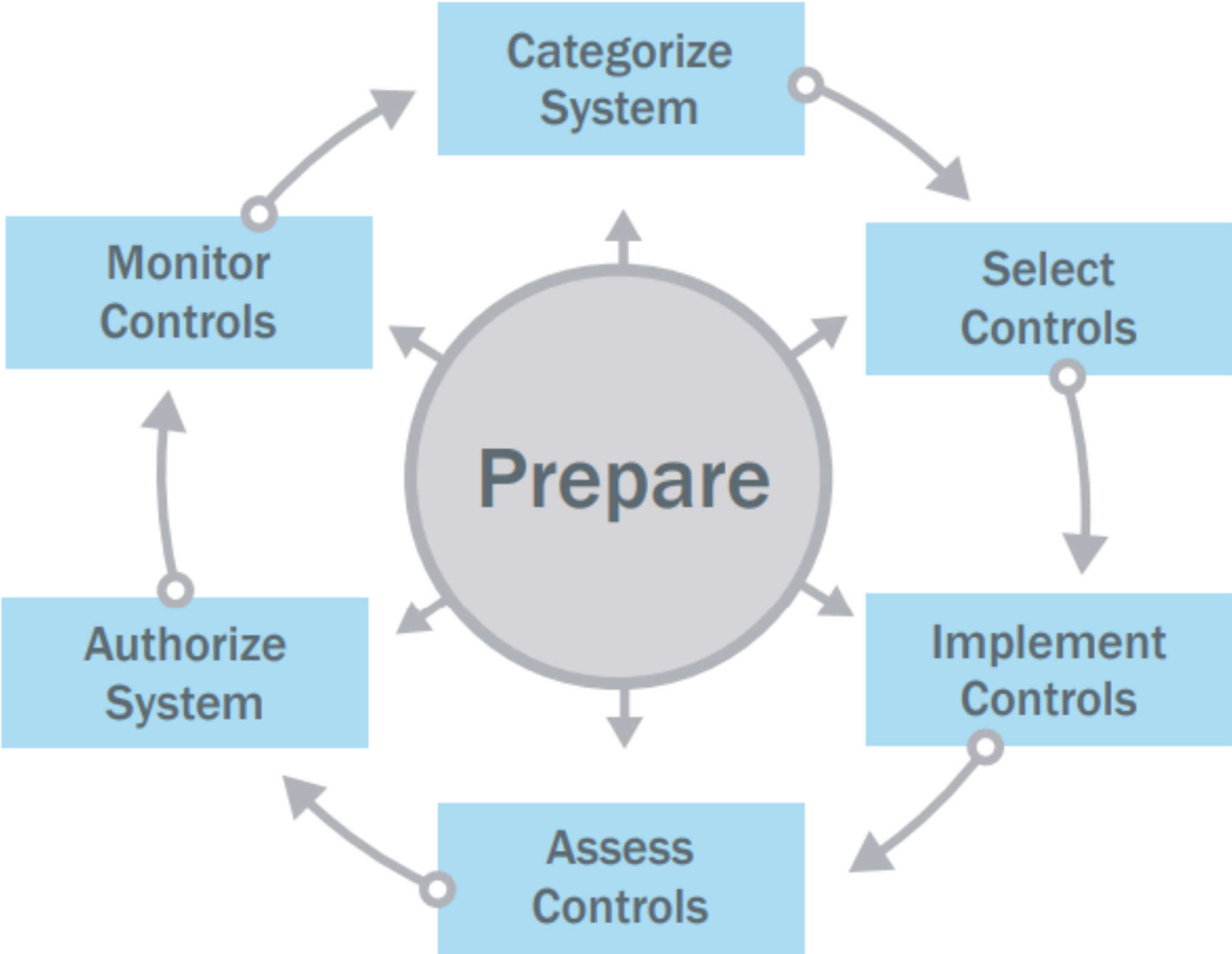
NIST cybersecurity framework as a policy guideline



* NIST = National Institute of Standards and Technology

(Source: https://www.linkedin.com/pulse/nist-cybersecurity-framework-shanneece-alberts)

Risk management framework steps



(Source: Energy Management Information Systems Cybersecurity Best Practices https://www.energy.gov/sites/default/files/2022-07/emis-cybersecurity-best-practices.pdf)

Further reading

- Four Types of Analytics with Example and Applications https://www.projectpro.io/article/types-of-analytics-descriptive-predictive-prescriptive-analytics/209
- Ultimate Guide to Building Analytics: Making Big Data Approachable https://www.buildingsiot.com/ultimate-guide-to-building-analytics-making-big-data-approachable-bd
- Ensuring Safety in Smart Buildings: The Importance of Cybersecurity and Automation https://www.waylay.io/articles/ensuring-safety-in-smart-buildings