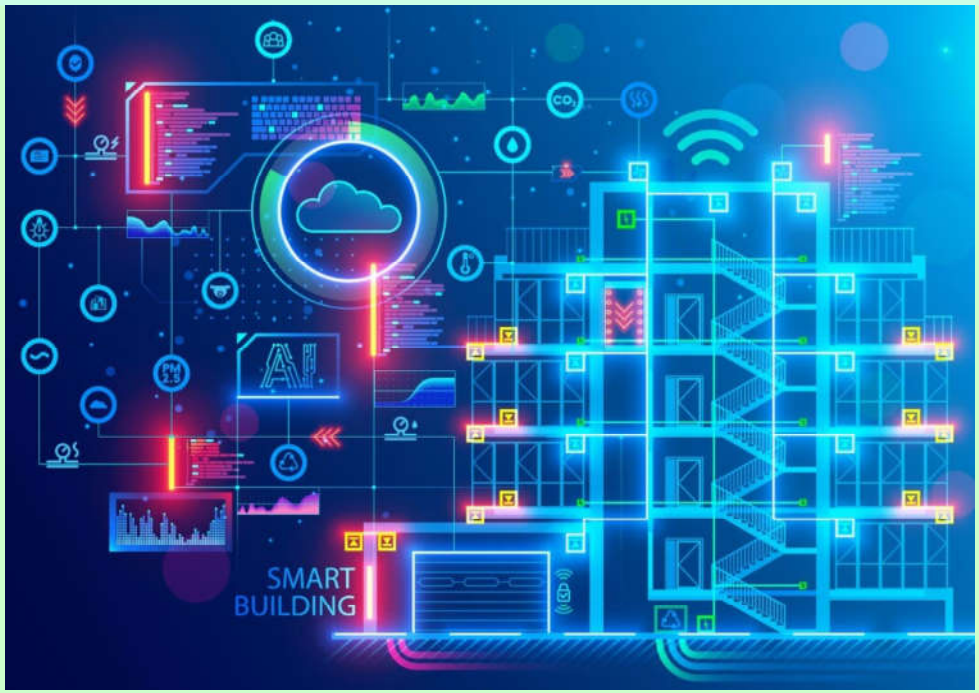
IDAT7219 Smart Building Technology

http://ibse.hk/IDAT7219/



Smart Energy Management

智能大廈科技

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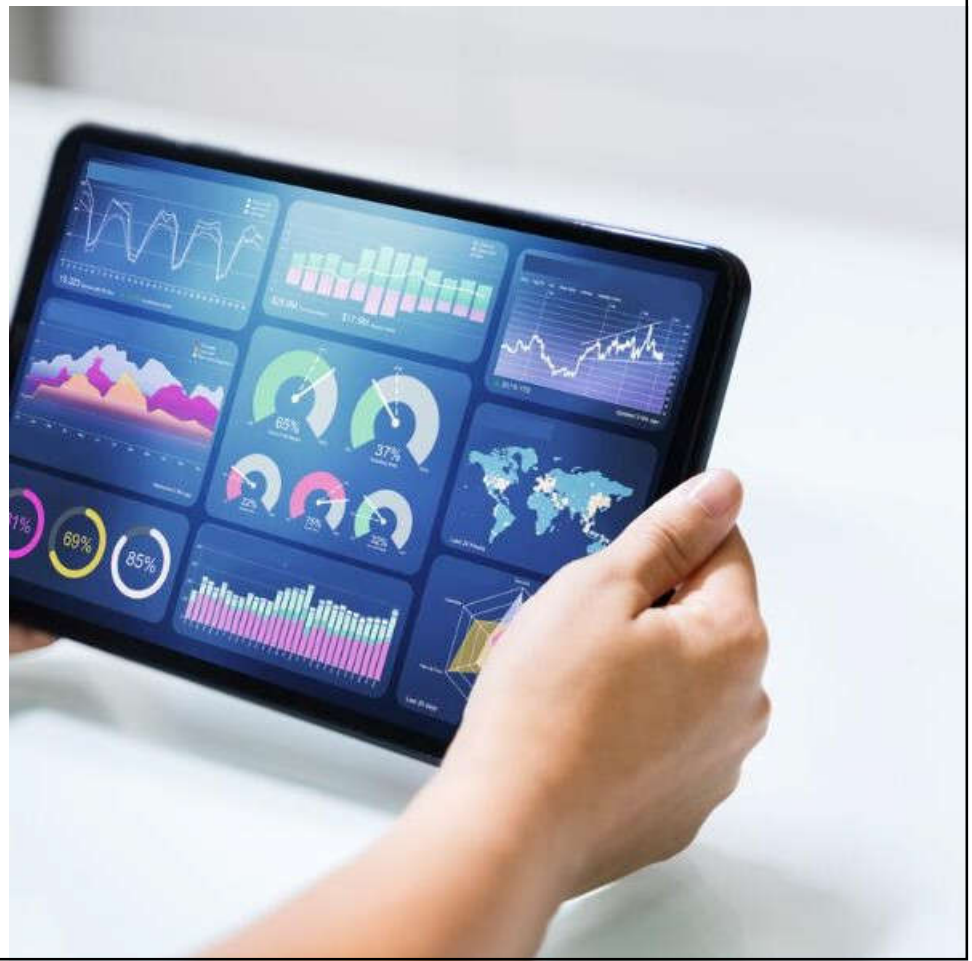
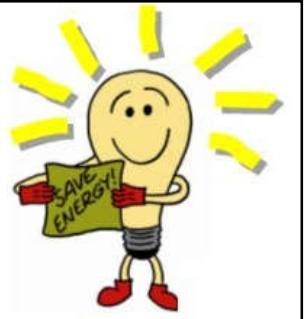
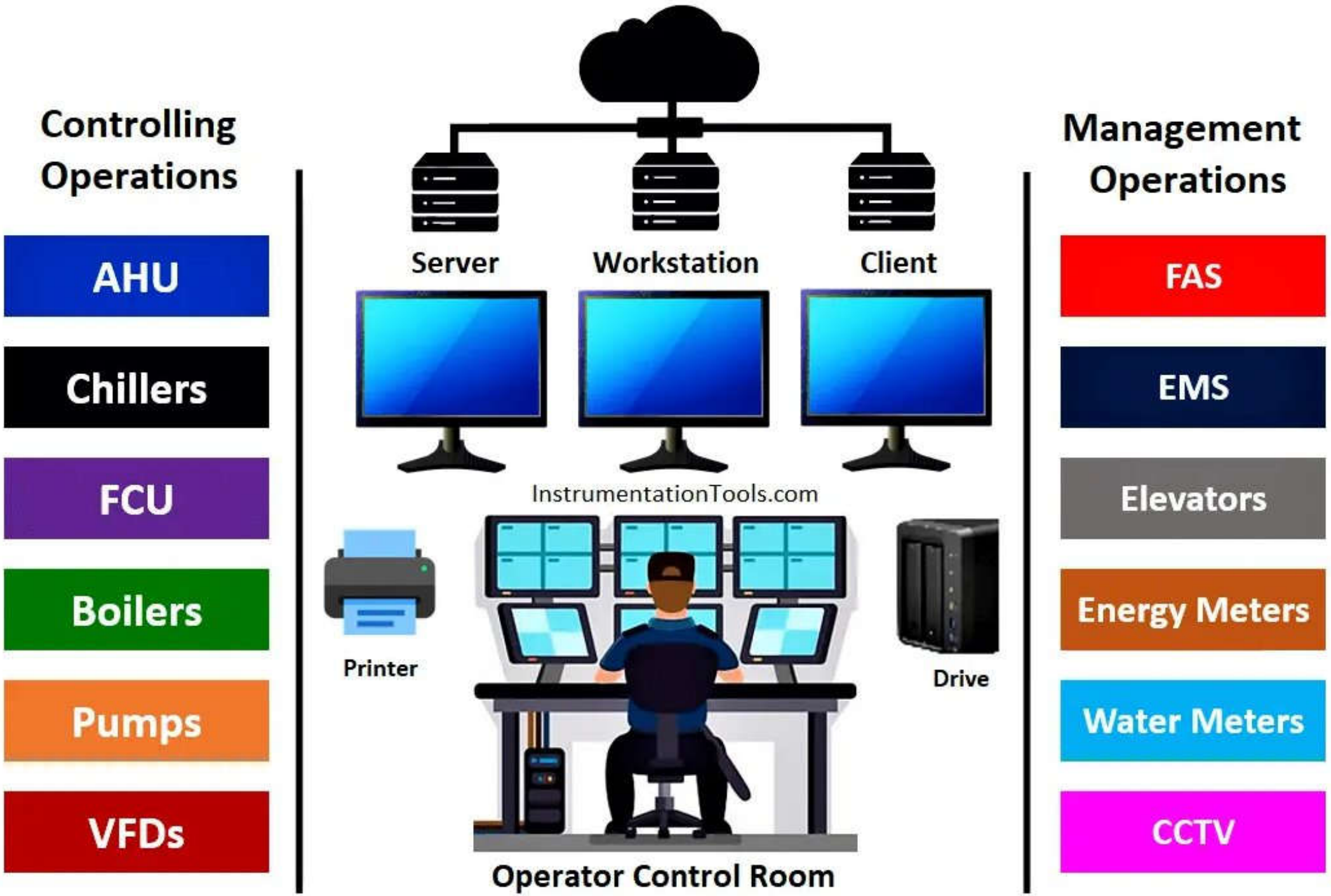


Basic principles



- Energy management
  - Process of monitoring, controlling & conserving energy in a building or organization
- Building energy management (BEM)
  - A long-term strategy dedicated to continuous improvement & energy efficiency
  - BAS/BMS can be used to provide real-time monitoring & integrated control of a wide range of building systems, energy use, environmental conditions to optimise performance & comfort

Controlling & management operations of building automation system



(Source: https://instrumentationtools.com/building-management-system/)

Basic principles

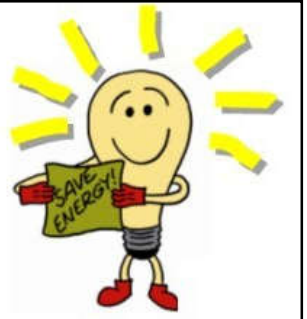
- Energy management to reduce operating costs
  - Optimal start & stop of plant
  - Building warm up & cool down cycles
  - Automatic seasonal plant sequence selection
  - Seasonal temperature setting adjustments
  - Load based control strategies
  - Economy cycle control including CO_2
  - Equipment runtime monitoring & duty cycling
  - Occupancy control & control setback

Building Energy Management Systems - How much energy can be saved

Energy conservation opportunities	**Estimated energy savings***
Turn up temperature to 25.5ºC in summer	5% of cooling cost for each ºC raised
Turn back temperature to 20ºC in winter	9% of heating cost for each ºC set back
Maintain air-conditioning units by annual check-ups and adjustments	15% of cooling cost
Maintain furnace at maximum efficiency by annual check-ups and adjustments	10% of heating cost
Set back domestic water heater from 60 to 43ºC	6-12% of hot water cost
Maximise use of daylight	50-60% of lighting cost
Improve lighting maintenance	10% of lighting cost
Turn off unnecessary lights	17% of lighting cost
Reduce lighting	15-28% of lighting in existing buildings 25-50% of lighting in new buildings
Use insulating glass	10-13% of cooling and heating costs
Insulate hot water pipes and storage tanks	15% of water heating costs
Provide adequate insulation for roof	20% of cooling and heating costs

(* For typical examples only)

Basic principles



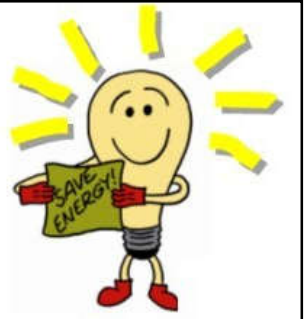
- Typical steps of energy management:
  - 1. Meter energy consumption & collect the data
  - 2. Identify opportunities to save energy & estimate how much energy each opportunity could save
  - 3. Take action to target the opportunities to save energy
  - 4. Track progress by analyzing data to determine the effectiveness of implemented energy-saving measures

Typical functions of energy management system

- ➤ Data acquisition & monitoring
- ➤ Data analysis & reporting
- ➤ Load management & control
- ➤ Demand response
- ➤ Energy efficiency measures
- ➤ Predictive maintenance
- ➤ Renewable energy integration
- ➤ Cost analysis & budgeting
- ➤ Regulatory compliance
- ➤ Remote monitoring & control

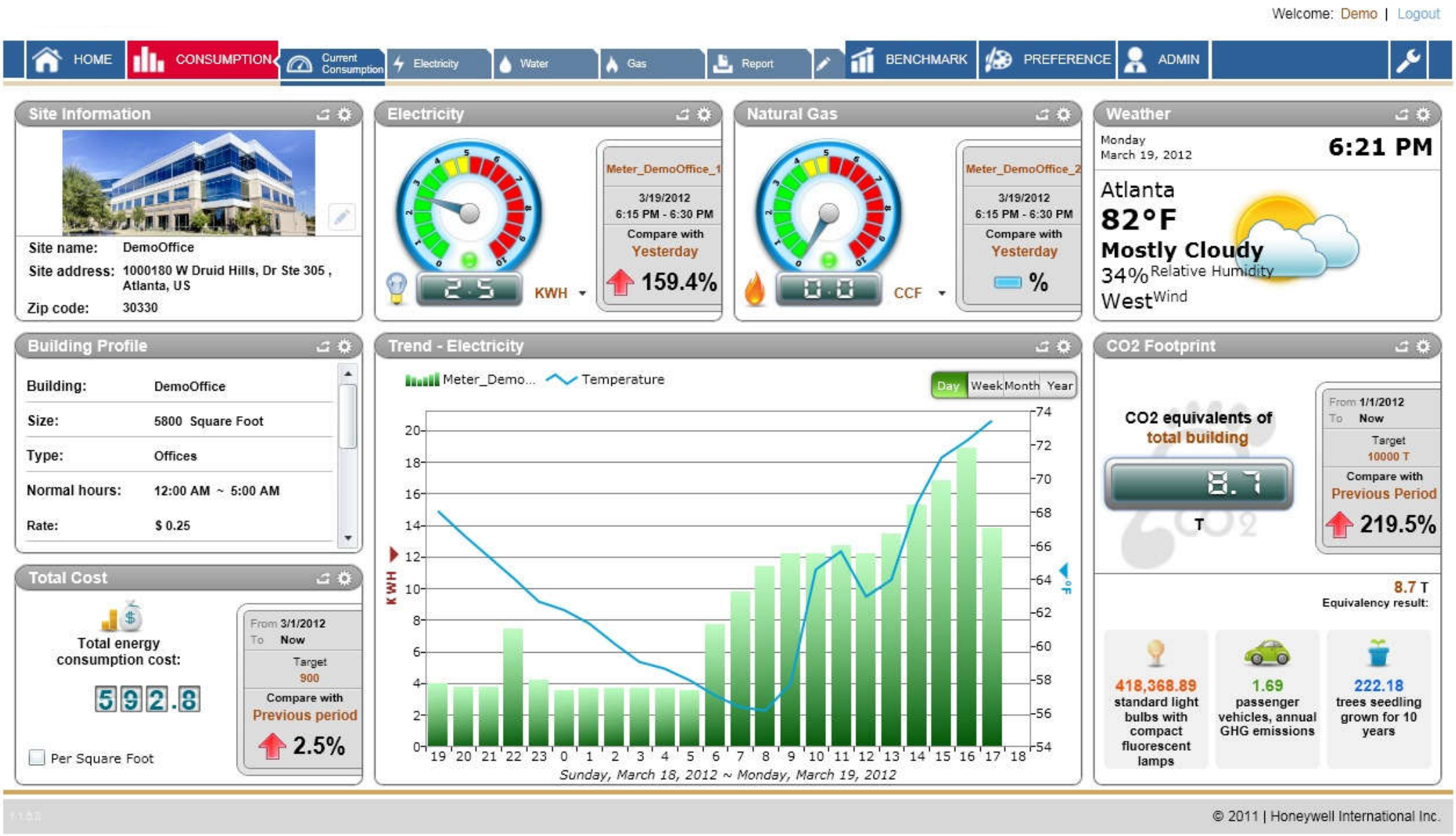
(Source: https://medium.com/@akashkoringa12/ems-power-saving-calculation-energy-management-systems-9788f4ea6d7c)

Basic principles



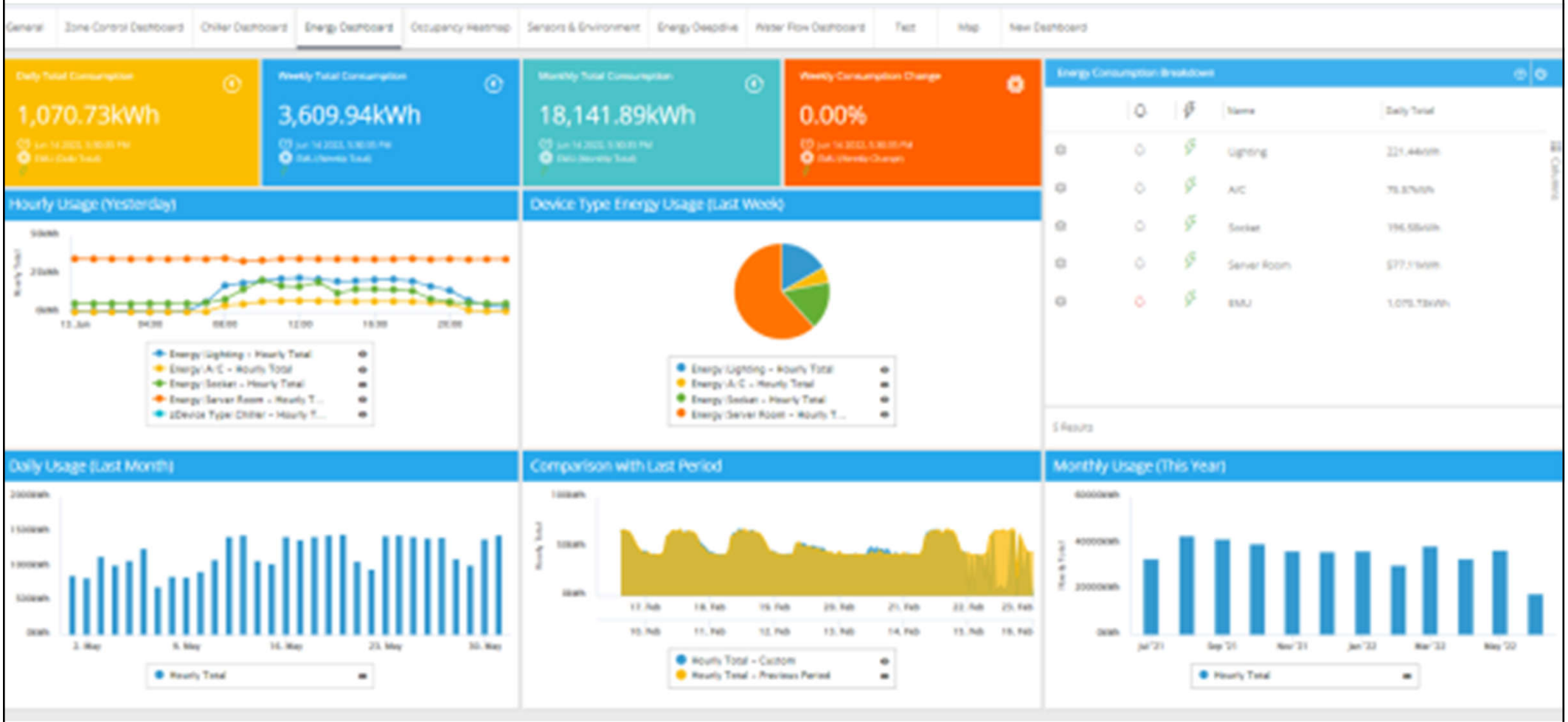
- Major building energy management functions:
  - 1. Dashboard: provides key information which is optimized & intuitive to use
  - 2. Monitoring: on equipment, major plants, energy, power, water, fuel gas, operation & maintenance
  - 3. Alarms: real-time alerts for equipment & systems
  - 4. Data visualization: graphical representation of live & historical data
  - 5. Analytics: to support informed decisions

An example of energy dashboard for buildings



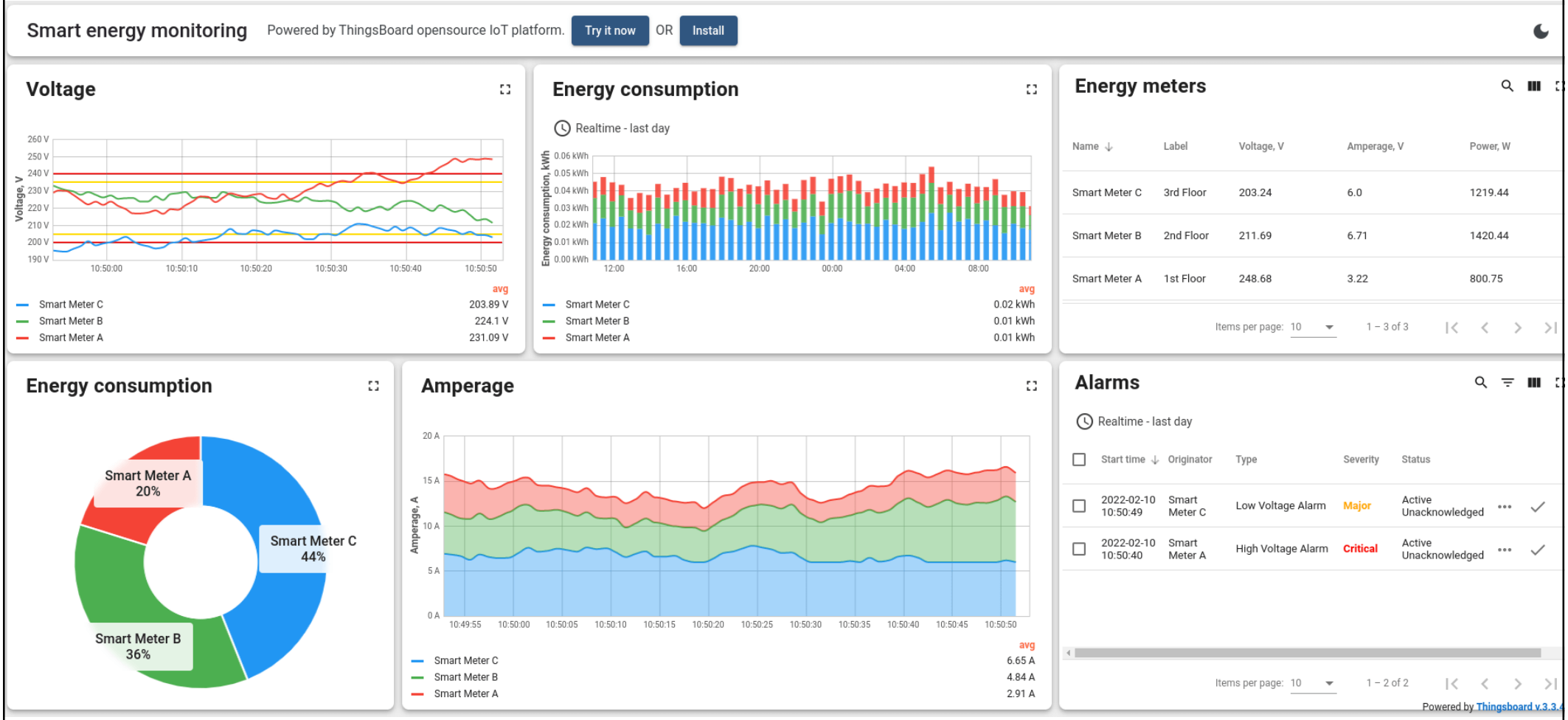
(Source: https://hbsmicrosites.honeywell.com)

Dashboards provide user visibility into energy consumption, equipment status, space utilisation & occupant comfort conditions so as to identify peak usage hours, compare usage trends, quantify cost savings & improve energy management strategies



(Source: https://www.clpsec.com/indoor-environment-control/)

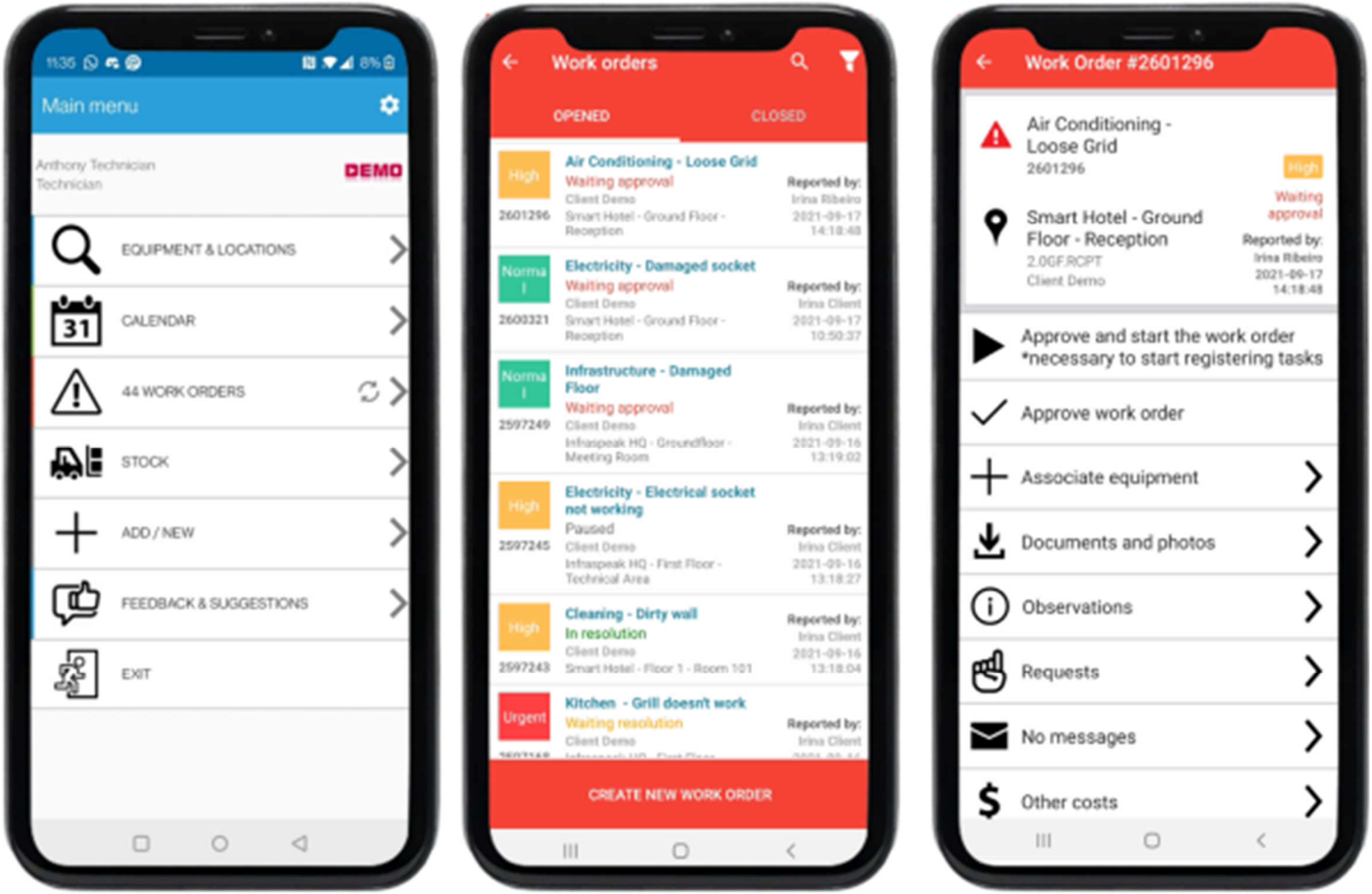
Smart energy monitoring with real-time dashboards



View live demo: https://demo.thingsboard.io/dashboard/e8e409c0-f2b5-11e6-a6ee-bb0136cc33d0?publicId=963ab470-34c9-11e7-a7ce-bb0136cc33d0

(Source: https://thingsboard.io/smart-energy/)

Mobile app platforms for building & facility management



(Source: https://www.clpsec.com/digitalised-facility-management-solution/)

Basic principles

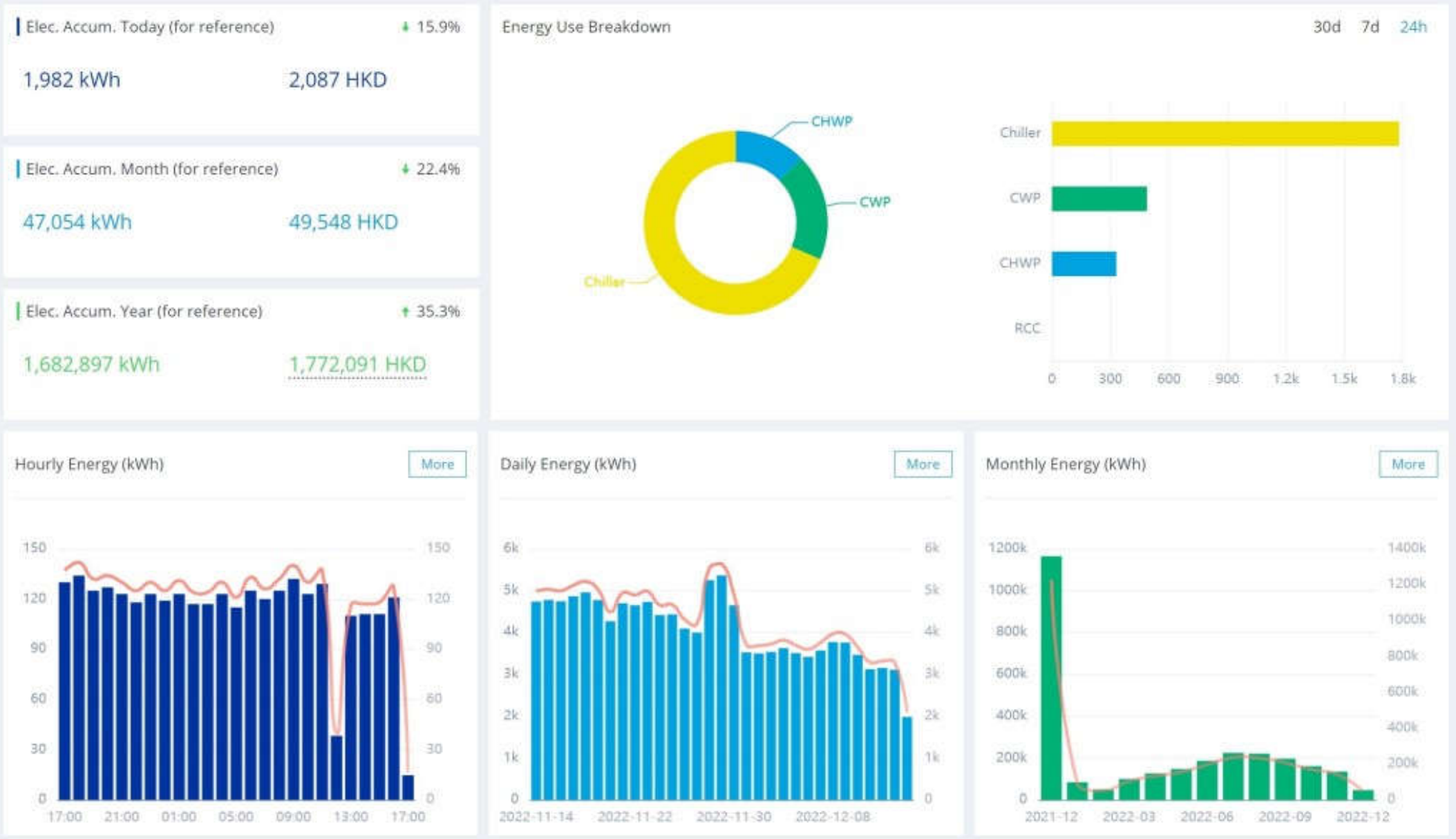
- Key objectives of energy management:
  - Centralized monitoring & intelligent controls to automate operations
  - Fault detection & diagnosis to support predictive maintenance
  - Energy analytics & optimization of performance

Chiller plant analytics & fault detection diagnosis (FDD)

- A diagnostic engine that turns data into actionable knowledge, allowing facility managers to understand how the main components of a plant are performing
- Also calculates the electrical consumption for the given load & conditions for each chiller and provides detailed analytics
- An alarm will be raised if a fault is detected

(Source: https://www.clpsec.com/supply-side-hvac-optimisation/)

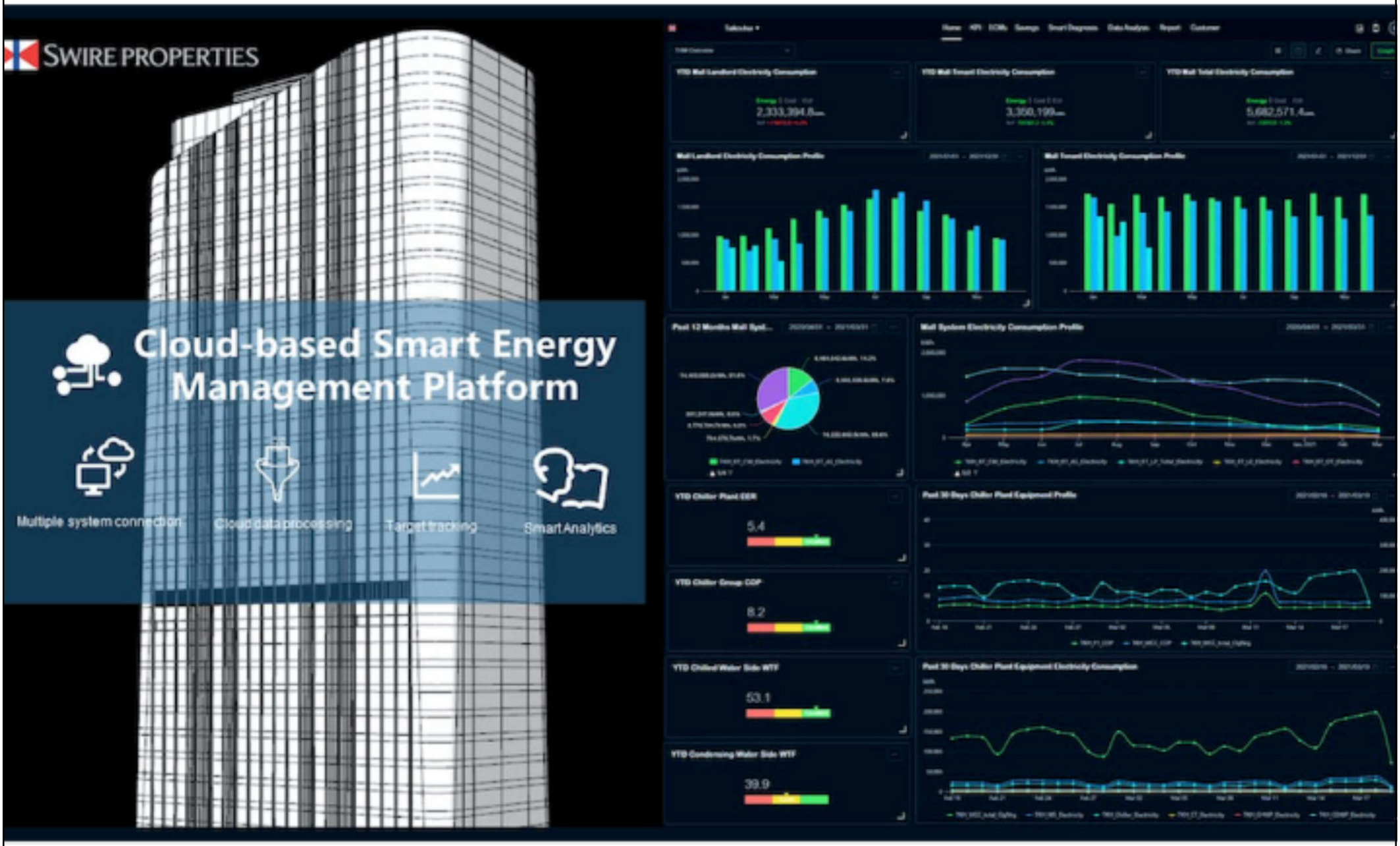
Cloud-based building analytics platform



Major features: fault detection and diagnostics (FDD), energy management, key performance indicators (KPIs), automatic reporting

(Source: https://www.clpsec.com/building-analytics/)

Cloud-based smart energy management platform



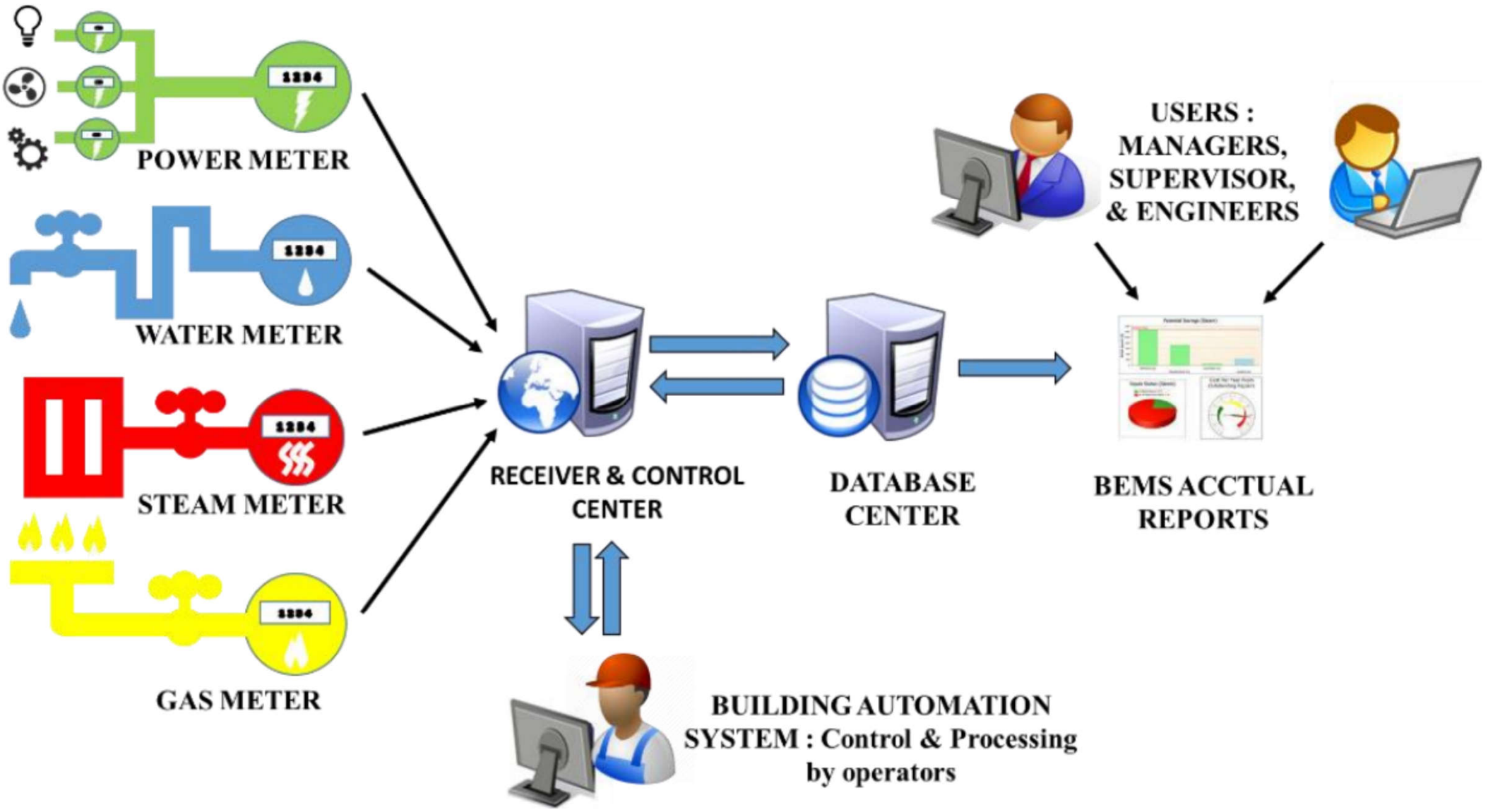
(Source: https://sd.swireproperties.com/2021/en/performance-environment/energy/smart-energy-management)

BEM operations

- Use of BAS data
  - Energy monitoring
  - Fault reports & maintenance scheduling

- Energy monitoring process:
  - 1. Data collection (energy use data & breakdowns)
  - 2. Data analysis (e.g. which indicates a problem or malfunction)
  - 3. Reporting (show energy use of each part)
  - 4. Action (make effective use of the reports)

Basic concept of a building energy management system (BEMS)

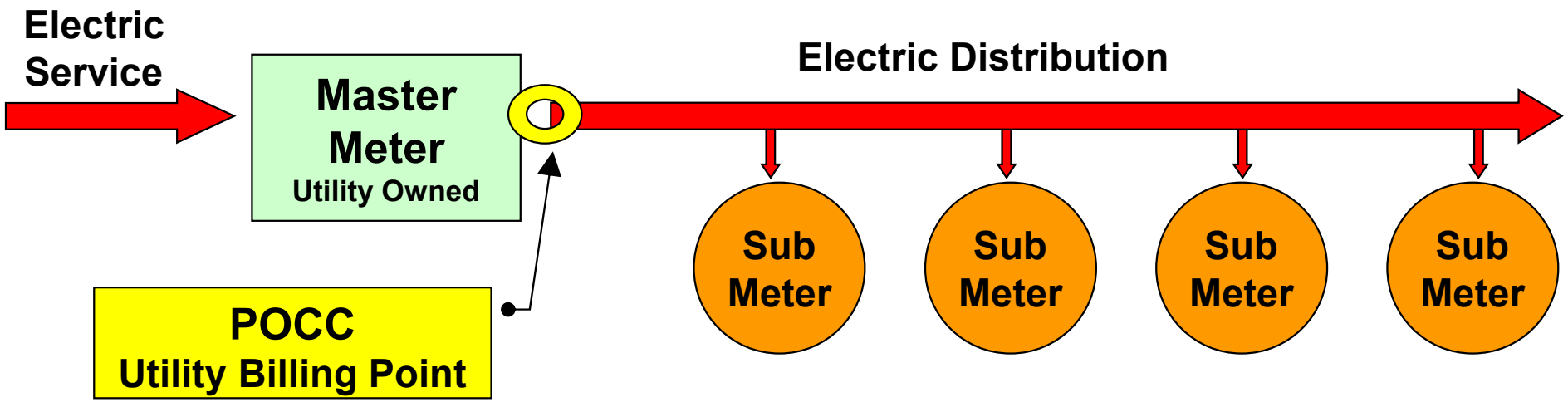


(Source: Chin J. & Lin S.-C., 2016. A behavioral model of managerial perspectives regarding technology acceptance in building energy management systems, *Sustainability*, 8 (7) 641. https://doi.org/10.3390/su8070641)

BEM operations

- Energy metering equipment
  - Meter module: e.g. on electrical circuits
  - Display module: show energy consumption rate
  - Data logger: store & transmit data
  - Data transmission system: connect data loggers & communicate the data
  - Computer & related analysis software
- Maintenance operations
  - Equipment runtime & conditions, faults & alarms

Typical metering equipment



POCC – Point of Common Coupling, the point where control passes from the Electric Utility to the building Owner

Electricity meter

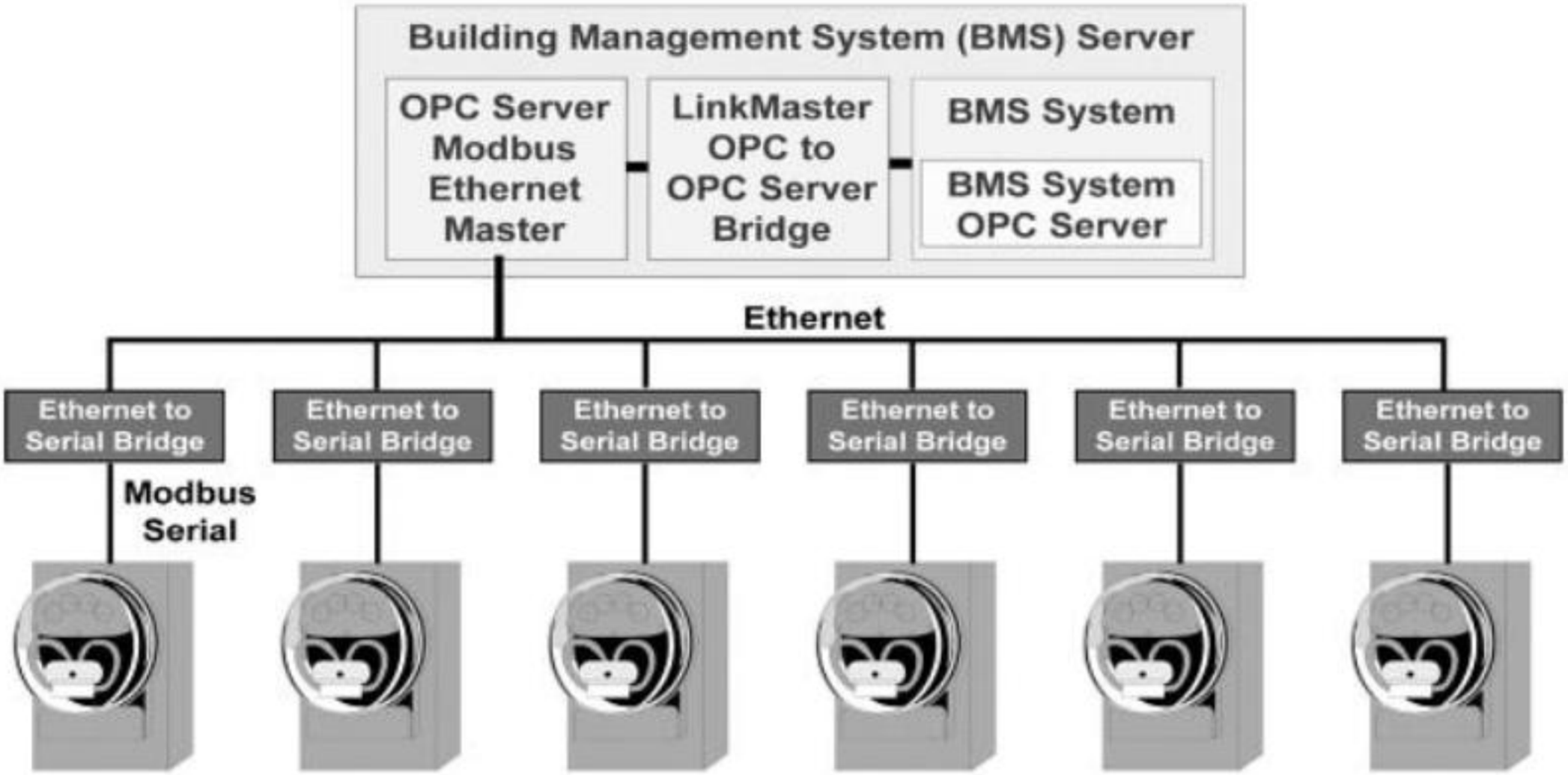
Gas meter

Water meter

Also chilled, hot water & steam meters

(See also: http://en.wikipedia.org/wiki/Utility_submeter)

Metering data from a BAS/BMS server made available to a local area network using an OPC server



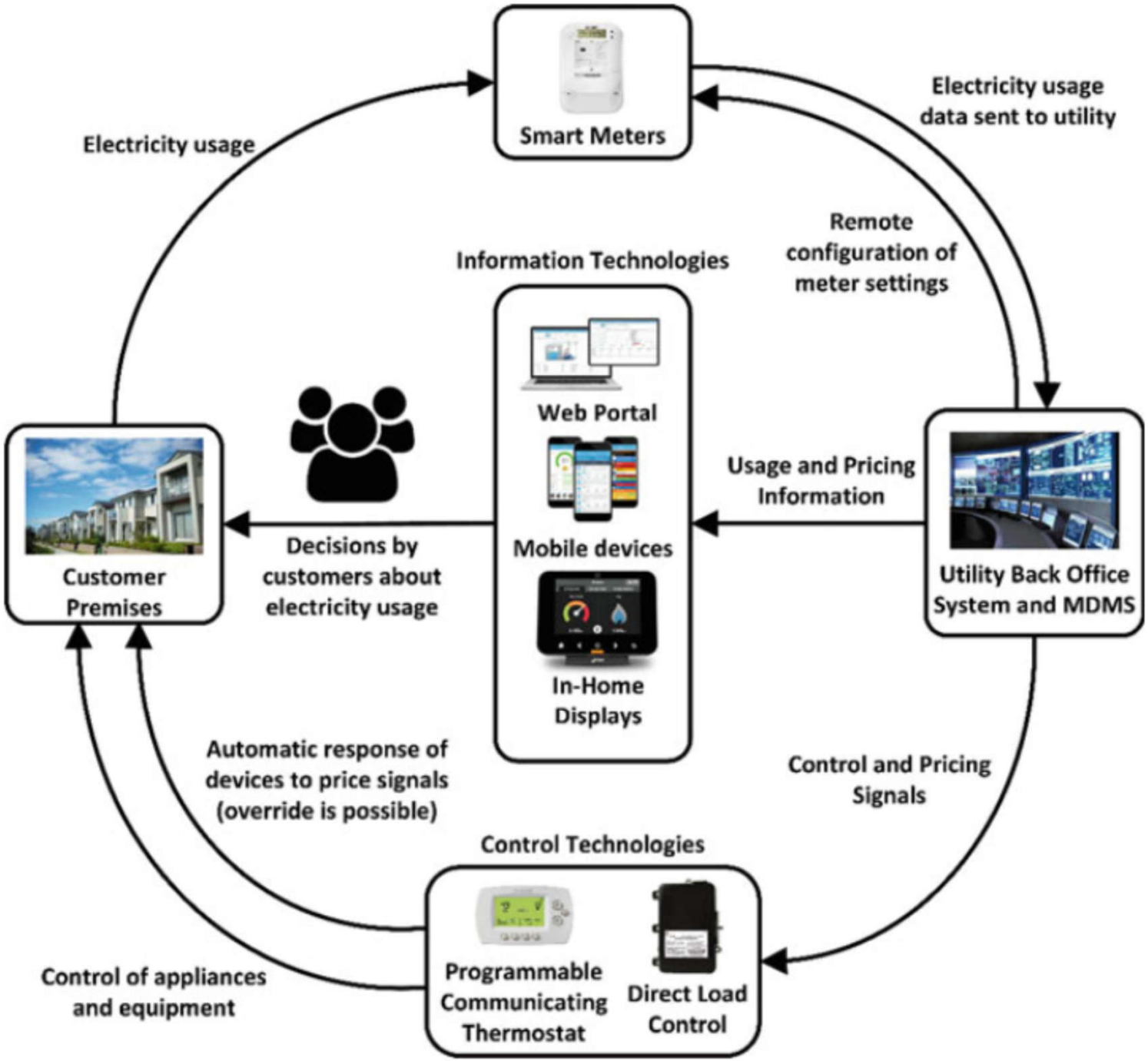
(OPC = Object Linking and Embedding (OLE) for Process Control)

(Source: Capehart, B. L. and Middelkoop, T., 2011. *Handbook of Web Based Energy Information and Control Systems*)

BEM operations

- IoT smart meters
  - Combine conventional energy meters with the Internet of Things (IoT) technology for real-time data collection & transmission
  - Use communication protocols e.g. Wi-Fi, cellular networks, or other wireless technologies
  - Can be used for energy management, grid monitoring, smart homes & industrial facilities to enable remote monitoring & control

Typical smart metering system for smart metering applications



(Source: Abdeslam D. O. (ed.), 2023. *Smart Meters: Artificial Intelligence to Support Proactive Management of Energy Consumption*, Springer, Cham. https://doi.org/10.1007/978-3-031-27556-2)

BEM operations

- Uses of metered data
  - Energy billing & procurement
    - Measure tenant energy use, verify utility bills, identify best utility rate tariffs, and participate in demand response programs
  - Measure, verify & optimize performance
    - Diagnose equipment & systems operations; benchmark utility use; identify potential retrofit/ replacement projects; and monitor, diagnose & communicate power quality problems

BEM operations

- Uses of metered data (cont'd)
  - Manage utility use
    - Monitor existing utility usage & utility budgeting support
  - Baseline development + measurement & verification (M&V) of savings
    - Such as in energy savings performance contracts (ESPC) & utility energy services contracts (UESC)
  - Promote energy use awareness for building managers & occupants

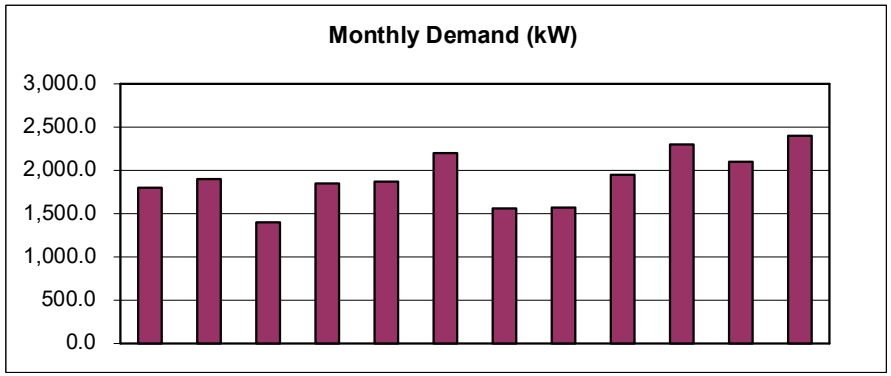
Example of analysing the electricity billings

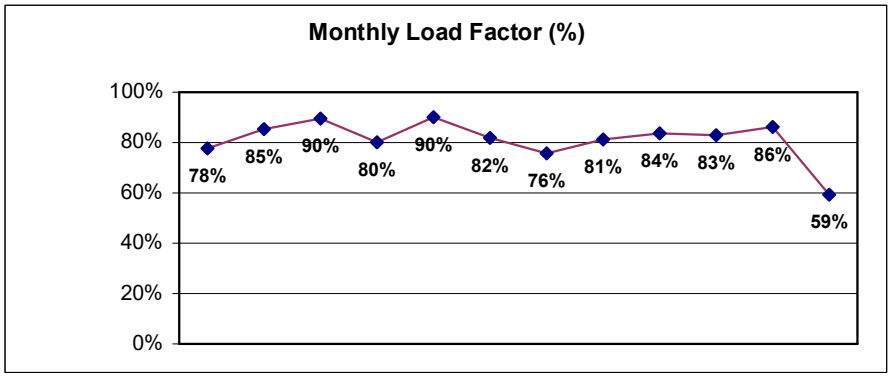
Electricity Consumption Data

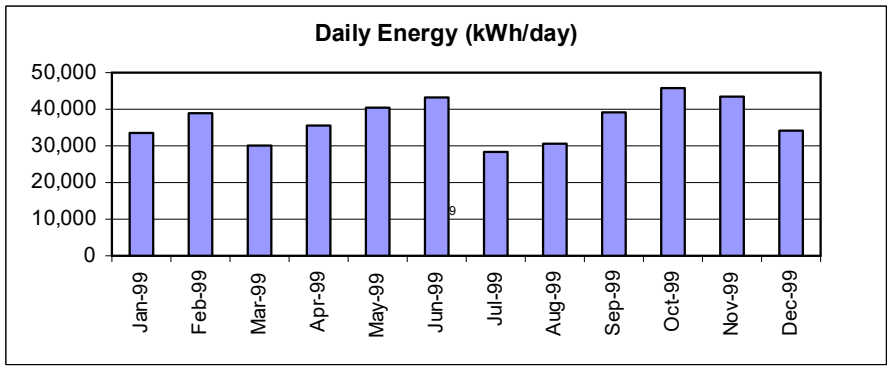
Location: ABC Facility

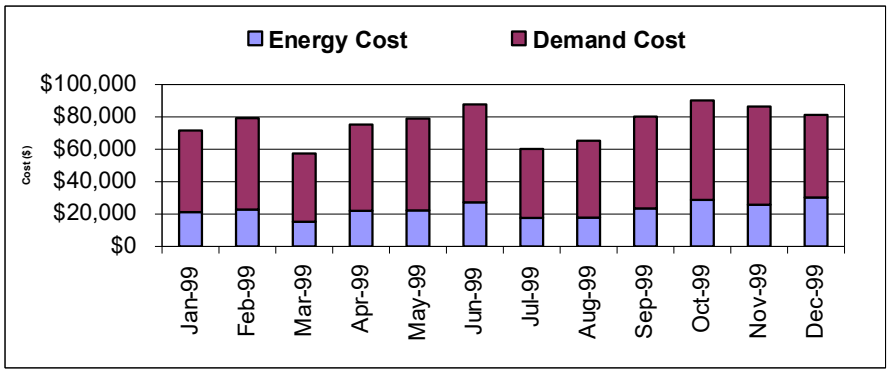
[C:\Project Files\Audit Manual\Spreadsheets\[Electricity Cost.xls]Electicity Consumption Data]

Billing Date	Metered kVA	Metered kW	Power Factor	Billed kW	Energy kWh	Days	Daily kWh	Load Factor	Demand Cost	Energy Cost	Adjust (+/-)	Sub Total	Total Cost
01/01/99		1,800.0		1,800.0	1,006,703	30	33,557	78%	$21,250	$50,365	($11,147)	$71,615	$64,701
02/01/99		1,900.0		1,900.0	1,206,383	31	38,916	85%	$22,750	$56,441	($13,204)	$79,191	$70,607
03/01/99		1,400.0		1,400.0	842,286	28	30,082	90%	$15,250	$42,144	($9,263)	$57,394	$51,501
04/01/99		1,850.0		1,850.0	1,102,176	31	35,554	80%	$22,000	$53,315	($12,132)	$75,315	$67,606
05/01/99		1,870.0		1,870.0	1,213,021	30	40,434	90%	$22,300	$56,641	($13,252)	$78,941	$70,287
06/01/99		2,200.0		2,200.0	1,339,599	31	43,213	82%	$27,250	$60,438	($14,716)	$87,688	$78,080
07/01/99		1,560.0		1,560.0	850,195	30	28,340	76%	$17,650	$42,540	($9,438)	$60,190	$54,304
08/01/99		1,570.0		1,570.0	948,747	31	30,605	81%	$17,800	$47,467	($10,429)	$65,267	$58,677
09/01/99		1,950.0		1,950.0	1,213,798	31	39,155	84%	$23,500	$56,664	($13,308)	$80,164	$71,536
10/01/99		2,300.0		2,300.0	1,373,054	30	45,768	83%	$28,750	$61,442	($15,111)	$90,192	$80,337
11/01/99		2,100.0		2,100.0	1,347,059	31	43,454	86%	$25,750	$60,662	($14,731)	$86,412	$76,699
12/01/99		2,400.0		2,400.0	1,024,475	30	34,149	59%	$30,250	$50,984	($11,685)	$81,234	$74,418
Totals/Max		**2,400.0**		**2,400.0**	**13,467,496**	**364**			**$274,500**	**$639,104**	**($148,415)**	**$913,604**	**$818,752**





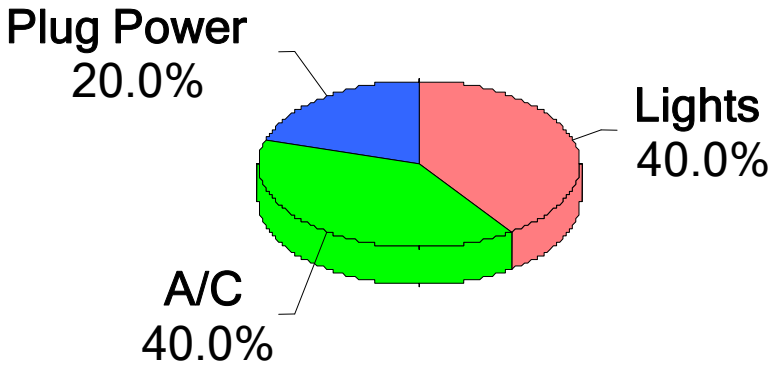




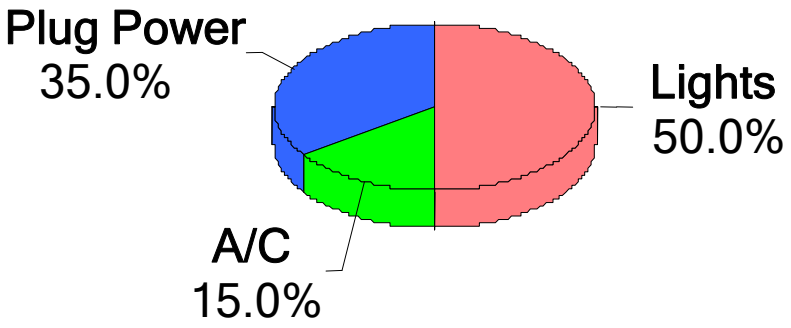
(Source: Department of Minerals and Energy, South Africa)

Analysis of the demand & energy use

Demand



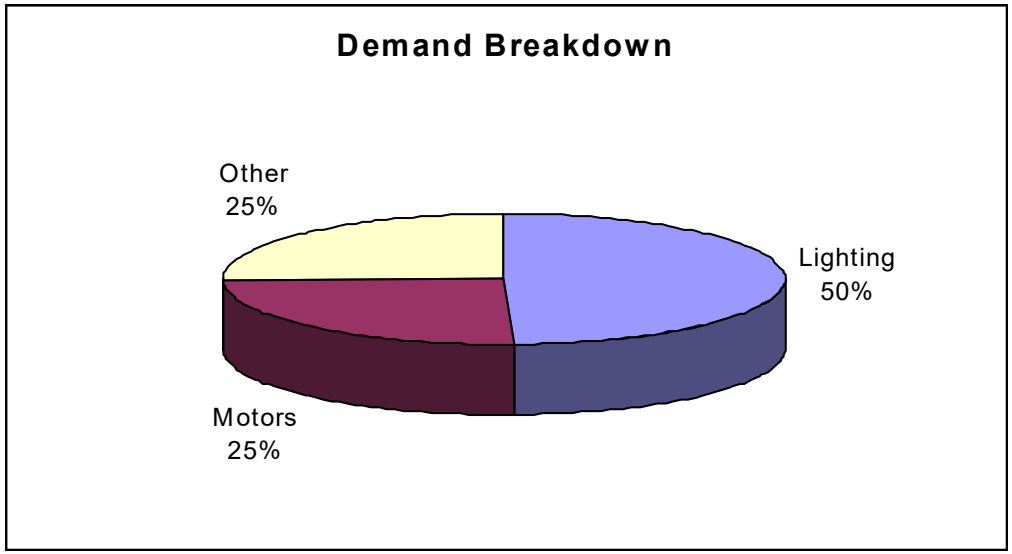
Energy

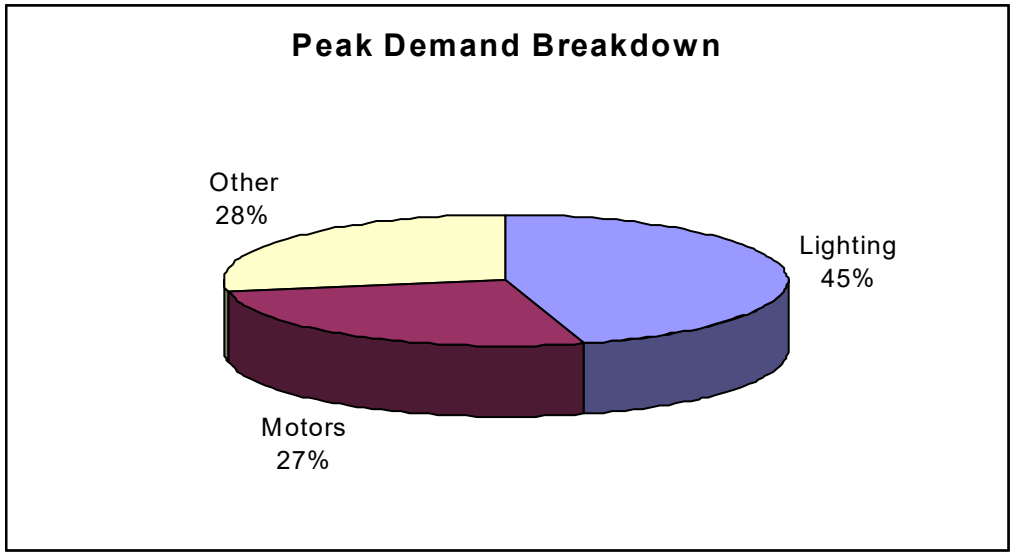


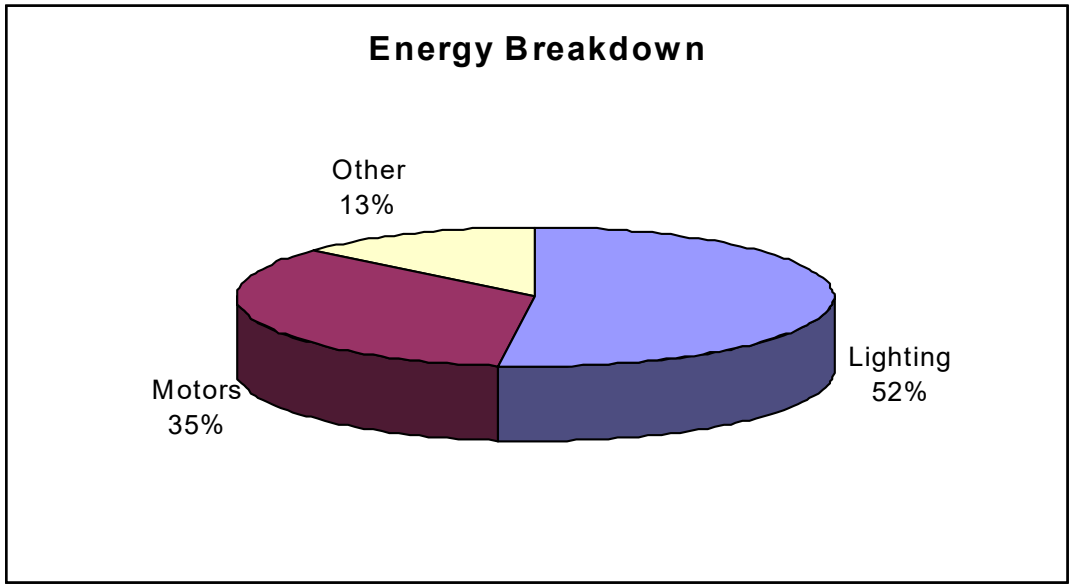
Item	Units	Formula
Quantity	(a number)	
Unit Load	kW	
Total kW	kW	Quantity. x Unit Load.
Hrs/Period	hours	
kWh/Period	kWh	Total kW x Hrs/Period
Diversity Factor (Div'ty Factor)	0 - 100%	
Peak kW	kW	kW x Diversity Factor

(Source: Department of Minerals and Energy, South Africa)

Breakdown of demand, peak demand & energy







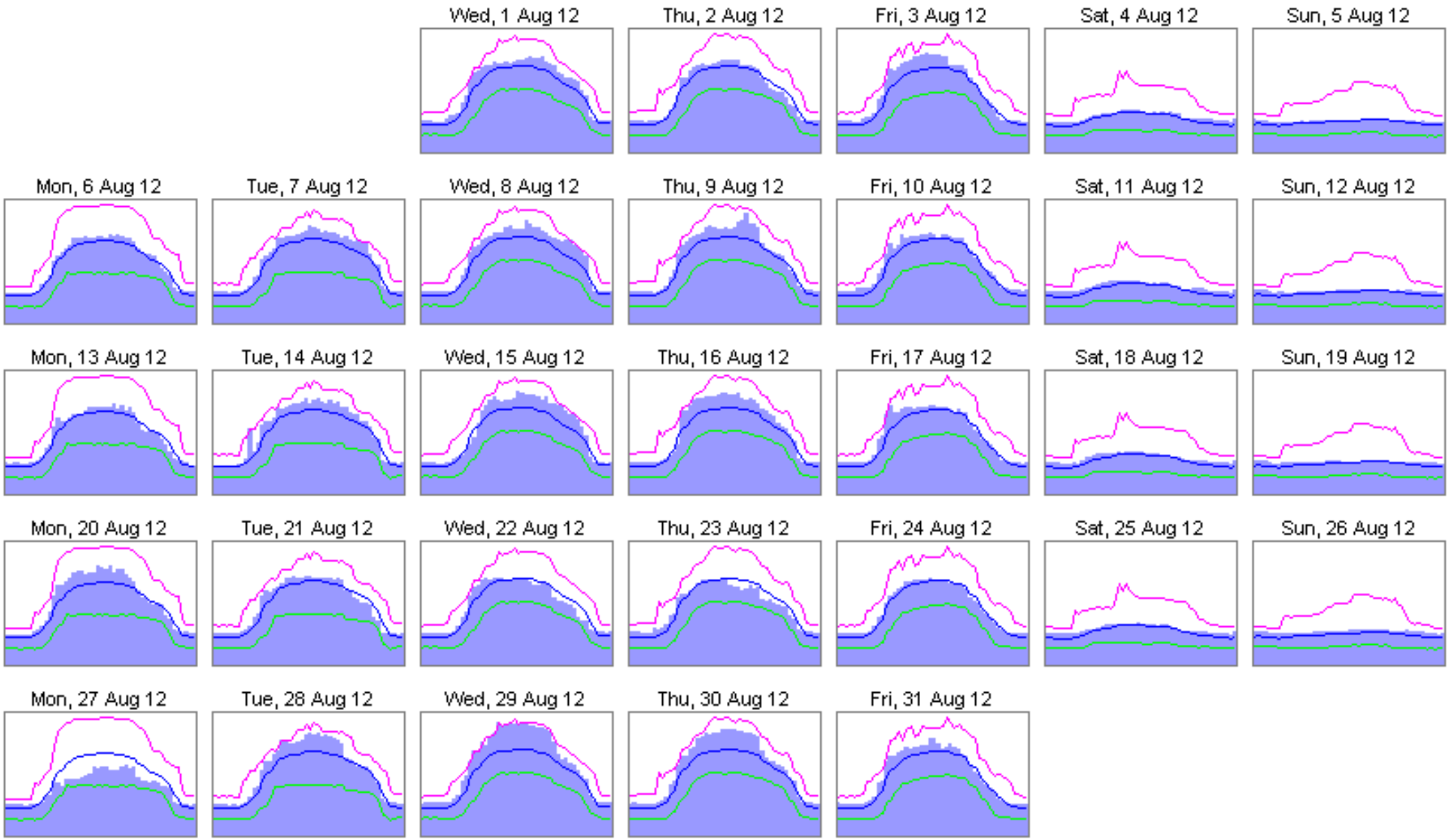
(Source: Department of Minerals and Energy, South Africa)

Demand analysis

- Energy assessment & demand analysis: to discover the patterns/profiles of energy usage
  - Hourly demand profile
  - Peak demand profile
- Understanding the time patterns of energy use
  - Study the electrical demand profile & identify possible energy management opportunities
  - Identify opportunities for power factor correction

(* See also: How to Use Energy Profiles to Find Energy Waste http://www.energylens.com/articles/identify-energy-waste)

A month's energy profiles with hourly data for each day

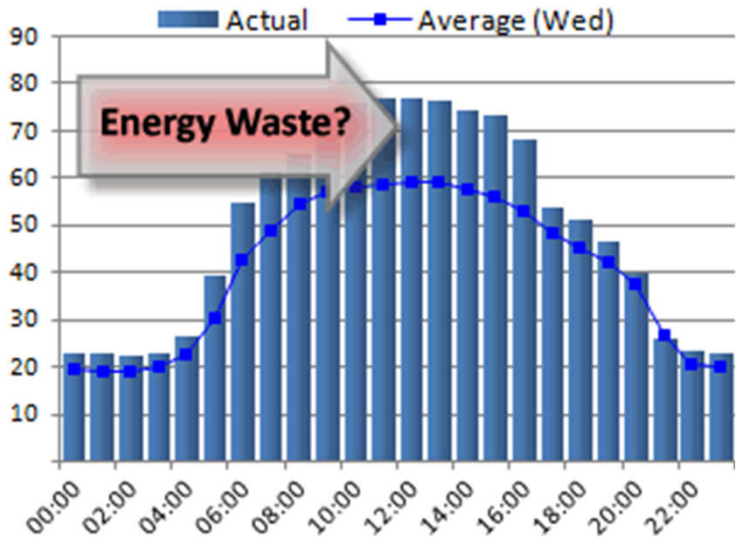


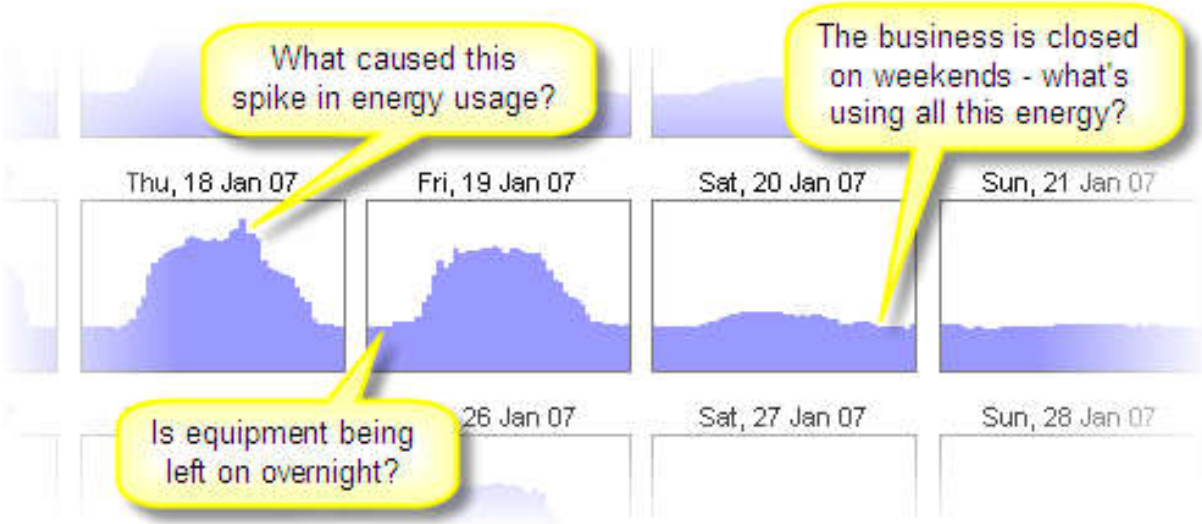
All chart scales run from 0 to 1191.3 kW (average power over half-hour interval). Maximum, average, and minimum profiles are included for each day of the week.

(Source: Energy Monitoring Charts and Tables http://www.energylens.com/outputs)

Demand analysis

- Patterns revealed:
  - Peak demand
  - Night load
  - Start-up & shut-down
  - Weather effects
  - Loads that cycle
  - Interactions
  - Occupancy effects
  - Problem areas





(* See also: Energy Monitoring Charts and Tables http://www.energylens.com/outputs)

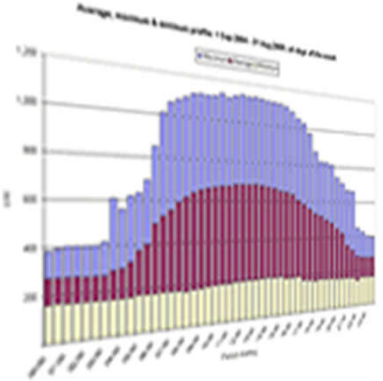
Demand analysis

- Analyse the profile
  - Require facility operational knowledge
  - Mark scheduled events on the profile
  - Correlate events with:
    - Demand increase, decrease, cycling, peaks
  - Reconcile with demand on utility bills
  - Investigate unknown patterns

"There's always a savings opportunity in a new demand profile"

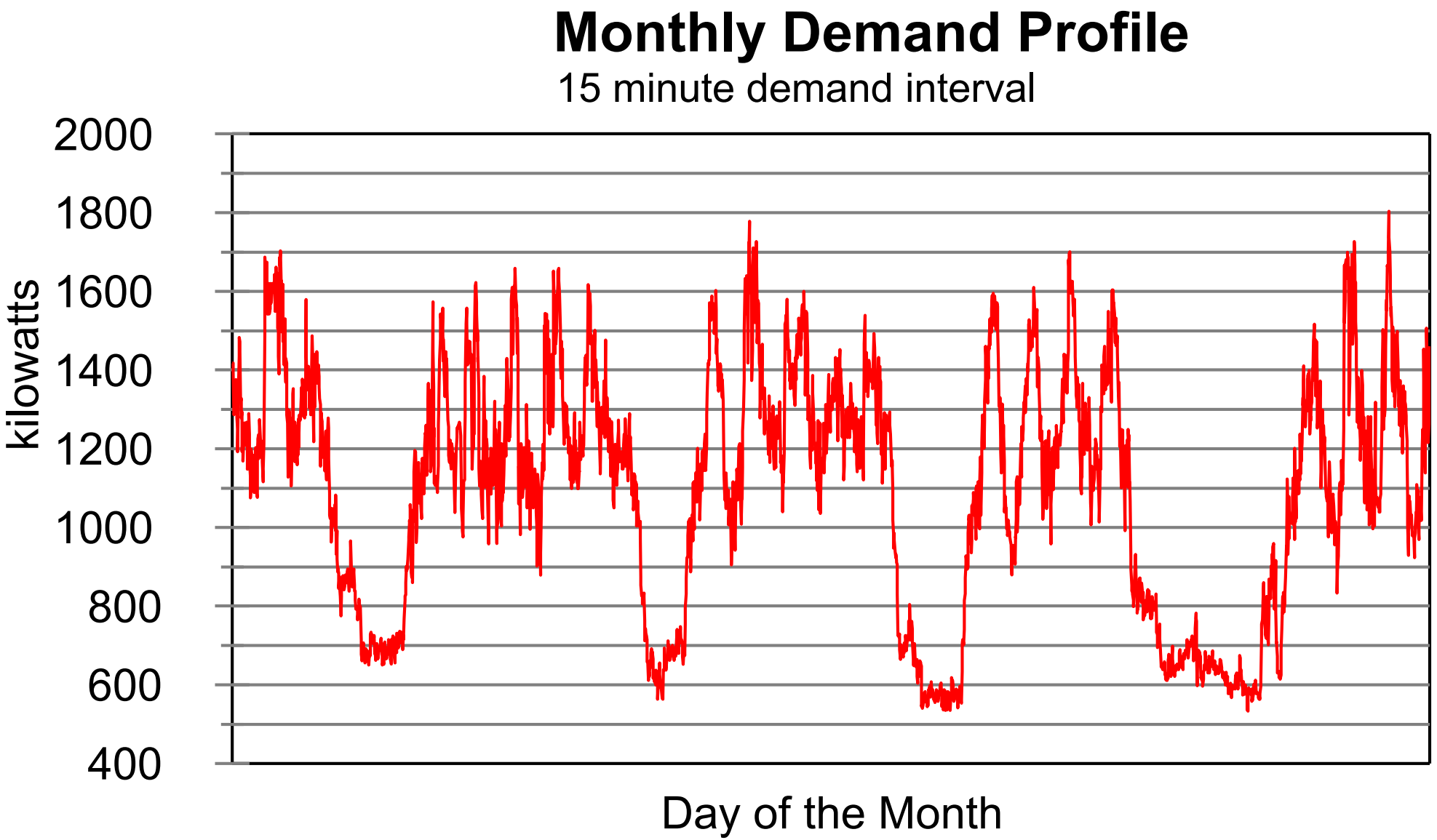
Demand analysis

- Obtaining a demand profile
  - Periodic utility meter readings
  - Recording clip-on ammeter measurements
  - Basic recording power meter
  - Multi-channel recording power meters
  - A facility energy management or SCADA (supervisory control & data acquisition) system
  - A dedicated monitoring system



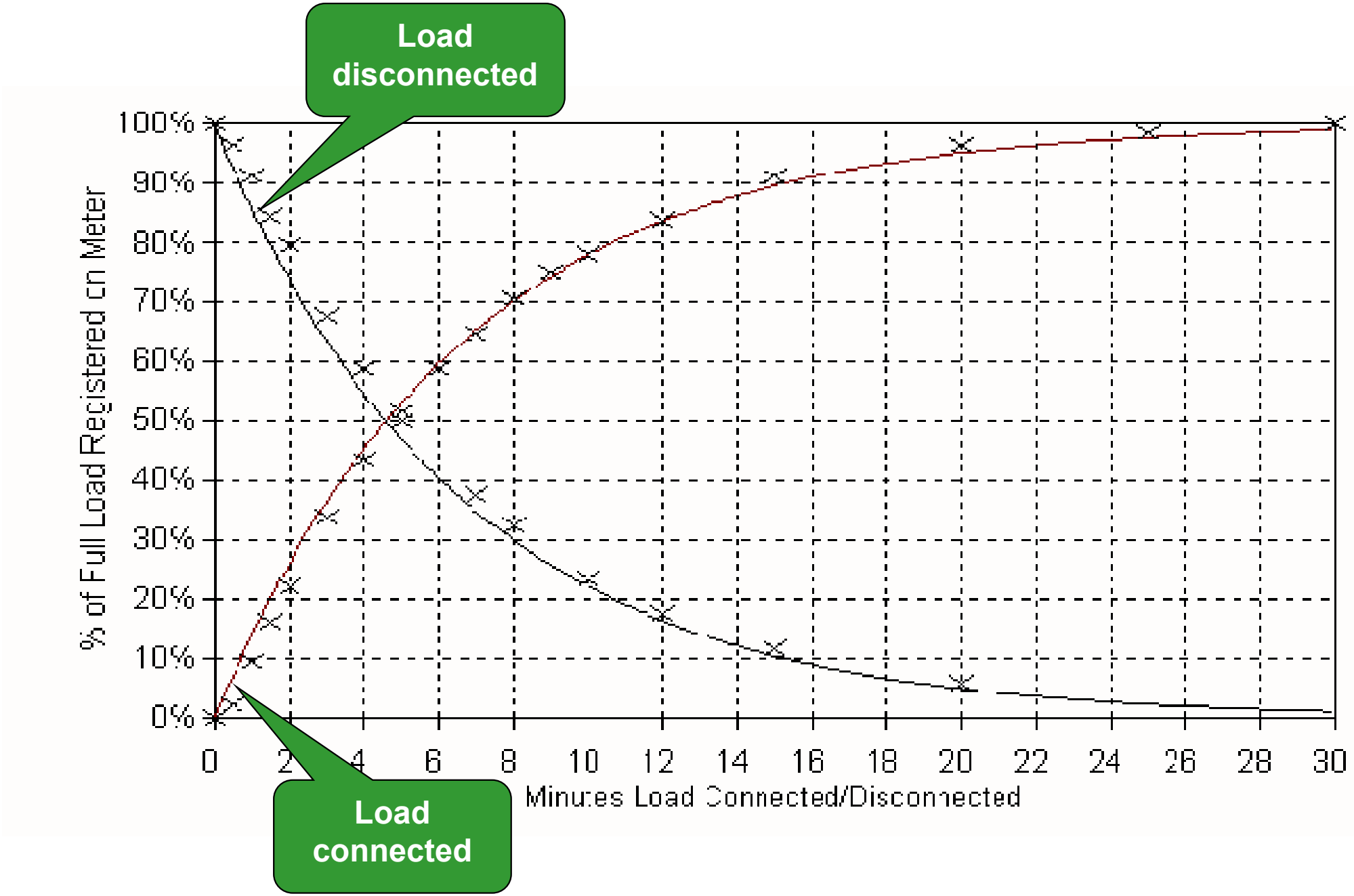
Videos: Analyzing energy data (9:09) & loading energy data (6:54) with Energy Lens
http://www.energylens.com/videos/

Study of daily or monthly profile



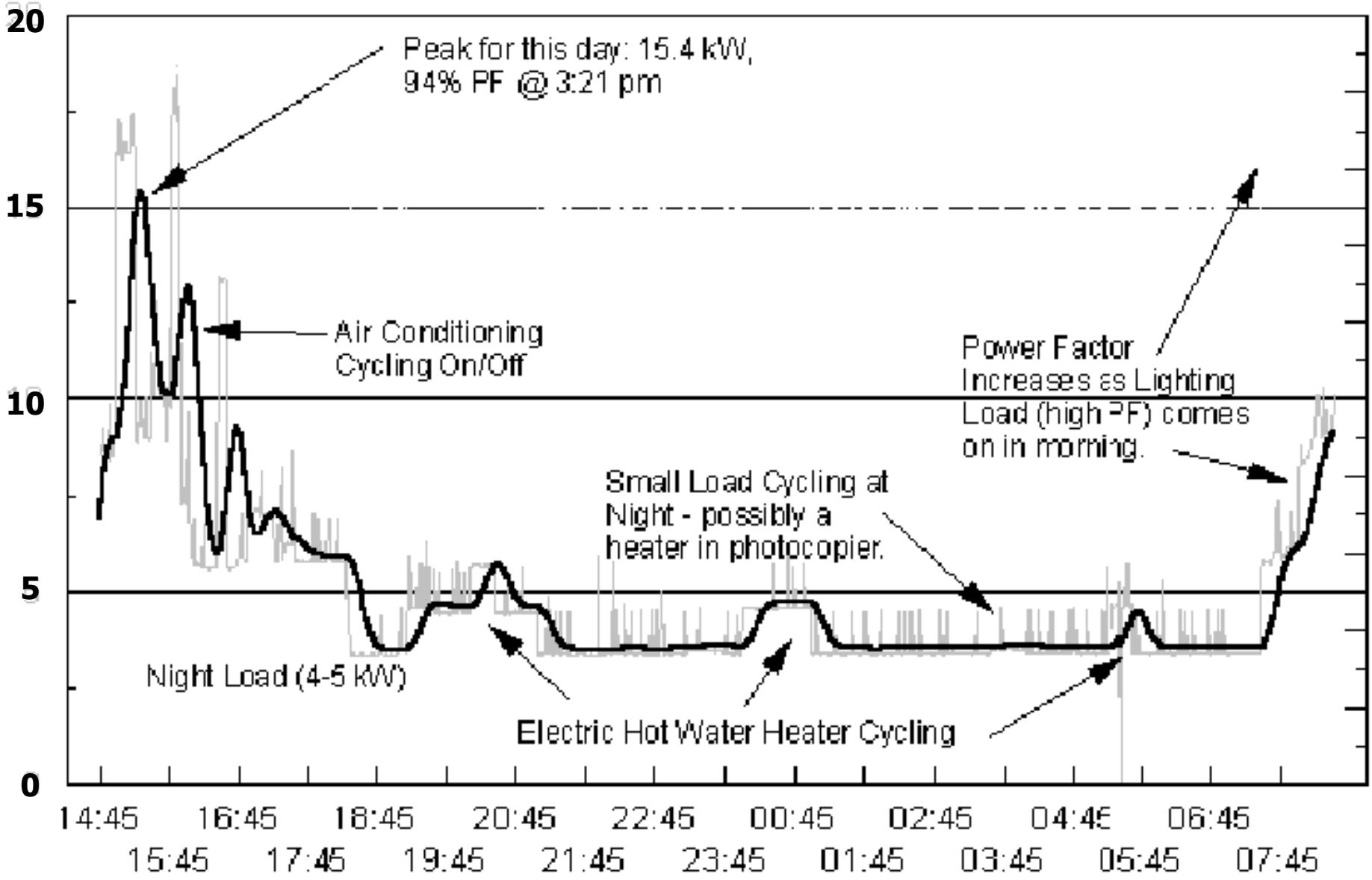
(Source: Department of Minerals and Energy, South Africa)

Meter response (time delay)



(Source: Department of Minerals and Energy, South Africa)

What the demand meter sees



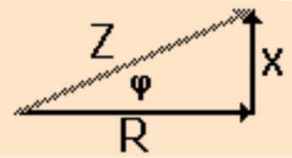
(Source: Department of Minerals and Energy, South Africa)

Demand analysis

- Savings opportunities
  - Scheduling – reduce startup peaks
  - Infrequent demand peaks – avoidable
  - Shift on-peak to off-peak usage pattern
  - Equipment loading – consider sequencing
- Correct power factor – on peak
  - At service entrance
  - In the distribution system
  - At the point of use power factor (PF)

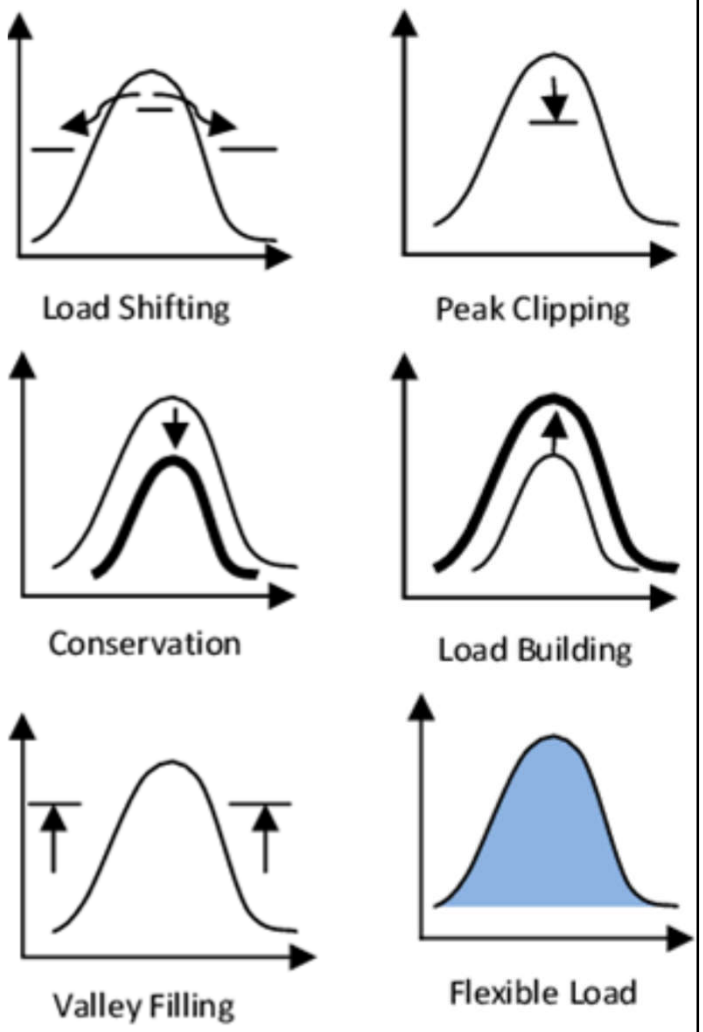
$$P_{avg} = VI \cos \varphi$$

$$\text{POWER FACTOR} = \cos\varphi = \frac{R}{Z}$$

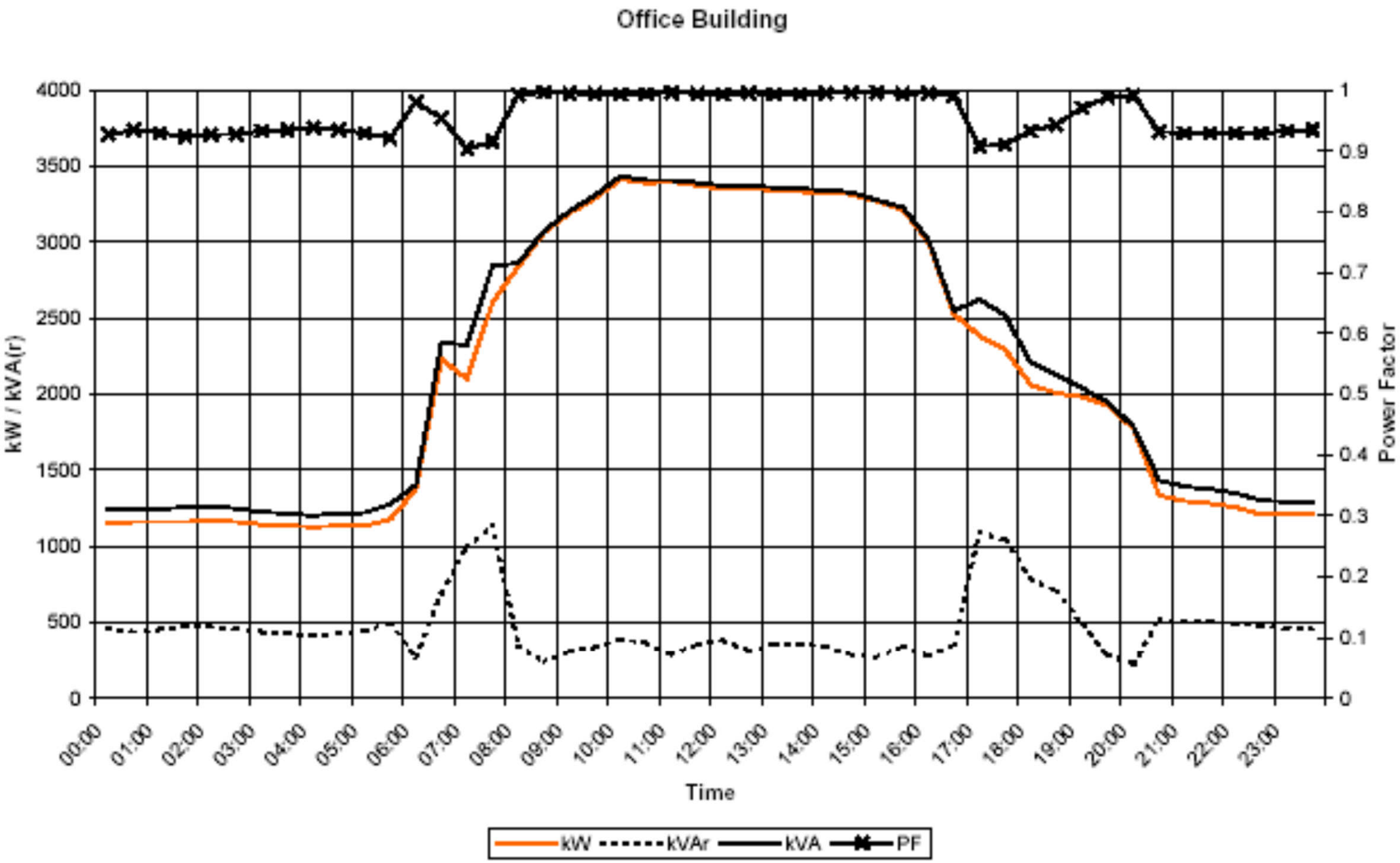


Demand analysis

- Peak demand control
  - Eliminate accidental peaks
  - Shift activity “off-peak”
  - Peak demand warning for staff
  - Interlock equipment
  - Load shedding system
  - Use generator to “clip” the peak
- Demand side management



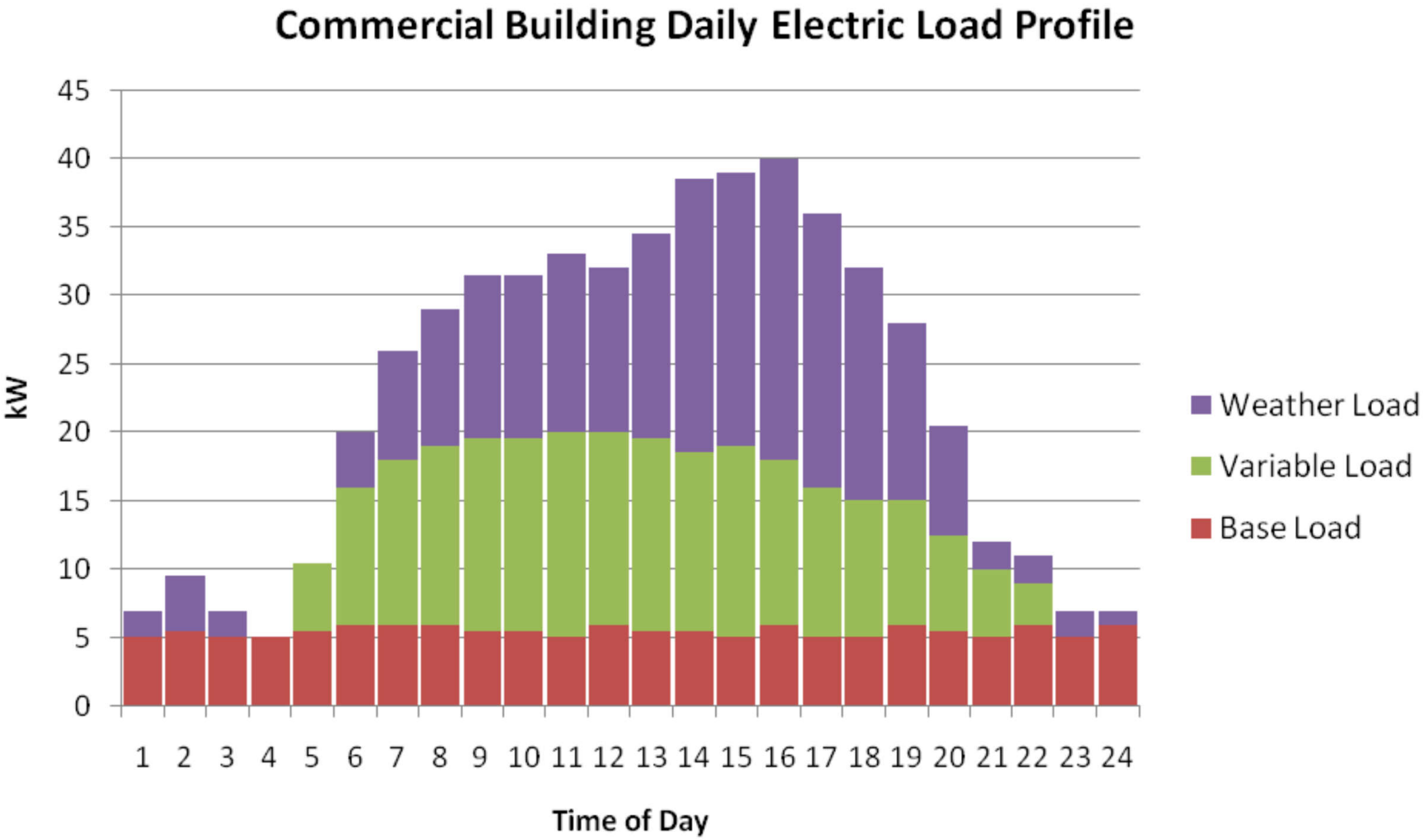
Can you analyse this energy & demand profile?



(Source: Department of Minerals and Energy, South Africa)

Typical commercial building daily electric load profile

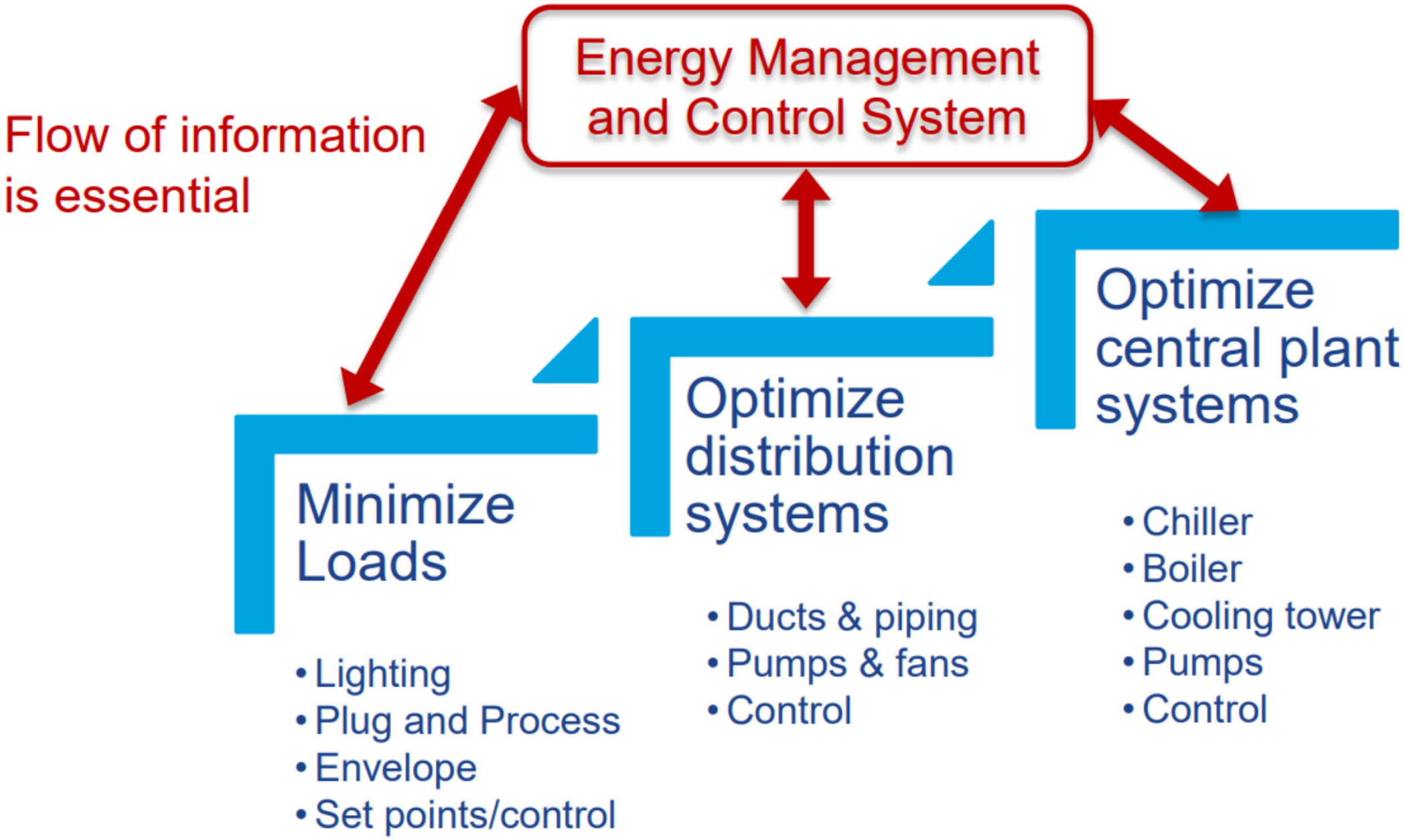
Could you interpret & explain this?



BEM strategies

- Systematic approach to energy management
  - Measurement & visualization
    - Improve transparency of current energy usage
  - Diagnosis, analysis & implementation
    - Analyse building energy usage from various angles & take appropriate actions by finding the exact cause of energy waste
  - Verification & continuous improvement
    - Use data collected to ensure desired results are being achieved & offer further measures for improvement

System approach to building energy management & control system



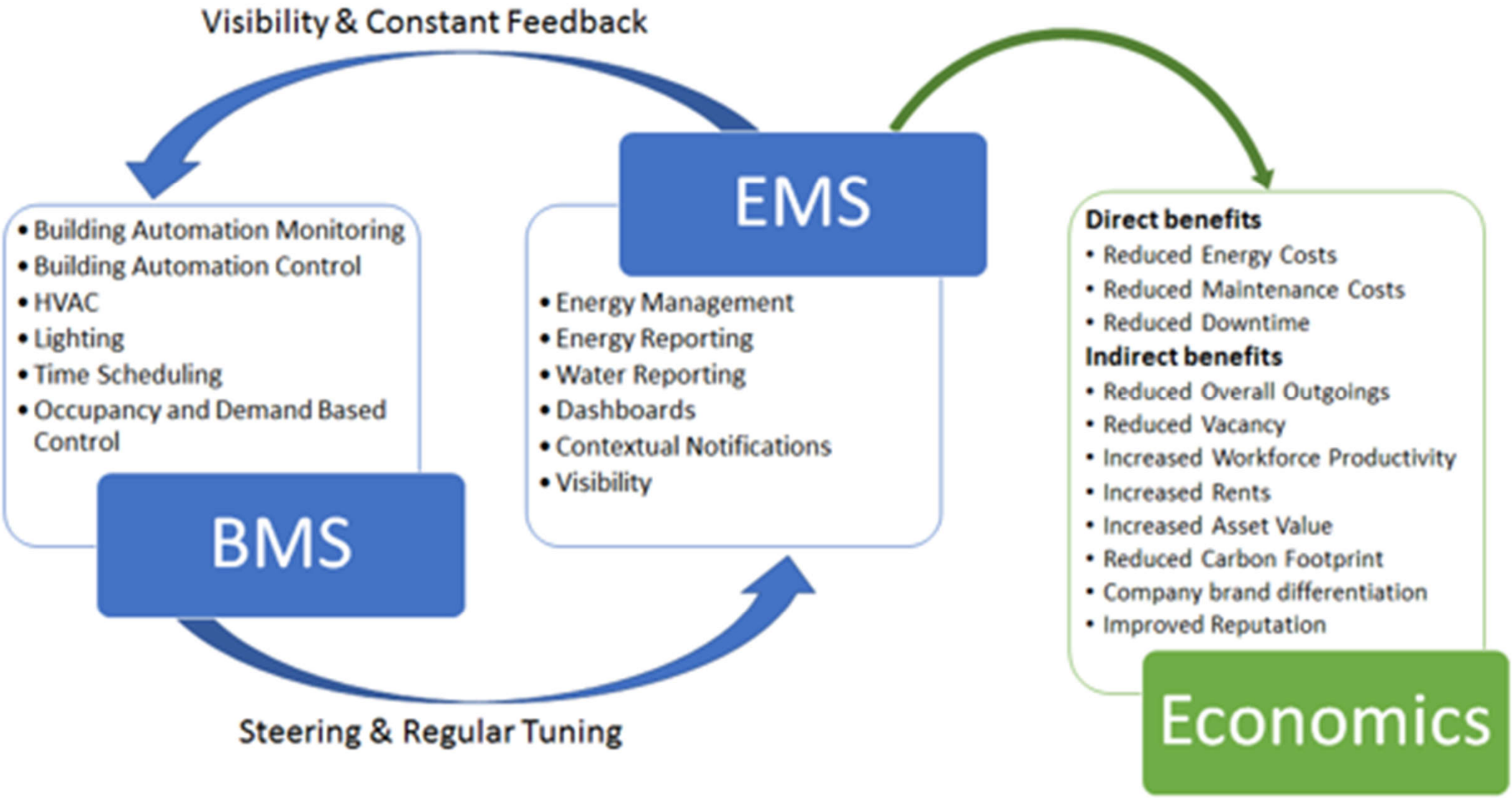
(Source: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/systems_approach_to_central_plant_hvac_optimization.pdf)

BEM strategies

- Top 5 tips for successful energy management
  - 1. Identify sources of energy consumption
    - Pinpoint the specific areas that are utilizing the most energy & break down the energy consumption
  - 2. Collect the utility bill data
  - 3. Analyse meter, operation & other related data
  - 4. Identify opportunities to save on energy & costs
    - Develop a comprehensive understanding on how energy is being consumed
  - 5. Track your progress

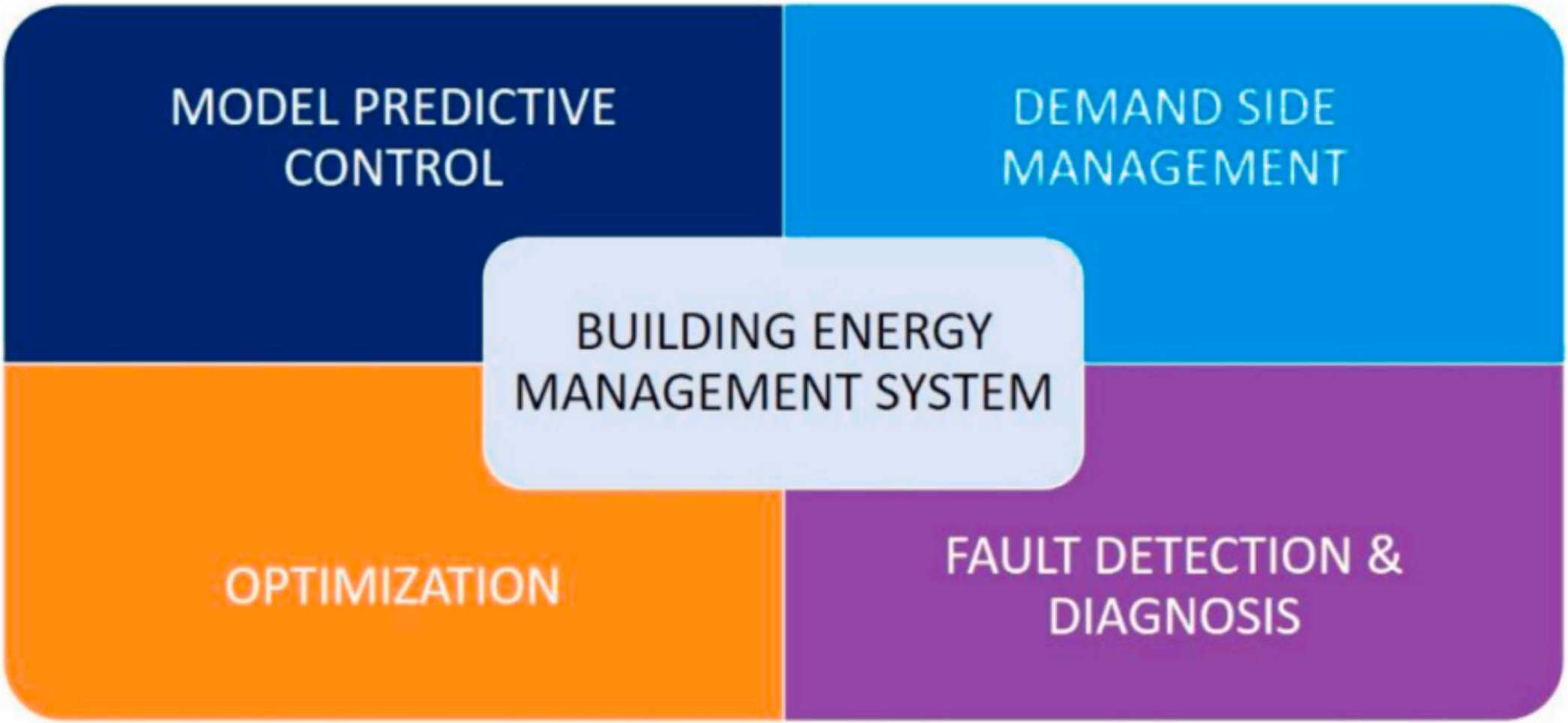
(Source: https://urjanet.com/blog/top-5-tips-successful-energy-management/)

Combining energy management system (EMS) & building management system (BMS) to improve asset performance



(Source: https://www.automatedbuildings.com/news/aug17/articles/optergy/170724024606optergy.html)

Strategies for building energy management

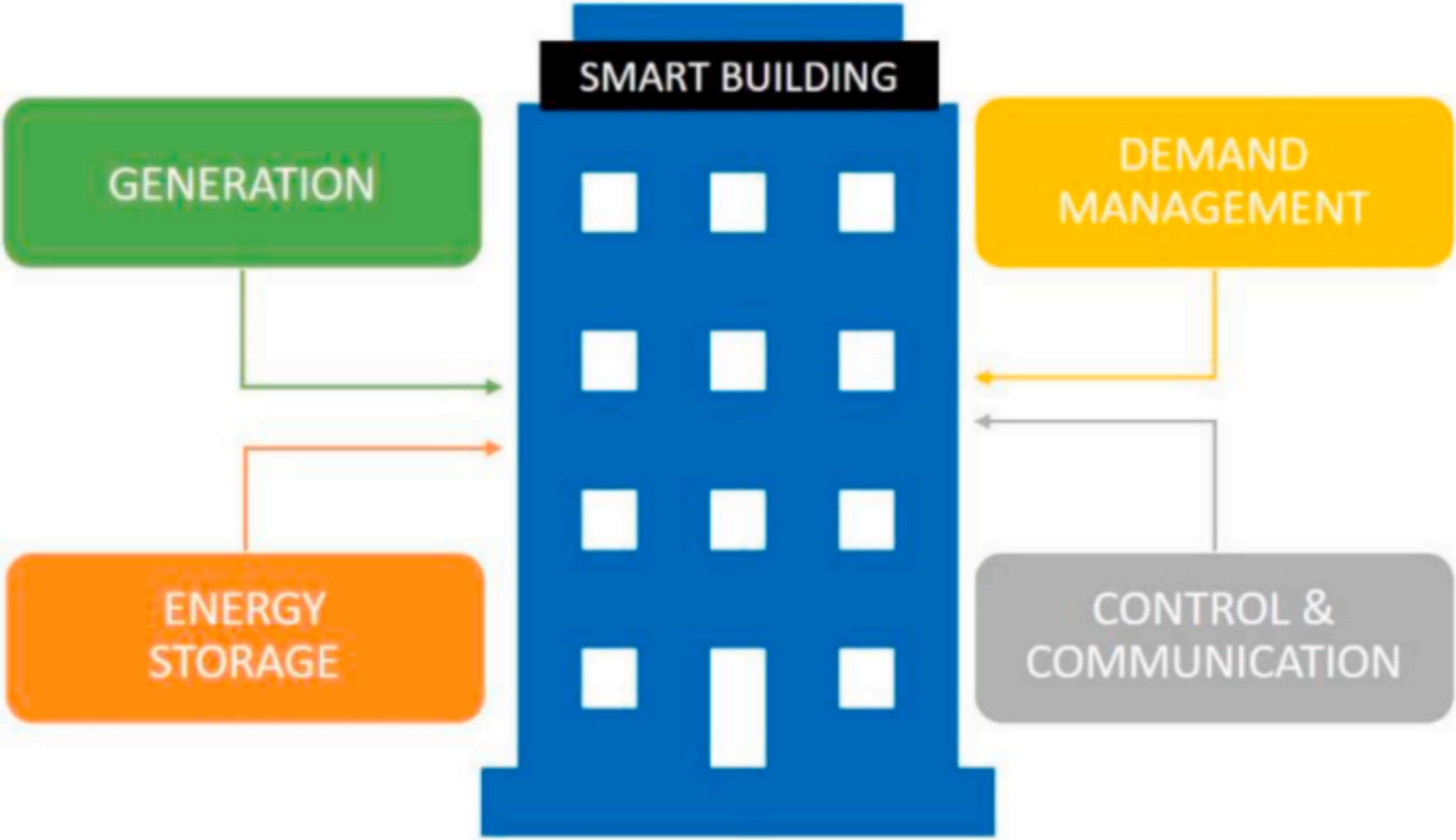


(Source: Mariano-Hernández D., Hernández-Callejo L., Zorita-Lamadrid A., Duque-Pérez O. & García F. S., 2021. A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis, *Journal of Building Engineering*, 33: 101692. https://doi.org/10.1016/j.jobe.2020.101692)

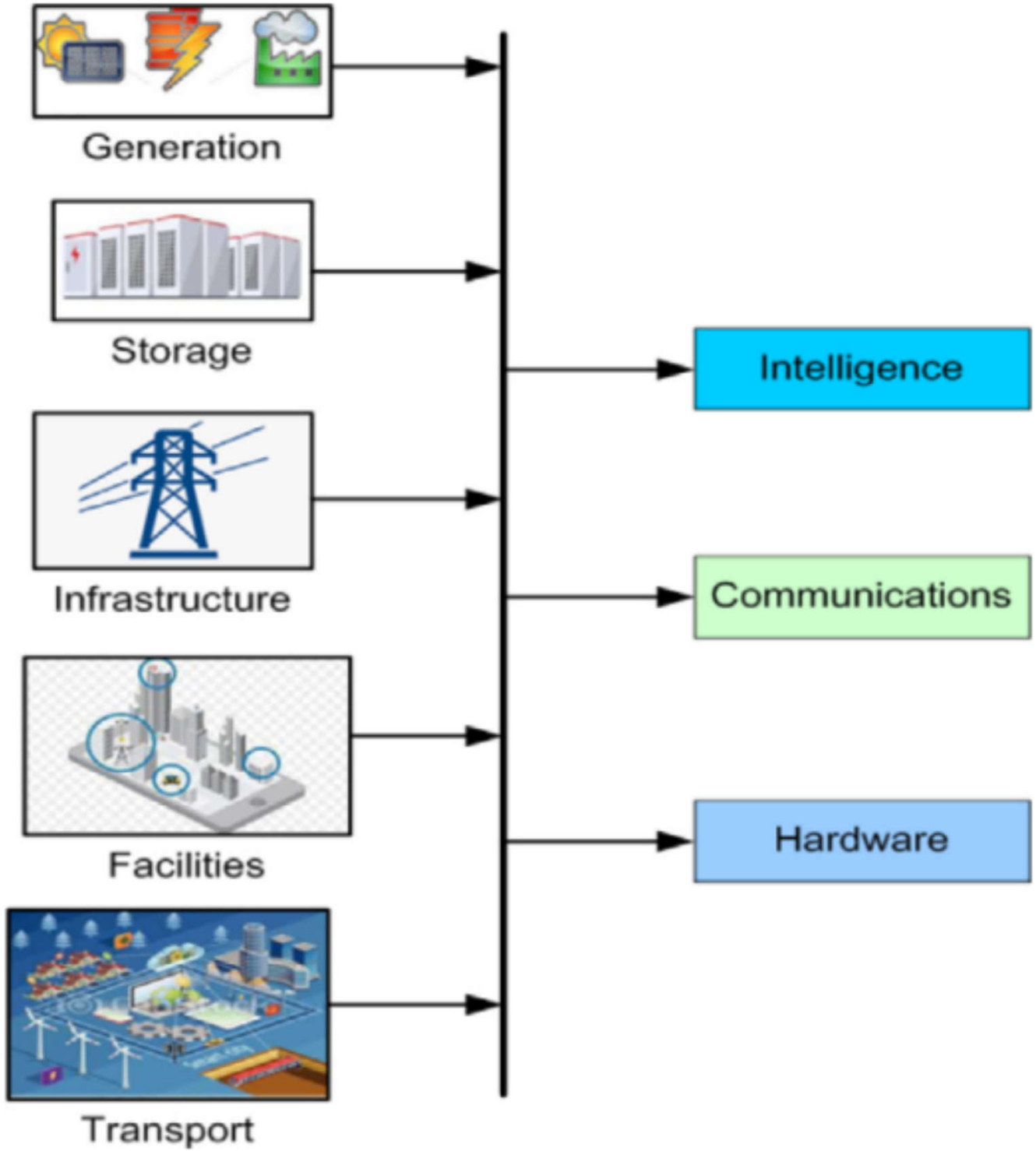
BEM strategies

- Strategies for building energy management
  - 1) Model Predictive Control (MPC)
    - White-box model, black-box model & grey-box model
  - 2) Demand Side Management (DSM)
    - Energy efficiency + Demand response
  - 3) Optimization
    - Stochastic + Robust
  - 4) Fault Detection & Diagnosis (FDD)
    - Data-driven based + Knowledge-driven based

General description of related systems inside smart buildings



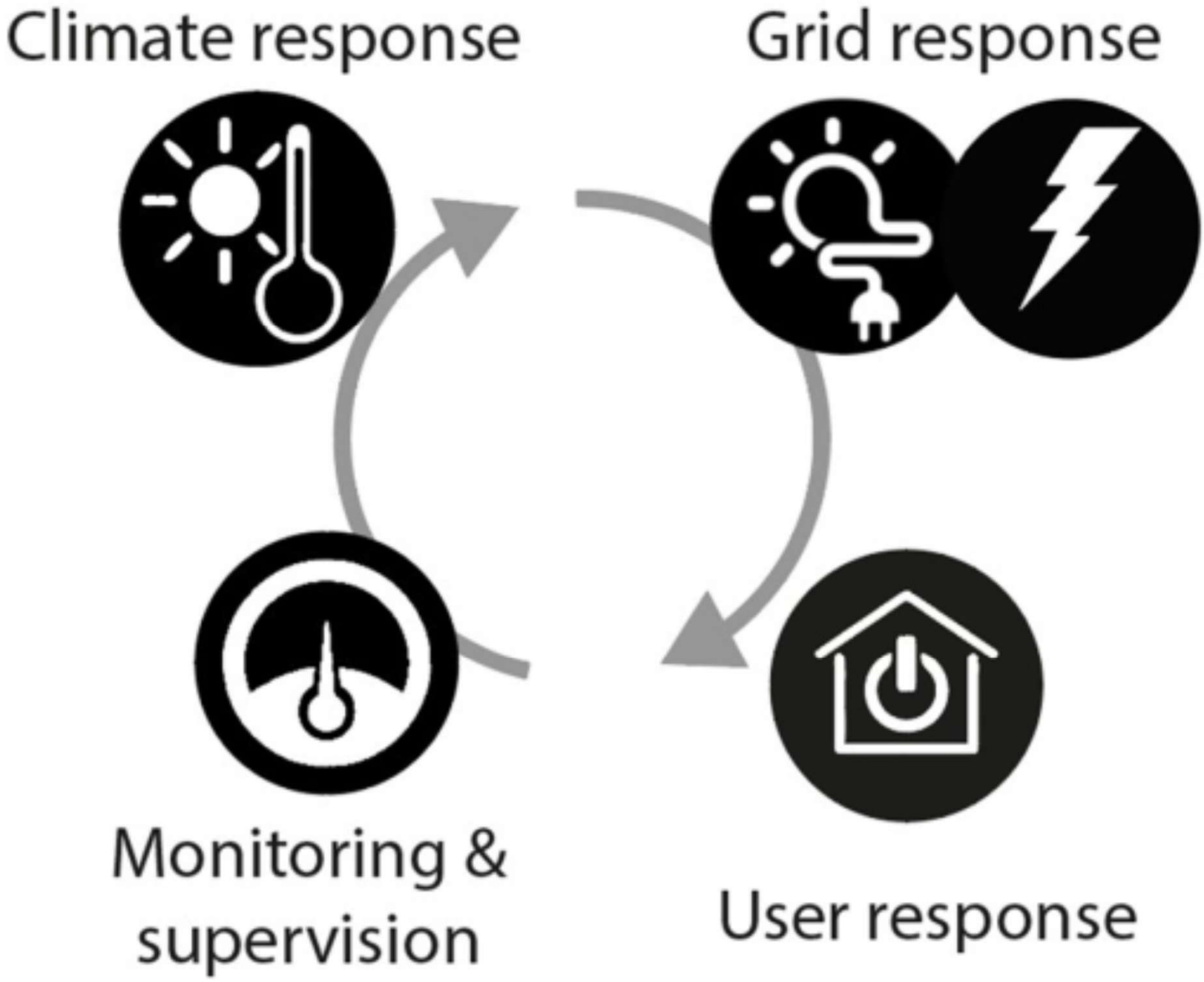
(Source: Mariano-Hernández D., Hernández-Callejo L., Zorita-Lamadrid A., Duque-Pérez O. & García F. S., 2021. A review of strategies for building energy management system: Model predictive control, demand side management, optimization, and fault detect & diagnosis, *Journal of Building Engineering*, 33: 101692. https://doi.org/10.1016/j.jobe.2020.101692)



Energy contribution sectors in the smart city

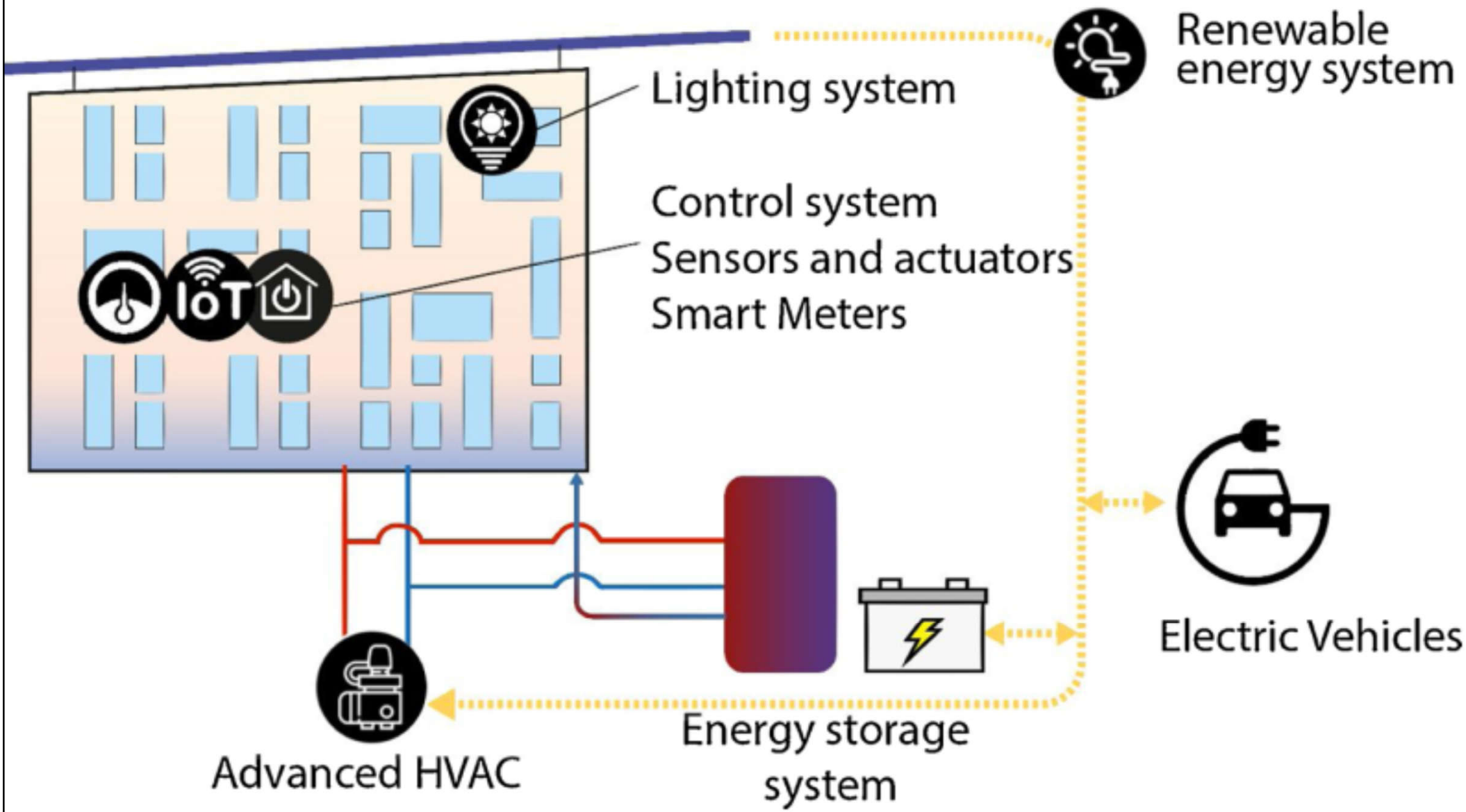
(Source: Pandiyan P., Saravanan S., Usha K., Kannadasan R., Alsharif M. H. & Kim M.-K., 2023. Technological advancements toward smart energy management in smart cities, *Energy Reports*, 10: 648-677. https://doi.org/10.1016/j.egyr.2023.07.021)

Smart buildings basic functions



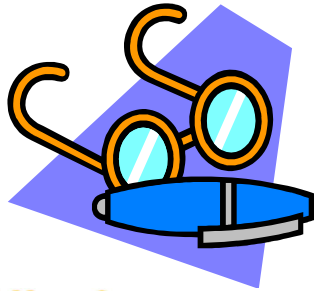
(Source: Dakheel J. A., Pero C. D., Aste N. & Leonforte F., 2020. Smart buildings features and key performance indicators: A review, *Sustainable Cities and Society*, 61: 102328. https://doi.org/10.1016/j.scs.2020.102328)

Key technologies in smart buildings



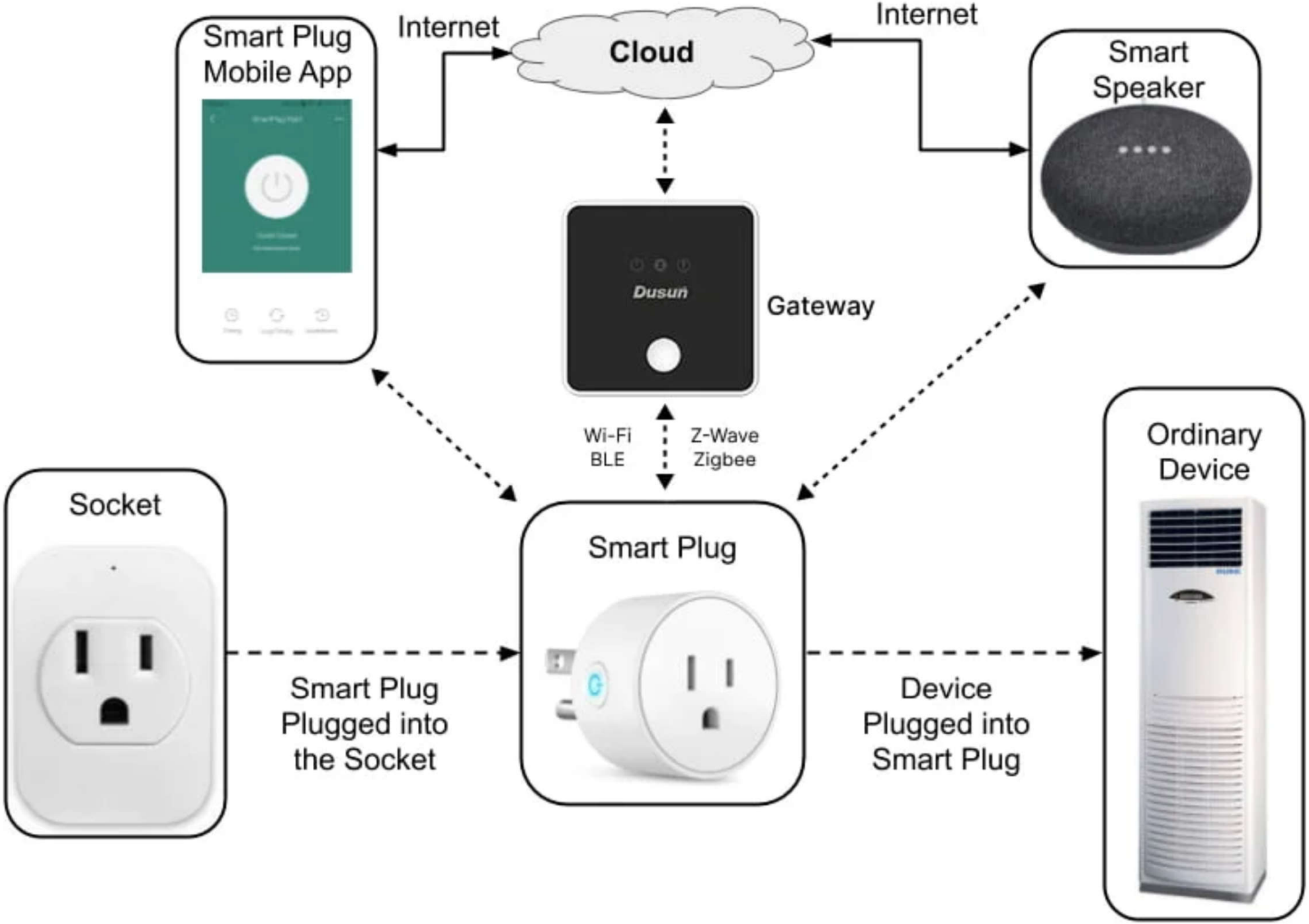
(Source: Dakheel J. A., Pero C. D., Aste N. & Leonforte F., 2020. Smart buildings features and key performance indicators: A review, *Sustainable Cities and Society*, 61: 102328. https://doi.org/10.1016/j.scs.2020.102328)

Smart energy



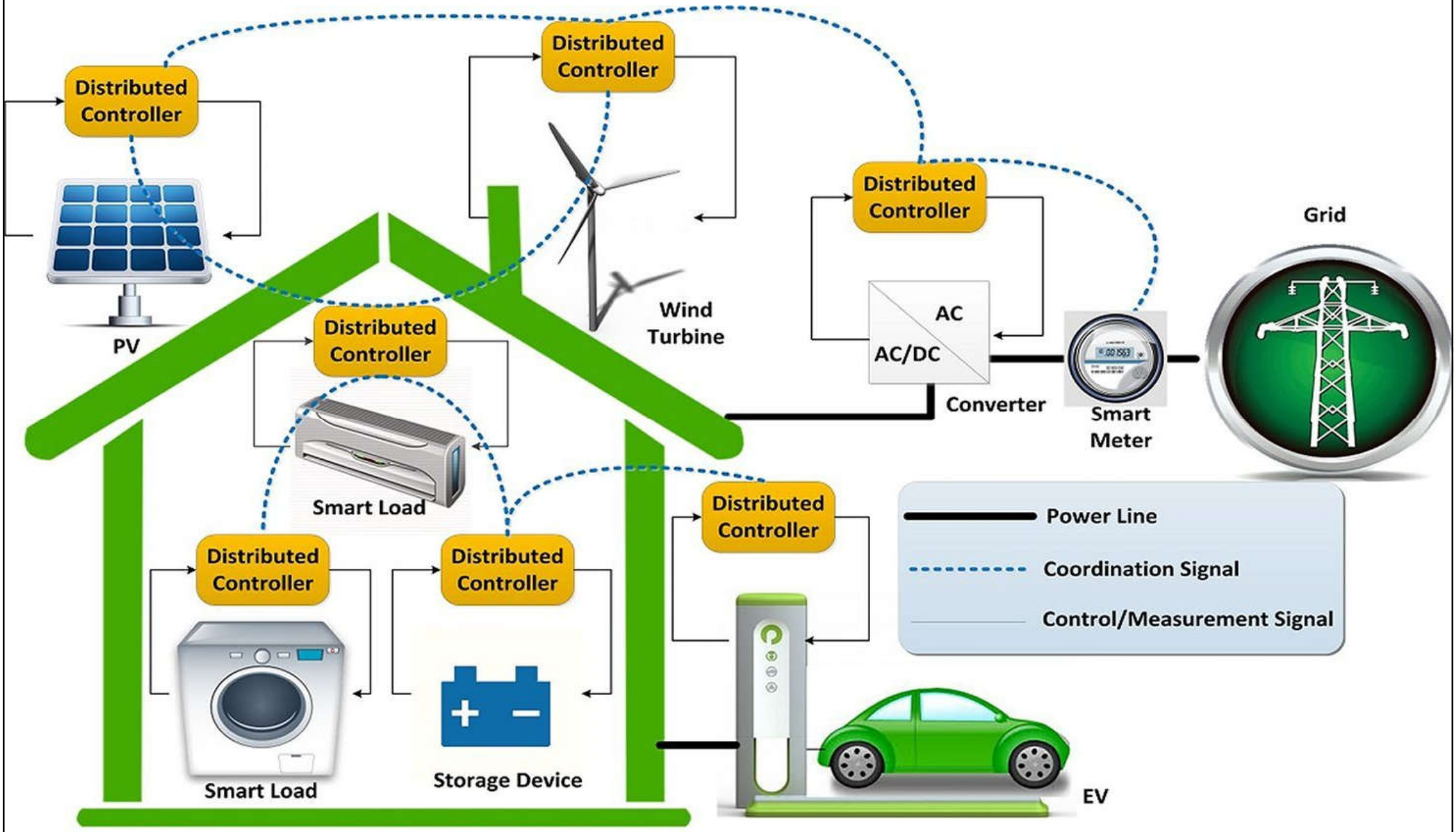
- Smart energy management (SEM)
  - Leverage the connectivity & Internet of Things (IoT) to track, measure, control & optimizes energy consumption throughout the building(s)
  - Adoption of microgrids, energy storage, electric mobility, localized grids for cities, communities, & campuses that are self-sufficient & can disconnect from the traditional grids to operate independently
  - Provide power backup in case of emergencies & contribute towards clean energy future

Basic concept of smart plug for energy monitoring & management



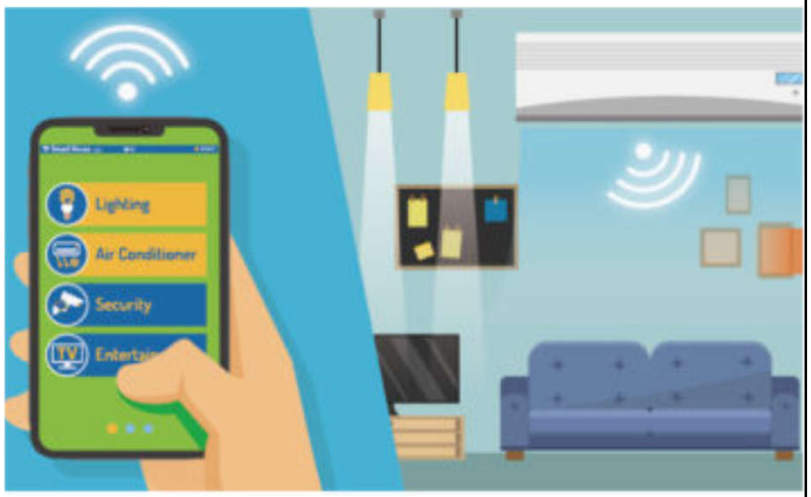
(Source: https://www.dusuniot.com/case-study/zigbee-multiple-gateway-hub-for-home-energy-monitoring/)

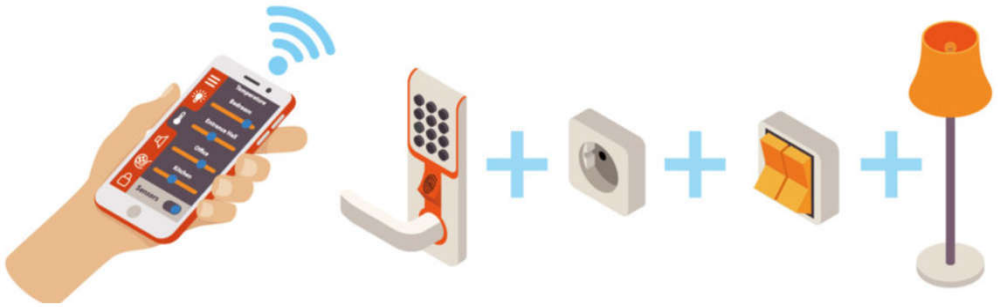
Smart home energy management system

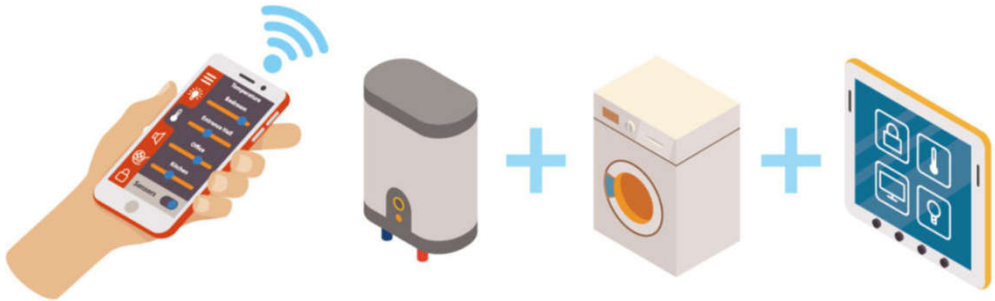


(Source: https://www.solarchoice.net.au/blog/home-energy-management-systems-a-smart-way-to-save/)

Energy saving devices & applications at home







(Source: https://www.allion.com/aiot/smart-energy-management-system/)

Smart energy concept in smart cities

2. Smart Energy Data Analytics

- Building & Area IoT Mesh Network
- AI-based Building Management System
- Edge Computing-based Distributed Energy Optimization Model

1. Intelligent Energy

- Digital Twin-based City Energy Management System
- Energy Blockchain Billing System
- Optimal Energy-Traffic Information System
- Automatic Driving Electric Vehicle

3. Energy Prosumer

- Blockchain-based P2P Energy Trading System
- ESS-based Distributed Energy Management System

4. Energy Security for City

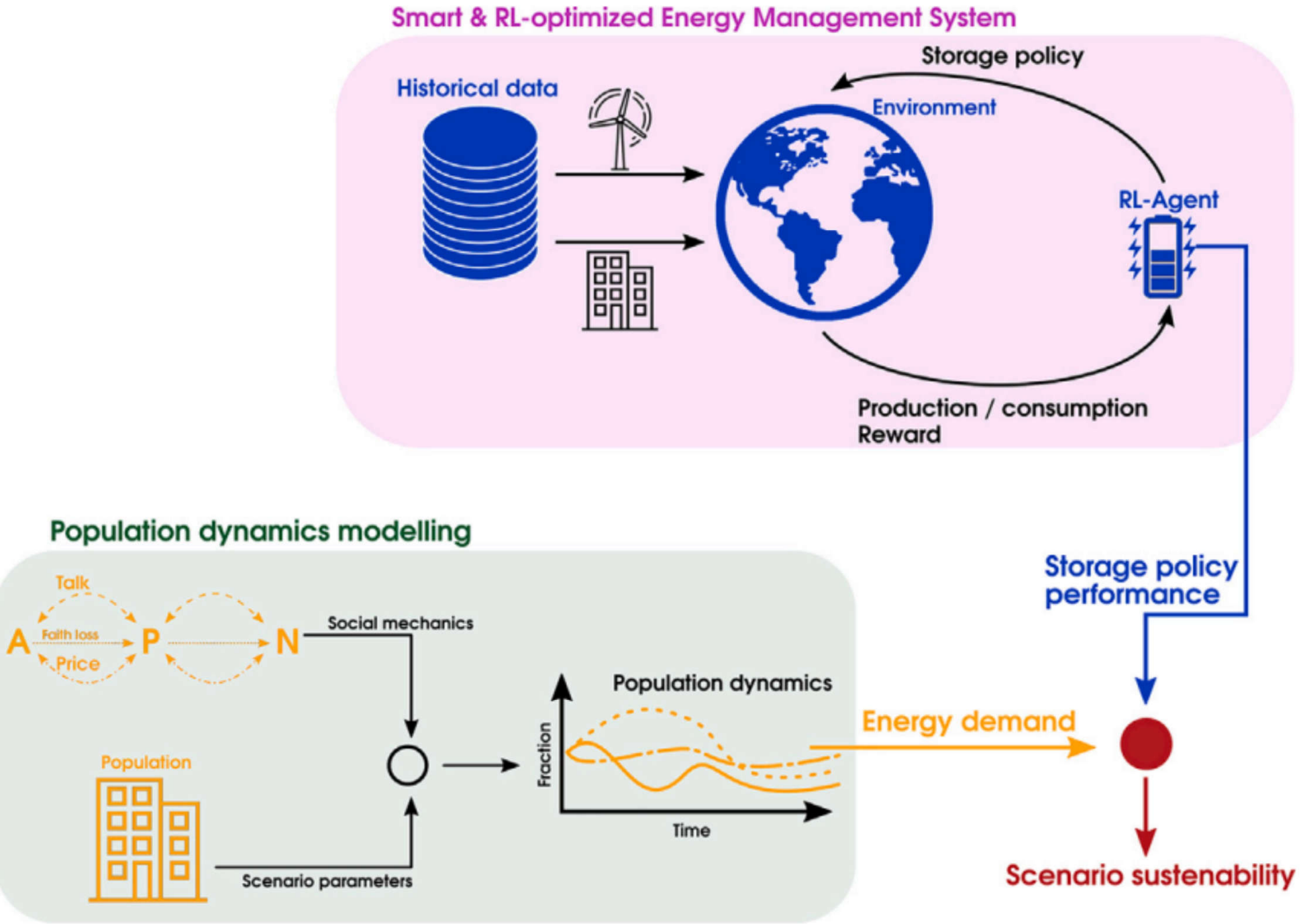
- Security Twin System (Smart energy city safety system based on AR/VR)

5. Renewable Energy

- Sustainable Zero Energy Building
- Hybrid Renewable Energy Generator
- Energy Remodeling and Retrofit

(Source: https://galooli.com/glossary/what-is-smart-energy/)

Smart energy management system framework

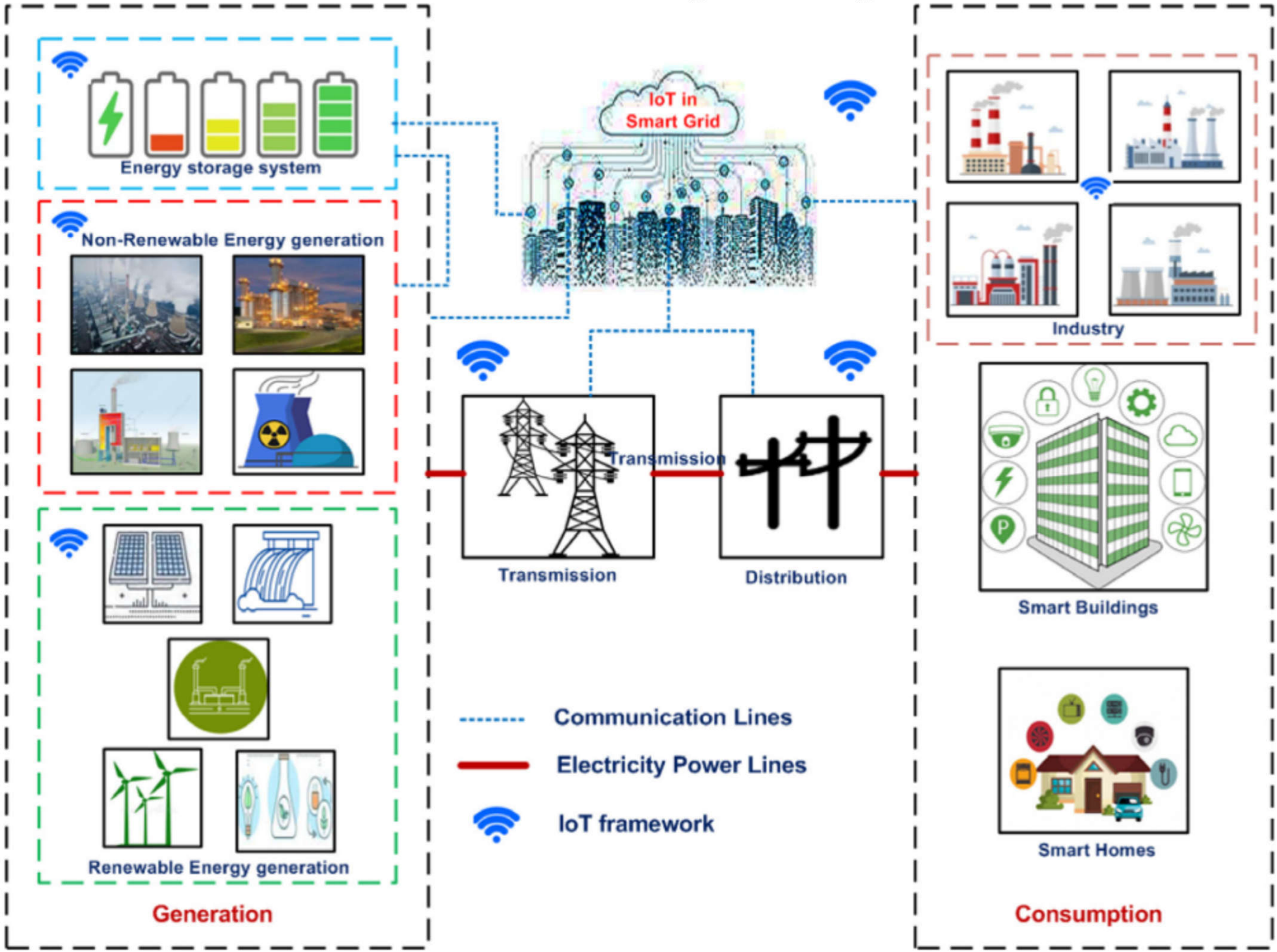


(Source: Mounsif M. & Medard F., 2023. Smart energy management system framework for population dynamics modelling and suitable energy trajectories identification in islanded micro-grids, *Energy and AI*, 13: 100242. https://doi.org/10.1016/j.egyai.2023.100242)

Smart energy

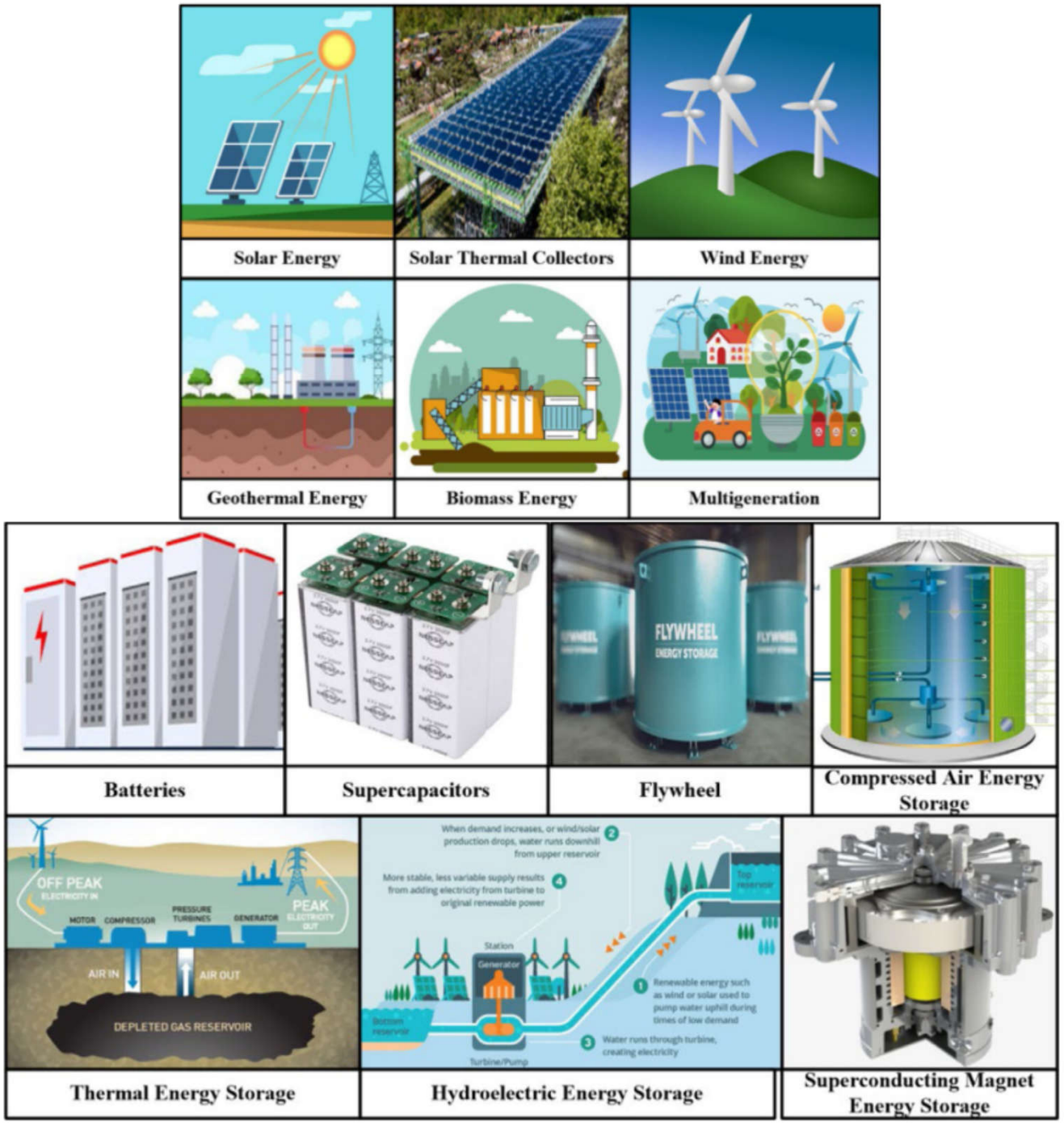
- Technologies supporting smart energy management in smart cities:
  - 1. Smart grids: enable real-time monitoring
  - 2. Renewable energy sources: e.g. solar, wind
  - 3. Energy storage: ensure reliable energy supply
  - 4. Smart buildings: optimize energy use
  - 5. Electric vehicles: reduce carbon emissions
  - 6. Smart home: provide convenience & efficiency
  - 7. Data analytics: identify inefficiencies

Model of smart grid design



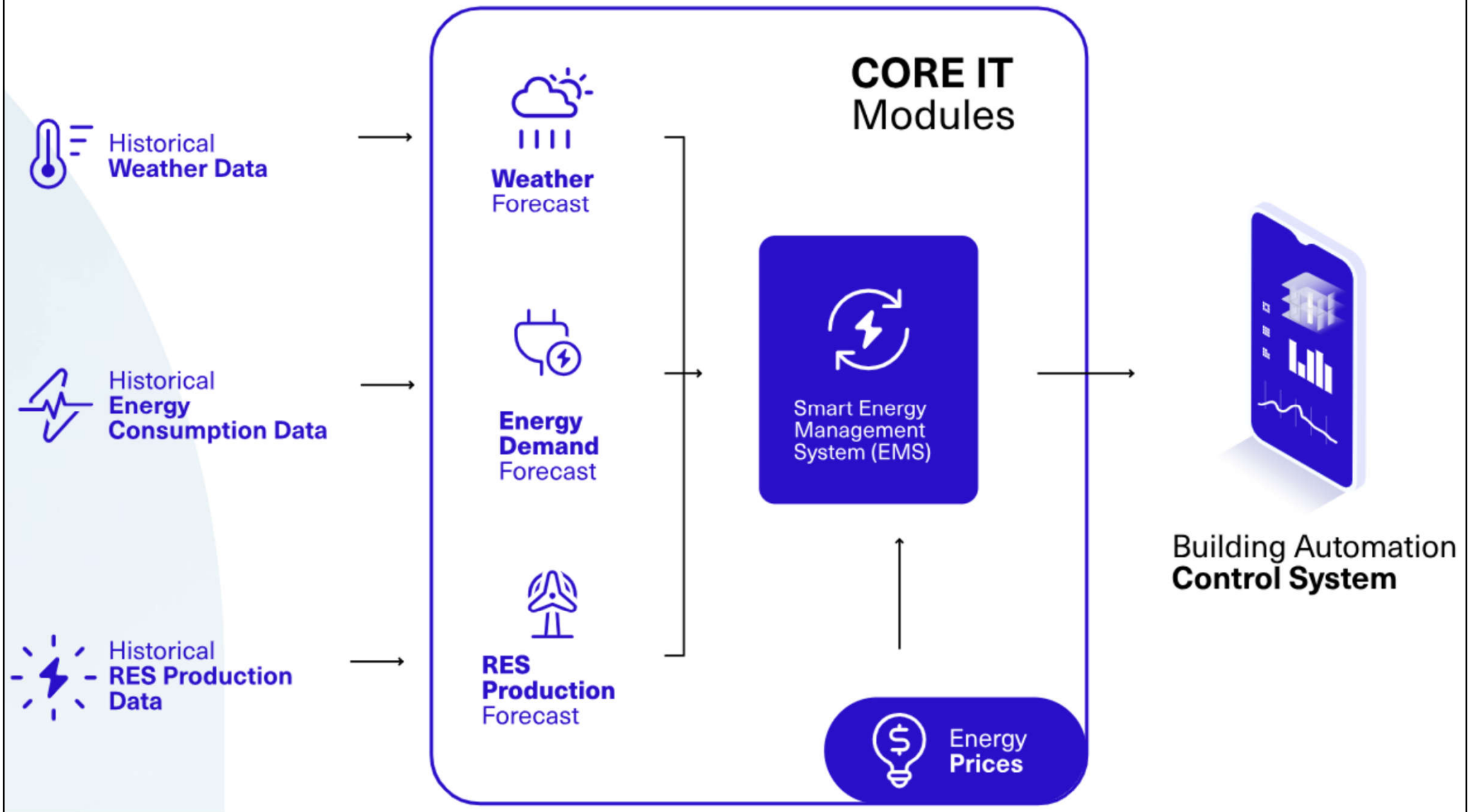
(Source: Pandiyan P., Saravanan S., Usha K., Kannadasan R., Alsharif M. H. & Kim M.-K., 2023. Technological advancements toward smart energy management in smart cities, *Energy Reports*, 10: 648-677. https://doi.org/10.1016/j.egyr.2023.07.021)

Renewable energy resources & energy storage systems



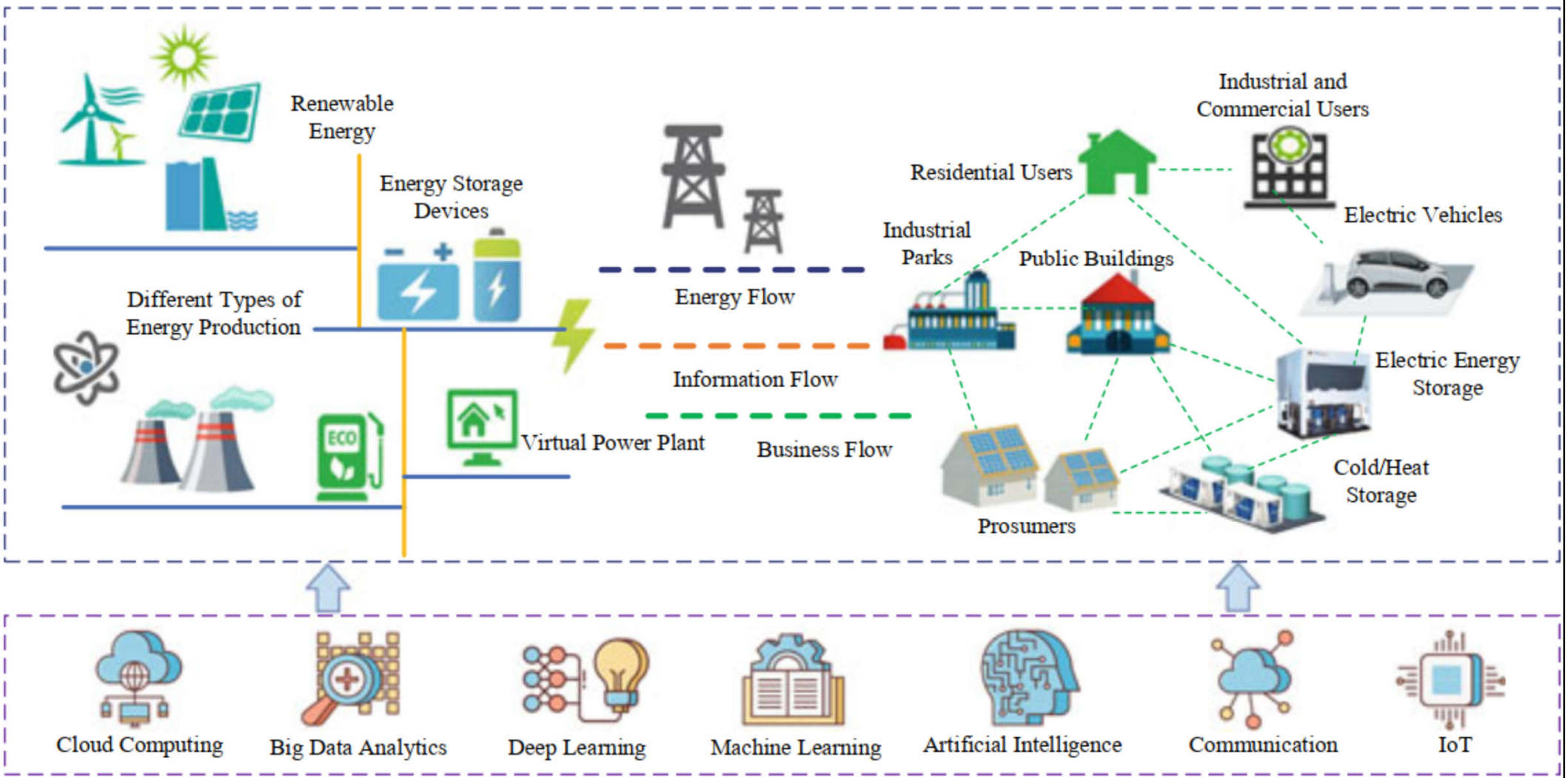
(Source: Pandiyan P., Saravanan S., Usha K., Kannadasan R., Alsharif M. H. & Kim M.-K., 2023. Technological advancements toward smart energy management in smart cities, *Energy Reports*, 10: 648-677. https://doi.org/10.1016/j.egyr.2023.07.021)

Smart energy management system integrated with building automation control system



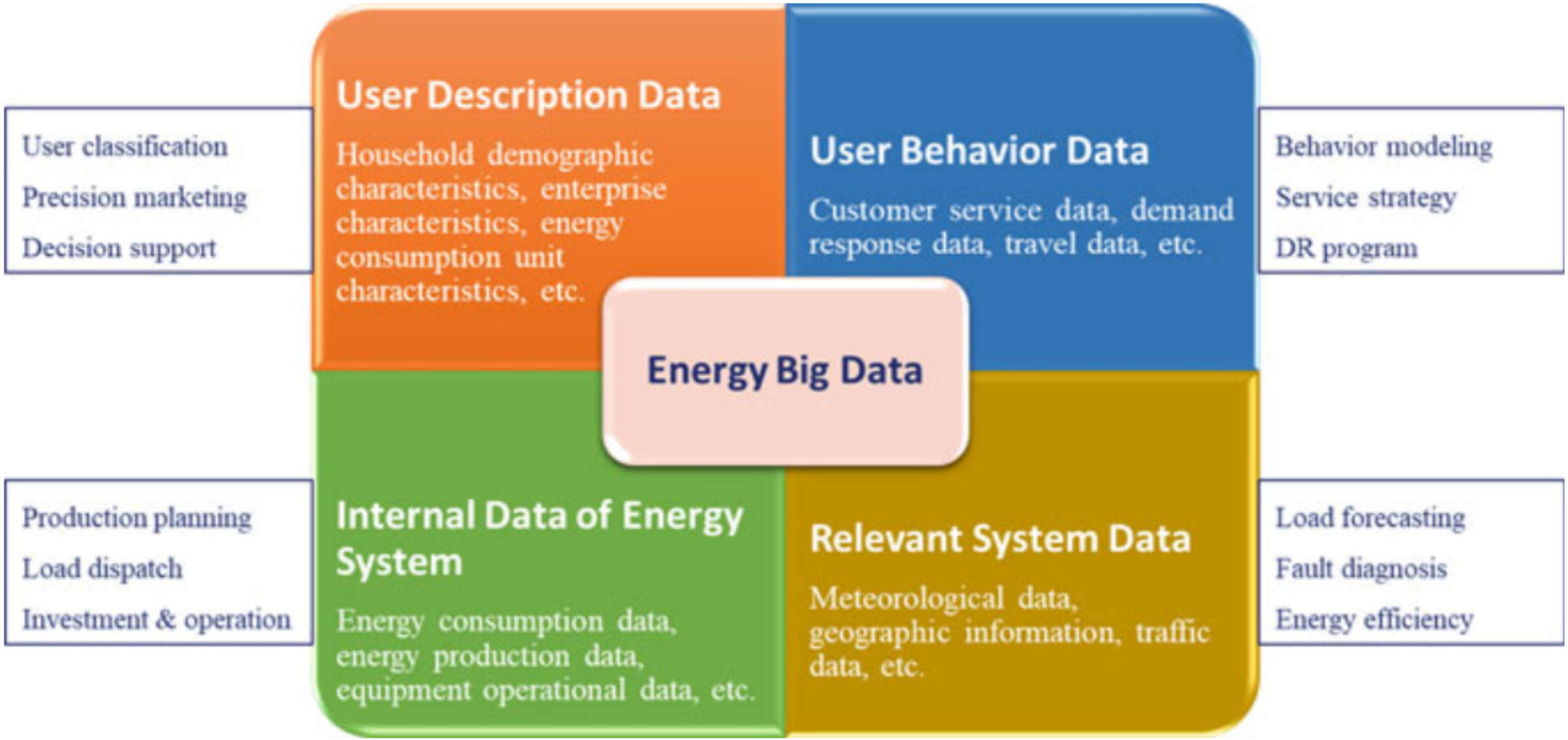
(Source: https://www.core-innovation.com/smart-energy-management)

Energy Internet environment



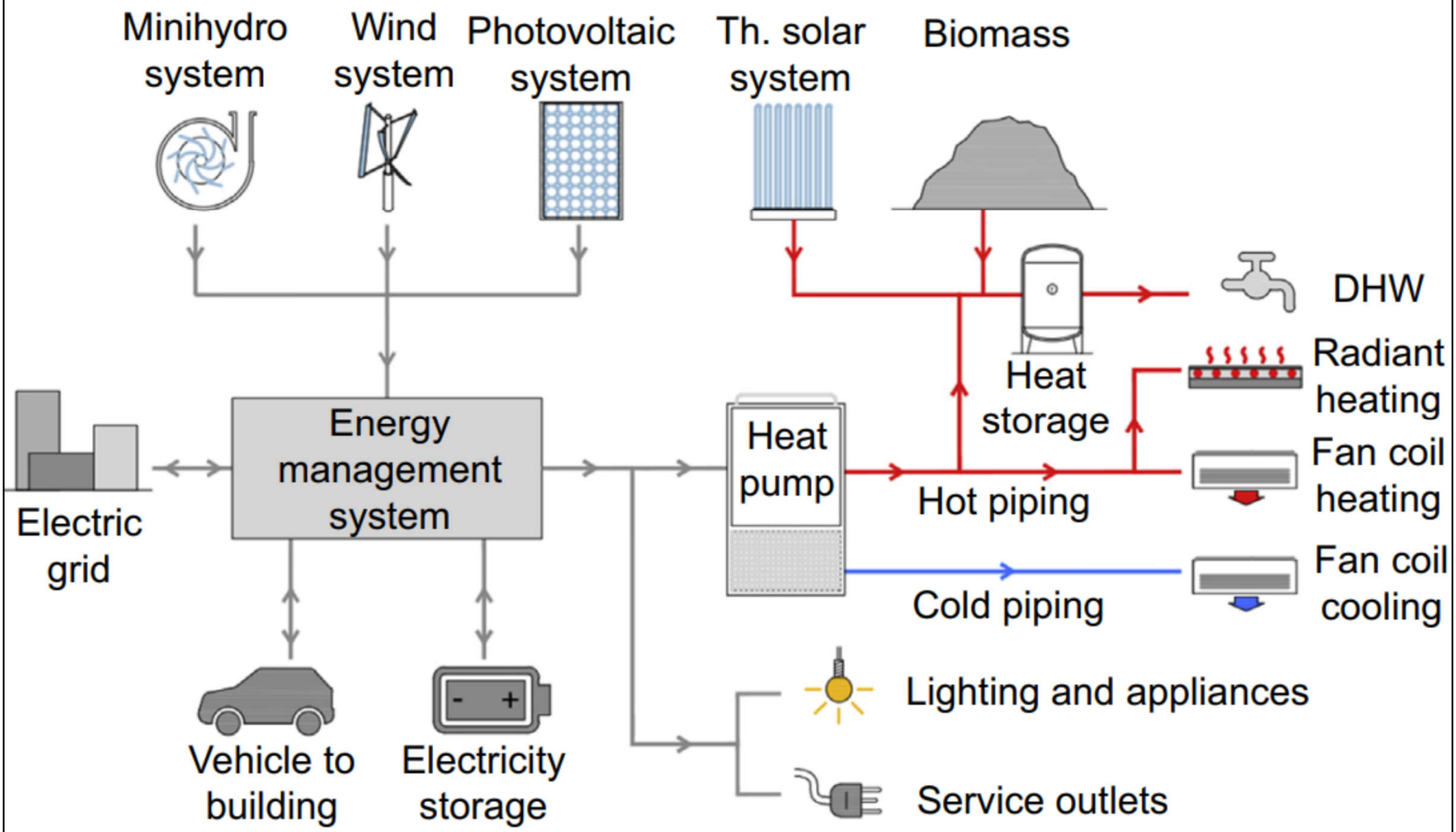
(Source: Zhou K. & Wen L., 2023. *Smart Energy Management: Data Driven Methods for Energy Service Innovation*, Springer Singapore. https://doi.org/10.1007/978-981-16-9360-1)

Energy big data sources & applications



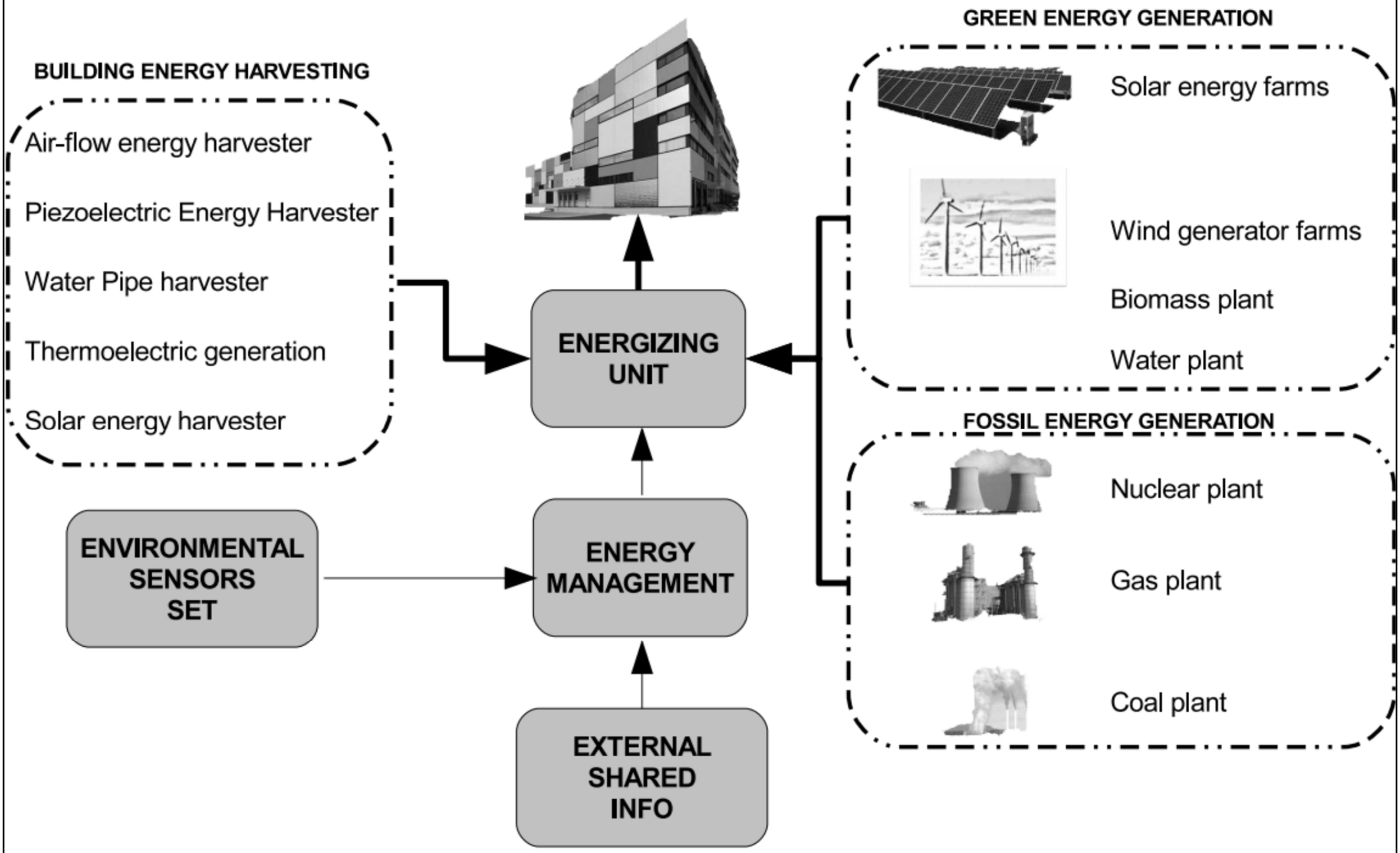
(Source: Zhou K. & Wen L., 2023. *Smart Energy Management: Data Driven Methods for Energy Service Innovation*, Springer Singapore. https://doi.org/10.1007/978-981-16-9360-1)

Building energy equipment system scheme



(Source: Casini M., 2016. *Smart Buildings: Advanced Materials and Nanotechnology to Improve Energy-Efficiency and Environmental Performance*, Woodhead Publishing, Duxford, UK. https://doi.org/10.1016/C2015-0-00182-4)

Energy sources management in a Smart Building: energy harvesting vs. external green energies & traditional fossil energies



(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)

Further reading

- Smart energy monitoring - live demo: https://demo.thingsboard.io/dashboard/e8e409c0-f2b5-11e6-a6ee-bb0136cc33d0?publicId=963ab470-34c9-11e7-a7ce-bb0136cc33d0
- Smart energy & water monitoring for districts - live demo: https://demo.thingsboard.io/dashboard/3a1026e0-83f6-11e7-b56d-c7f326cba909?publicId=322a2330-7c36-11e7-835d-c7f326cba909
- How to Use Energy Profiles to Find Energy Waste http://www.energylens.com/articles/identify-energy-waste
- Energy Monitoring Charts and Tables http://www.energylens.com/outputs