MEBS6005 Building Automation Systems

http://ibse.hk/MEBS6005/

Building Energy Management

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Nov 2023

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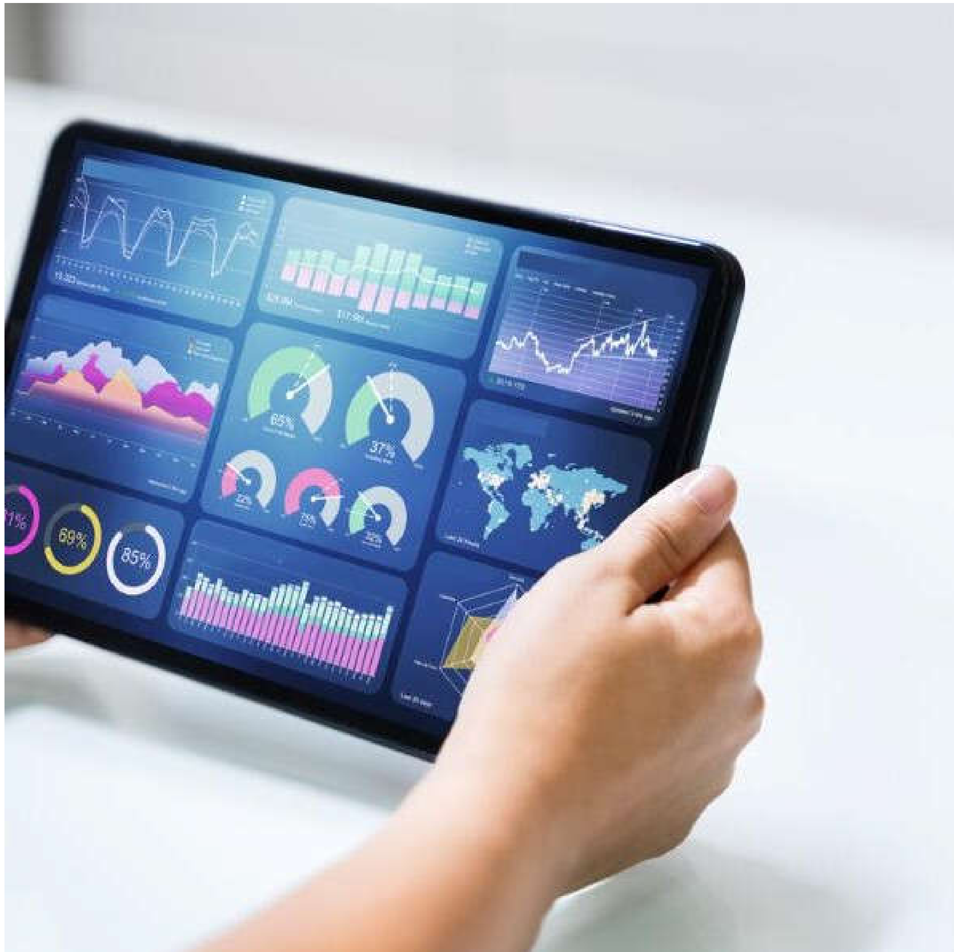


Basic principles

- 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

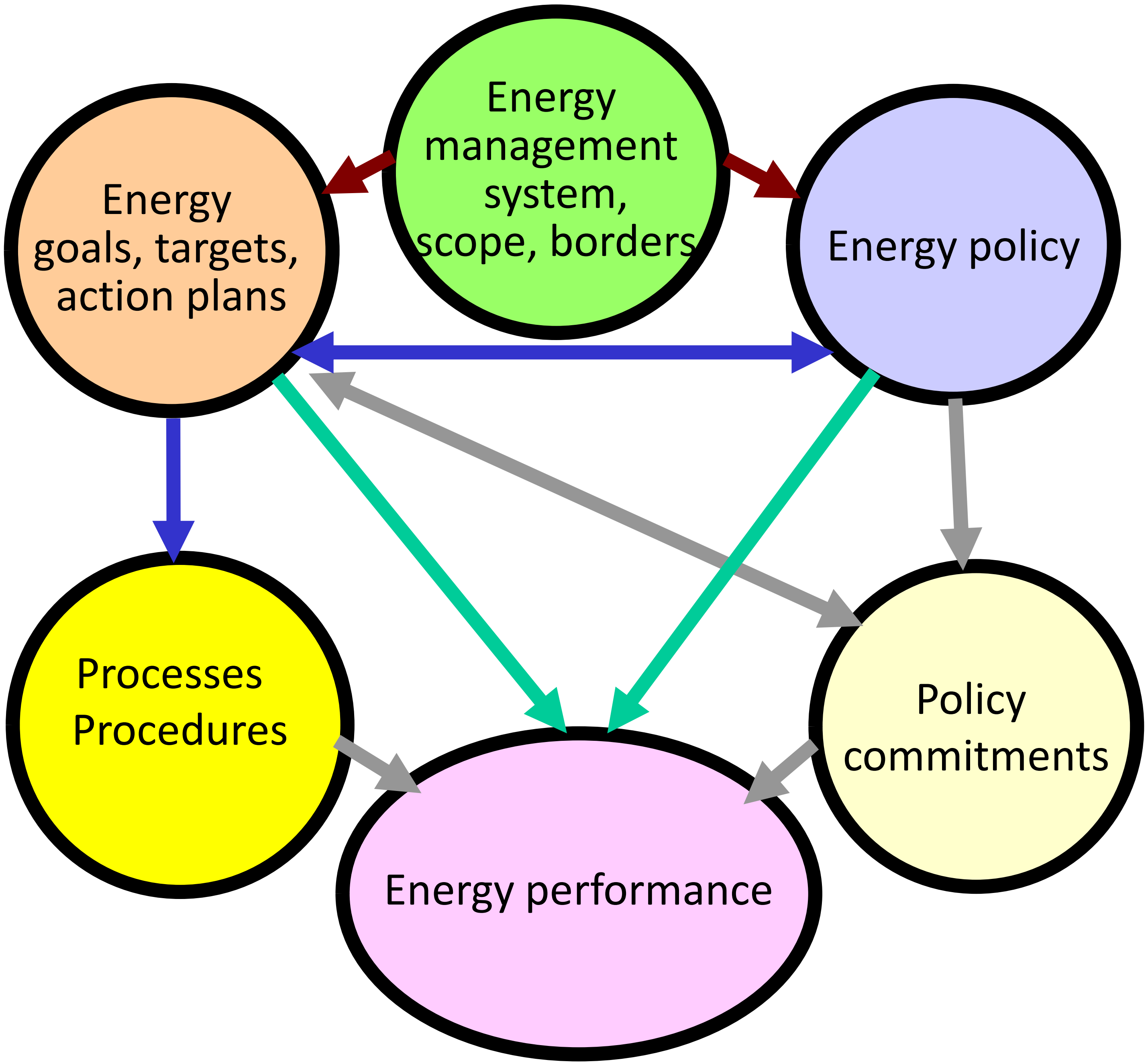
Definition of Energy Management Systems (EnMS)

'A set of interrelated or interacting elements that establish an energy policy and energy goals as well as processes and procedures to achieve those goals'

ISO 50001:2011 definition

(Source: ISO 50001:2011 Energy Management Systems)

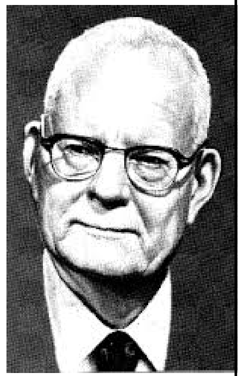
Energy Management Systems logics: focus on energy performance



(Source: ISO 50001:2011 Energy Management Systems)

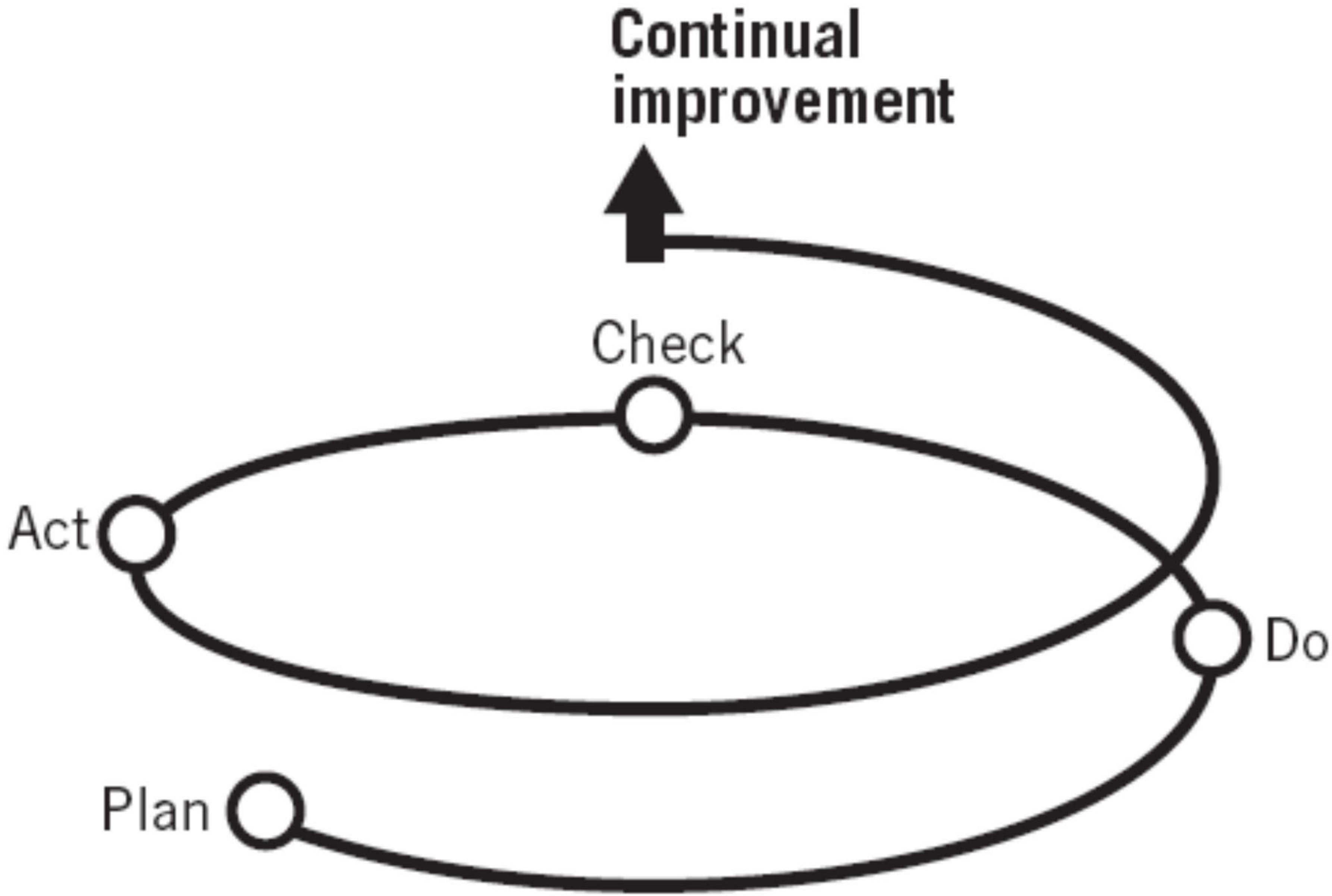
Basic principles

- The energy management system (EnMS) concept builds upon the Plan-Do-Check-Act (PDCA) cycle of management developed by Dr. W. Edward Deming*
  - Cycle for continuous learning & improvement
- EnMS is a collection of processes, procedures, and tools designed to engage staff at all levels within an organization in managing energy use on an ongoing basis



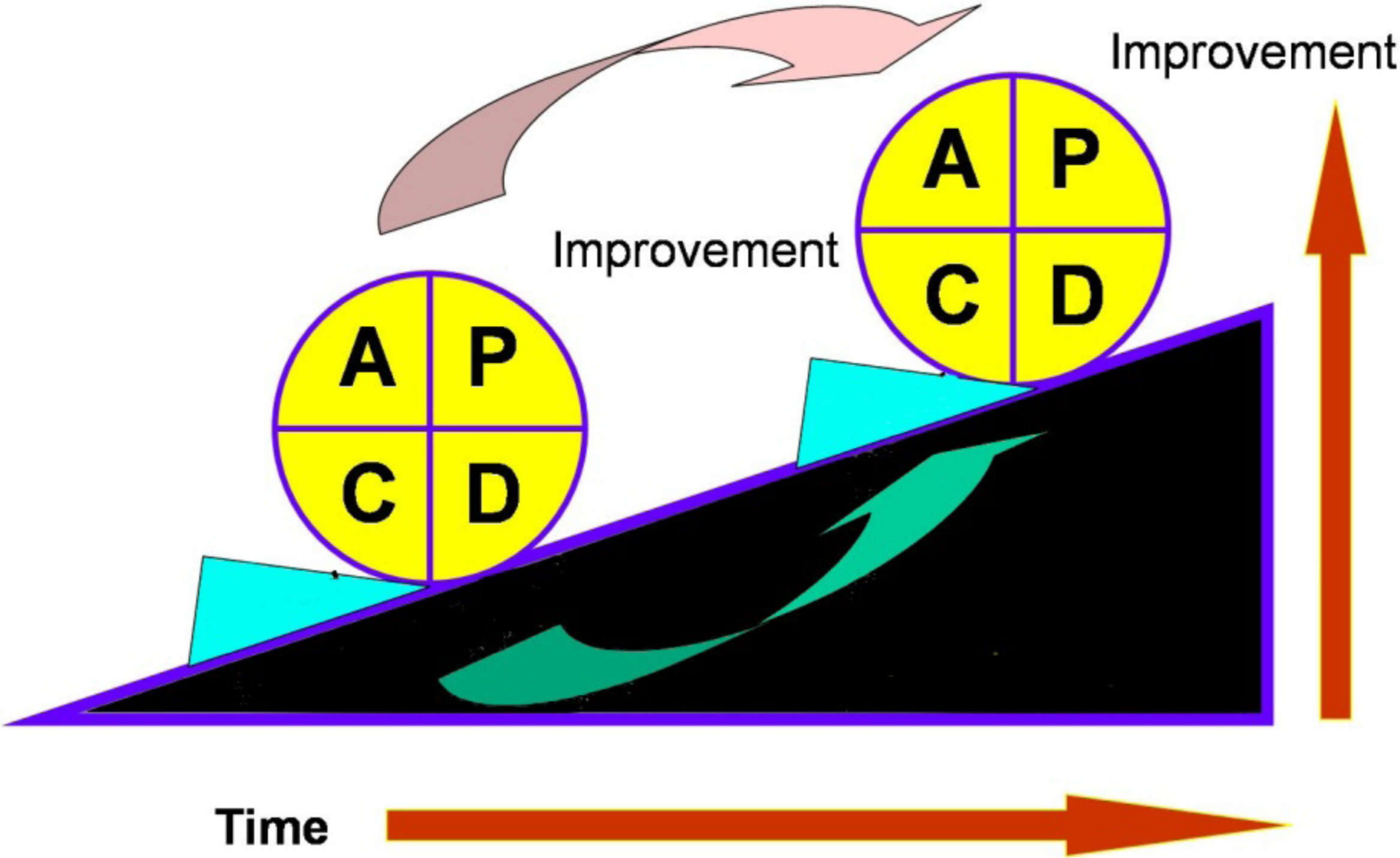
(* See also PDCA - Wikipedia https://en.wikipedia.org/wiki/PDCA)

Four steps of the management process (for continual improvement)
Plan-Do-Check-Act (PDCA) cycle



(Source: The New Economics, by Dr. W. Edwards Deming)

Plan-Do-Check-Act cycle for continuous improvement



(Source: http://iso14001certification.com/)

Plan-Do-Check-Act approach for energy management

Plan	Do
• Obtain insight (energy audit) • Get management commitment • Nominate energy champion • Policy, objectives, structure • Assign responsibilities • Develop programme(s) • Set targets and measures • Set priorities, develop action plans	• Create awareness • Train key resources • Implement projects • Monitor progress • Lock in the gains – Set new targets • Communicate results • Celebrate success
Check	**Act**
• Review results • Verify effectiveness • Examine opportunities for continual improvement	• Correct deficiencies • Review original energy policy • Review objectives and targets • Review energy program • Update action plans • Start the cycle anew

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)

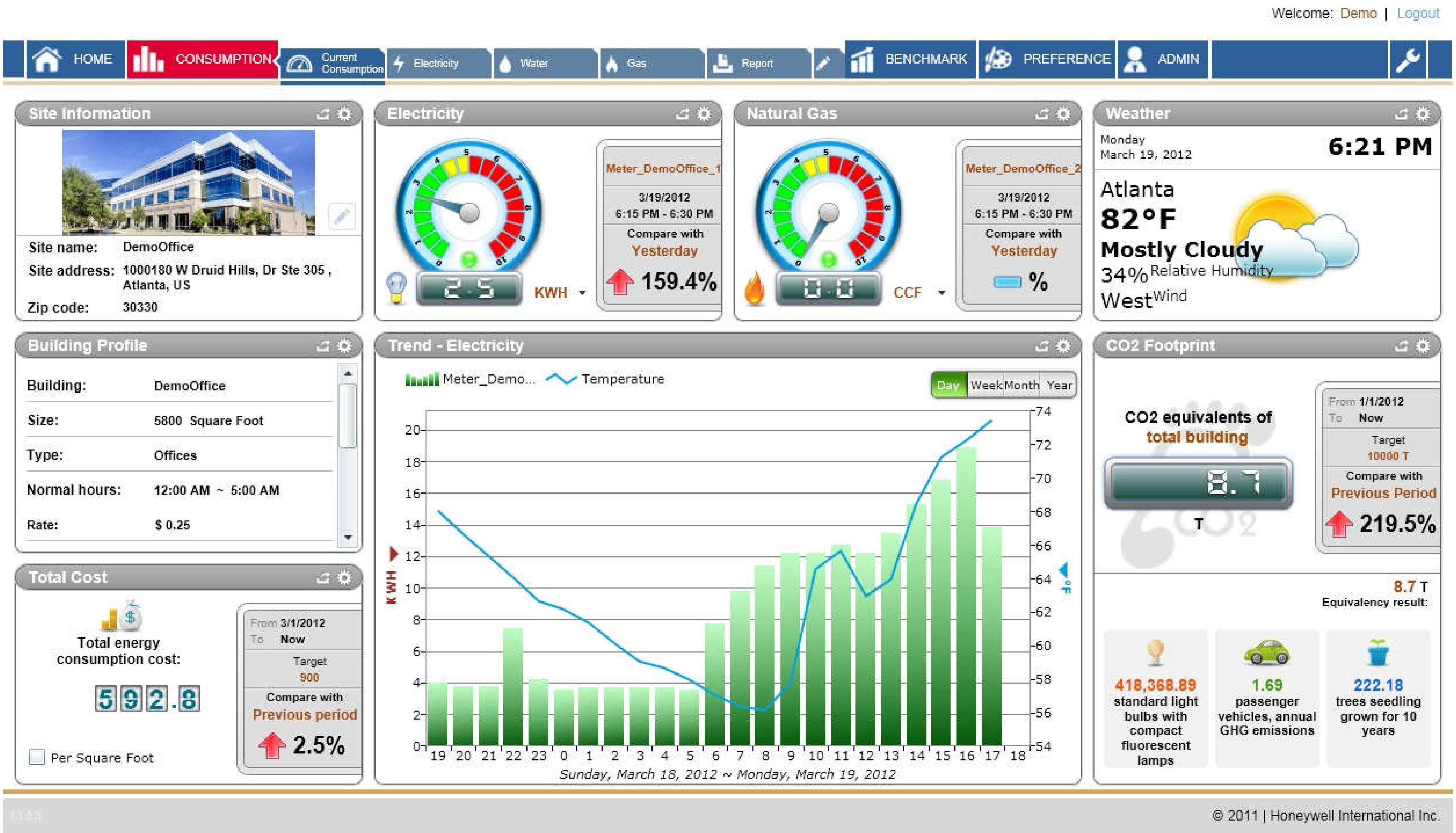
Basic principles

- 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

BEM functions

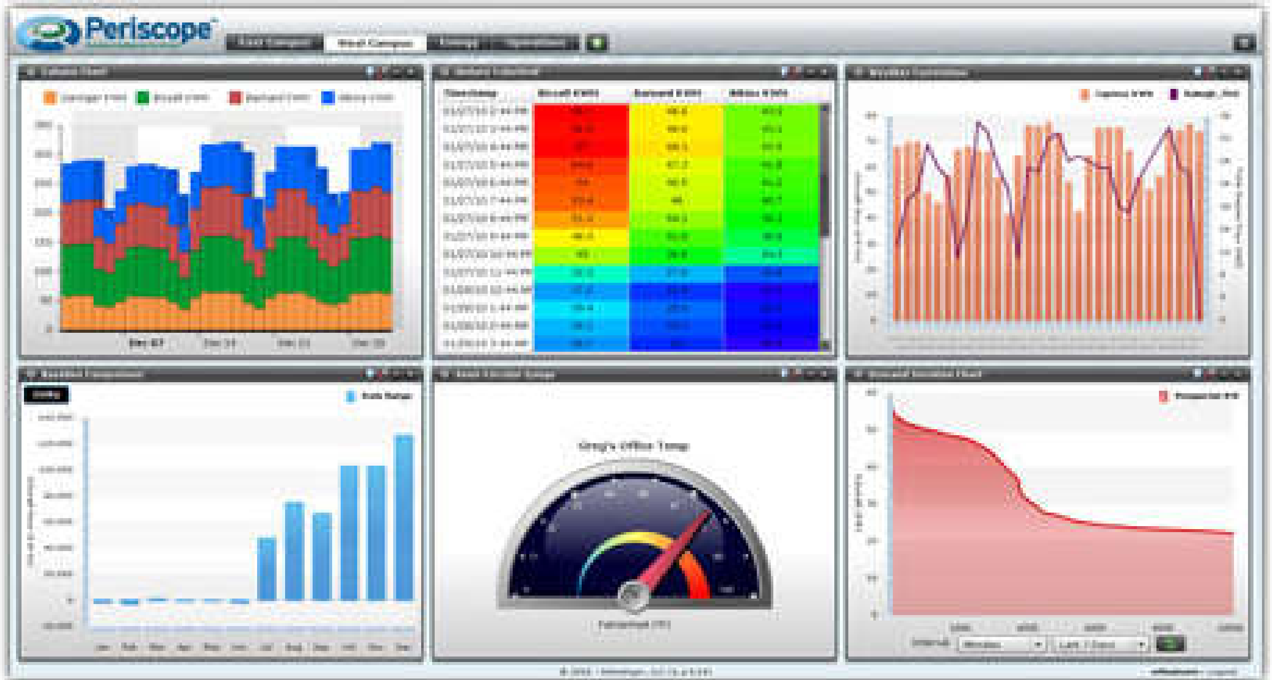
- Building energy management functions:
  - 1. Dashboard: provides key information which is optimized & intuitive to use
  - 2. Monitoring: on equipment, major plants, energy, power, water, fuel gas, operation & maintenance
  - 3. Alarms: real-time alerts for equipment & systems
  - 4. Data visualization: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

An example of energy dashboard for buildings



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

Typical dashboards for building energy management



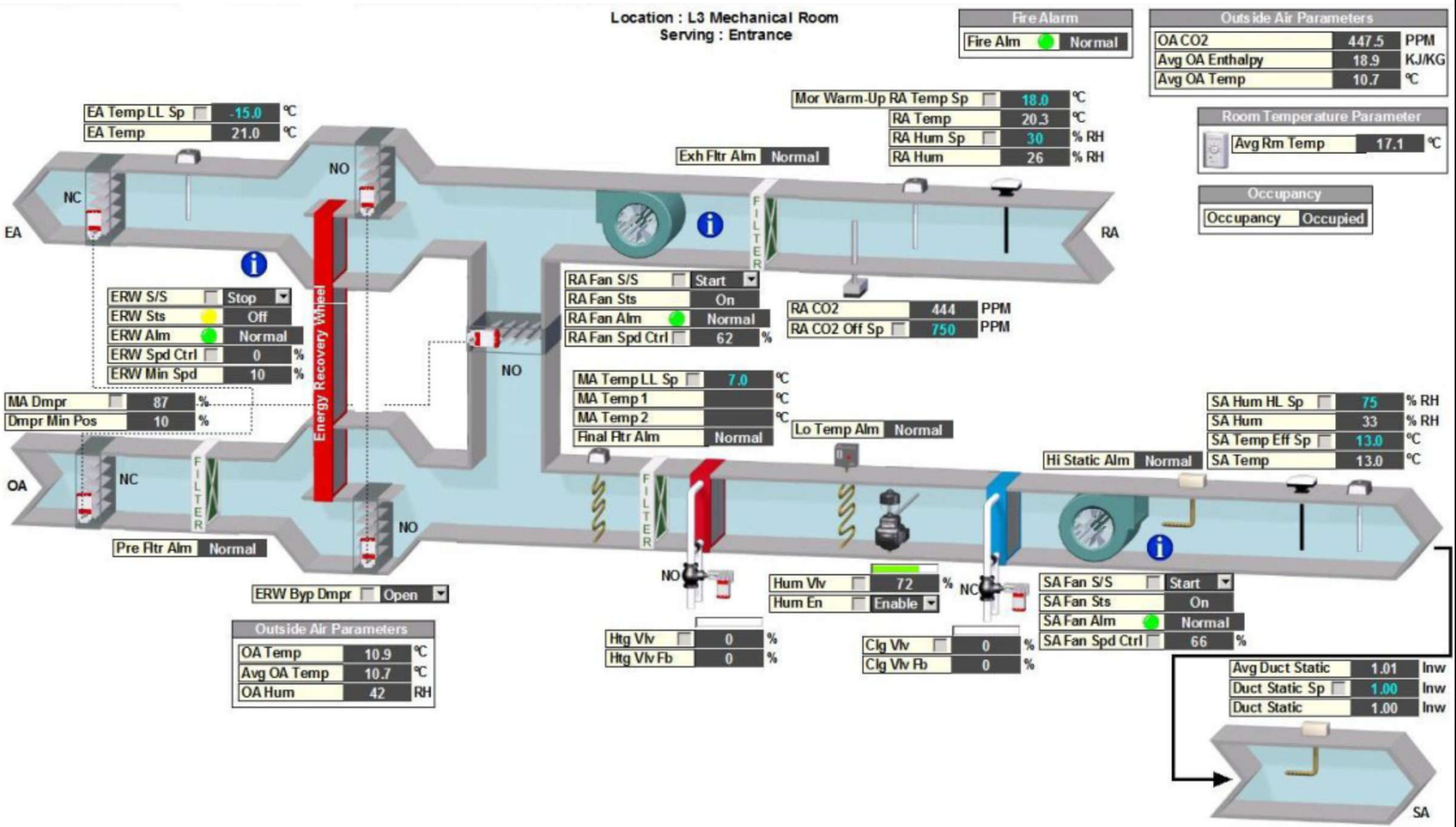
(Source: https://bmienergy.com/energy-management-systems)

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)

Example of air handling unit (AHU) system control

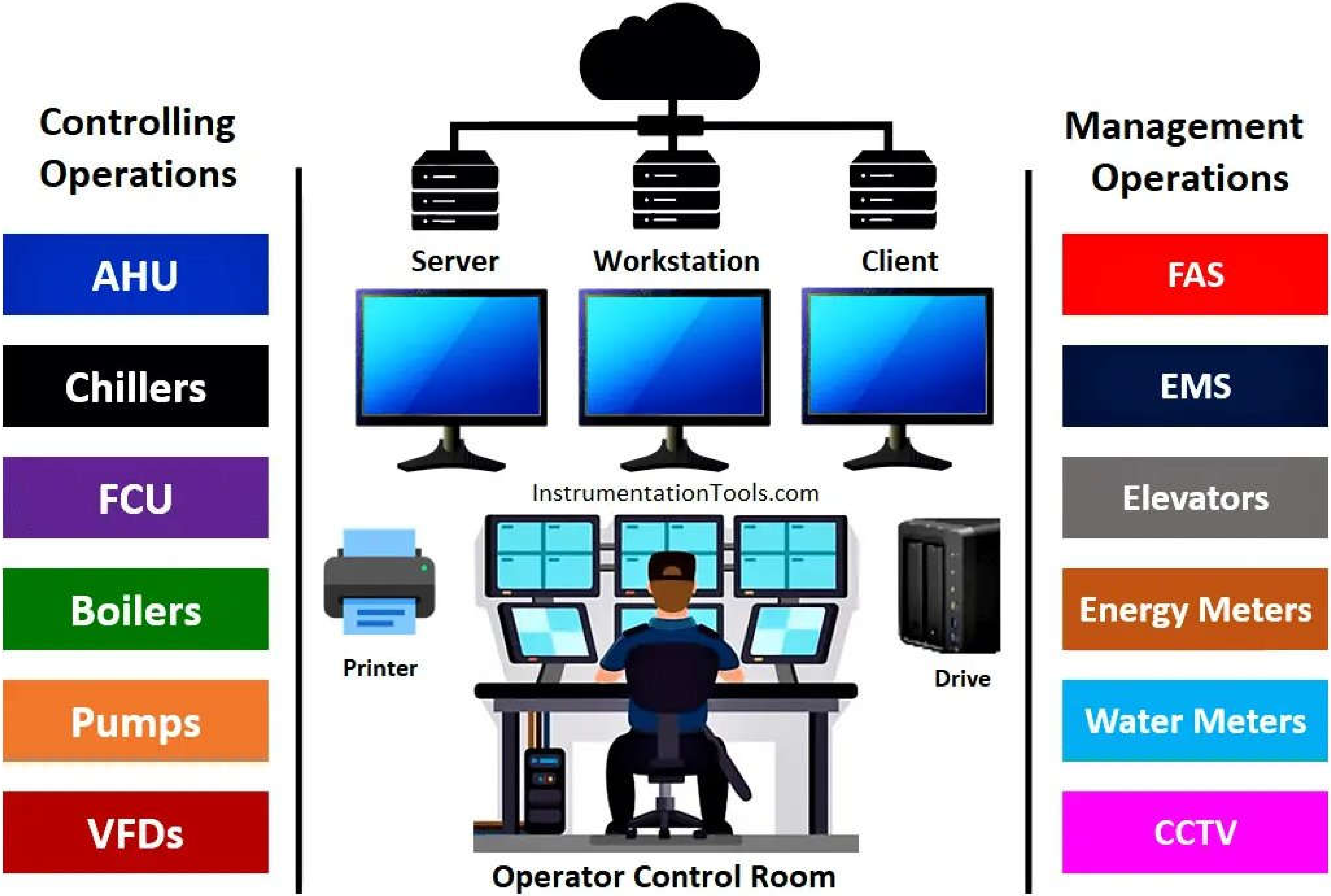


(Source: University of Toronto)

BEM functions

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

Controlling & management operations of building automation system



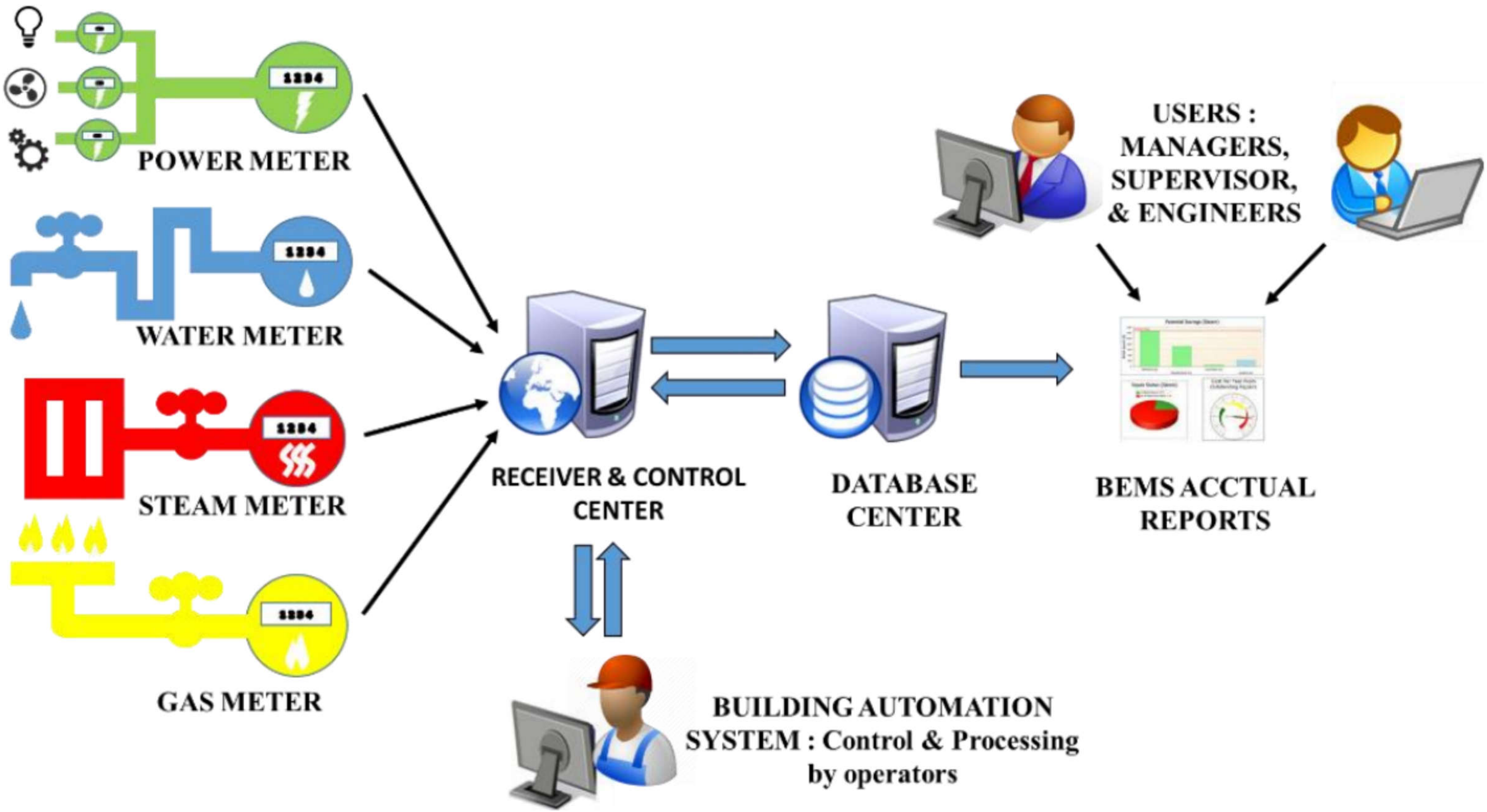
(Source: https://instrumentationtools.com/building-management-system/)

BEM functions

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

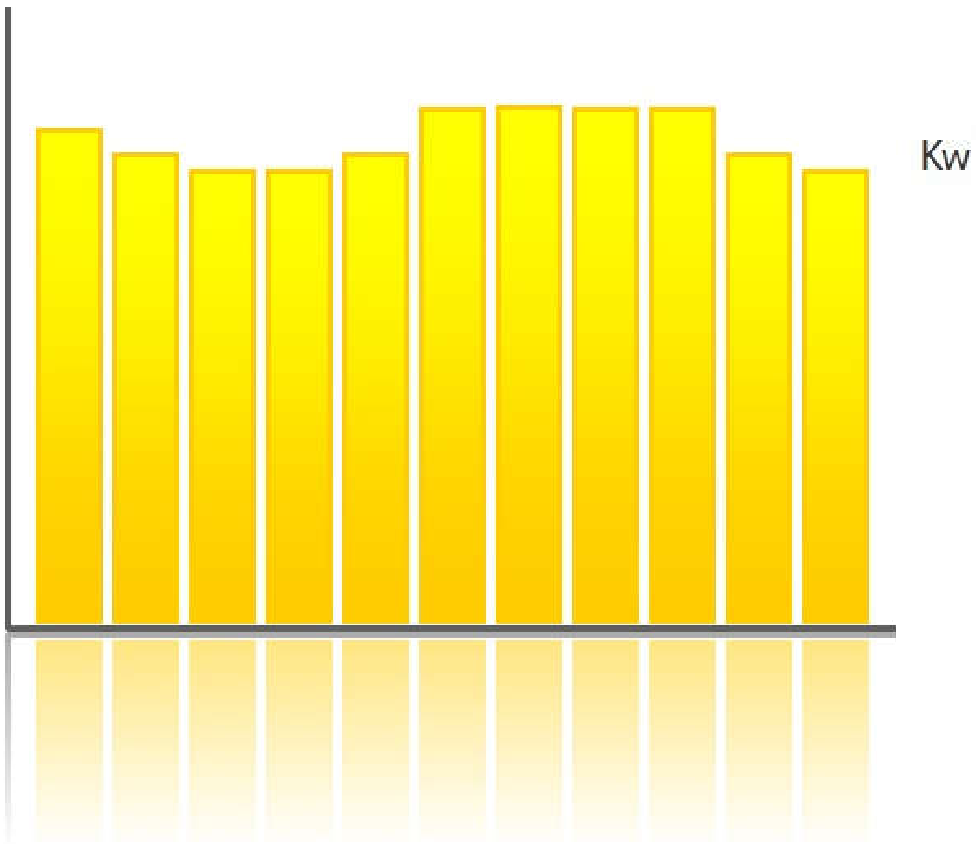
- Energy monitoring process
  - 1. Data collection (energy use data & breakdowns)
  - 2. Data analysis (e.g. which indicates a problem or malfunction)
  - 3. Reporting (show energy use of each part)
  - 4. Action (make effective use of the reports)

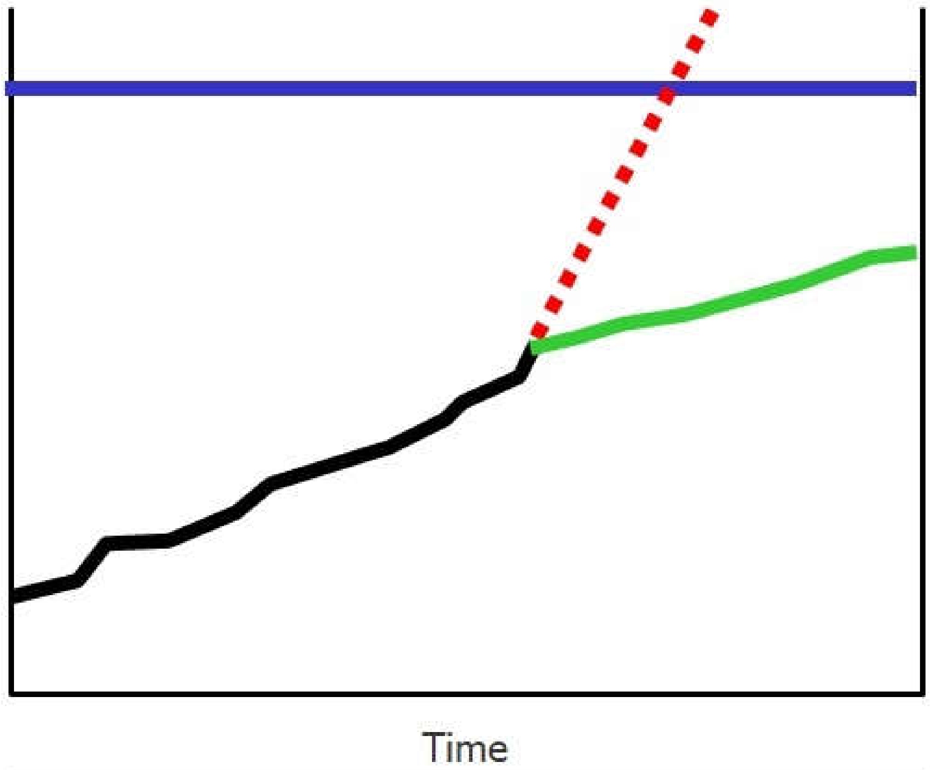
Basic concept of a building energy management system (BEMS)

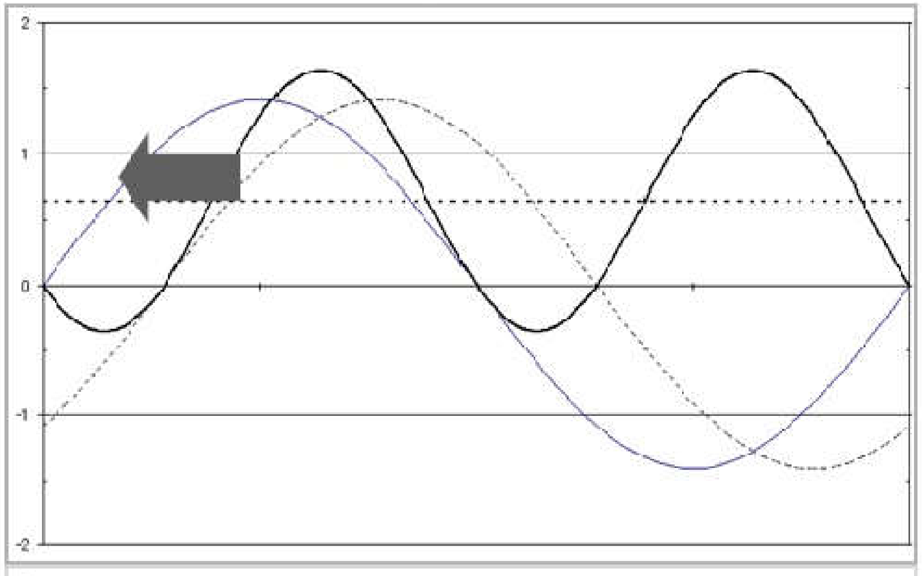


(Source: Chin J. & Lin S.-C., 2016. A behavioral model of managerial perspectives regarding technology acceptance in building energy management systems, *Sustainability*, 8 (7) 641. https://doi.org/10.3390/su8070641)

Energy demand control & power demand/power factor control







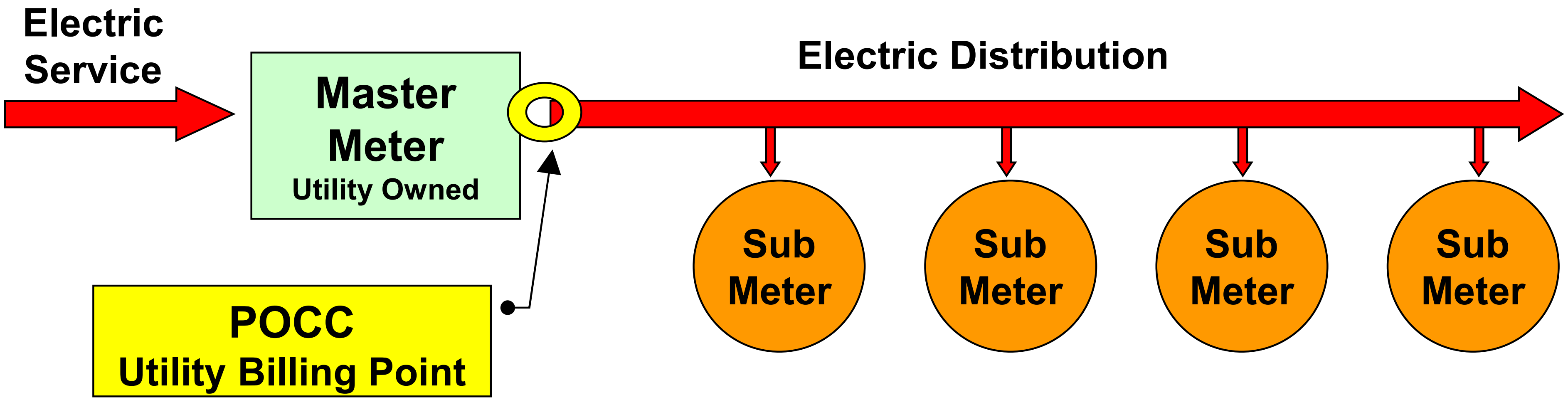
(Source: https://vn.azbil.com/ourbusiness/business_building/p267/)

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

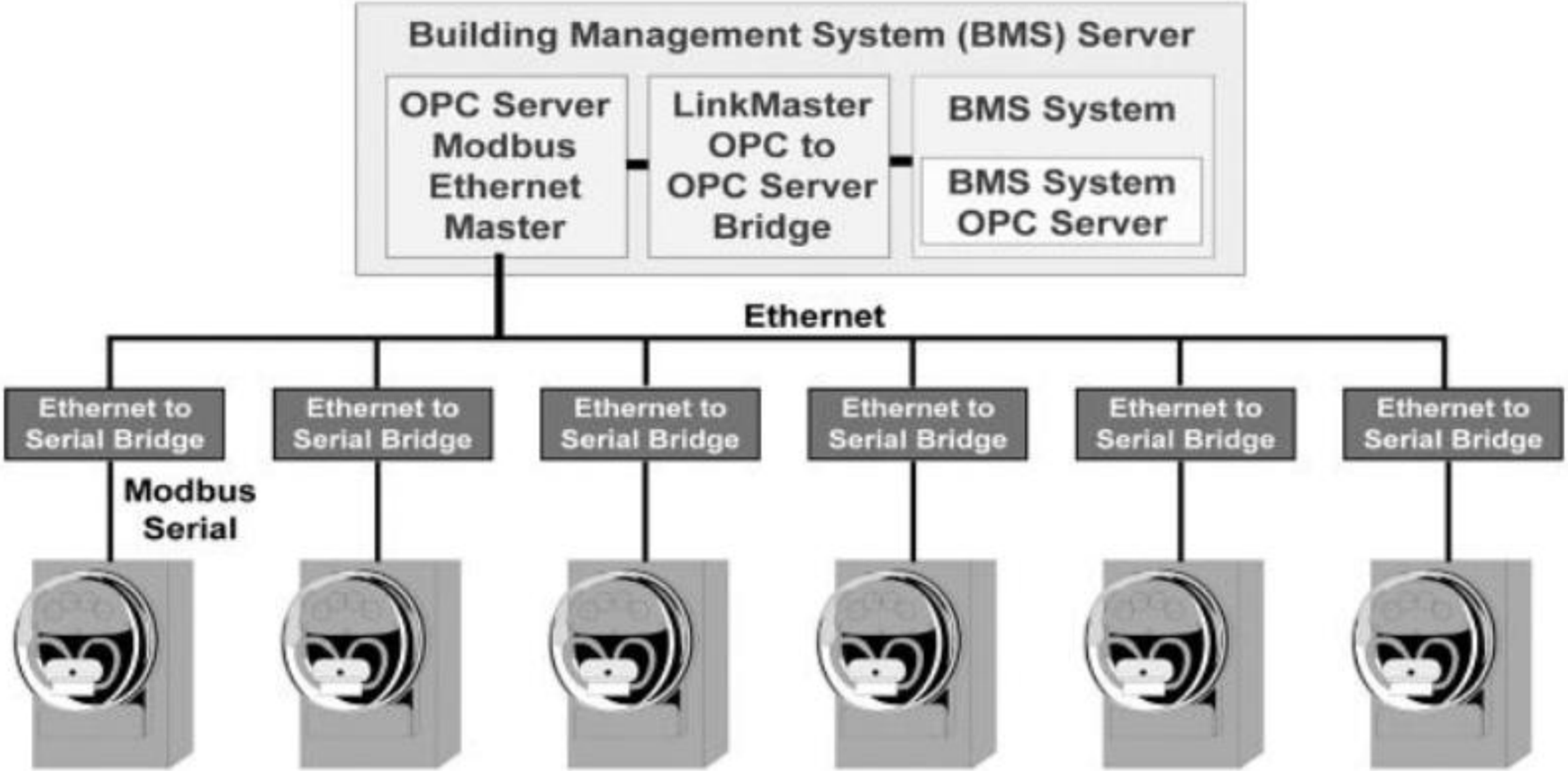
Gas meter

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

- 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

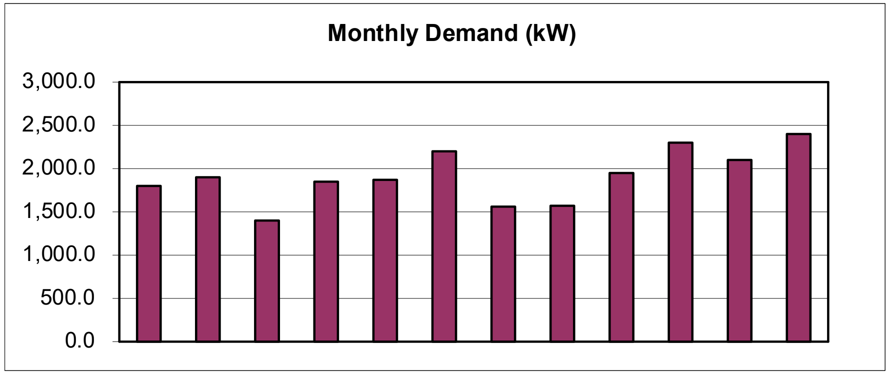
Example of analysing the electricity billings

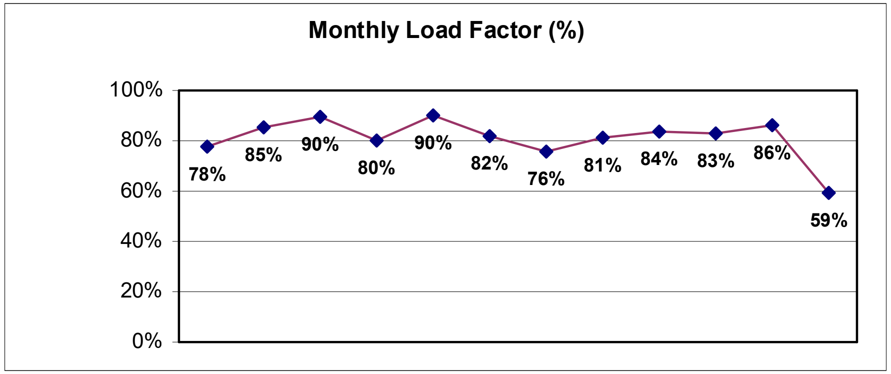
Electricity Consumption Data

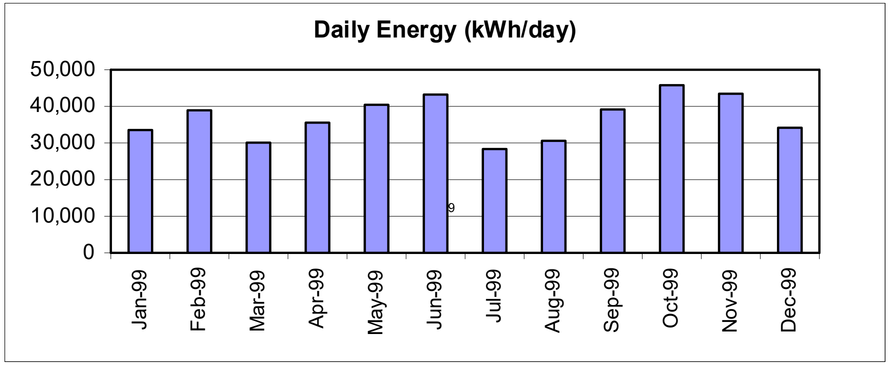
Location: ABC Facility

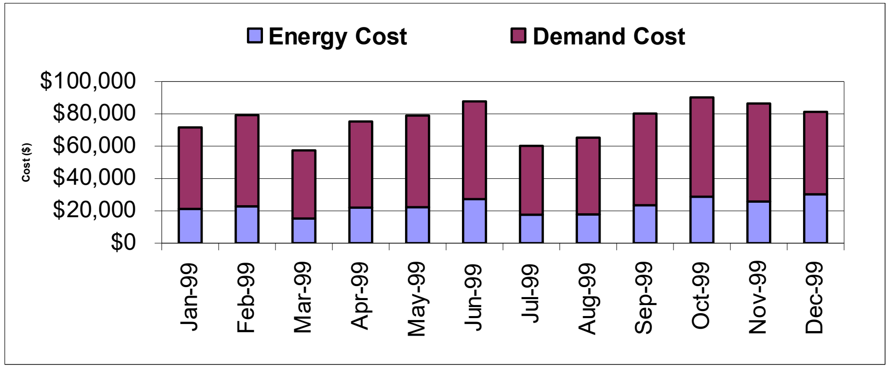
[C:\Project Files\Audit Manual\Spreadsheets\[Electricity Cost.xls]Electicity Consumption Data]

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)

Estimated energy usage breakdown in an example building

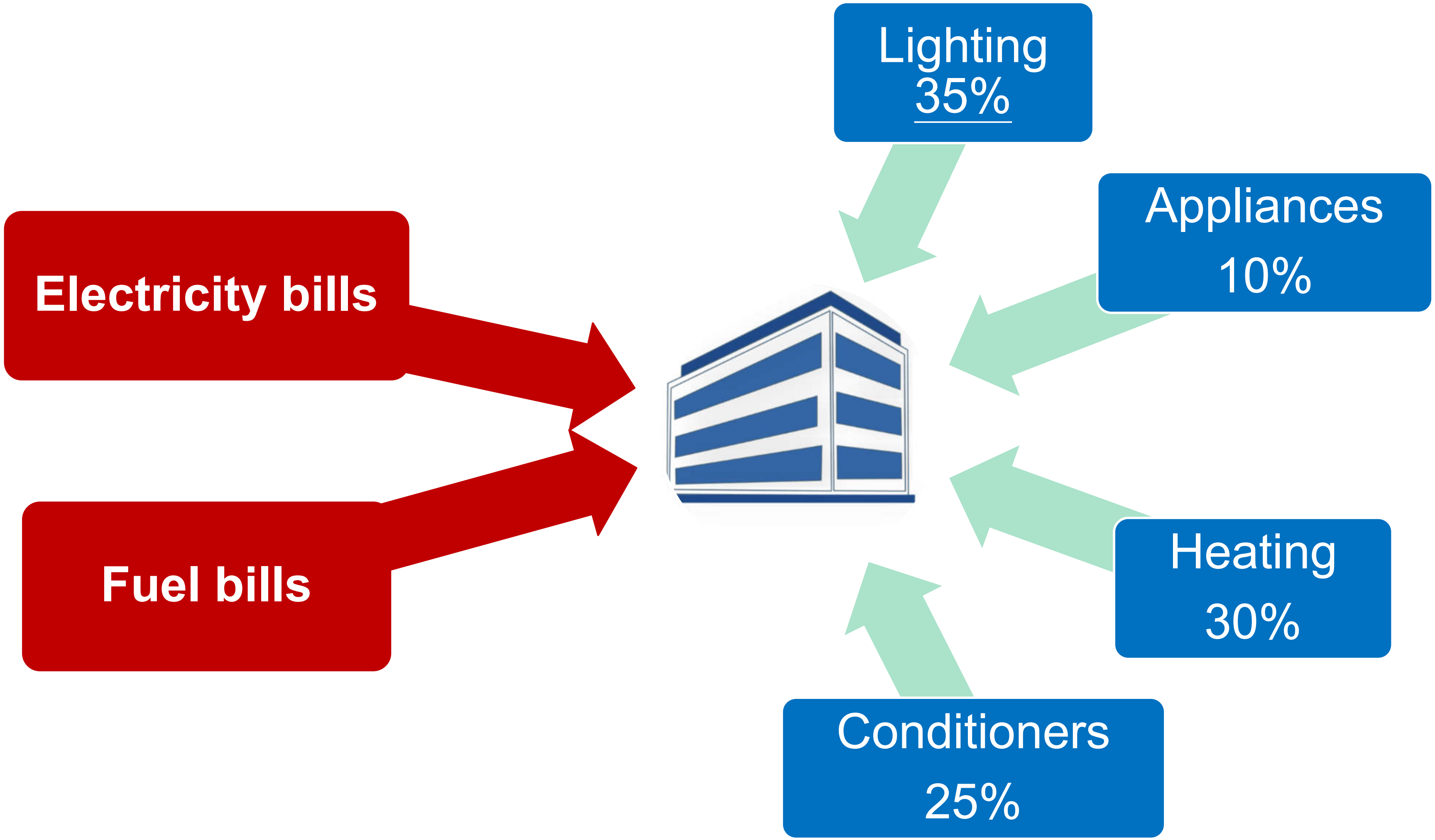
- **ELECTRICITY** 684 000 kWh/yr
  - **LIGHTING** 180 000 kWh/yr — Fluorescent throughout, with sodium for external and car park lighting
  - **FANS** 162 000 kWh/yr — Four air handling units, a supply and extract for each floor
  - **PUMPS** 27 000 kWh/yr — Heating, DHW and cooling pumps all on the same distribution board
  - **OFFICE EQUIPMENT** 112 500 kWh/yr — PCs, printers, photocopiers, plus kettles, vending machines, etc
  - **COOLING** 90 000 kWh/yr — Two central screw compressors with integral heat rejection
  - **COMPUTER ROOM** 76 500 kWh/yr — Air-conditioned computer room
  - **OTHER ELECTRICITY AND CATERING** 36 000 kWh/yr — Ovens plus dishwasher supplied from the main DHW system
- **GAS** 531 000 kWh/yr
  - **SPACE HEATING** 427 500 kWh/yr — Central high-efficiency gas boilers supplying heating and hot water
  - **DHW** 72 000 kWh/yr — Separate central storage water heaters
  - **CATERING** 31 500 kWh/yr — Various ovens, hobs, etc

(Source: EEBPP, 2002. *Metering energy use in new non-domestic buildings*, General Information Leaflet 65, Energy Efficiency Best Practice programme (EEBPP), UK. https://shmmetershop.co.uk/wp-content/uploads/2018/07/gil065.pdf)

BEM operations

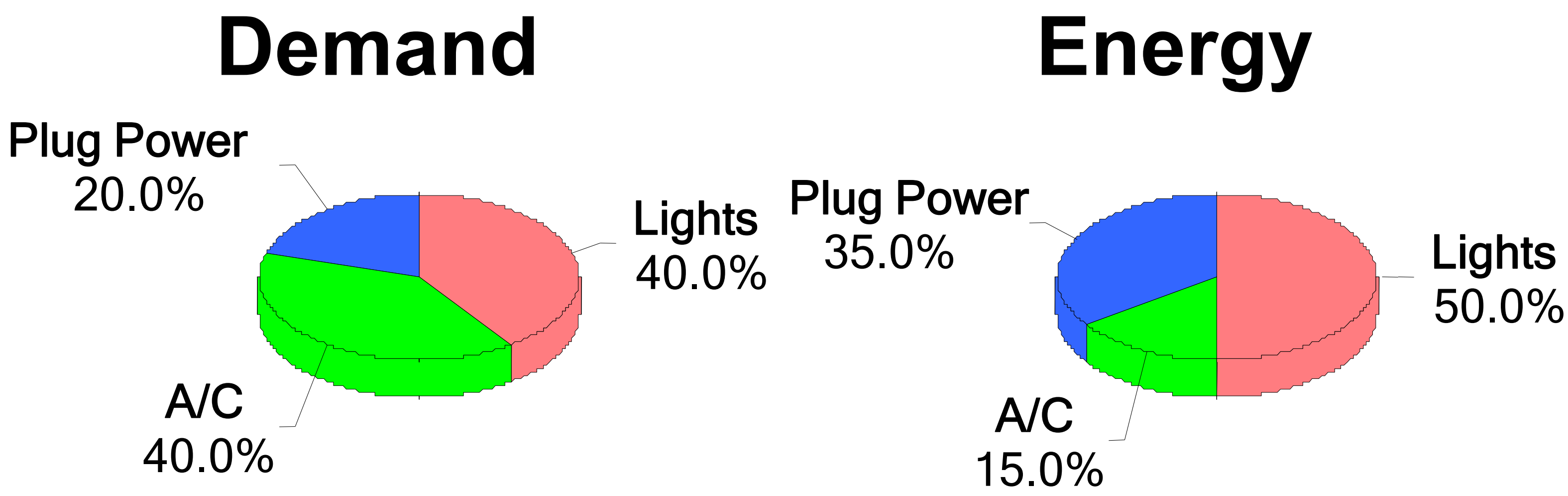
- Understand where energy is used
  - Create an energy load inventory & reconcile it to consumption data
- Analyse the load inventory
  - Where is electricity used?
  - How much - i.e. consumption
  - How fast - i.e. demand
- Why inventory? Focus your efforts; establish a basis for savings calculations

Develop & investigate the "energy balance" (or energy profile)



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

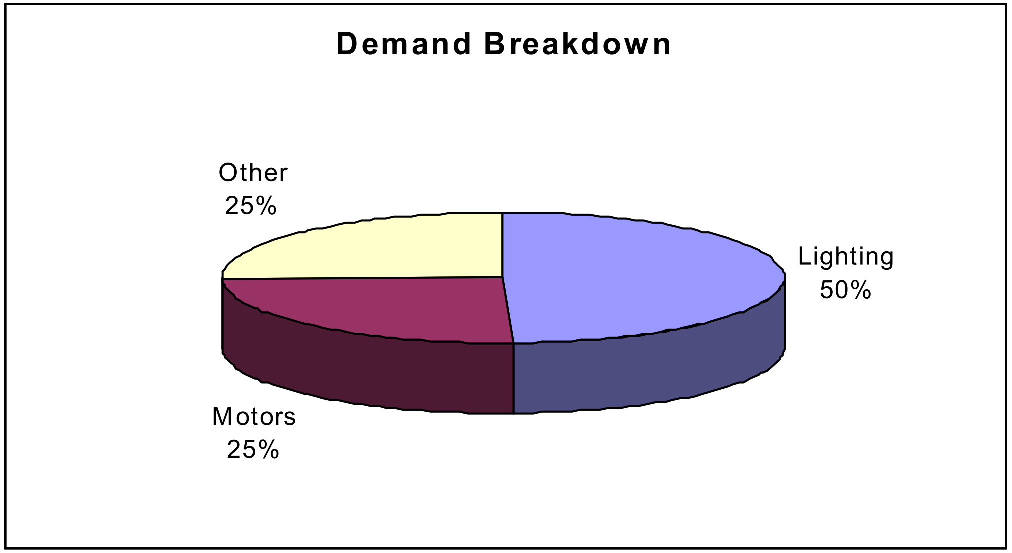
Analysis of the demand & energy use

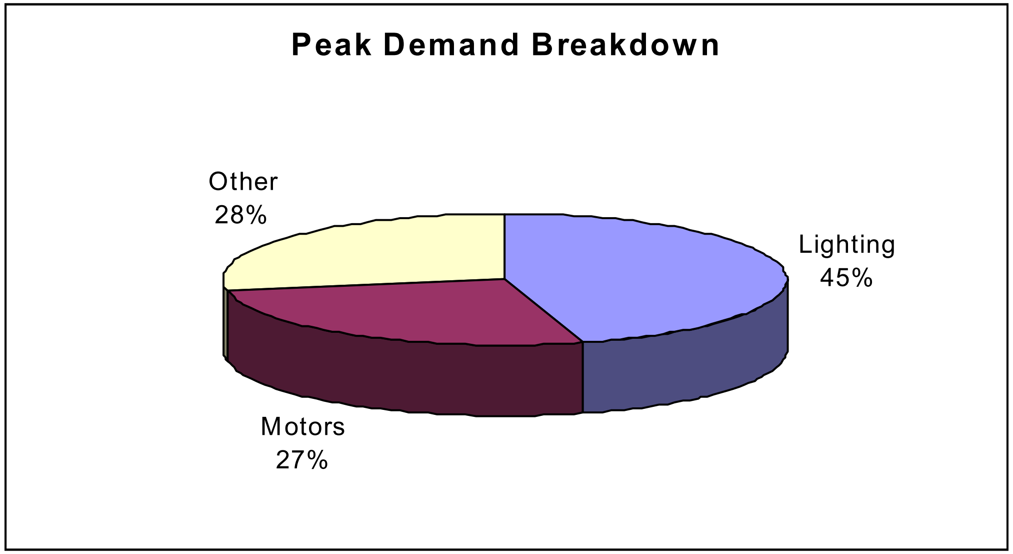


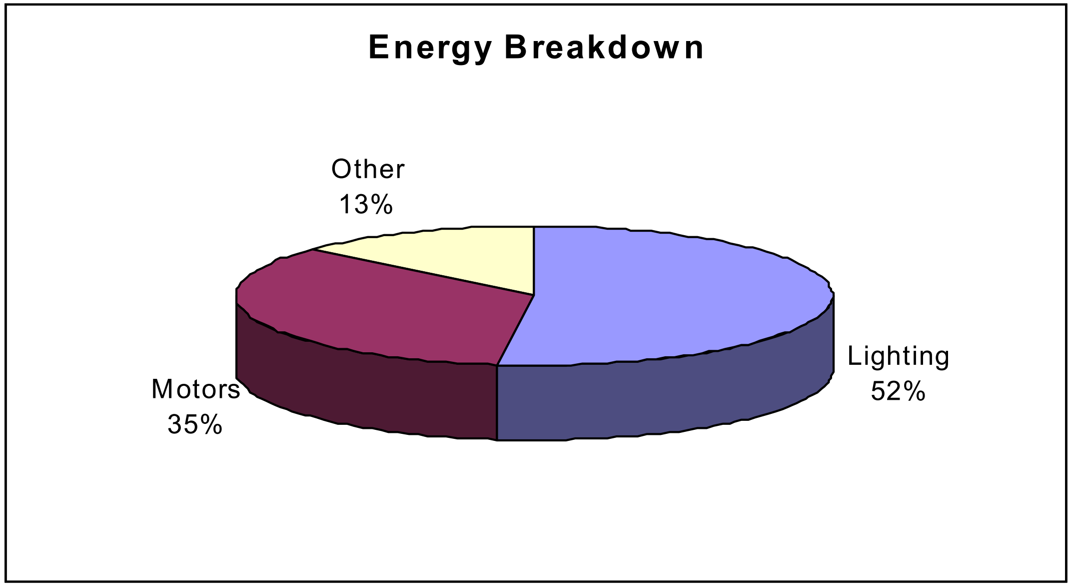
Item	Units	Formula
Quantity	(a number)	
Unit Load	kW	
Total kW	kW	Quantity. x Unit Load.
Hrs/Period	hours	
kWh/Period	kWh	Total kW x Hrs/Period
Diversity Factor (Div'ty Factor)	0 - 100%	
Peak kW	kW	kW x Diversity Factor

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

Breakdown of demand, peak demand & energy







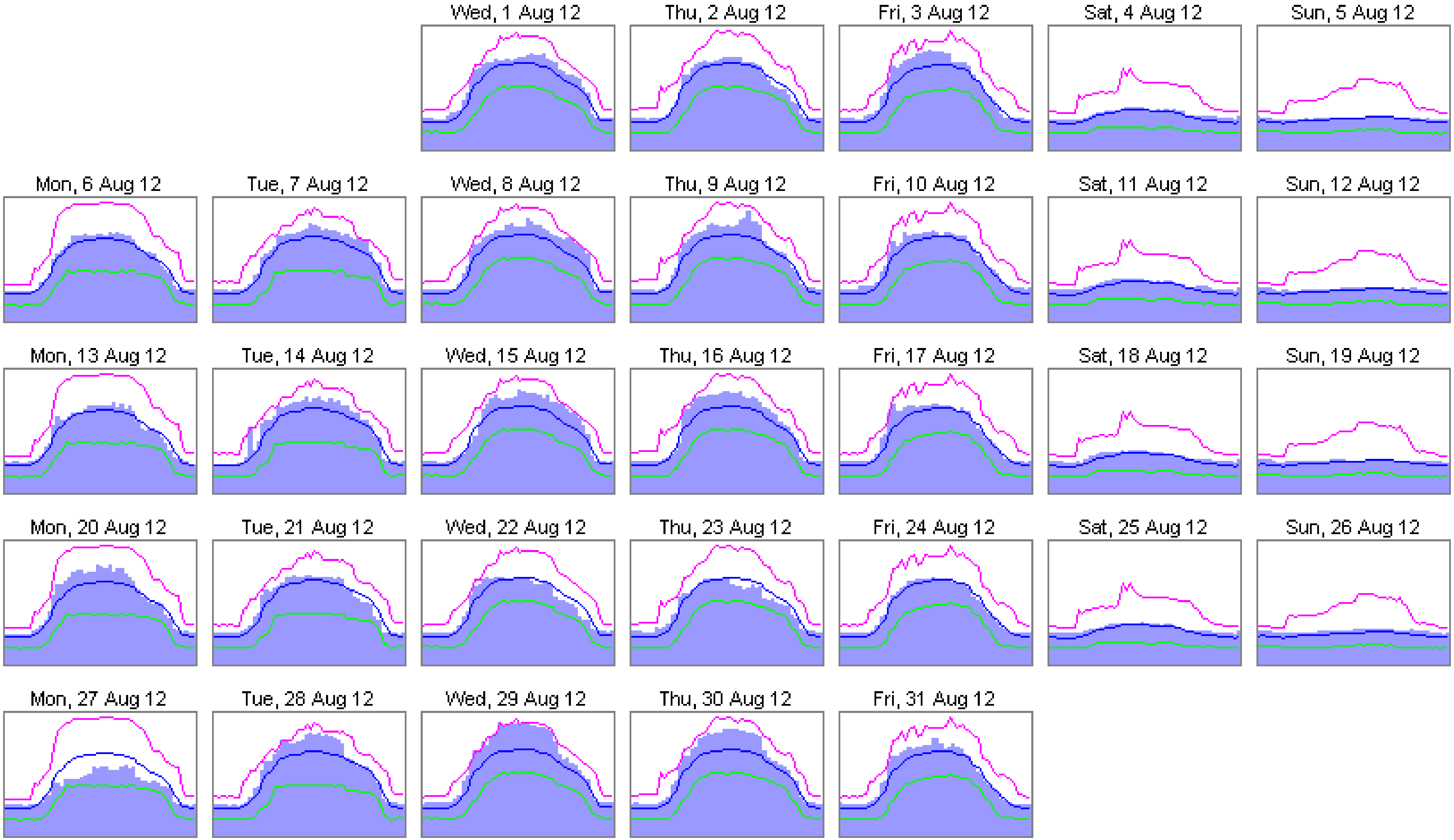
(Source: Department of Minerals and Energy, South Africa)

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)

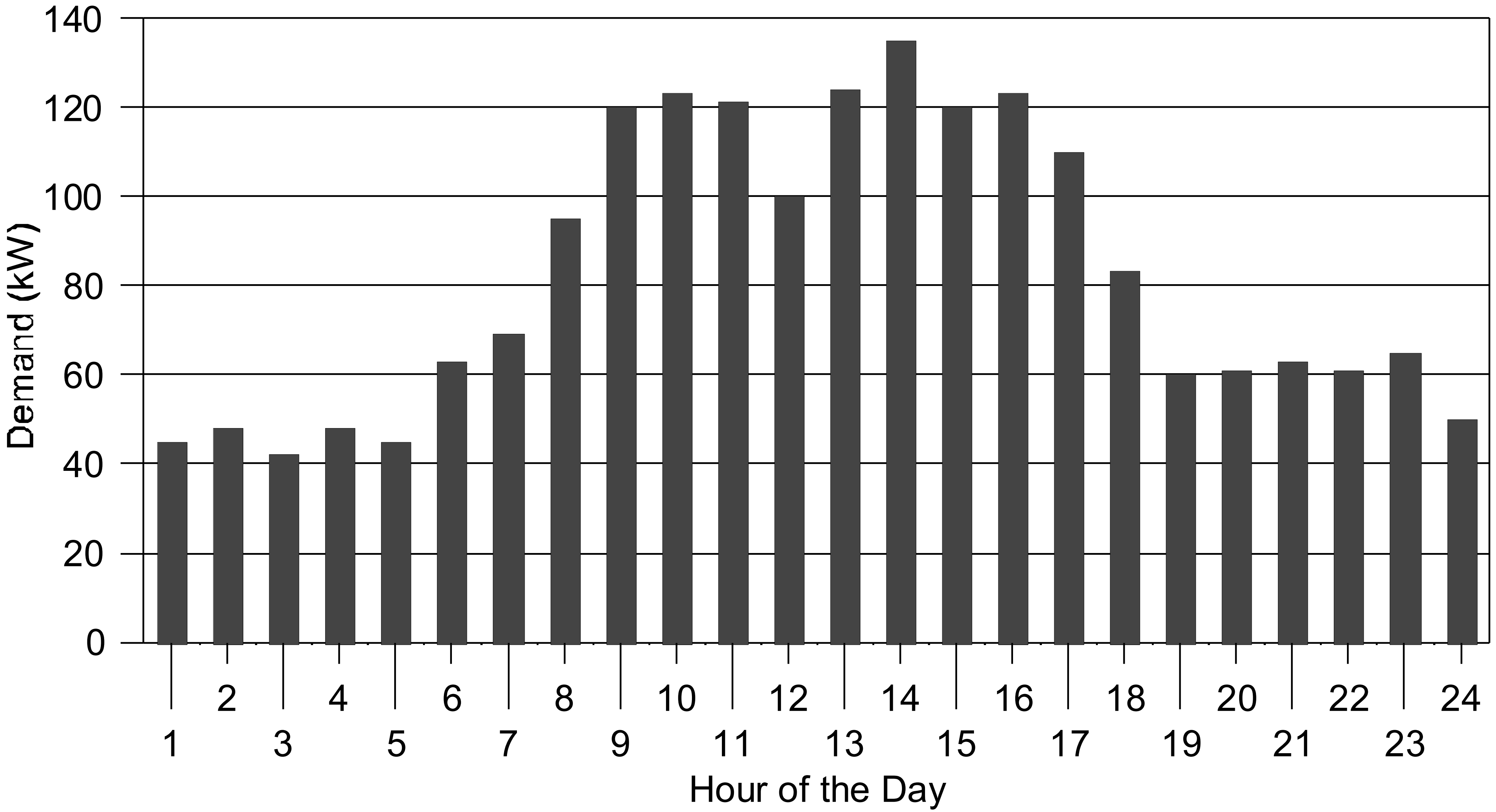
A month’s energy profiles with hourly data for each day



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.

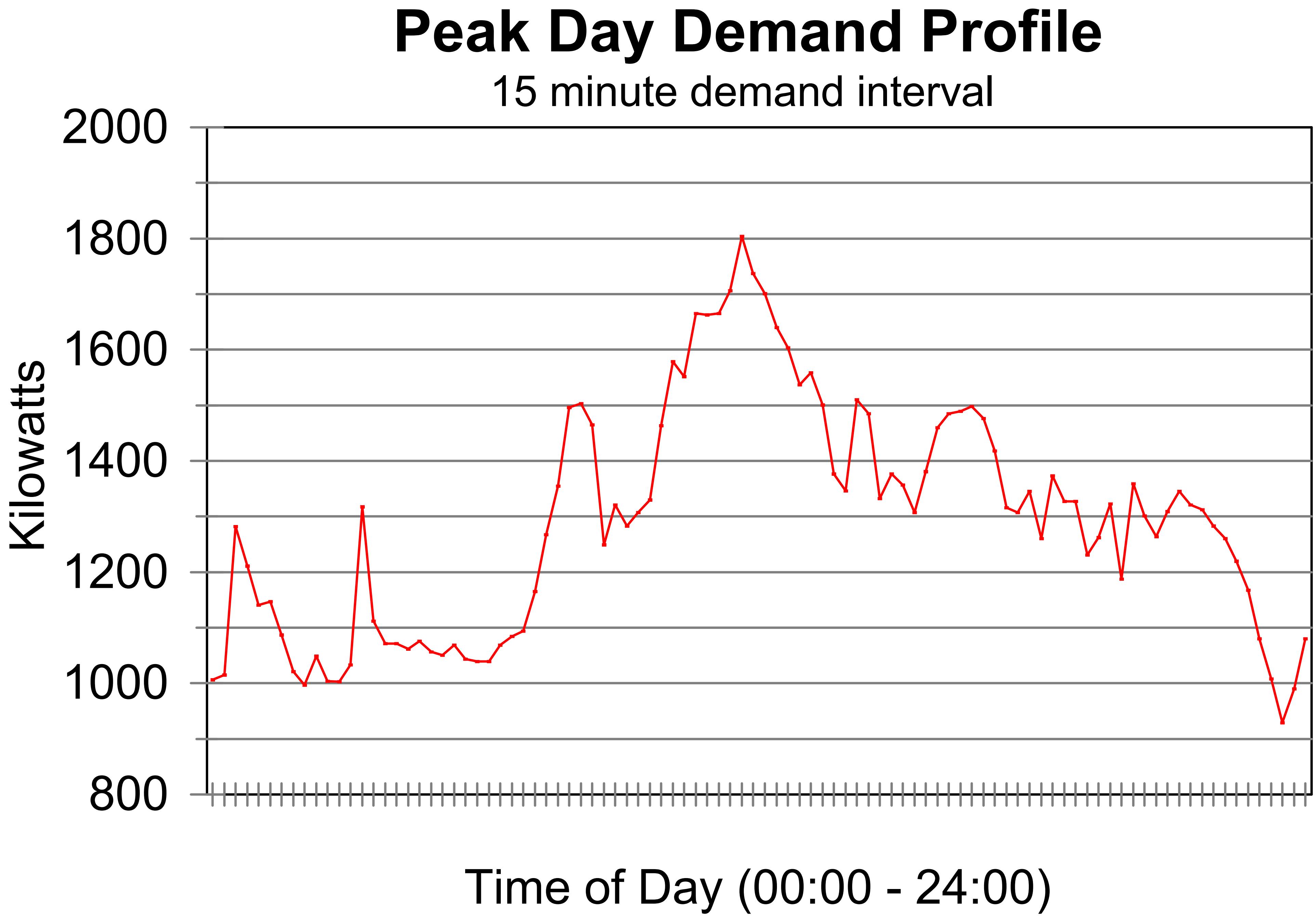
(Source: Energy Monitoring Charts and Tables http://www.energylens.com/outputs)

Hourly demand profile



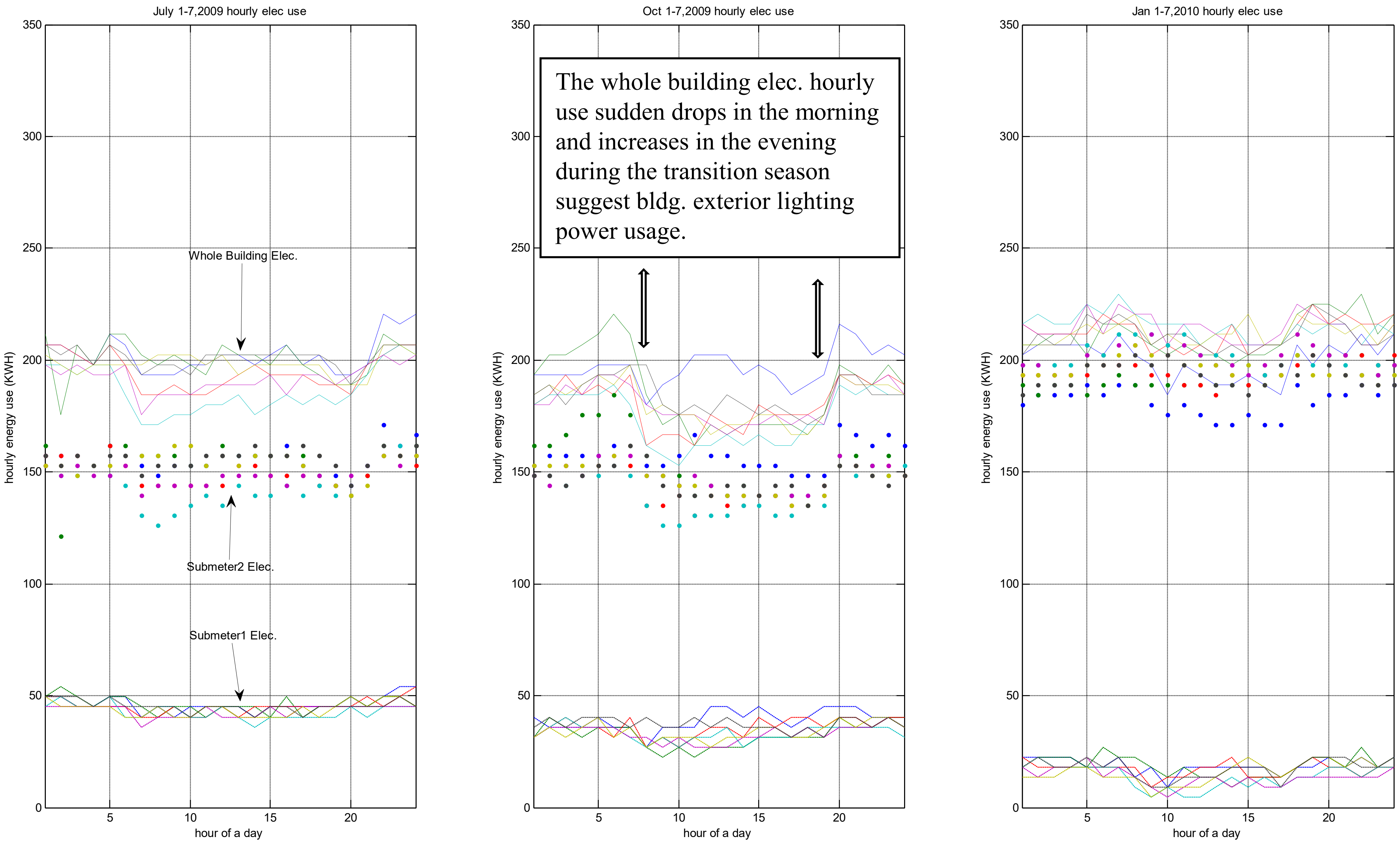
(Source: Department of Minerals and Energy, South Africa)

An electrical fingerprint



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

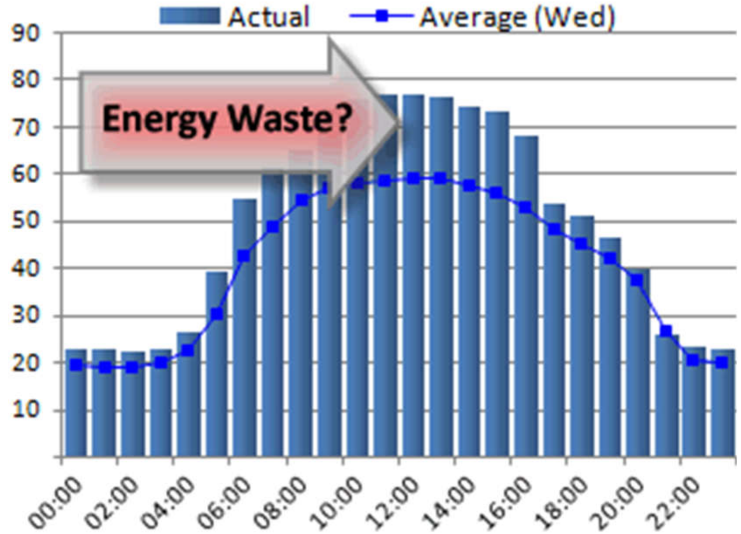
Example of demand analysis based on hourly data

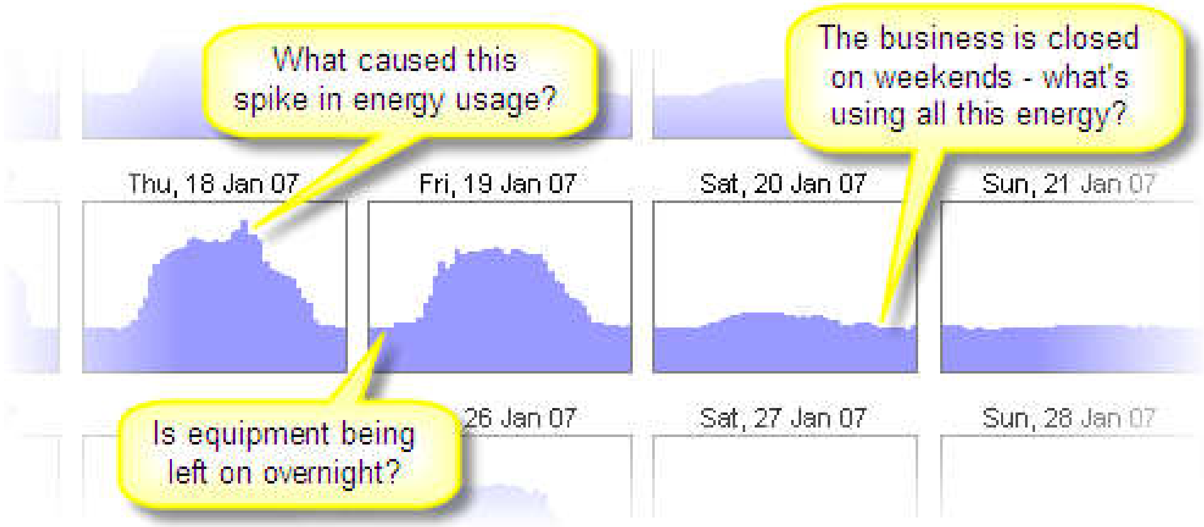


[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

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)

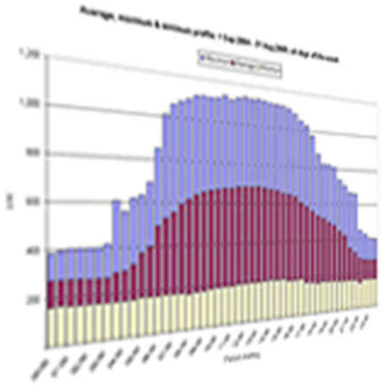
Demand analysis

- 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"

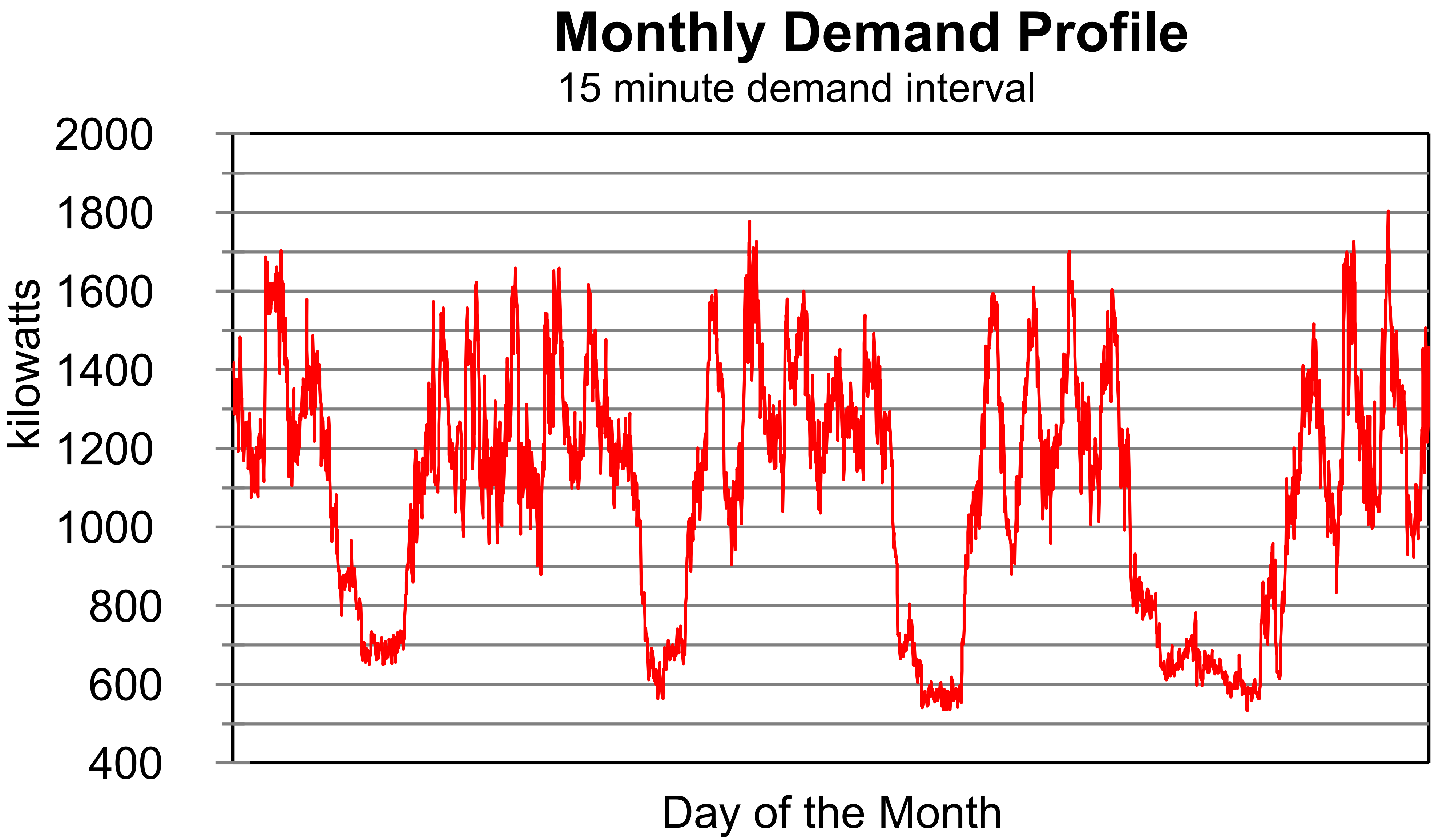
Demand analysis

- 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



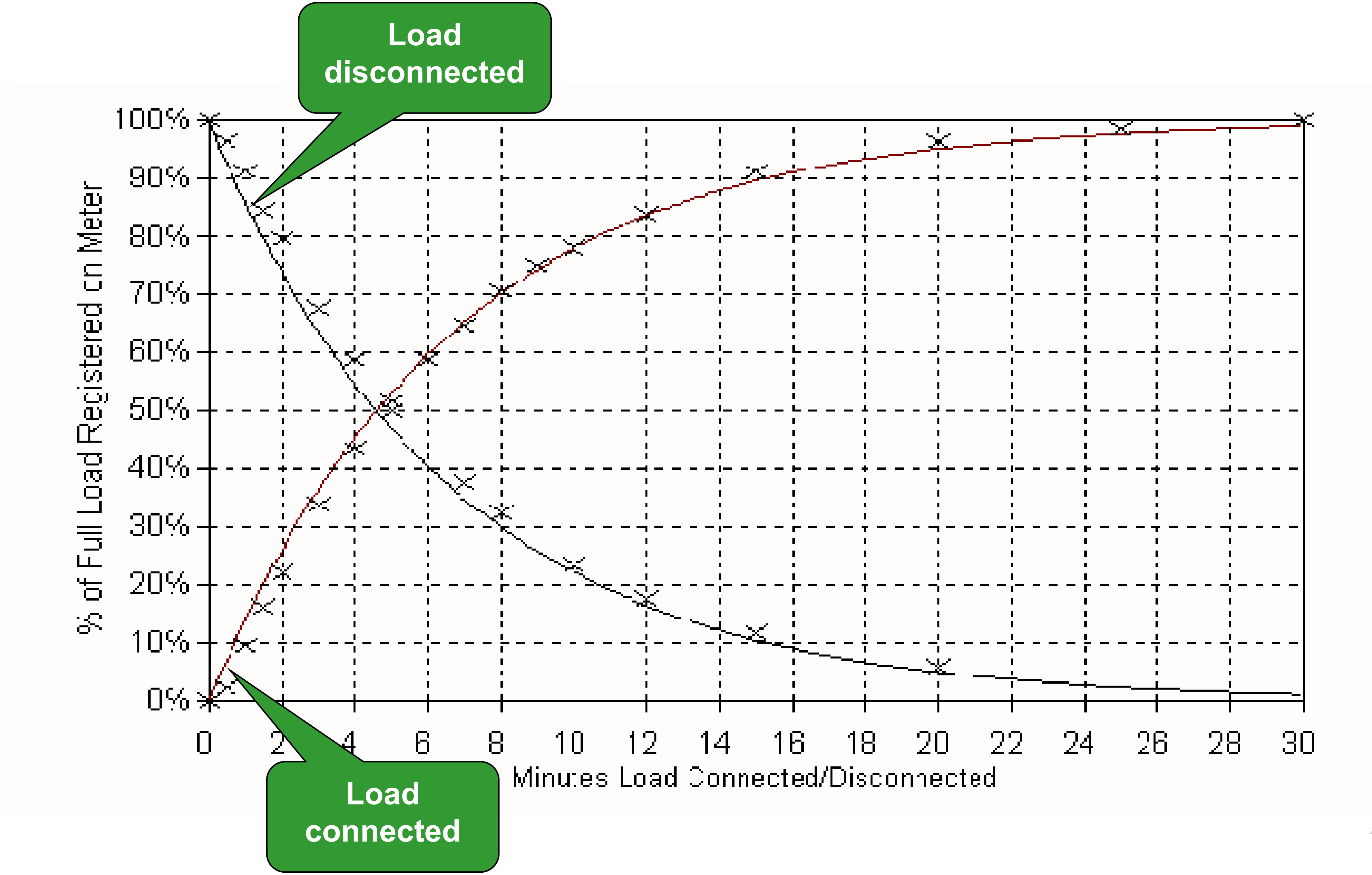
Videos: Analyzing energy data (9:09) & loading energy data (6:54) with Energy Lens
http://www.energylens.com/videos/

Study of daily or monthly profile



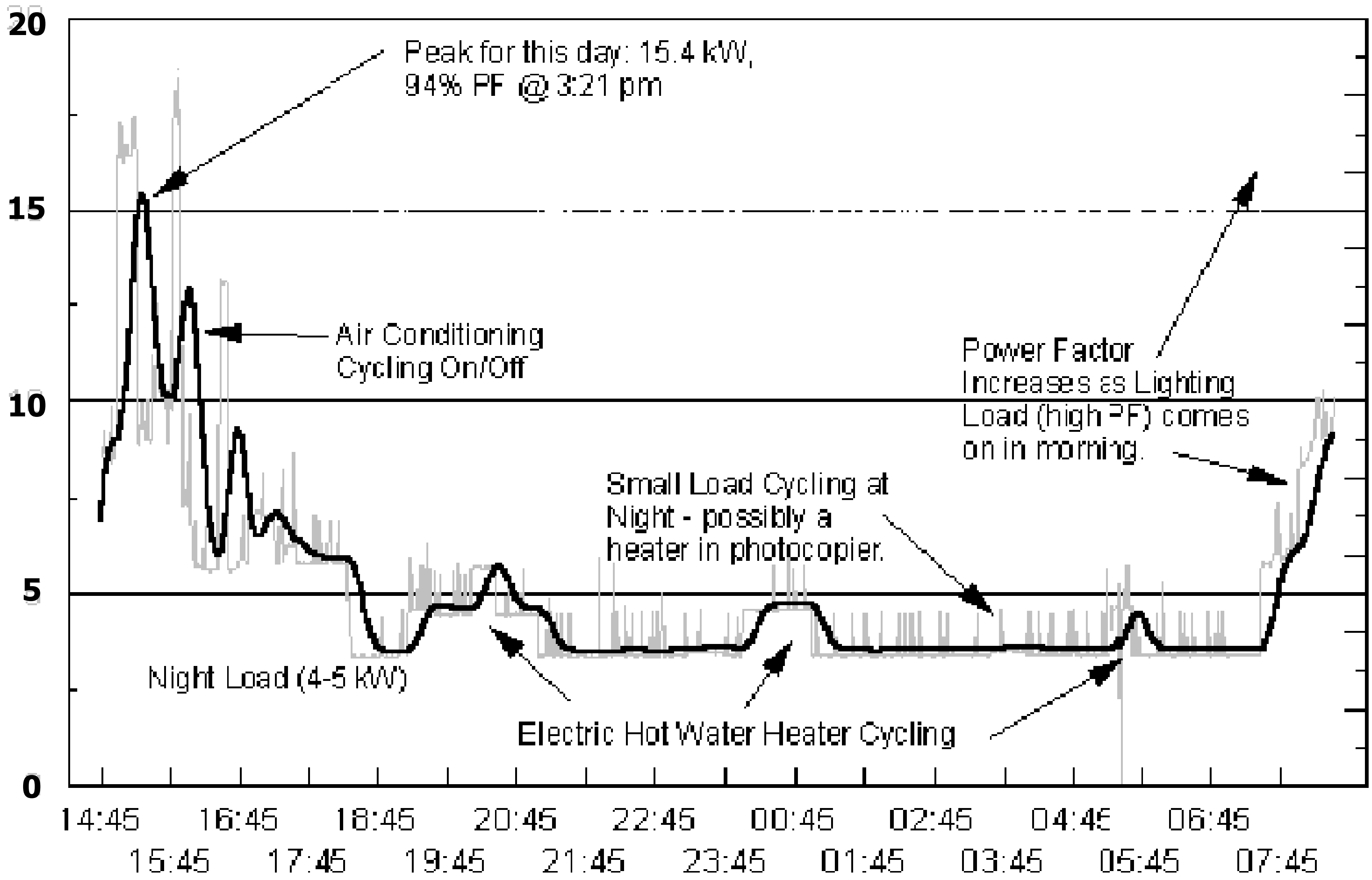
(Source: Department of Minerals and Energy, South Africa)

Meter response (time delay)



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

What the demand meter sees



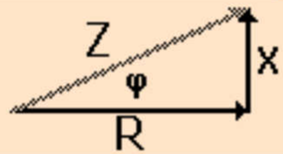
(Source: Department of Minerals and Energy, South Africa)

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)

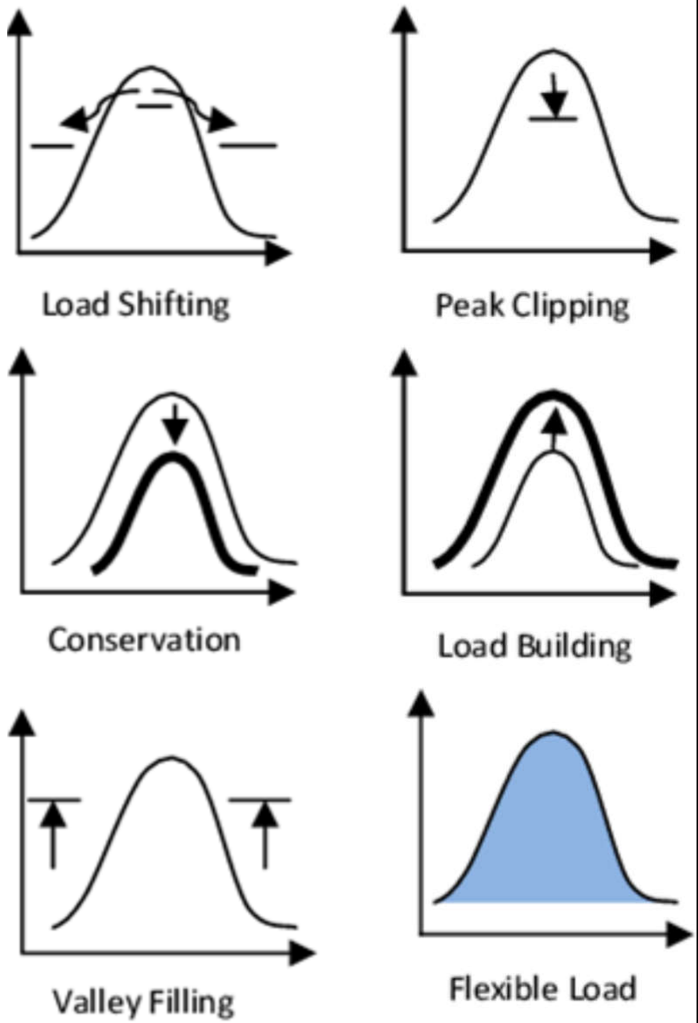
$$P_{avg} = VI \cos \varphi$$

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

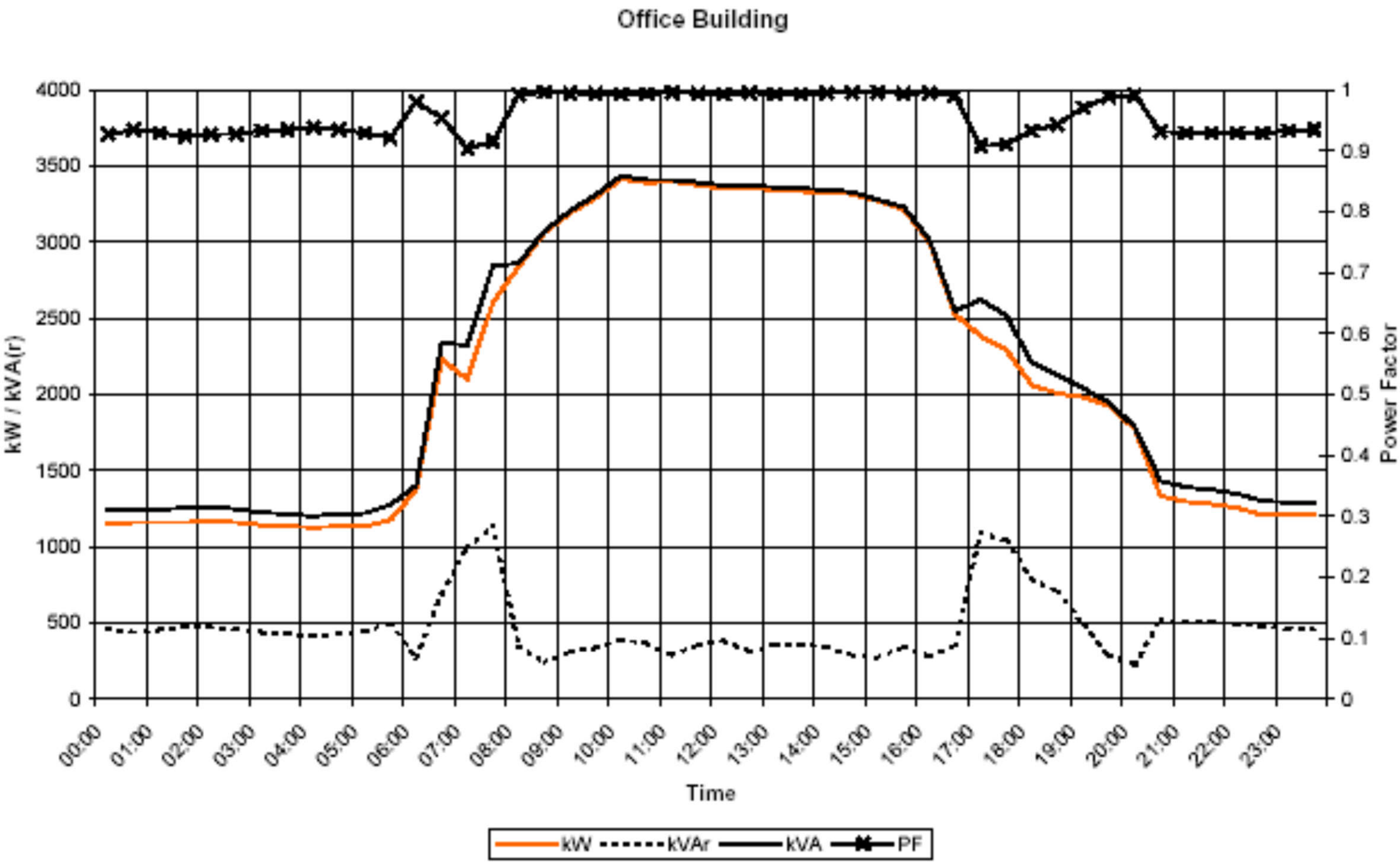


Demand analysis

- 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



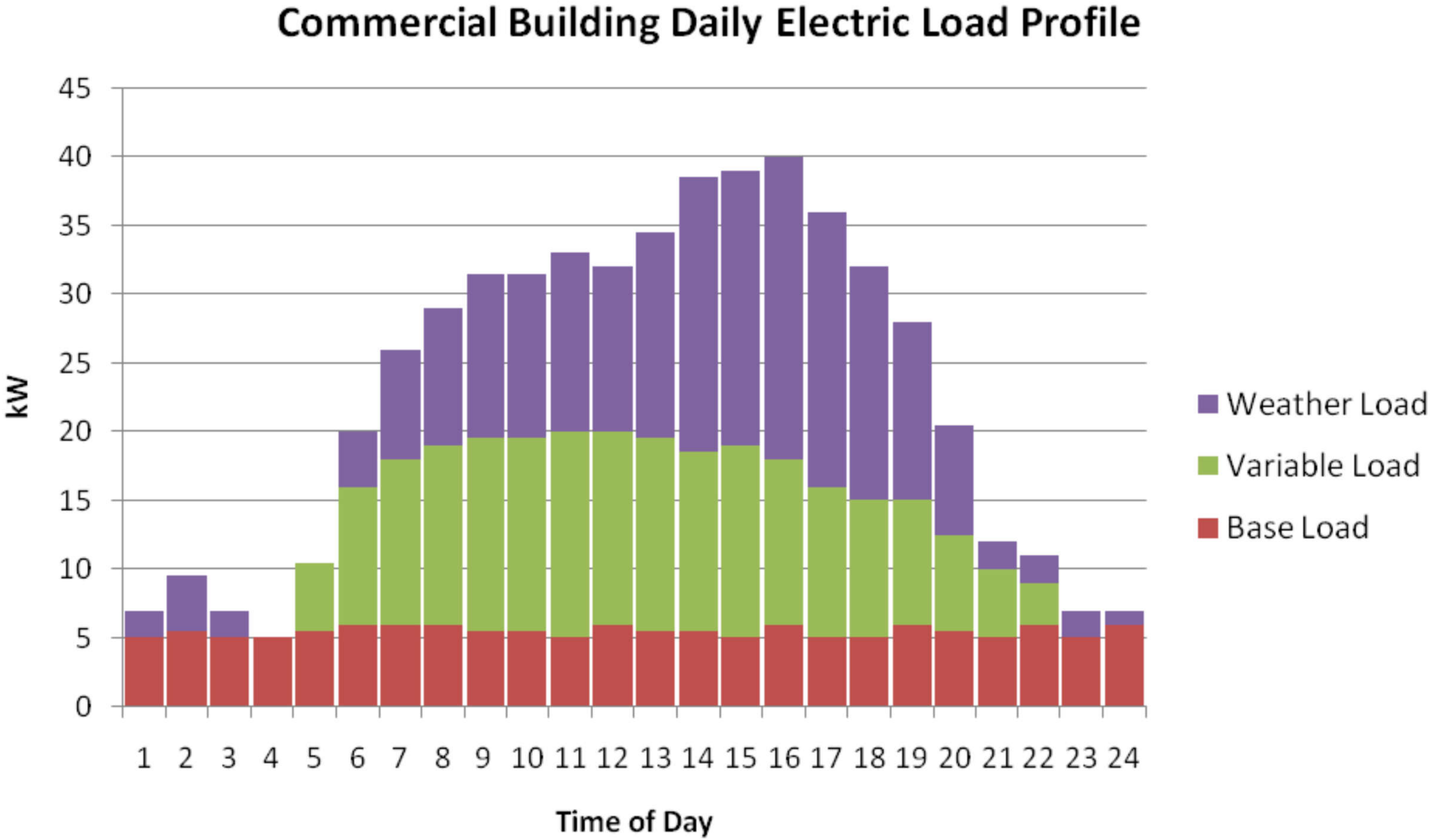
Can you analyse this energy & demand profile?



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

Typical commercial building daily electric load profile

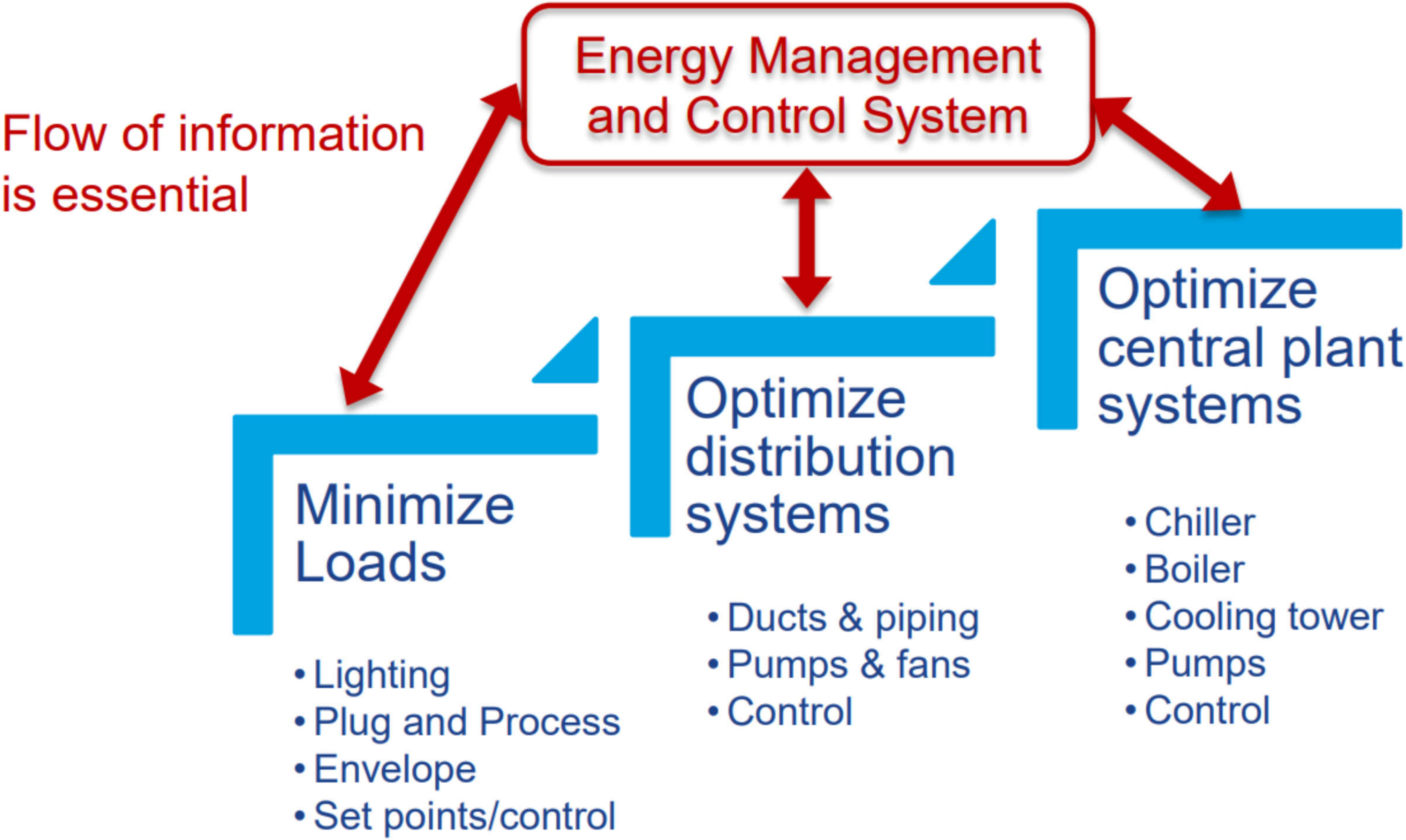
Could you interpret & explain this?



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



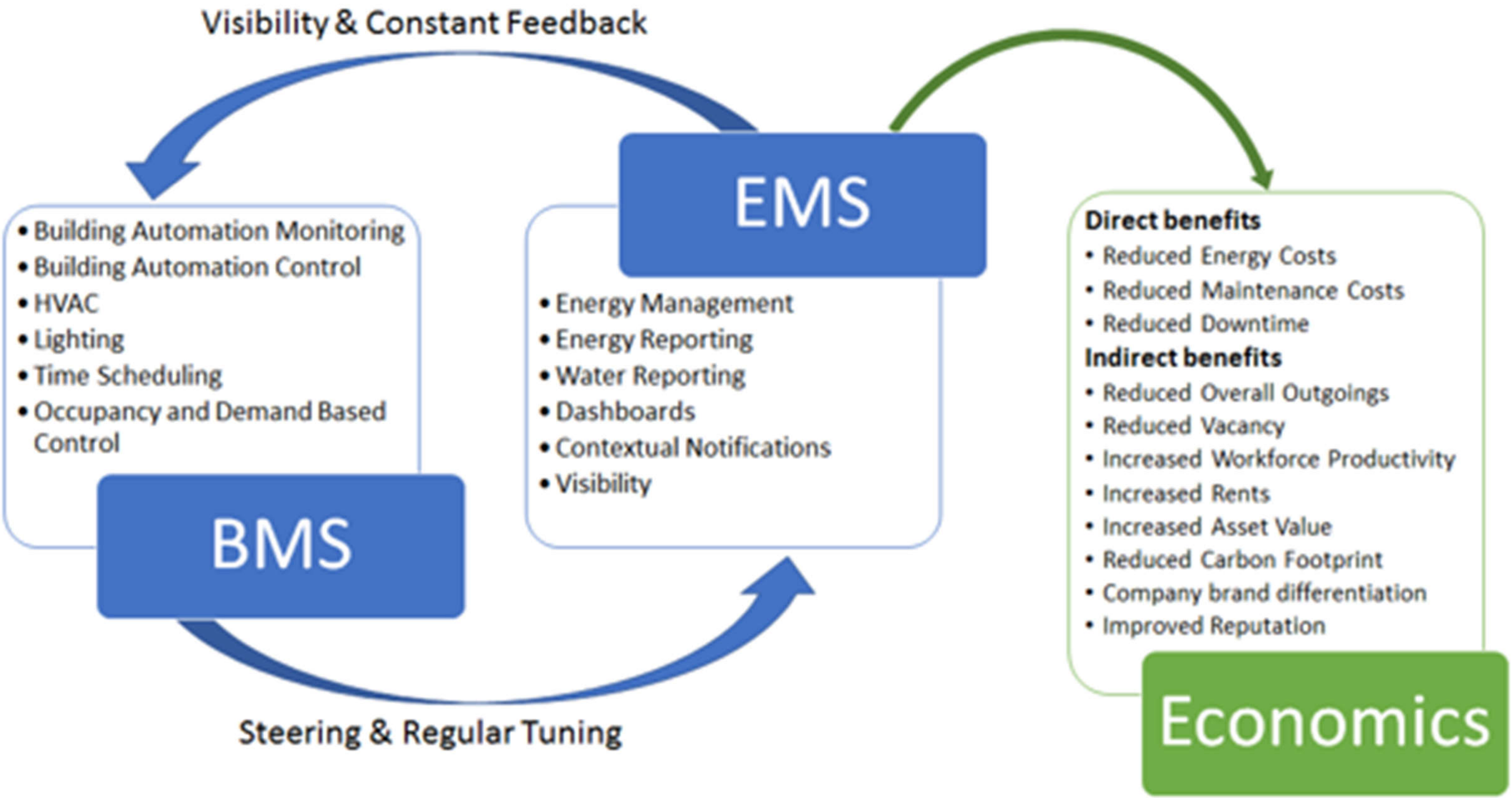
(Source: https://betterbuildingssolutioncenter.energy.gov/sites/default/files/systems_approach_to_central_plant_hvac_optimization.pdf)

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

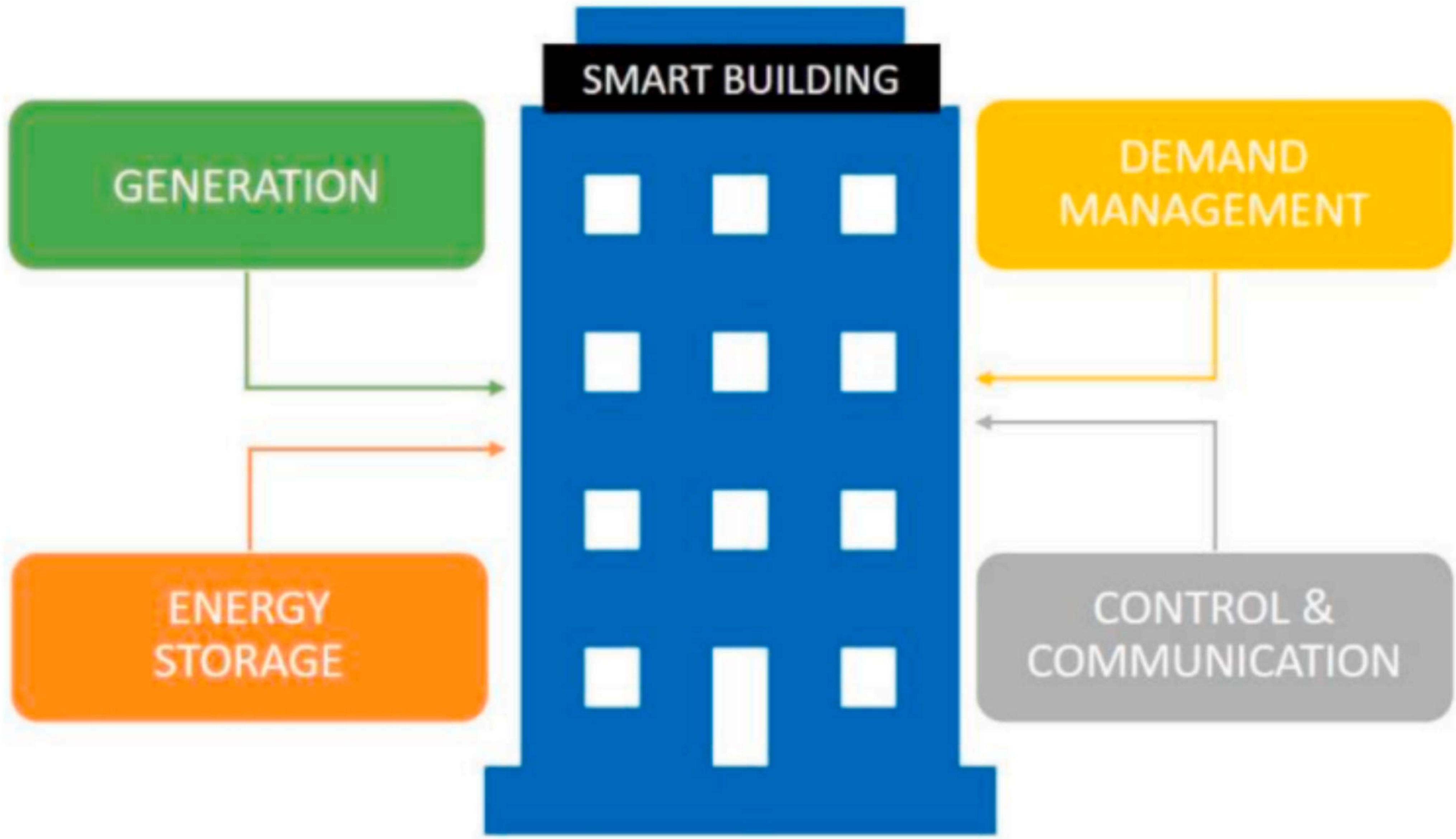
(Source: https://urjanet.com/blog/top-5-tips-successful-energy-management/)

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



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

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)

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

BEM strategies

- Predictive maintenance (PdM) 預測性維護
  - Use data analysis to identify operational anomalies & potential equipment defects, enabling timely repairs before failures occur
  - It aims to minimize maintenance frequency, avoiding unplanned outages & unnecessary preventive maintenance costs
  - Use historical & real-time data from various parts to model performance, monitor conditions & anticipate problems before they happen

(Source: https://fiixsoftware.com/maintenance-strategies/predictive-maintenance/)

Predictive Maintenance VS Traditional Maintenance

Predictive Maintenance	Traditional Maintenance
Proactive Approach	Reactive Approach
Maintenance performed when actually required	Maintenance performed on predetermined intervals
Cost effective	Cost inducing
Only performed when required, hence most time-effective	Time consuming
Prevents equipment failures in the first place	Can lead to unplanned downtime

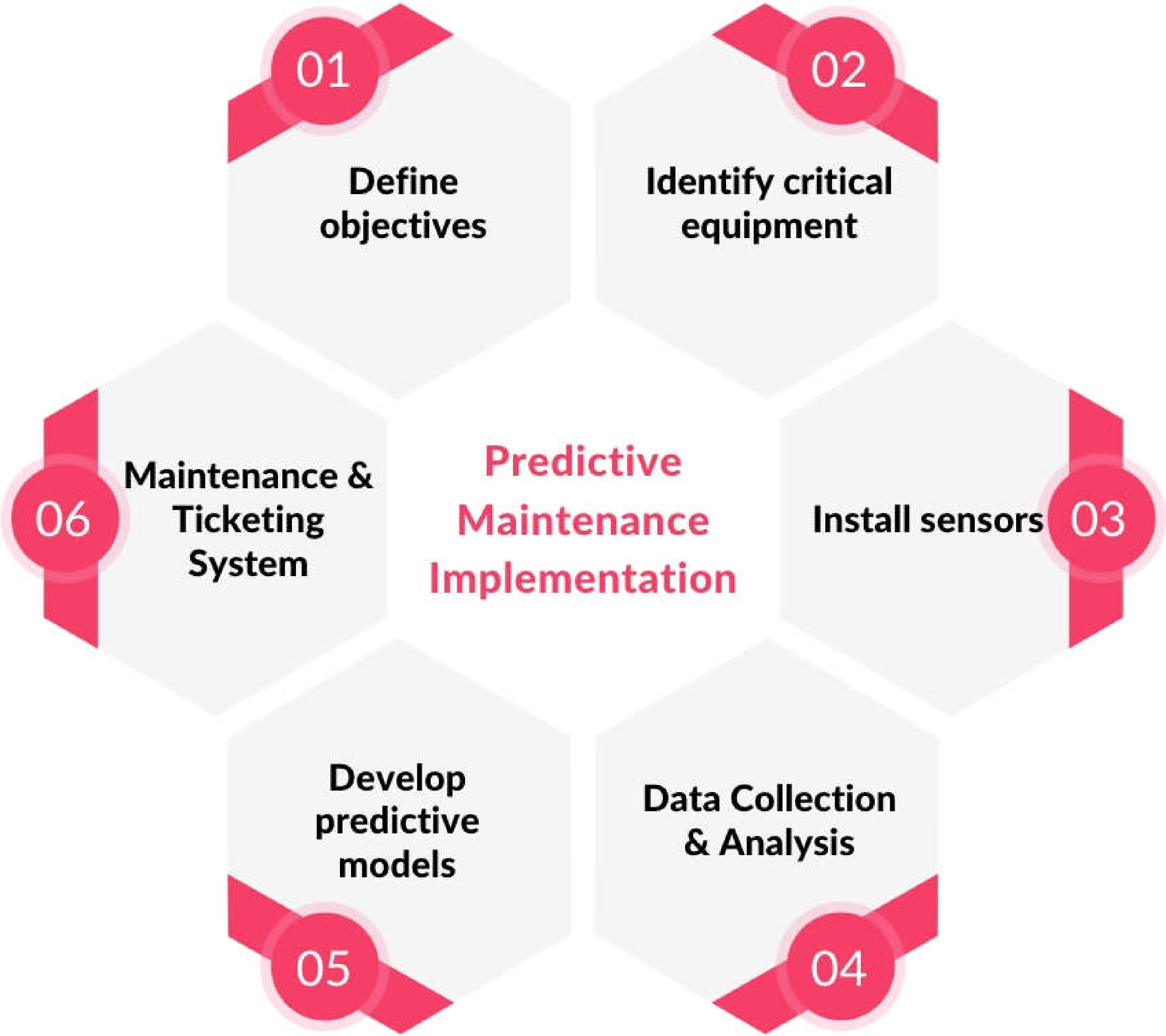
(Source: https://www.zenatix.com/predictive-maintenance-a-comprehensive-guide/)

BEM strategies

- Key components of predictive maintenance:
  - 1. Condition monitoring
    - Monitoring the equipment to detect any changes that may indicate a potential failure
  - 2. Data collection & analysis
  - 3. Machine learning & artificial intelligence (AI)
  - 4. Predictive analytics
  - 5. Maintenance planning & scheduling
  - 6. Performance tracking

(Source: https://www.zenatix.com/predictive-maintenance-a-comprehensive-guide/)

Implementation of predictive maintenance



(Source: https://www.zenatix.com/predictive-maintenance-a-comprehensive-guide/)

Further reading

- PDCA - Wikipedia https://en.wikipedia.org/wiki/PDCA
- 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
- Combining Energy and Building Management Systems to Improve Asset Performance https://www.automatedbuildings.com/news/aug17/articles/optergy/170724024606optergy.html