MECH4423 Building Energy Management and Control Systems

http://ibse.hk/MECH4423/

Building Energy Management

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- Energy management system
- ISO 50001
- Energy information system
- Building energy audits
- Building retrofit

Energy management system

- Energy Management is the process of *monitoring*, *controlling* & *conserving* energy usage in a building or organization
  - Typical steps:
    - Metering energy consumption & collecting the data
    - Identifying opportunities to save energy & estimating how much energy each opportunity could save
    - Taking action to target the opportunities to save energy
    - Track progress by analyzing data to determine the effectiveness of implemented energy-saving measures

Energy management system

- What is energy management system (EnMS)?
  - A system includes:
    - Resources – financial resources, human resource & technology
    - Procedures/Regulations, programs in order to manage & implement activities
  - Scope:
    - Areas related to energy consumption in company
  - Purpose:
    - Provide methods & programmes clearly to implement energy savings in order to achieve planned objectives

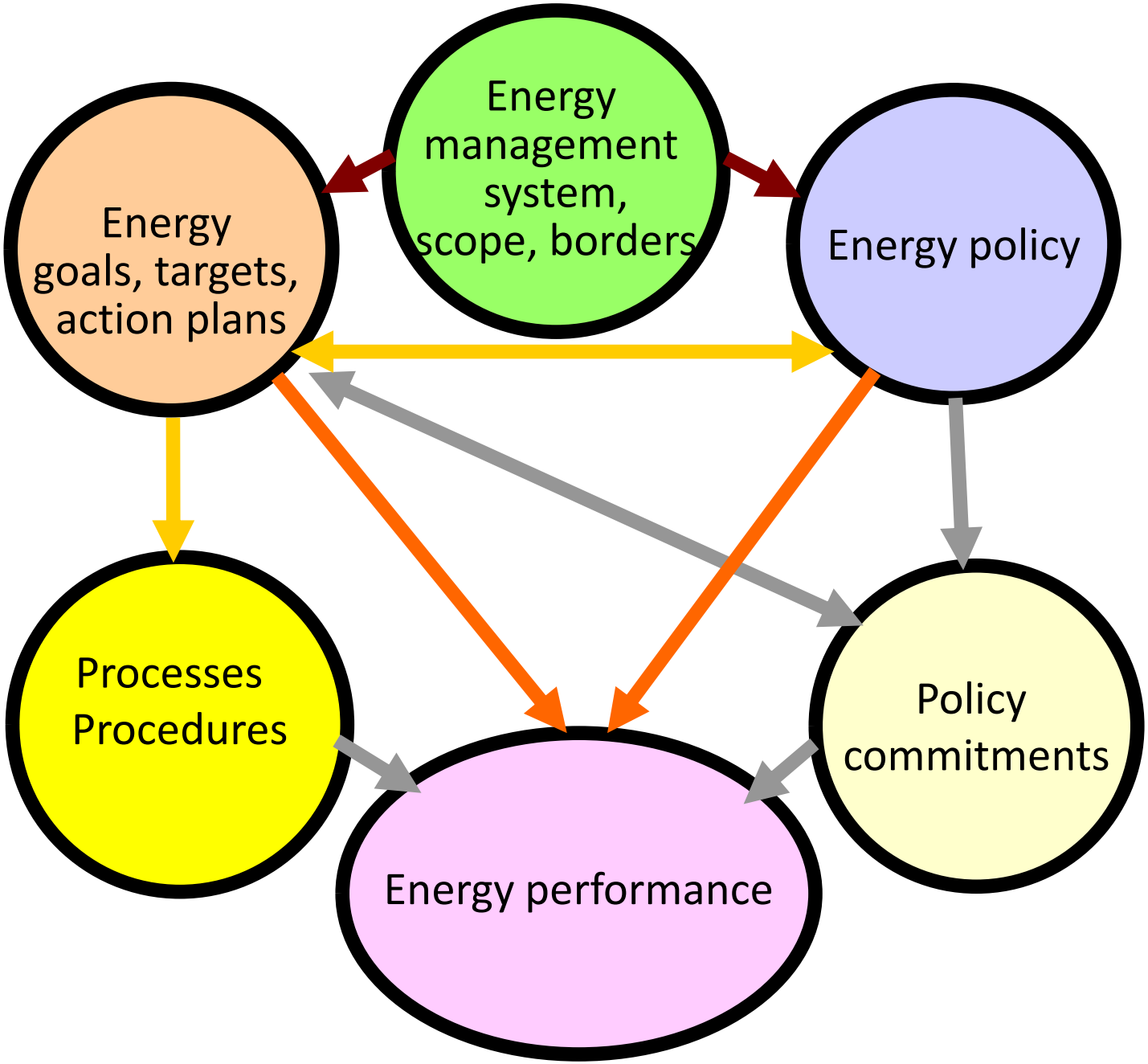
Energy Management Systems (EnMS)

'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

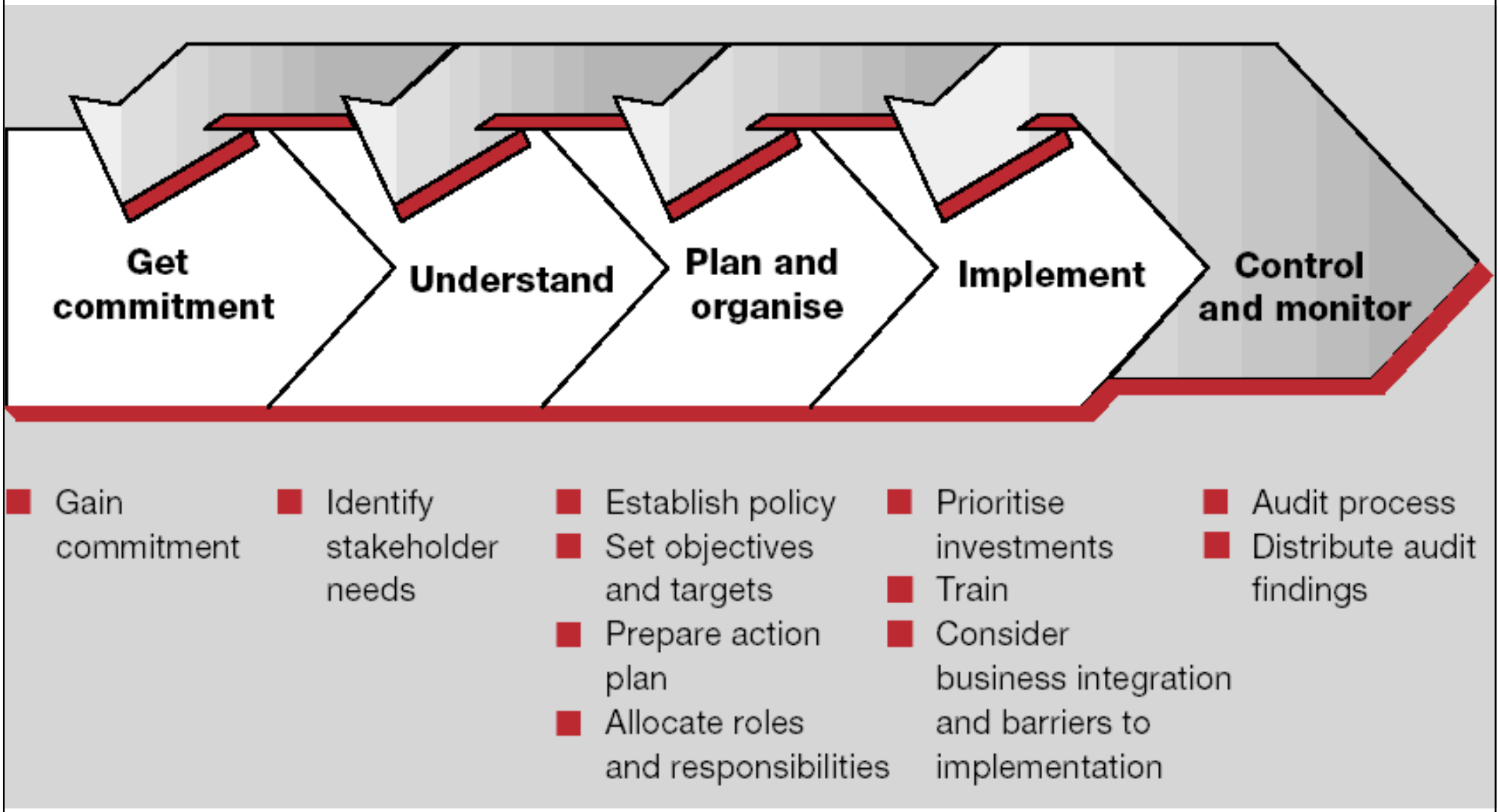
(Source: ISO 50001)

Energy Management Systems logics: focus on energy performance



(Source: ISO 50001)

A systematic approach to energy management



Energy management system

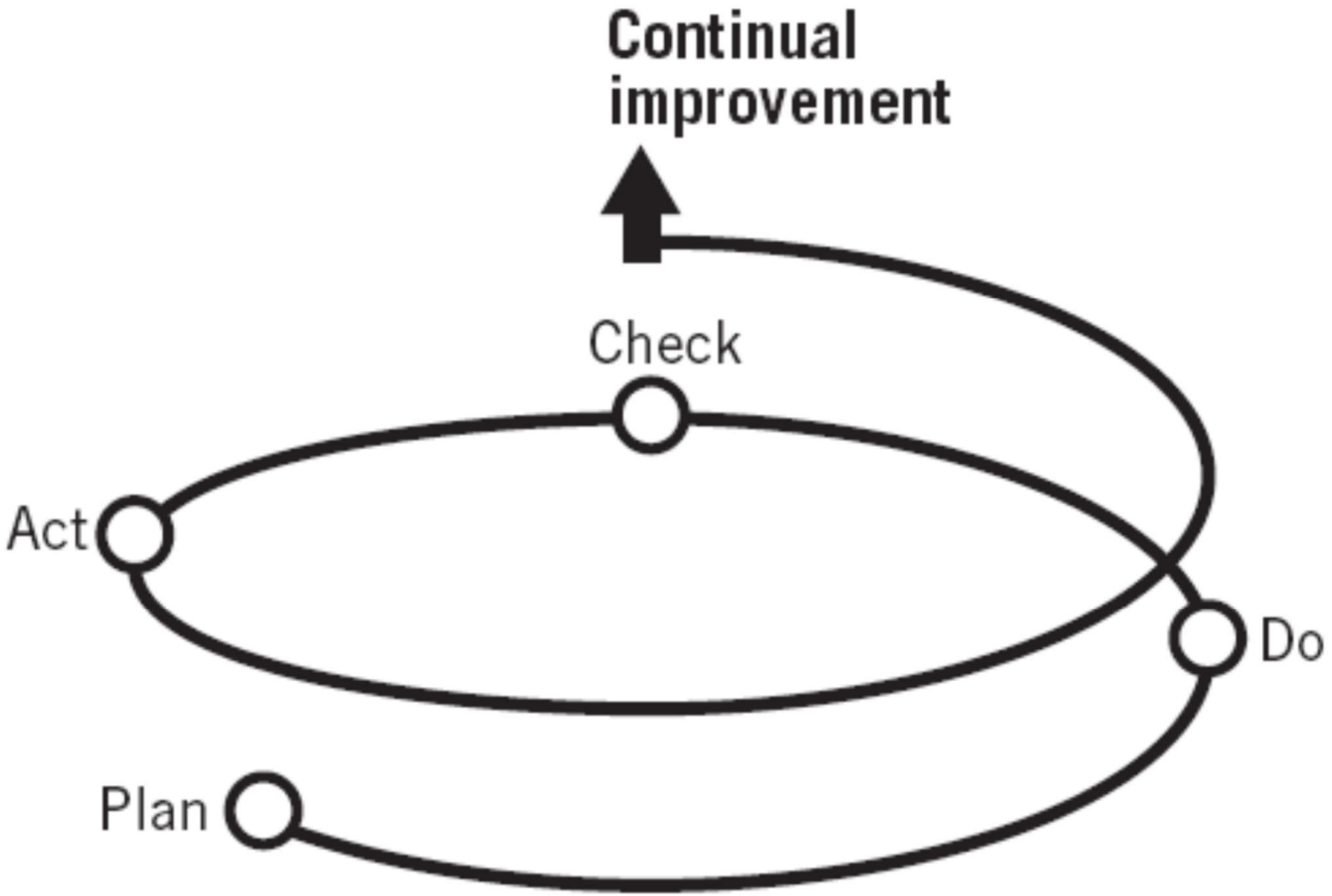
- The energy management system (EnMS) concept builds upon the Plan-Do-Check-Act (PDCA) cycle of management developed by Dr. W. Edward Deming*

- EnMS is a collection of processes, procedures & tools designed to engage staff at all levels within an organization in managing energy use on an ongoing basis

(* See also http://en.wikipedia.org/wiki/W._Edwards_Deming)

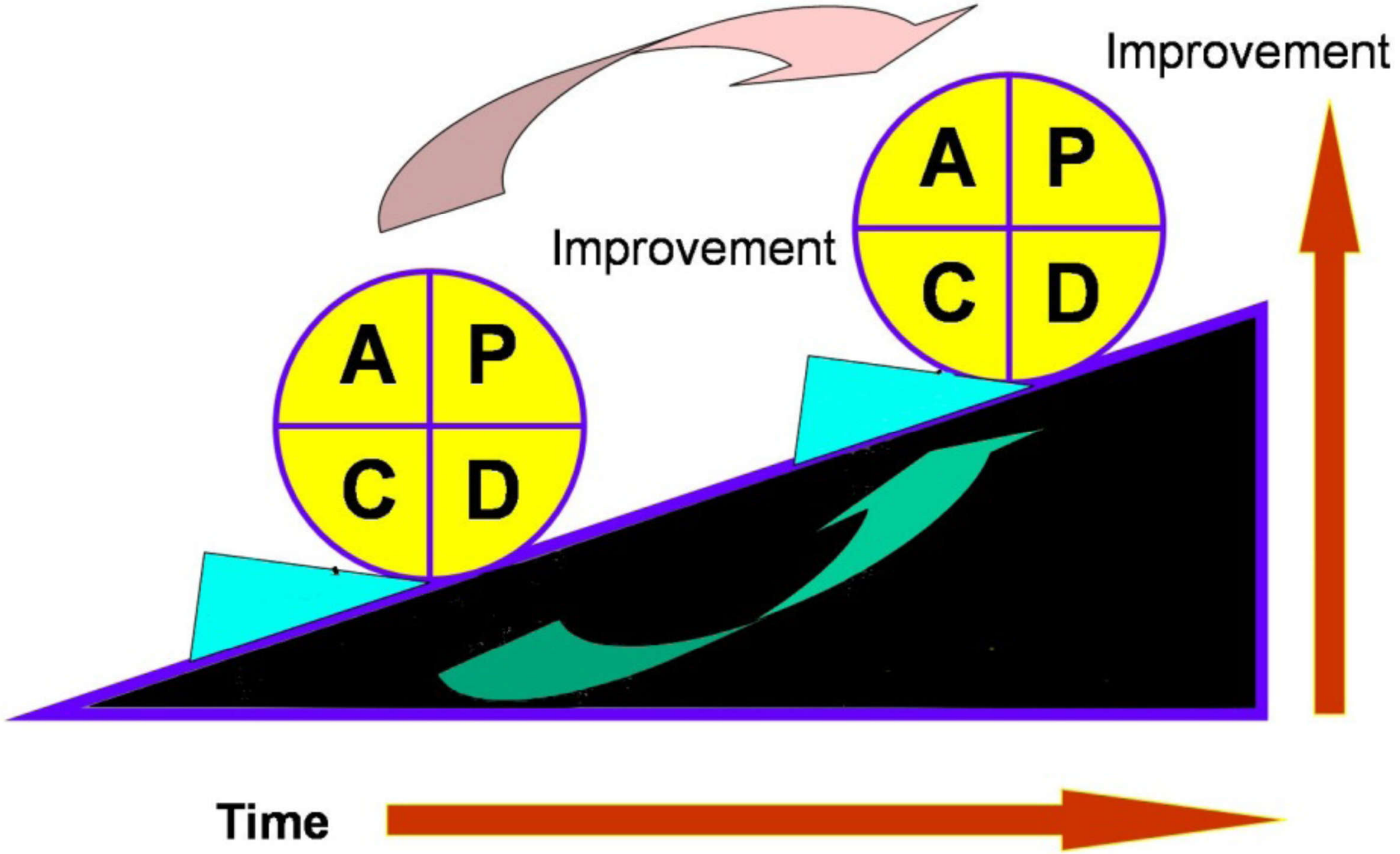
Four steps of the management process (for continual improvement)

Plan-Do-Check-Act (PDCA) cycle



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

Plan-Do-Check-Act cycle for continuous improvement



(Source: ISO 50001)

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 & 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 & targets • Review energy program • Update action plans • Start the cycle anew

ISO 50001:2011 Energy Management Systems

International standard on energy management system, issued in 6/2011
- Integrate with ISO 9001, ISO 14001 & OHSAS 18001
- Improves Energy Performance

International Organization for Standardization

	Countries/Scope	Standard
Old energy management system	Denmark	DS2403:2001
	Sweden	SS627750:2003
	Ireland	IS 393:2005
	Spain	UNE 216301:2007
Present energy management system	UE-27 EN 16001	Effect from 07/2009
	China GB / T 23331-2009	Effect from 11/2009
	United State ANSI/SME 2000	Effect from 2008 From 2010
Future energy management system	World ISO 50001 (from EN 16001)	Issued in 06/2011

STRUCTURE:

1. Scope

2. Normative references

3. Terms and definitions

4. Energy management system requirements

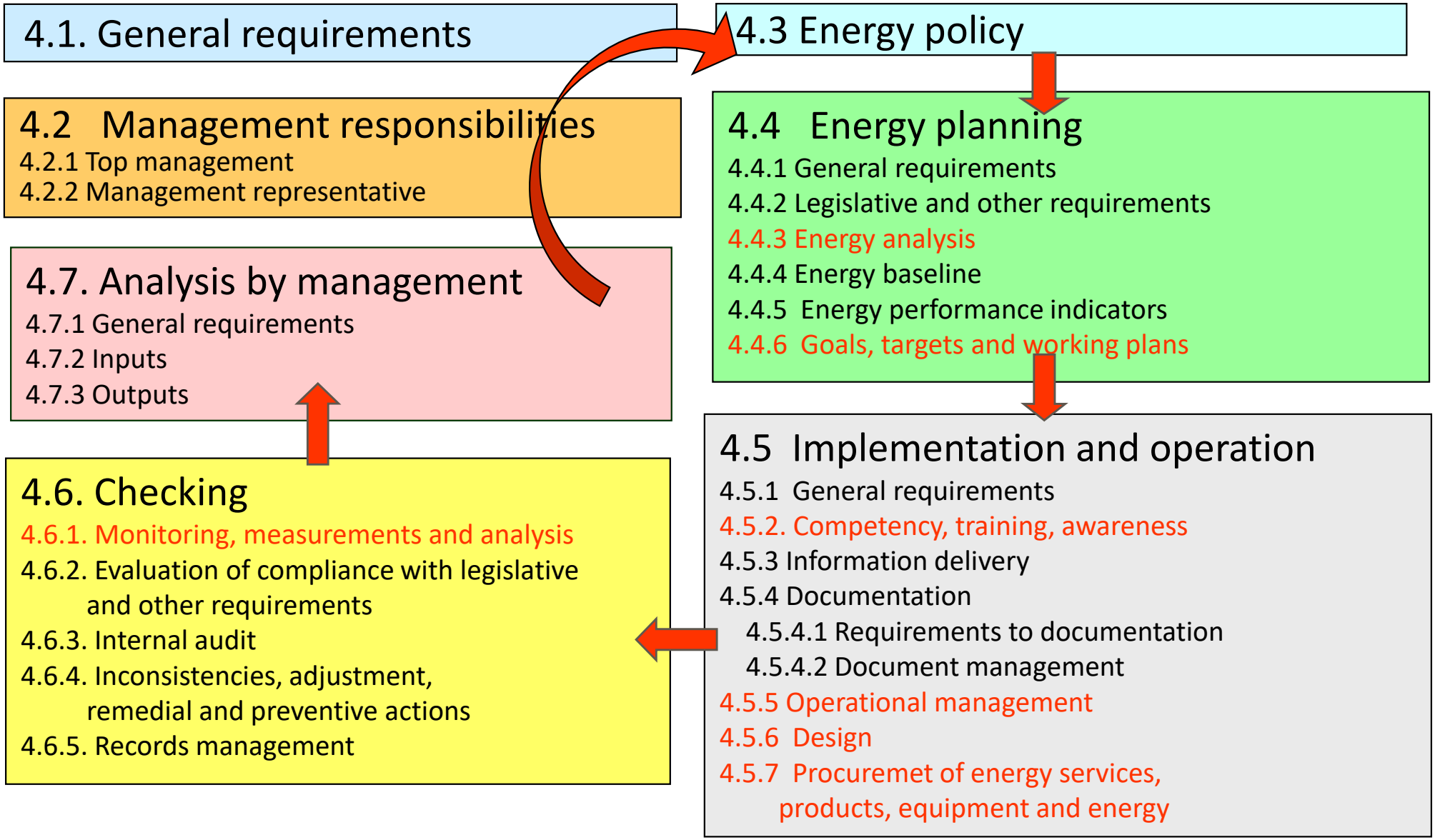
- 4.1. General requirements
- 4.2. Management responsibility
- 4.3. Energy policy
- 4.4. Energy planning
- 4.5. Implementation and operation
- 4.6. Checking
- 4.7. Management review

Annex provide guidance for using standard

(Source: ISO 50001; See also http://en.wikipedia.org/wiki/ISO_50001)

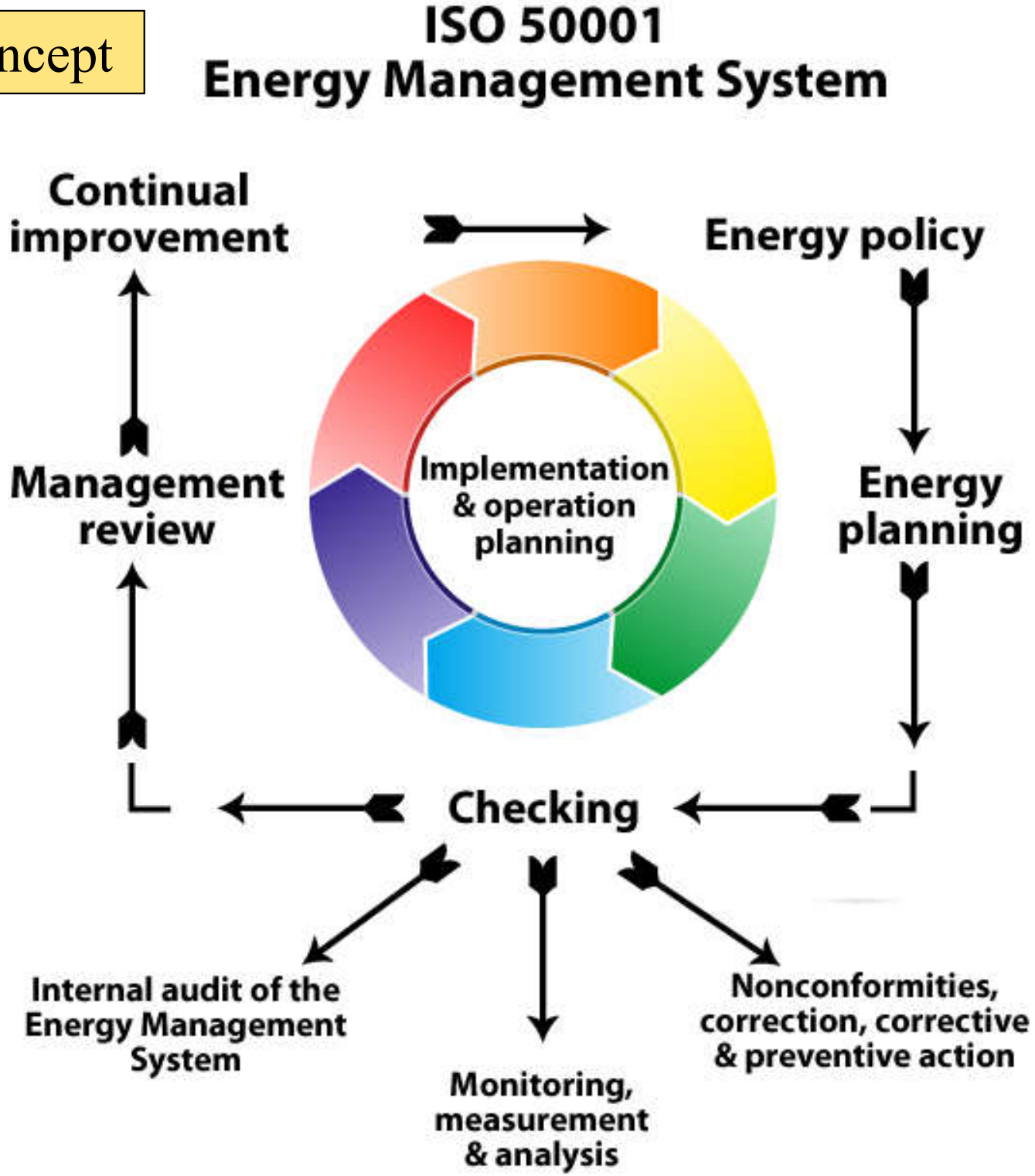
Structure of ISO 50001 requirements: 22 elements

Section 4. Requirements to EnMS



(Source: ISO 50001)

Overall concept



(Source: ISO 50001)

Process for establishing energy management systems

Current assessment

- Energy policy
- Organizational structure
- Motivation
- Measurement/Monitoring
- Communication –Training
- Investment of energy

Design

- Establish energy team
- Train to enhance awareness
- Define energy policy
- Design documentation of energy management system

Deploy

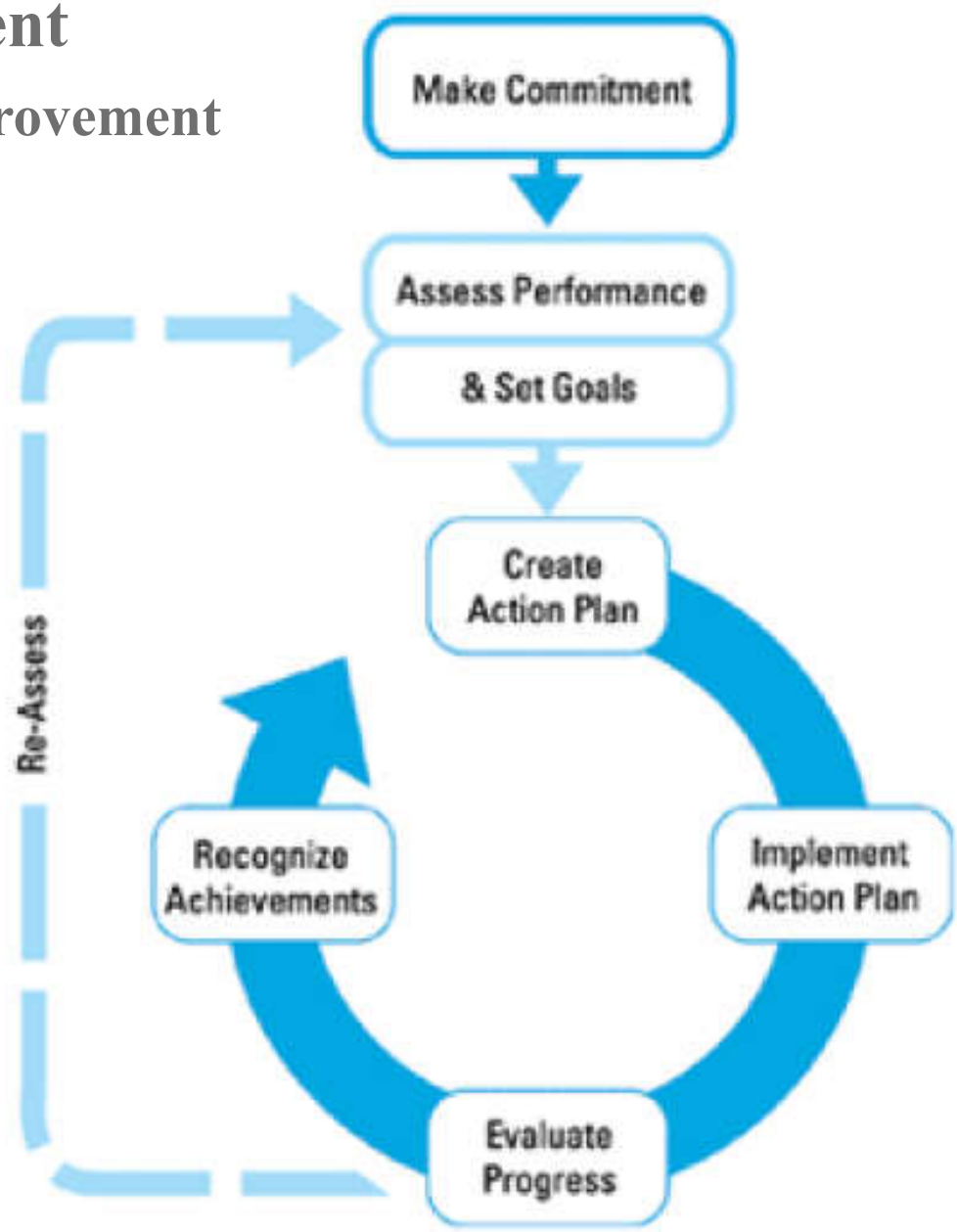
- Identify areas, equipment of significant energy use & parameters need to test
- Monitor & record data of energy consumption
- Conduct energy audit (energy performance, energy savings solution)
- Establish objectives & plan
- Implement plan
- Motivate & communicate energy savings
- Evaluate efficiency of energy management system

(Source: ISO 50001)

Guidelines for energy management from Energy Star Buildings

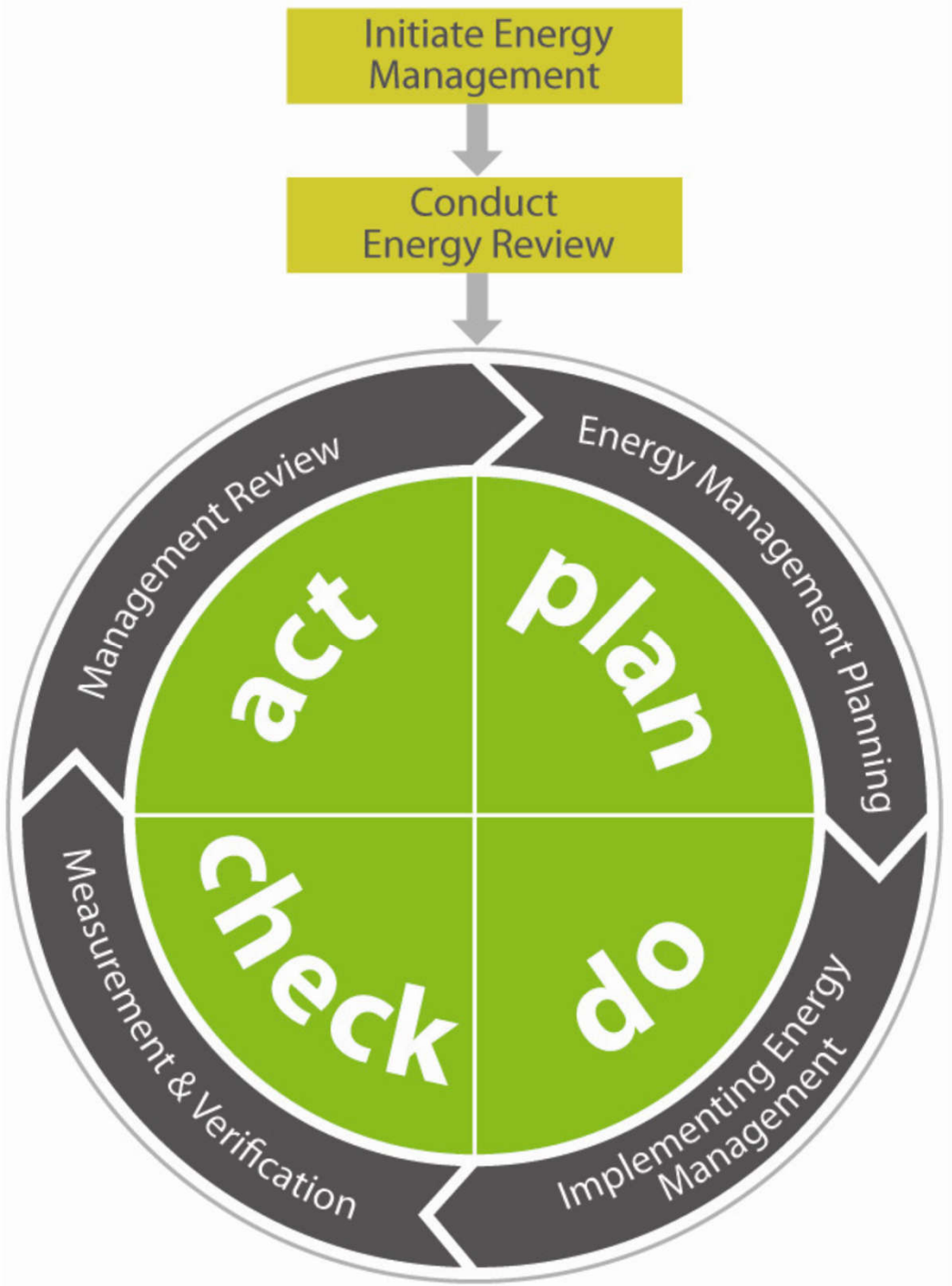
Guidelines for Energy Management

- **STEP 1: Commit to Continuous Improvement**
- **STEP 2: Assess Performance**
- **STEP 3: Set Goals**
- **STEP 4: Create Action Plan**
- **STEP 5: Implement Action Plan**
- **STEP 6: Evaluate Progress**
- **STEP 7: Recognize Achievements**



(Source: Energy Star Buildings https://www.energystar.gov/buildings)

Steps within Energy Management Systems



(Source: ISO 50001)

ISO 50001

- Implement an energy management system
  - 1. Initiating an Energy Management Program: Understanding basic concepts & requirements; getting organization leadership commitment; establishing an energy team; developing an energy policy
  - 2. Conducting an Energy Review: Collecting energy data; analyzing energy consumption & costs; identifying major energy uses; conducting energy assessments; identifying potential opportunities
  - 3. Energy Management Planning: Setting a baseline; determining performance metrics; evaluating opportunities & selecting projects; developing action plans

ISO 50001

- Implement an energy management system (cont'd)
  - 4. Implementing Energy Management: Obtaining resource commitments; providing training & raising awareness; communicating to all stakeholders; executing action plans
  - 5. Measurement and Verification: Including the knowledge & skills required to monitor, measure, verify, track & document energy use & savings
  - 6. Management Review: Reviewing progress; modifying goals & action plans as needed

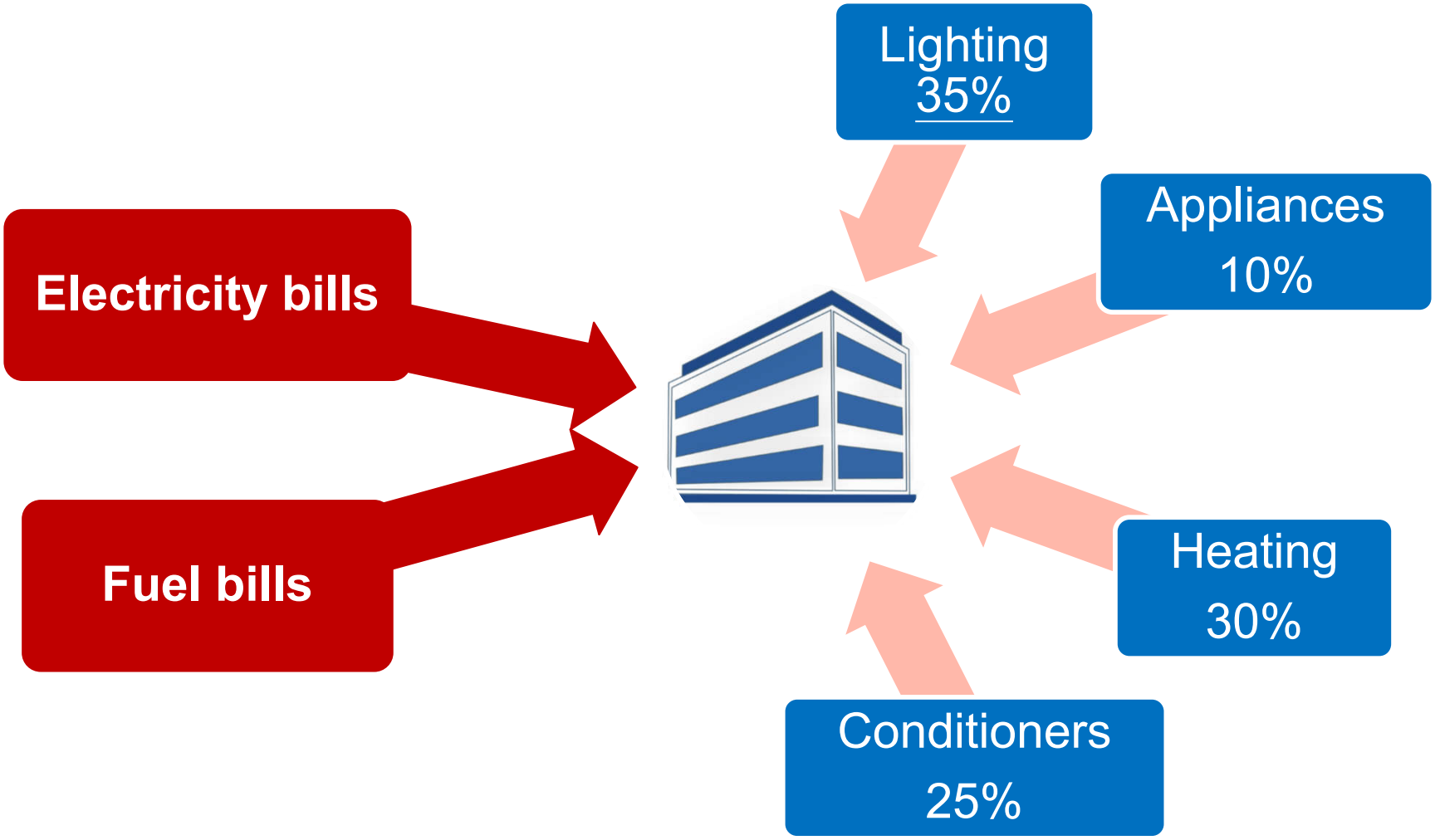
Management commitments & resources

(Source: ISO 50001)

ISO 50001

- Conducting an energy review
  - To assess current situation
  - To understand how the energy is used
  - To calculate energy expenses
  - To determine EnMS priorities
  - To create a basis for decision making

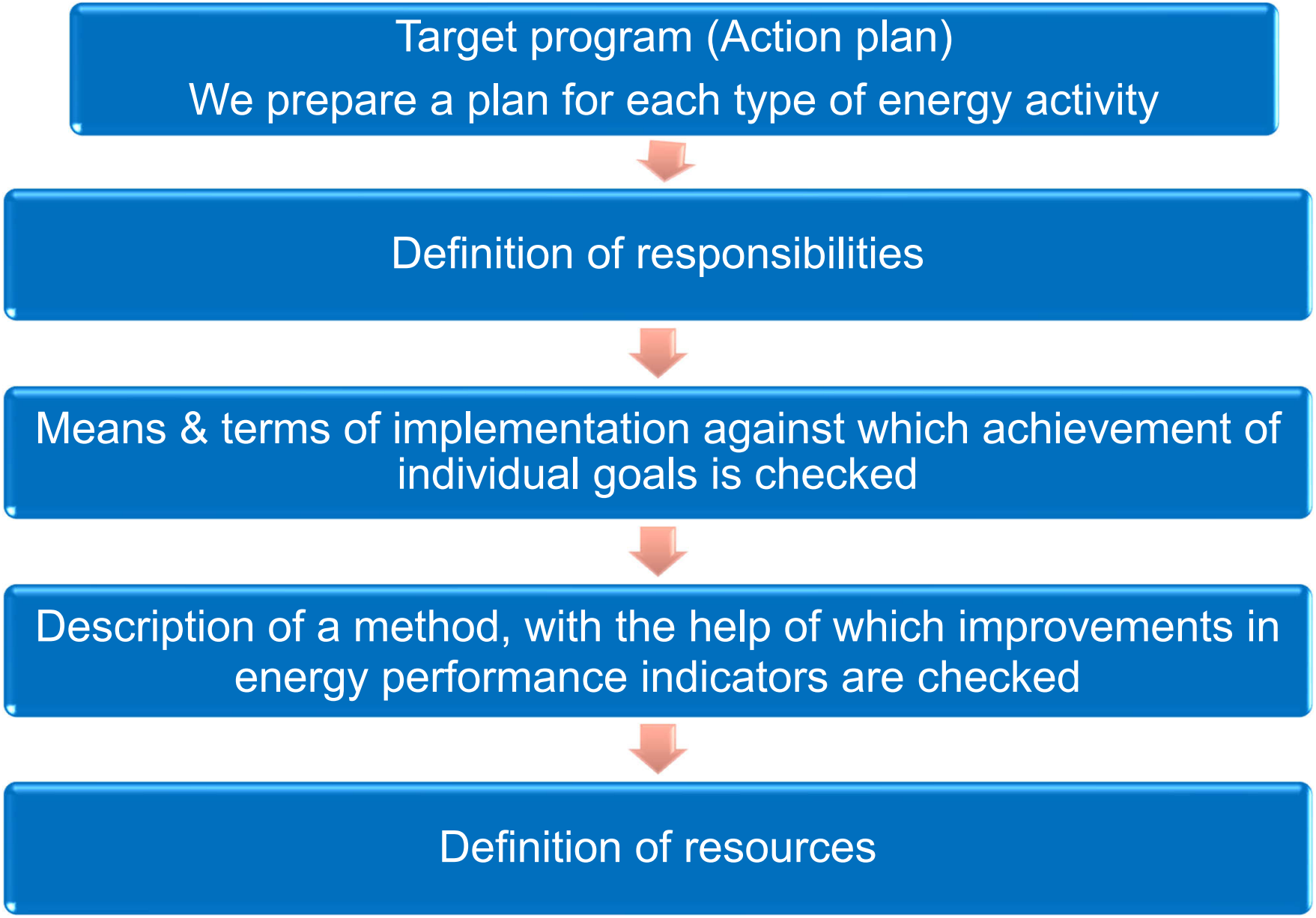
Develop & investigate the “Energy Balance” (or energy profile)



ISO 50001

- Planning (setting goals and targets)
  - Prioritized opportunities
  - Draft action plan
  - Energy efficiency indicators
  - Verification plan
  - Targets for savings
- Verification plan
  - Determine how to measure action plan efficiency

What does Action Plan mean?



ISO 50001

- Implementation & operation
  - Distribution of responsibilities
  - Competency, training of human resources, awareness
  - Documentation
  - Energy manual
  - Control of documentation
  - Management of production
  - Design & procurement

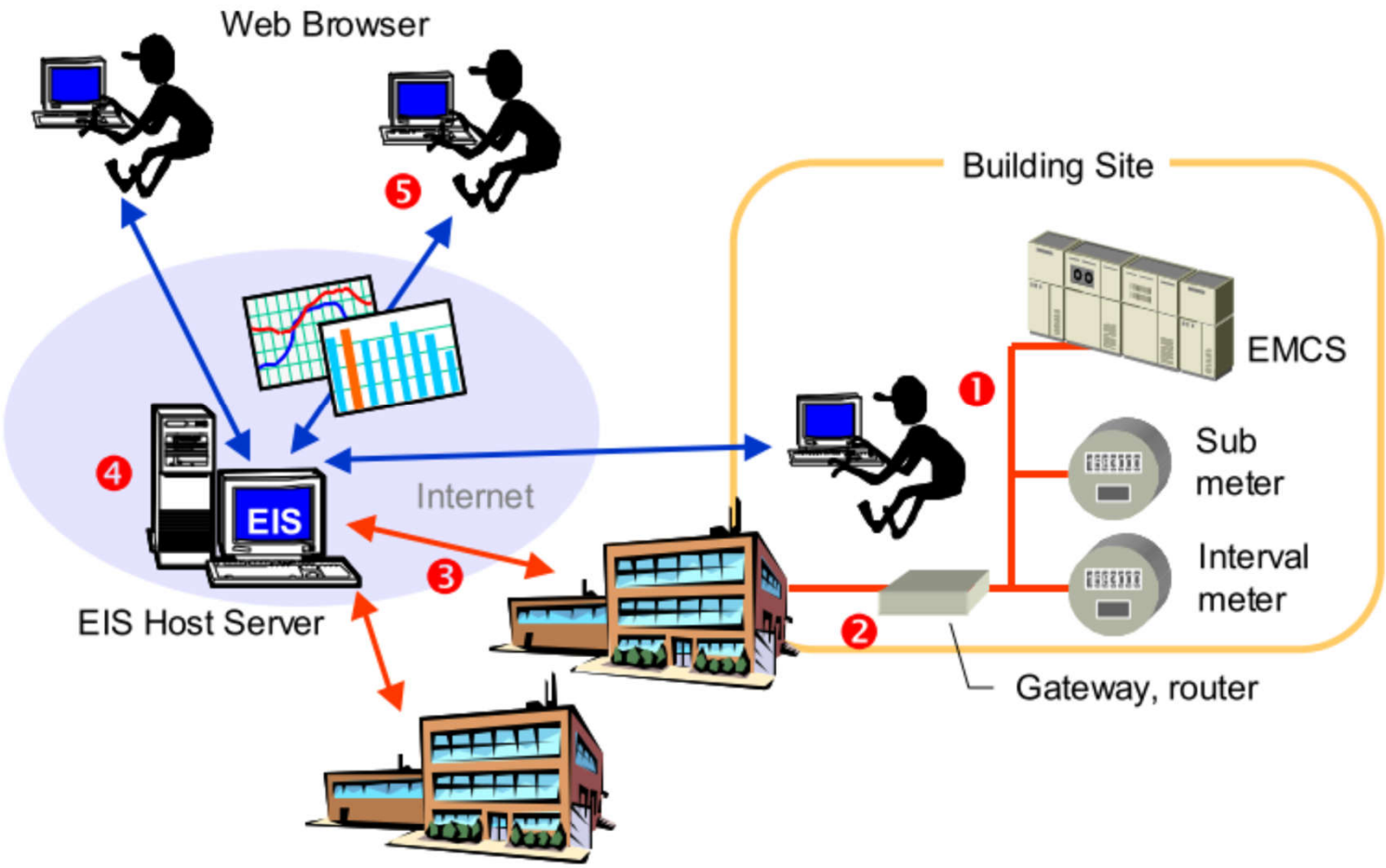
ISO 50001

- Checking
  - Measurements & monitoring
  - Measurements plan
  - Energy audits & plan of their implementation
  - Assessment of compliance
  - Control of reporting
  - Remedial & preventive actions

Energy information system

- Energy Information System (EIS)
  - A system for the collection, analysis & reporting of data relating to energy performance that supports energy management & decision making
  - May be stand-alone, part of an integrated system or a combination of several different systems
  - Typical elements include sensors & instruments, data infrastructure & software tools
    - Such as meters, software, billing data, bldg. info, etc.
    - Include external & internal sources of data

Typical architecture of an energy information system (EIS)



(1) Data are collected at the building

(2) A communication device dispatches data

(3) The data is sent to a database server via Internet.

(4) The database server stores and archives the data

(5) EIS users access the server remotely by a web browser

(Source: Motegi, N., Piette, M. A., Kinney, S. and Dewey, J., 2003. Case studies of energy information systems and related technology: operational practices, costs, and benefits, In *Proceedings of the International Conference for Enhanced Building Operations*, October 13-15, 2003, 10 pages. https://hdl.handle.net/1969.1/5195)

Energy information system

- Basic features of EIS:
  - Monitoring & collection of energy data
  - User-friendly web browser interface accessible from anywhere via Internet
  - Visualization of the time-series data
  - Tools to assist in understanding energy consumption trends & energy saving opportunities

Energy information system

- Possible benefits of EIS:
  - Early detection of poor performance
  - Effective performance reporting
  - Auditing of historical operations
  - Identification & justification of energy projects
  - Evidence of success
  - Support for energy budgeting & management accounting
  - Energy data to other systems

Energy information system

- Latest trends of web-based EIS
  - Energy dashboards & analytics tools
    - Energy data analysis & visualization
    - Actively engage multiple stakeholders
  - Energy dashboard examples:
    - https://www.datapine.com/dashboard-examples-and-templates/energy
    - https://www.fusioncharts.com/demos/dashboards/smart-energy-monitoring-dashboard/
    - https://energy.ubc.ca/energy-and-water-data/ion-system/

An example of energy dashboard for buildings

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

Energy information system

- Data types & sources
  - Consumption
    - Essential for energy & environmental management
    - Electricity & gas; sometimes also water & fuels
    - Through metering & sub-metering
  - Cost $$
    - From tariffs or actual billings
  - Drivers (variables or influencing factors)
    - Any factor that influences energy consumption, e.g. weather & indoor conditions

Energy information system

- Two main types of drivers:
  - *Activity drivers*: features of the organisation's activity, e.g. hours worked, tonnes produced, nos. of guests, opening hours
  - *Condition drivers*: the influence not determined by the activity but by prevailing conditions, e.g. weather (like temperatures)

Energy information system

- Data on driver
  - Activity or production-related drivers
    - From business management info system
    - Such as output volume
  - External climate
    - Such as daily max./min. temperatures, cooling/heating degree days (*DD*) = cumulative number of degrees in a month or year above/below a base temp. (18.3 °C)*

$$DD = (1\,\text{day}) \cdot \sum (t_{outdoor} - t_{base})^{+}$$

(* See also: http://en.wikipedia.org/wiki/Degree_day, http://www.degreedays.net/introduction)

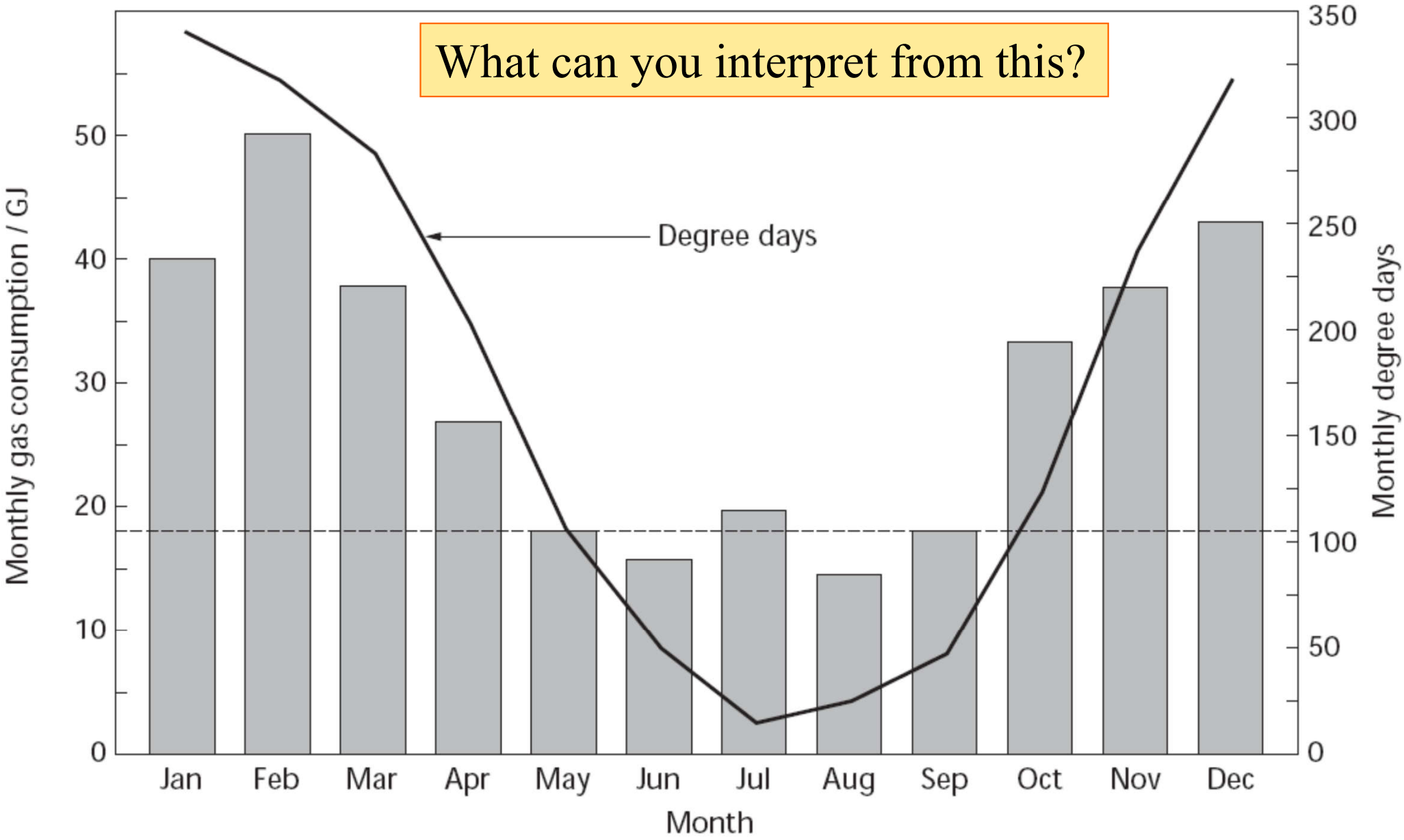
Energy information system

- Cost of data collection (incl. time & money)
  - Meter reading & calibration
  - Software & software support
  - Hardware & hardware support
  - System operators
  - External contracts
- Data quality
  - Good quality data ≠ High accuracy data
  - Must be repeatable & dependable

Energy information system

- "***Unanalysed data is information overload***"
- *Transform* data into information
  - The desired info output will influence which analytical techniques are used
- Two stages of data analysis
  - Stage 1. Looking only at energy
    - Convert meter readings to consumption figures
    - Compare current period with same period previous year
  - Stage 2. The use of energy data & drivers

Histogram of monthly fuel consumption versus degree-days

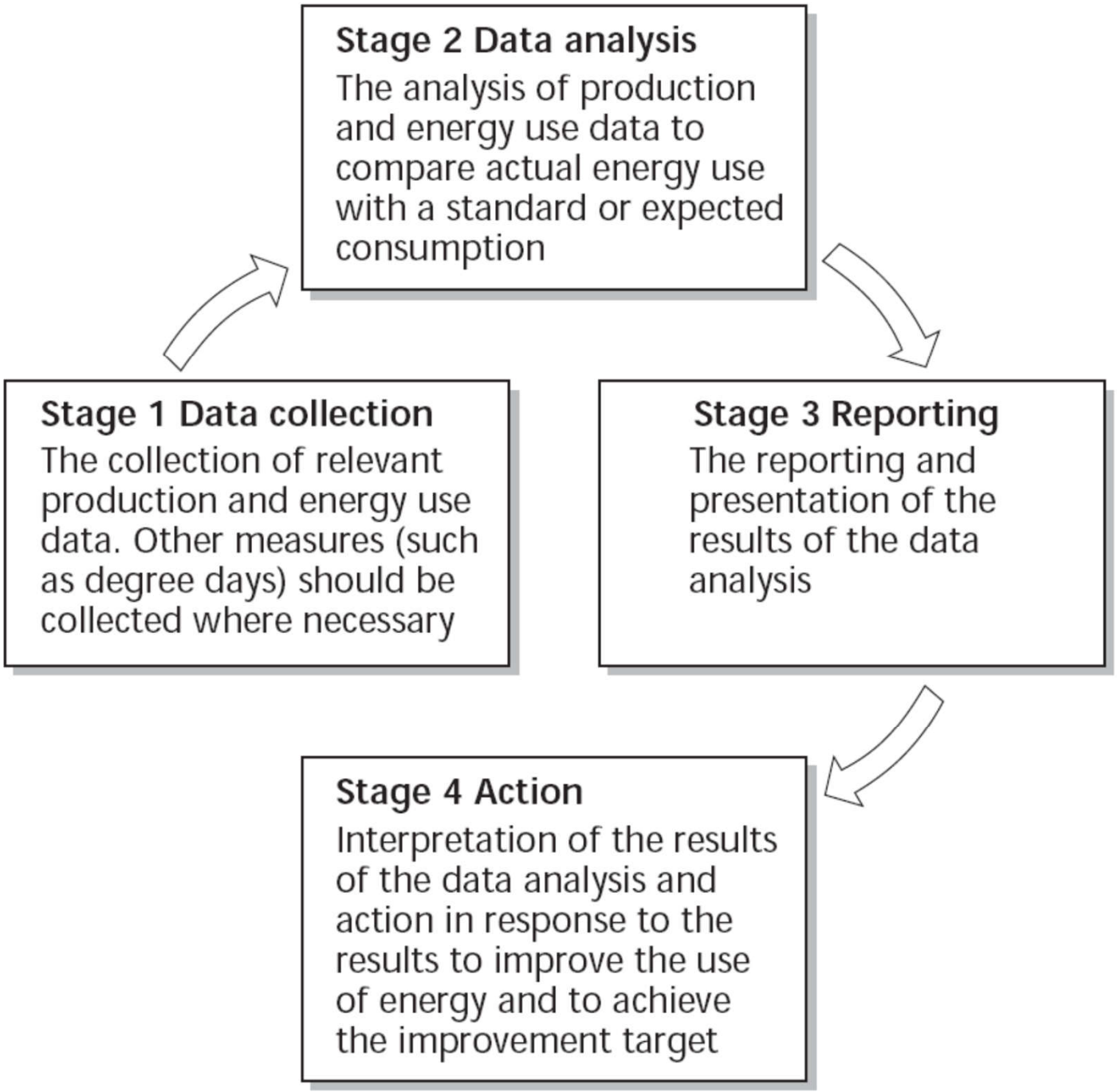


(Source: Energy Efficiency in Buildings: CIBSE Guide F)

Energy information system

- Leading questions, e.g.
  - Why does this (consumption) happen?
  - Should that happen?
  - Is that what we expect?
  - Can we do better?
  - How well do we compare?
  - What are the key influencing factors?
  - How can they be improved?

Monitoring & targeting (M&T) process



(Source: Energy Efficiency in Buildings: CIBSE Guide F)

Building energy audits

- What is Energy Audit (能源審核)?
  - Examination of an energy system or equipment to ensure that energy is being used *efficiently*
    - Process to check for areas of *inefficiency*
  - It is a top-down initiative. Its result depends on the resources being allocated by top management
  - Aims to identify energy management opportunities (**EMO**) & means for improvement
  - In many ways, an energy audit is similar to financial accounting & auditing

Building energy audits

- Overview of energy audit
  - Collection & analysis of relevant information that may affect building energy consumption
  - Review the information, analyse the conditions & performances of existing equipment, systems & installations, & the energy bills
  - Compare with performances at relevant energy efficient modes of operation
  - Identify areas of energy inefficiency & the means for improvement

Building energy audits

- Benefits of energy audit
  - Financial
    - Reduce energy & other running costs
    - Reduce maintenance costs
  - Operational
    - Improve building management
    - Increase productivity via improved working conditions
  - Environmental
    - Reduce CO_2 emission & conserve resources

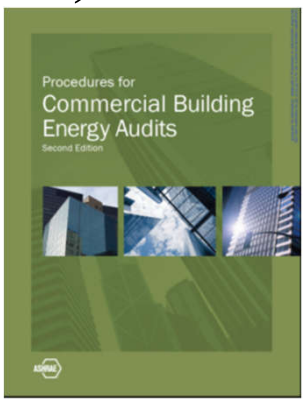
Building energy audits

- Auditing steps: (* see also HK Energy Audit Code)
  - Step 1 – Collection of Building Information
  - Step 2 – Review of Energy Consuming Equipment
  - Step 3 – Identification of EMO
  - Step 4 – Cost Benefit Analysis of EMO
  - Step 5 – Recommendations
  - Step 6 – Compiling Energy Audit Report

(* HK Energy Audit Code https://www.emsd.gov.hk/beeo/en/pee/EAC_2021.pdf)

Building energy audits

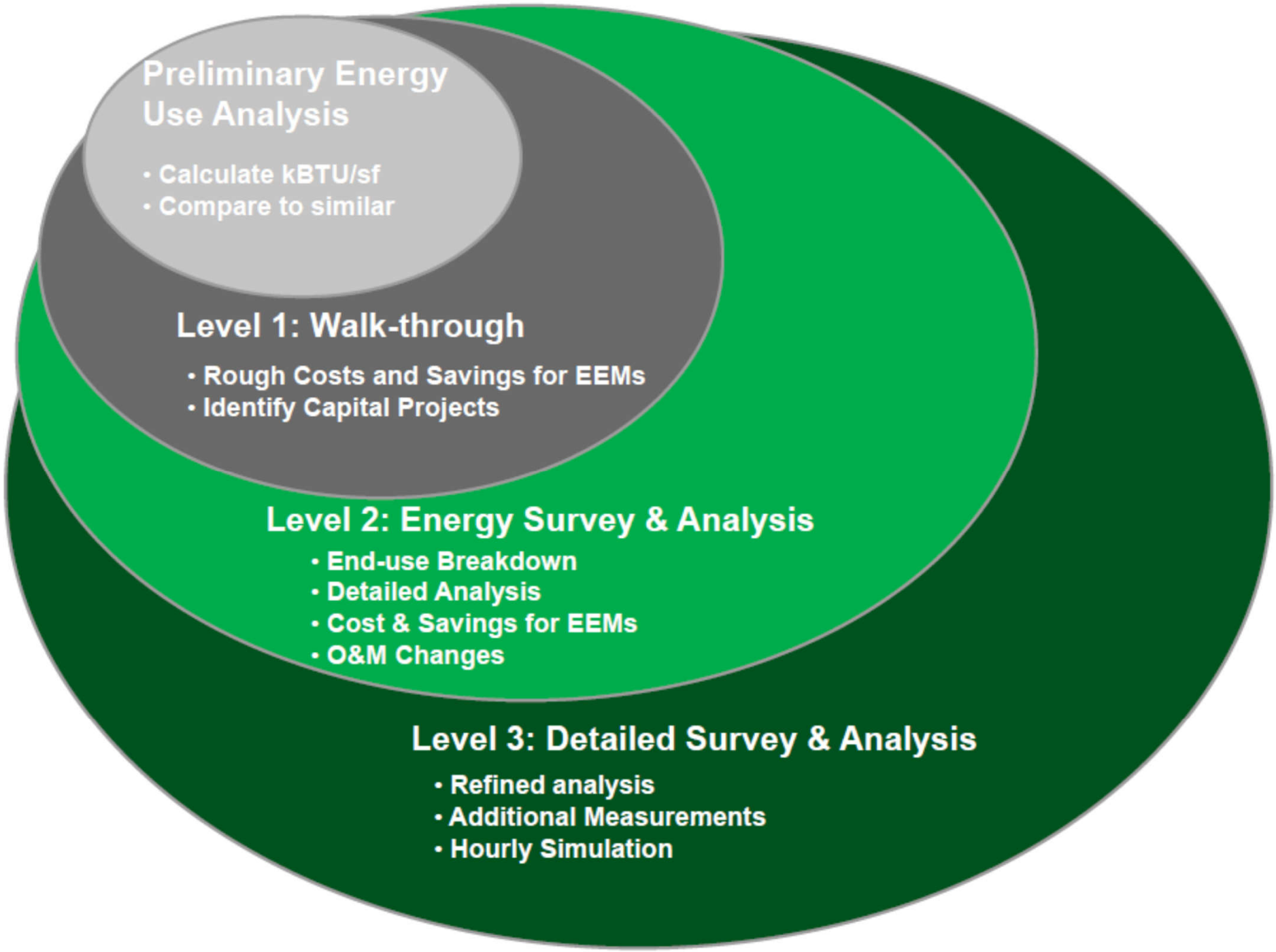
- Levels of effort of energy audit (ASHRAE)*
  - Preliminary Energy-Use Analysis (PEA)
  - Level 1 – Walk-Through Analysis
  - Level 2 – Energy Survey and Analysis
  - Level 3 – Detailed Analysis of Capital-Intensive Modifications



- Also, Targeted Audits (of a specific system or end use, e.g. the chiller plant)

(* Source: ASHRAE 2011. *Procedures for Commercial Building Energy Audits*, Second Edition)

Relationship of energy audit levels 1, 2 & 3



(Source: ASHRAE 2011. *Procedures for Commercial Building Energy Audits*, Second Edition)

Energy audit level summary: Process

Process	Level		
	1	2	3
Conduct Preliminary Energy Analysis (PEA)	●	●	●
Conduct walk-through survey	●	●	●
Identify low-cost/no-cost recommendations	●	●	●
Identify capital improvements	●	●	●
Review M&E design, condition and O&M practices		●	●
Measure key parameters		●	●
Analyse capital measures (savings & costs including interaction)		●	●
Meet with owner/operators to review recommendations		●	●
Conduct additional testing/monitoring			●
Perform detailed system modeling			●
Provided schematic layouts for recommendations			●

(Source: ASHRAE 2011. *Procedures for Commercial Building Energy Audits*, Second Edition)

Energy audit level summary: Report

Report	Level		
	1	2	3
Estimate savings from utility rate change	●	●	●
Compare EUI (energy use index) to that of similar sites	●	●	●
Summarize utility data	●	●	●
Estimate savings if EUI met target	●	●	●
Estimate low/cost / no-cost savings		●	●
Perform detailed end-use breakdown		●	●
Estimate capital project costs & savings		●	●
Complete building description & equipment inventory		●	●
General description of considered measures		●	●
Recommended M&V (measuremt. & verification) method		●	●
Financial analysis of recommended EMOs		●	●
Detailed description of recommended measures			●
Detailed EMO cost estimates			●

(Source: ASHRAE 2011. *Procedures for Commercial Building Energy Audits*, Second Edition)

Example of EMO summary table

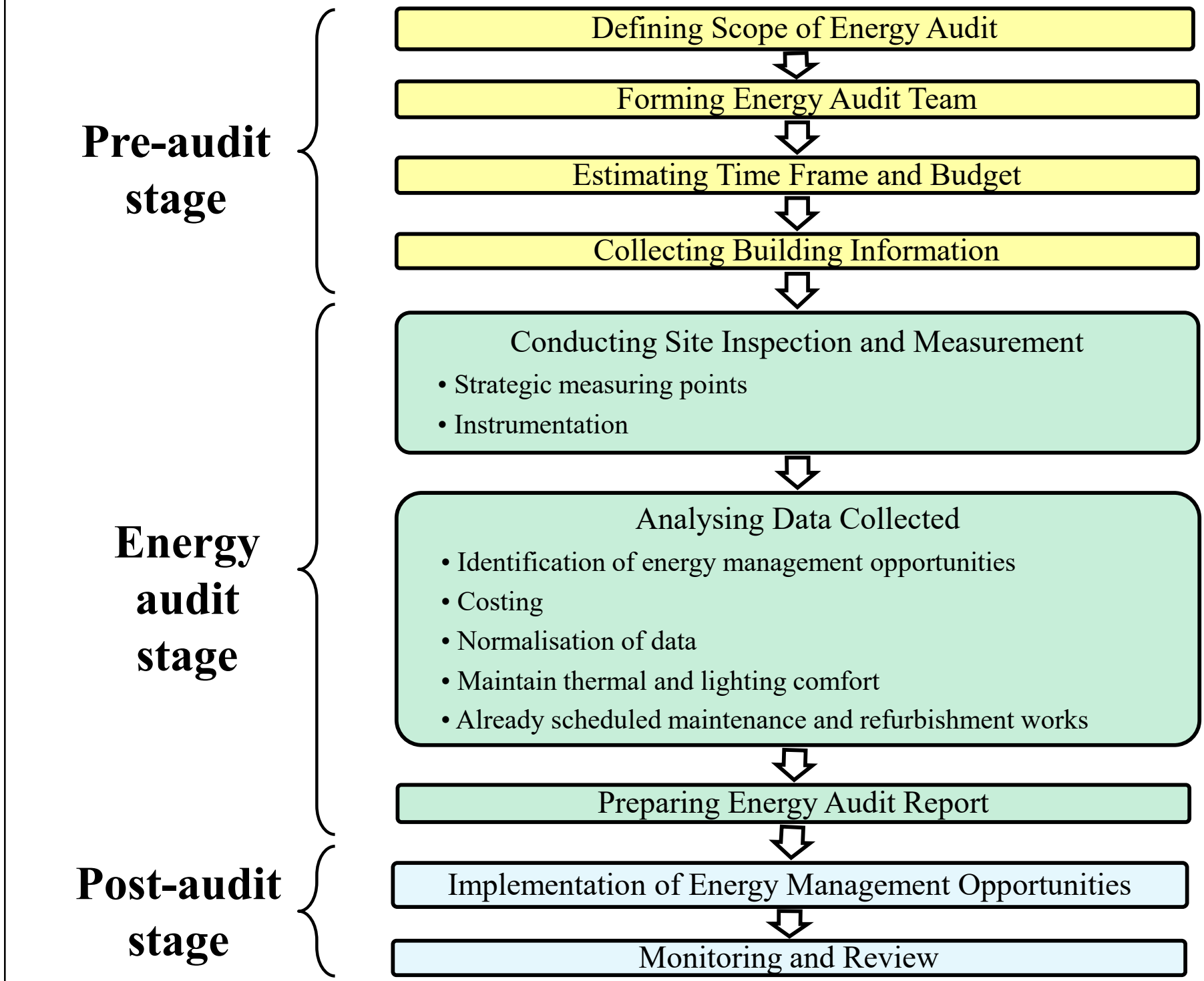
Measure Number	Measure Description	Annual Energy and Cost Savings					Payback with Incentive				
		Peak Savings (kW)	Electricity Savings (kWh)	Gas Savings (therms)	Total Cost Savings	CO_2 Savings (tons)	Measure Cost	Potential WG&E Incentive	Net Measure Cost	MIRR	Simple Payback (yr)
	Lighting Measures										
EEM-1	Reduce Garage Lighting to Half Overnight	0.0	34,465	0	$ 3,447	18.9	$ 750	$ 375	$ 375	27%	0.1
EEM-2	Install Photocell To Control Lobby Lights	1.4	4,047	0	$ 405	2.2	$ 2,047	$ 503	$ 1,544	7%	3.8
EEM-3	Install Photocell to Control Outdoor Lights and Schedule	0.0	15,257	0	$ 1,526	8.4	$ 1,795	$ 897	$ 897	17%	0.6
EEM-4	Re-Commission Lighting Controls	0.0	109,102	0	$ 10,910	59.9	$ 9,720	$ 4,860	$ 4,860	19%	0.4
EEM-5	Install Bi-Level LED Fixtures in Garage	6.3	84,765	0	$ 8,476	46.5	$ 7,127	$ 8,257	$ 88,870	6%	10.5
	Kitchen Measures										
EEM-6	Kitchen Hood and Fan Upgrade:	0.0	138,763	5,989	$ 18,668	111.2	$ 33,085	$ 13,800	$ 19,285	17%	1.0
EEM-7	Install Controls to Schedule Two Pan Chillers in Servery	0.0	9,907	0	$ 991	5.4	$ 1,400	$ 700	$ 700	16%	0.7
EEM-8	Kitchen AC-5 - Expand Outside Air Intake Area	2.2	5,192	0	$ 519	2.9	$ 1,464	$ 689	$ 775	15%	1.5
EEM-9	Install Controls to Schedule Temperature Setbacks for Kitchen AC-5	0.0	1,010	907	$ 827	5.9	$ 1,000	$ 500	$ 500	17%	0.6
	Main Air Handler Measures (Occupied Hours Only)										
EEM-10	Repair Economizers and Convert to Dry Bulb Temperature Control	0.0	155,576	0	$ 5,558	85.4	$ 25,089	$ 12,542	$ 12,542	15%	0.8
EEM-11	Supply Air Temperature Optimization and Duct Static Pressure Reset	1.4	178,563	0	$ 7,856	98.1	$ 18,506	$ 9,253	$ 9,253	18%	0.5
EEM-12	Install VFDs on Exhaust Fans	(4.7)	31,858	0	$ 3,186	17.5	$ 33,853	$ 2,396	$ 31,456	6%	9.9
	SUB-TOTALS	**6.5**	**768,505**	**6,896**	**$ 2,368**	**462.3**	**$ 225,830**	**$ 54,772**	**$ 171,058**	**12%**	**2.1**
TOTALS (Recommended Measures)		**6.5**	**768,505**	**6,896**	**$ 82,368**	**462.3**	**$ 225,830**	**$ 54,772**	**$ 171,058**	**12%**	**2.1**

(Source: www.kw-engineering.com)

Building energy audits

- Energy audits can be carried out by
  - Building manager or internal staff (in-house)
  - External consultant or professionals
- Typical stages of energy audit:
  - 1. Pre-audit stage
  - 2. Energy audit stage
  - 3. Post-audit stage

Procedure of energy audit



Instruments for energy audit & measurements

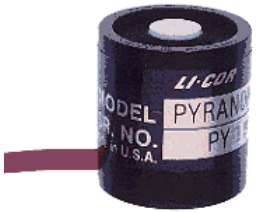
Anenometer

Luxmeter

Infrared thermometer

Sling psychrometer

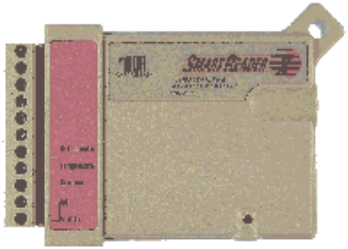
Temp. logger



Pyranometer

Clamp-on ammeter

Multimeter



Temp + RH logger

Infrared camera

Typical structure of an energy audit report

Executive Summary

- Overview of the audit, EMOs identified
- Recommended actions, briefing on implementation plan

Introduction and Building Information

- Objectives, energy audit scope, audit team
- Building characteristics (type, floor areas, operation)

Description of the Equipment/Systems Audited

- System types, capacity ratings, zoning, operation hours etc.

Energy Data and Survey Findings

- Historical energy consumption of the building
- System performance evaluation, O&M practices

Energy Management Opportunities

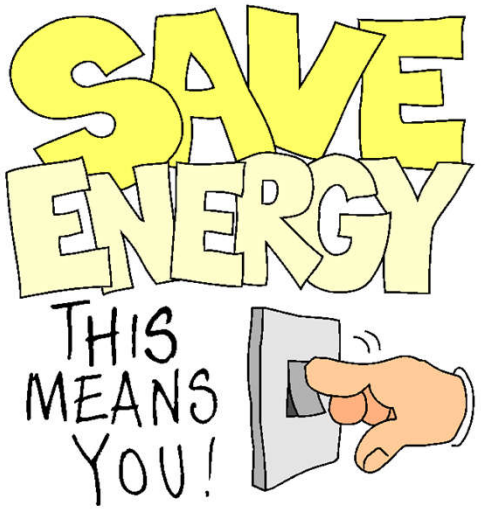
- Identification & evaluation of potential EMOs
- List of recommended EMOs and implementation plan

Conclusions and Recommendations

Assessing the costs & benefits

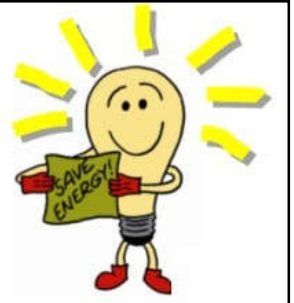
- **Benefits**:
  - direct energy savings
  - indirect energy savings
  - comfort/productivity increases
  - operating & maintenance cost reductions
  - environmental impact reduction
  - O&M savings

- **Costs**:
  - direct implementation costs
  - direct energy costs
  - indirect energy costs
  - O&M cost increase



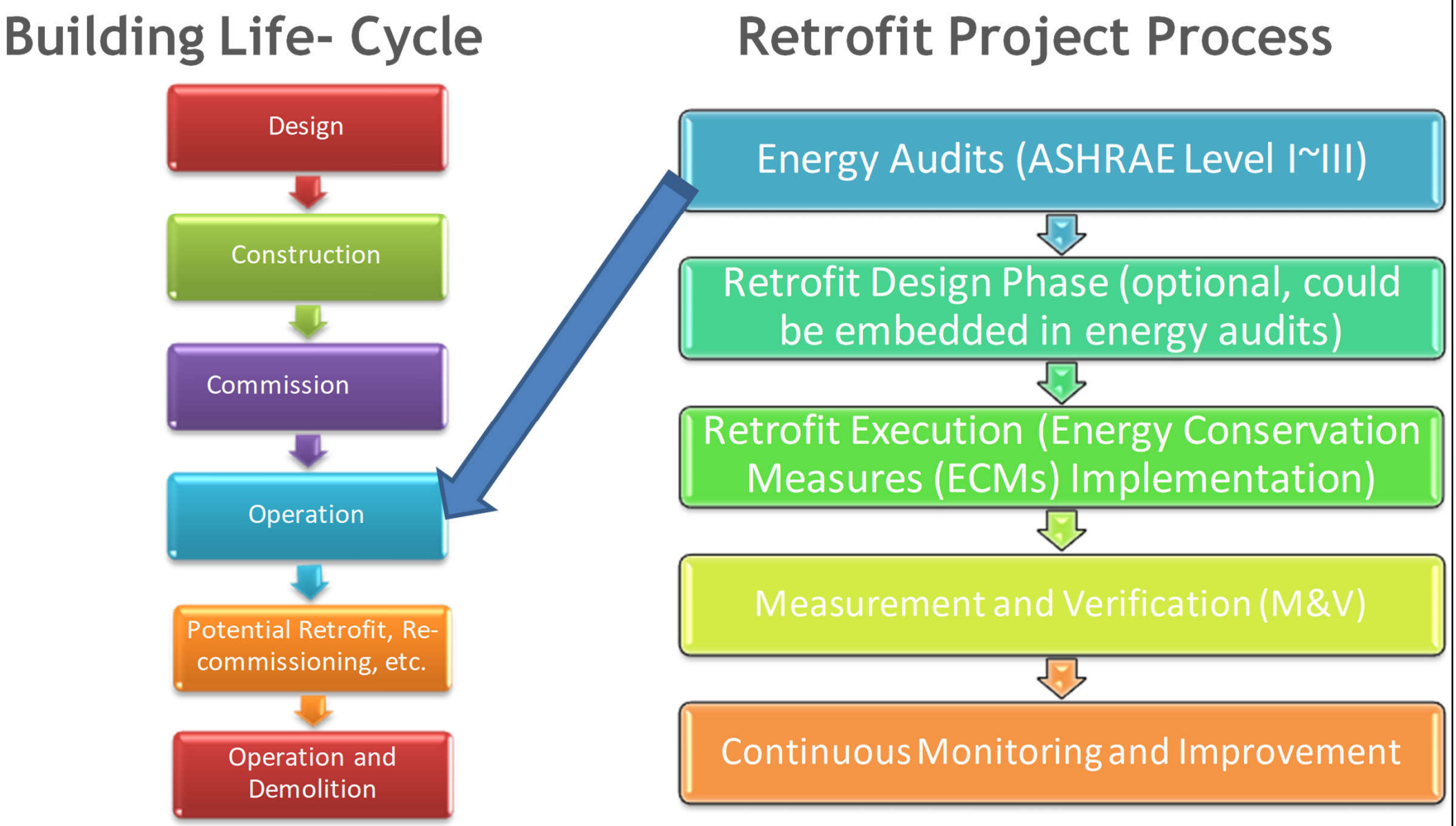
(Source: Department of Minerals and Energy, South Africa)

Building energy audits



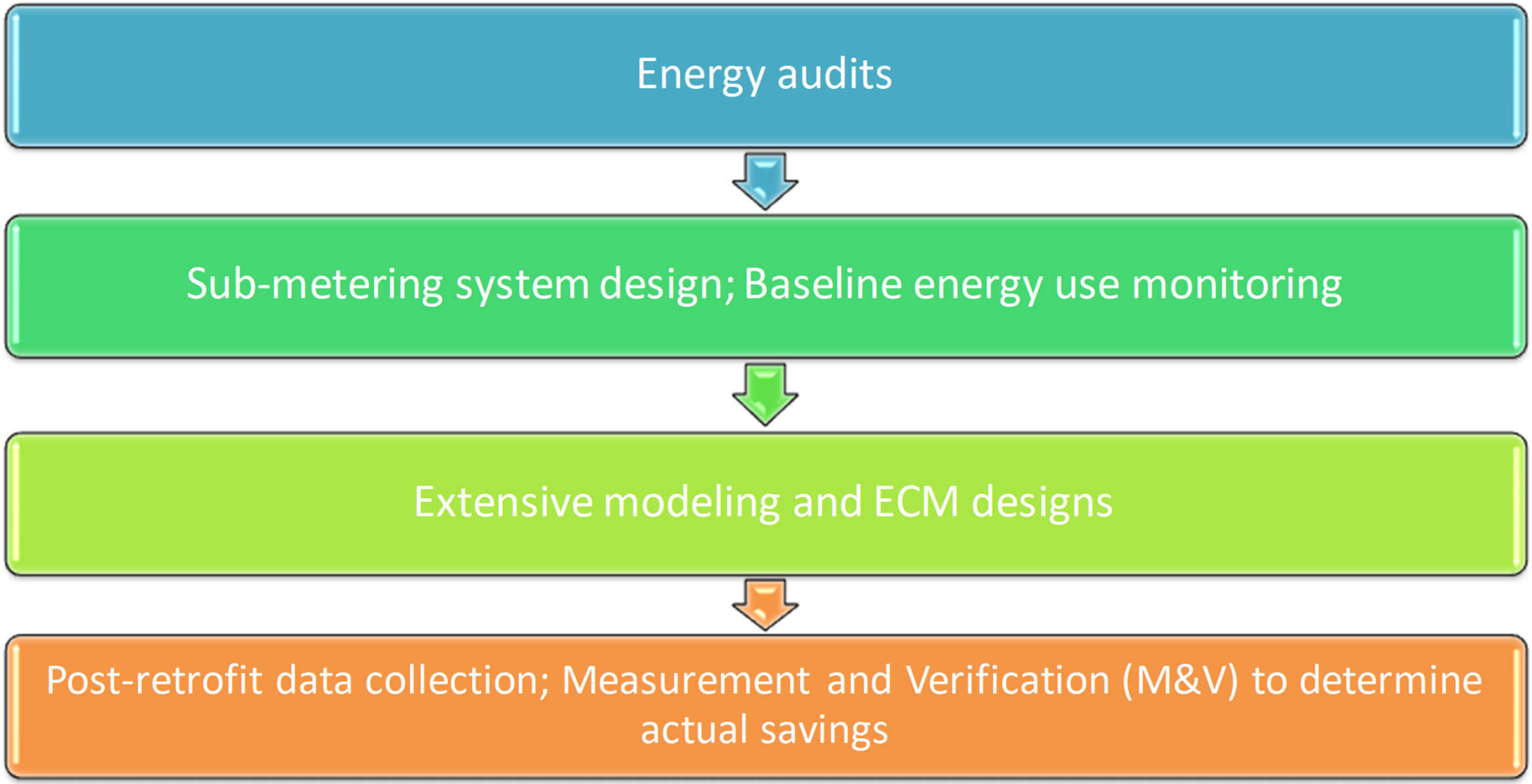
- Three categories of EMOs:
  - ***Category I (no cost)***: "Low-hanging fruit"
    - Housekeeping measures which are improvements with practically no cost investment & no disruption to building operation
  - ***Category II (low cost)***:
    - Changes in operation measures with relatively low cost investment
  - ***Category III (high cost)***:
    - Relatively higher capital cost investment to attain efficient use of energy

Building life cycle & building retrofit process



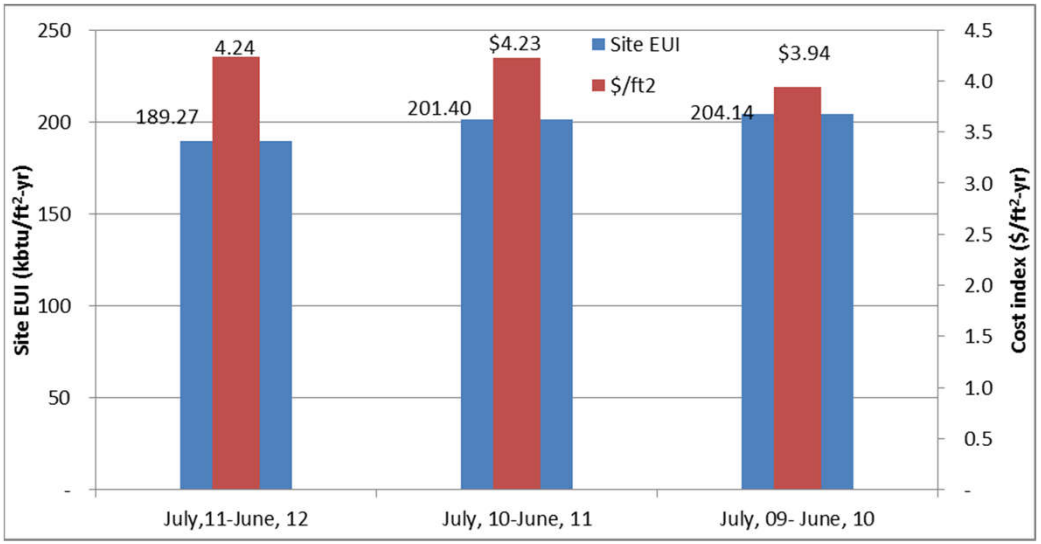
[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

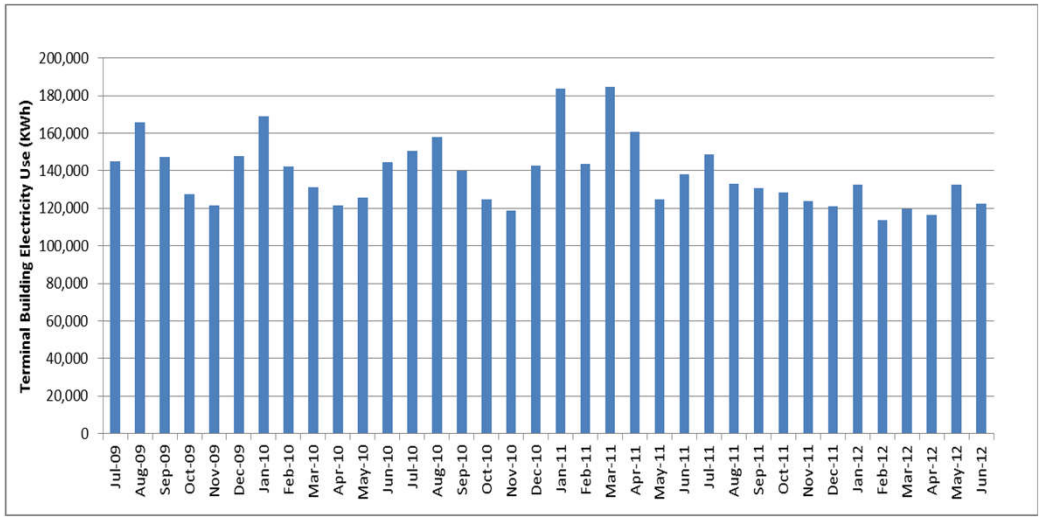
Various stages of building retrofit

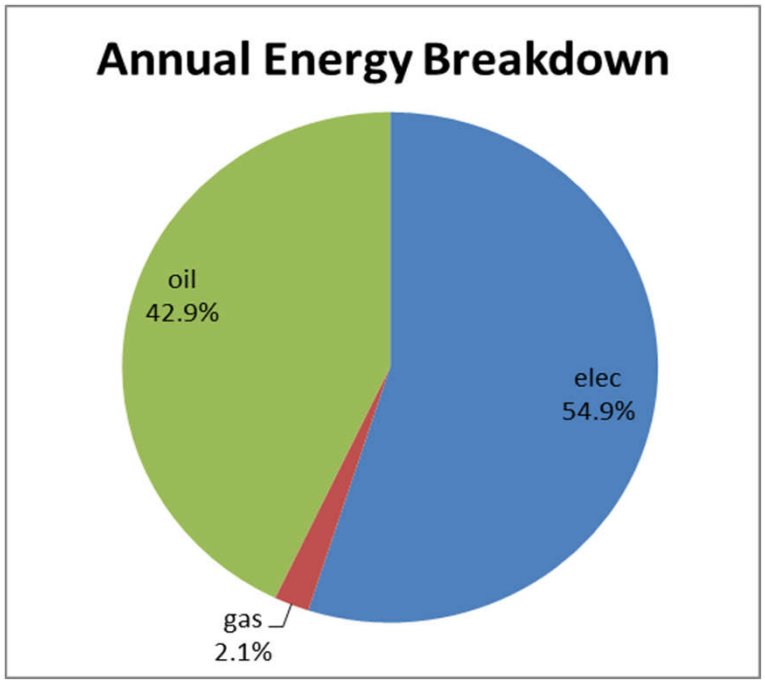


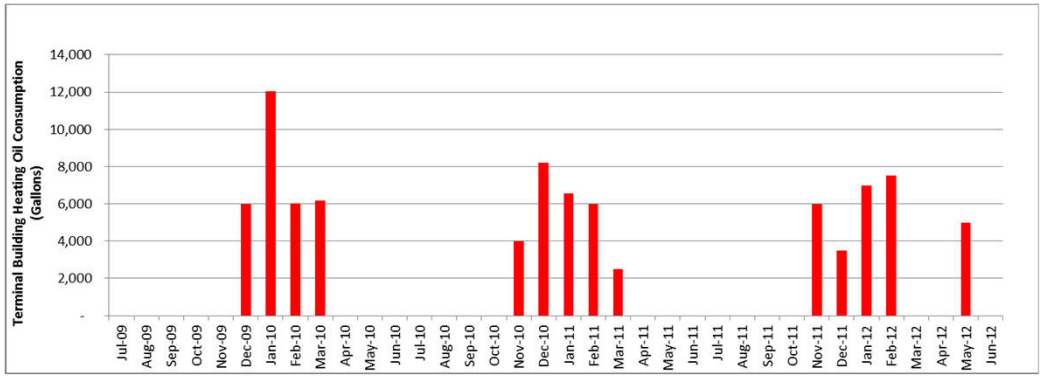
[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

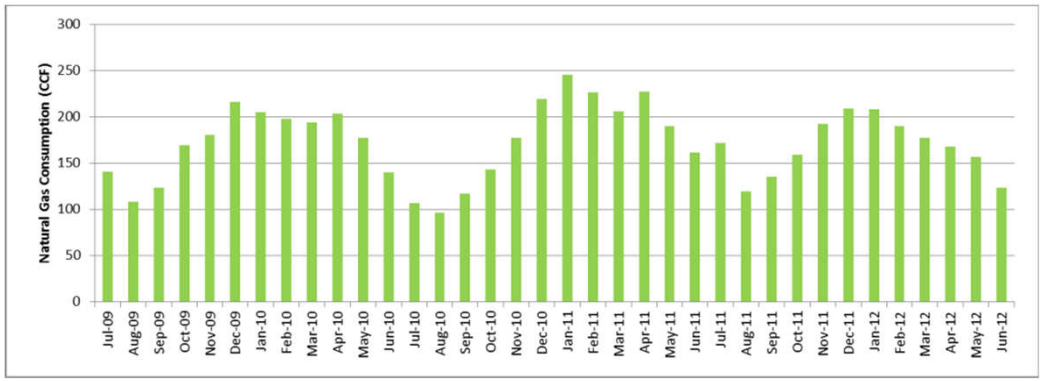
Example of utility bill analysis during energy audit





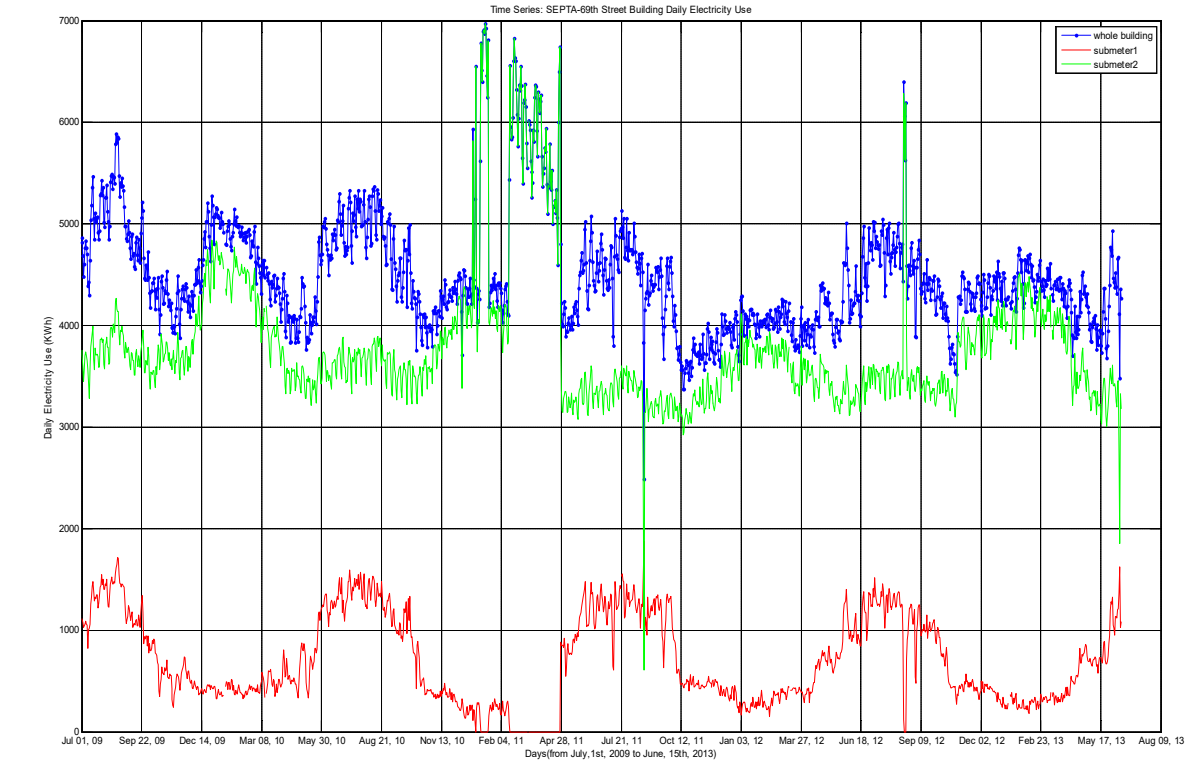


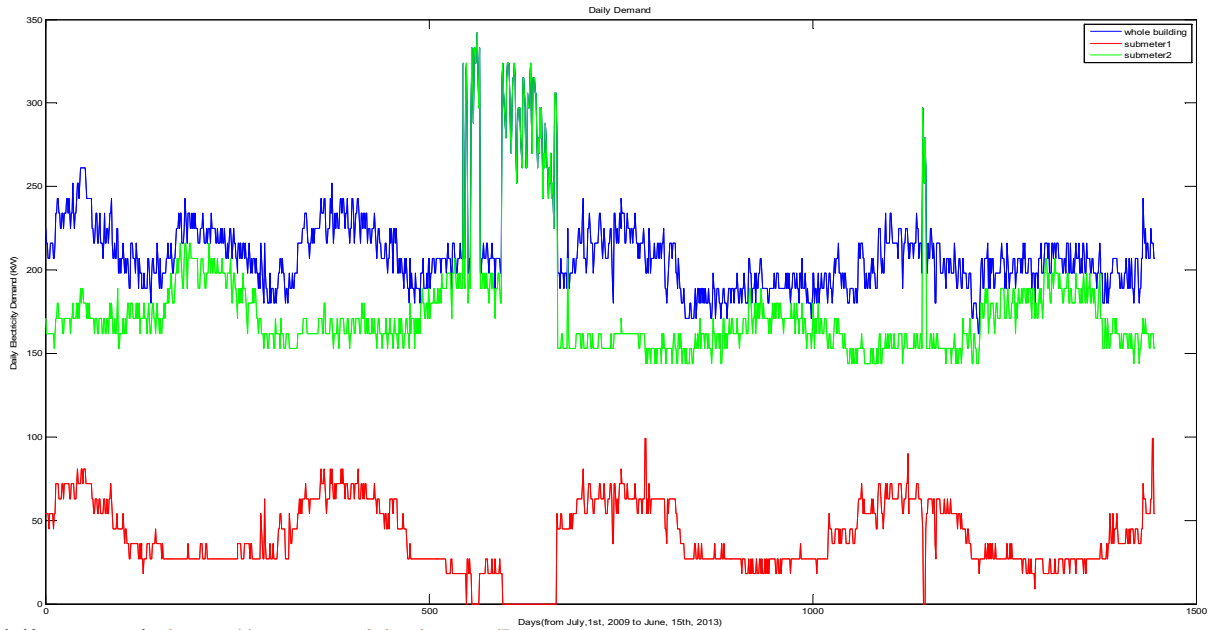




[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

Example of time-series data analysis during energy audit

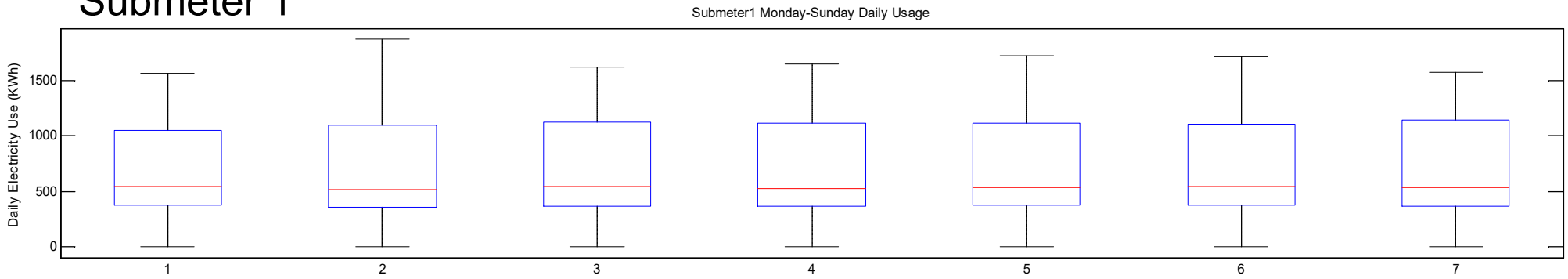




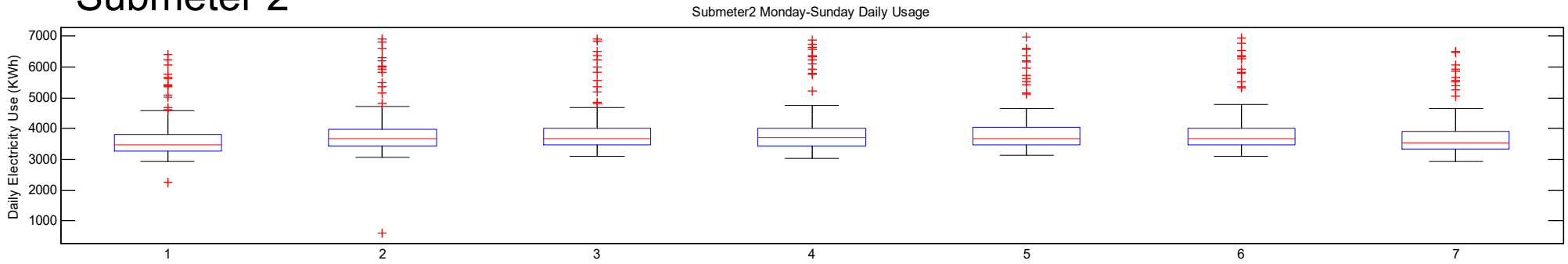
[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

Example of statistical data analysis during energy audit

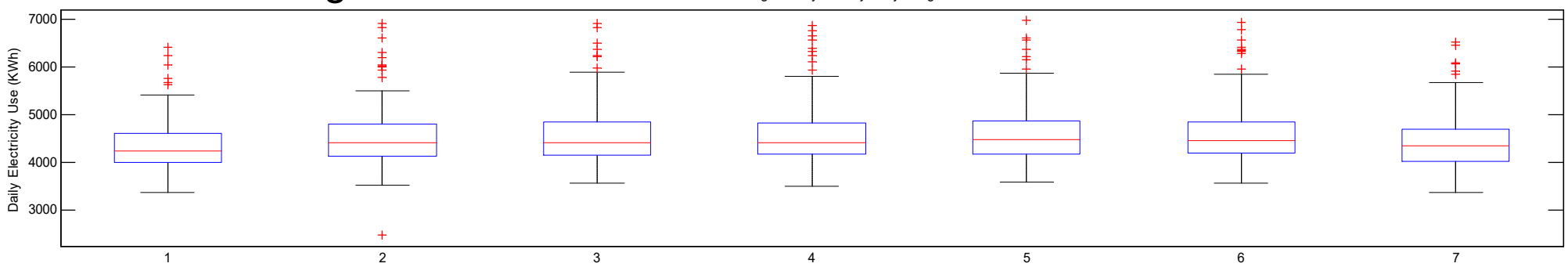
Submeter 1



Submeter 2

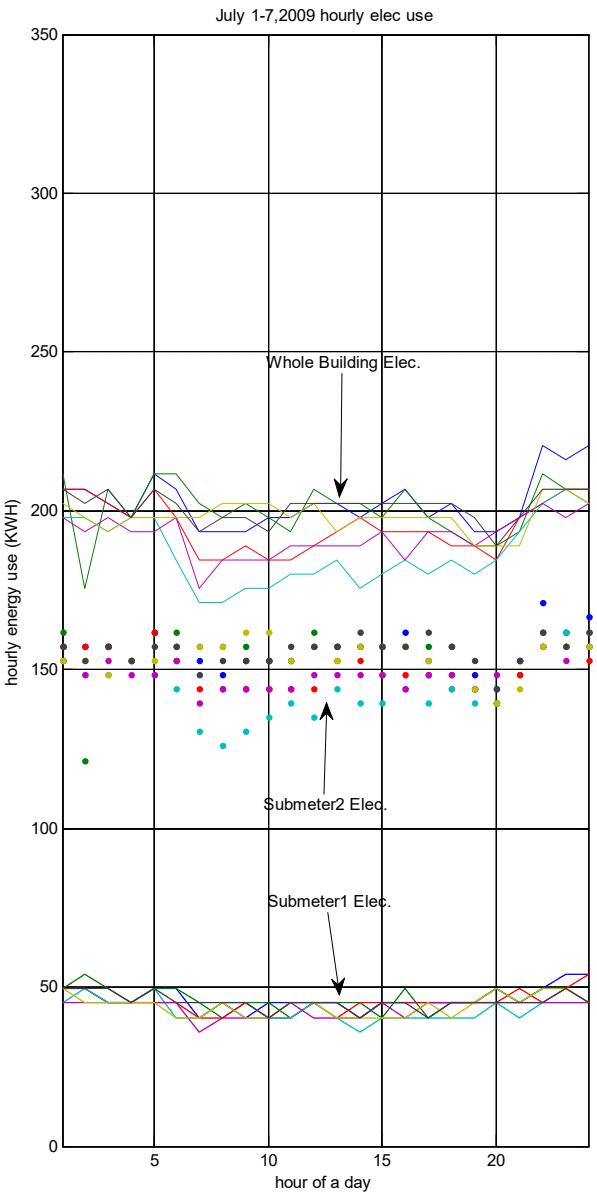


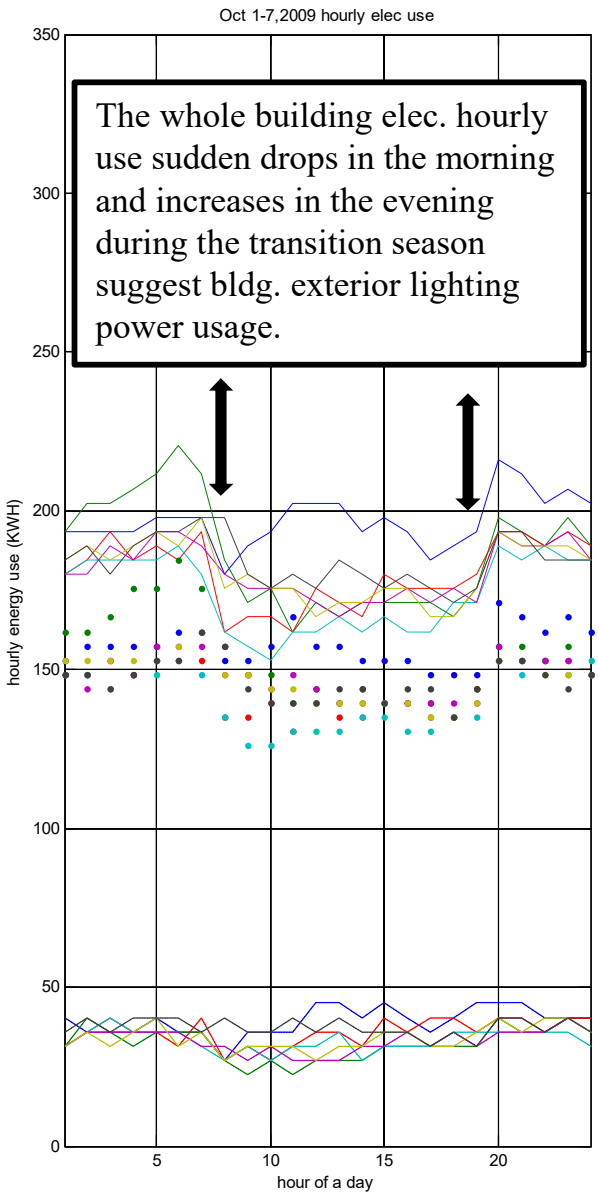
Whole building

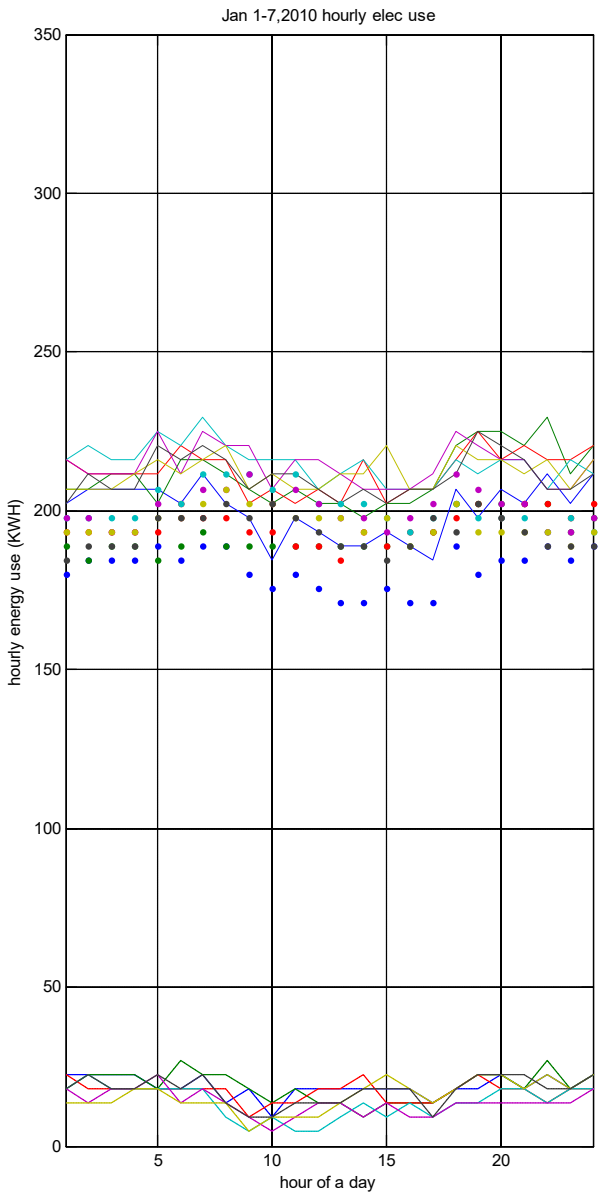


[Source: Energy Efficient Buildings Hub http://www.eebhub.org/]

Example of demand analysis based on hourly data







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

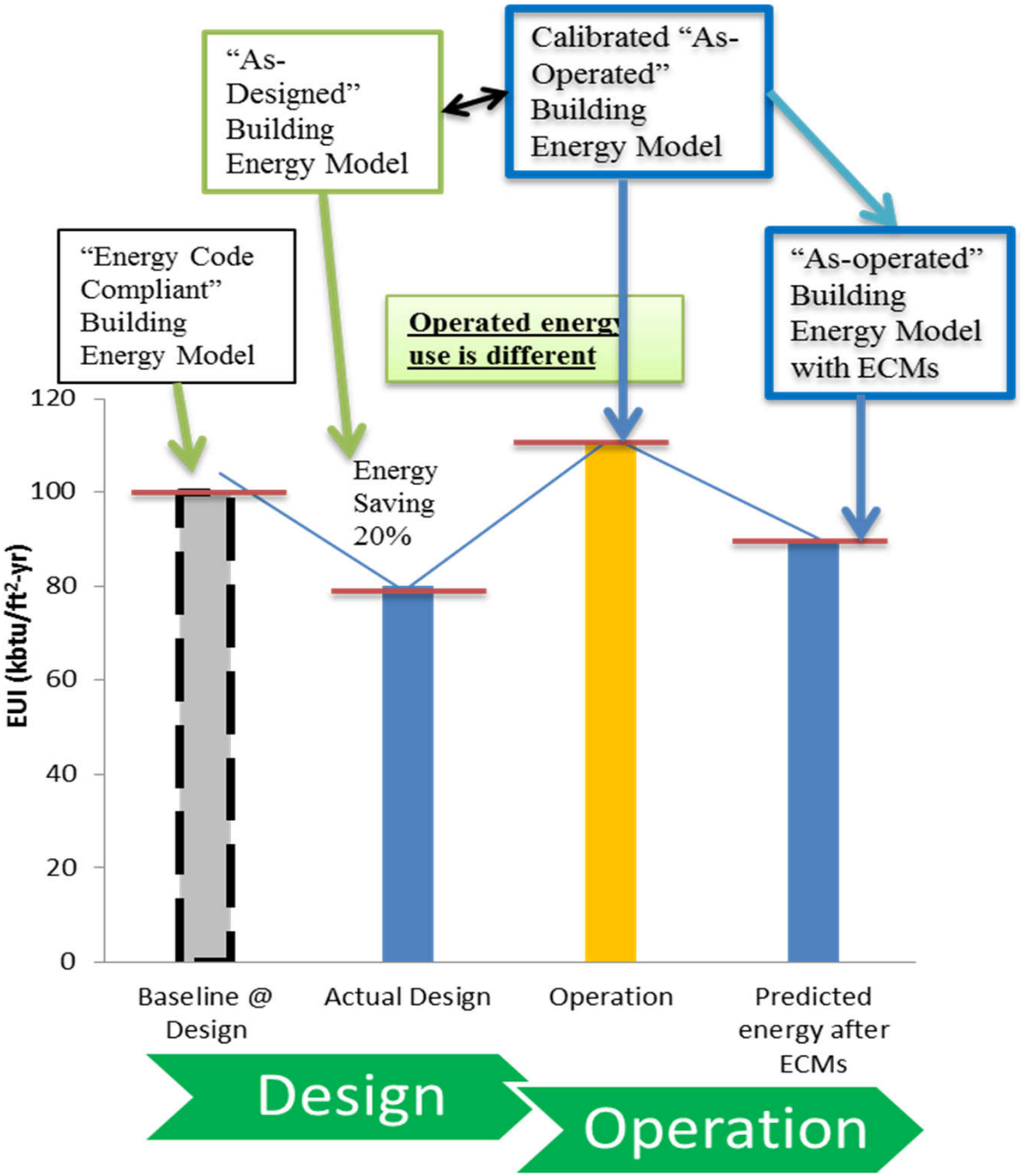
Building retrofit

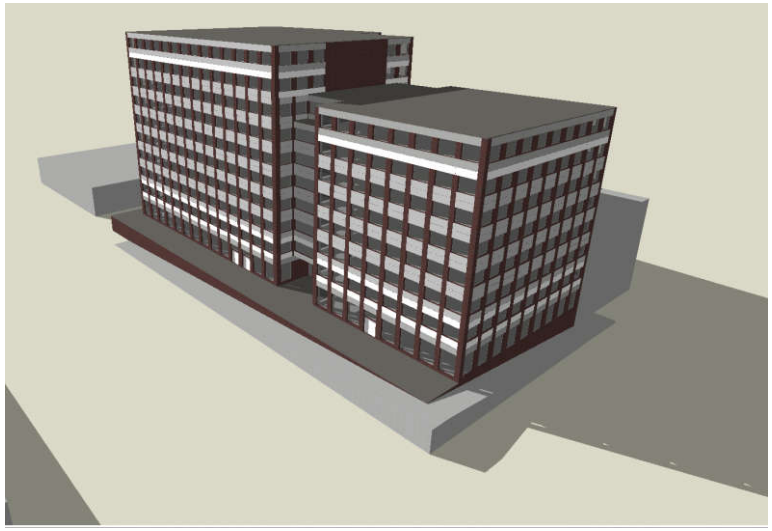
- Typical energy saving measures
  - Replace existing boilers with properly sized new boilers
  - Upgrade or replace existing chiller plant
  - Convert constant volume hot and chilled water distribution systems to variable volume distribution system (variable speed drives VSDs)
  - Add or update the BMS & controls
  - Lighting retrofits (replace with LED, etc.)

Building retrofit

- Install monitoring system & collect baseline building operation data
  - Sub-metering end uses
  - Better understand building operations & thermal comfort/indoor air quality levels
  - Calibrate building energy models
  - Prepare for M&V to determine actual savings
- Extensive modelling & design of energy conservation measures

Use calibrated building energy model to predict energy savings

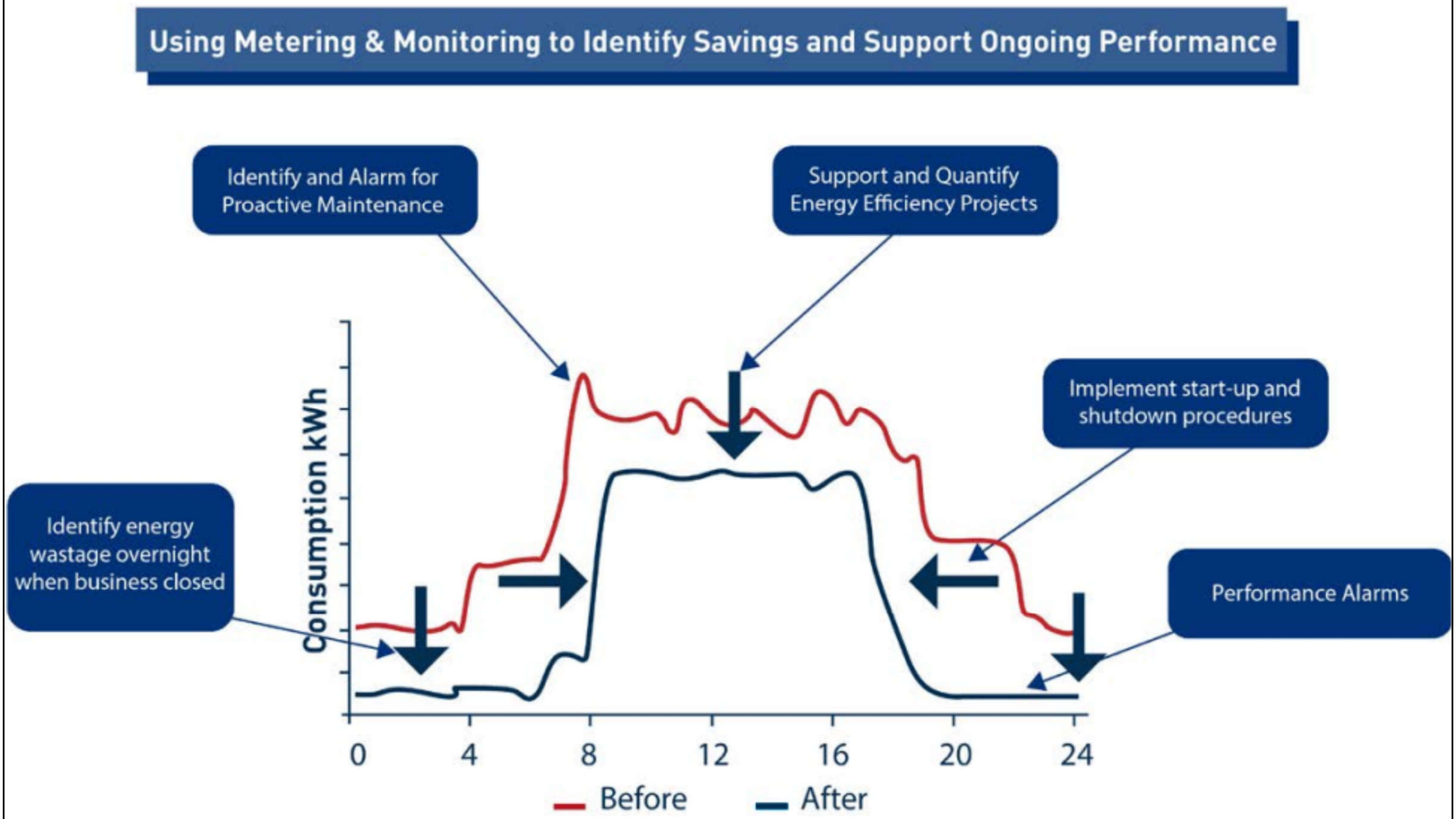




- Model will be calibrated using the monitored operational variables to reflect "as-operated" conditions;
- After the modeling results show a good match to sub-metered energy use, the model can be used for ECM savings prediction

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

Typical electricity consumption profile before & after energy management procedures



[Source: Effective energy management for business https://www.carbontrust.com/our-work-and-impact/guides-reports-and-tools/effective-energy-management-for-business-guide]

Further readings

- ISO 50001 -- Wikipedia http://en.wikipedia.org/wiki/ISO_50001
- The Carbon Trust, 2013. *Energy Management - A Comprehensive Guide to Controlling Energy Use* https://www.theade.co.uk/assets/docs/resources/ctg054_energy_management_comprehensive_guide.pdf
- Energy Audit Code 2021 Edition https://www.emsd.gov.hk/beeo/en/pee/EAC_2021.pdf
- Technical Guidelines on Energy Audit Code 2021 Edition (TG-EAC 2021) https://www.emsd.gov.hk/beeo/en/pee/TG-EAC_2021.pdf