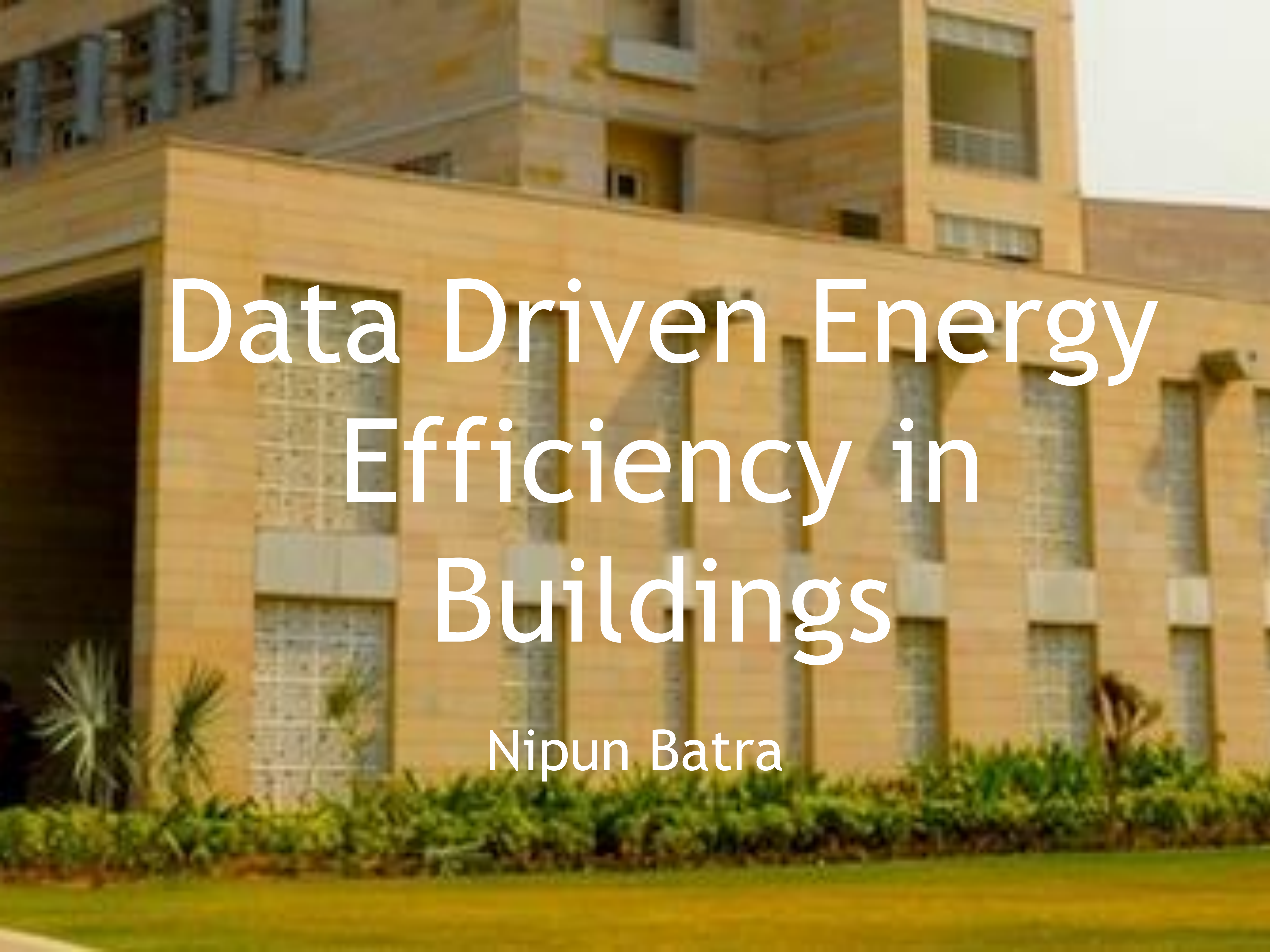


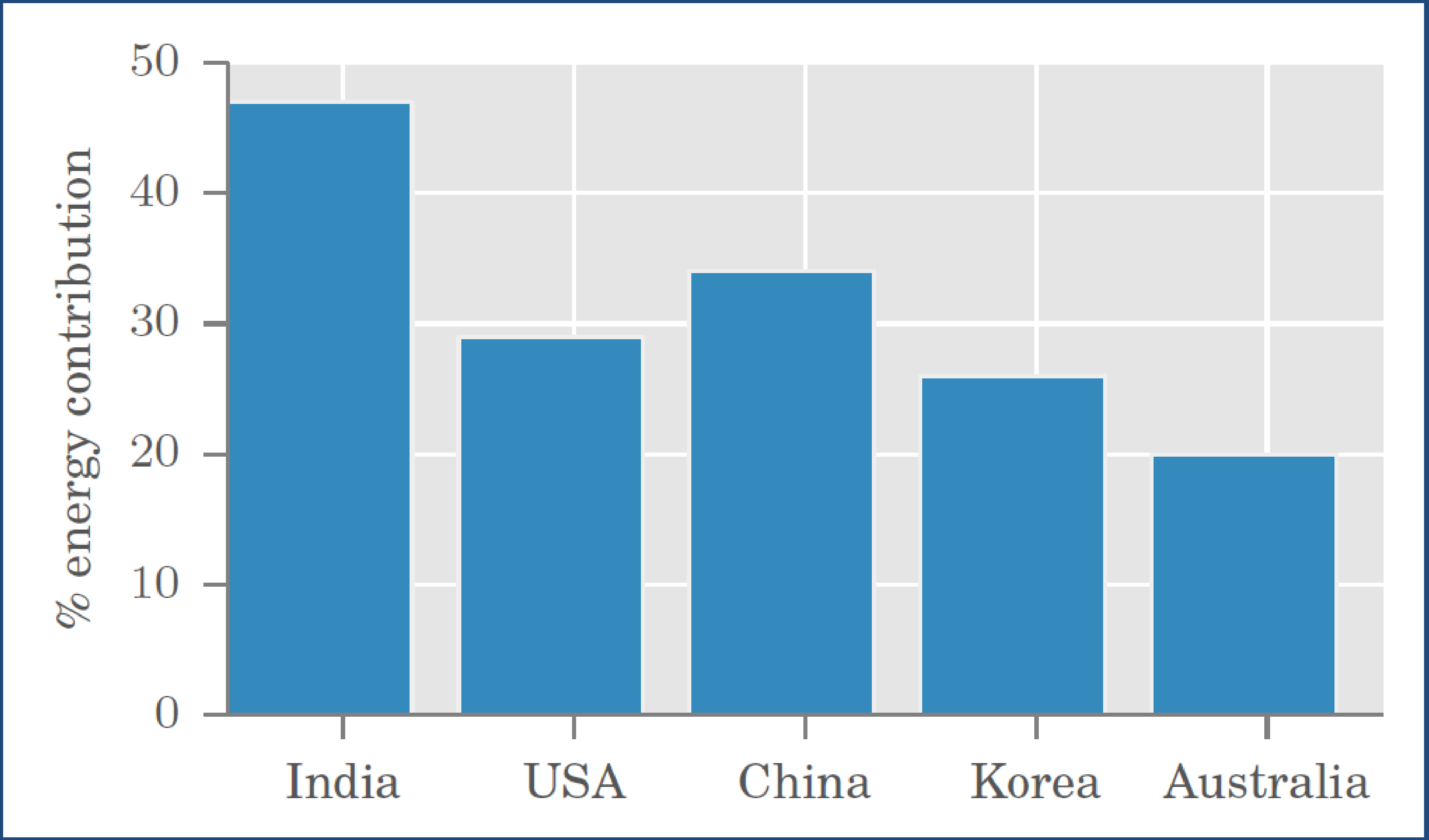
Data Driven Energy Efficiency in Buildings

Nipun Batra

Why study buildings?

People spend majority of the time inside buildings

Buildings contribute significantly to overall energy



Buildings are getting constructed at rapid rate

From buildings to energy efficient buildings

A glimpse into the future

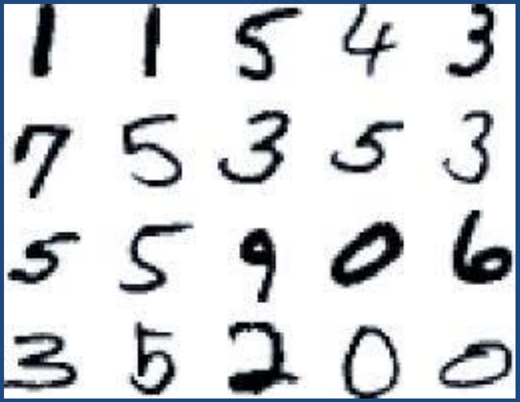
Video 1

Can data help?

"If you cannot measure it, you cannot improve it"

MNIST data set

- Instigated machine vision research
- Can buildings also benefit from data?



Traditional energy data collection

1. **Sporadic** – Energy audits (once in few years)
2. **Manual** – Utility companies collect water and electricity readings

Where does building energy data come from?

Smart meters

- National rollouts
- Enable **high resolution** and **automated collection**

Water meters

Ambient sensors

- Measuring motion, light, temperature
- Ease of availability and installation

Building management systems

- Computer systems for controlling heating and lighting
- Typically used in commercial buildings
- Operated by facilities
- Sense several points:
  - Cameras
  - Temperature for heating and ventilation control
  - Light intensity for lighting control

Soft-sensor streams

- Firewall network traffic
- Access control
- WiFi access points

How to collect this data?

Sensor deployments

- Well studied in prior literature

Sensor deployment design goals

- Low power consumption
- Wide network coverage
- Robust
- Deployment ease

Is sensor deployment in buildings any different?


Aesthetics and occupant comfort matters!


Surprisingly hostile environment

- Occupant interaction drops with time
- Wireless spectrum may get clogged due to additional sensors

How do sensors communicate data?

- Several automation standards exist- Modbus, BACnet, LonWork (proprietary)
  - Mostly developed for automation and not for monitoring
- At the home level powerline protocols (X10, Insteon) also used
  - Exploit existing powerline for data communication
- Protocols such as Zigbee, 802.15.4 used on wireless nodes

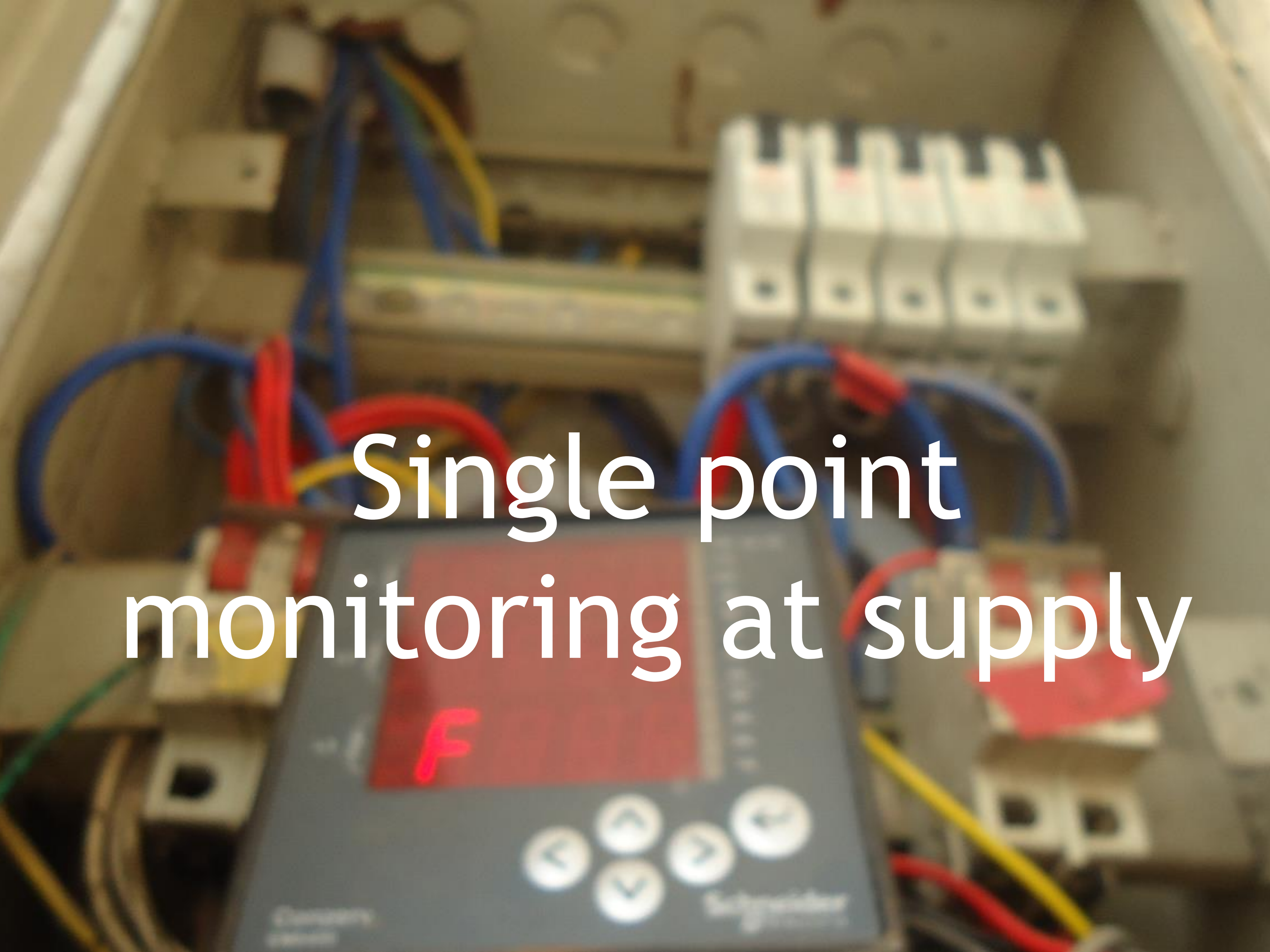
The Internet of Things revolution

- IP based sensor data communications
- Sensors can leverage existing service oriented architectures
- Allows interconnection between computers, phones and sensors

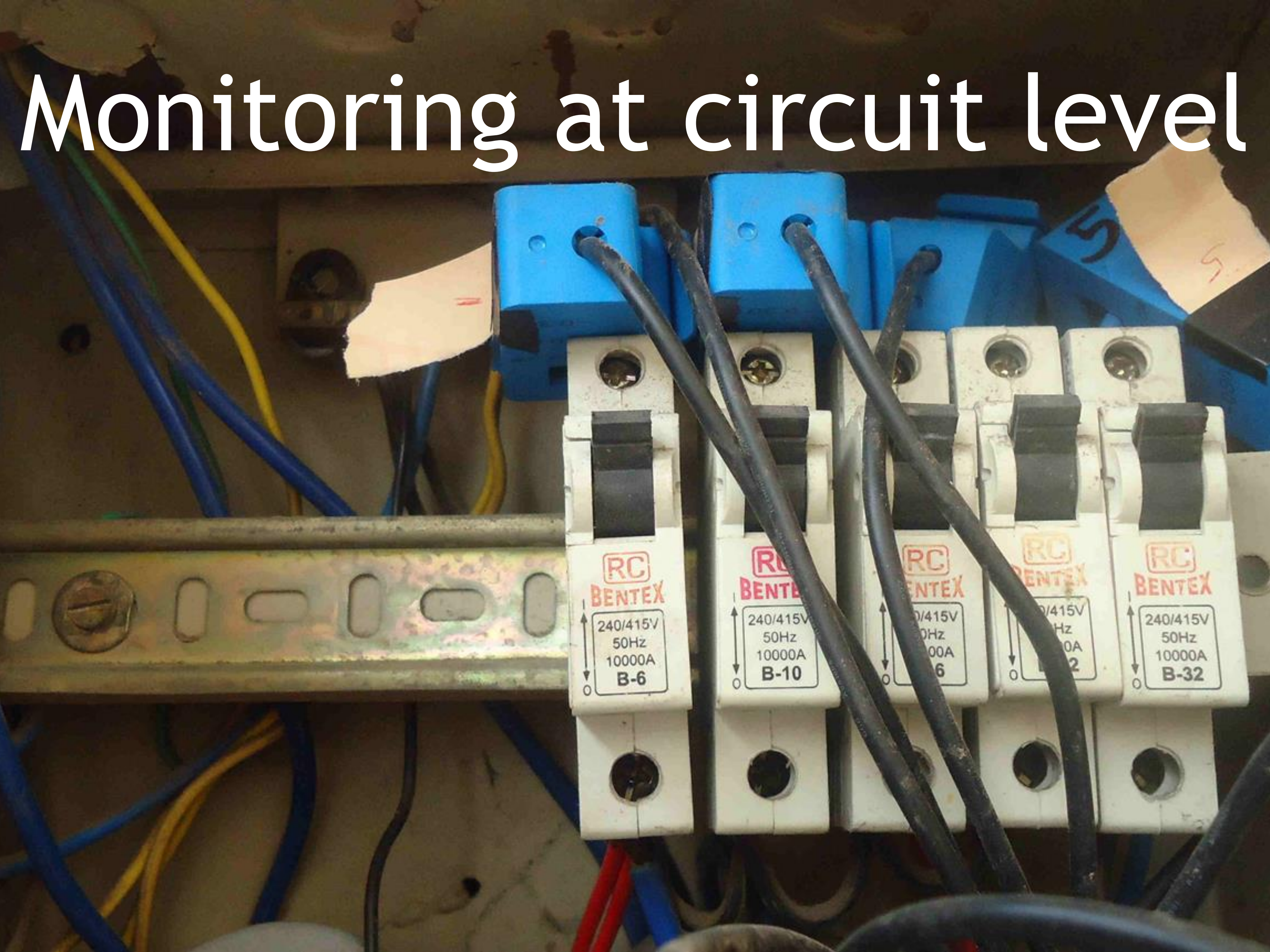
Instrument optimally

- How much to sense?
- Where to sense?
- Consider the example of electricity monitoring

Spatial criterion for optimality

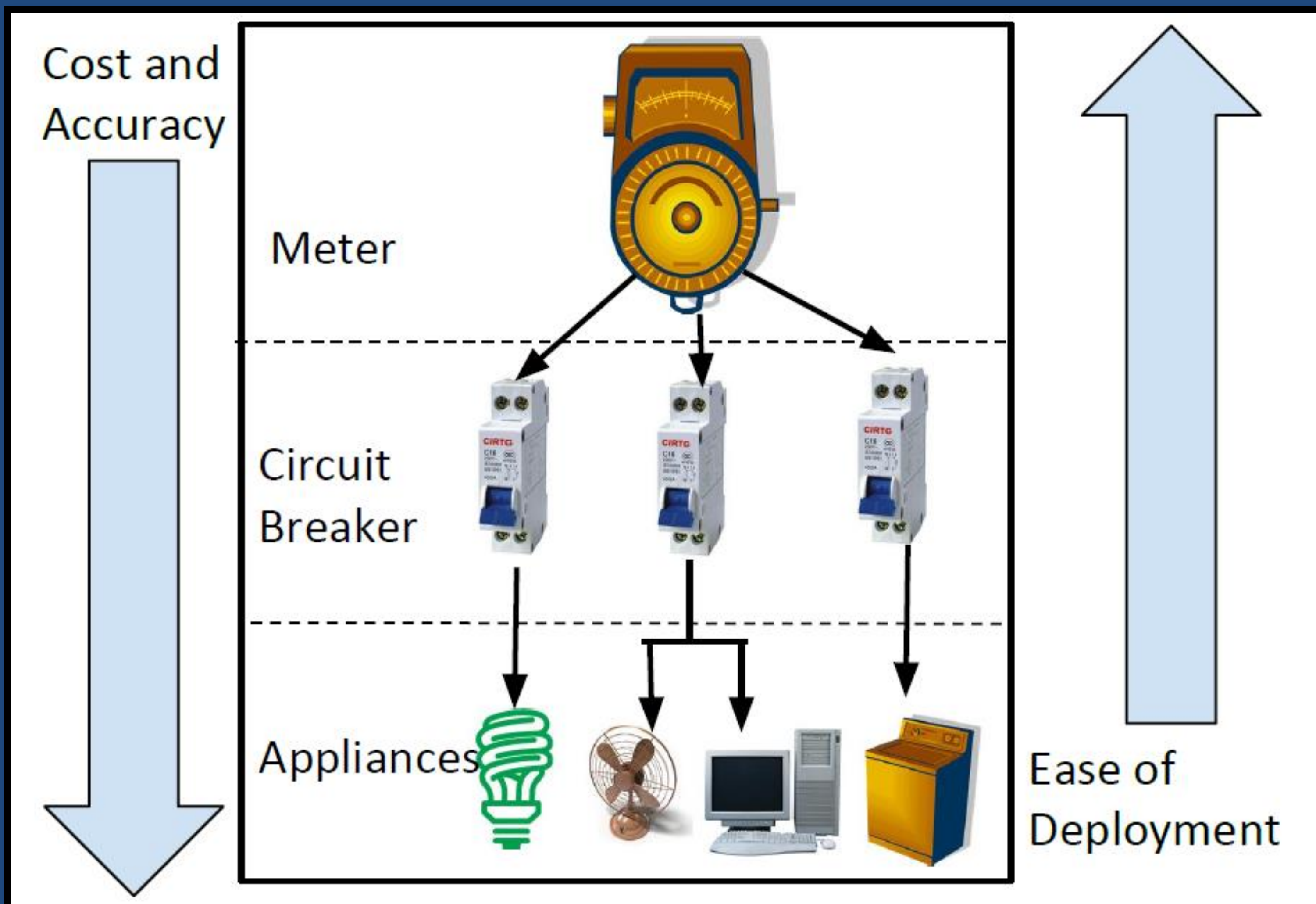

Single point
monitoring at supply

Monitoring at circuit level



Monitoring at individual appliance level

Cost-Accuracy Tradeoff



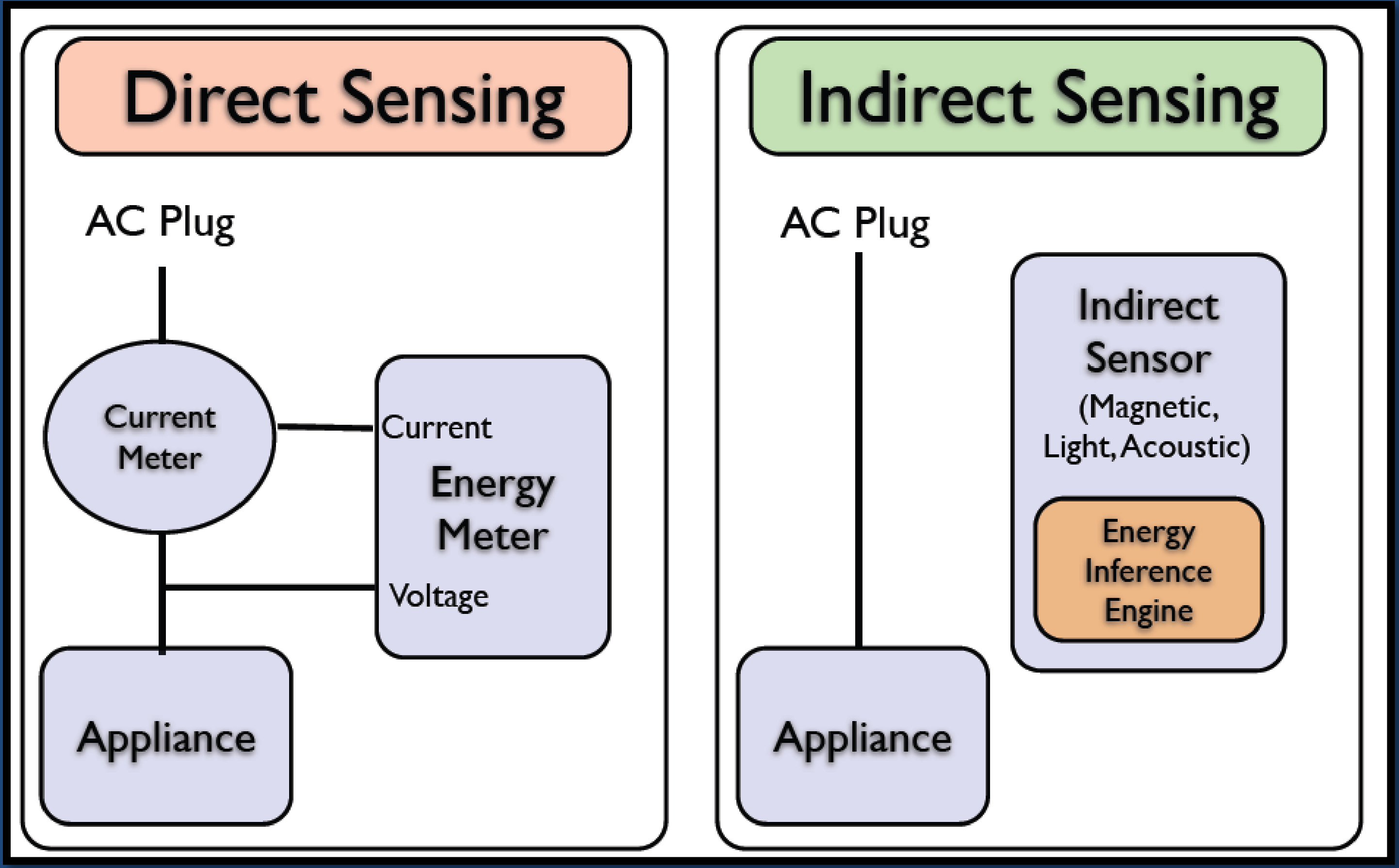
Temporal optimality criterion

Cost
And
Information
content

Rate	Application
Once every few years	Energy auditing
Once a month	Electricity billing
Once a day	Commercial building power factor checking
Once every < 15 min	Automated meter reading
Several thousand samples every second	High frequency energy disaggregation

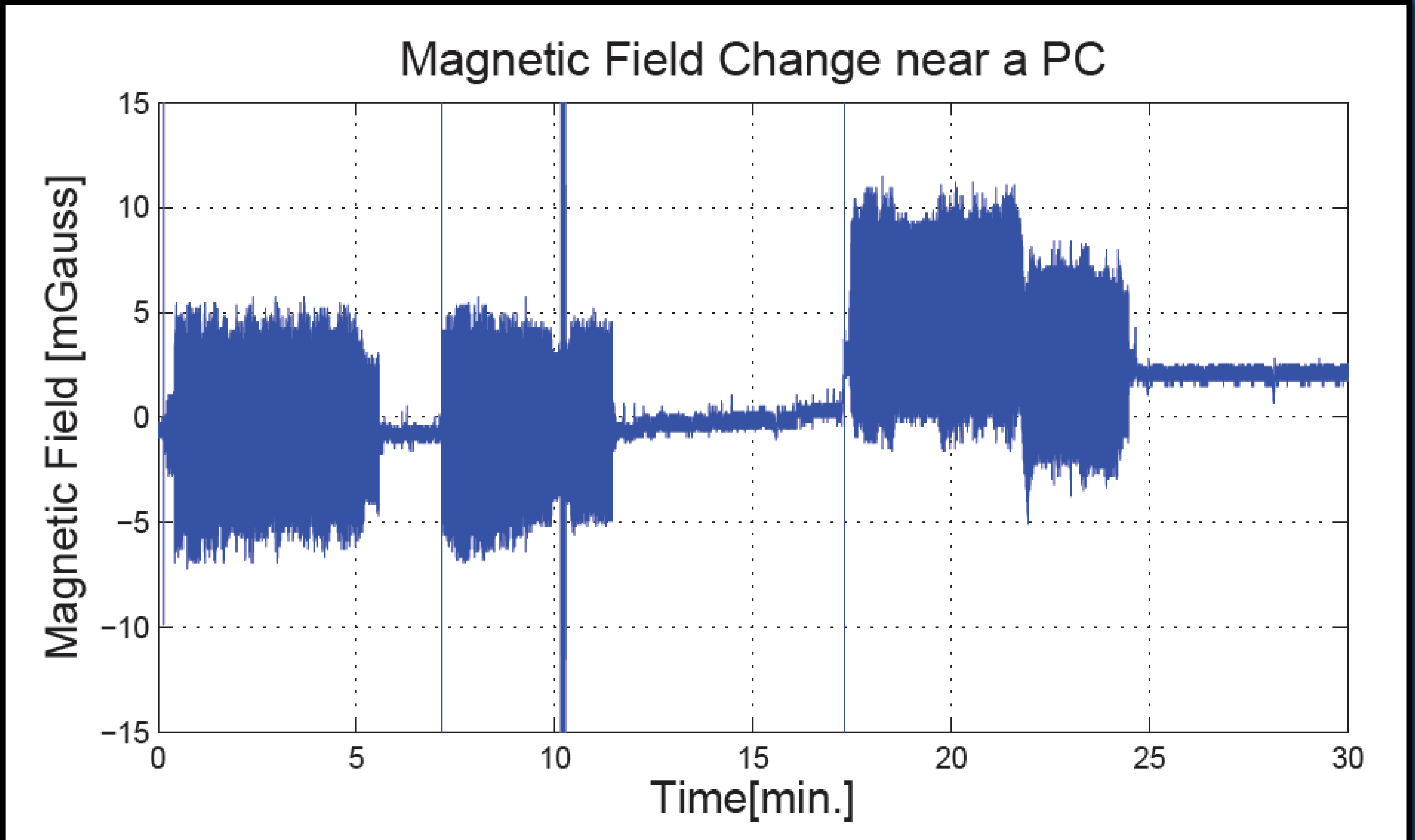
Instrument optimally: Challenges and Opportunities

Indirect Sensing

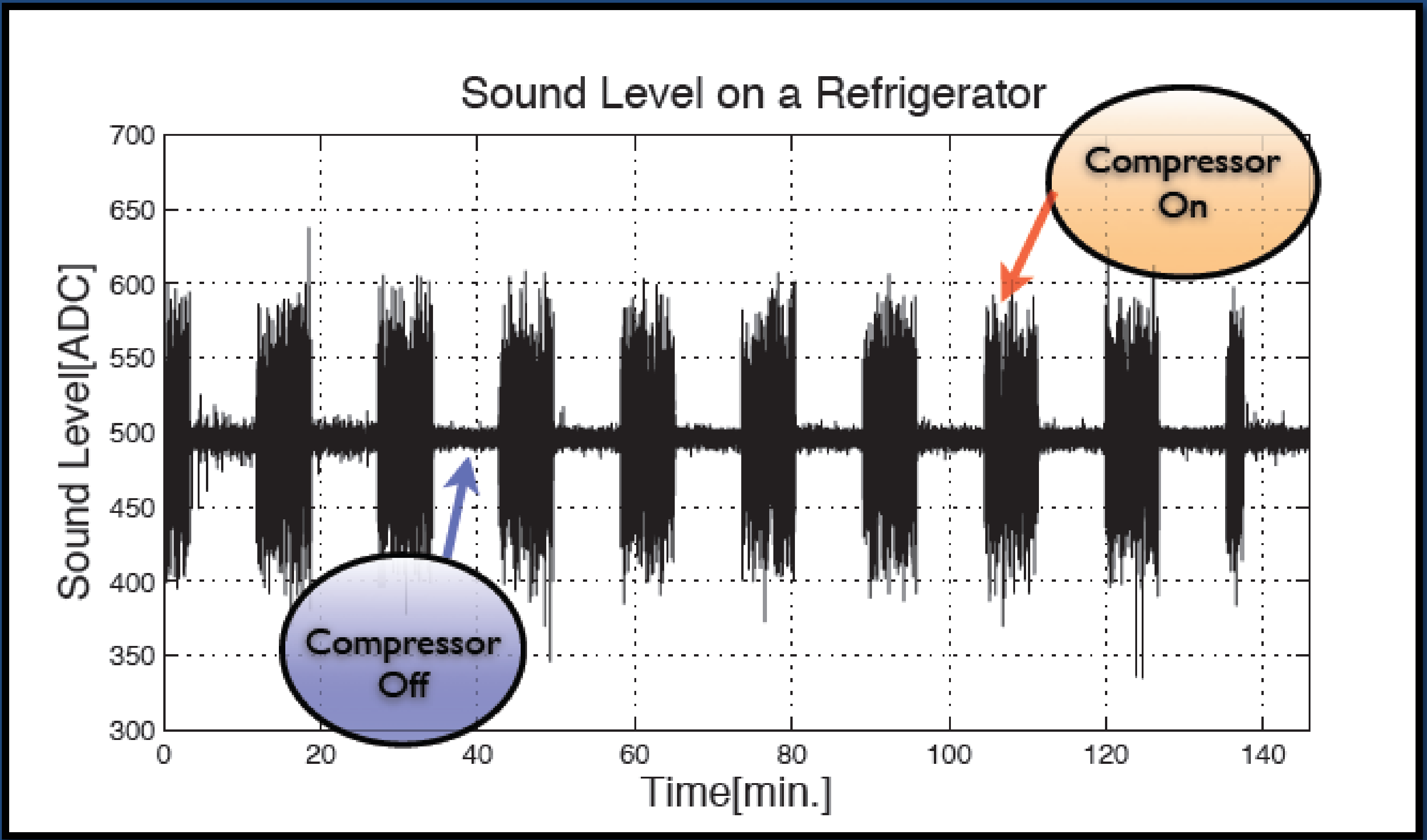


Kim et al. Viridiscope

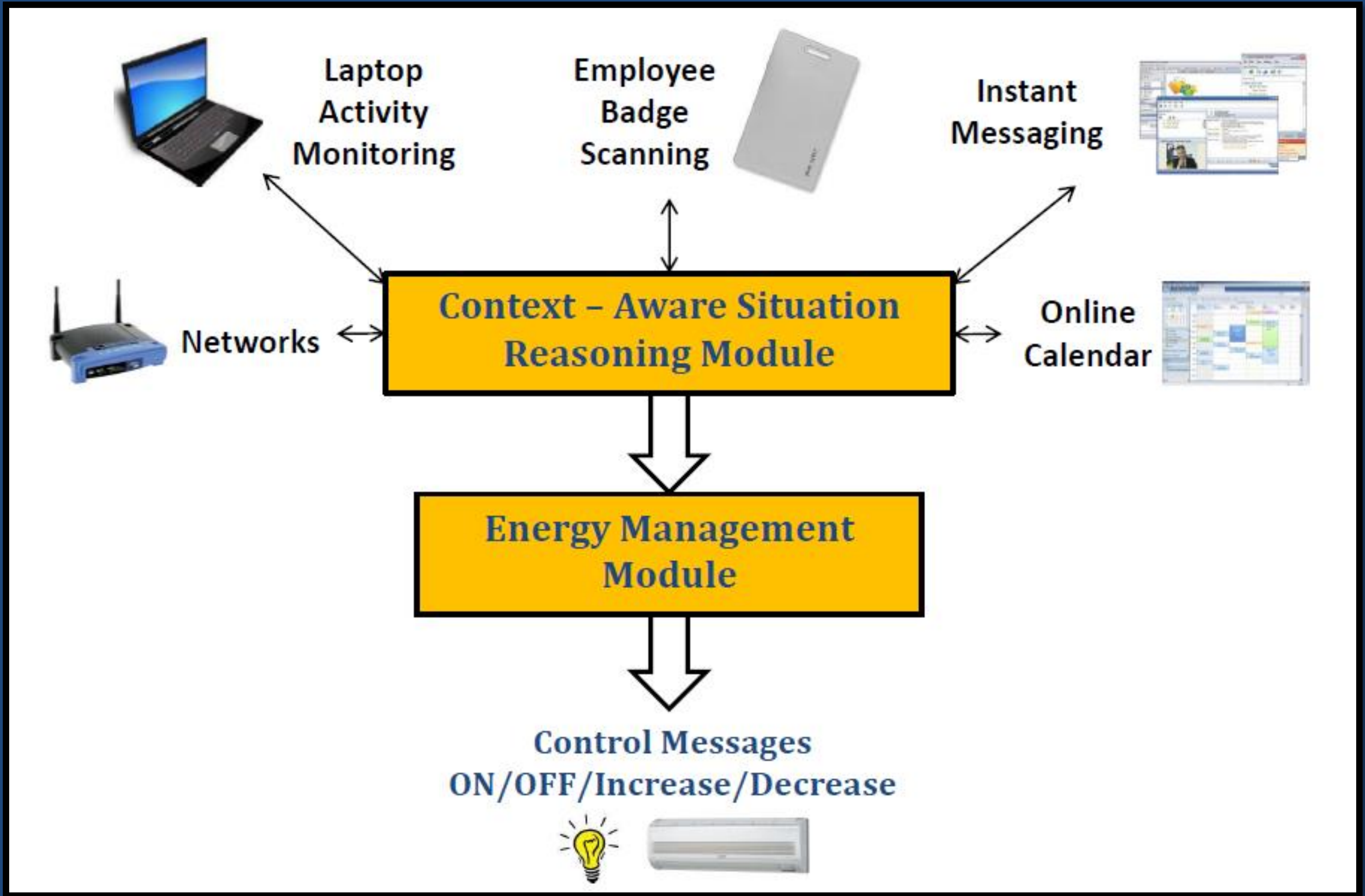
Magnetic sensor to detect power (Kim et al. Viridiscope)



Sound sensor to detect refrigerator power (Kim et al. Viridiscope)



Utilizing existing infrastructure for energy management (Softgreen)



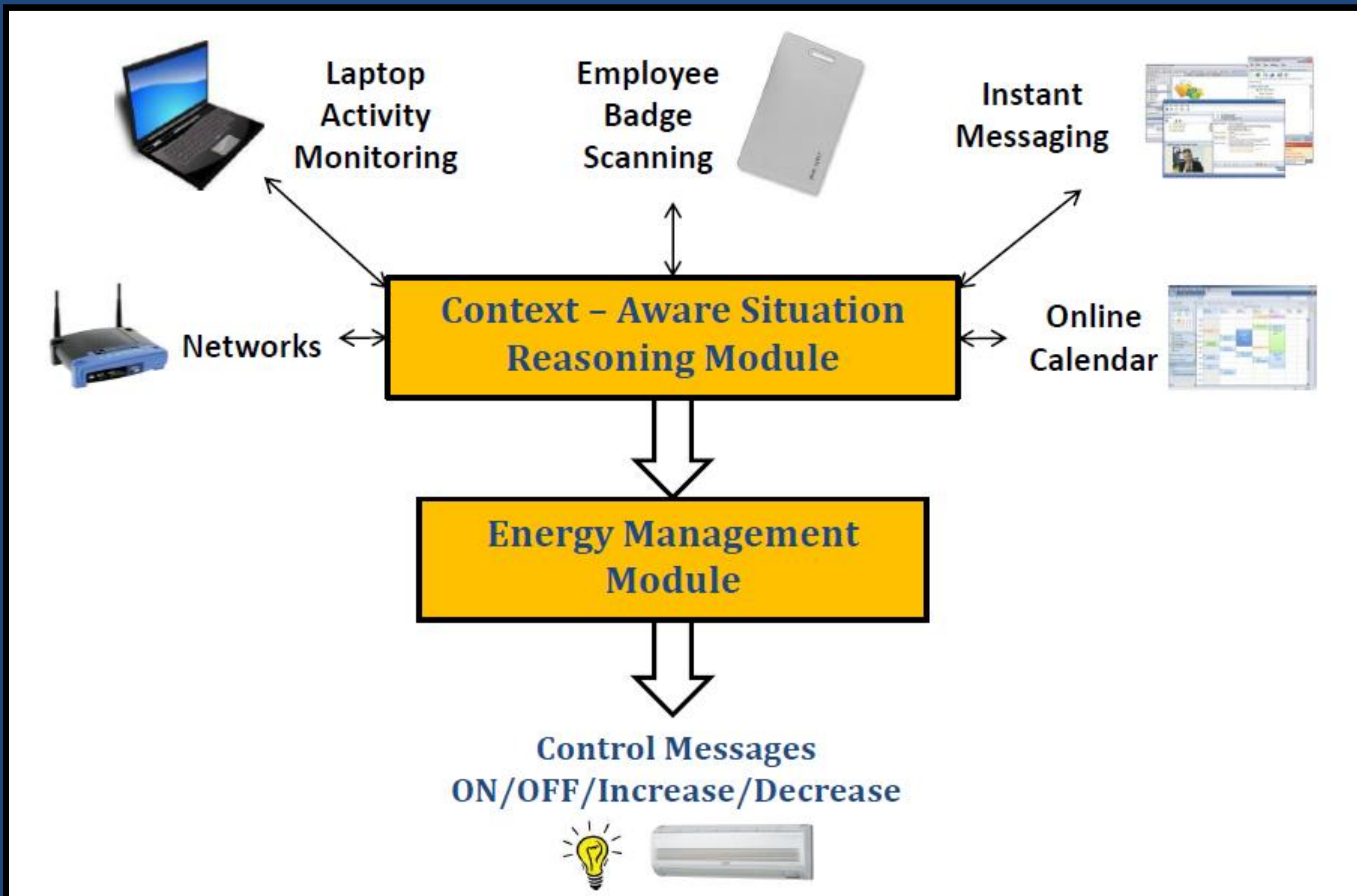
Optimal sensor placement

- Reducing the divide between theory and practice
- Previous research mostly based on empirical understanding

Interconnect sub-systems

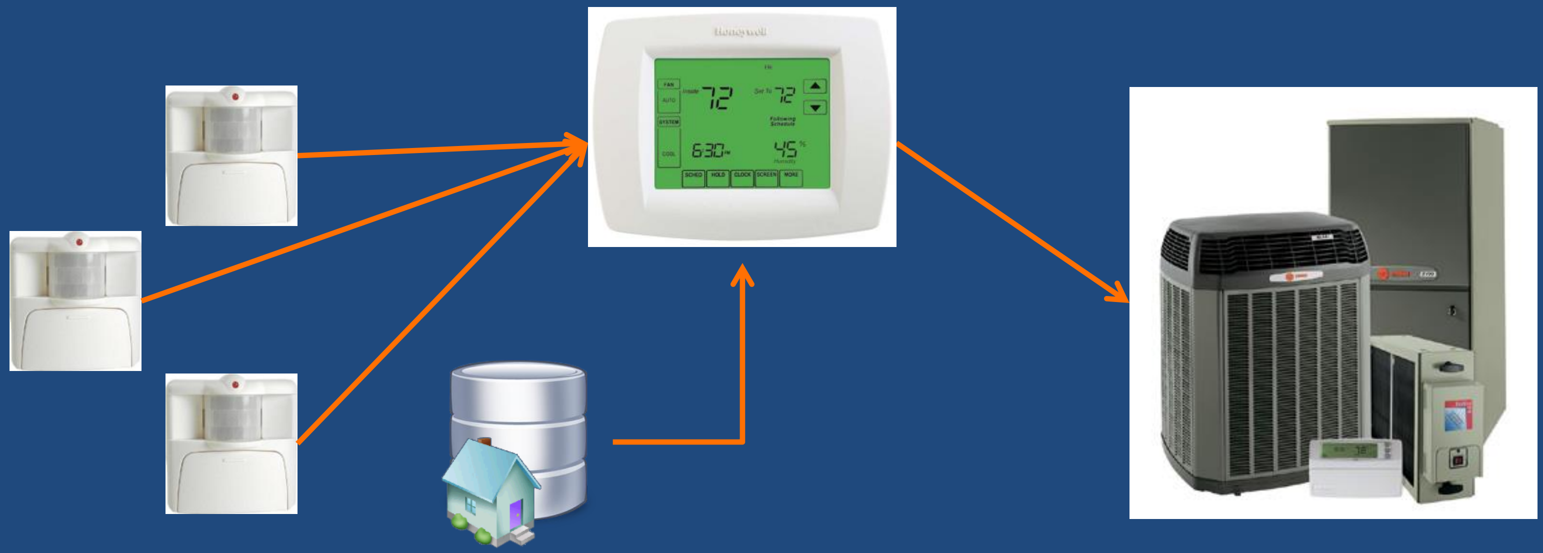
- Buildings consist of multiple sub-systems:
  - Utility (electricity, water, gas)
  - Security and Access
  - Air conditioning
  - Lighting
- Sum of information from these sub-systems >> information from a system in isolation

Softgreen revisited



Smart Thermostat

Interconnecting motion and door sensors to thermostat to make it energy efficient



Lu et al. Smart thermostat

Interconnect sub-systems: Challenges and Opportunities

Application complexity and portability

- Every building is different
  - Different sub-systems
  - Different sensors and controllers
  - Different communication protocols and BMS
- Interconnection thus difficult
- Developed applications in the past often ad-hoc tuned to specific deployment

Vendor locked communication

- Different sub-systems may employ vendor locked solutions
- Making interconnections difficult
- Often simplified by putting extra gateway devices which expose data over IP
  - At increased cost

Unstructured data

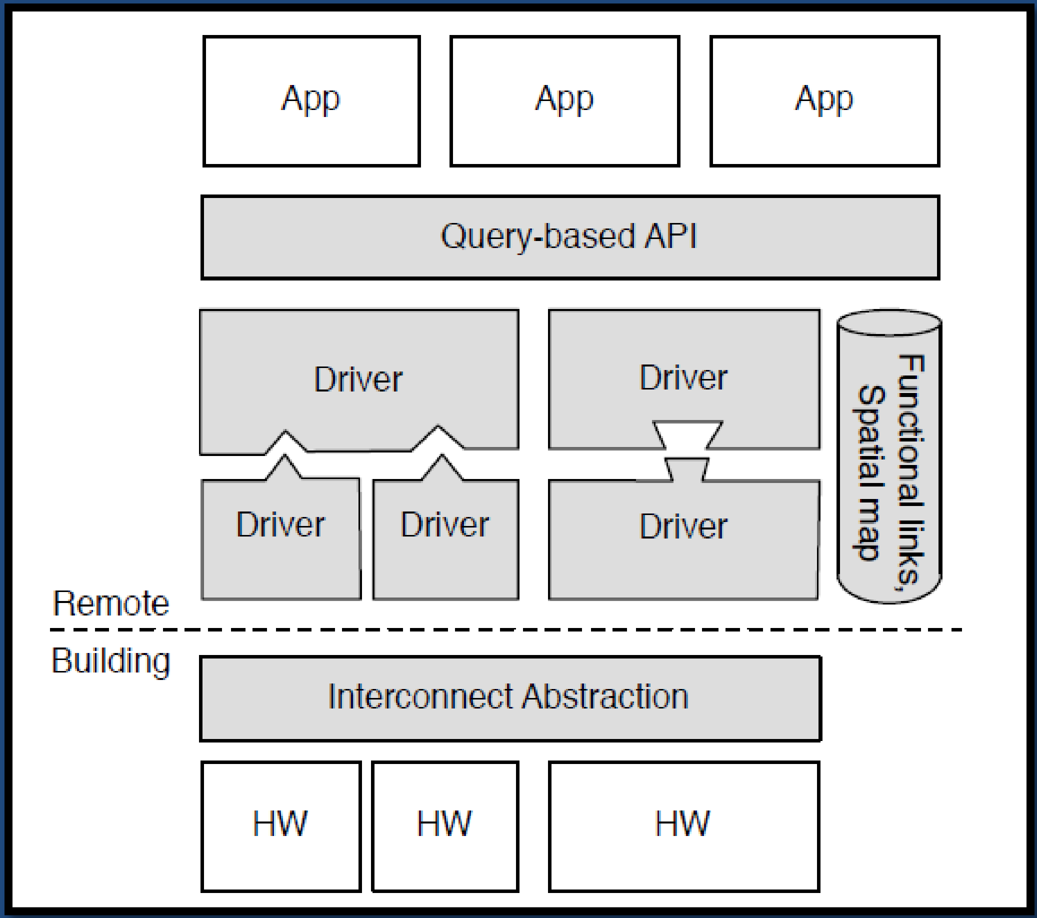
- CAD layouts, hand written notes
- Often manual overhead in obtaining important metadata
- Krikouv et al. use image processing to decode CAD drawings
- Need to develop structured ways of capturing such metadata

Inter-department communication gap

- Individuals have in-depth knowledge of their areas
- Interconnecting requires understanding across different areas

A step towards easier interconnections- Software-oriented buildings

- Principles of software engineering applied to buildings
- Preparing a building stack inspired by networking stack



Krioukov et al. BAS

Inferred decision making

- Transforming data into actionable insights
- Identify inefficiencies, raise alerts

Power outages

Earlier customers call utility to inform about power outages

Inferred decision making →

From smart meter data utilities can detect power outages immediately

Lighting control

Adjust lights according to fixed time interval (decided during audit) using motion sensor

Inferred decision making →

Adjust lights according to ambient light, occupancy, individual lighting preference

HVAC control

Turn on the chillers from 9 AM to 6 PM

Inferred decision making

Zonal chilling based on occupancy

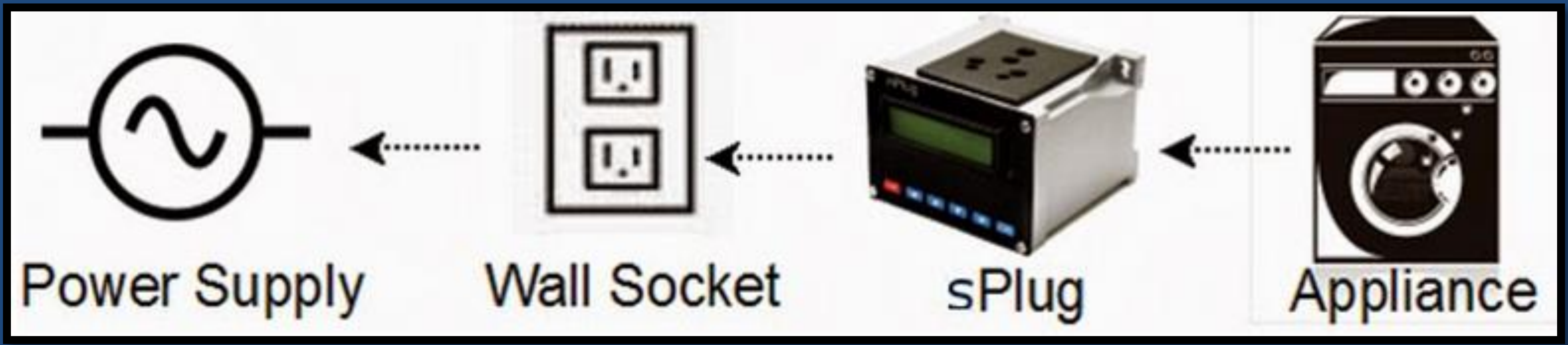
Inference approach categorization

Centralized vs Distributed

- Centralized all data resides and processing on single machine
- Distributed data and processing on multiple machines
- Increase in data and privacy concerns→ need to look into distributed operations

SocketWatch (Ganu et al.)

- Sits between appliance and socket
- Decides independently if appliance is anomalous
- Conventional centralized approaches would relay the data to a computer for the same



Supervised vs Unsupervised

- Supervised requires labeled data; hard to collect
- Unsupervised work on “discovery”

Online vs Offline

- Offline: create model once from static data
- Online: model can adapt to incoming data
- Imagine if Google's indexing were to be offline

Ideal algorithm

- Distributed
- Unsupervised
- Online

Inferred decision making: Challenges and Opportunities

Water Energy nexus

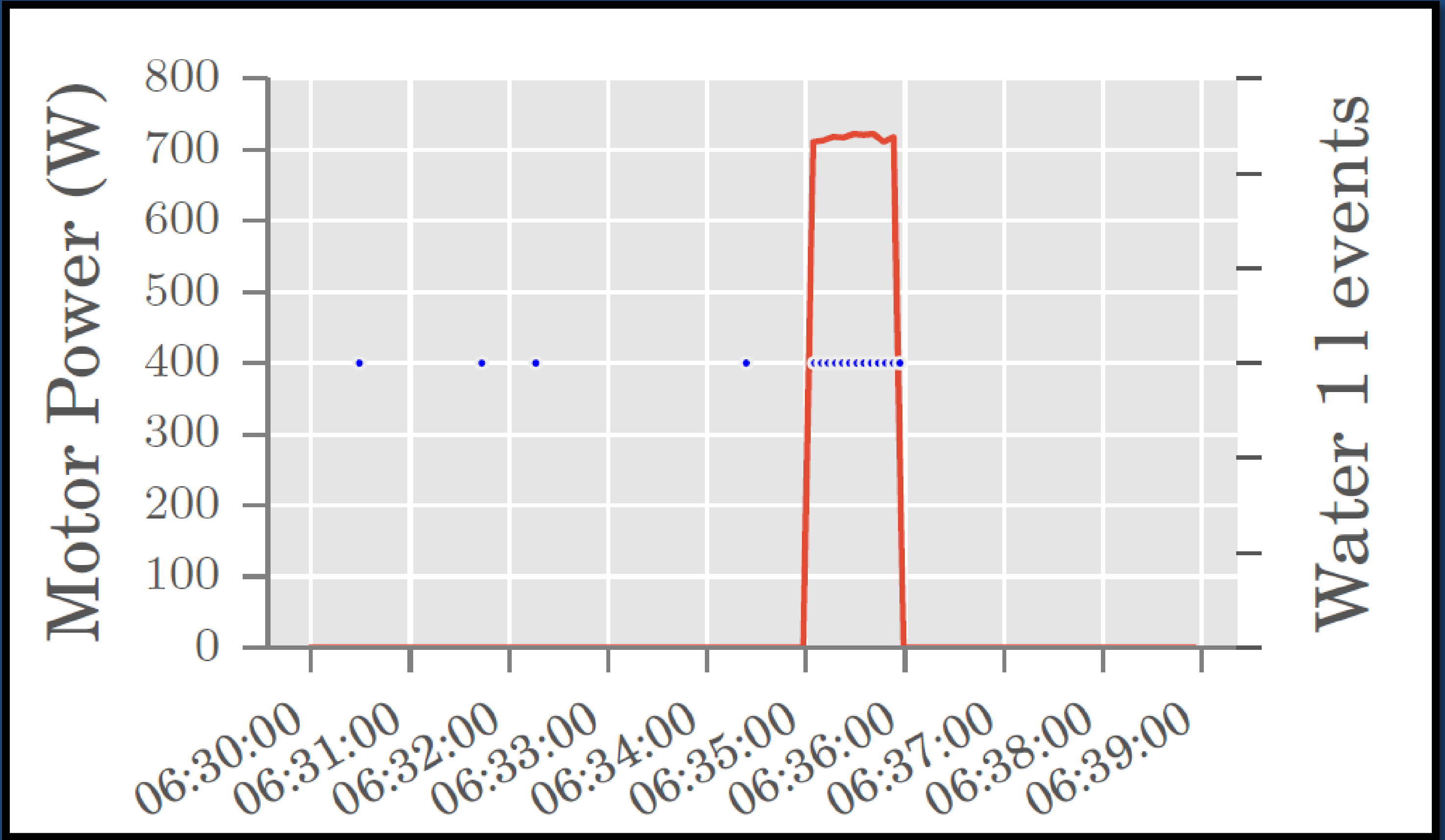
- Energy and water two sides of same coin
- Water-energy nexus
  - Water used to generate electricity
  - Electricity used to treat water
- We will discuss 2 (of many) levels where this water-energy nexus exists

Commercial Complexes

- Different grades of water
- Internal water treatment
- Tradeoffs:
  - Buying water from utility vs internal treatment (energy costs)
  - Which grade of water has most energy impact
  - Does rainwater harvesting help to save energy

Residential apartments (India)

- Pump water to tank- this uses electricity
- Energy- water rate optimization



Collection of ground truth

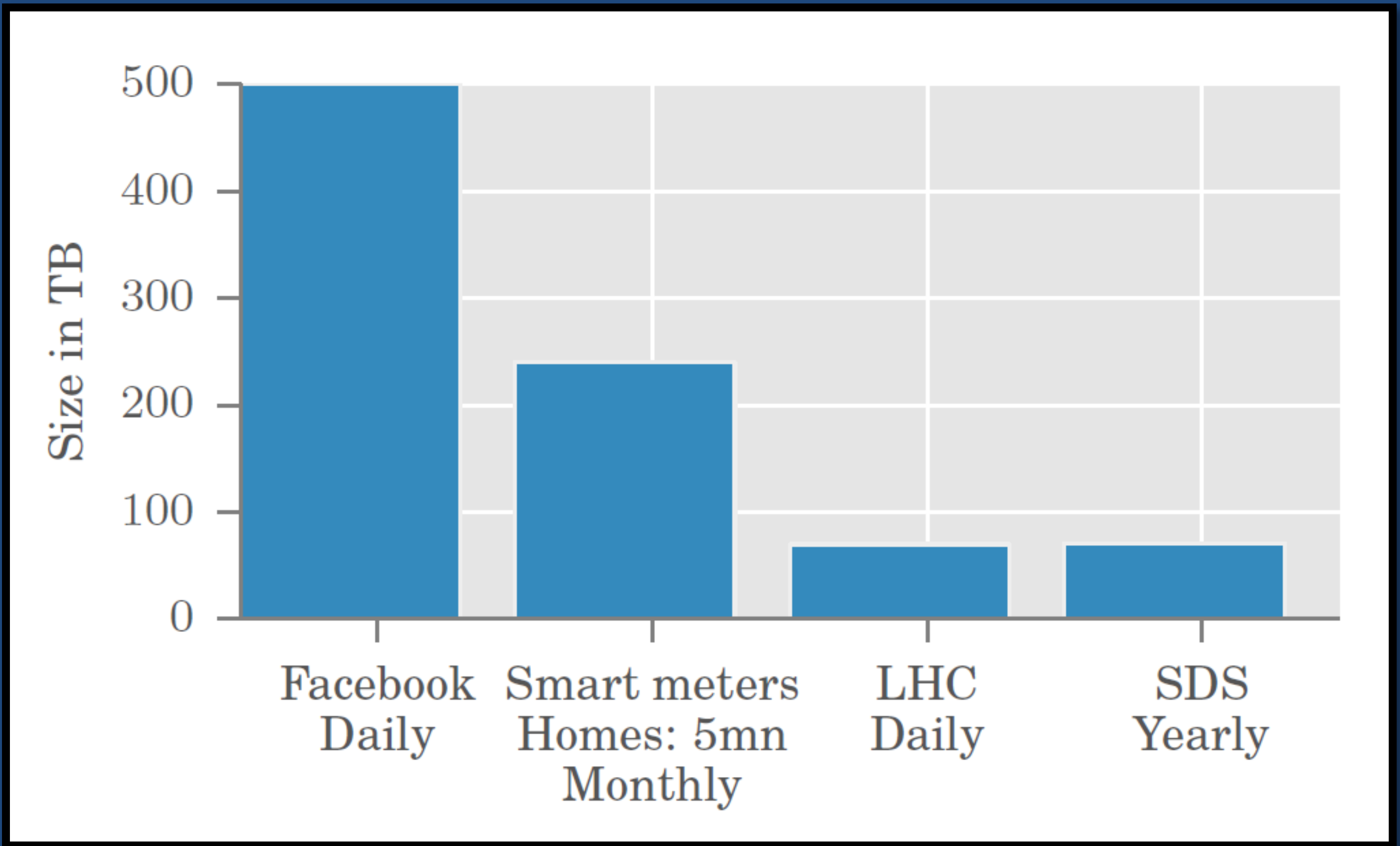
- Need to collect ground truth to establish inference approach statistics
- No easy way to collect ground truth:
  - Taking notes
  - Video camera (highly intrusive)
  - Making grad students poll regularly (not at IIITD atleast ☺)

Towards simulators

- Can allow for easy comparison
- Caveat: Real data is real data..Can never be simulated fully

Moving towards tractable algorithms

- Size of data increasing at rapid rate
- Comparable to "big" data problems



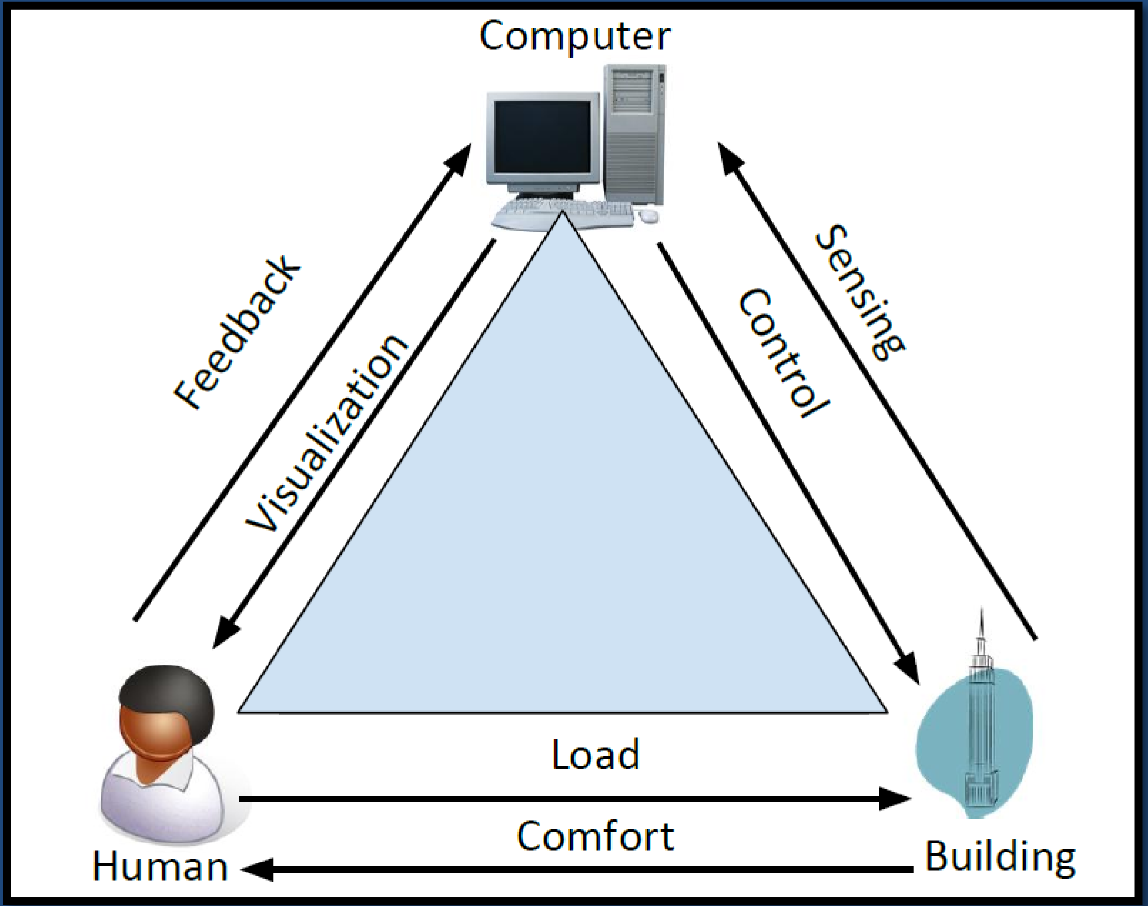
LHC: Large Hadron Collider

SDS: Sloan Digital Sky (Astronomy)

Involve occupants

Energy efficient buildings encompass HBCI- Human Computer Building Interaction

Let us look into these



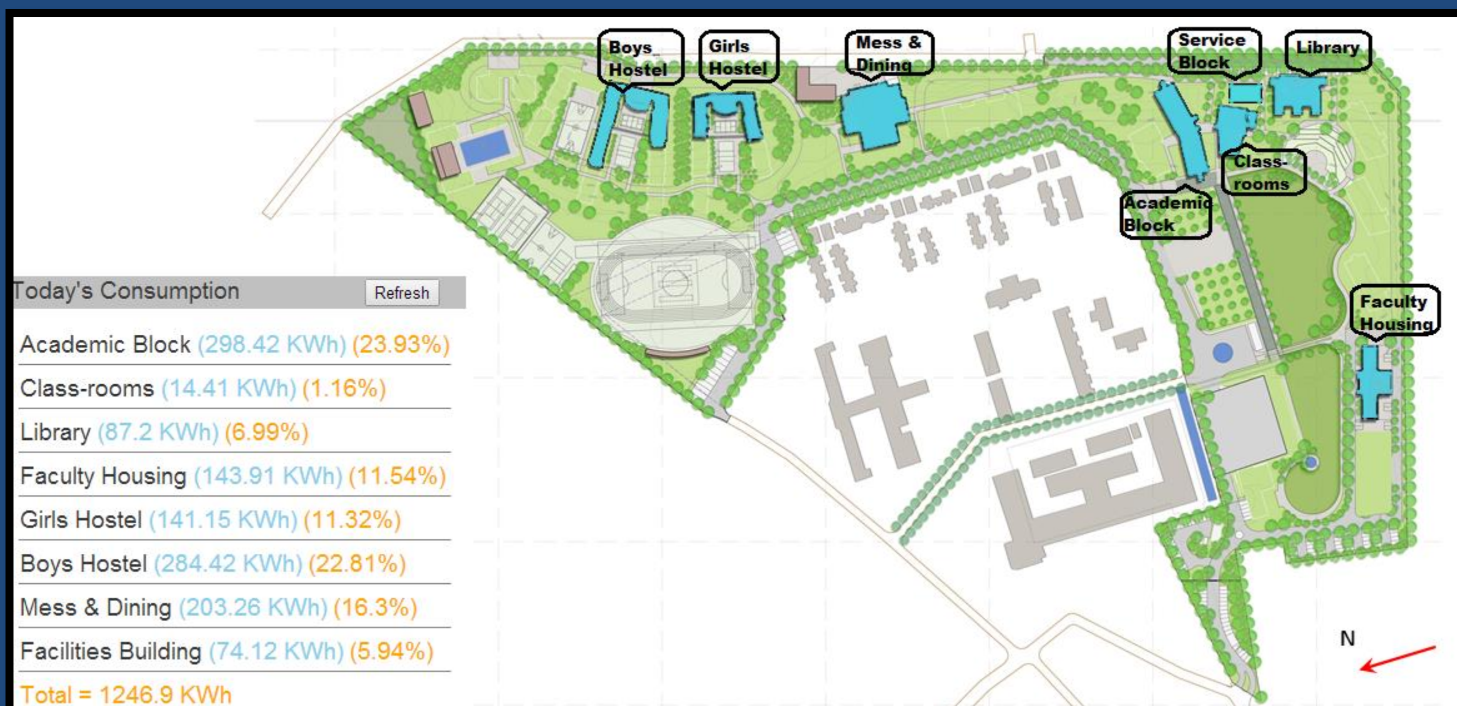
Occupants provide feedback for improved computation

- Occupants (and belongings) as sensors:
  - Cell phones ubiquitous. Used for:
    - Energy apportionment
    - Localization
    - Occupancy control
  - Body sensing (too intrusive)

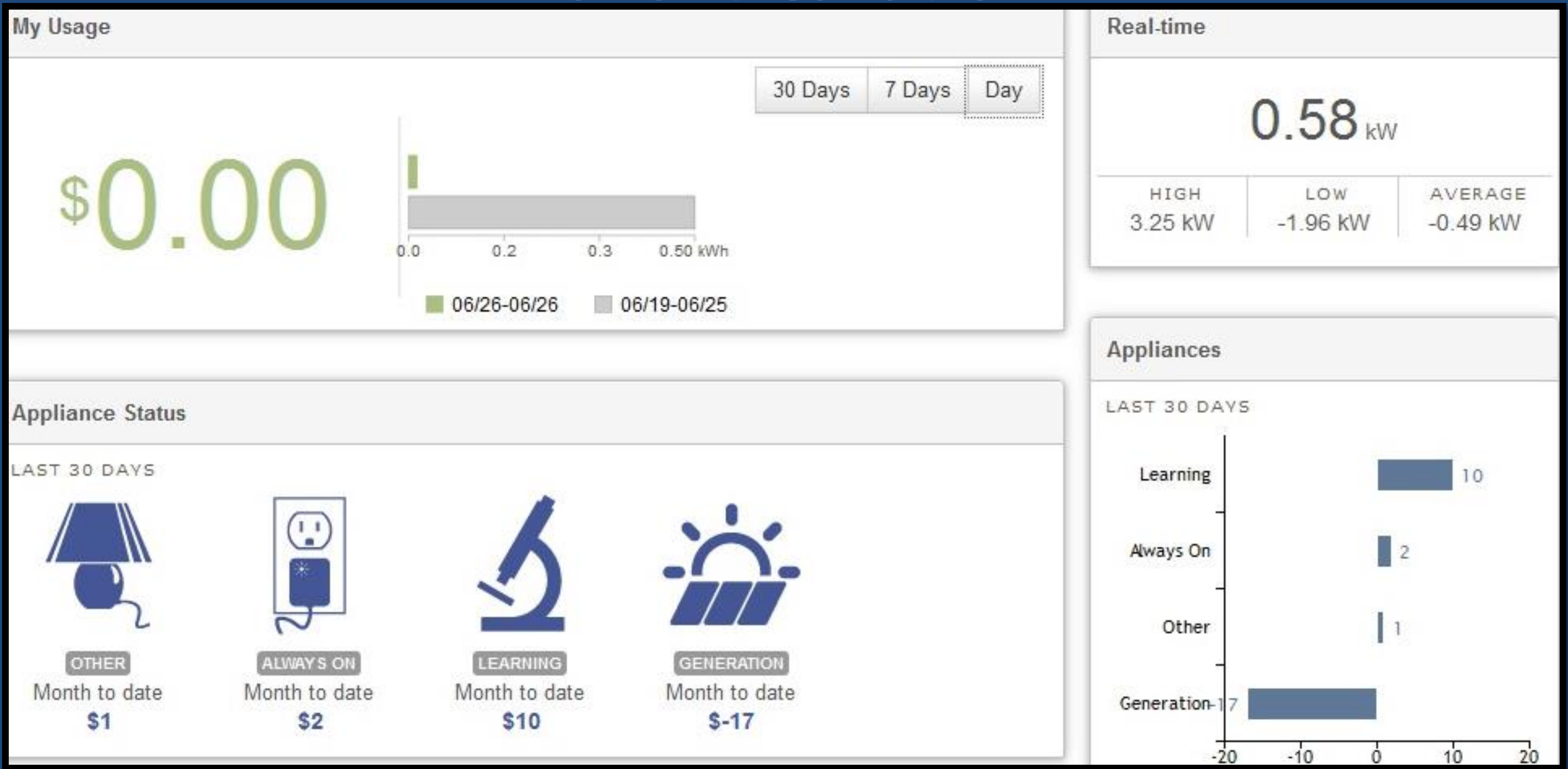
Computation to provide feedback to occupants

Energy dashboards

Broad understanding of energy consumption



Personalized feedback



[PlotWatt interface]

Novel interaction

Energy memento

Power aware cord

Borrowed from Pierce et al. Beyond energy monitors

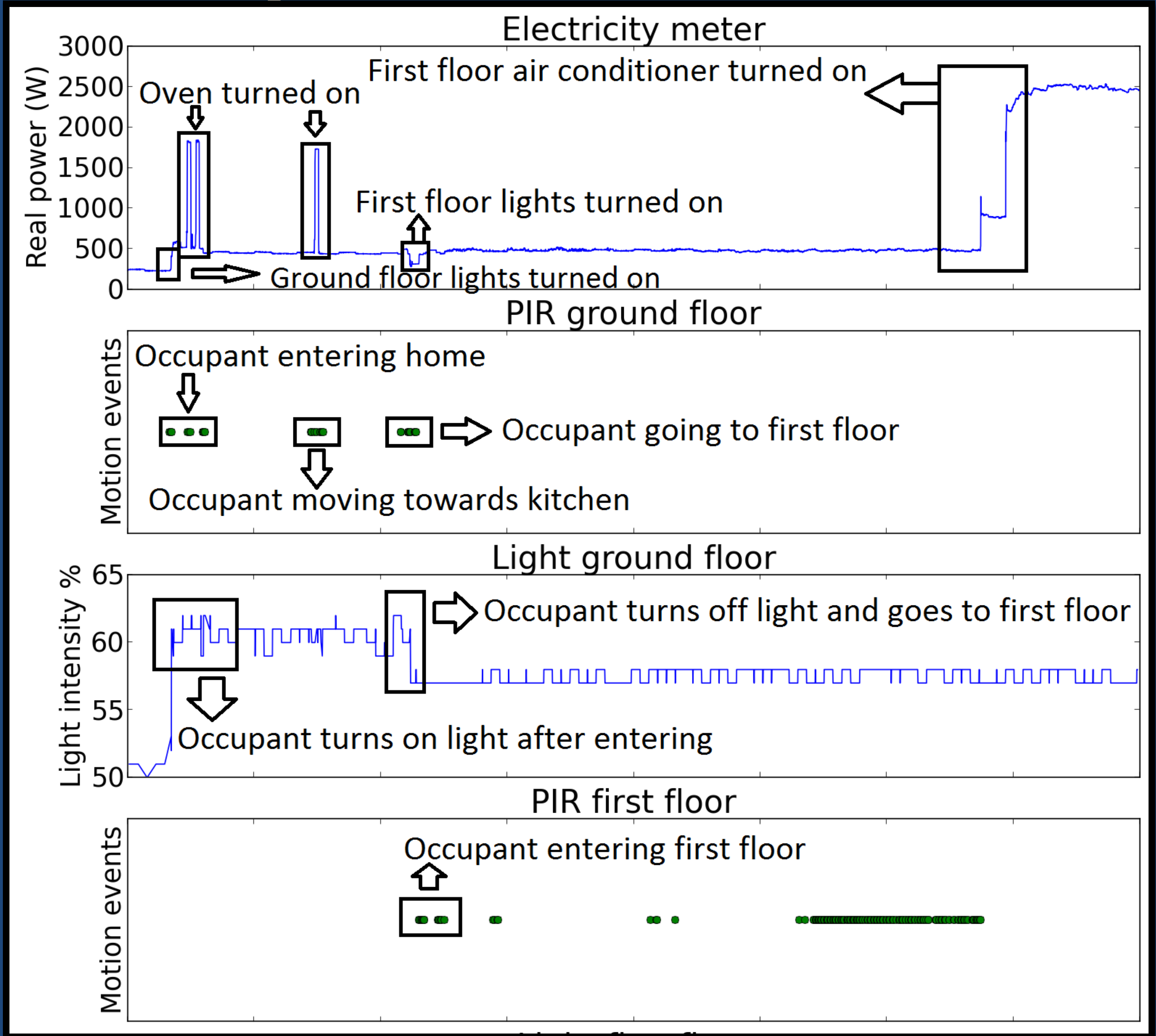
Water awareness

Video 2

Involve occupants: Challenges and Opportunities

Privacy concerns

The smart meter alone can reveal a lot of information, more so when interconnected



Opportunity

To develop privacy preserving architectures

Indifferent occupant attitude

- Occupants do not often pay for their electricity (eg. in commercial buildings) Why bother?
- Even when they pay, interest fades with time
- Critical to develop mechanisms for sustained interactions (Maybe need to take help from the HCI folks)

Intelligent operations

- Till now all the energy efficiency exists ONLY on paper
- Intelligent operations translate these into real actions
- Requires interaction with control system-which is complex. Let us discuss through an example

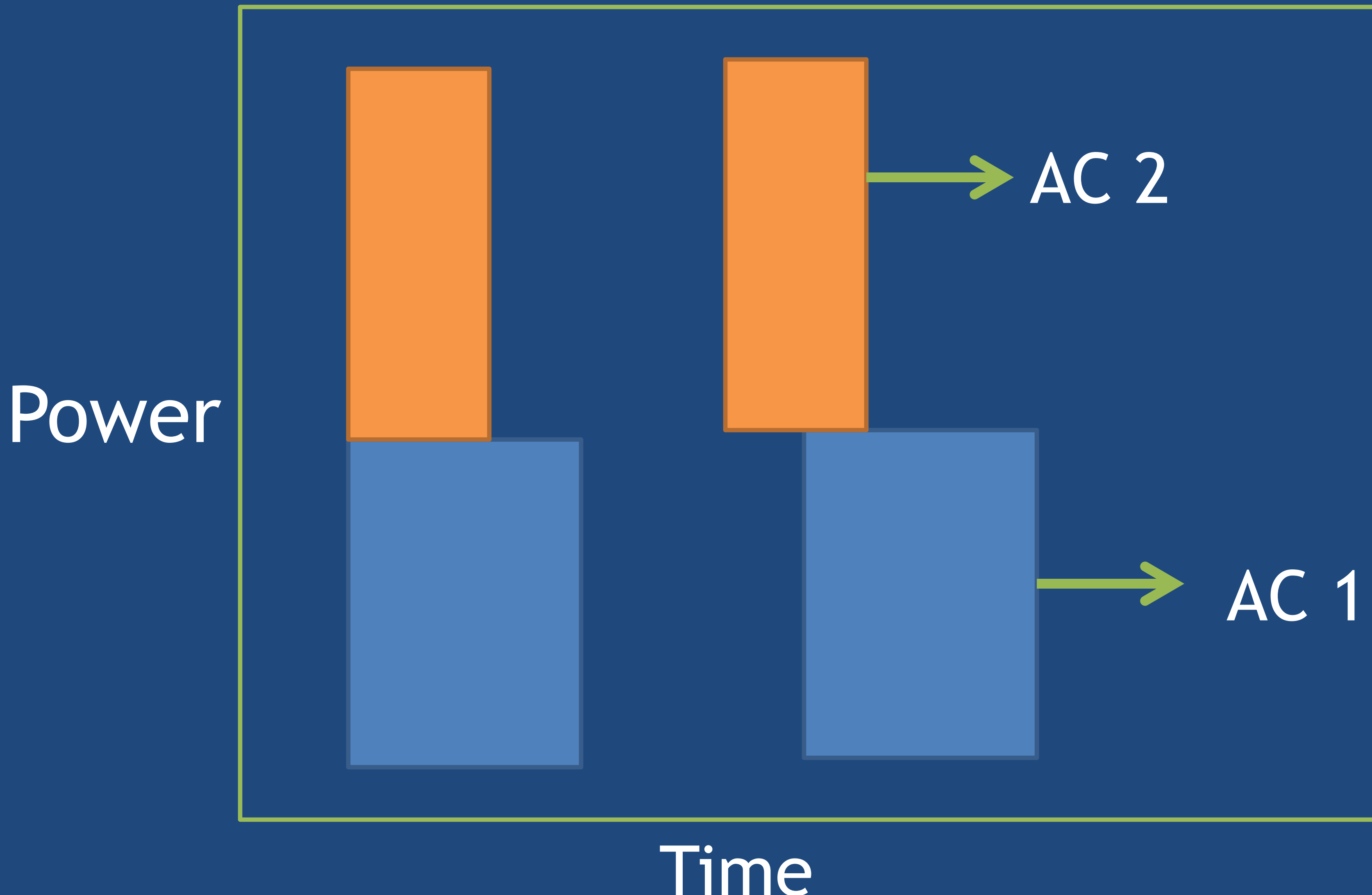
Peak demand flattening

- Electricity demand peaks at certain times of the day→ Electricity expensive at this time
- Utilities have to bear the expenses of firing additional generators
- Can we shift energy consumption from peak to non-peak hours? Let us look into two ways

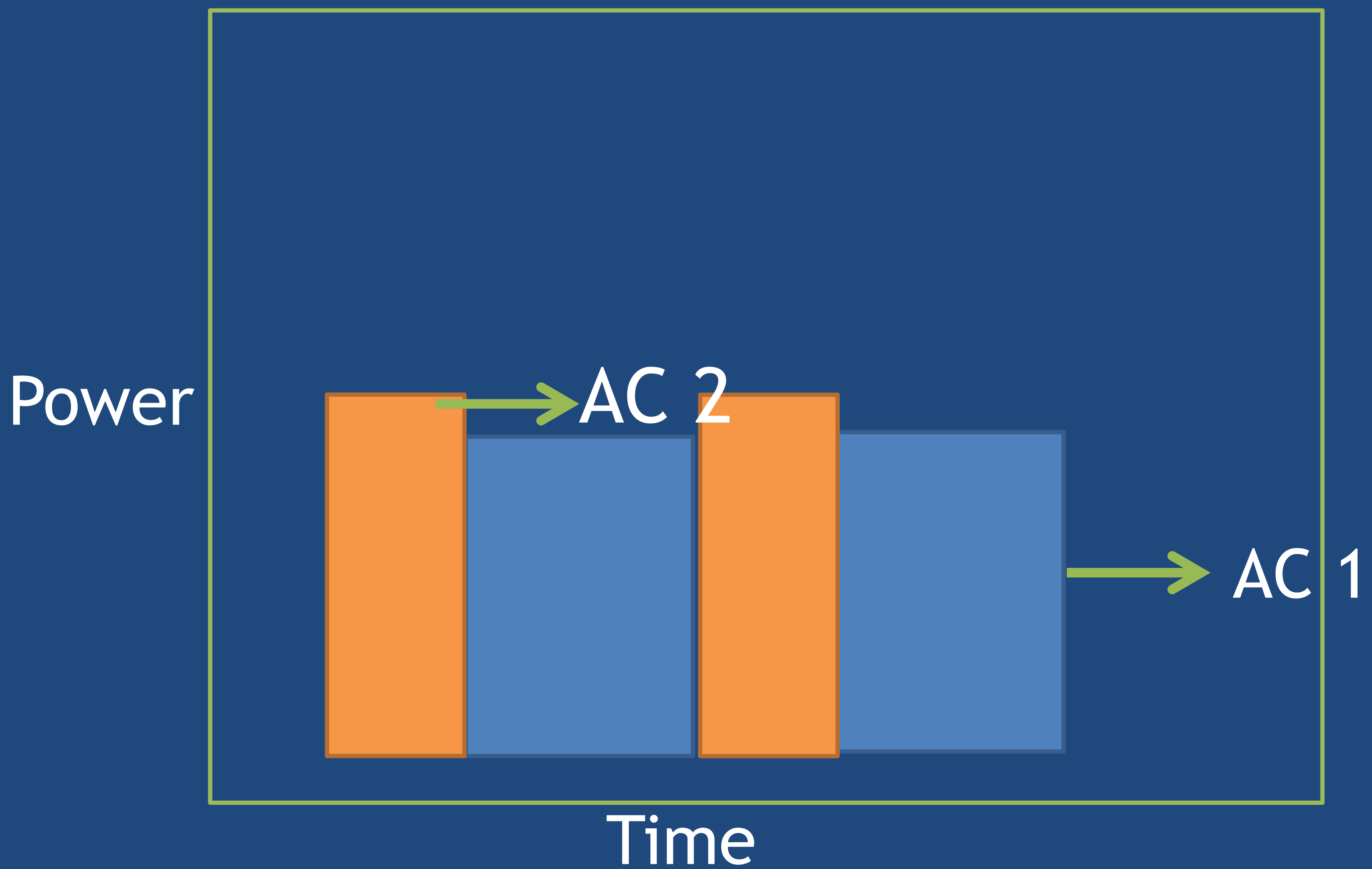
Load (Appliance) flexibility

- Loads are of two types:
  - Interactive (TV, Microwave)
  - Non-interactive (Fridge, AC)
- Method I: Consciously use interactive loads in non-peak hours
- Method II: Schedule non-interactive loads for flatter load profiles. Let us see an example of 2 ACs

Without scheduling



With scheduling



Using additional batteries

Video3

http://player.vimeo.com/video/76362710

Intelligent operations: Challenges and Opportunities

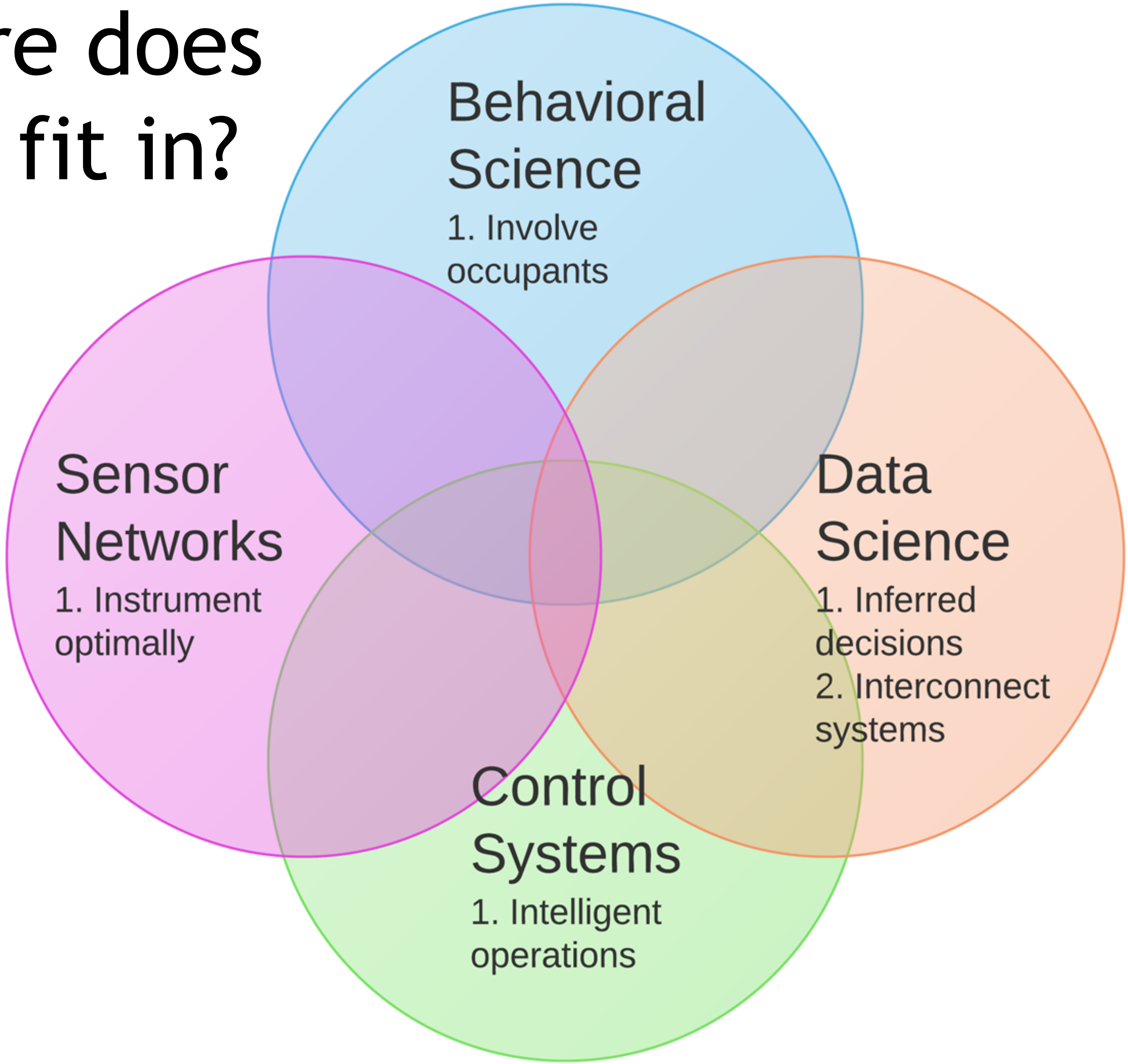
Significant up front cost

- Buying batteries and integrating with existing supply
- Granting additional switching capabilities to electric appliances
- Needs governments to step up

Complex control environment

- Bad things do happen
- Ariane V crash [Video 4]
- Real world brings unforeseen challenges
  - Can't be emulated in any simulator
  - Control engineers- "If it ain't broke, why fix it?"
  - Calls for development of reliable theoretical guarantees that all cases are covered

Where does it all fit in?



Key takeaways

Buildings consume significant energy, are constructed at rapid rate → need to look into efficiency

“Data is the new oil”
Data can help make buildings more energy efficient

5 Is of data driven building energy efficiency

Instrument optimally to get data

Interconnect sub-systems to exploit relationships

Inferred decision making to translate data to insights

Involve occupants

Intelligent operations to realize the other four Is

Golden Rule

Sophistication must match across the five Is for optimal energy efficiency

Thank you