Being SMART
The Role of Timely Analytics

Krithi Ramamritham
IIT Bombay

Center
for
Urban Sc. & Engg.

Smart
Energy
Informatics
Lab

Towards Sustainable Energy

Reduce

- Consumption
- Peaks
- Reliance on unsustainable energy sources

Towards Sustainable Energy

Reduce

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Reuse resources

Towards Sustainable Energy

Reduce

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- Reliance on unsustainable energy sources

Reuse resources

Recycle resources

Towards Sustainable Energy

Reduce

- Consumption
- Peaks
- Reliance on unsustainable energy sources

Reuse resources

Recycle resources

The 3 R's

Towards Sustainable Energy

Be SMART

Reduce

- Consumption
- Peaks
- Reliance on unsustainable energy sources

Reuse resources

Recycle resources

The 3 R's

Being Smart

clever, bright, intelligent, able,
shrewd, astute, perceptive, savvy

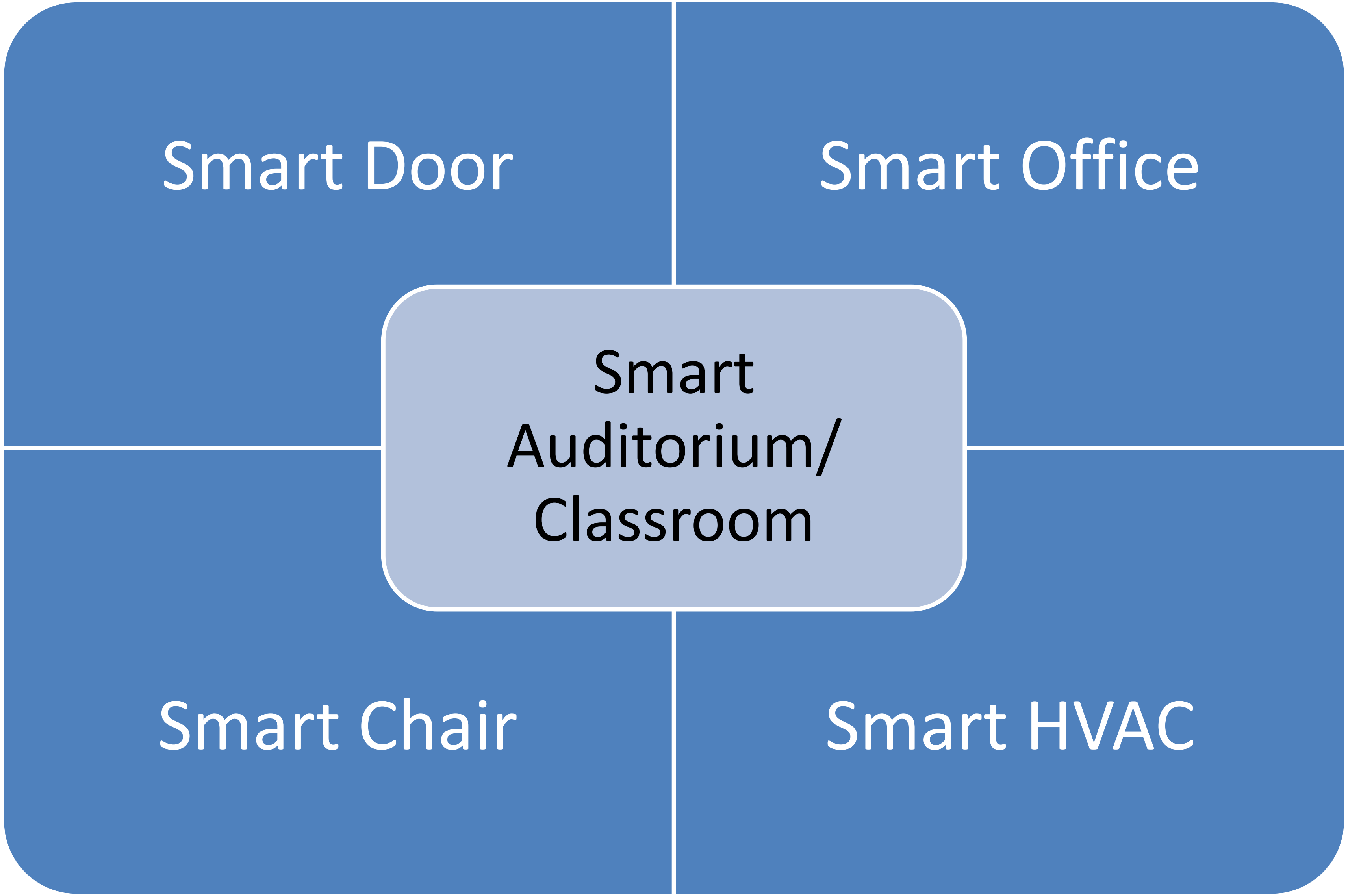
brisk, energetic, vigorous

fast, rapid, swift, lively

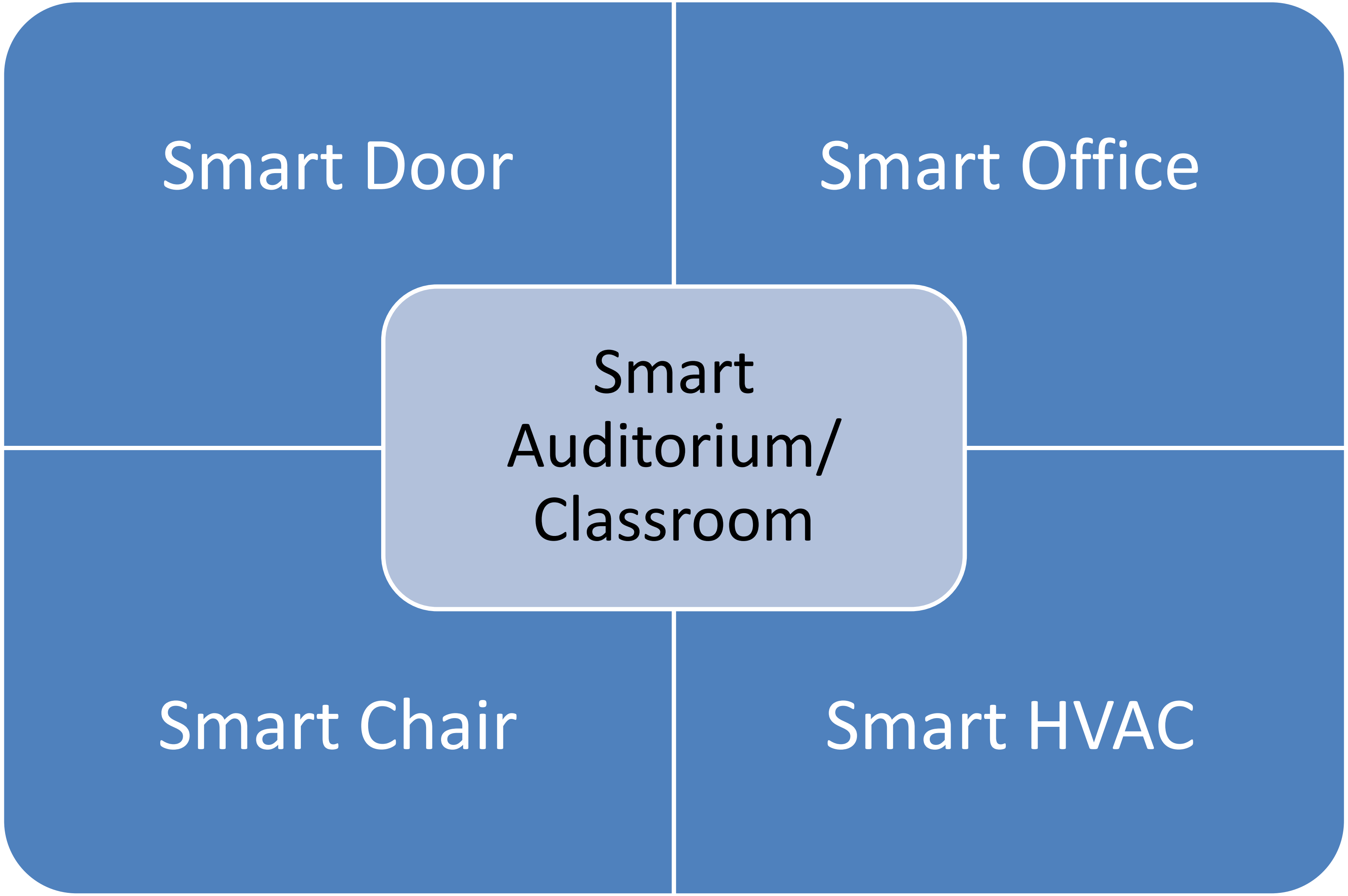
sharp-witted, quick-witted
quick on the uptake

SMART Energy

Smart buildings
Smart campuses
Smart grids
Smart cities



Smart buildings
Smart campuses
Smart grids
Smart cities



Spotlight:
Smart Classroom

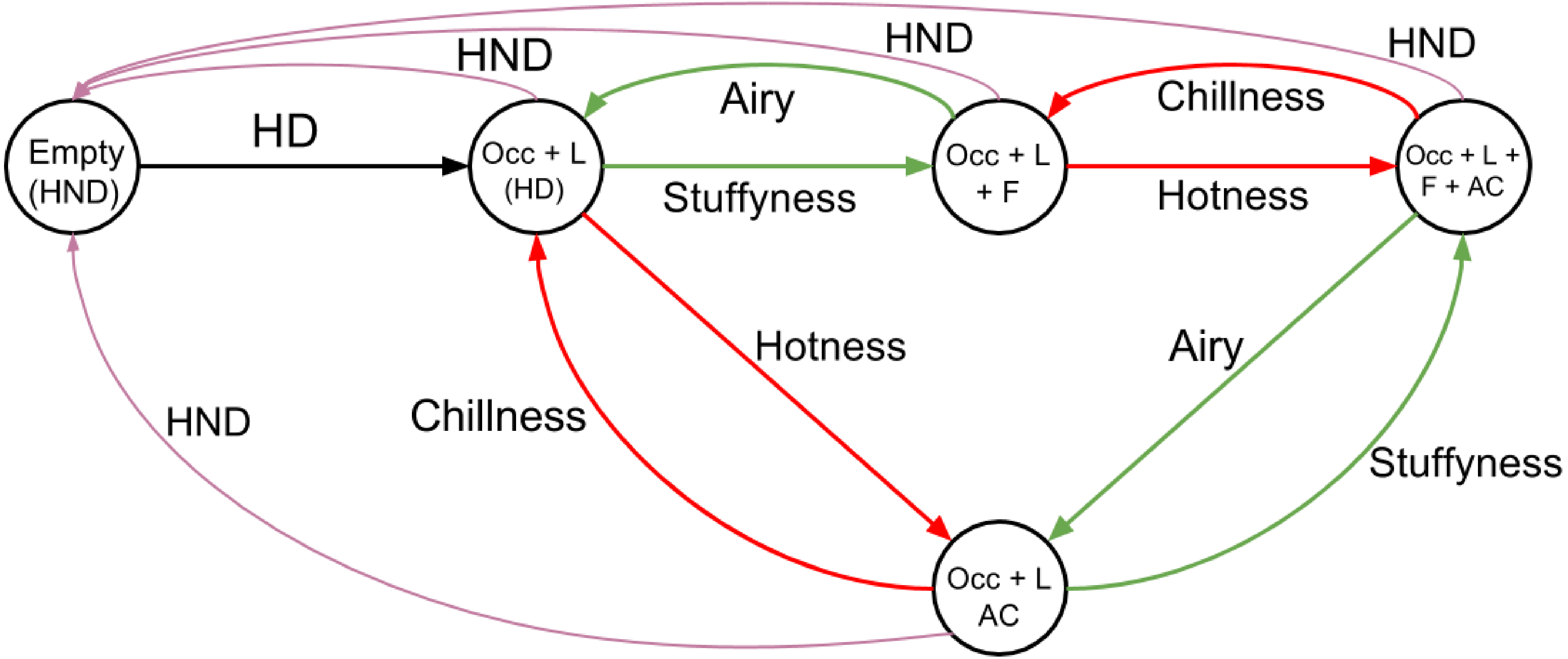
The Smart Classroom Complex

Spotlight:
Smart Classroom

The Smart Classroom Complex

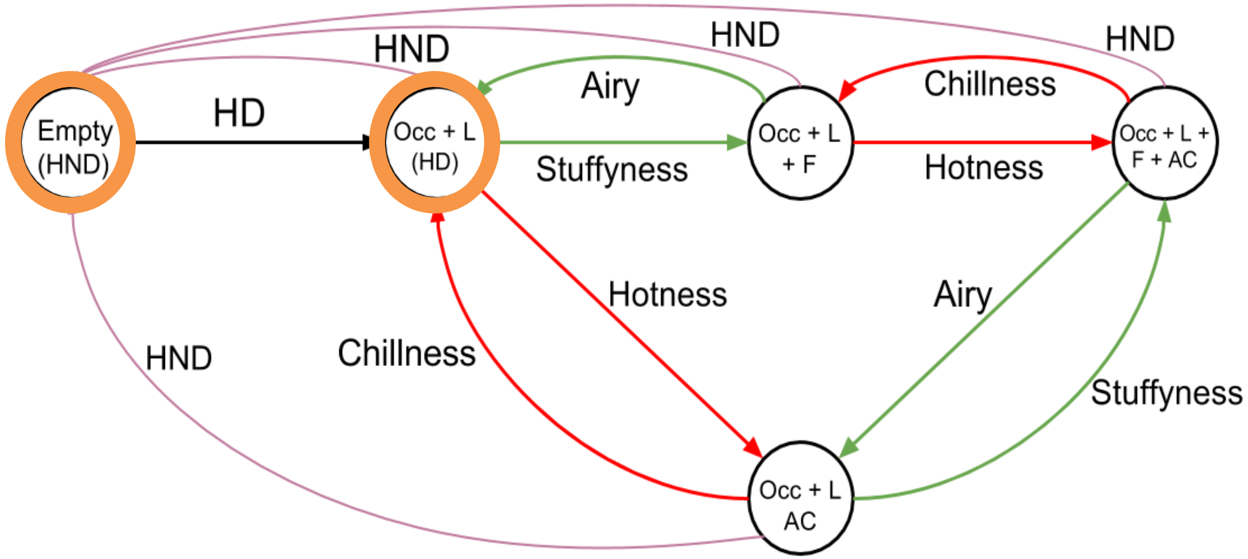
Energy Consumed ONLYIF Occupied

The Smart Classroom Complex



Occ - Occupied
HD - Human Detected
HND - Human Not Detected

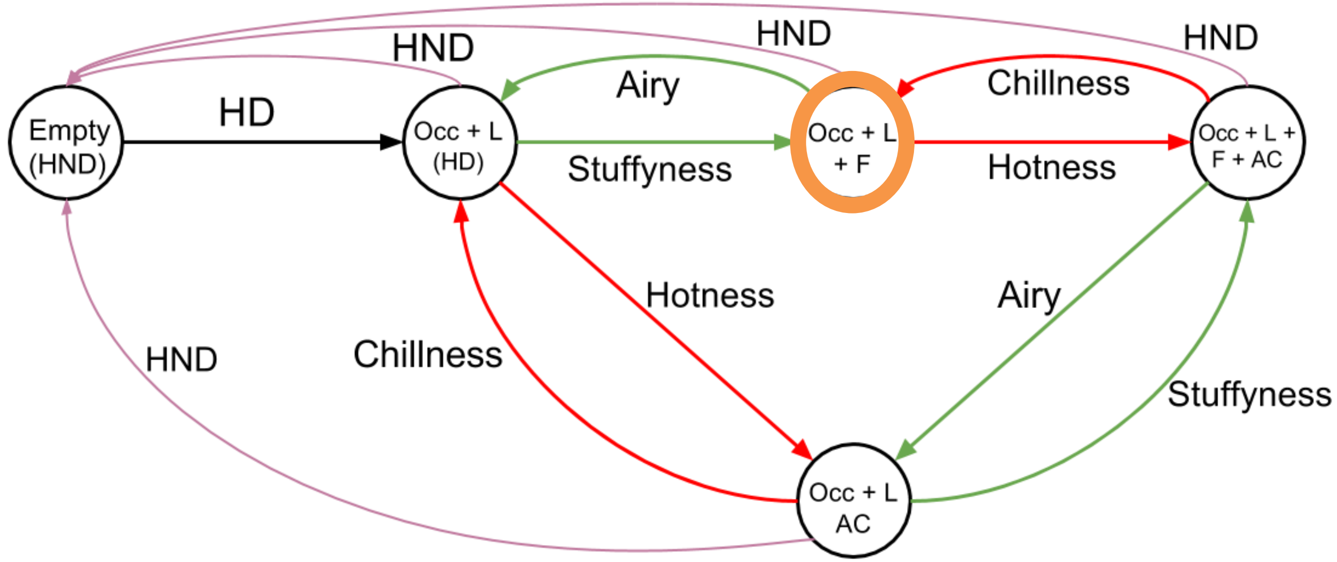
L- Lights
F - Fans
AC - Air Conditioners


Empty (HND)
HD
Occ + L (HD)
HND
Airy
Stuffyness
Occ + L + F
HND
Chillness
Hotness
Occ + L + F + AC
HND
Hotness
Airy
HND
Chillness
Stuffyness
Occ + L AC

Sense Temperature & Humidity

Analyze Temperature & Humidity > Threshold of Fan

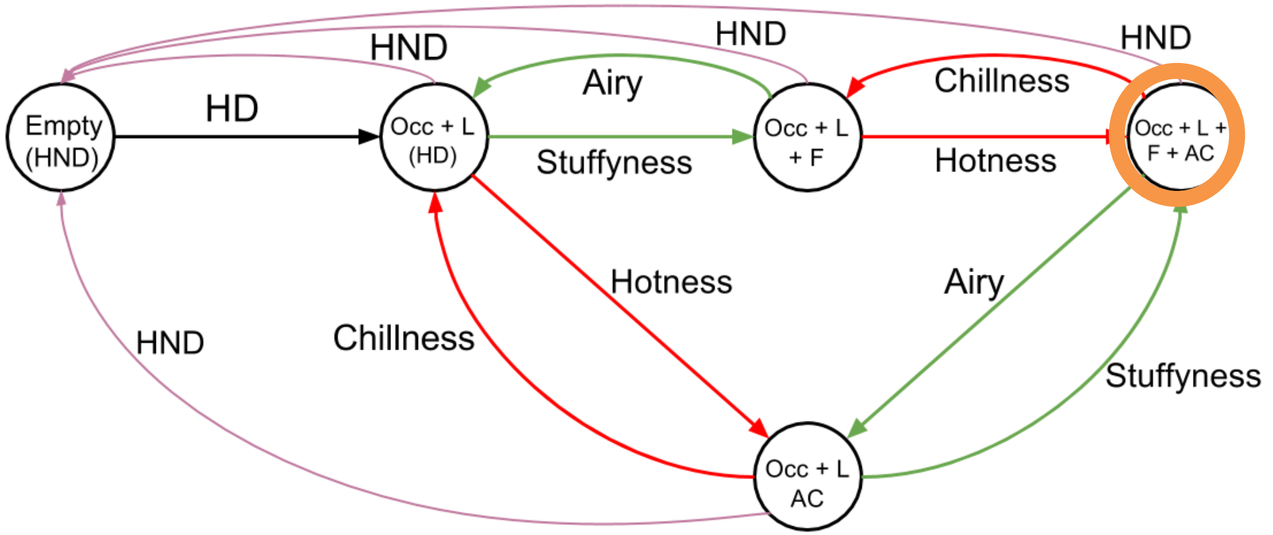
Respond Turn ON Fans



Sense Temperature

Analyze Temperature > Upper Threshold of AC

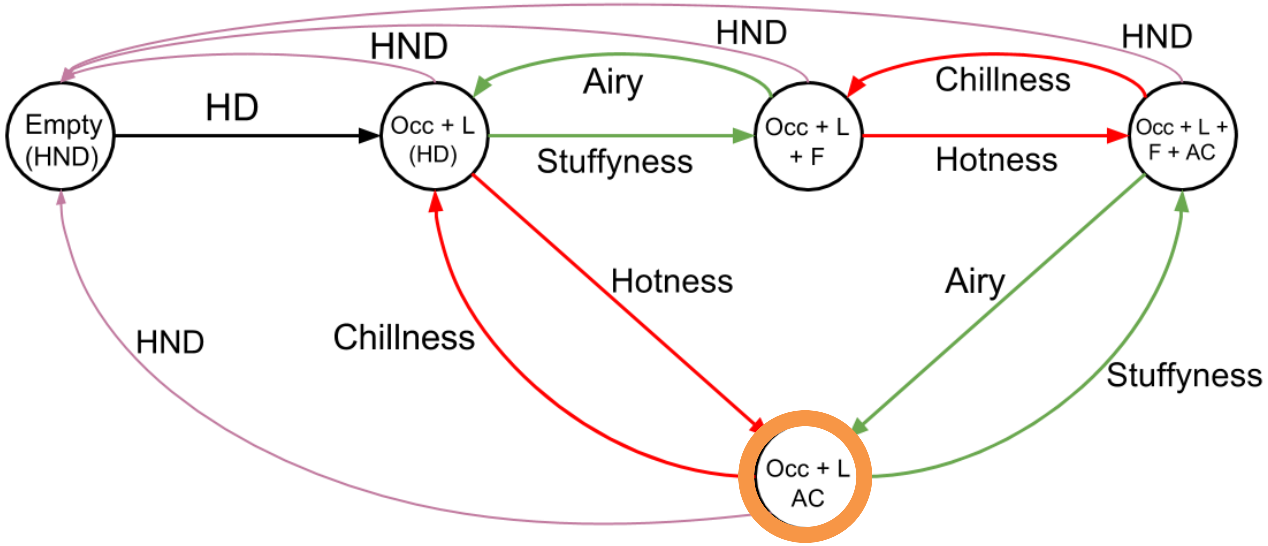
Respond Turn ON AC

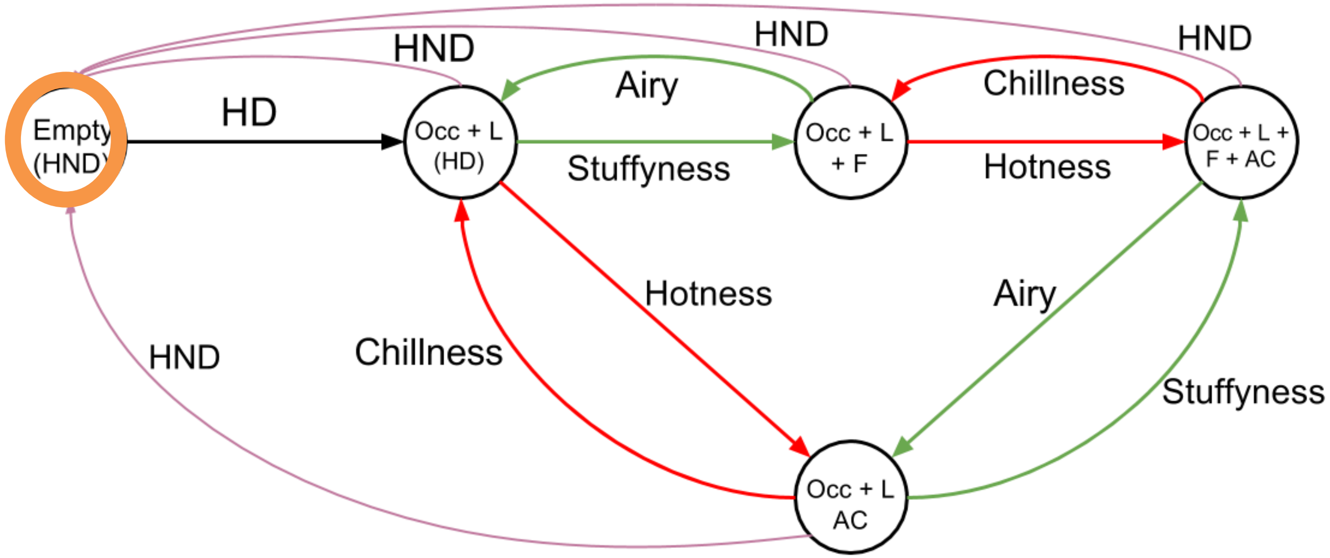


Sense Temperature & Humidity

Analyze Temperature > Upper Threshold of AC
Temperature & Humidity < Threshold of Fan

Respond Turn OFF Fans

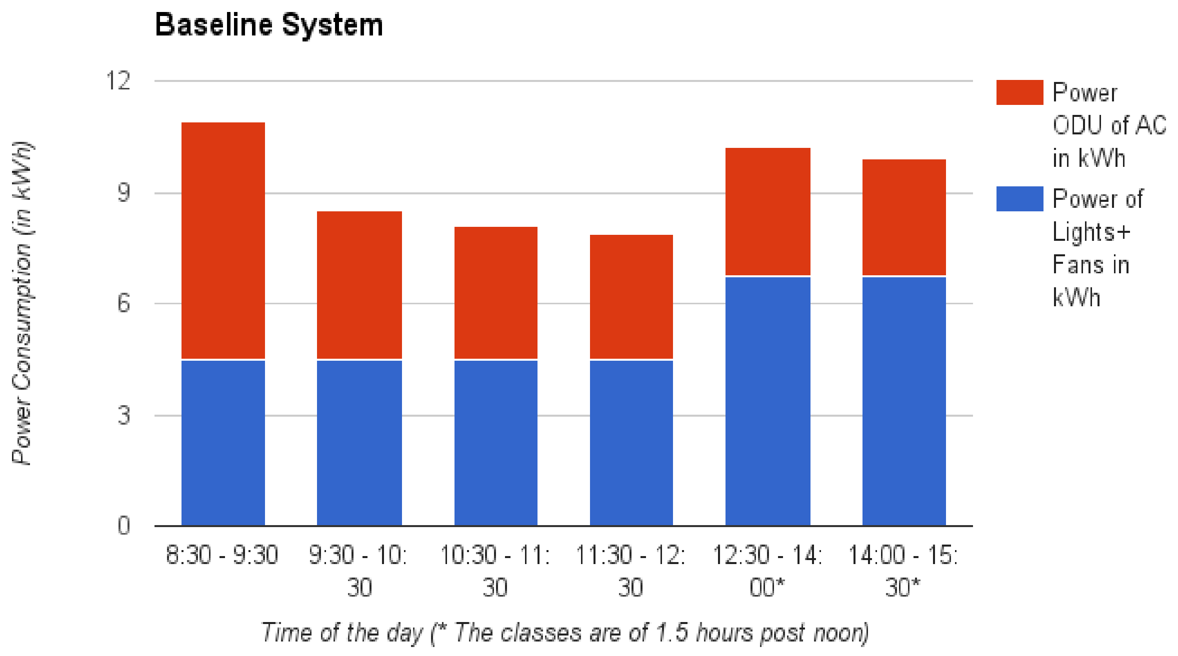




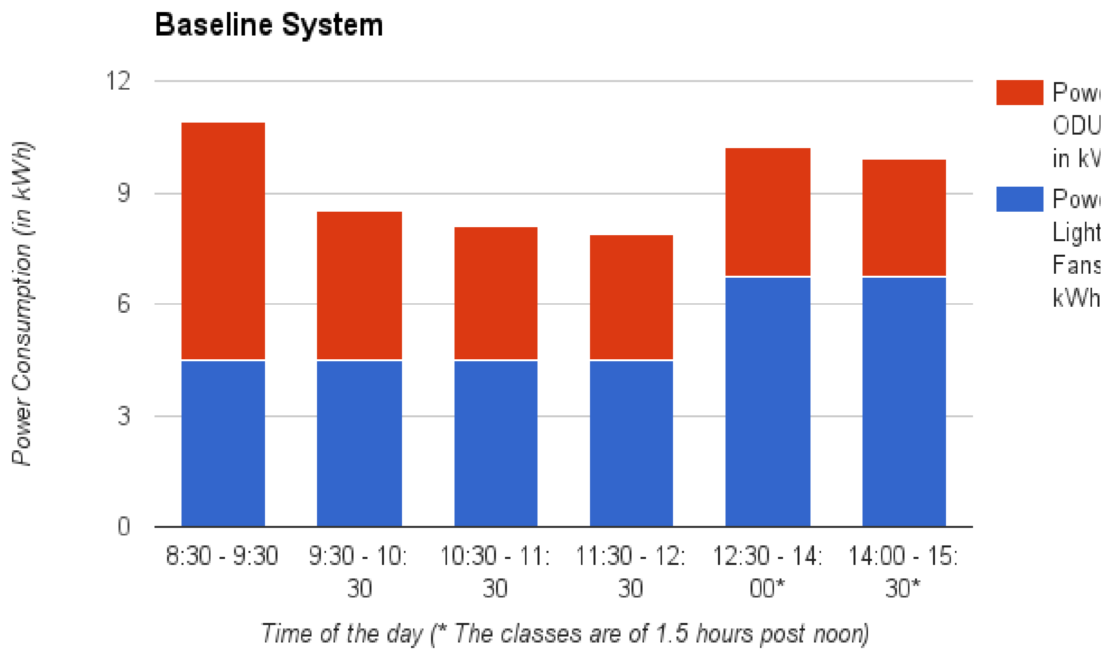
Zero Occupancy

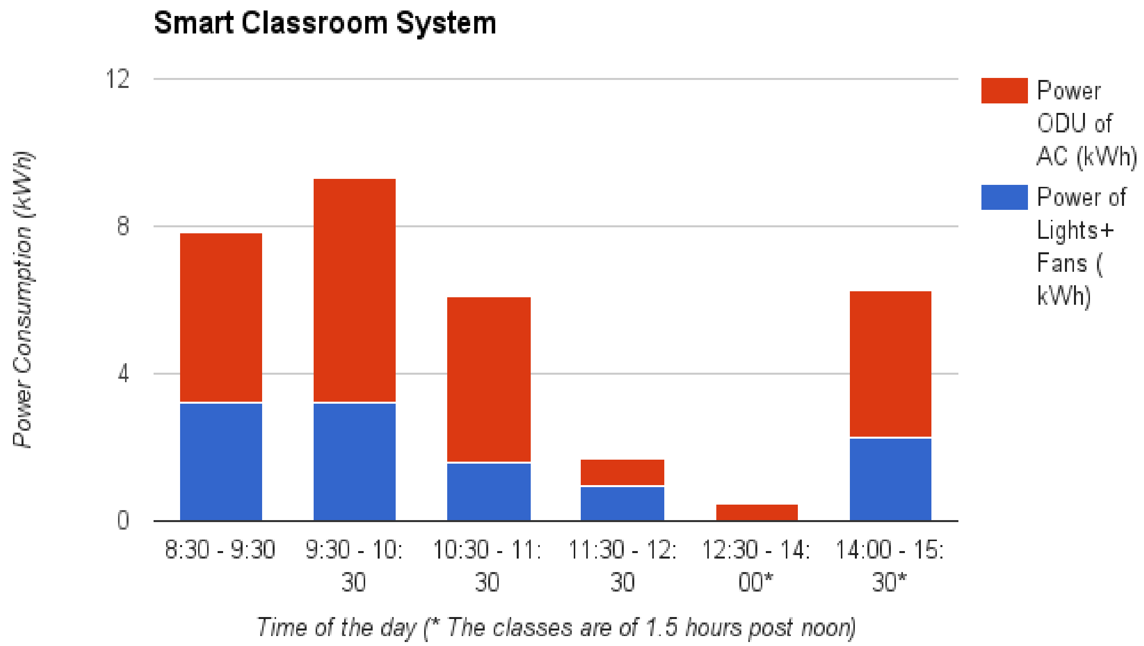
Zero Consumption

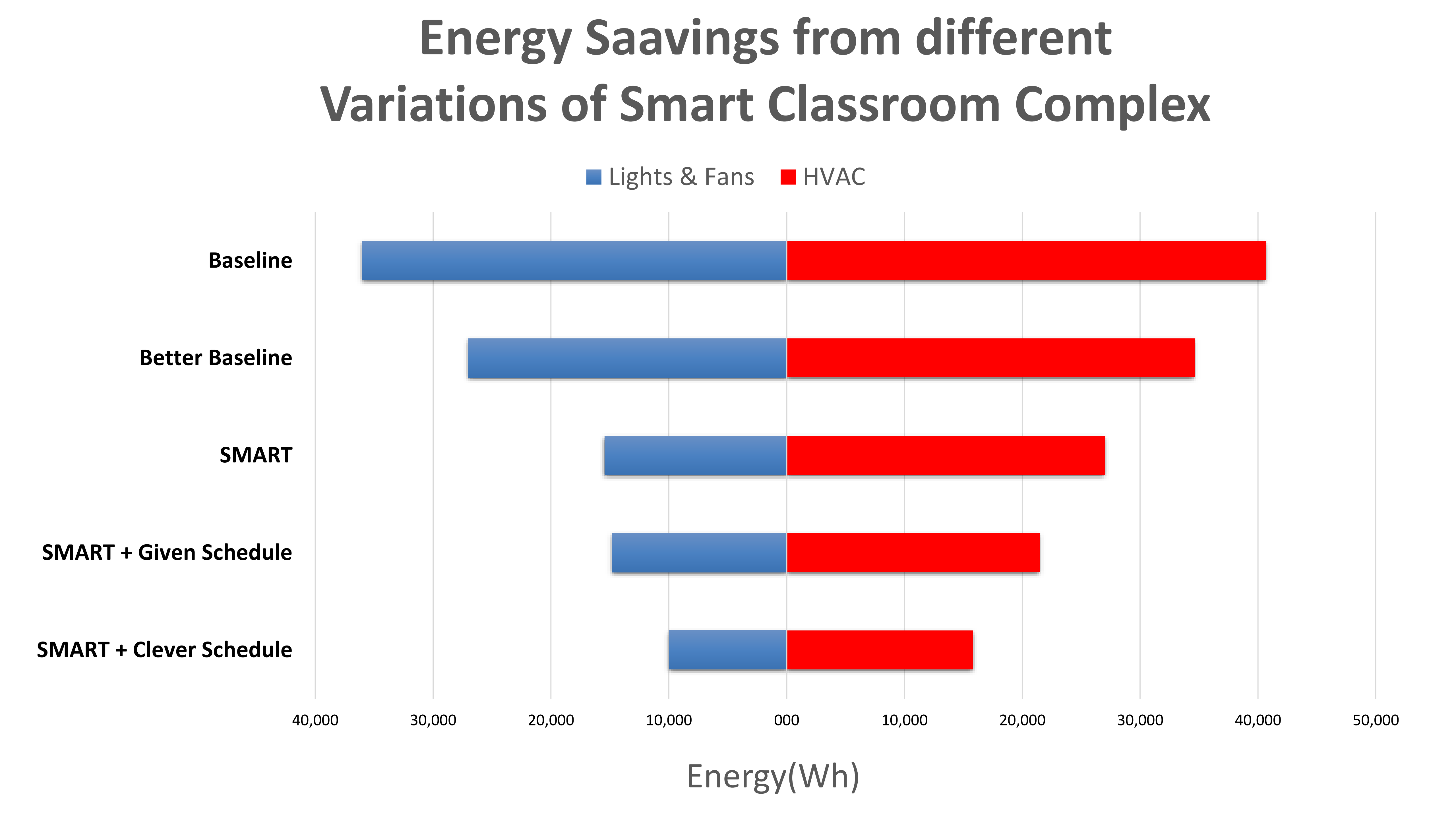
Energy savings



Energy savings

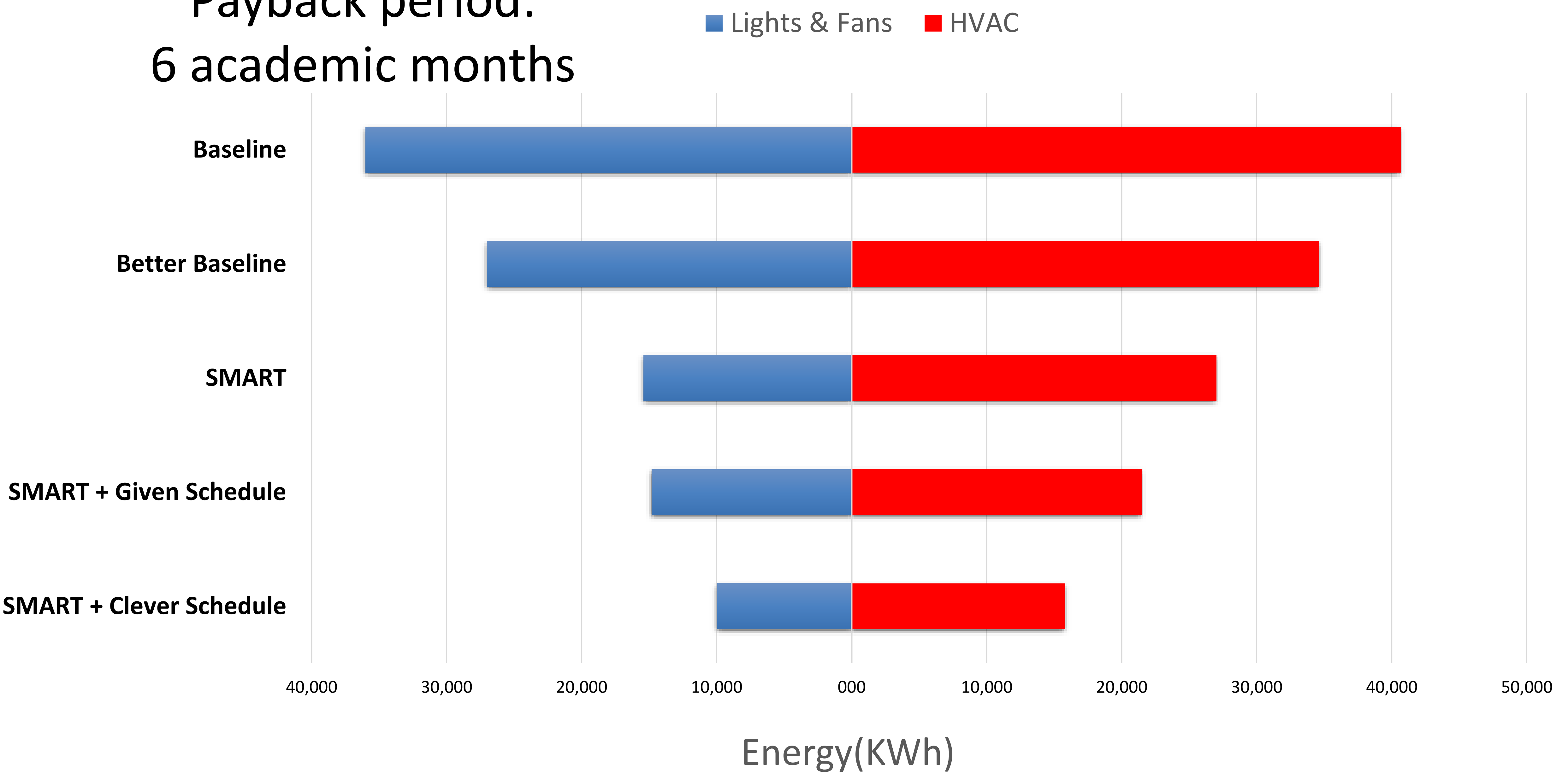


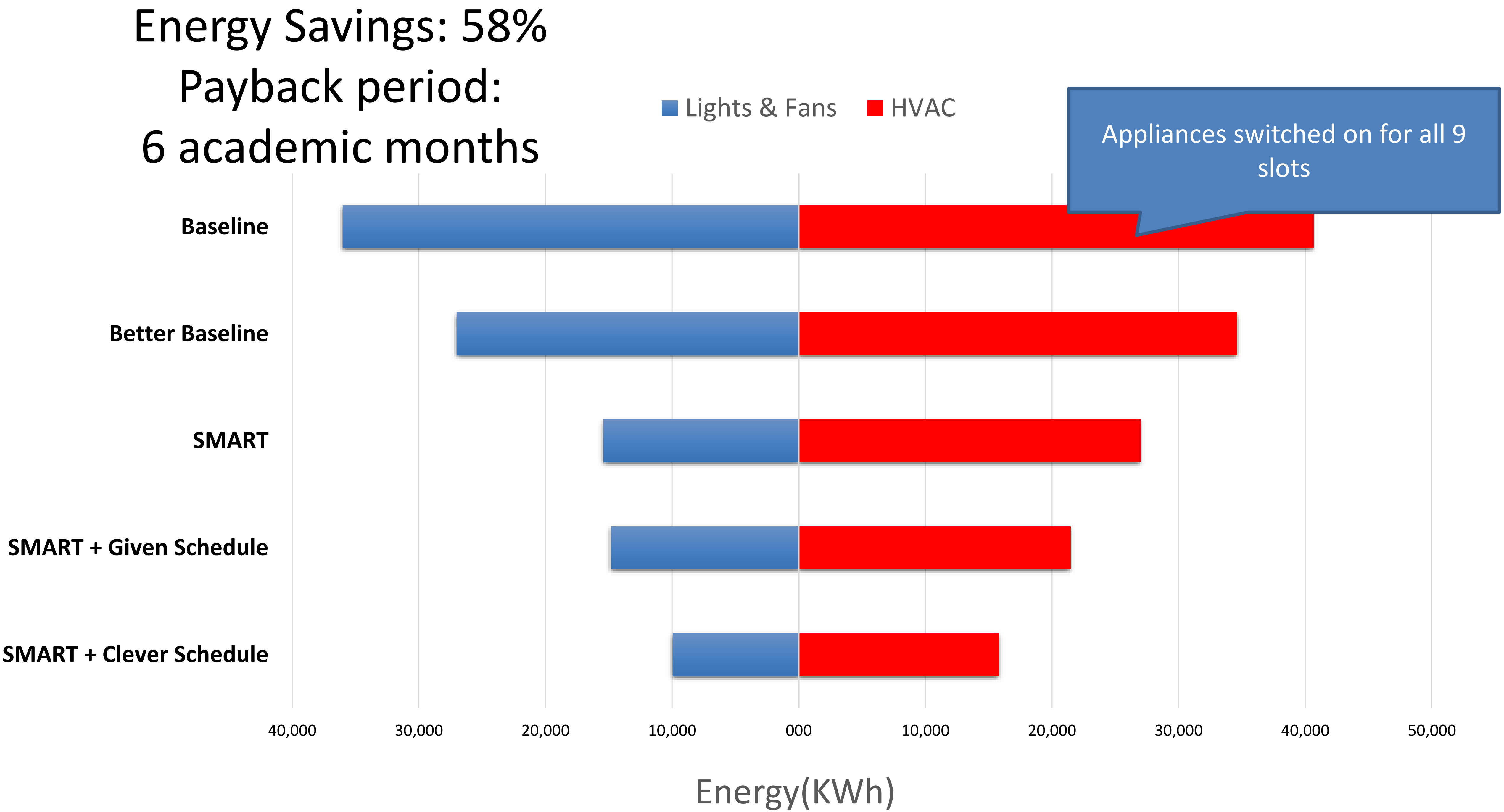




Energy Saavings from different Variations of Smart Classroom Complex
Lights & Fans
HVAC
Baseline
Better Baseline
SMART
SMART + Given Schedule
SMART + Clever Schedule
40,000
30,000
20,000
10,000
000
10,000
20,000
30,000
40,000
50,000
Energy(Wh)

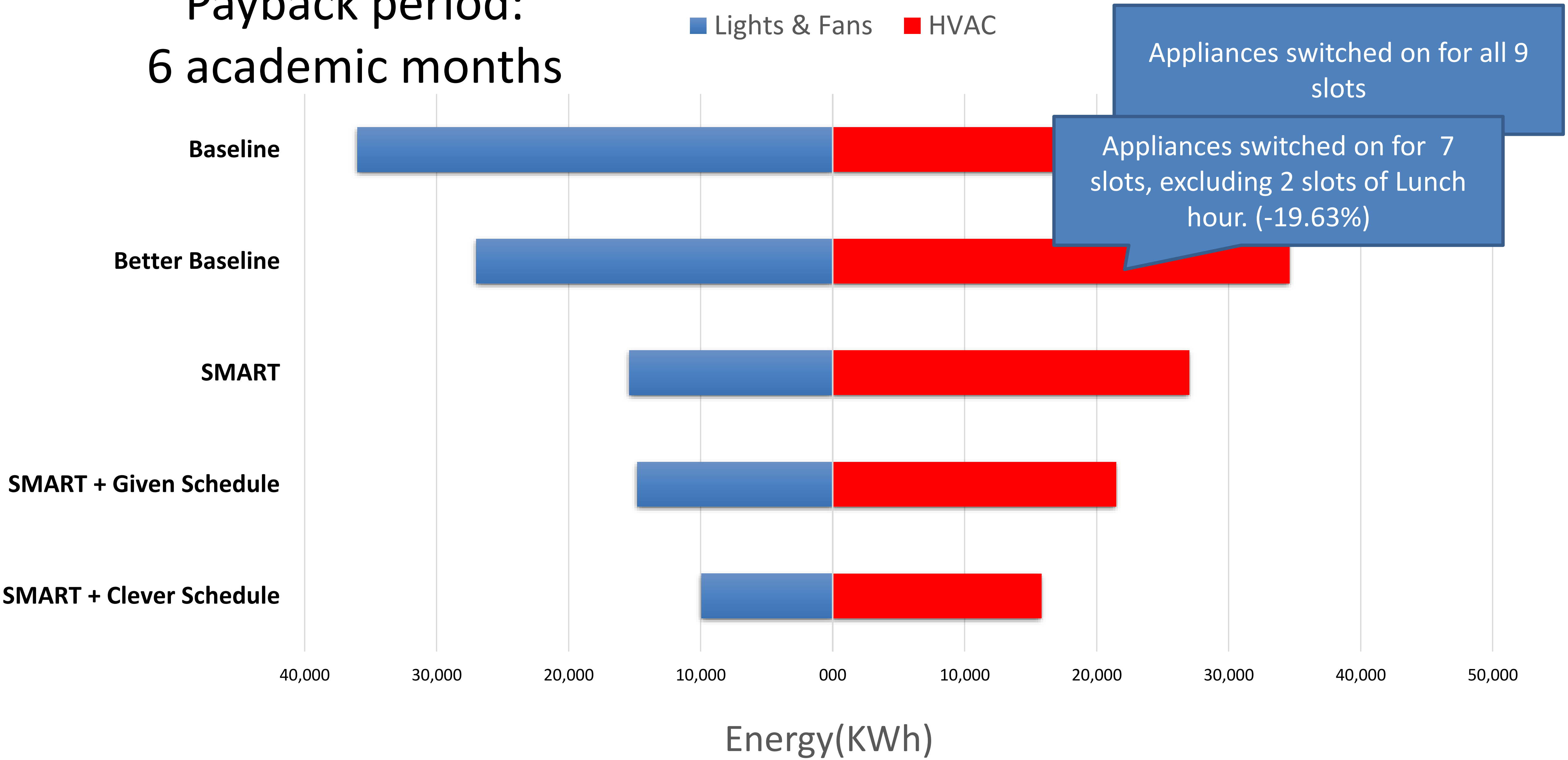
Energy Savings: 58%
Payback period: 6 academic months





Energy Savings: 58%
Payback period:
6 academic months
Lights & Fans
HVAC
Appliances switched on for all 9 slots
Baseline
Better Baseline
SMART
SMART + Given Schedule
SMART + Clever Schedule
40,000
30,000
20,000
10,000
000
10,000
20,000
30,000
40,000
50,000
Energy(KWh)

Energy Savings: 58%
Payback period: 6 academic months



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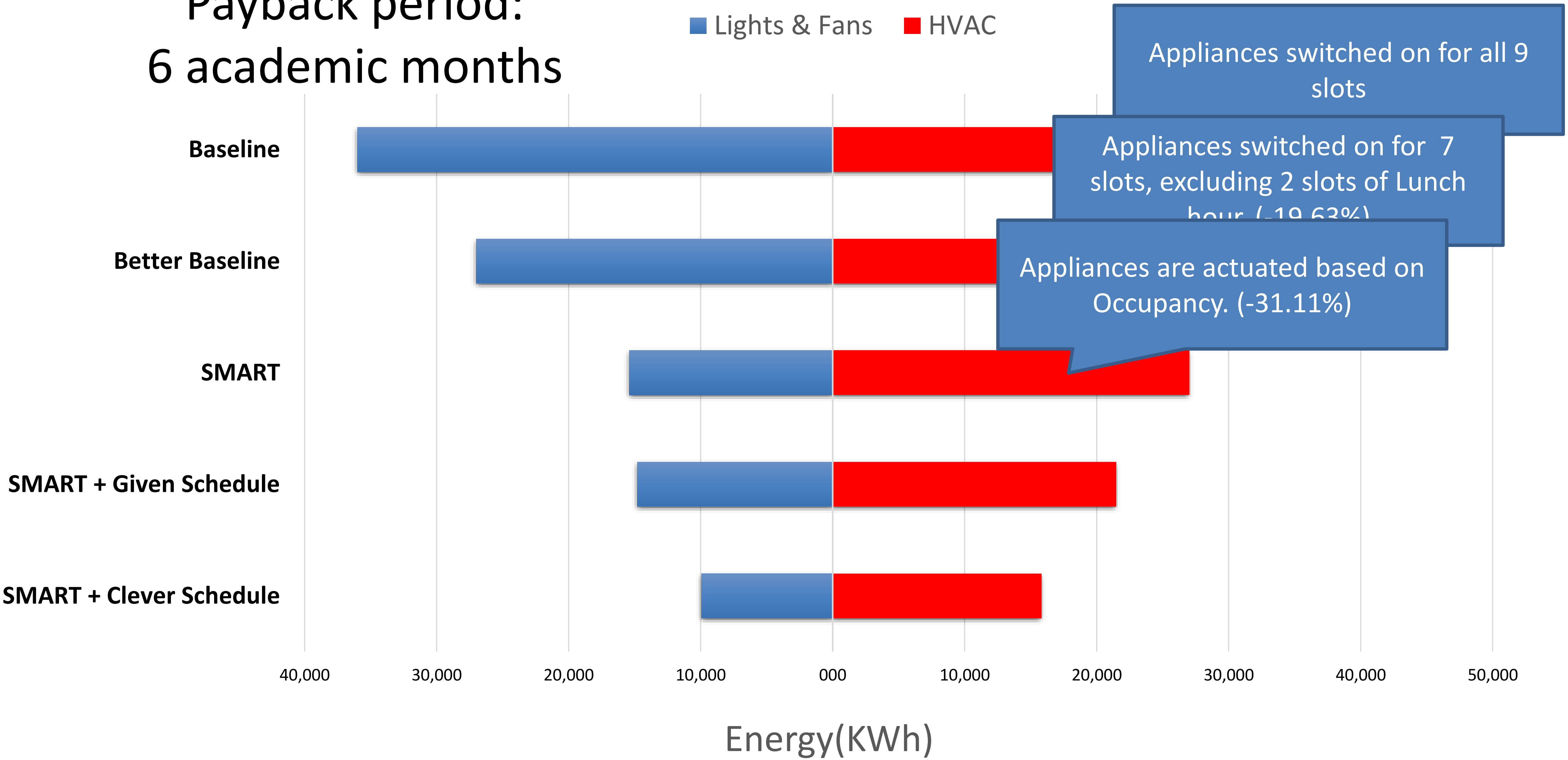

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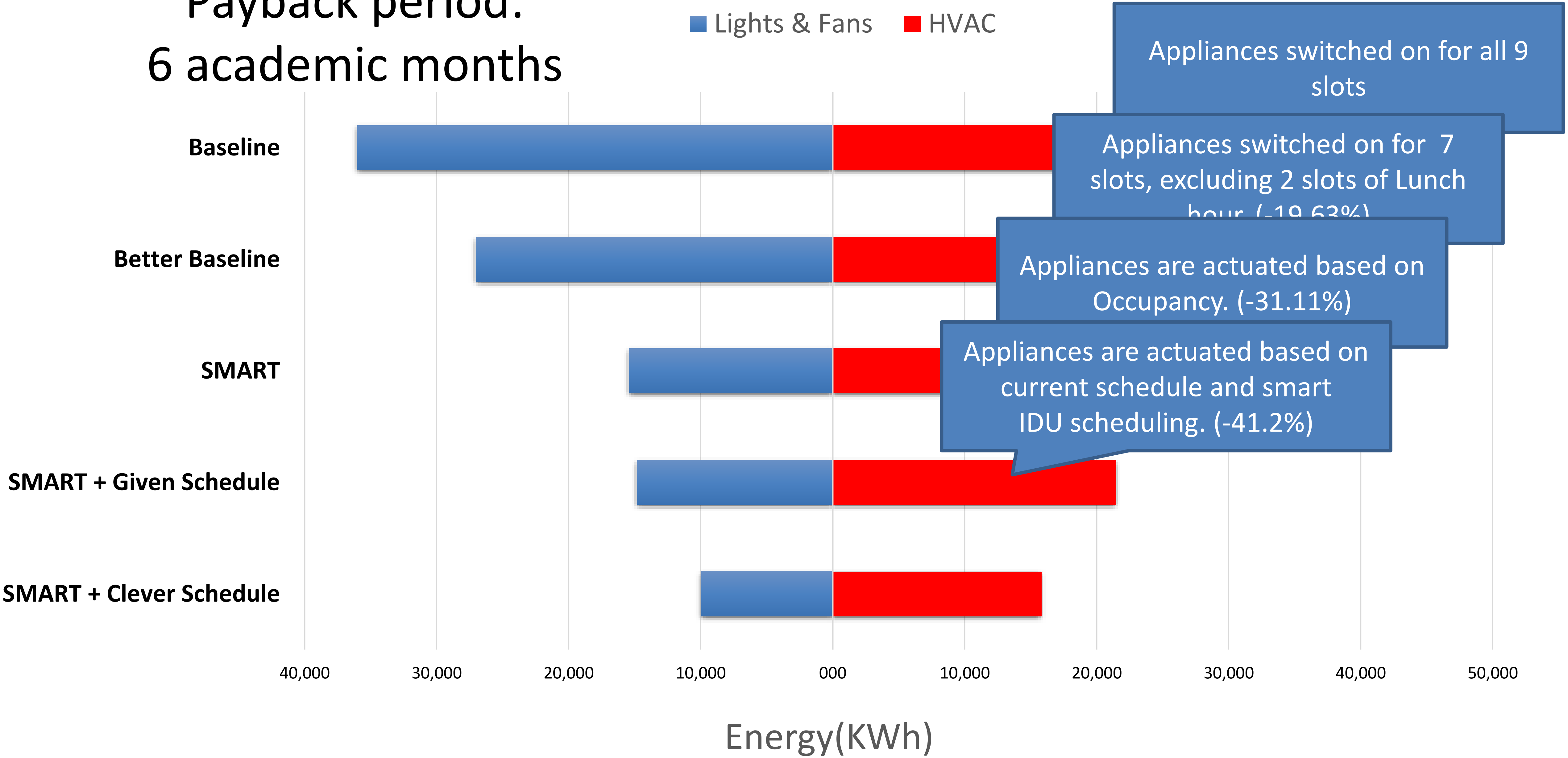

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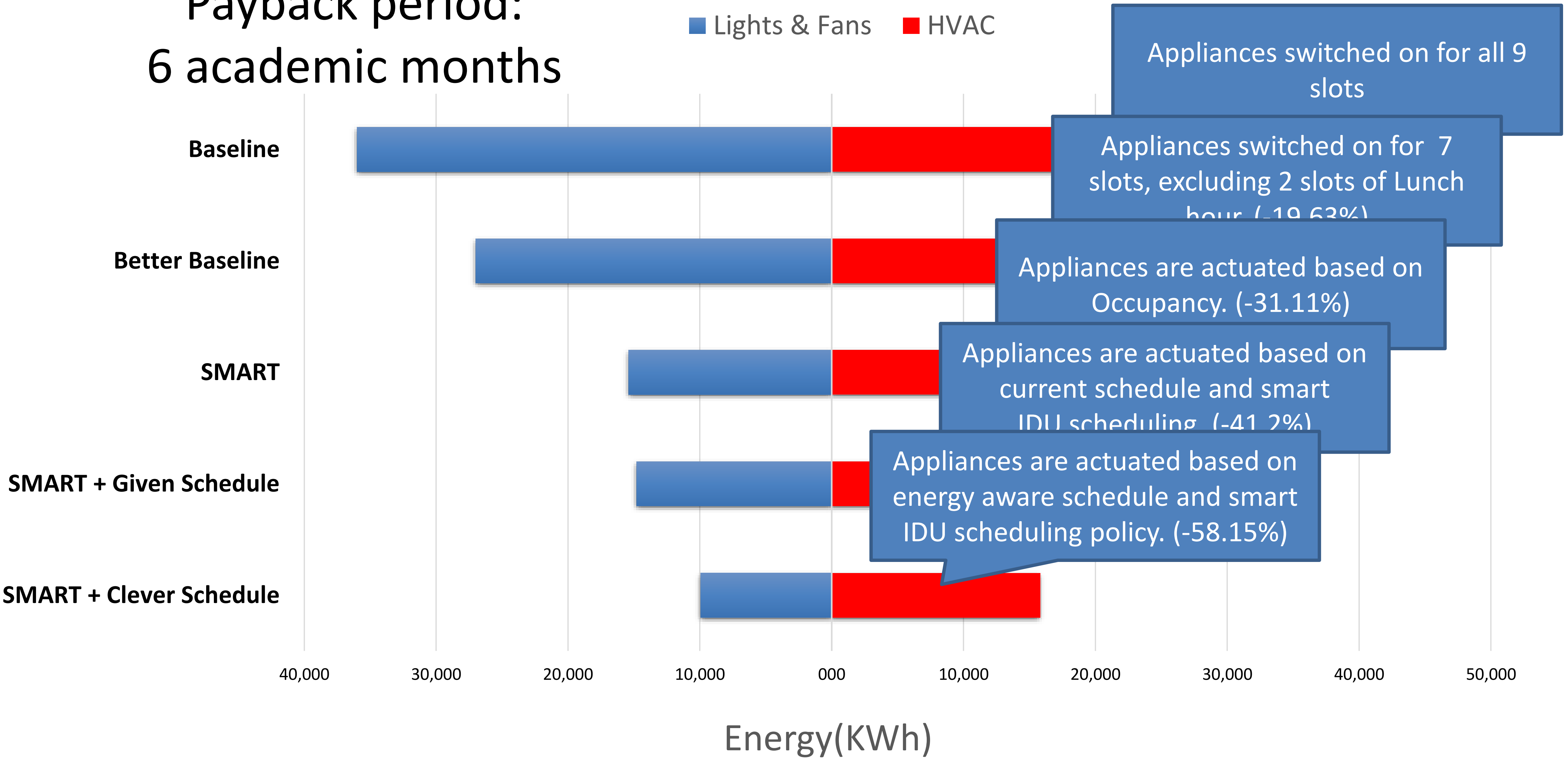


Room Scheduling to Reduce Consumption

Old Schedule

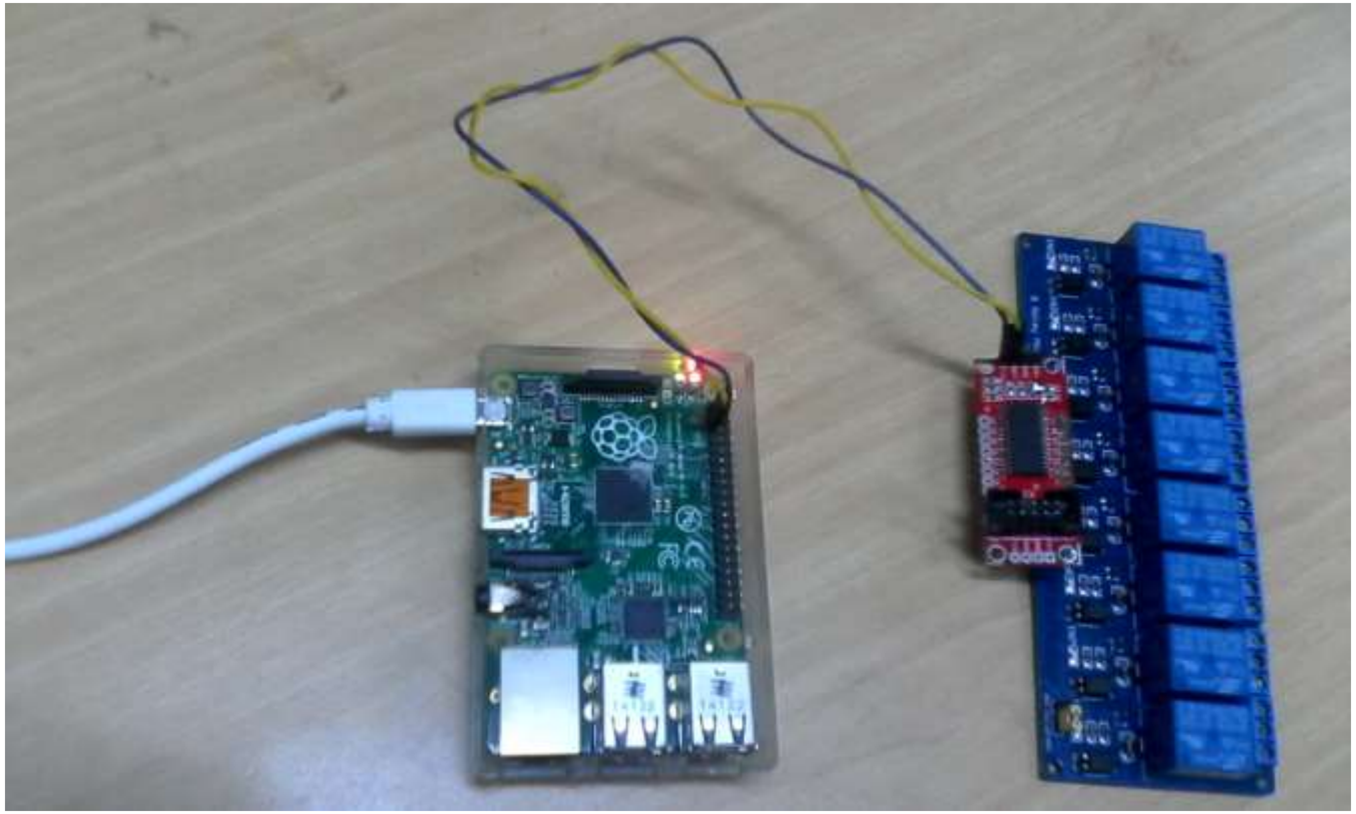
Slot	SIC-205	SIC-305	SIC-201	SIC-301
1				
2	HS 490 (12)		CS 681 (38)	CS 435 (68)
3			CS 735 (53)	CS 718 (38)
4		CS 632 (10)	CS 743 (31)	
5				
6				
7	CS 735 (14)		CS 736 (36)	CS 741 (54)
8				
9				CS 775 (20)

New Schedule

Slot	SIC-205	SIC-305	SIC-201	SIC-301
1				
2	HS 490 (12)	CS 681 (38)		CS 435 (68)
3	CS 718 (38)			CS 735 (53)
4	CS 743 (31)	CS 632 (10)		
5				
6				
7	CS 735 (14)	CS 736 (36)		CS 741 (54)
8				
9		CS 775 (20)		

SIC 201 and sic 301 are large classrooms

9



Deploying Sensors:
What to sense? How to sense?

Observability:

A Principled Approach to Deploying Sensors

Is space occupied?

PIR sensors

Camera sensors

Blind spots

False positives/negatives

Sensing Occupancy (Ranking)

Alternatives	Correctness	Prompt-ness	Data	Resilience to Network Problems	Cost Efficiency
PIR	5	2	1	1	1
PIR Array	4	3	2	3	2
Camera	3	1	5	5	3
Camera + PIR	2	5	4	4	4
Camera + PIR Array	1	4	3	3	5

Sensing Occupancy (Properties)

Alternatives	False Positive	False Negative	Network Usage	Zonal Occupancy
PIR	High	High	None	No
PIR Array	High	Low	None	Yes
Camera	Medium	Medium	High	No
Camera + PIR	Low	Low	High	No
Camera + PIR Array	Low	Low	Low	Yes

Factors affecting the choice of sensors

Choosing a combination of sensors:

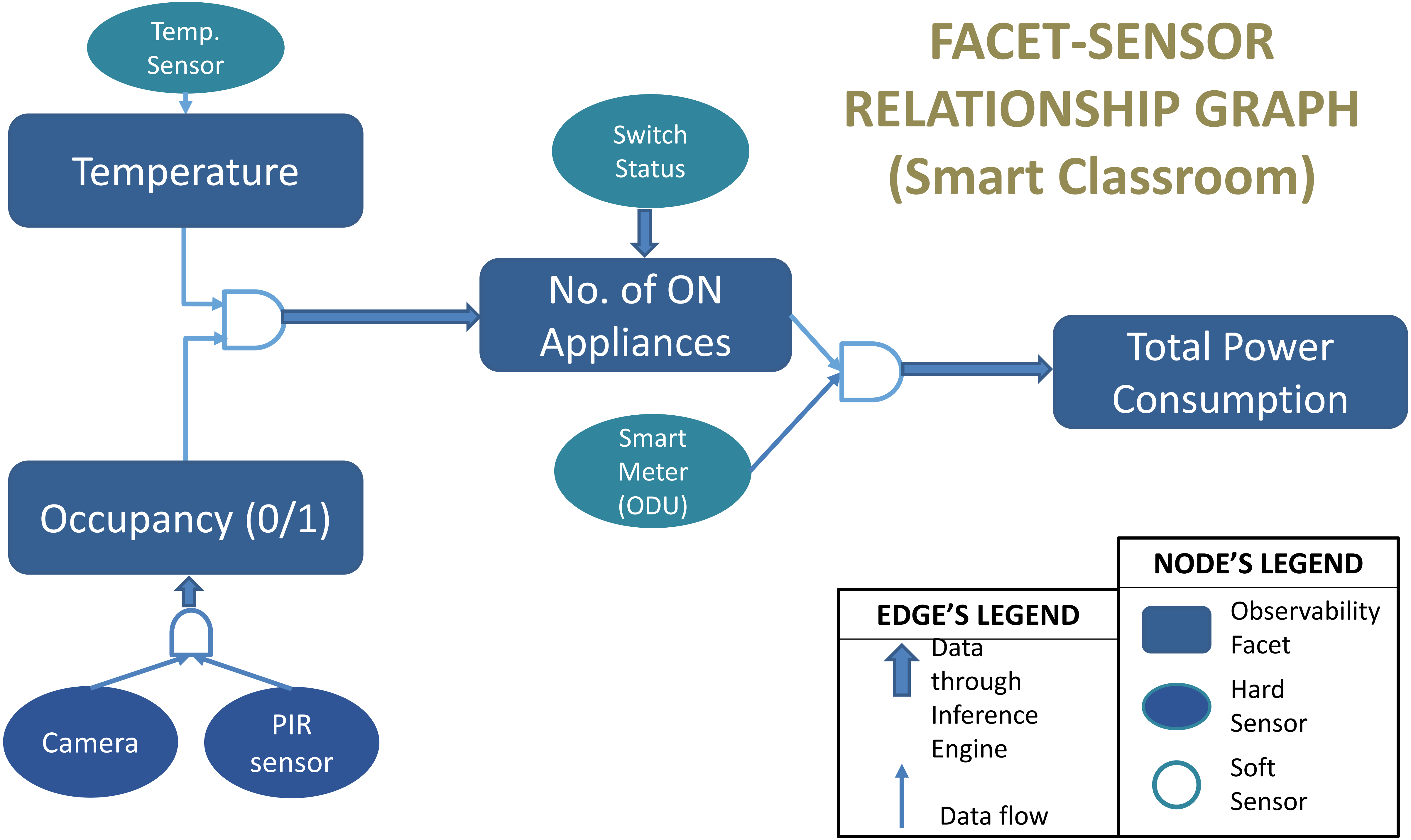
based on

- what is already available
- accuracy, maintainability, granularity, granularity, reliability

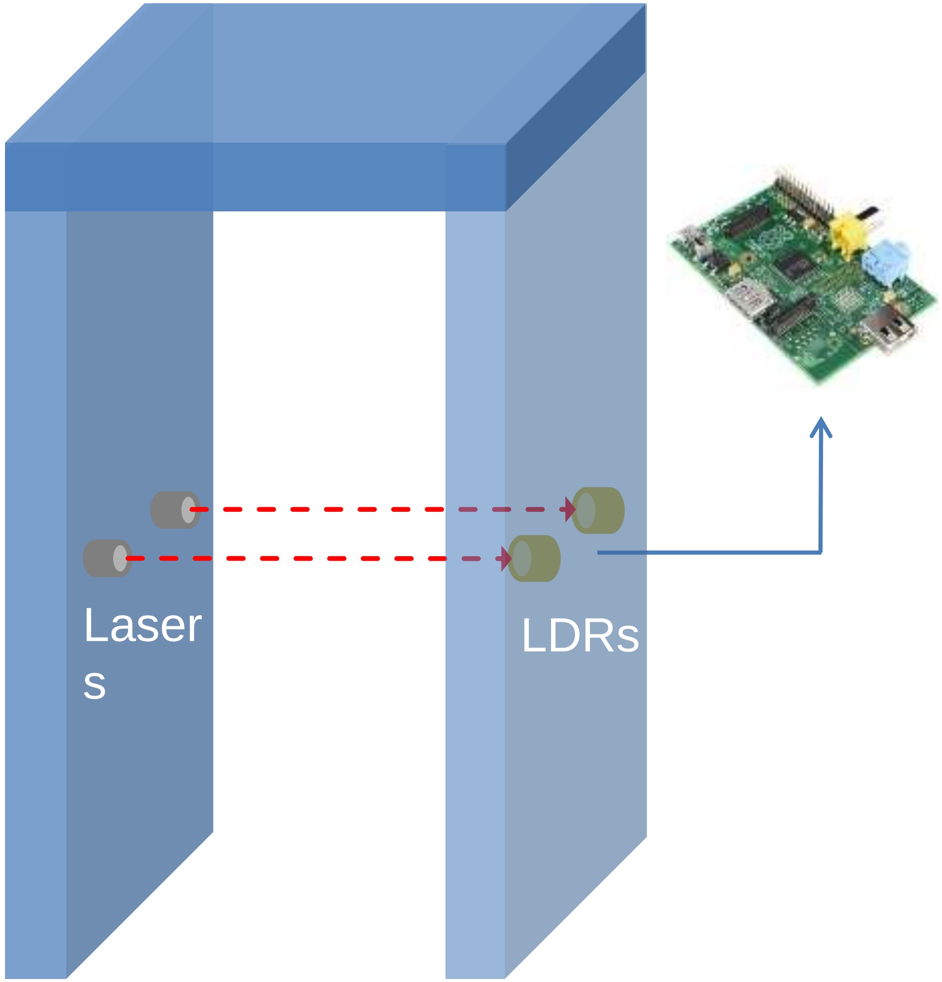
If the accuracy from current sources does not meet accuracy needs do we need a dedicated physical sensor?

If the inference requires more than one input, for example occupancy and temperature, will reliability be affected?

FACET-SENSOR RELATIONSHIP GRAPH (Smart Classroom)



#Occupants



Goal: Be counted,
while walking in/out
at normal pace

Sense Entry/Exit

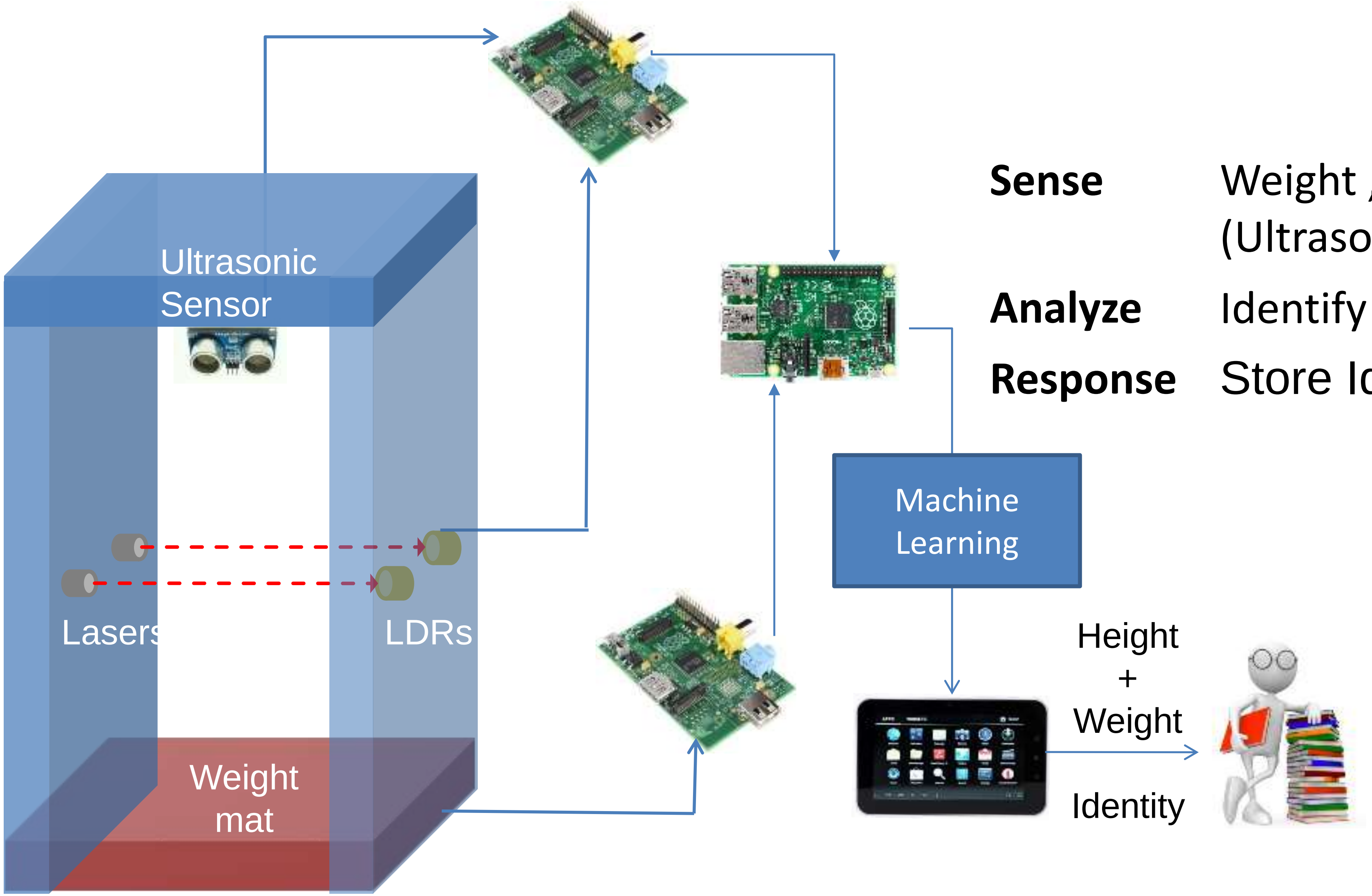
Analyze Hand or Torso?

- Intra Laser Threshold

Response Update Occupancy Count

Entering/Leaving?

Who is in the room?



Sense	Weight , Height (Ultrasonic sensor)
Analyze	Identify User
Response	Store Identity info

PROBLEM: MULTIPLE MATCHES

CLASSIFICATION USING DIFFERENT FEATURES

Disambiguation through Sensor Fusion

From ***height + weight*** based (***hard sensor***) information

IDENTIFY   the set of possible occupants given occupants list

-- {A,B,C}

Applicable to spaces with limited number of users, e.g., offices, class rooms

Disambiguation through Sensor Fusion

From ***height + weight*** based (***hard sensor***) information

IDENTIFY the set of possible occupants given occupants list

-- {A,B,C}

PRUNE set using ***soft sensors***

Applicable to spaces with limited number of users, e.g., offices, class rooms

Disambiguation through Sensor Fusion

From ***height + weight*** based (***hard sensor***) information

IDENTIFY   the set of possible occupants given occupants list

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PRUNE set using ***soft sensors***

(people's/rooms' schedules/occupancy, etc.)

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-- C is in a class

-- B usually comes after lunch

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From ***height + weight*** based (***hard sensor***) information

IDENTIFY   the set of possible occupants given occupants list

-- {A,B,C}

PRUNE set using ***soft sensors***

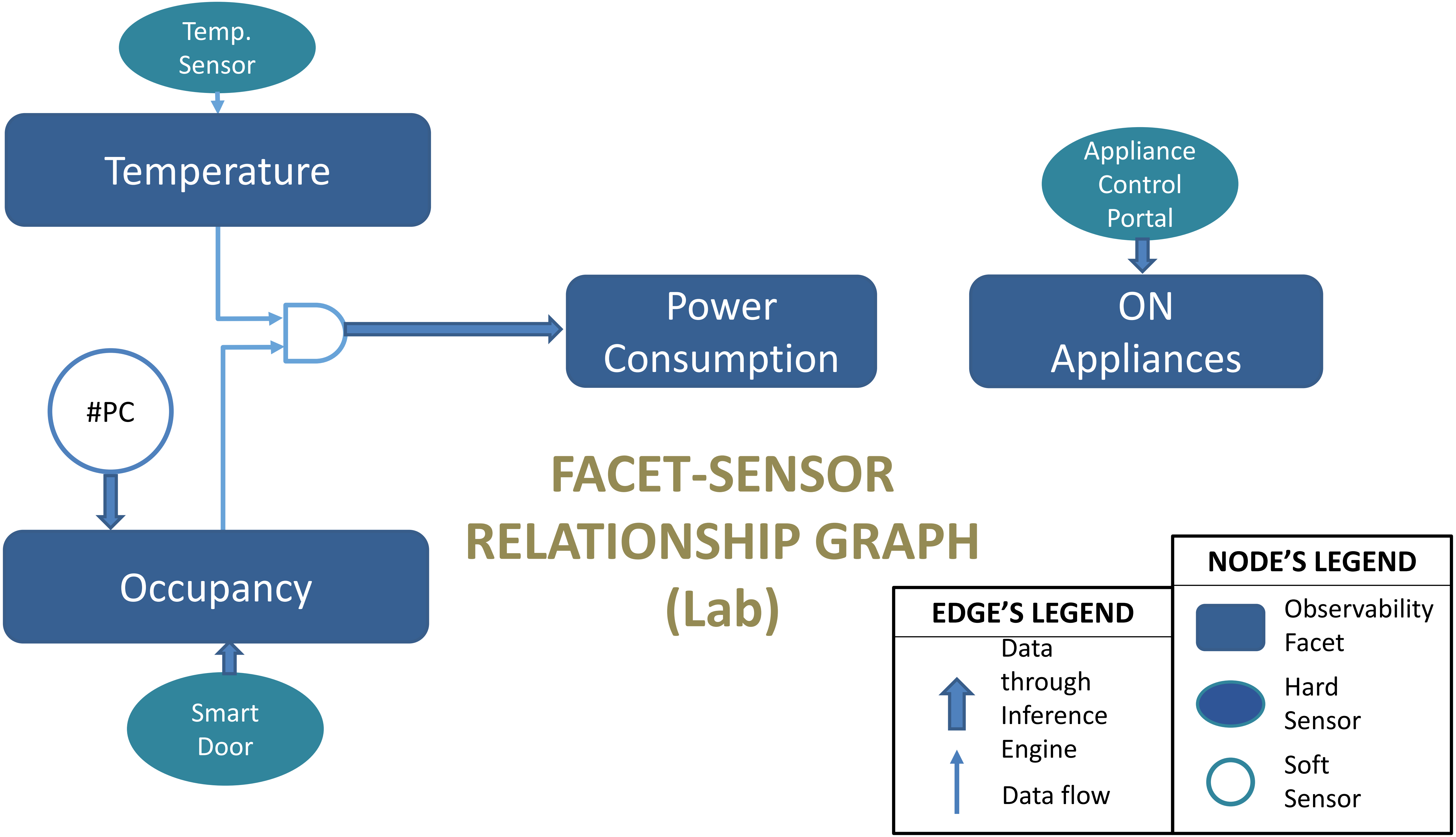
(people's/rooms' schedules/occupancy, etc.)

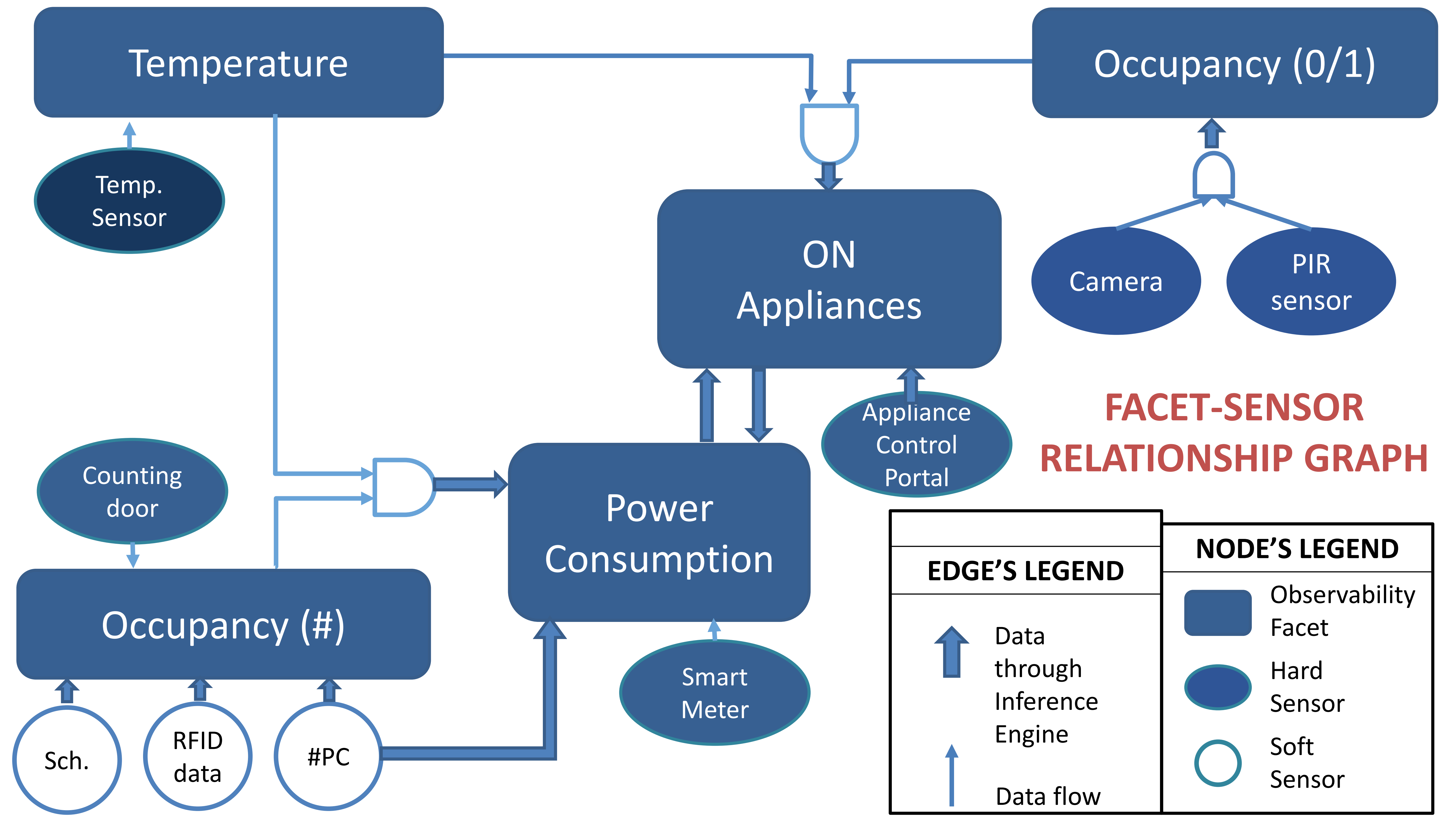
-- C is in a class

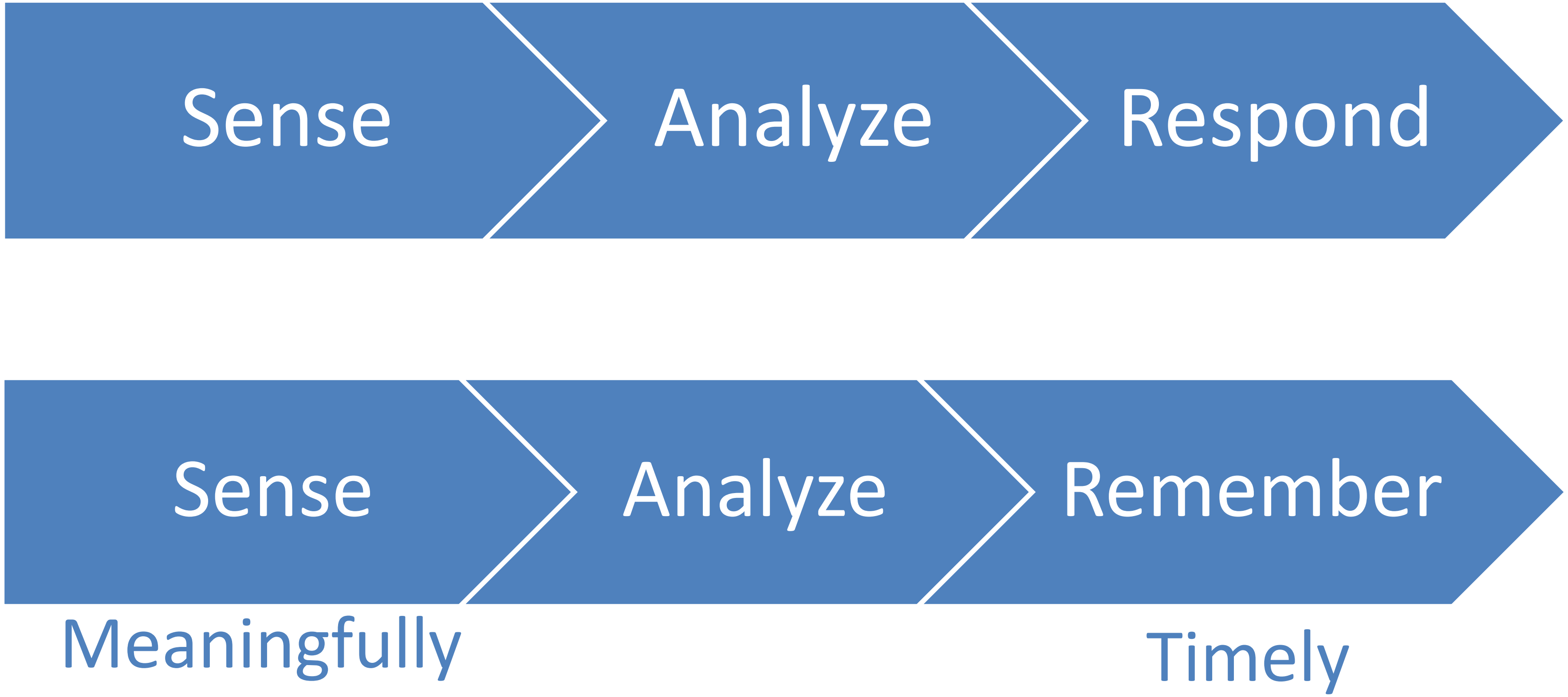
-- B usually comes after lunch

=> A is entering

Applicable to spaces with limited number of users, e.g., offices, class rooms


Temp. Sensor
Temperature
Power Consumption
Appliance Control Portal
ON Appliances
#PC
Occupancy
Smart Door
FACET-SENSOR RELATIONSHIP GRAPH (Lab)
EDGE'S LEGEND
Data through Inference Engine
Data flow
NODE'S LEGEND
Observability Facet
Hard Sensor
Soft Sensor


Temperature
Occupancy (0/1)
Temp. Sensor
ON Appliances
Camera
PIR sensor
Appliance Control Portal
FACET-SENSOR RELATIONSHIP GRAPH
Counting door
Power Consumption
Occupancy (#)
Smart Meter
Sch.
RFID data
#PC
EDGE'S LEGEND
Data through Inference Engine
Data flow
NODE'S LEGEND
Observability Facet
Hard Sensor
Soft Sensor


Sense
Analyze
Respond
Sense
Analyze
Remember
Meaningfully
Timely

Information can be sensed/inferred

Sense

- Schedule
- Time of Day

Analyze

- Machine Learning
- Logical Reasoning

Response

- Occupancy
  - Who?
  - Where?
  - How many?

Goal:
Achieve needed Observability of phenomena

Key Contributor to Smartness: Analysis

Location of sensors
Types of sensors – hard vs soft

Types of Analysis

Sense
- Schedule
- Time of Day

Analyze
- Machine Learning(SVM)
- Logical Reasoning

Response
- Number of Occupants & ID’s

Sense
- Temperature of different zones

Analyze
- Using Schedulab-ility analysis

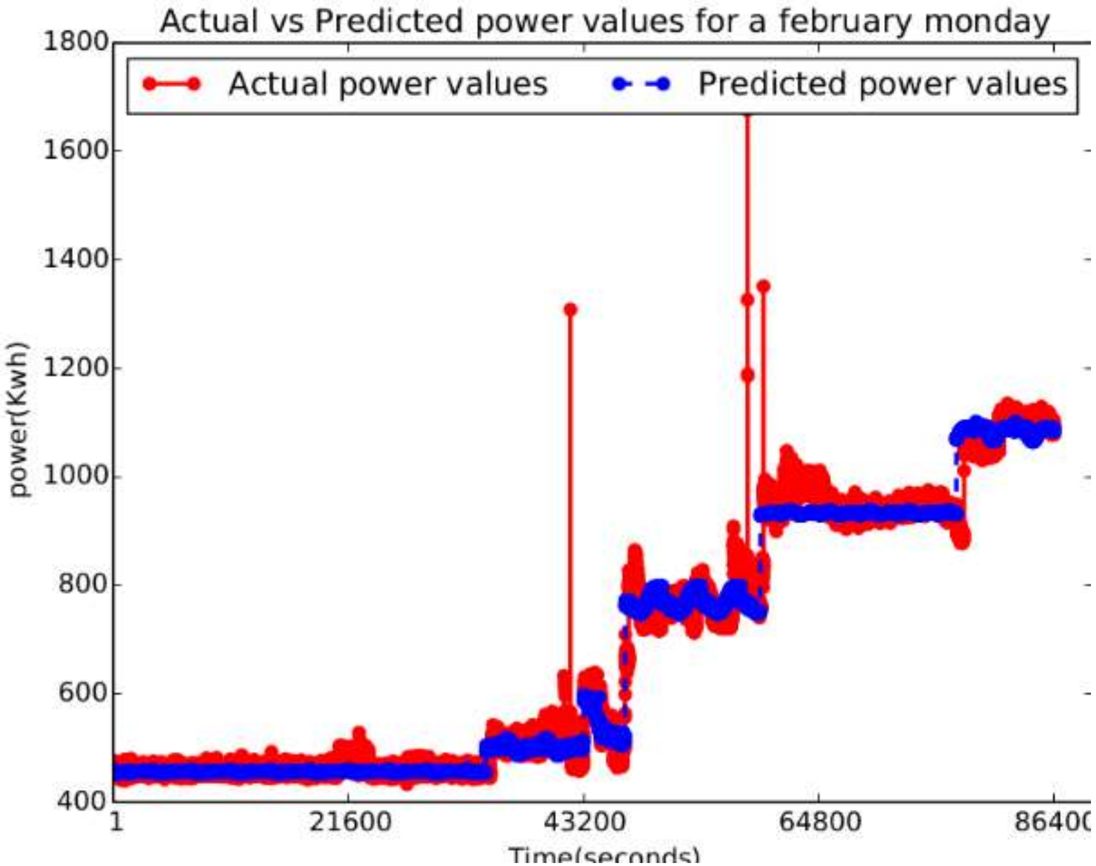
Respond
- Actuate minimum number of AC’s

Sense
- Temperature
- Time of Day

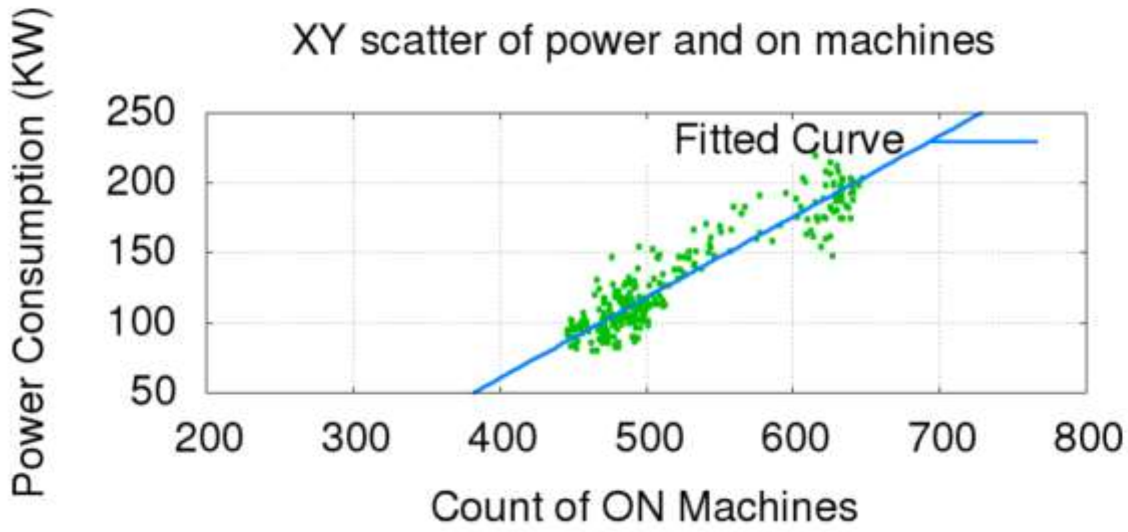
Analyze
- Machine Learning (ANN)

Response
- Power Consumption

Analysis:
- Model-based reasoning
- Exploiting correlated phenomena
- Regression

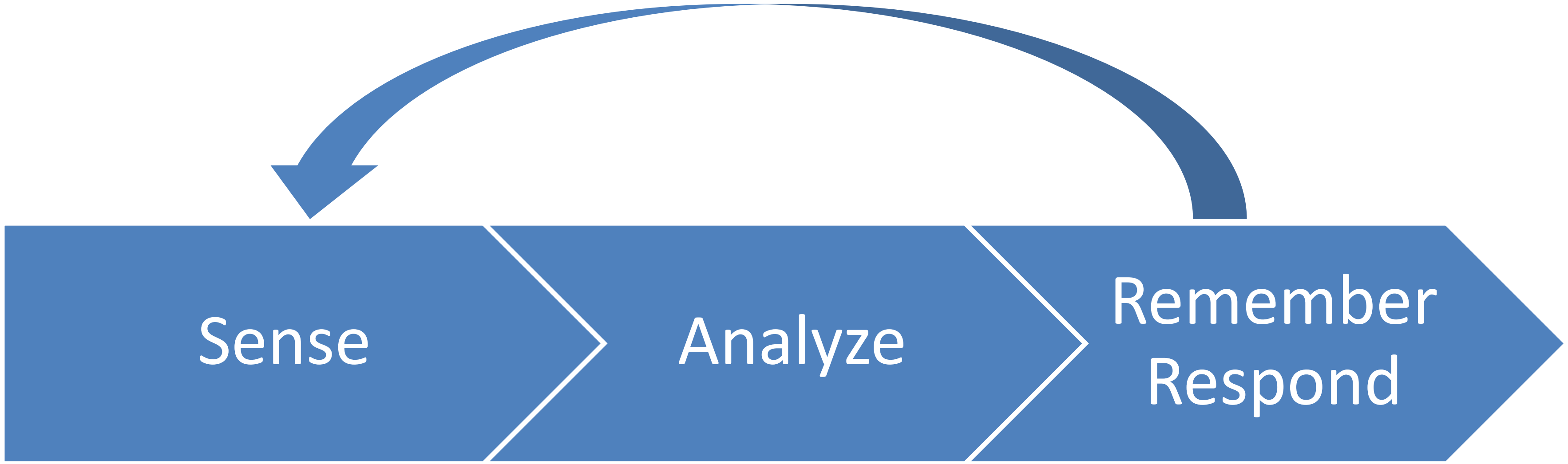


Inference Engines for predicting power consumption



SMART Design Philosophy

It is a continuous feedback-driven process



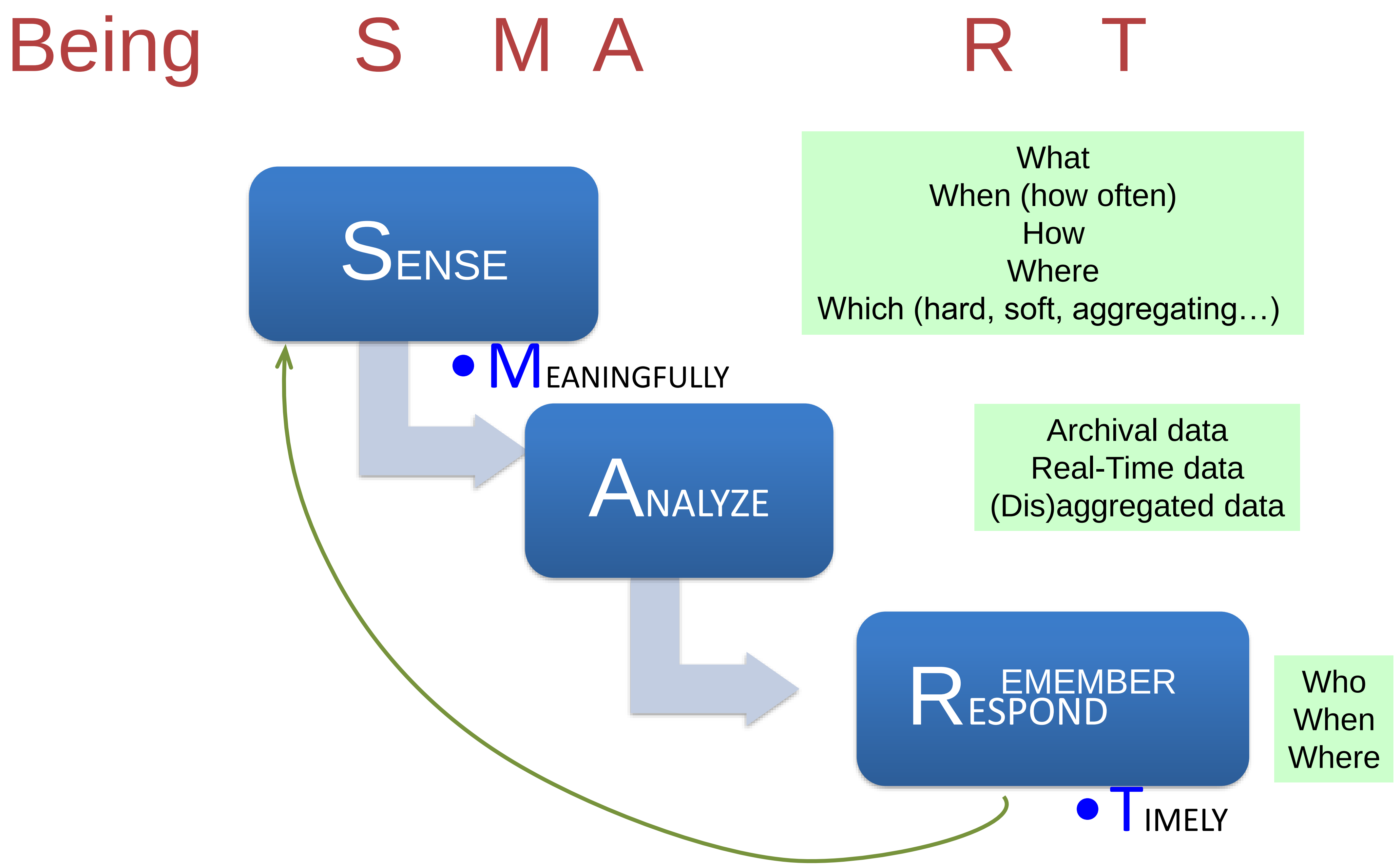
Meaningfully

Timely

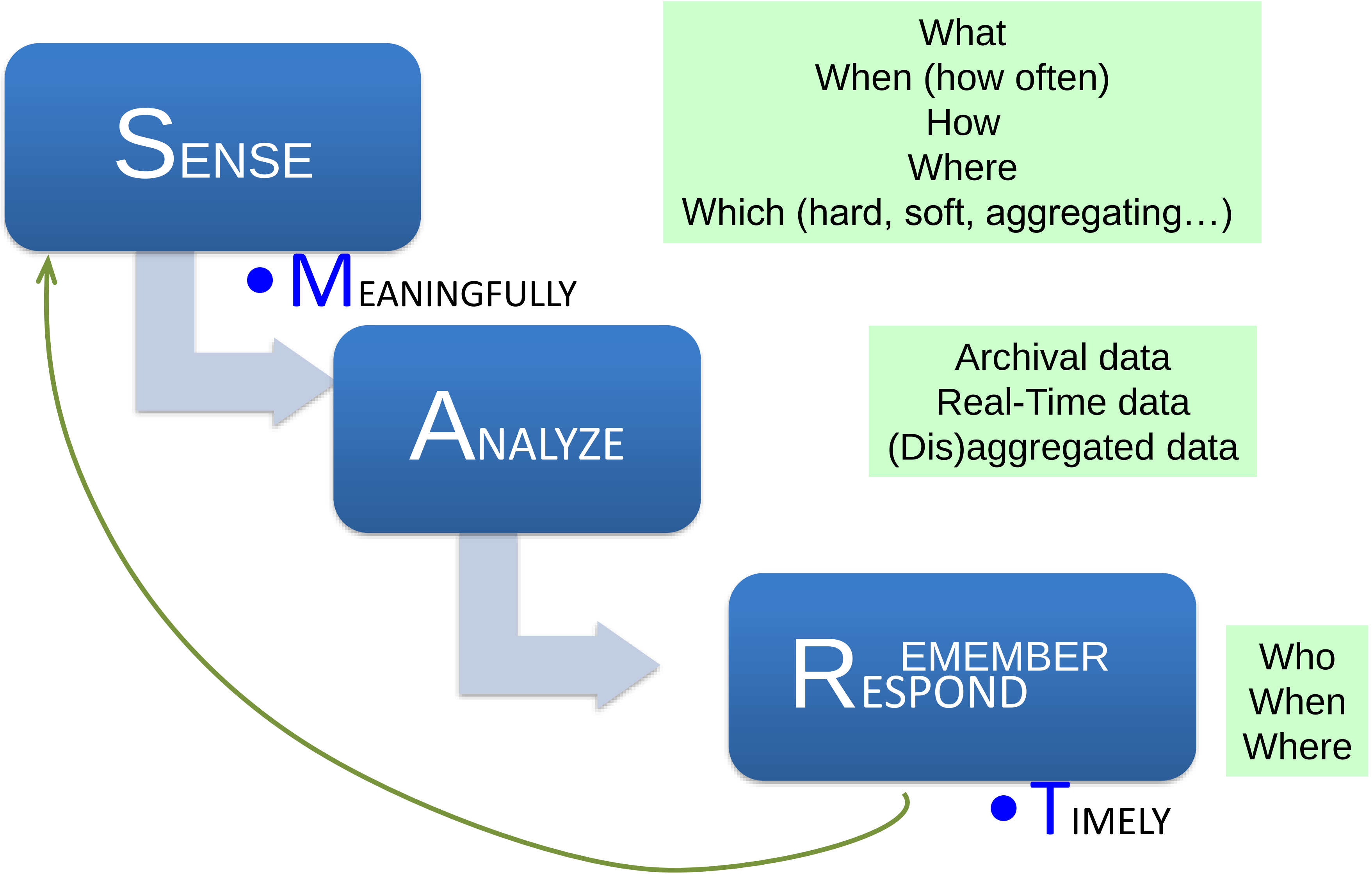
How?
What?
Where?
When (How Often)?
Which (Hard, Soft, Aggregating,….)?

Archival Data
Real-Time Data
(Dis)aggregated data

Who?
When?
Where?


Being S M A R T
SENSE
What
When (how often)
How
Where
Which (hard, soft, aggregating…)
• MEANINGFULLY
ANALYZE
Archival data
Real-Time data
(Dis)aggregated data
REMEMBER
RESPOND
Who
When
Where
• TIMELY

Being S M A R T



Applicable at

- *Design*
- *Deployment*
- *Initialization*
- *Run* Time

Smart Lecture Hall

Requesting people in the back rows to move to the front

Smart Lecture Hall

Requesting people in the back rows to move to the front

During this talk

we will save

Smart Lecture Hall

Requesting people in the back rows
to move to the front

During this talk

we will save

30% energy

Smart Lecture Hall

Requesting people in the back rows
to move to the front

During this talk

we will save

30% energy

$ 60

Smart Lecture Hall

Requesting people in the back rows
to move to the front

During this talk

we will save

30% energy

$ 60

2.5 trees

What does the system do?

What does the system do?

Goals

- Maintain comfort level
- Minimize use of energy

Inputs/ Sensed info

Occupancy related

- *How many people are there?*
- Who are they?
- *Where are they seated?*

Ambient conditions related

- What are the temperature variations across this space?
- What is the outside temperature?
- What is the energy consumption profile?
- *What is the deliverable comfort level given a limit on the max power available?*

Energy Source related

- Is renewable energy available?
- What is the power price structure?

Output/ Response

- Where should/do people sit?
- Which appliances should be ON?
- What should the HVAC settings be?

Spotlight
SMART
HVAC

Thermostatically Controlled Electrical Devices

Exhibit Periodic ON-OFF Operation

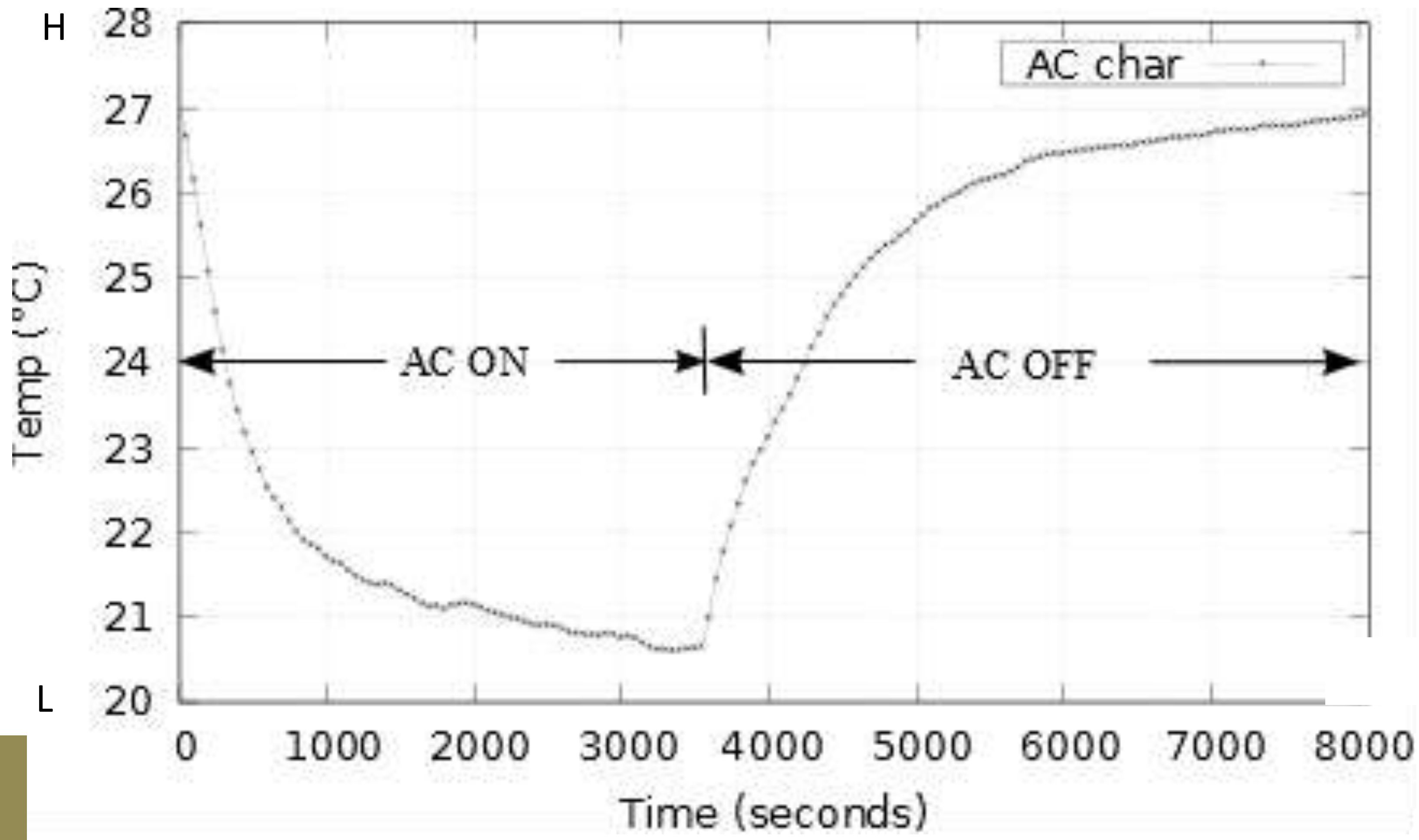
Air-Conditioners

Refrigerators

Room-heaters

Maintain Temp within [L, H]

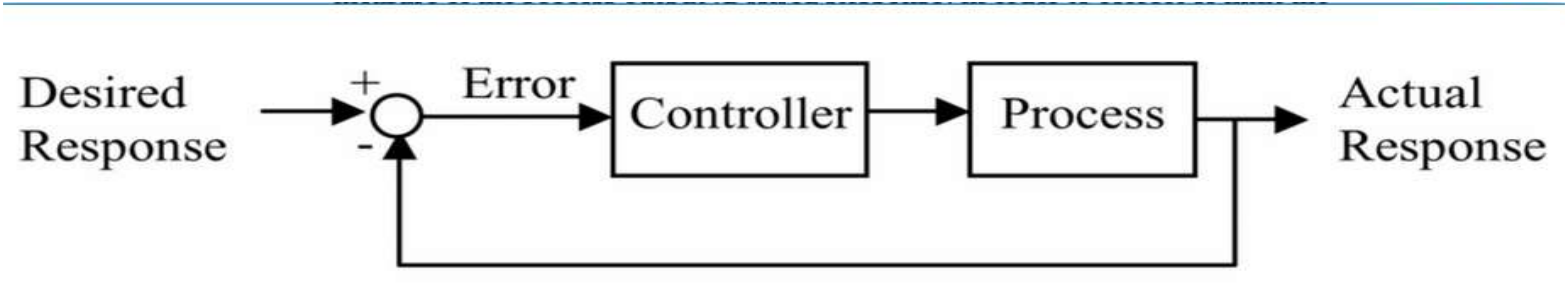
Behavior of a Cooling Unit

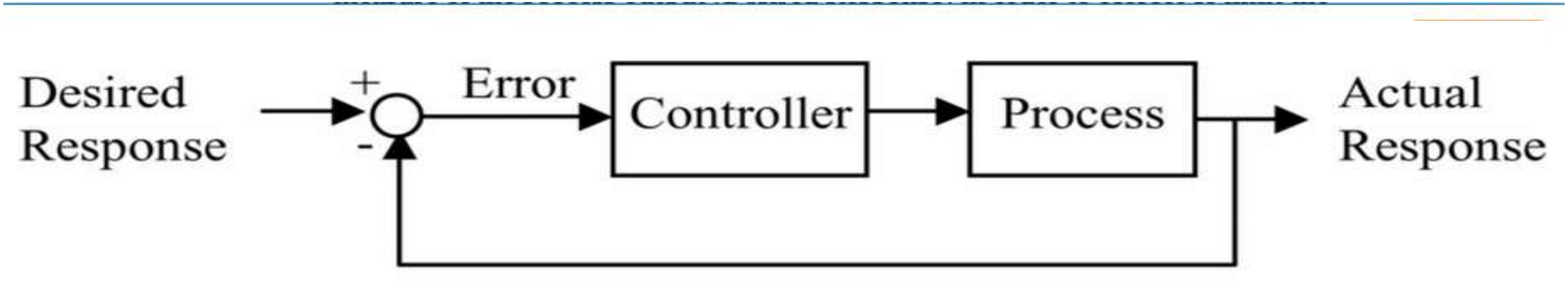


Run Time

Sense Temp
If Temp > H
Cooler_ON
If Temp < L
Cooler_OFF

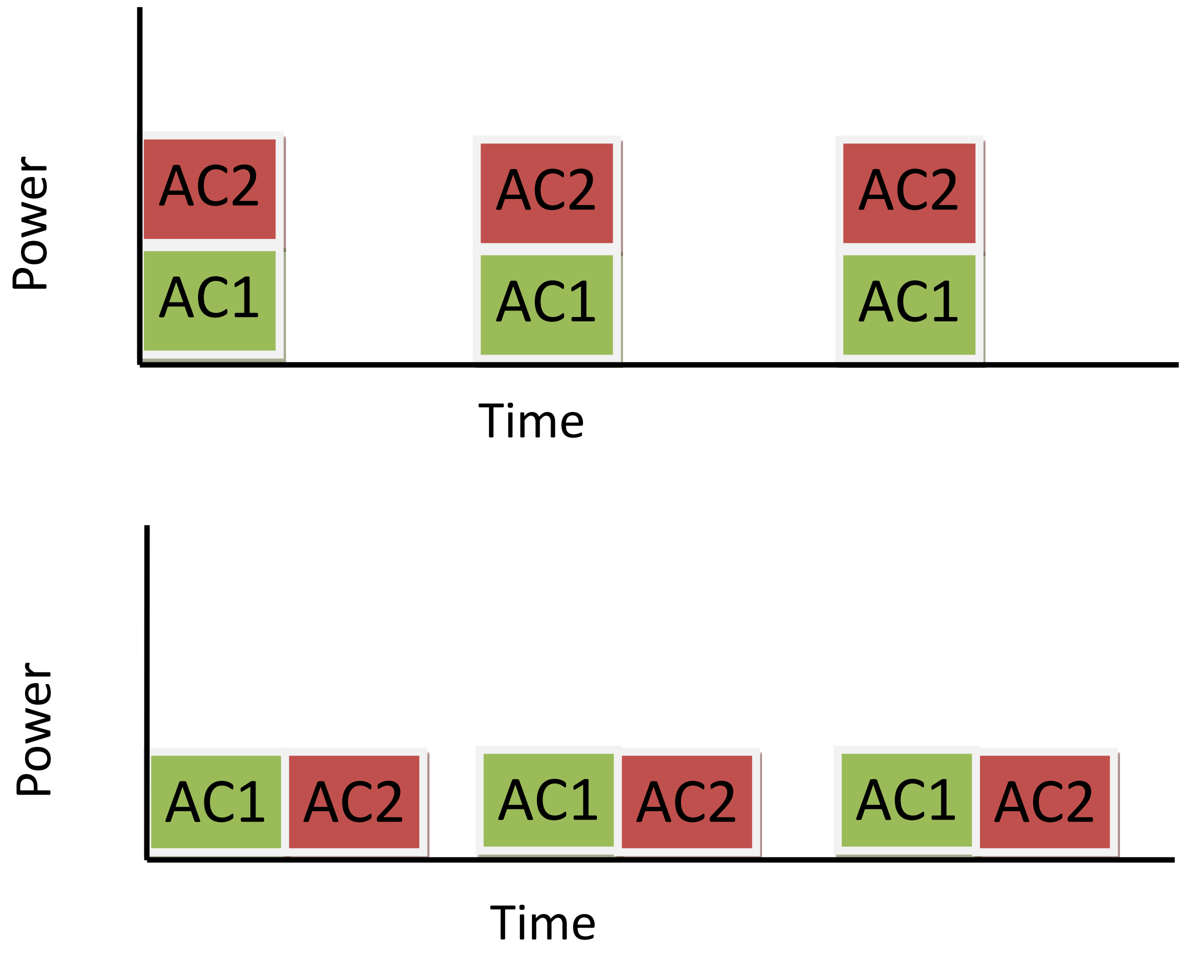
Feedback





Have to learn from the past

Smart Scheduling: Peak Demand Reduction



Thermal Comfort Band Maintenance Algorithm

Peak energy constraint:
At most *m* out of *n* devices can be *on*

n=3, *m*=2

Sense	Ambient Temp, Available Peak Power
Analyze	Schedulability
Respond	Set *m*, Temp Band

Thermal Comfort Band Maintenance Algorithm

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At most *m* out of *n* devices can be *on*

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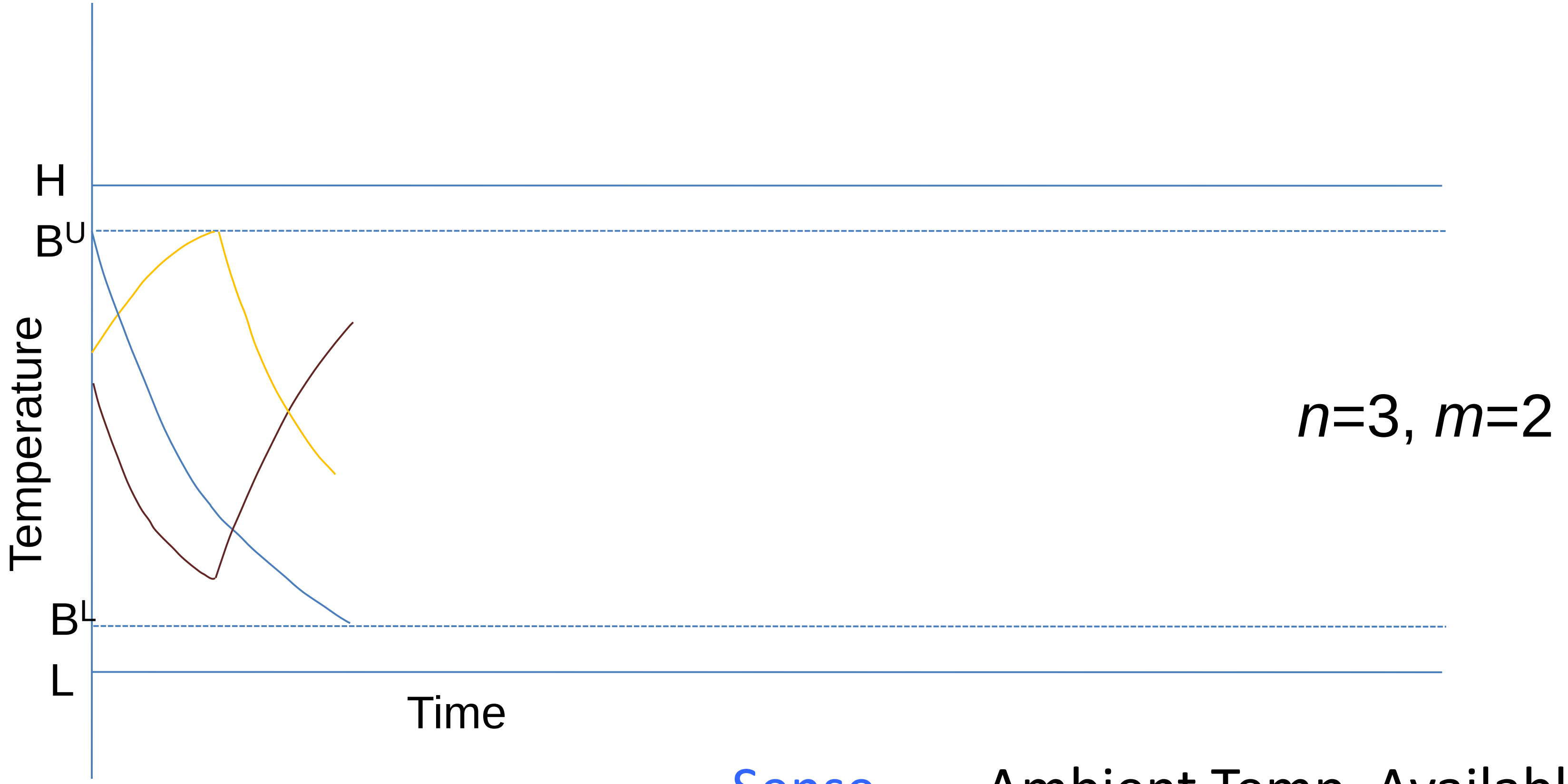

Sense Ambient Temp, Available Peak Power

Analyze Schedulability

Respond Set *m*, Temp Band

Thermal Comfort Band Maintenance Algorithm

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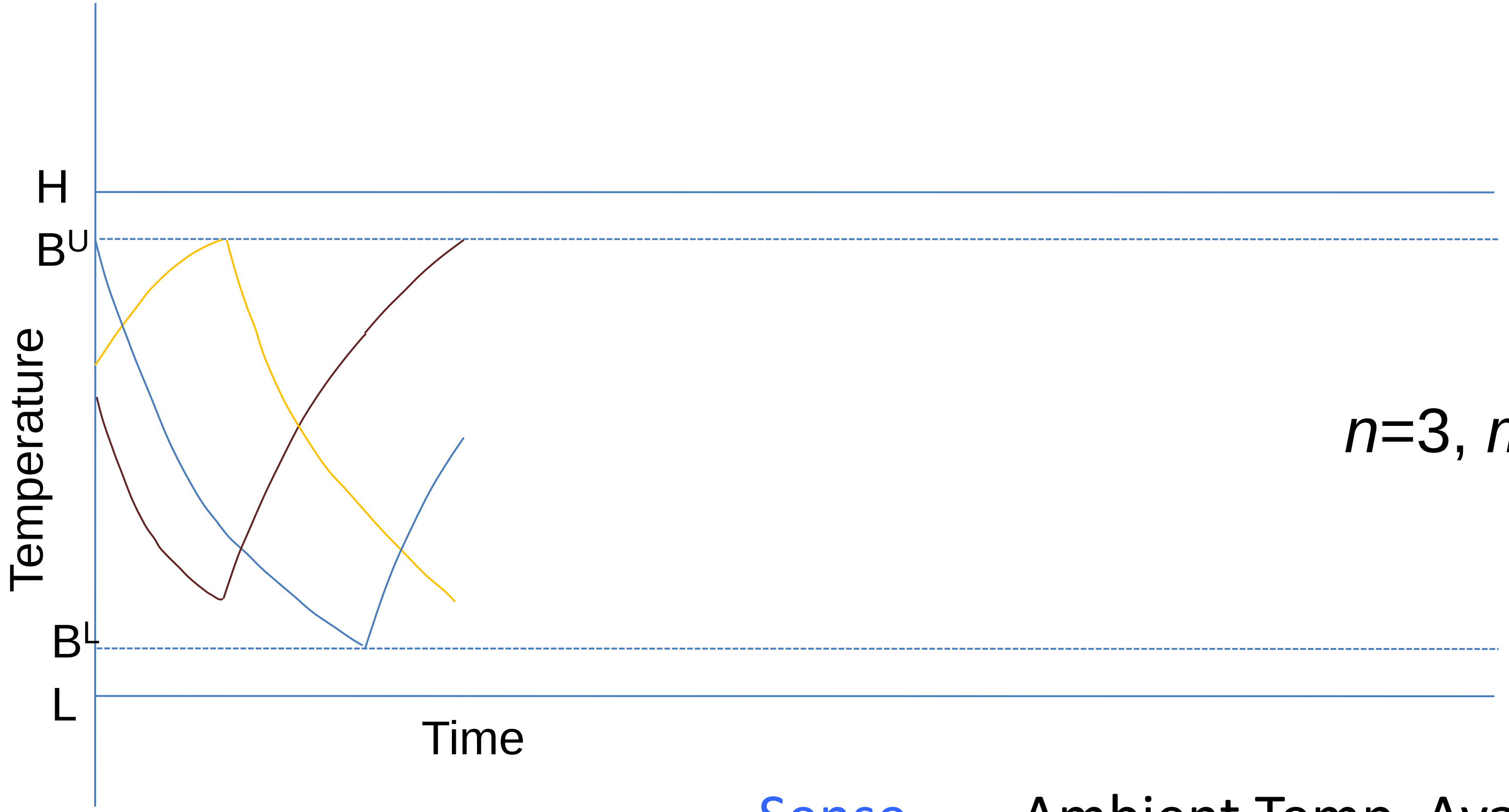

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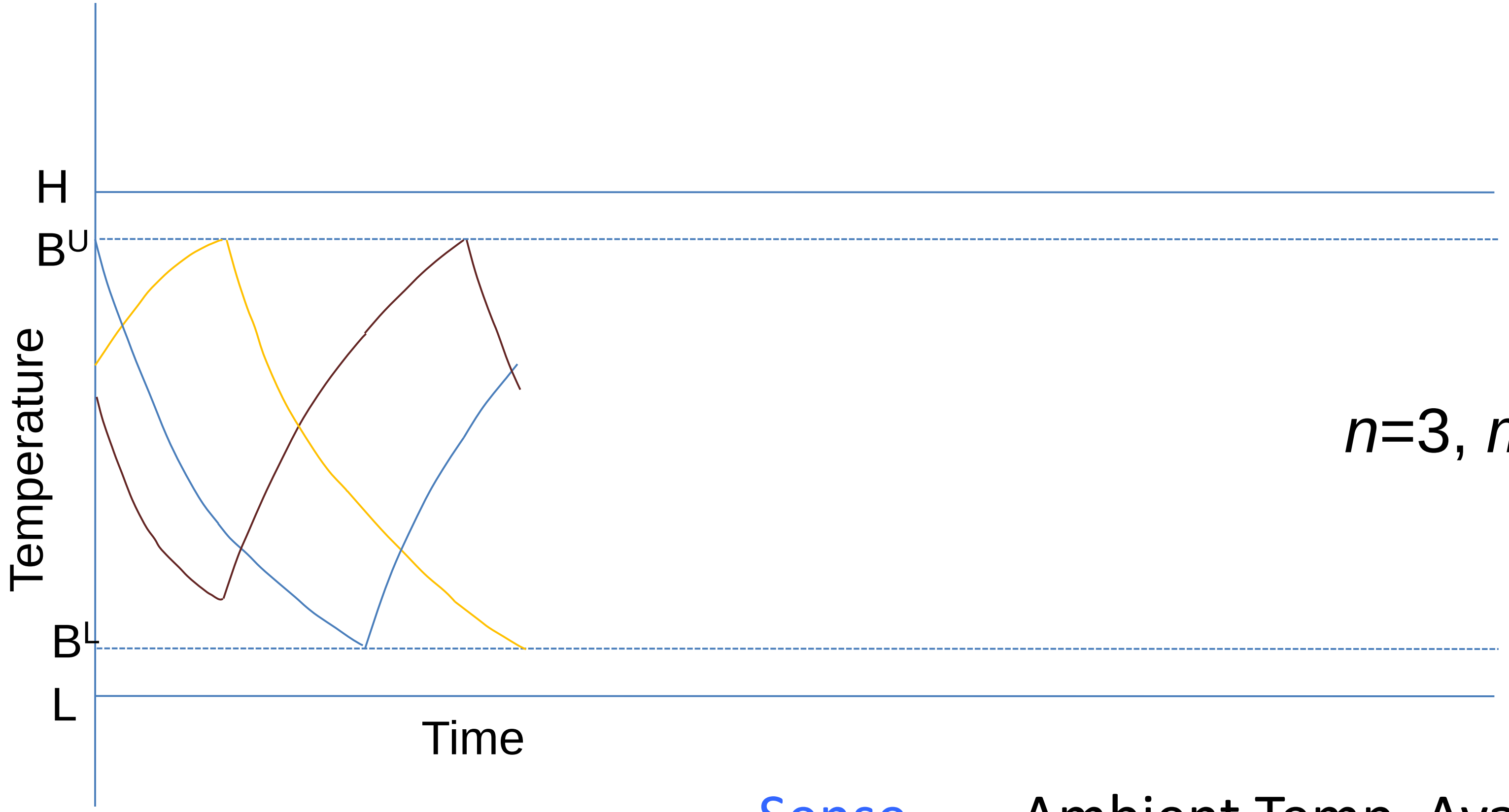

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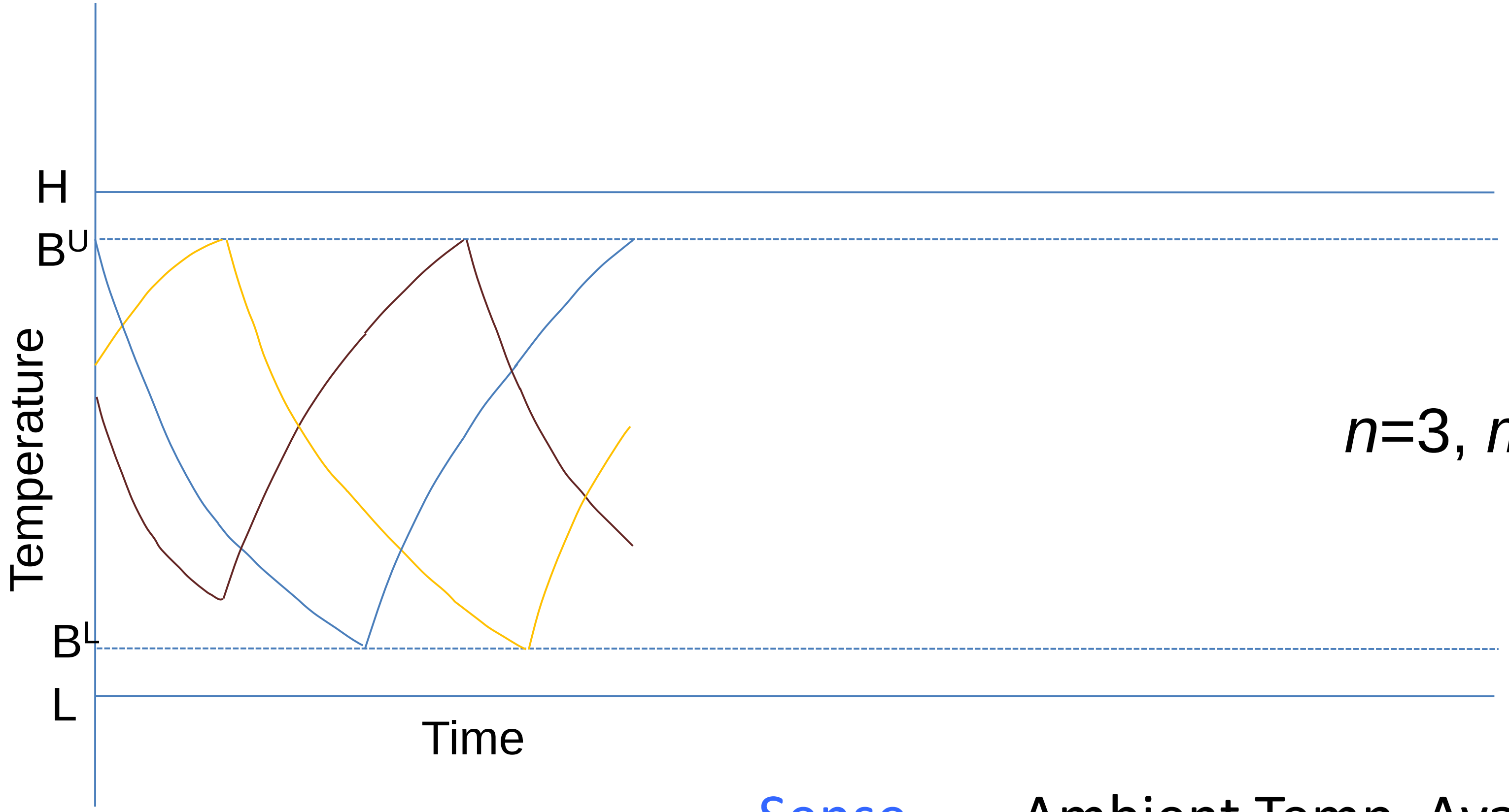

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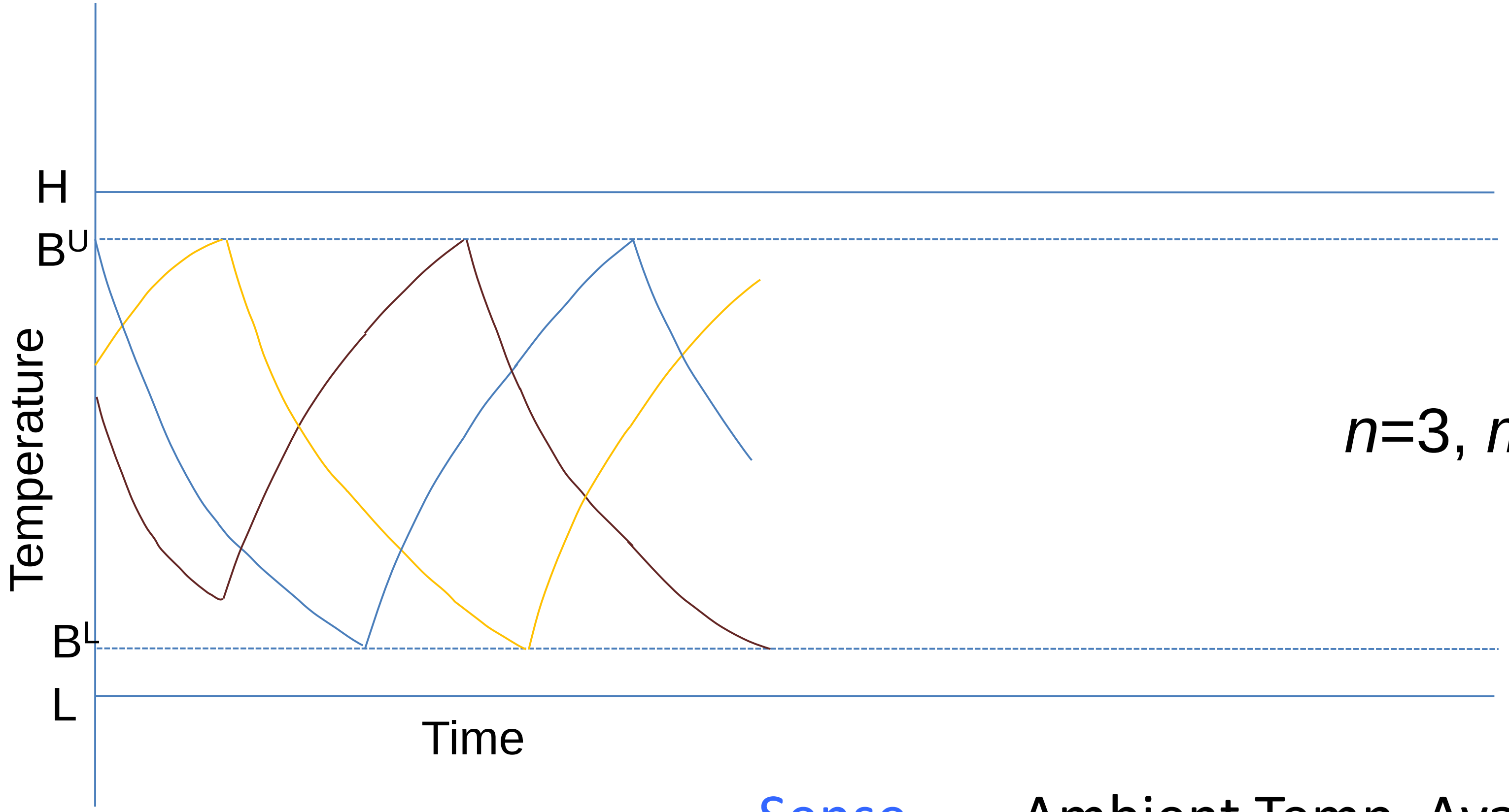

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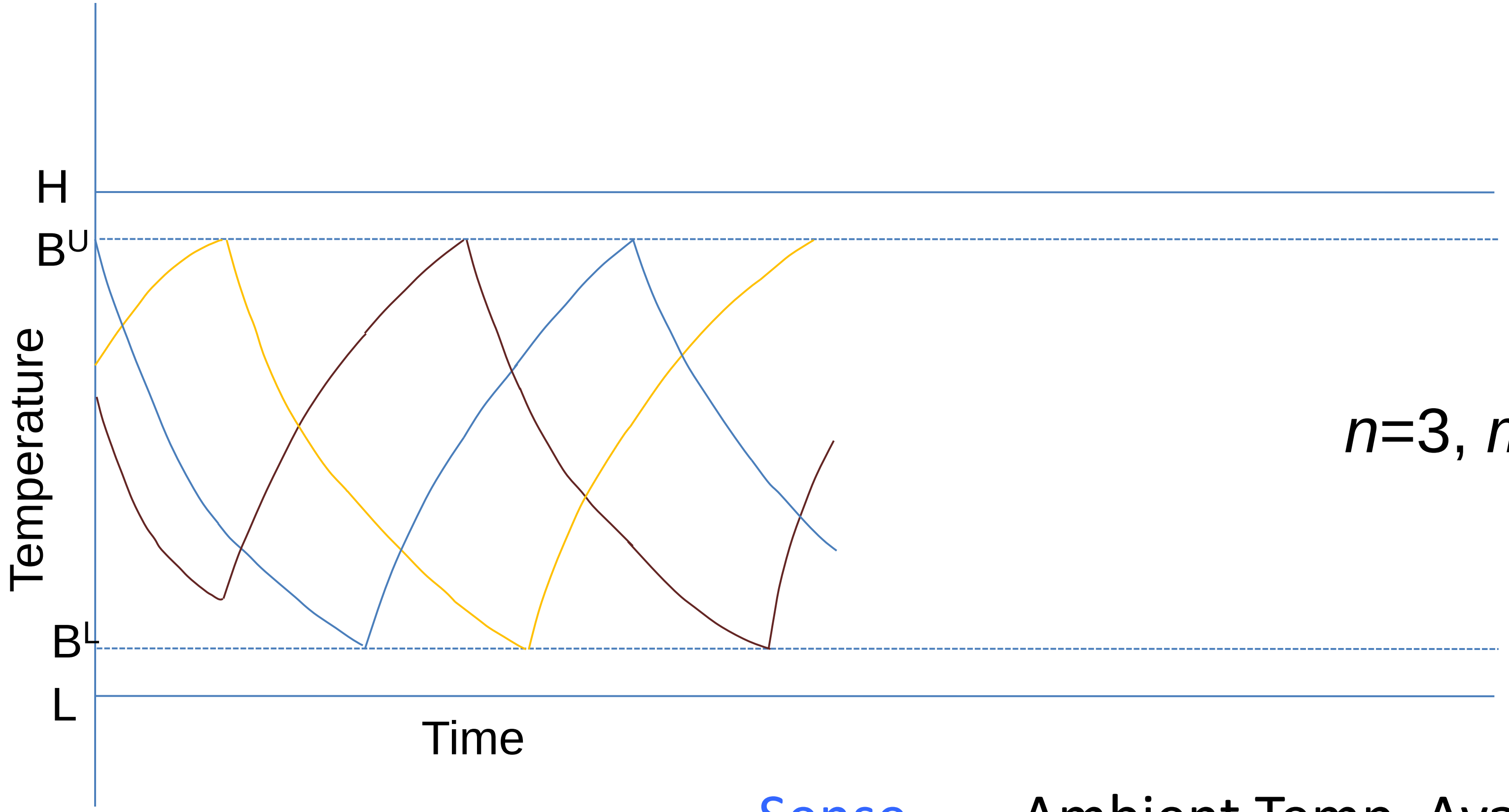
Peak energy constraint:

At most *m* out of *n* devices can be on



n=3, *m*=2

Sense Ambient Temp, Available Peak Power

Analyze Schedulability

Respond Set *m*, Temp Band

Thermal Comfort Band Maintenance Algorithm

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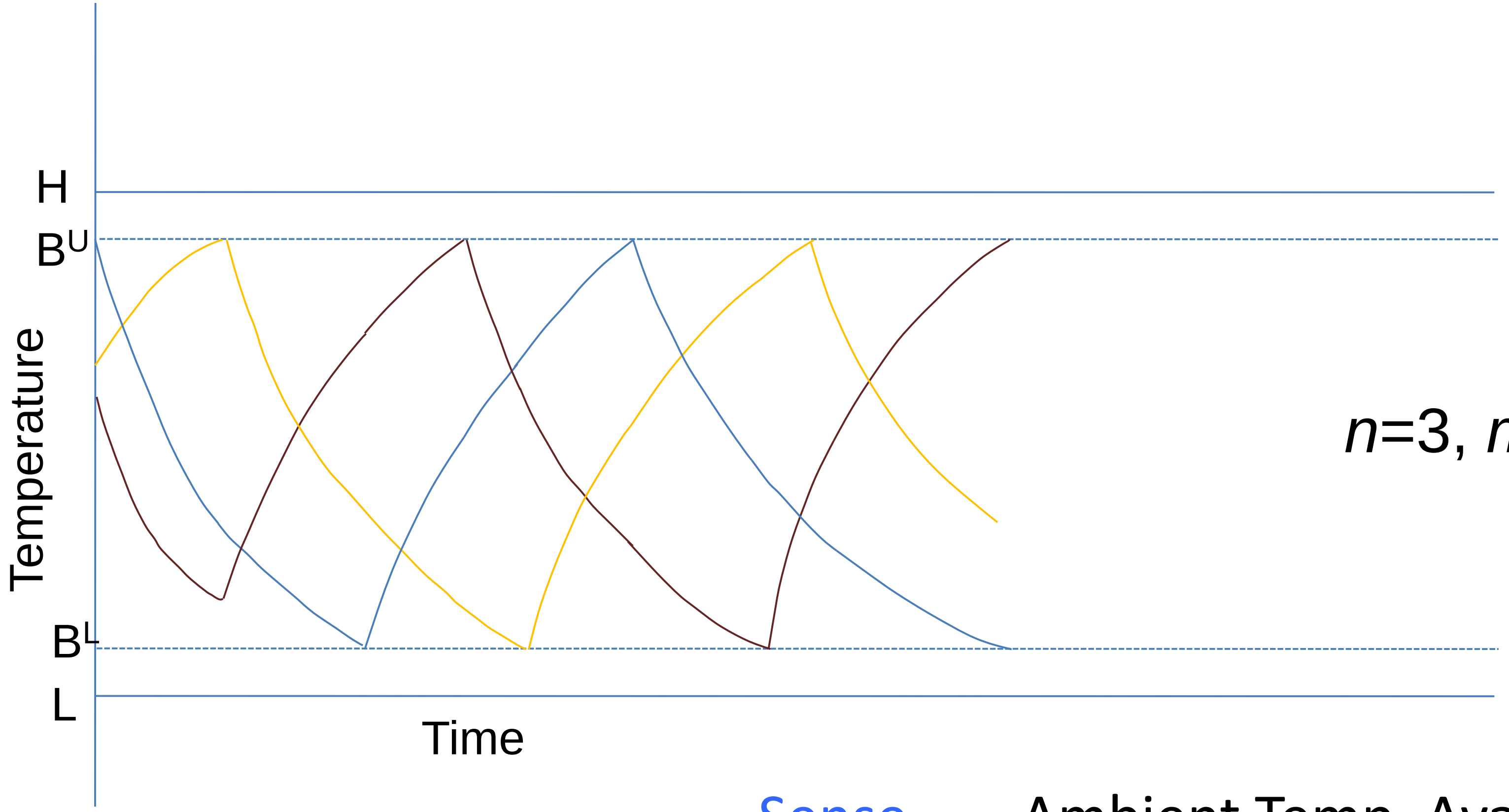

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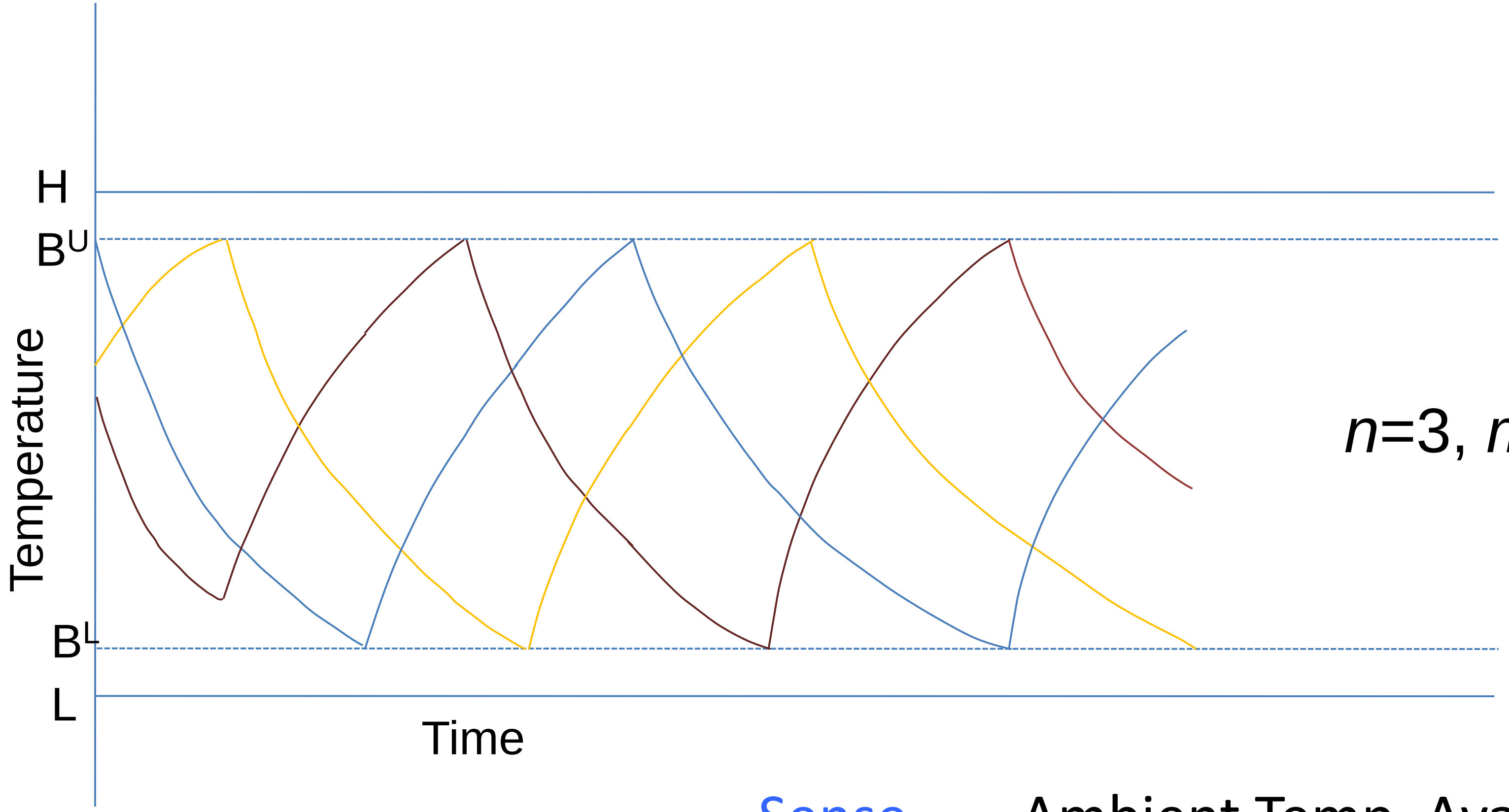

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Feasibility Analysis

Can the given band [L, H] to be maintained
by running at most '*m*' ACs at a time
-- using the characteristics of each of the ACs.

$$m \times abs(S_f) \geq (n - m) \times S_r$$

$$S_f = min(S_f^i \; | i = 1, 2 \cdots n)$$
$$S_r = max(S_r^i \; | i = 1, 2 \cdots n) \text{ at } T_i = B^U$$

Analysis:
Is Aggregate cooling greater than aggregate warming

S_f - slope of cooling curve
S_r - slope of warming curve

Demand-Response Management

Comfort band	***m***	***Feasible?***
23-25	3	Yes
23-25	2	No
24-26	2	Yes

Improved Schedulability by shifting comfort-band (5 ACs)

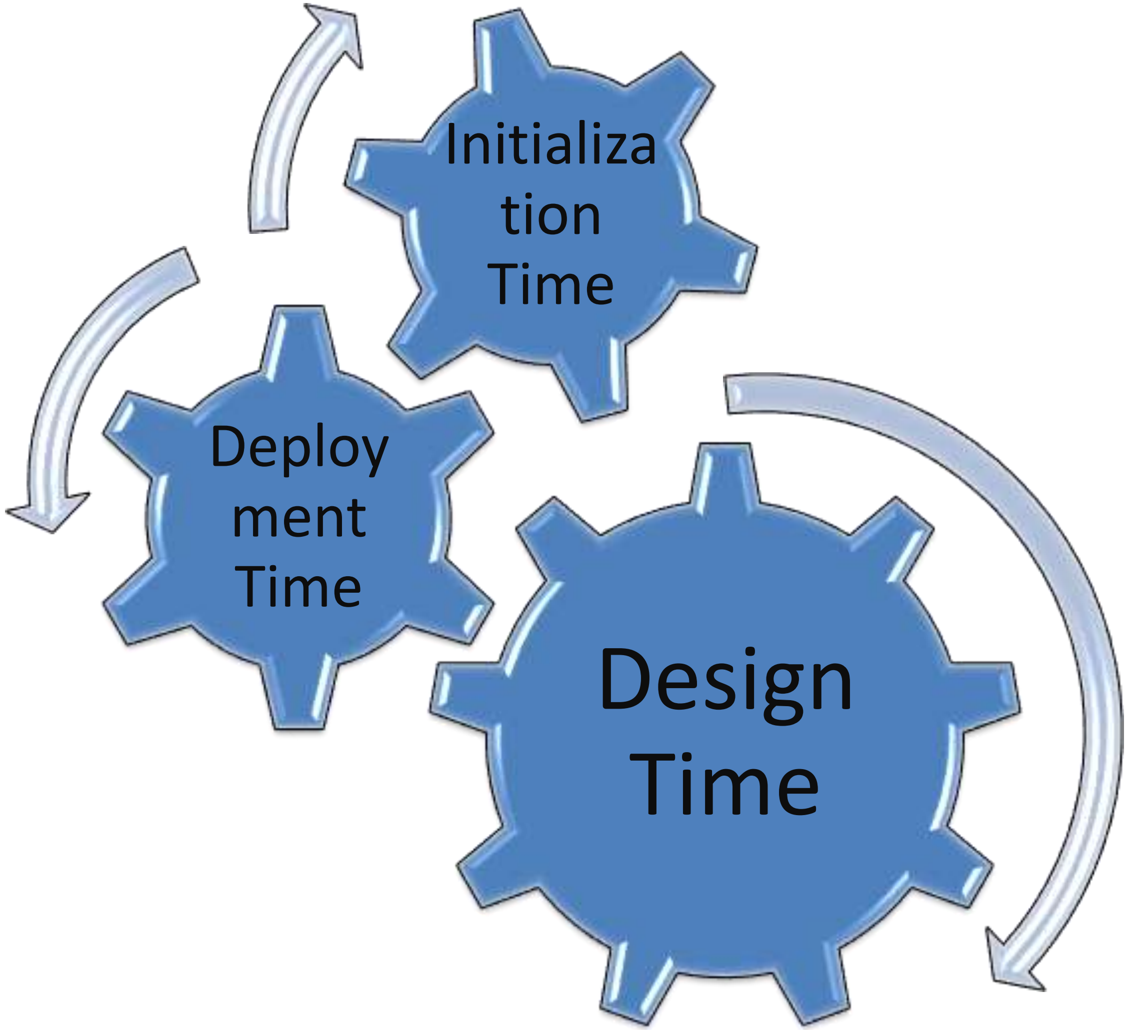
		Ambient 27^{0}C			Ambient 30^{0}C		
Comfort-band	**m**	$\Sigma\ S_f$	$\Sigma\ S_r$	**Feasibility**	$\Sigma\ S_f$	$\Sigma\ S_r$	**Feasibility**
23 – 25	2	0.149	0.140	Yes	0.35	0.53	No
24 – 26	2	0.218	0.098	Yes	0.46	0.35	Yes

Reinitialization Time

Smartness at all "TIMES"

Run-Time

+



Towards Sustainable Energy

Reduce need for unsustainable energy sources

- Reduce unnecessary consumption
- Flatten peaks in consumption

Increase reliance on sustainable energy sources

- Exploit renewables
- Store excess energy

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Need SMART Approaches

Using Stored/Renewable Energy

- batteries in home settings:

  peak flattening, reduced costs,

  smoothed intermittent sources,

  surviving grid outages

Using Stored/Renewable Energy

- batteries in home settings:
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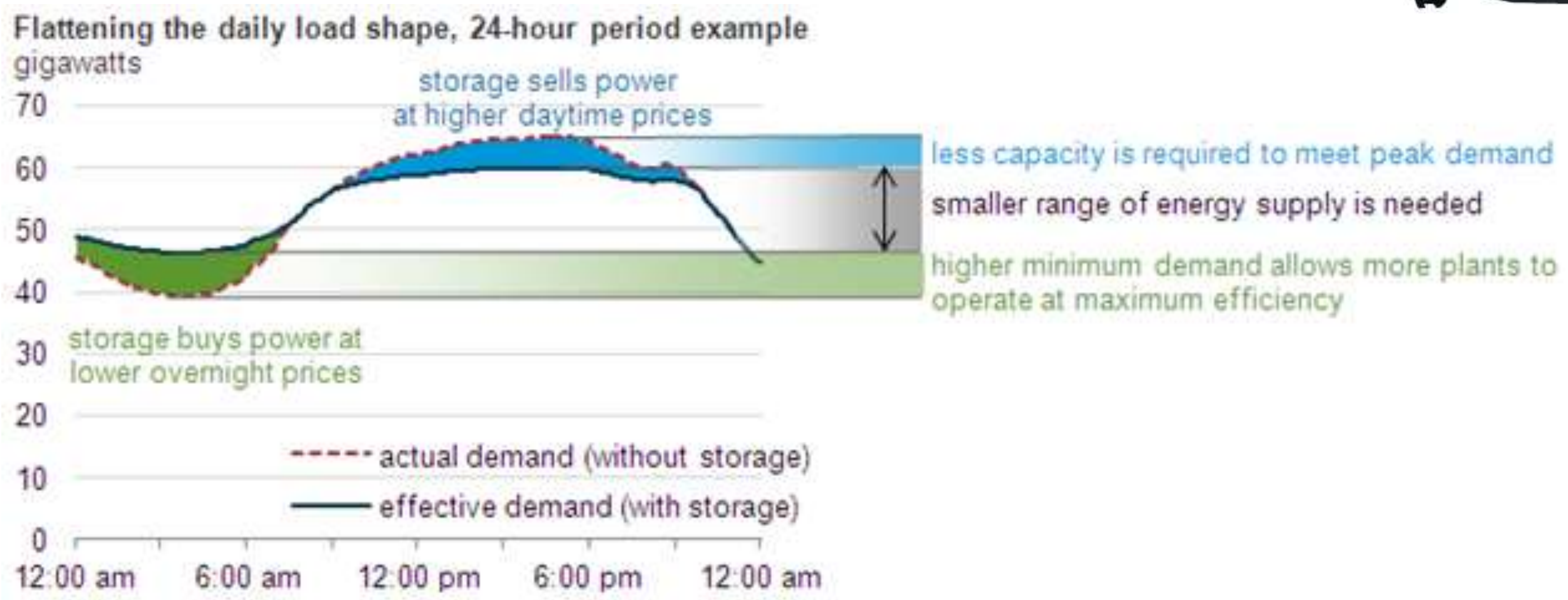

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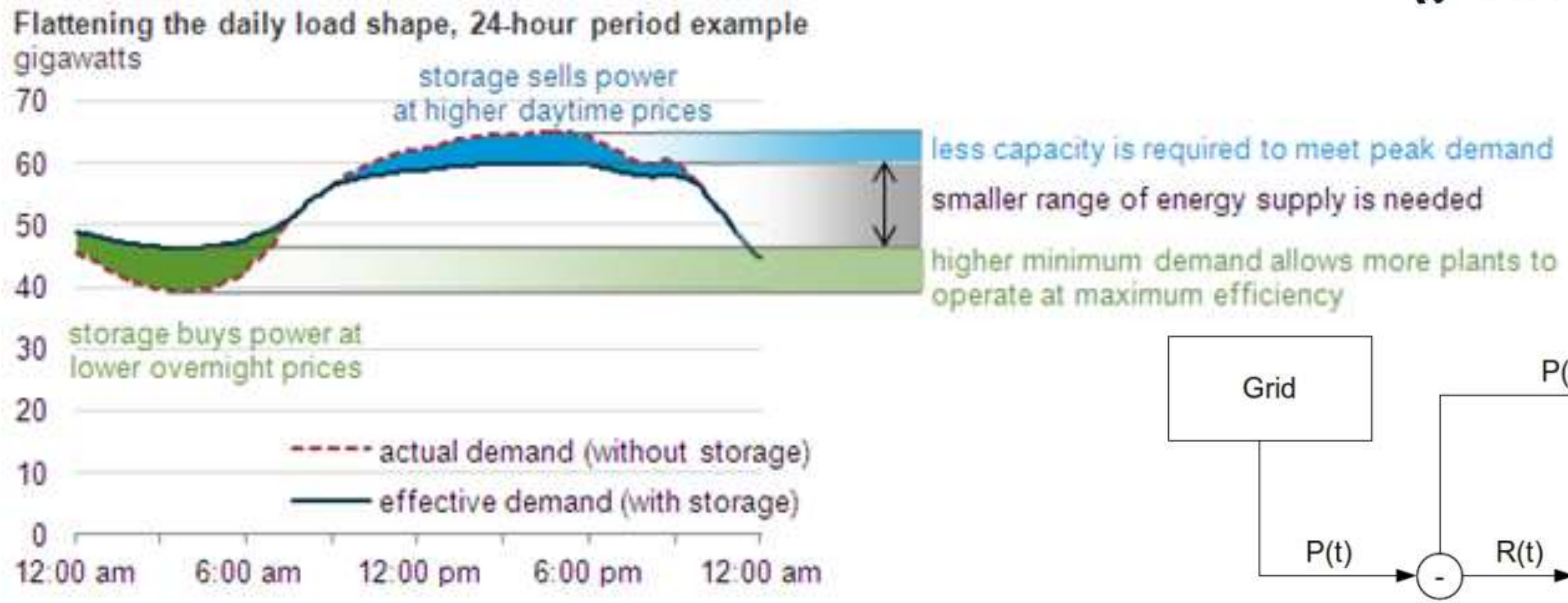
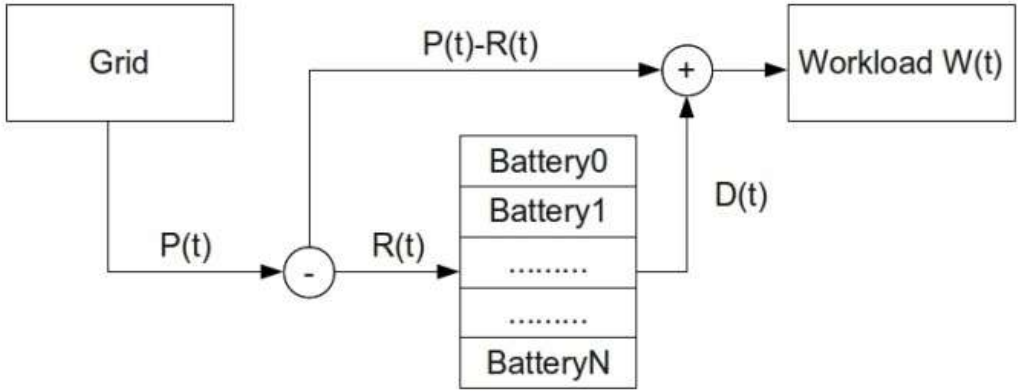




Towards Sustainable Energy

Reduce need for unsustainable energy sources

- Reduce unnecessary consumption
- Flatten peaks

Increase reliance on sustainable energy sources

- Exploit renewables
- Store excess energy during off-peak – avoid blackouts

Use energy efficient appliances

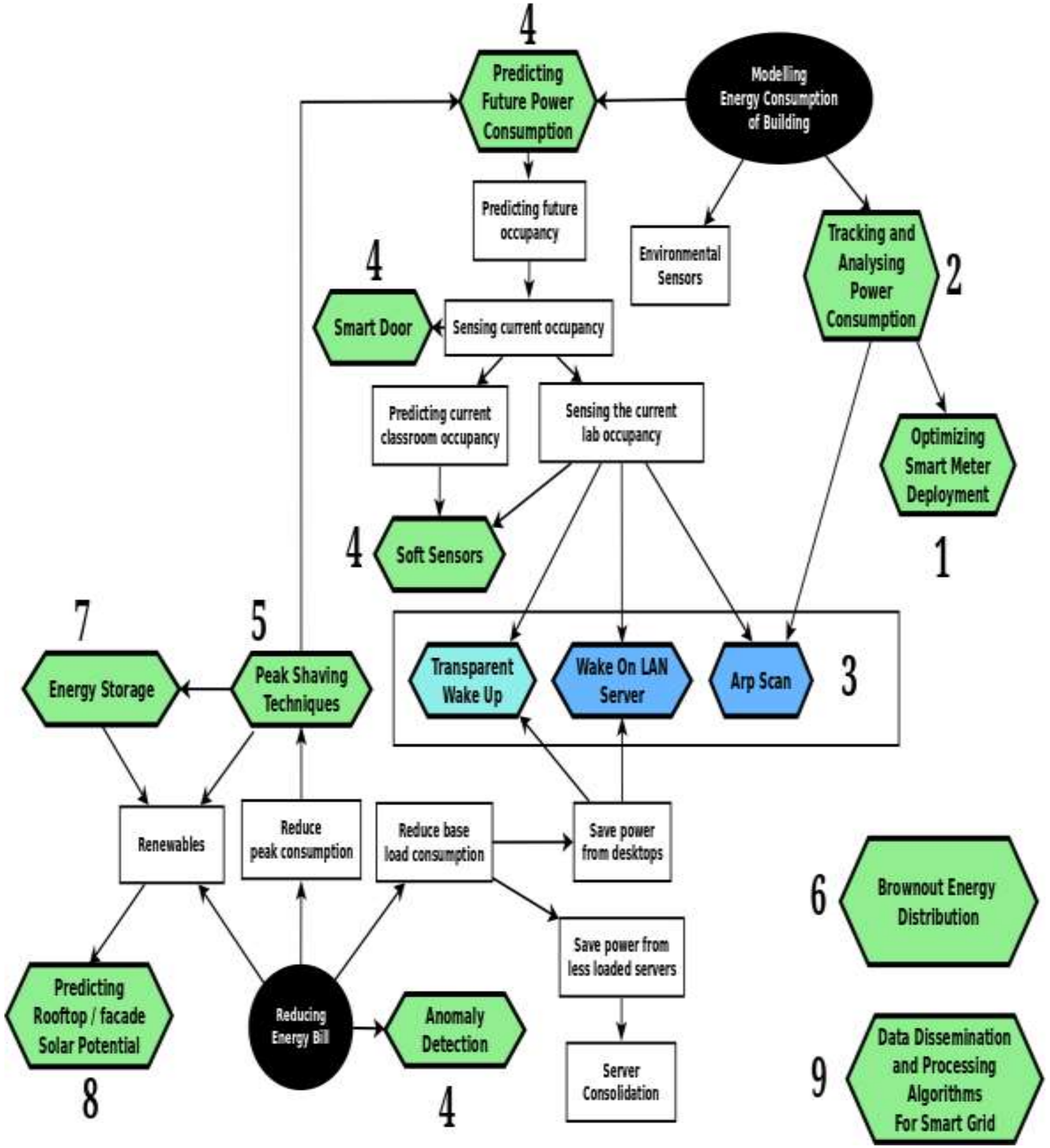
Turn off devices when not needed

Set comfort levels smartly

Exploit elasticity of appliance operations

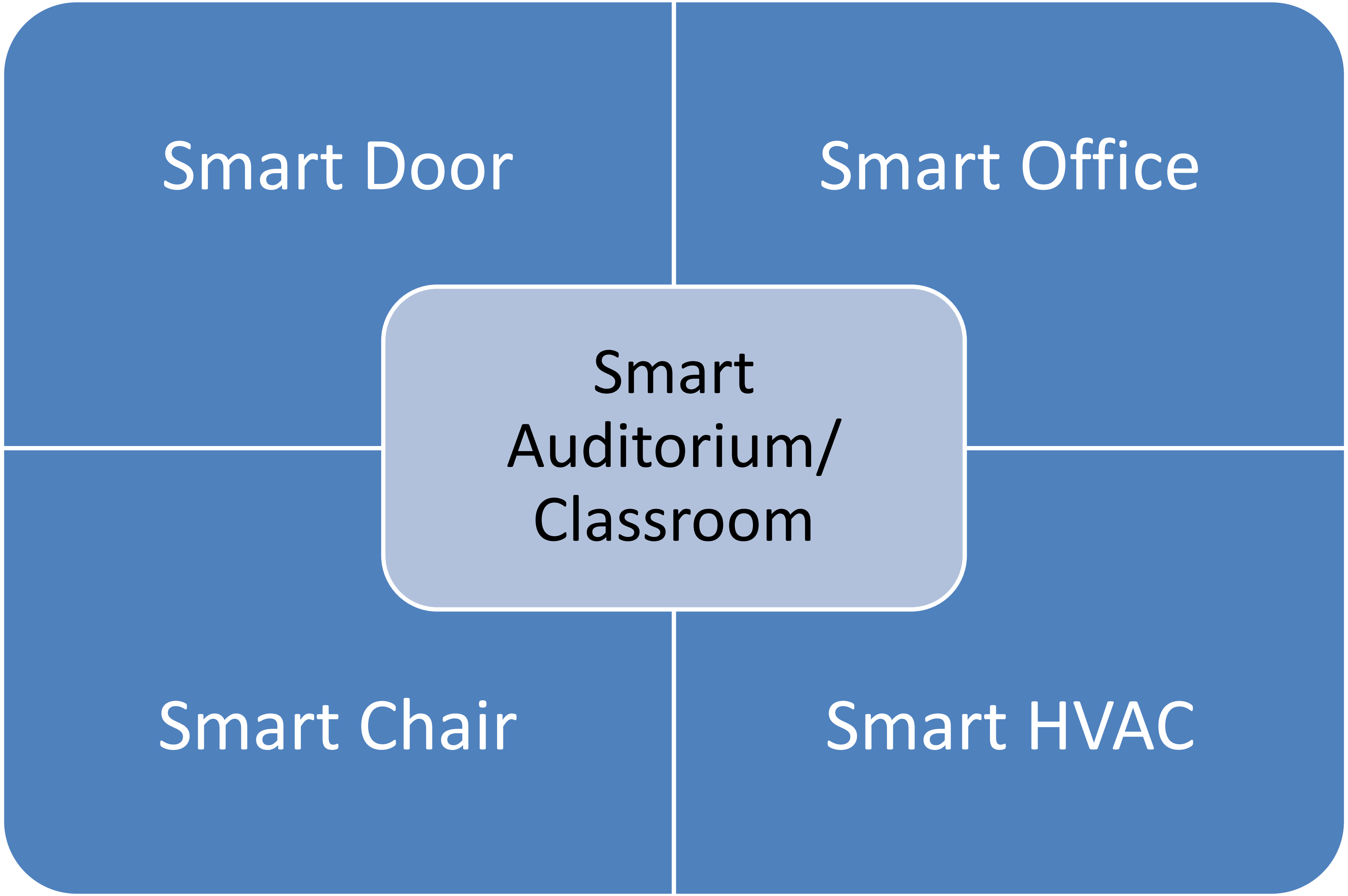
Store excess energy

Our Work In Perspective

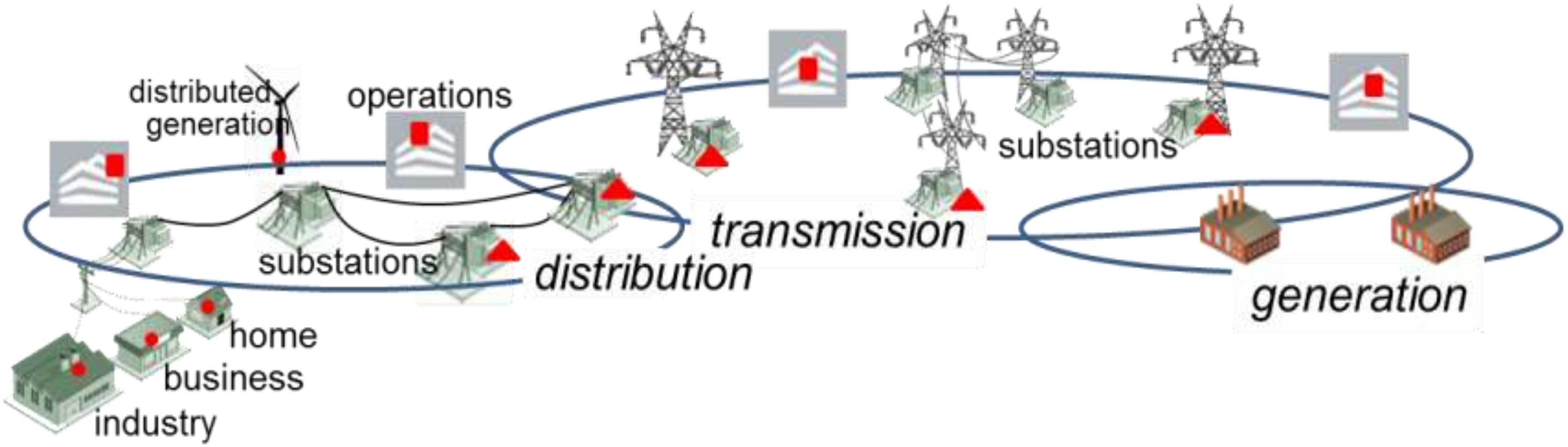


1.	Locating and Sizing Smart Meter Deployment in Buildings
2.	Smart Meter Data Analysis System
3.	Increasing Predictability and Minimizing Power Consumption
4.	Demand Forecasting using Occupancy Patterns
5.	Thermal Comfort-Band Maintenance and Adaptive Demand-Response Control
6.	Brownout Energy Distribution: Graceful Degradation of QoS in Smart Grids
7.	Energy Cost Minimization with SmartStore under Demand Based Static Pricing Schemes
8.	Solar Intensity Prediction
9.	Scaling up the capability of Smart Grids: Distributed Stream Computing
10.	Robust Strategies for PMU Placement

Smart buildings
Smart campuses
Smart grids
Smart cities

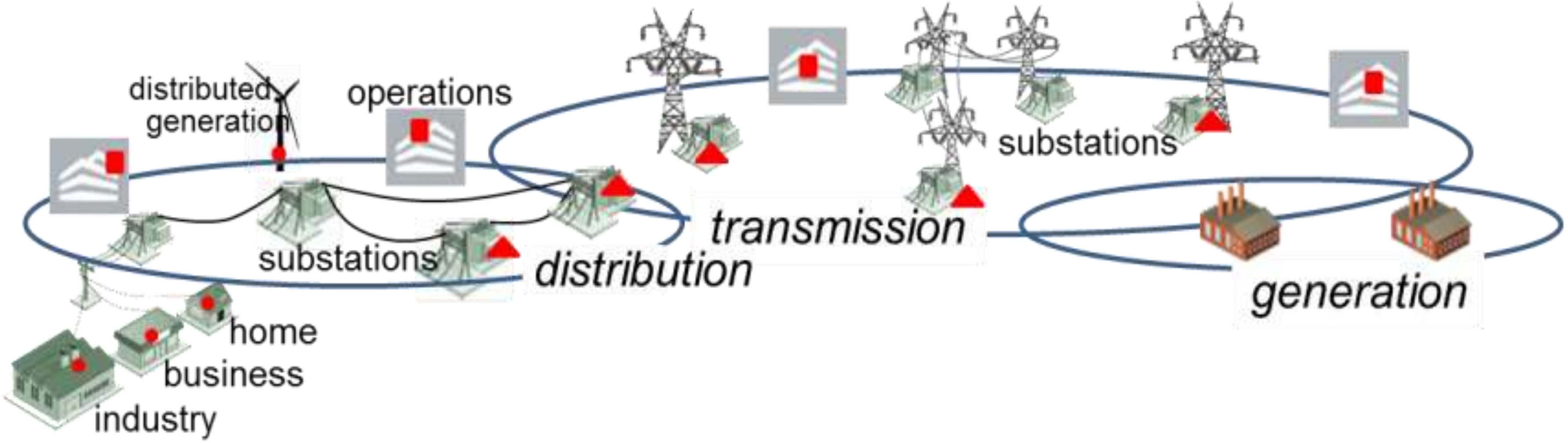


Smart Building/Home: Part of Smart Grid



Smart Building/Home: Part of Smart Grid

Grid monitoring: PMU placement, data distribution, event detection, state estimation



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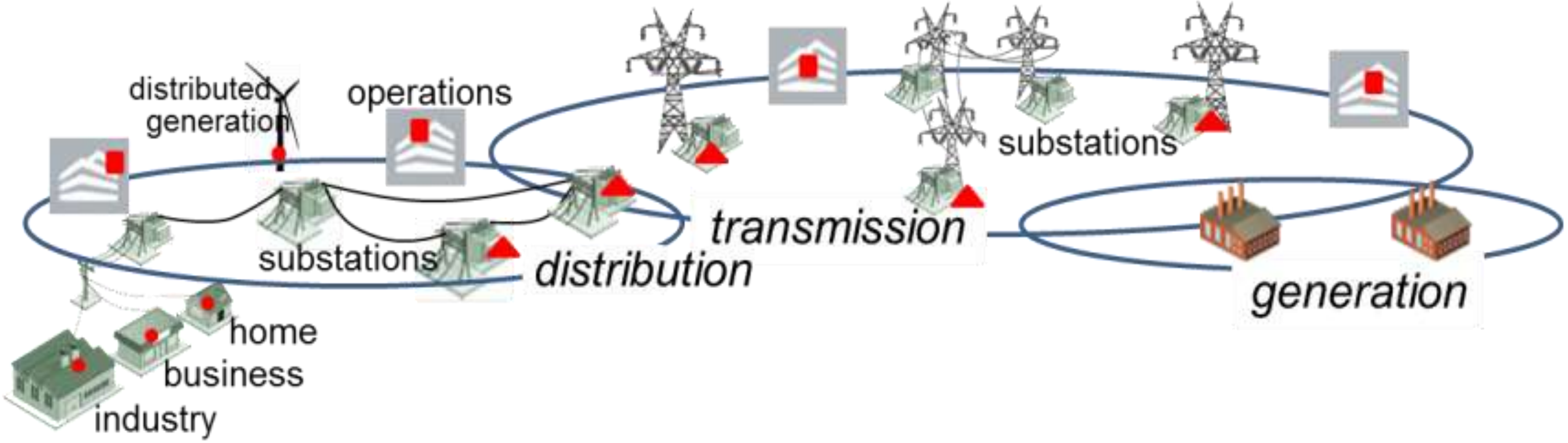
Prediction, modeling: intermittent, renewable source prediction, consumption models



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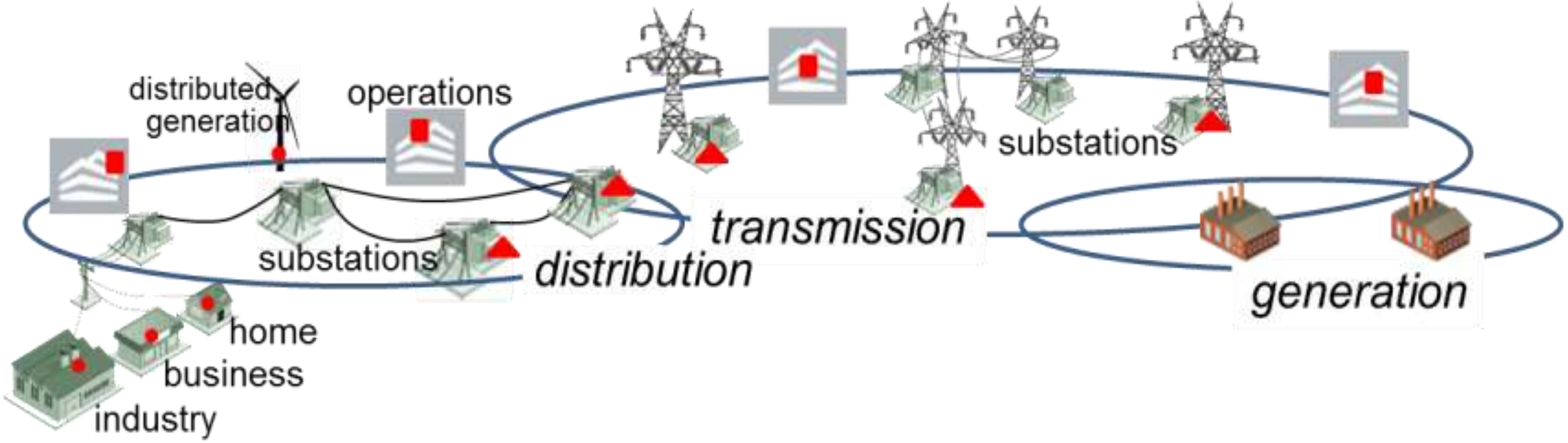

Energy Storage: battery use for peak smoothing, intermittent source buffering

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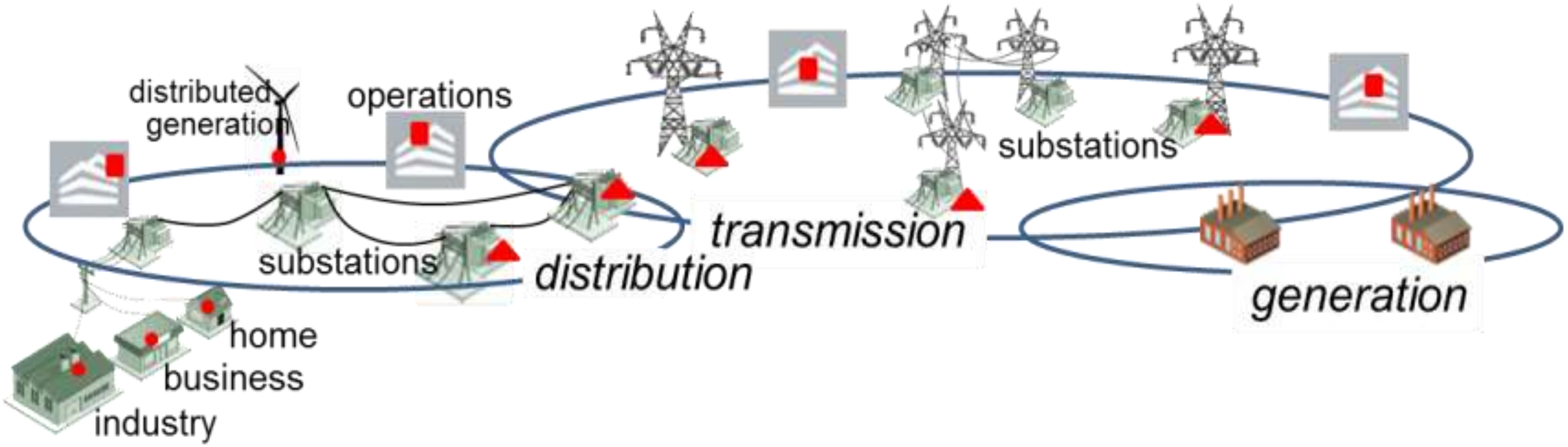

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Demand-side energy management: deferring elastic loads, **coordinating background loads**

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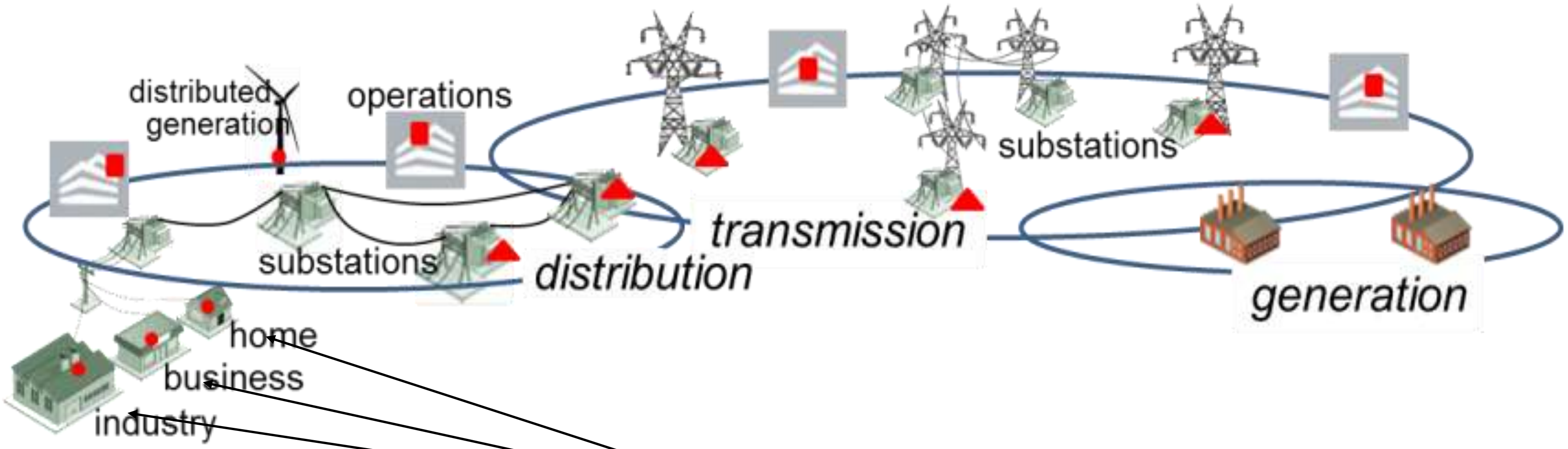

Energy Storage: battery use for peak smoothing, intermittent source buffering

Demand-side energy management: deferring elastic loads, **coordinating background loads**

Some Closing Thoughts…

Any time we answer a question or make a decision,
our response reflects our smartness

Smartness at all stages
--*Design Time, Deployment Time, Initialization Time, Run Time*
-- it is continuous feedback-driven, resource and time constrained

There is always a smarter way of doing something…
=> Today's smarter than yesterday's
=> Tomorrow's will be smarter than today's
Thorny questions -- Intrusion, privacy, security
Cost-effectiveness, payback period
High Tech should be used to achieve Low Cost
All Science and Engineering disciplines have a major role

Different topics in CS/EE contributing to smart things

- ***AI*** – reasoning, analytics, machine learning, data fusion, forecasting, planning, reinforcement learning
- ***Communication and networking, distributed systems*** -- light weight protocols, timely data delivery
- ***Embedded systems*** -- low energy / footprint devices, sensors
- **Autonomic computing**
- ***Algorithms*** -- optimization, data analysis, state estimation
- **Software engineering** -- v & v, embedded sw
- ***Databases*** -- *storage,* storage and retrieval *query processing/optimization, stream processing*
- ***Operating systems*** – caching prefetching, scheduling
- .....

Thanks a lot

Thanks to my collaborators