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NTU CMOS Emerging Technology Group: Exa-scale Cloud for Smart Community

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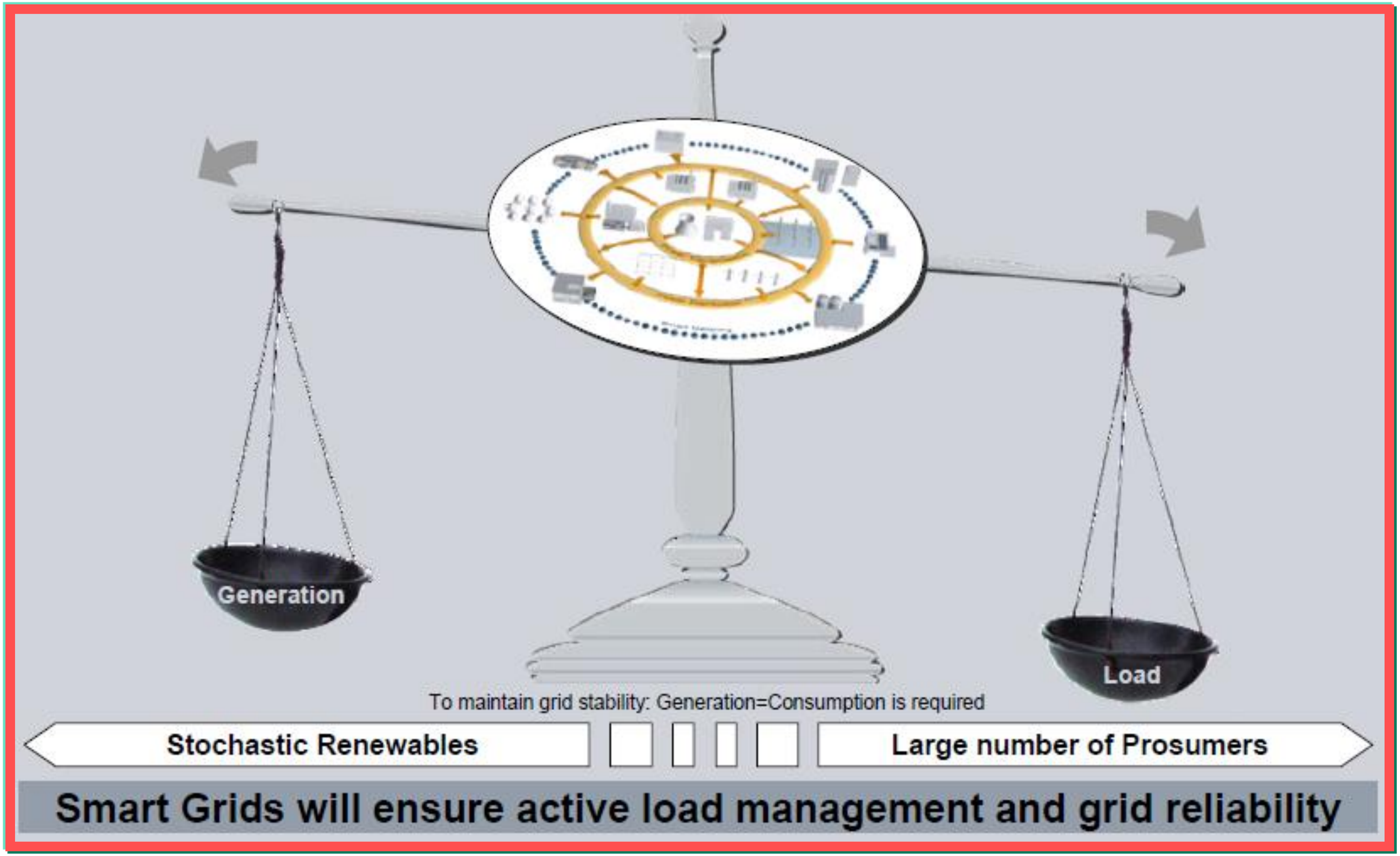
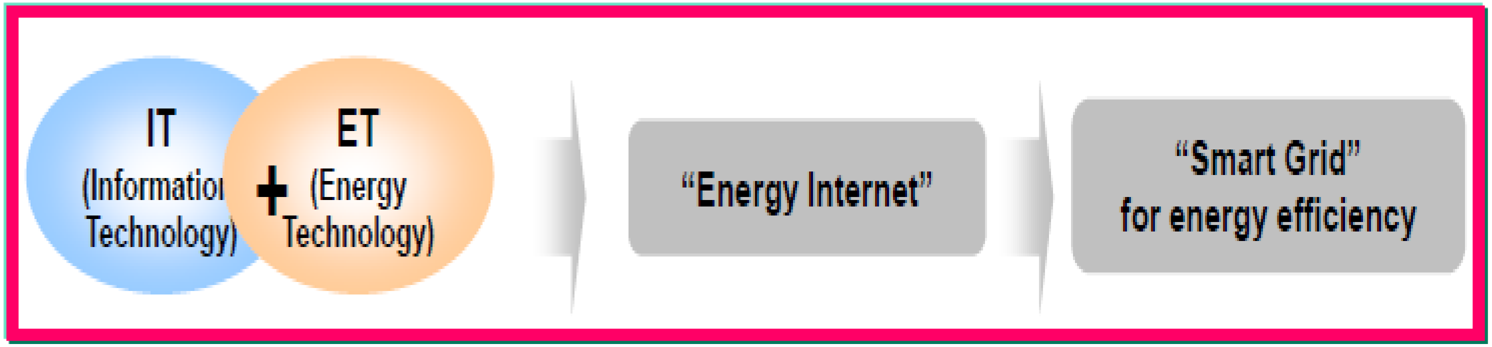
Challenges of Smart Building System



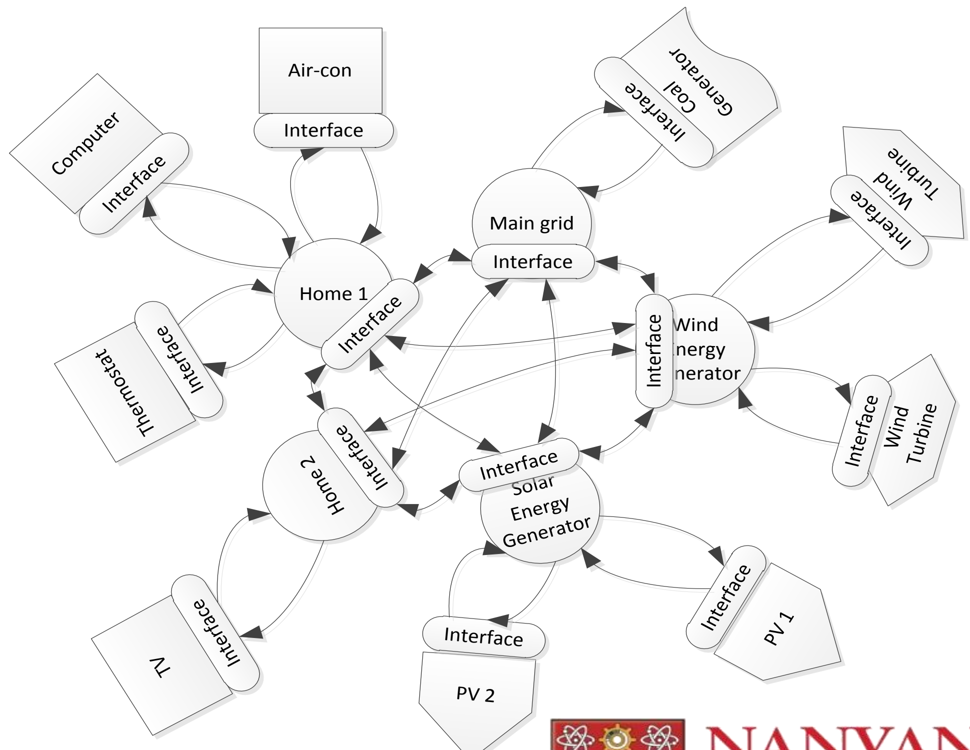
Energy Cloud System for Smart Building

- Existing Work: Agent-based Energy Cloud System
- Current Work: Multi-domain Data Fusion for Comfortability

Energy Cloud: Cyber Grid of Energy and Information Flows



- **Smart grid network**
  - Energy flow network
  - Information network
  - Sensor/Control network
- **Cyber-physical system**
  - Physical model: supply/demand,, transmission, storage
  - Cyber: Can manage? Can verify? Can optimize?



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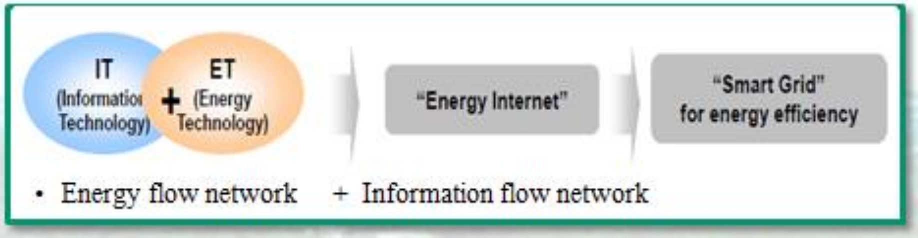
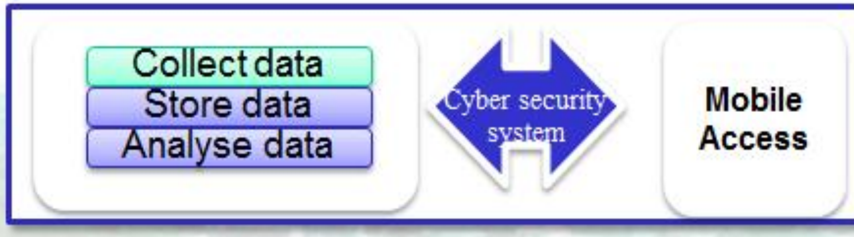
NTU Energy Cloud System:

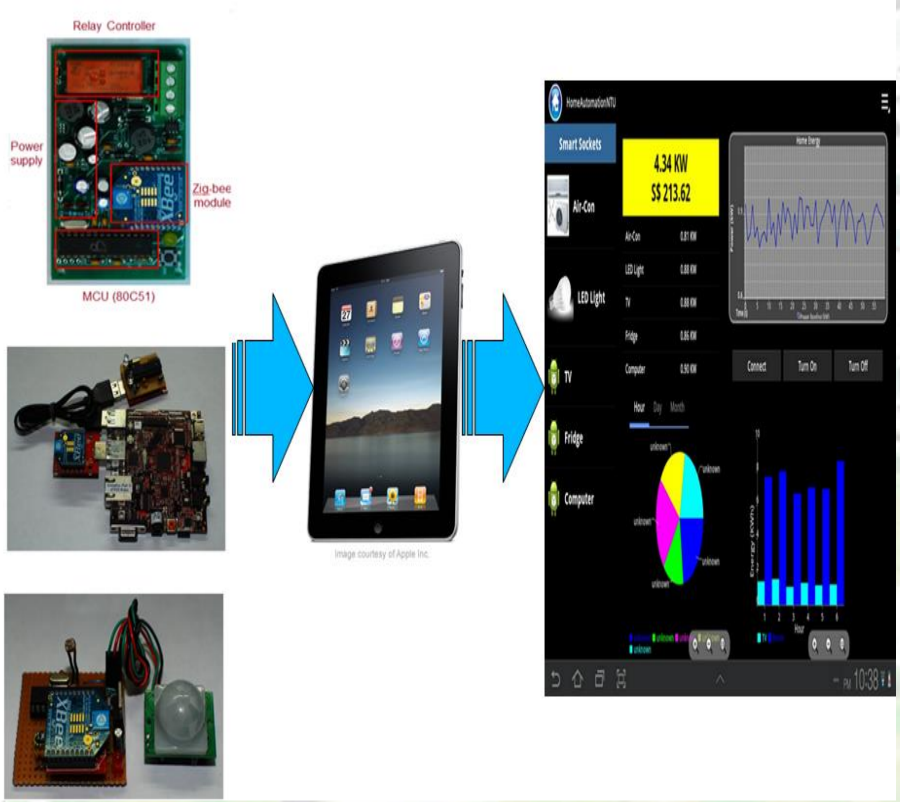
Infineon-NTU Design Competition First Prize Award



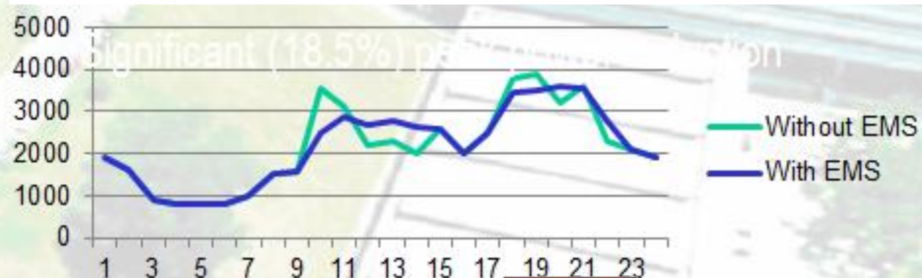
NTU Home Energy Cloud Database



Functionalities for NTU Campus Energy Database



1. Sensor platform to collect multi-domain data flow
2. Local NTU energy cloud server with data base
3. Multi-agent based demand-supply management
4. To be integrated within NTU-ECO campus



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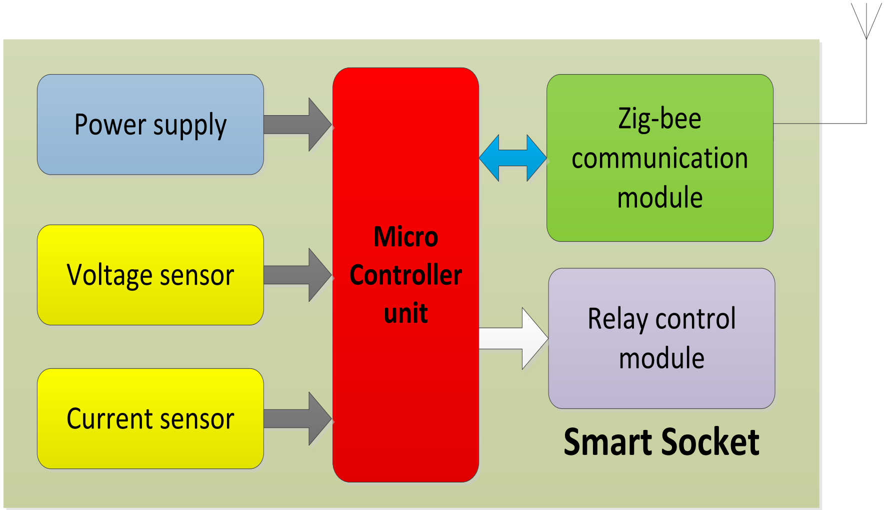
Website: http://www.ntucmosetgp.net/gallery/energy

Smart Socket: Hardware Layer



- Sense real-time load current and power consumption of appliance
- Transmit data by IEEE802.15.4 Zig-Bee protocol network
- Provide demand-response control by relay

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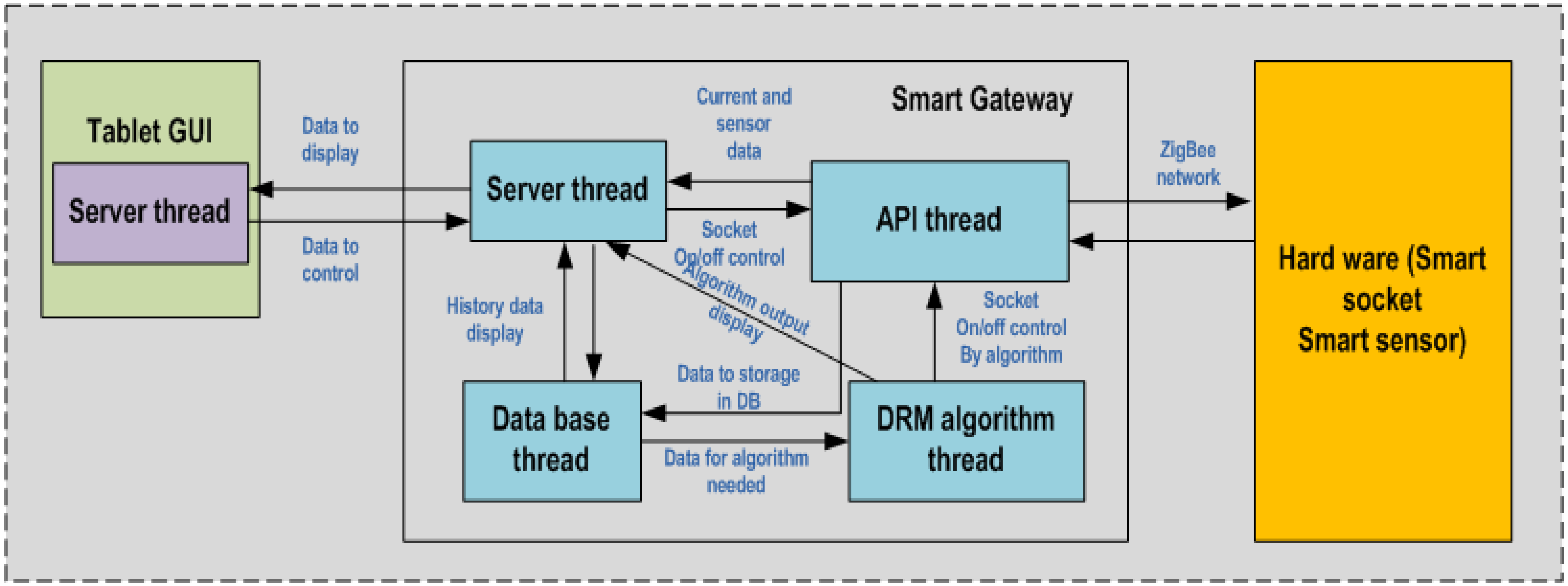
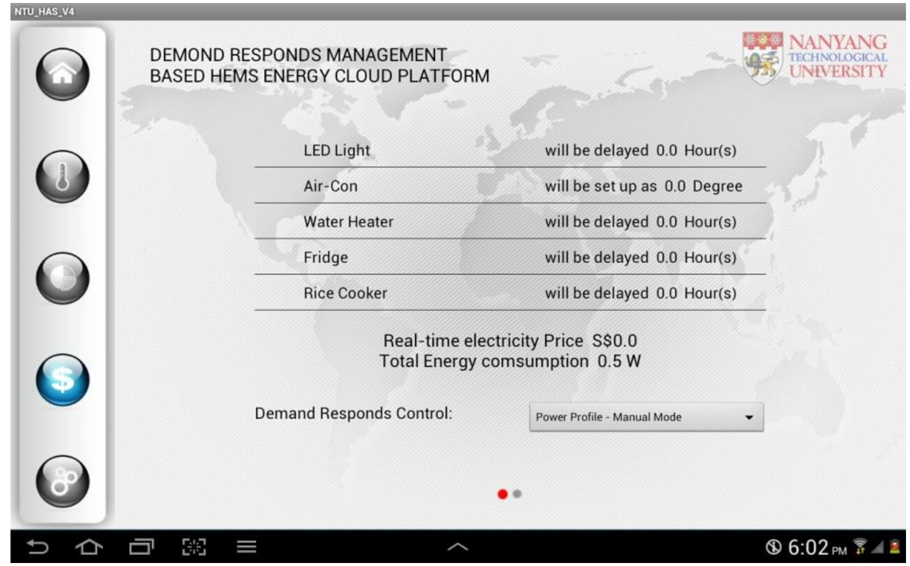
Smart Gateway: Middleware Layer



- Store energy profile data in database
- Perform energy profile data analysis
- Coordinate socket and terminal communication

Smart Terminal: Software Layer



- Provide cloud access via mobile devices with graphic user interface
- Display real-time home energy profile and update
- Enable setup of remote energy management

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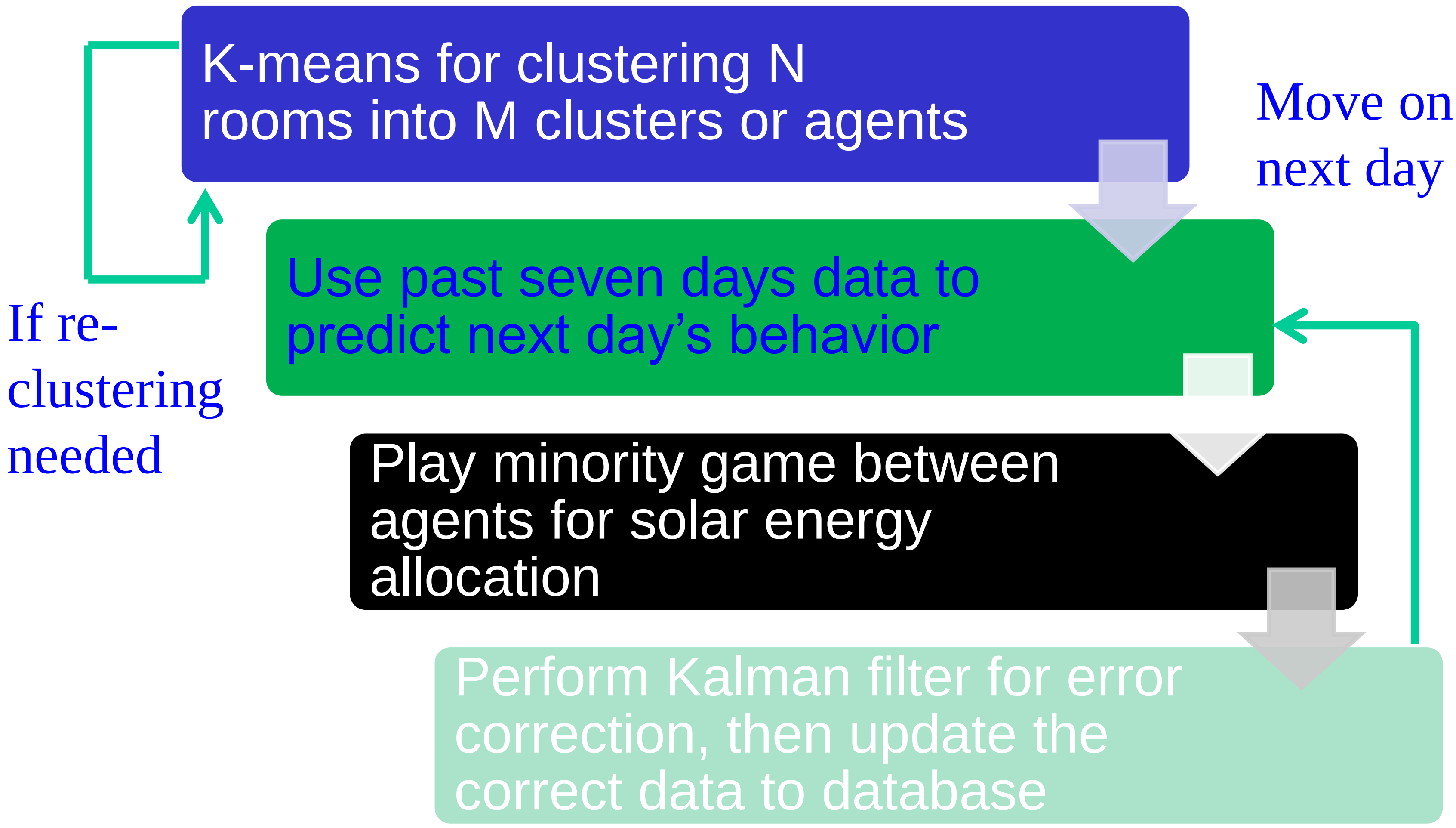
Multi-agent Core Engine

minority game based energy management system



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Agent Classification and Clustering

- **Different rooms have different energy usage profile, which can be used for characterization**
- **K-means clustering technique is introduced**
  - Easy to implement; High computing speed; Fast convergence
  - Three steps:
    1. Initialize clustering centers
    2. Divide points to certain set
    3. Re-set the centers

TABLE II: Center Movement in K-means Clustering

Divided into 2 clusters					
TimeStep	**1**	**2**	**3**	**4**	**...**
Center1	8.2838	4.7144	3.8271	3.8271	...
Center2	9.3377	10.363	9.8615	9.8615	...

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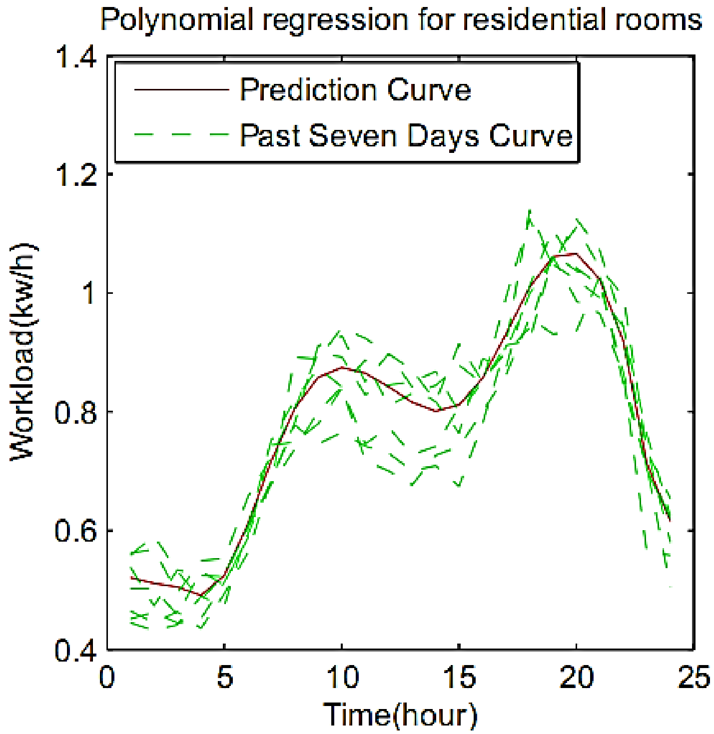
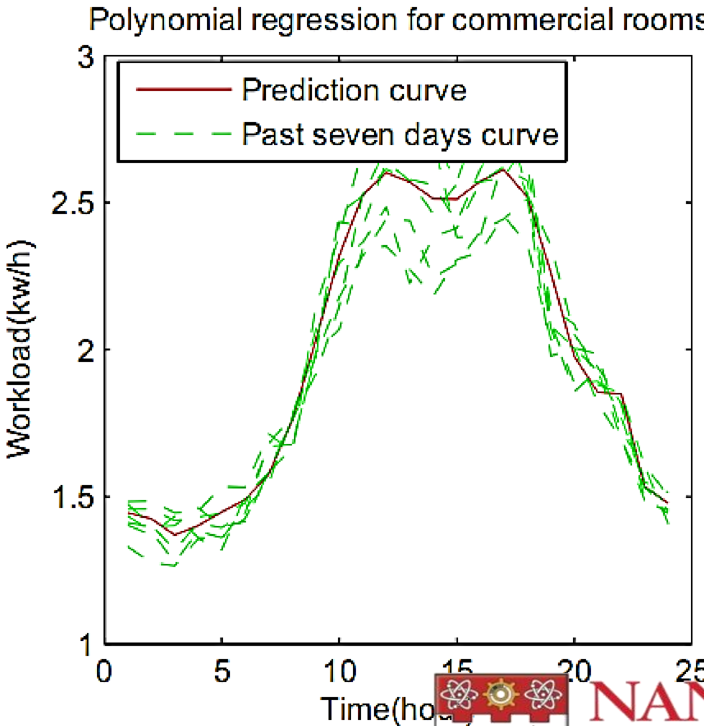
Agent Learning for Prediction

- **Polynomial regression technique**
  - Timescale is based on daily behavior
  - Polynomial order is up to 10, while higher order over 15 will lead to unstable result, where we consider 24 hours a day, 7 days a week

$$\arg min(\sum_{i=1}^{S}\sum_{j=1}^{U}(\sum_{n=0}^{N} a_n x_j^n - \mathbf{T}_{ij})^2 W_i), \quad S=7,\ U=24$$





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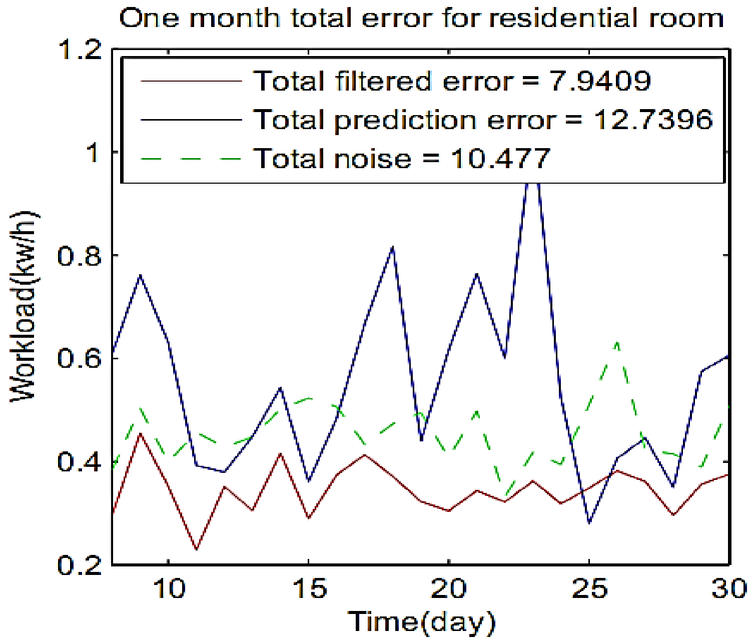
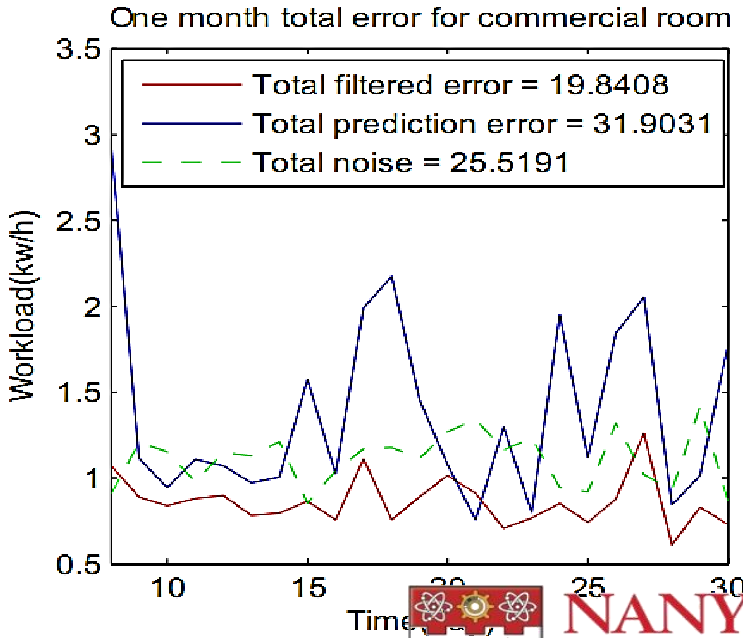
Agent Data Correction of Sensor Error

- **Energy meter/sensor have inherent noise**
- **Kalman filtering with feedback correction**
  - Time domain filter
  - The prediction result combined with measurement result from meter/sensor, determines the approximated value

$$\hat{\mathbf{x}}_i(k) = \tilde{\mathbf{x}}_i(k) + \mathbf{K}_i(k)(\mathbf{z}_i(k) - \tilde{\mathbf{x}}_i(k))$$

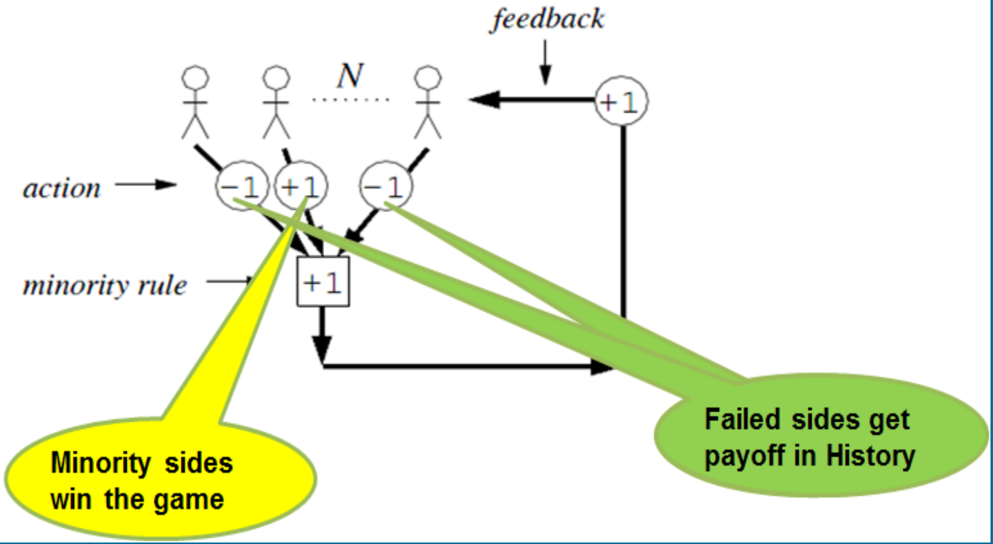
where K is the Kalman gain





Agent Resource Allocation by Minority Game

Equilibrium problem in multi-agent system:



Choose winner side from attractiveness:

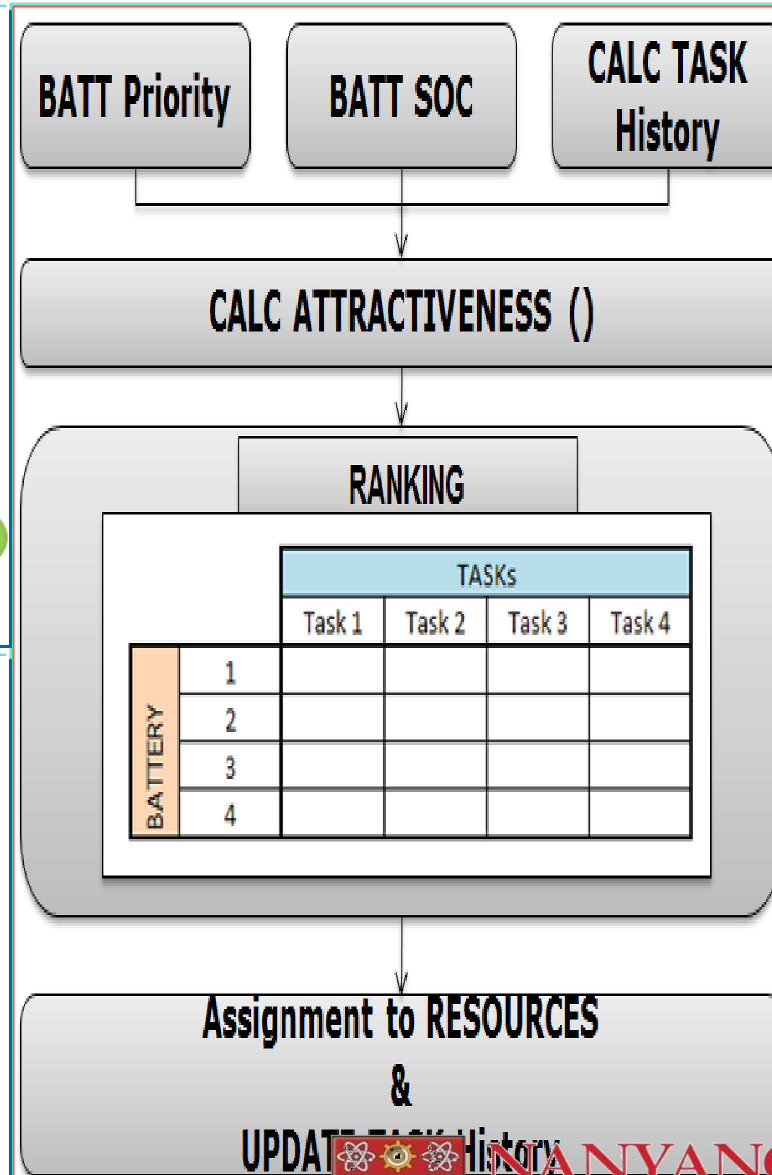
$$Attr(i,k) = a_{TP} * P_k + a_s * SOC(k) + a_H * (1 - H(i,k))$$

Priority of each supplier:
(include Pk and SOC(K))

$$P_k = 1 - current_{Present} / current_{Max}$$

History on each supplier:

$$H(i,k) = Suc(i,k) / Req(i)$$



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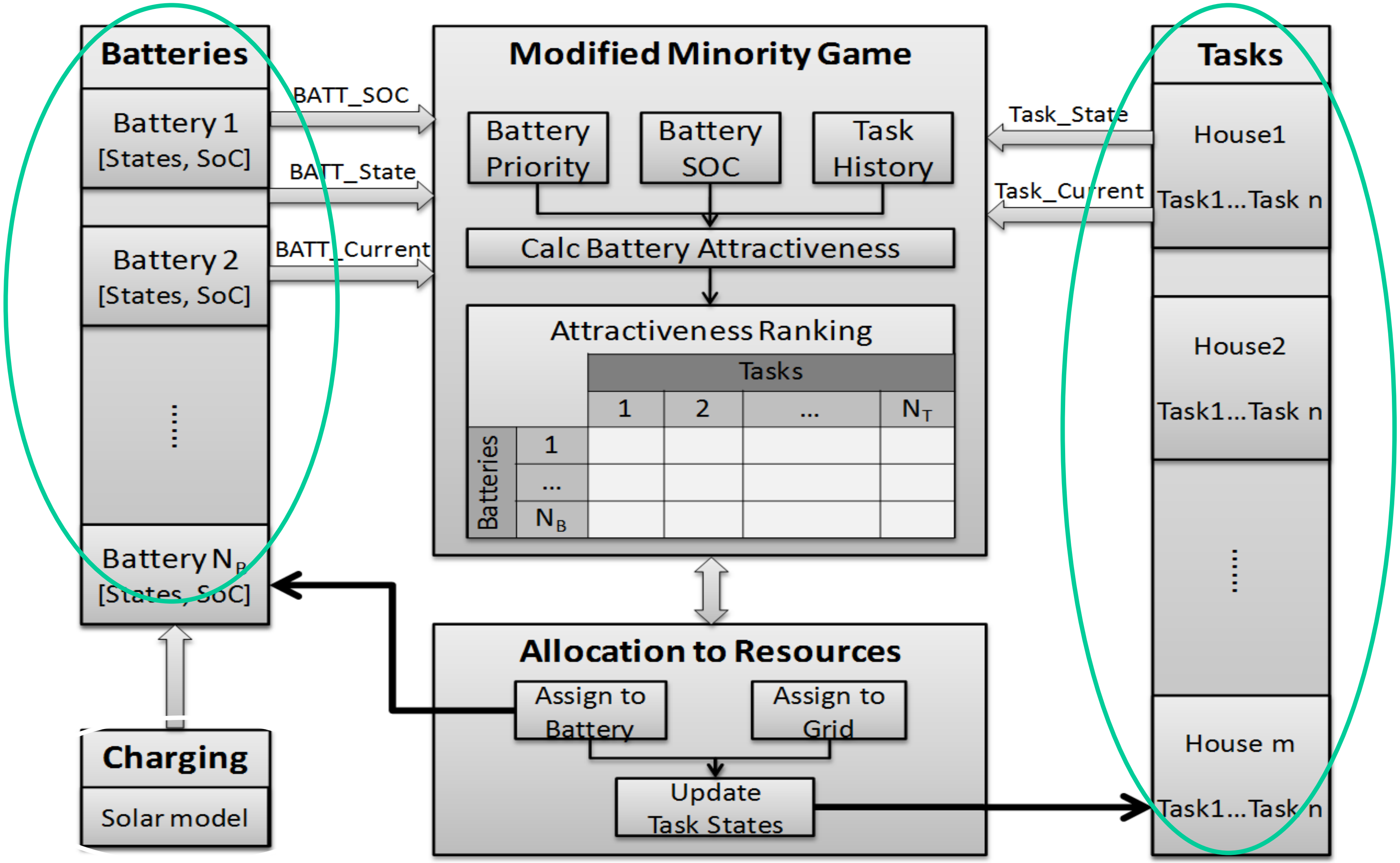
Minority Game based Demand-supply Matching



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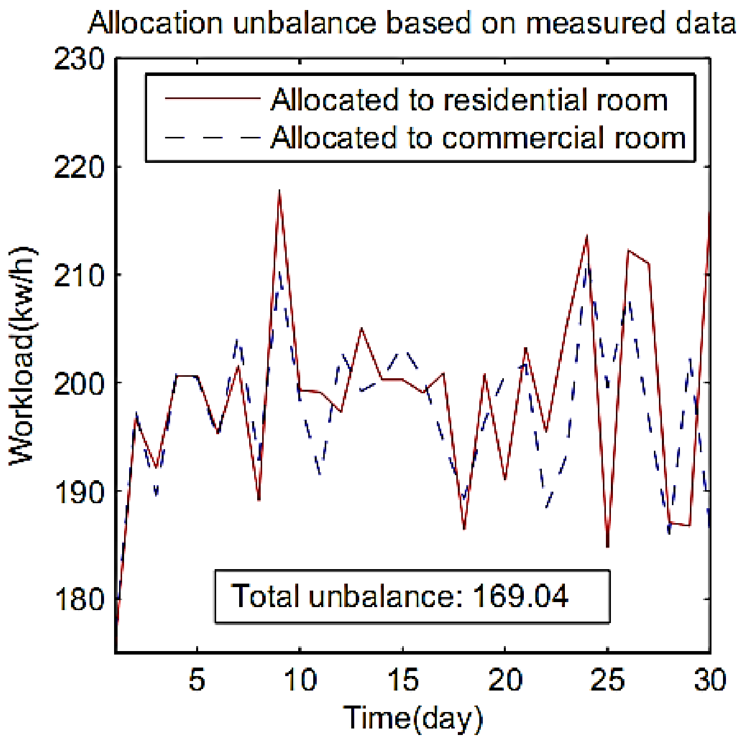
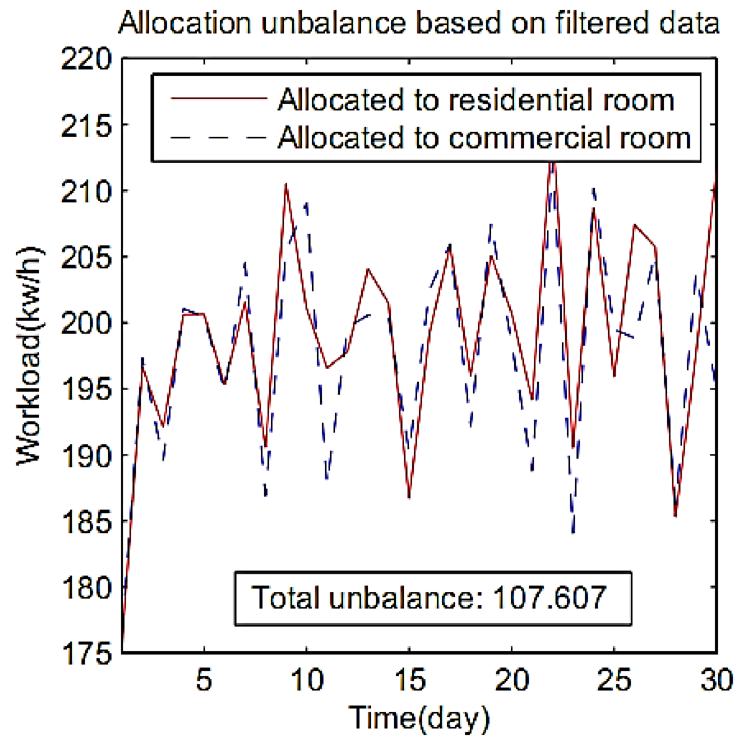
Fair Allocation of Renewable Energy (I)

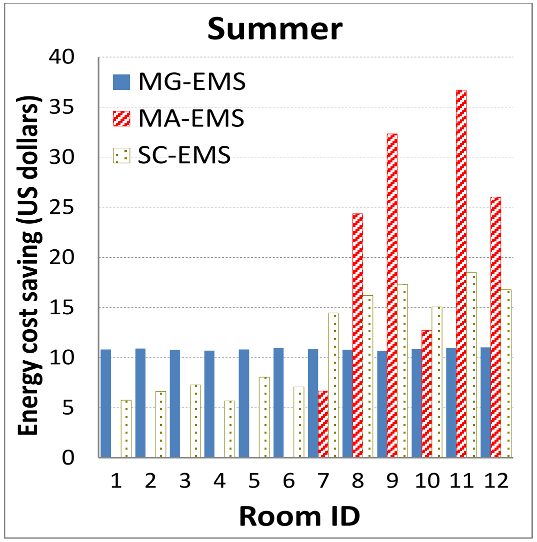


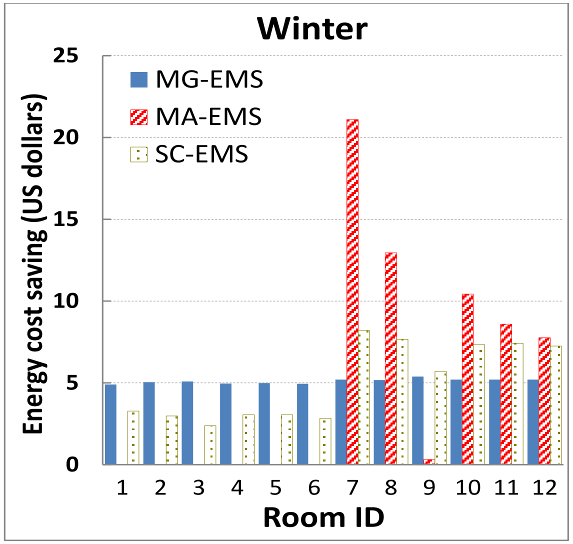


- The left figure shows the mismatch that solar energy allocated to residential rooms and that to commercial rooms are not equal
- Right figure shows after playing game, two types of rooms obtain almost equal solar energy

Fair Allocation of Renewable Energy (II)

- **Fair solar energy allocation**
  - 51x and 147x reductions in energy cost saving deviation in summer
  - 16x and 48x reduction in energy cost saving deviation in winter





Solar PV Area (m^2)	21	22	23	24	25
SC-EMS (US dollar)	4.36	4.55	4.77	4.97	5.17
MA-EMS (US dollar)	12.84	13.25	13.58	13.94	14.34
MG-EMS (US dollar)	0.07	0.08	0.09	0.13	0.11
SC-EMS/MG-EMS	60.1x	55.6x	53.5x	39.2x	47.9x
MA-EMS/MG-EMS	177.2x	161.9x	152.5x	109.9x	132.7x

Solar PV Area (m^2)	21	22	23	24	25
SC-EMS (US dollar)	1.98	2.07	2.16	2.25	2.34
MA-EMS (US dollar)	6.13	6.41	6.66	6.76	7.03
MG-EMS (US dollar)	0.11	0.14	0.15	0.14	0.14
SC-EMS/MG-EMS	17.3x	14.8x	14.6x	16.2x	16.3x
MA-EMS/MG-EMS	53.8x	46.0x	45.[illegible]	[illegible]	48.8x

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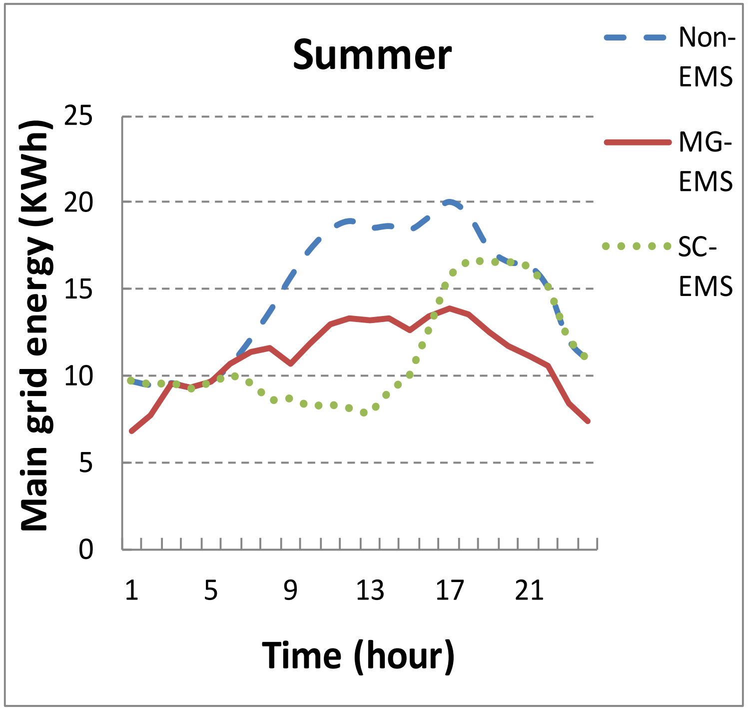
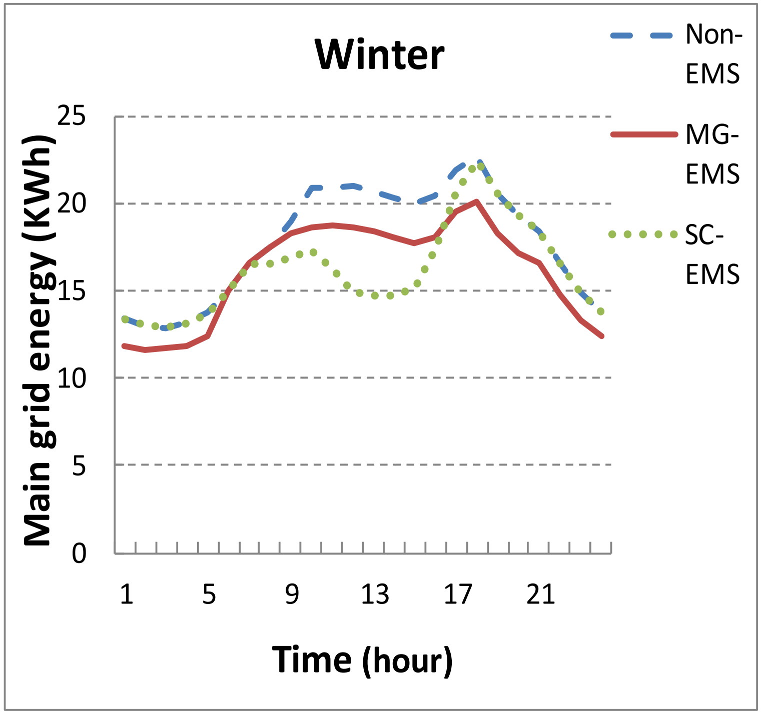
Peak Energy Reduction

- Peak main power grid energy demand reduction
  - 30.62% reduction by MG-EMS
  - 11.47% reduction by SC-EMS [UCSD]





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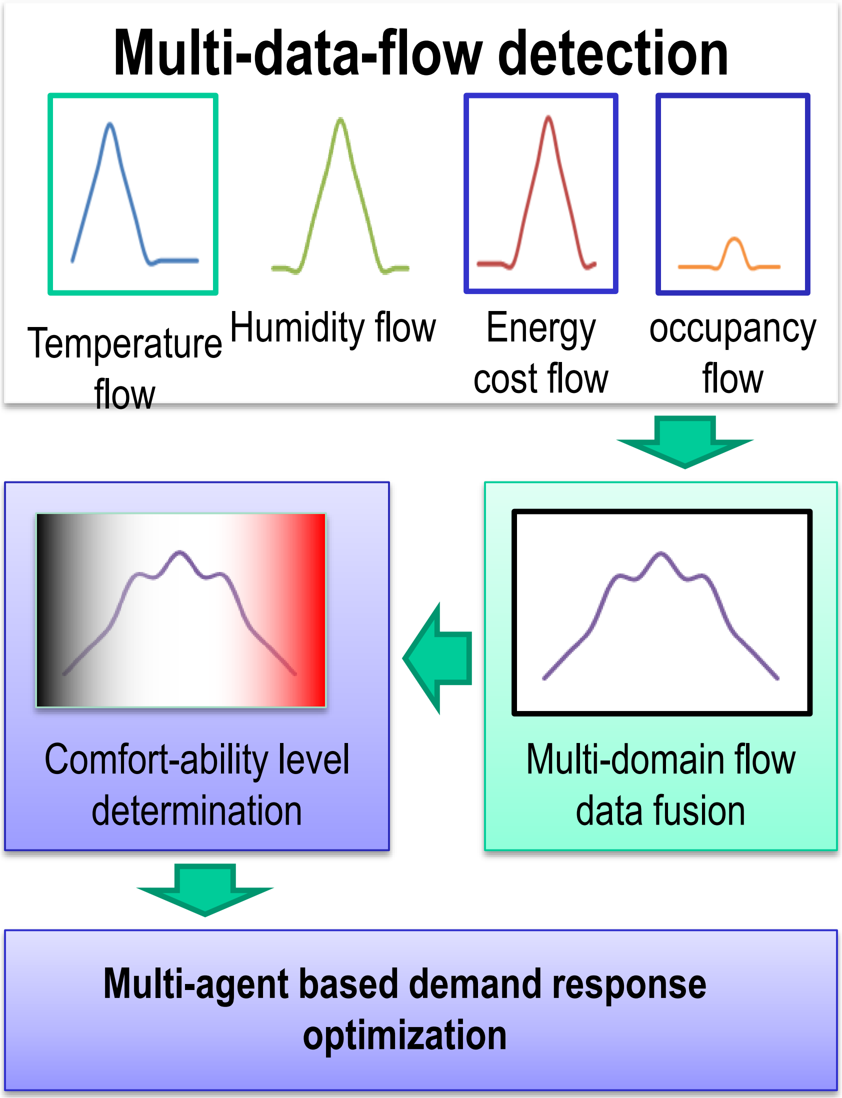
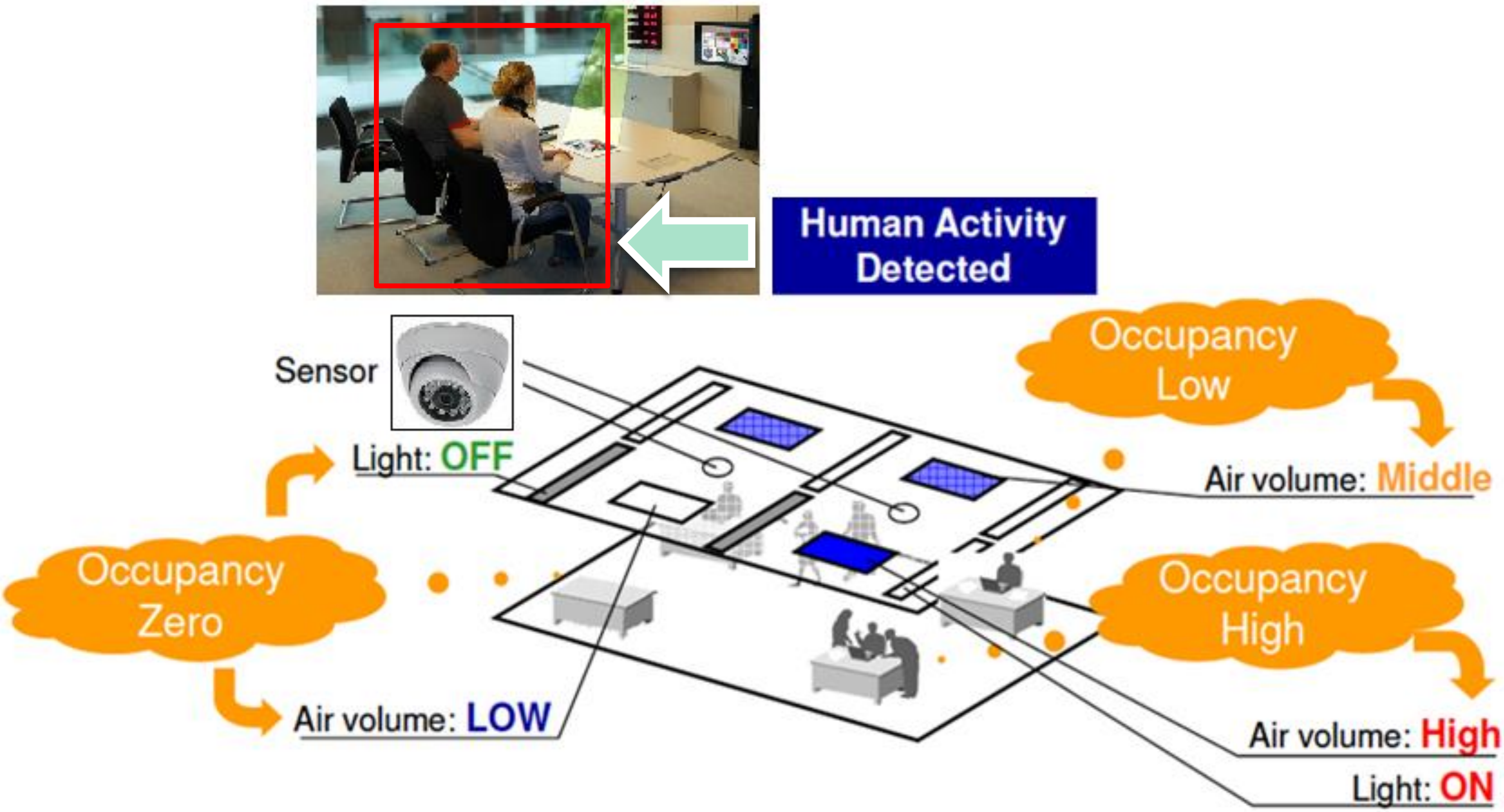
Multi-domain Sensor Data Flow Detection and Fusion for Smart Building

- **Flow: space distribution of energy, temperature, humidity and occupancy within rooms of one building**
- **Existing work can detect:**
  - Temperature flow
  - Humidity flow
  - Energy consumption flow
- **Problems to solve：**
  - The need of occupancy flow detection
  - The need of multi-domain flow data fusion
  - The need of comfort-ability level determination from fused data
  - The need of multi-agent based demand-response optimization

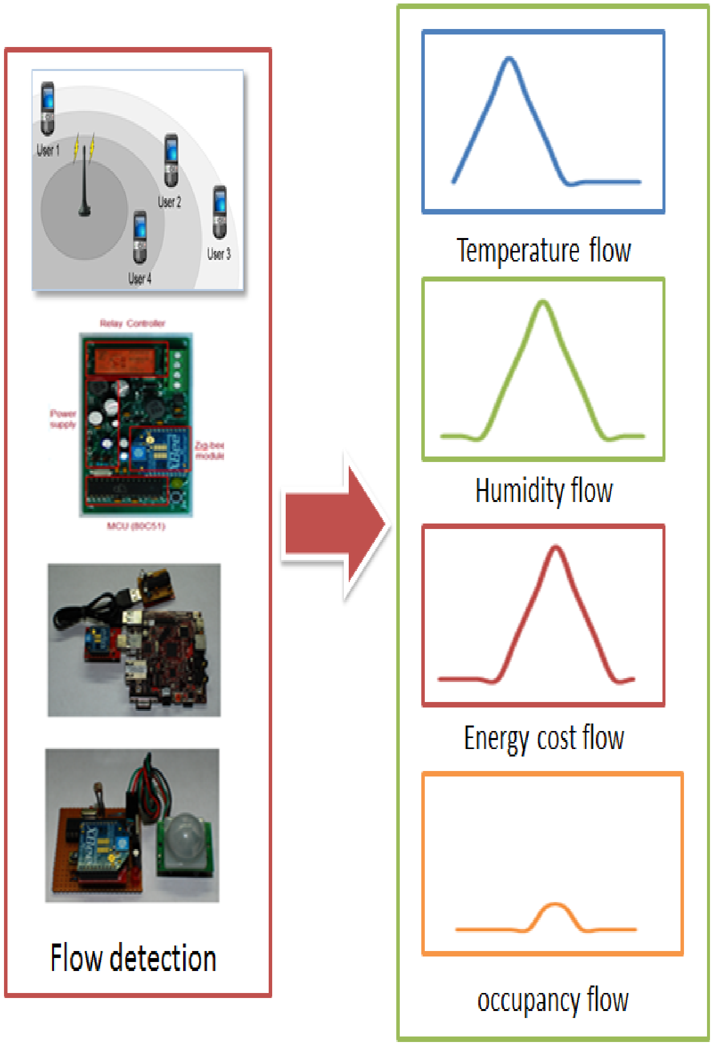


Occupancy Flow Detection by CMOS Image Sensor

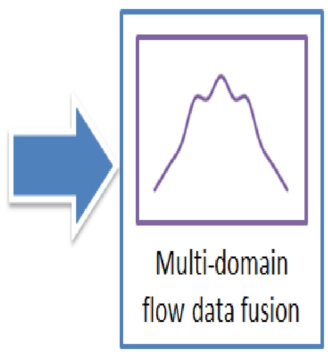
Occupancy flow detection by image sensor: Integrated into NTU-ECO campus project



Multi-domain Data Fusion for Comfort-ability



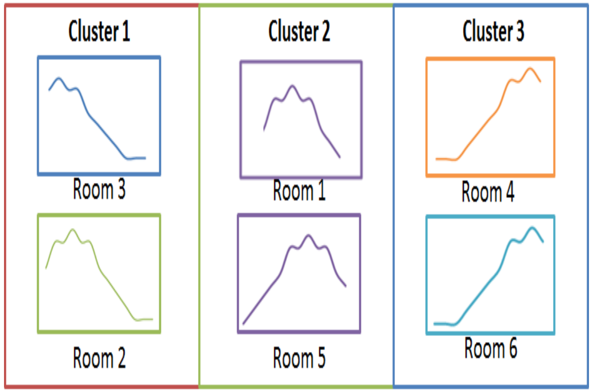
The fused data can be used to define comfort-ability. For example, the central value of fused data distribution is used:

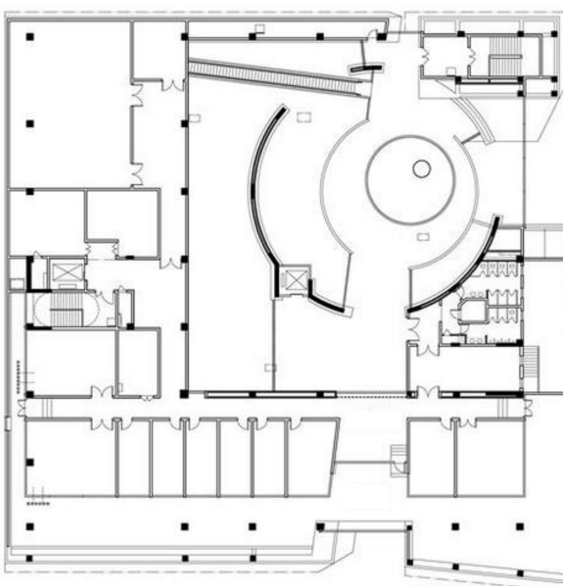


> conformability level 1: (1 people/m^2, 27C, 65 RH%)

> conformability level -1: (3 people/m^2, 22C, 70 RH%)

Demand-response Optimization by Comfortability





Thank you!

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