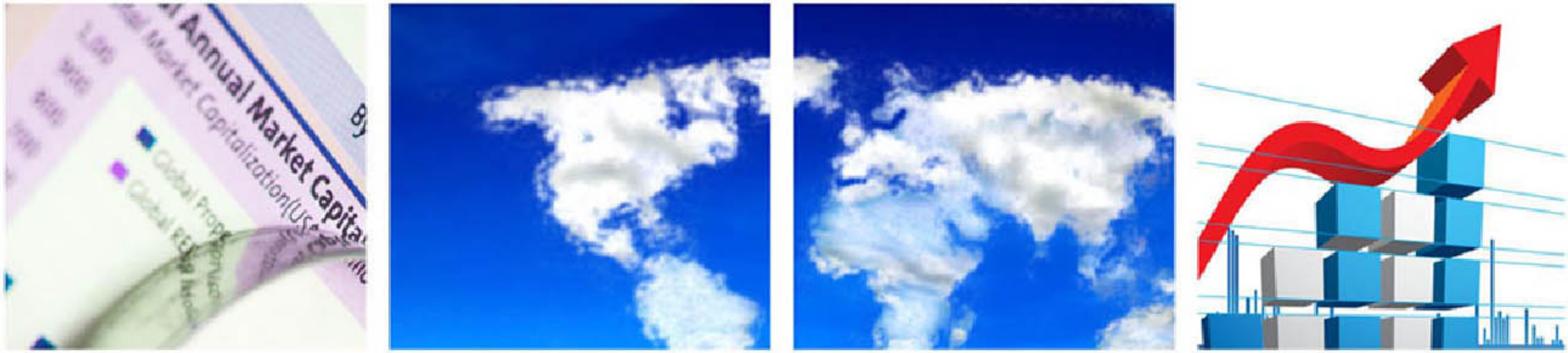

Chinese perspectives towards flexible energy buildings

Fulin Wang

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Tsinghua University

flwang@Tsinghua.edu.cn

Building Energy Research Centre, Tsinghua University

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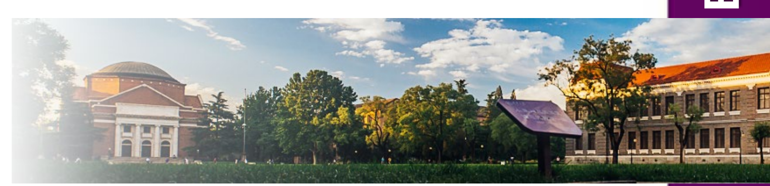
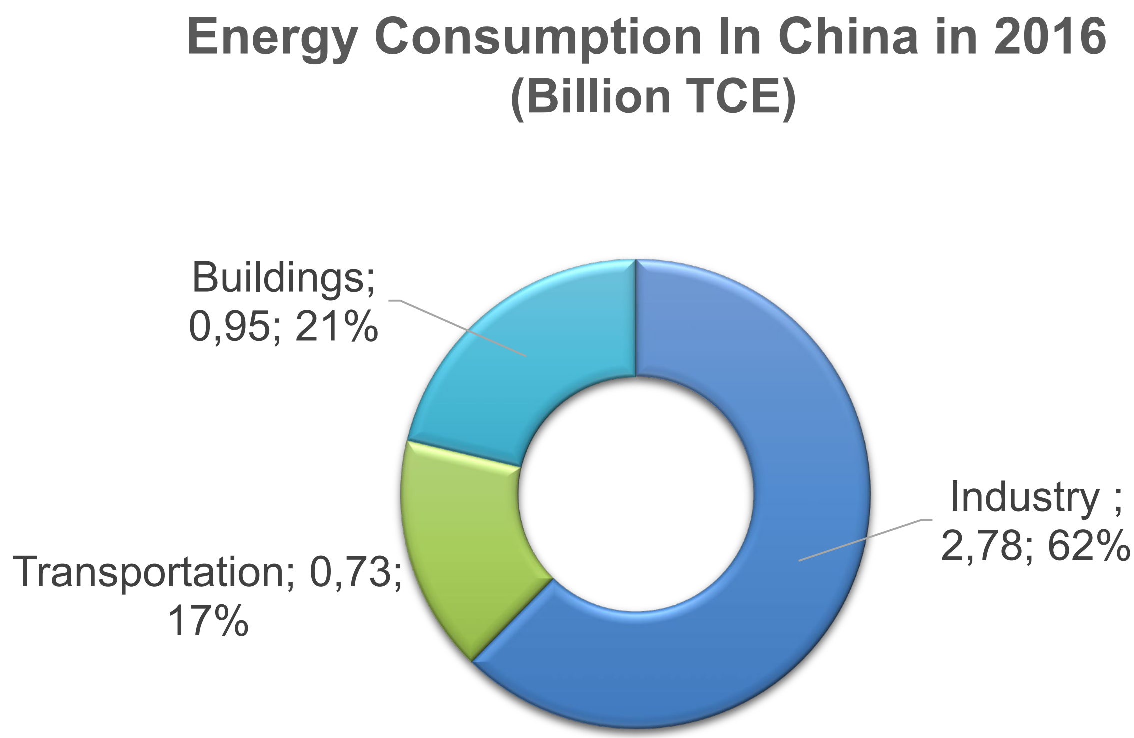
清华大学 建筑技术科学系

DEPARTMENT OF BUILDING SCIENCE, TSINGHUA UNIVERSITY



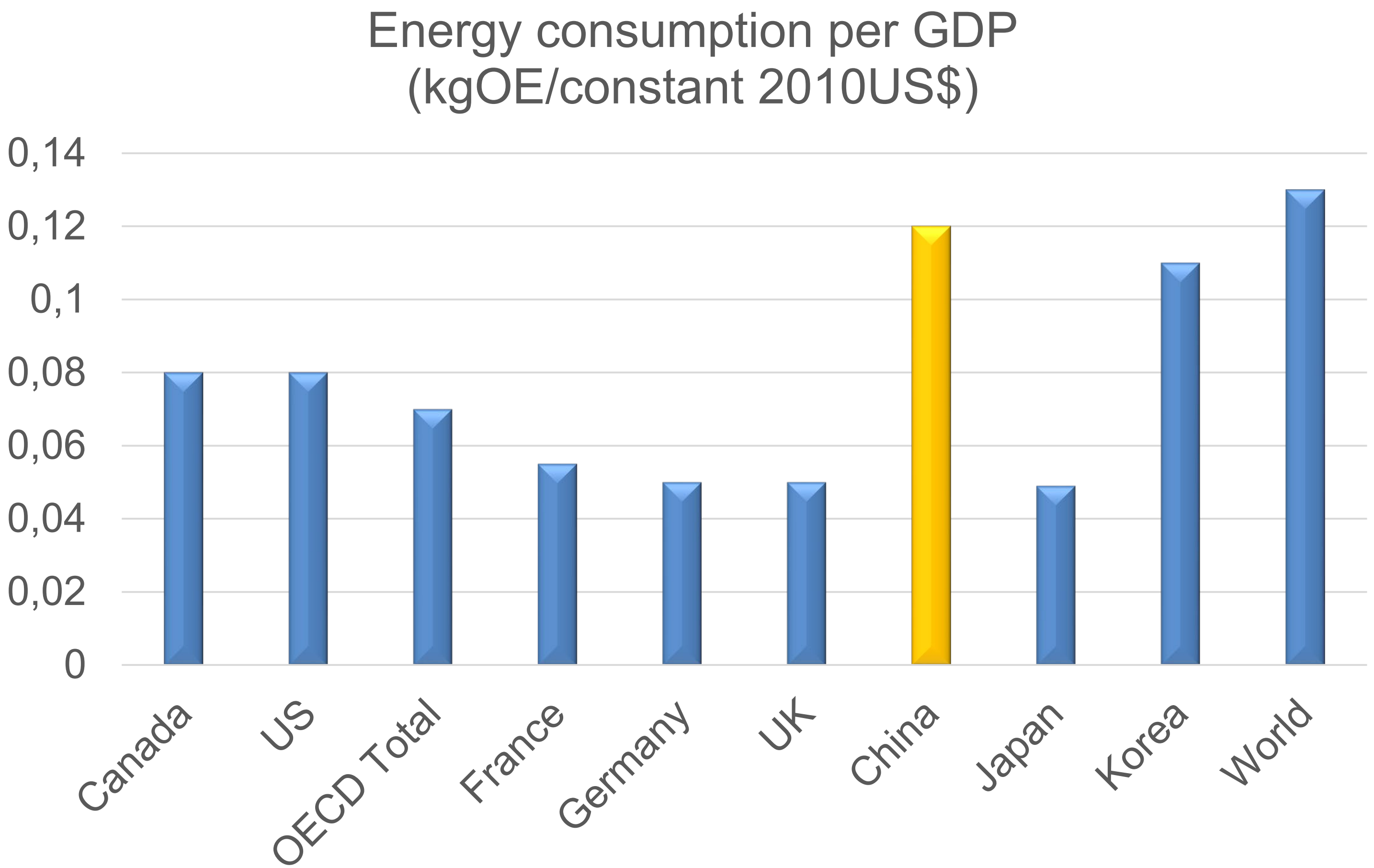
Contents

1. China Current Energy Situations

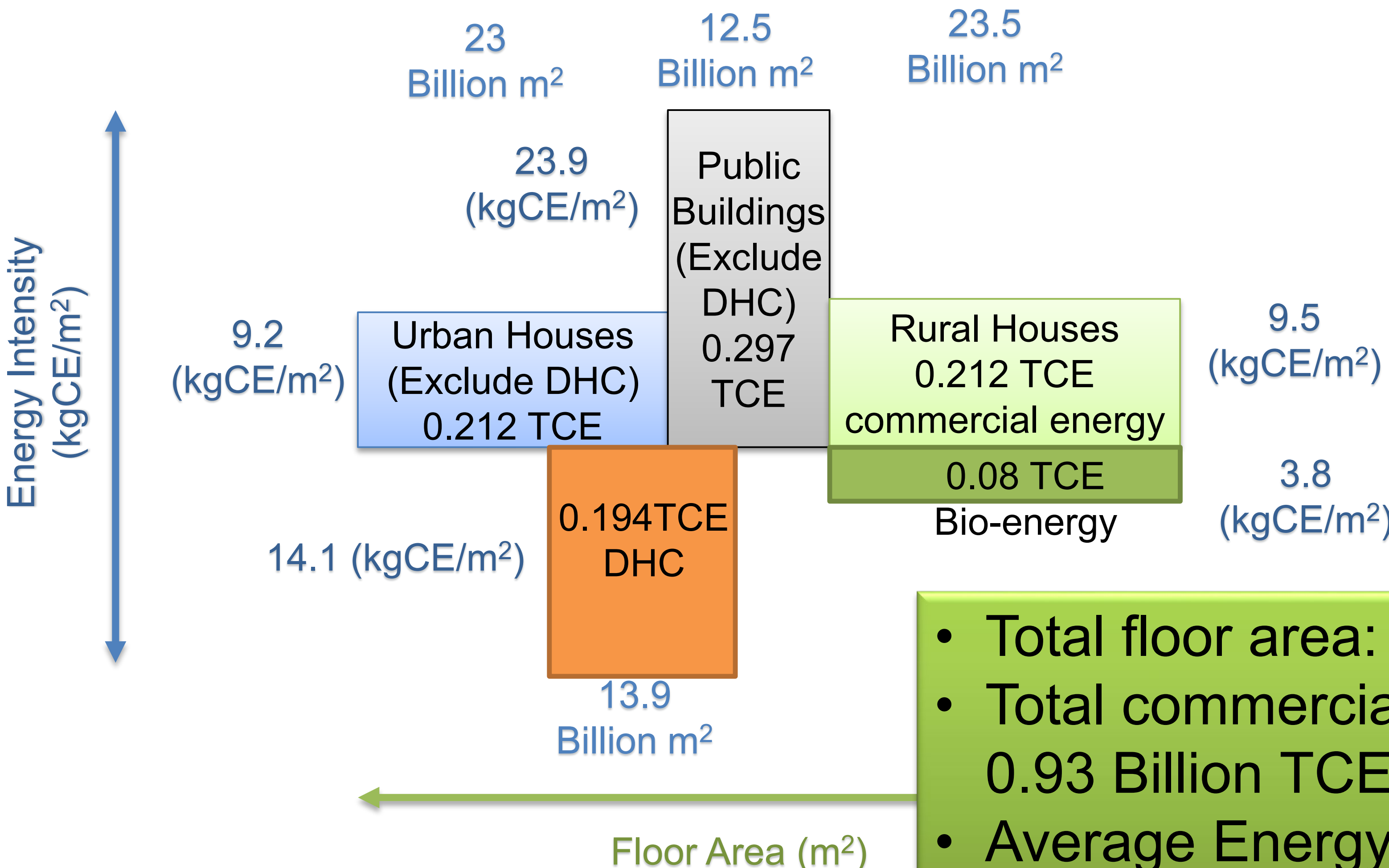


1 TCE (Ton Coal Equivalent) = 29.3 MJ

1. Chinese Current Energy Situations

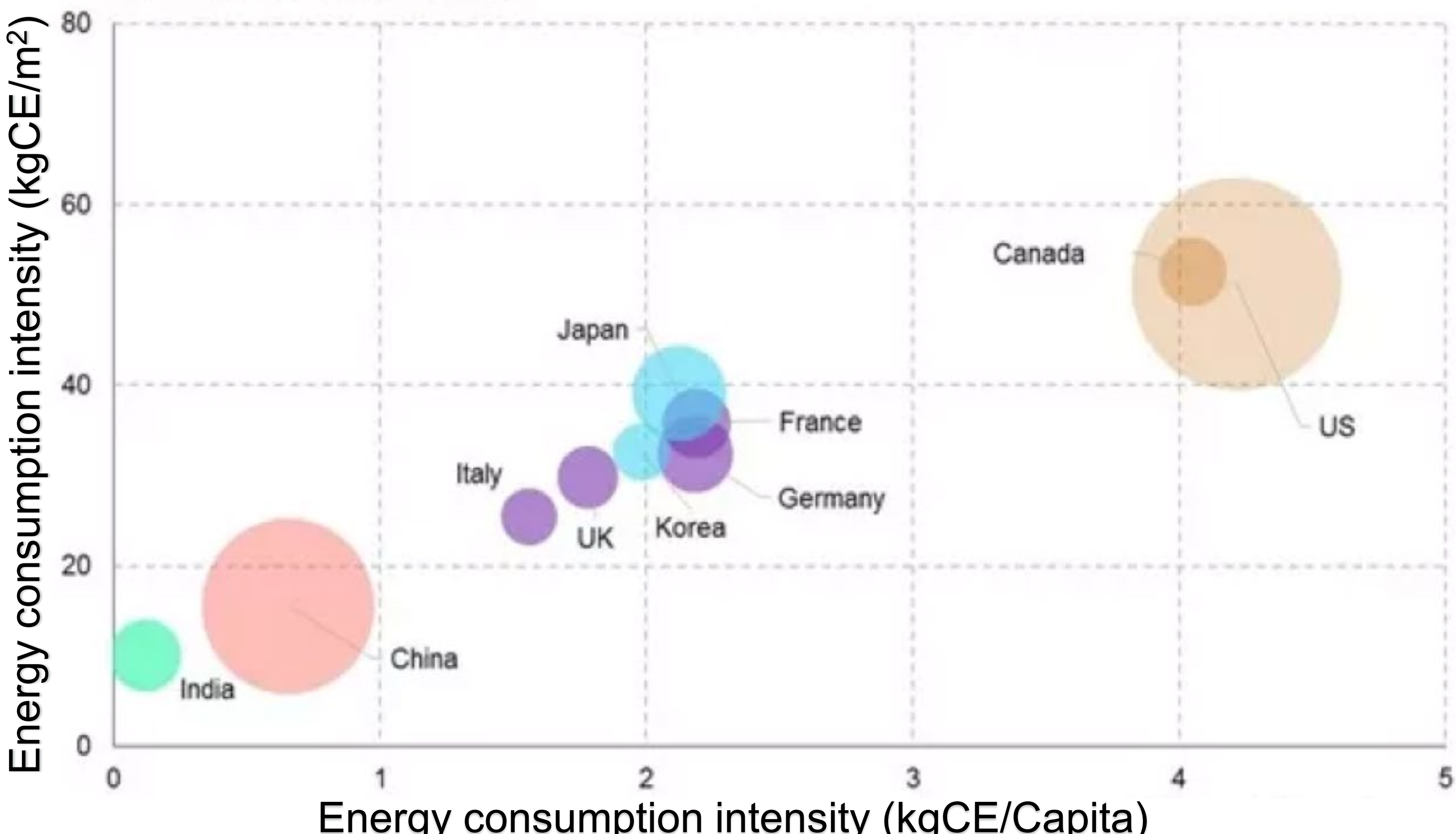


1. Chinese Current Energy Situations



- Total floor area: 59 Bm^2
- Total commercial energy: 0.93 Billion TCE
- Average Energy Intensity: 17 $kgCE/m^2$ floor area

1. China Current Energy Situations



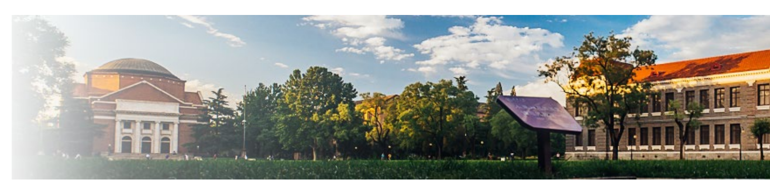
2. China Future Energy Roadmap

- Energy Consumption Limitation
  - Electricity : 10 trillion kWh/year
    - Production
      - Thermal Power: 4.5
      - Hydraulic power: 1.5
      - Nuclear power: 1.5
      - Wind power: 1.5
      - PV power: 1
    - Consumption
      - Building sector: 3
      - Transportation: 2
      - Industry: 5
  - Fuel burning: 1.9 billion TCE/year
    - Gas, Oil, Coal: 0.9
    - Bio-energy: 1.0

> - Electricity proportion increases from 20% to 60%
> - Renewable energy proportion increases from 26% to 55%

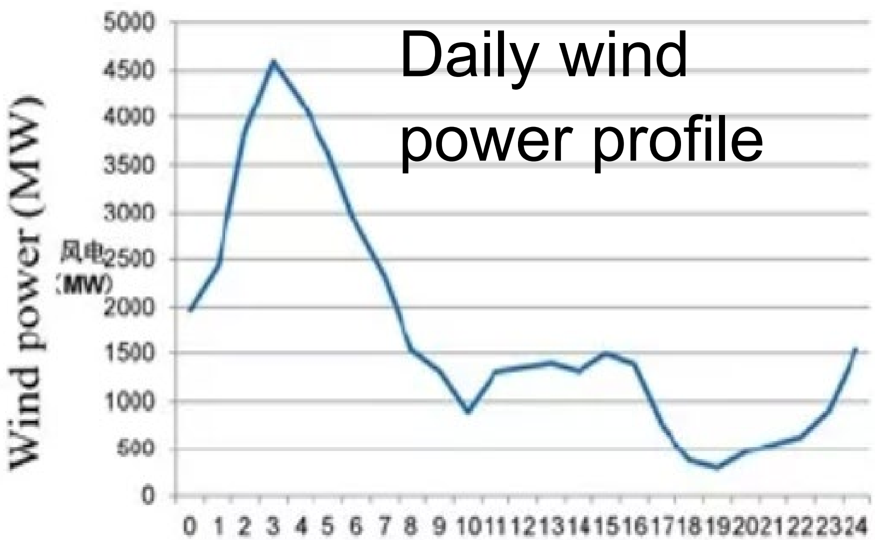
2. China Future Energy Roadmap

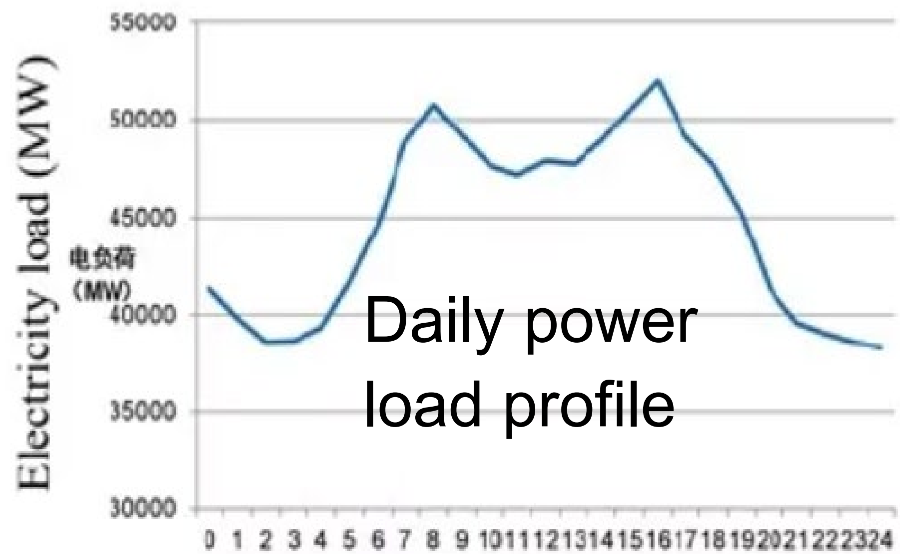
- Energy Technologies
  - District Heating
    - Utilize low-grade waste heat
      - Thermal power plant
      - Industrial factory
      - Small amount of gas used for peak load
      - Long-distance, high-Δt thermal transportation
        - ✓ Δt = 50°C, thermal energy loss is 6% per 100km
        - ✓ Δt = 100°C, thermal energy loss is 3% per 100km



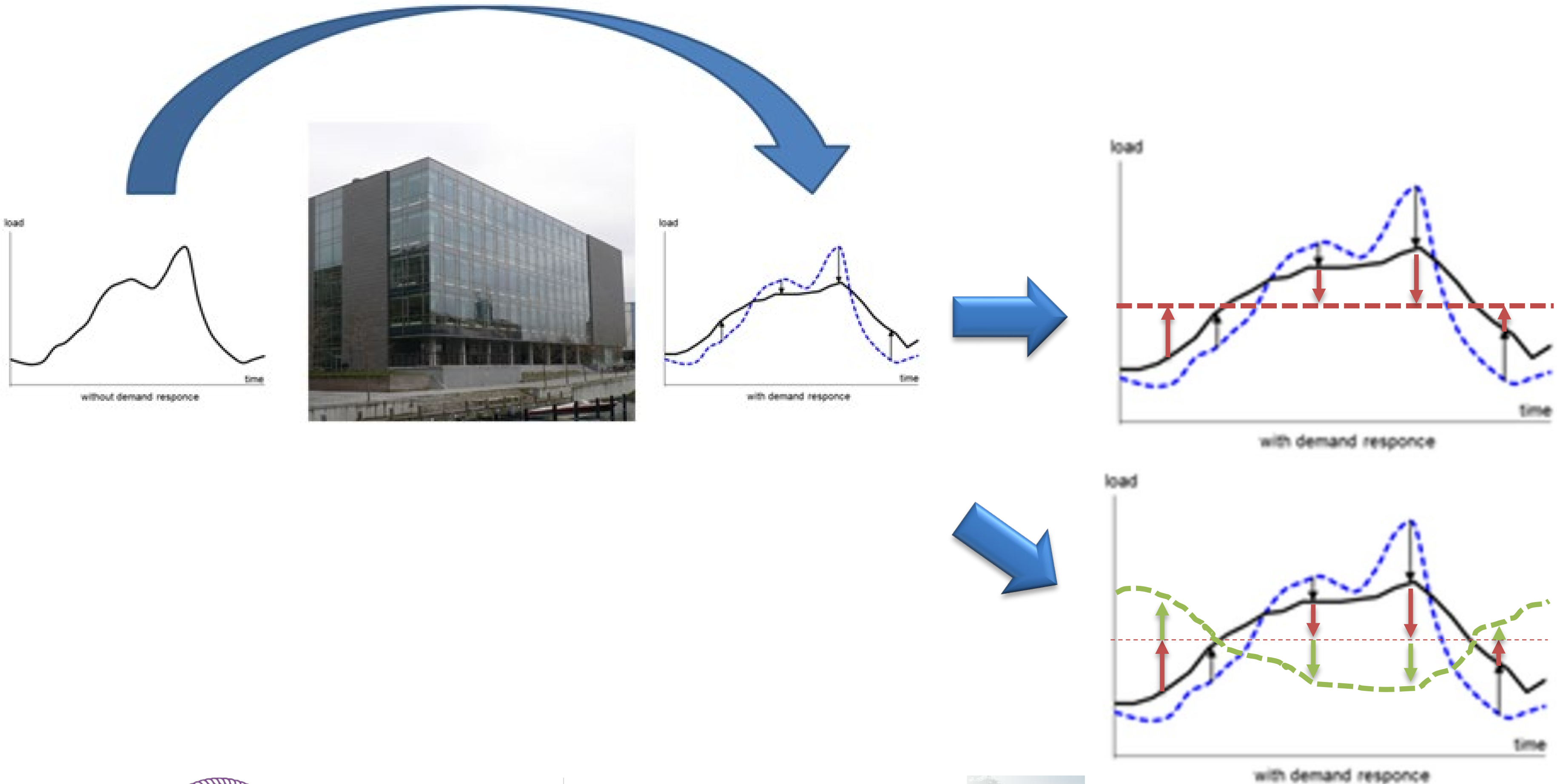
2. China Future Energy Roadmap

- Energy Technologies
  - Flexible Electricity System
    - Transport renewable energy from west to east
    - Hydraulic energy storage
    - Building DC power supply and distributed storage



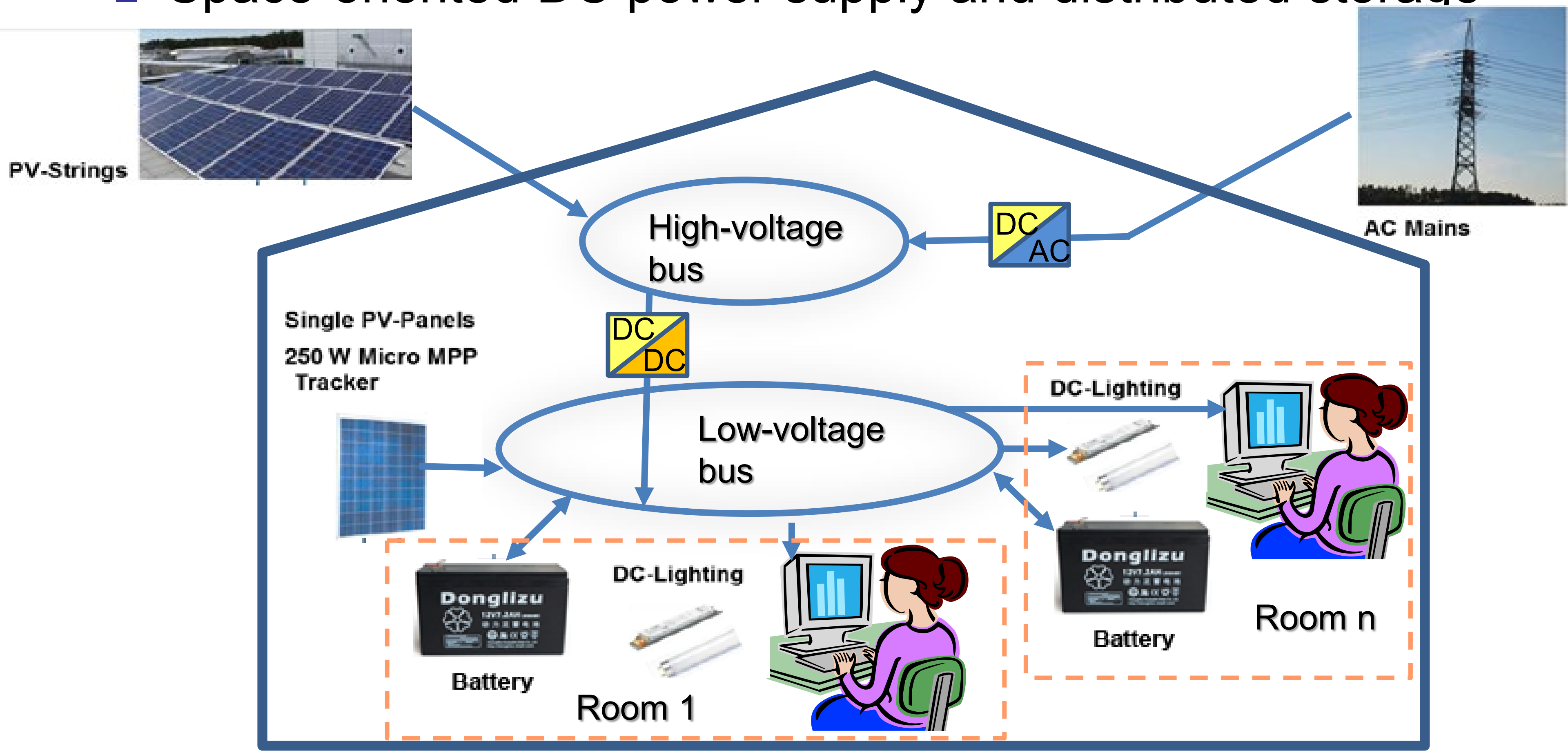


3. Building DC power supply and distributed storage



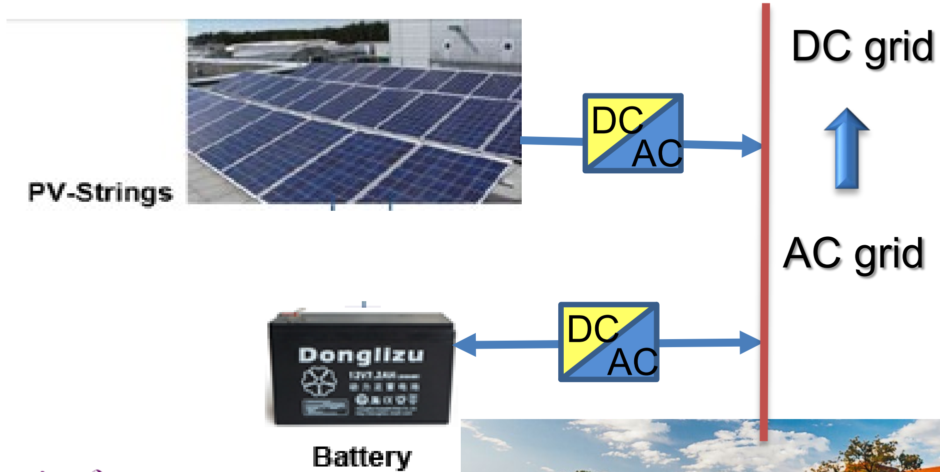
Solution

- Space-oriented DC power supply and distributed storage



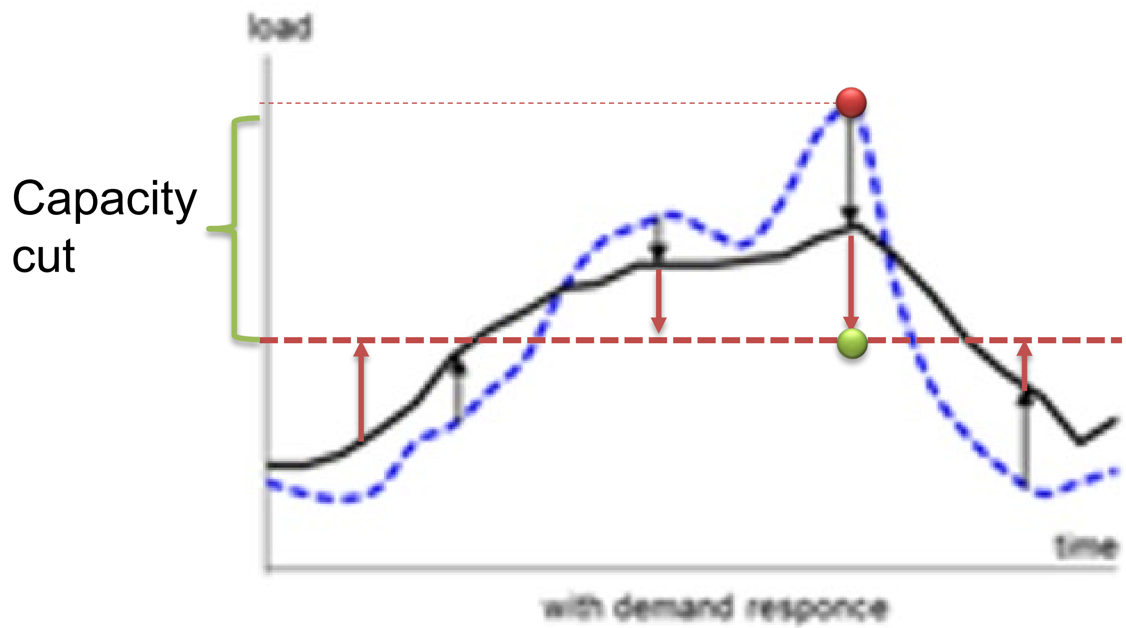
Why DC power + battery?

- The advantage of DC transmission was re-recognized due to the progress of power electronics techniques.
- Advantages compared with AC power
  - Needs not DC/AC inverter: Less hardware cost and energy loss
  - Higher efficiency of DC/DC voltage conversion
  - Higher power quality: No overtones
  - Less power transmission loss



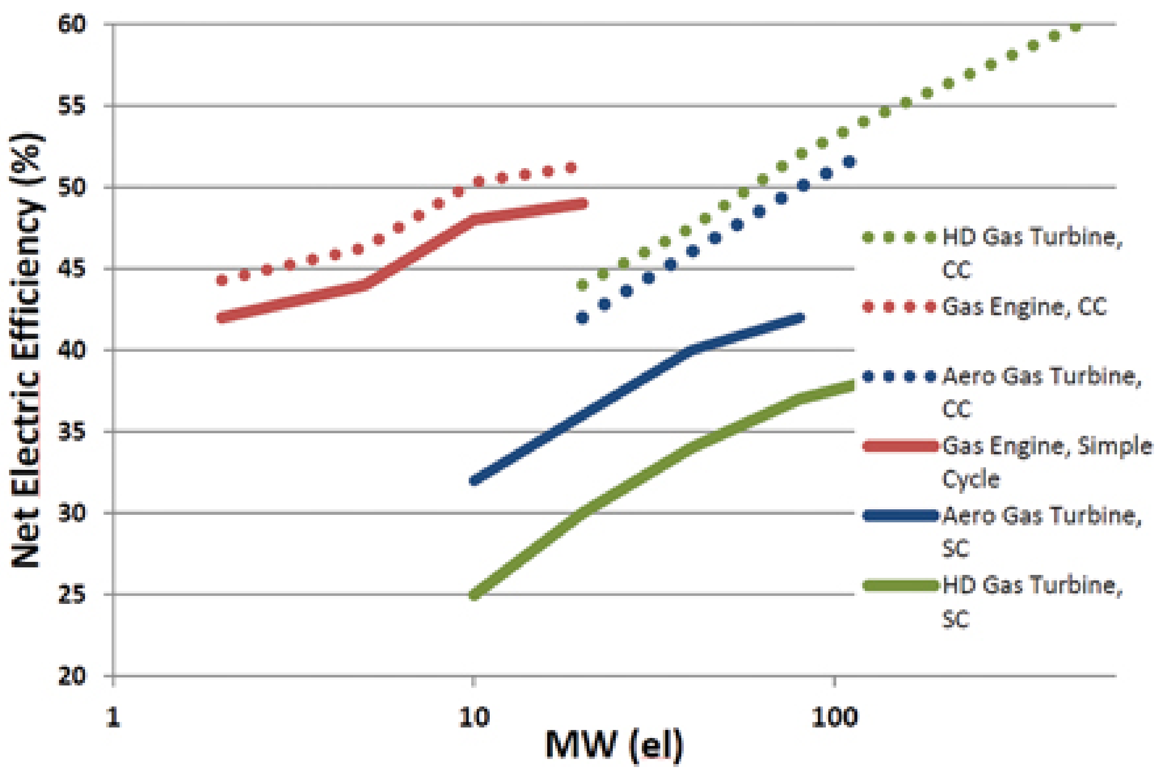
Benefits

- Reduce investment cost of power plant and grid
  - Lower capacity



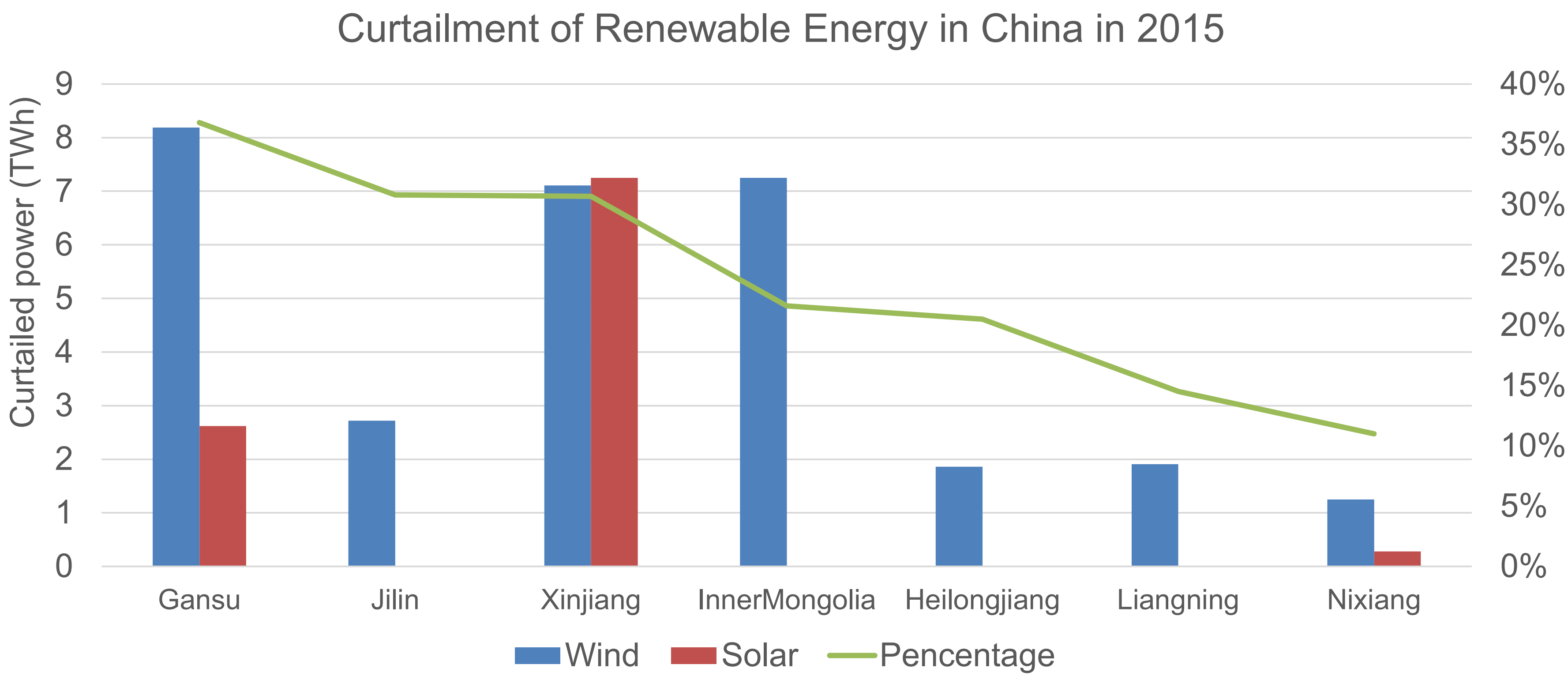
Benefits

- Reduce running cost by improved power generation efficiency
  - No low load operation



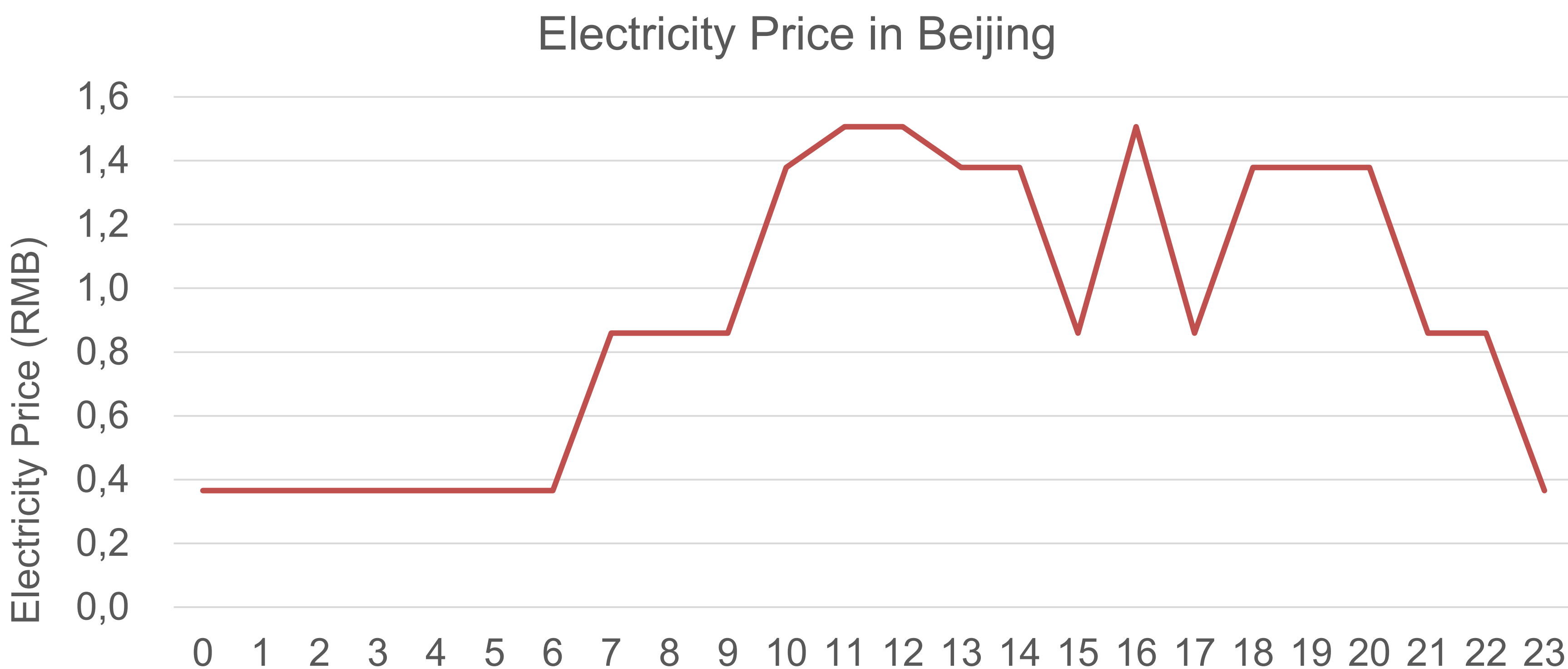
Benefits

- Accept renewable energy as much as possible
  - No curtailment of solar power and wind power



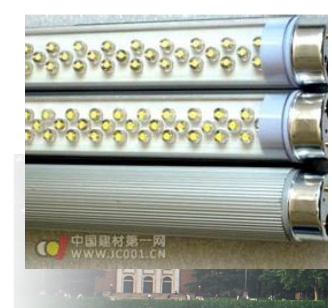
Benefits

- Save electricity bill for building owners
  - Utilize time-of-use tariffs



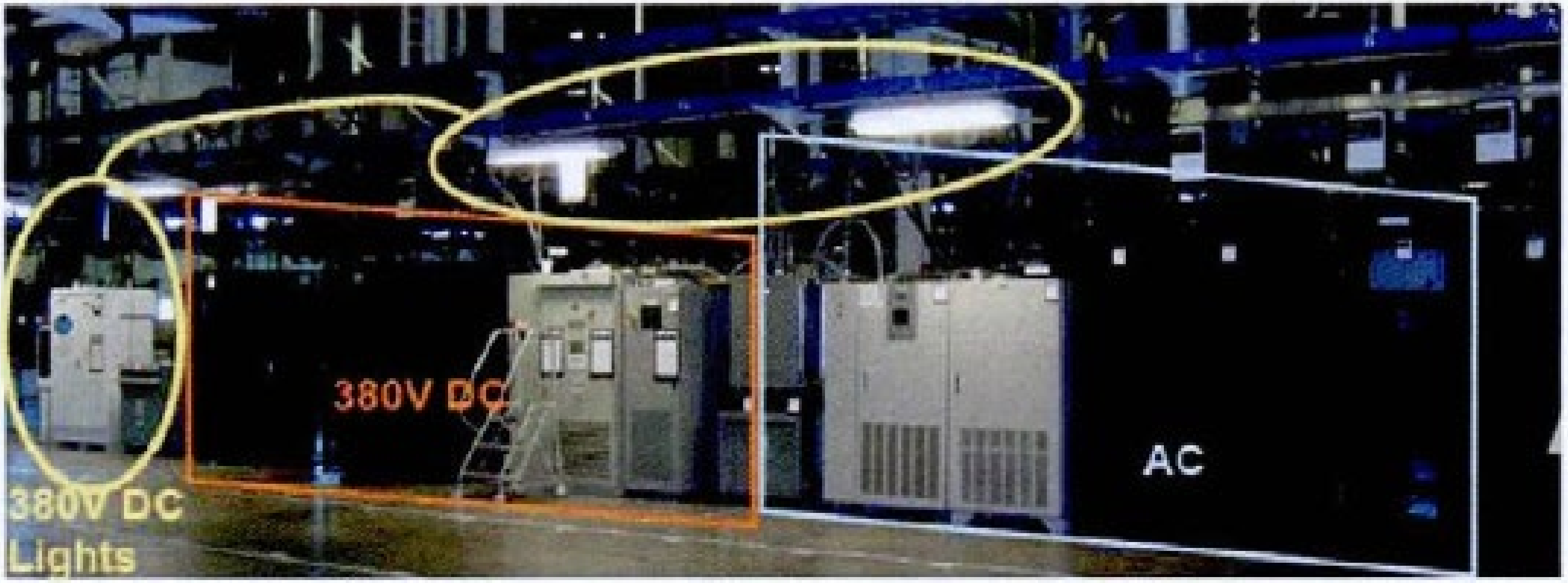
Feasibility

- Almost all appliances in buildings use DC power
  - LCD monitor
  - LED lights
  - Computer, printer
  - DC inverter driven air-conditioner
  - DC inverter driven chiller
  - Brushless DC motor and permanent magnet synchronous motor



Feasibility

- LBNL test-bed at a data center：Compared with AC power supply
  - Energy distribution efficiency improved by 7%
  - Equipment space saved by 33%
  - Hardware cost saved by 6%



Battery cost

- 0.5 CNY/kWh assuming a battery life of 1000 times charge/discharge
  - Cheaper than the grid electricity price.
- Tesla battery for home: PowerWall announced in 2015
  - Cost: 3500$@10kWh for ten years' service, i.e. 0.13$/kWh

1 POWERWALL

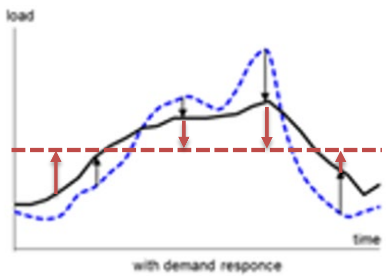
Order Summary

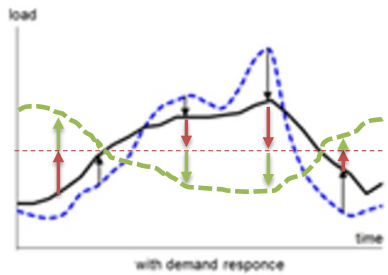
One 14 kWh Powerwall battery	$5,500
Supporting hardware	$700
Price for Powerwall equipment	$6,200

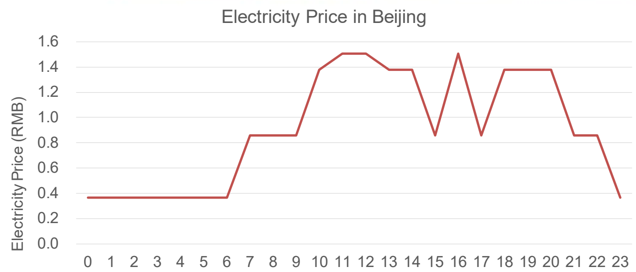
Requires $500 deposit for each Powerwall

https://www.tesla.com/powerwall?redirect=no

Control strategy







Constant power

Demand response

Minimum bill

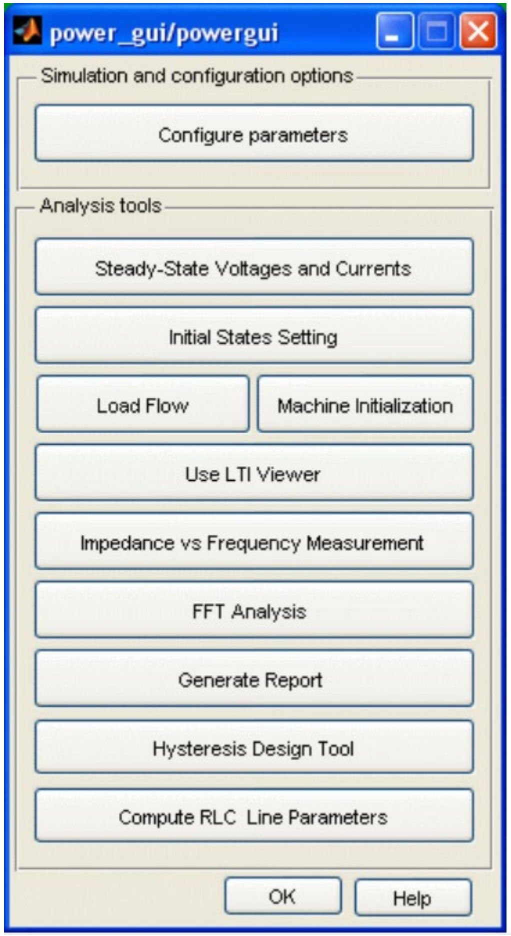
System design
（Key parameters）

Control strategy development

Test and application
（Quality, cost）

Methodology

- Simulation
  - Different scenarios
  - Design optimization
- Experiment
  - Detailed study:
  - Performance
  - Efficiency
  - Unexpected issues
- Demonstration
  - Actual building
  - True application



Battery Capacity Optimization

- Methodology

$$SOC(t) = \eta \int_0^t \left[P_{grid} - P_{load}(\xi) + P_{gen}(\xi) \right] d\xi$$

$$P_{load} = P_{AC} + P_{light} + P_{plug}$$

$$Q_{bat} = \max_{i=1}^{365} \left[\max_{t=1}^{24} SOC_i(t) - \min_{t=1}^{24} SOC_i(t) \right]$$

SOC is state of charge of Battery;

P_{grid} is the power taken from the grid;

P_{load} is the electricity load;

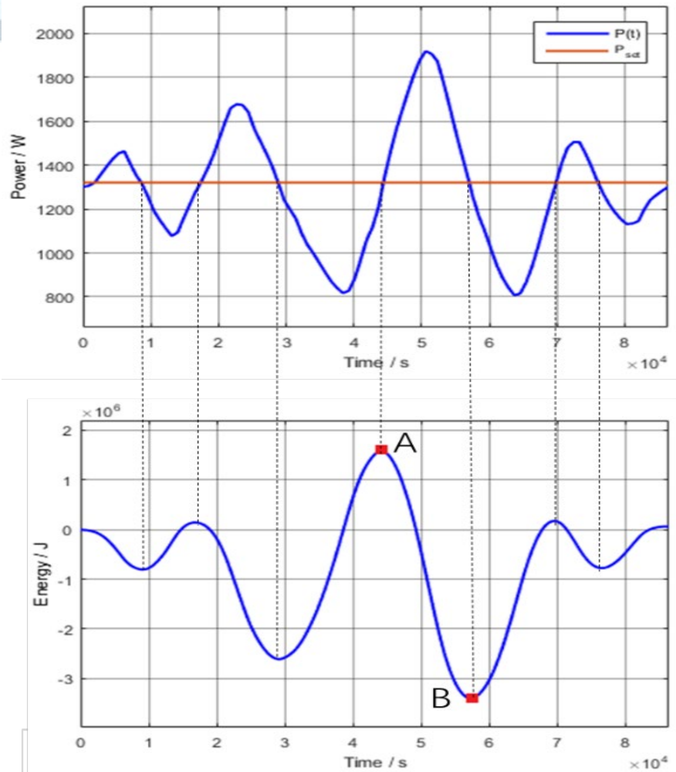
P_{AC} is the electricity load of air-conditioning system;

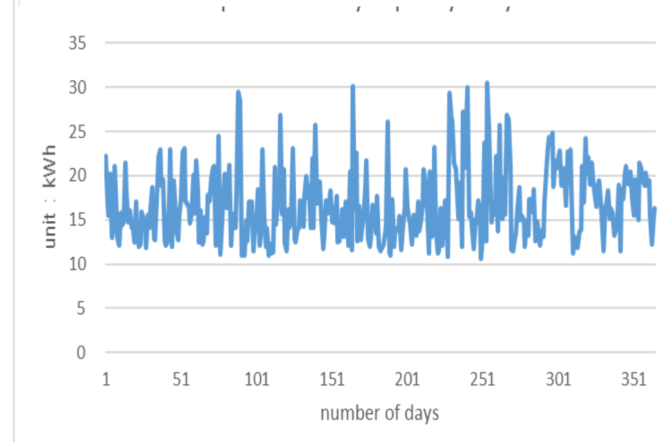
P_{light} is the electricity load of lighting system;

P_{plug} is the electricity load of plug in devices;

P_{gen} is the power generation;

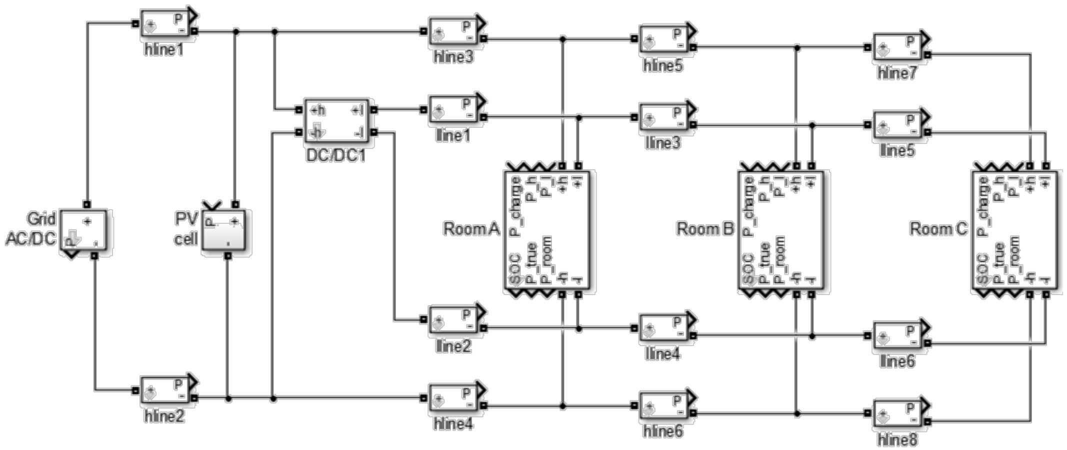
Q_{bat} is the battery capacity.



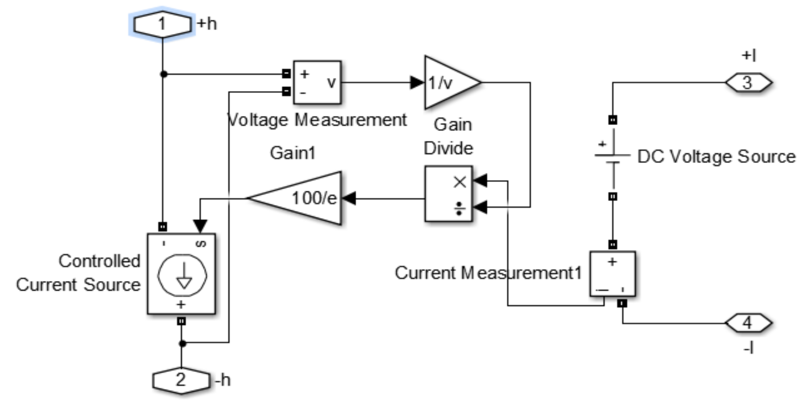


Simulation Study

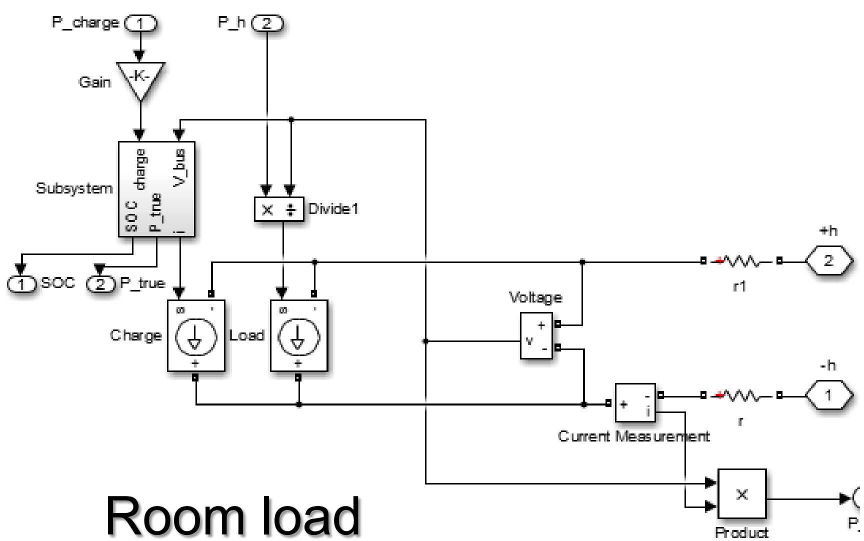
- Modeling



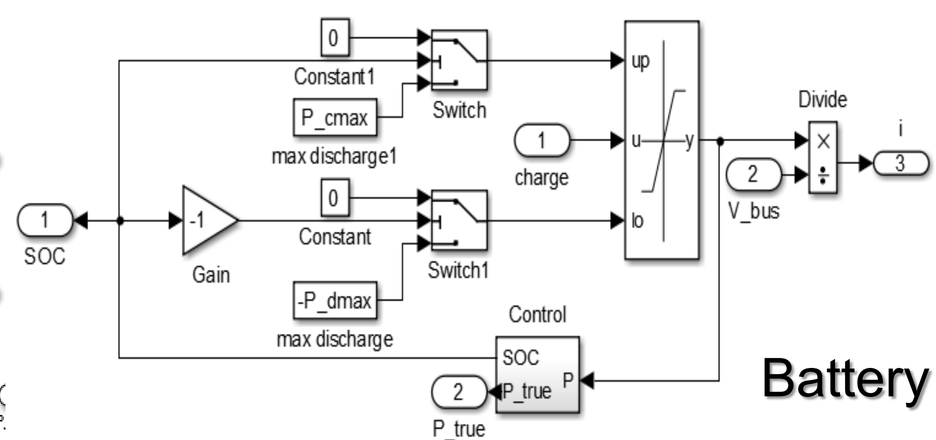
System



DC/DC



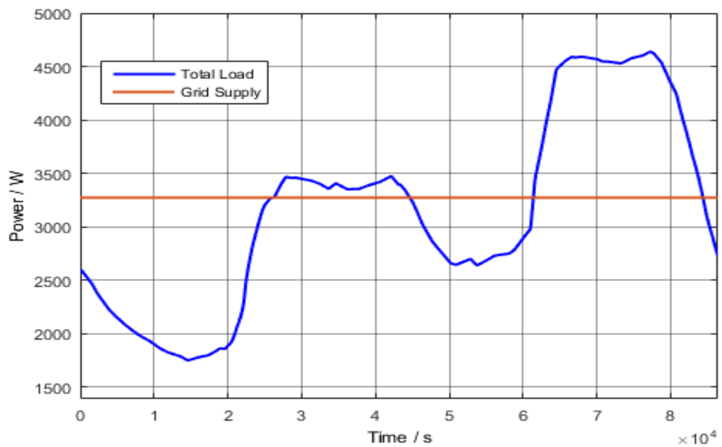
Room load

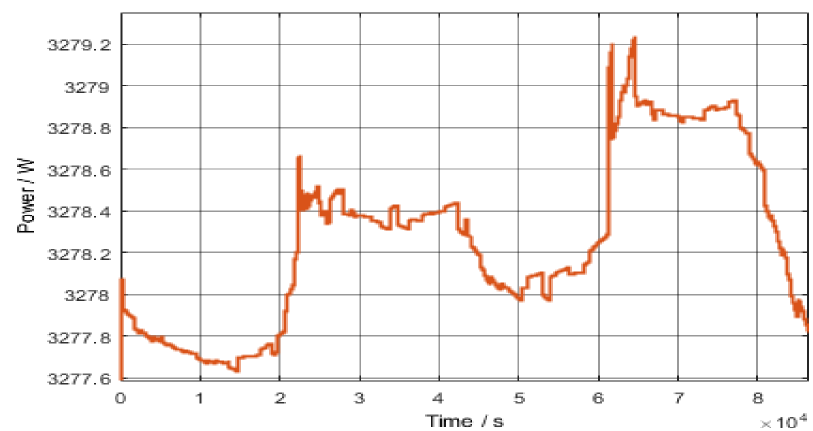


Battery

Simulation Study

- Simulation results
  - Power from grid can be controlled within the range of ±1W.

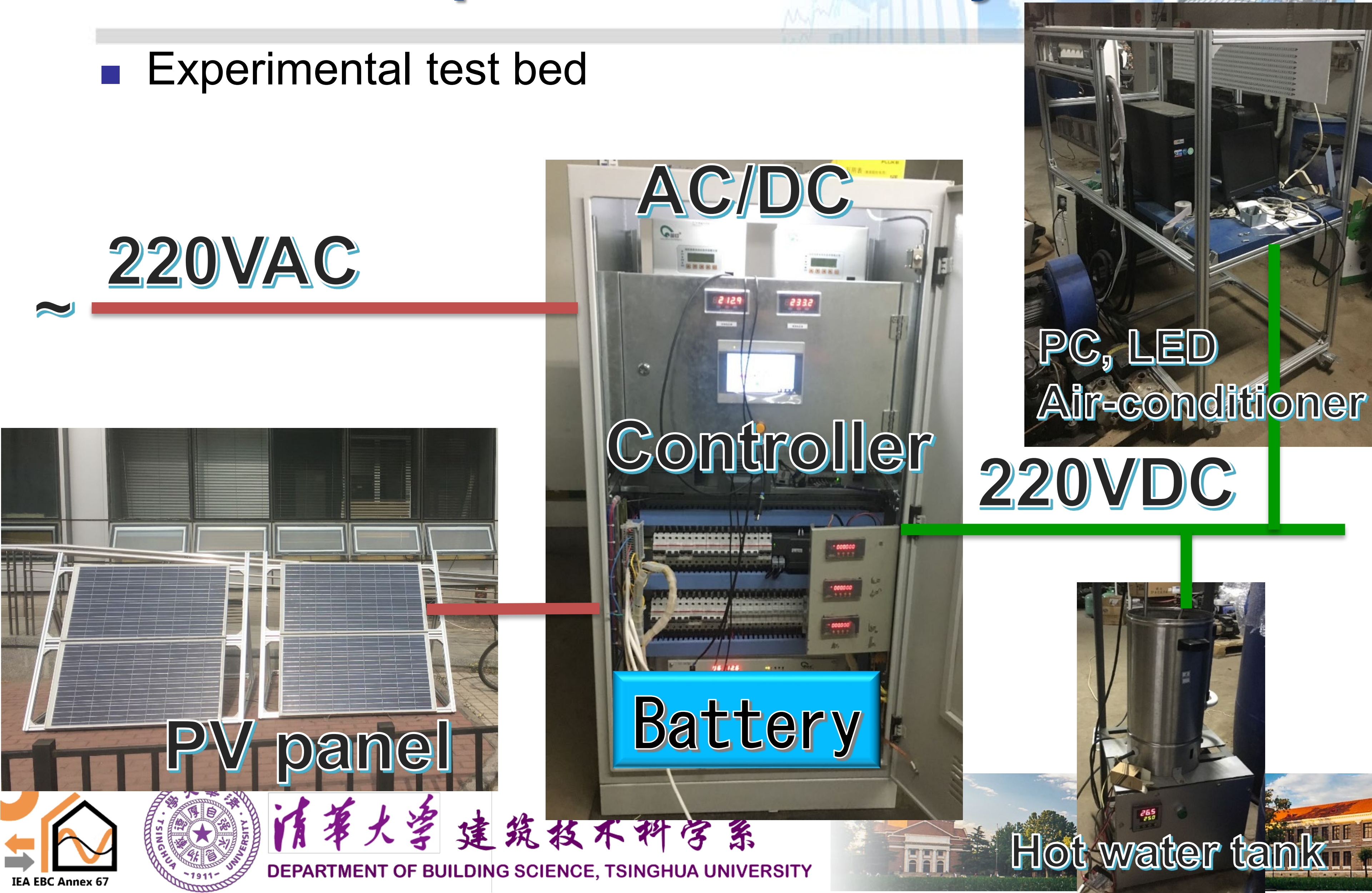




Room	Battery voltage (V)	P_{set} (W)	Battery capacity (Ah)
1	48	1000	76
2	48	1047	84
3	48	1100	95
Sum	-	3147	255

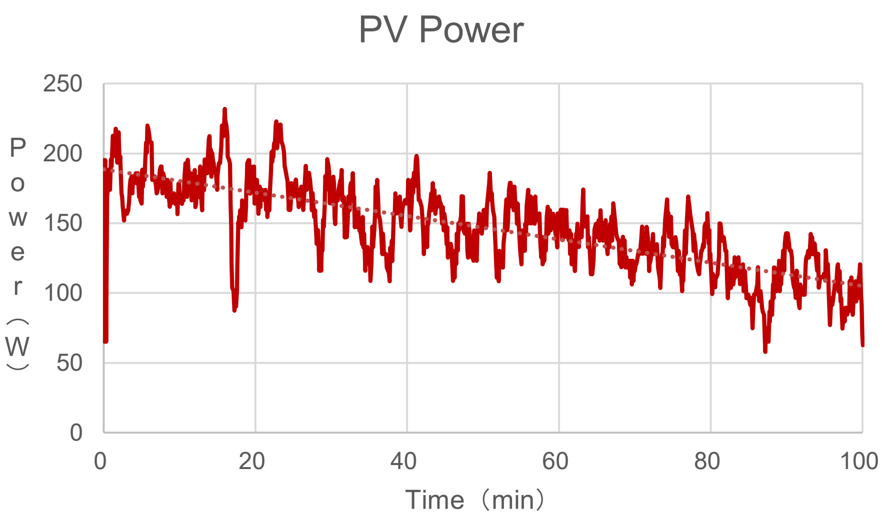
Experimental Study

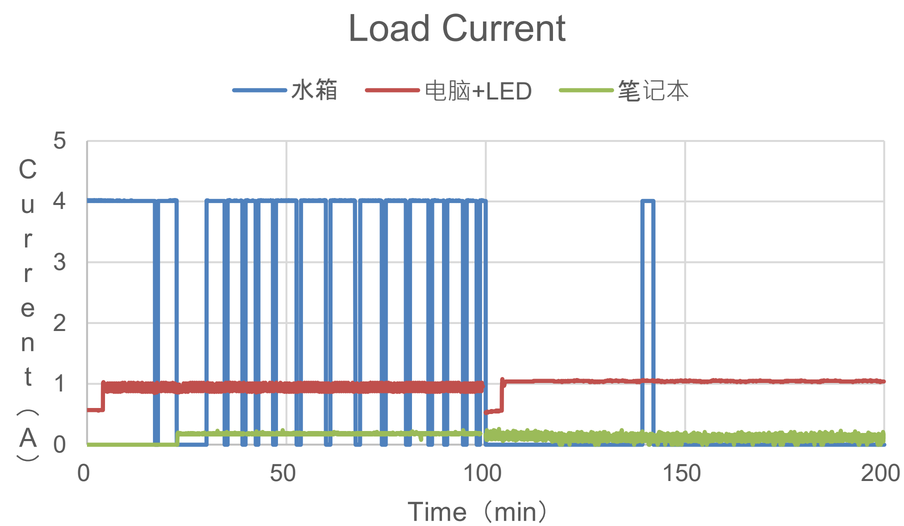
- Experimental test bed

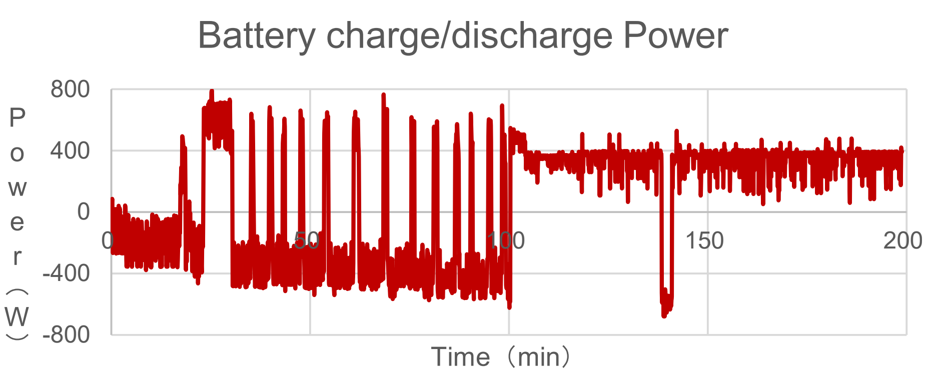


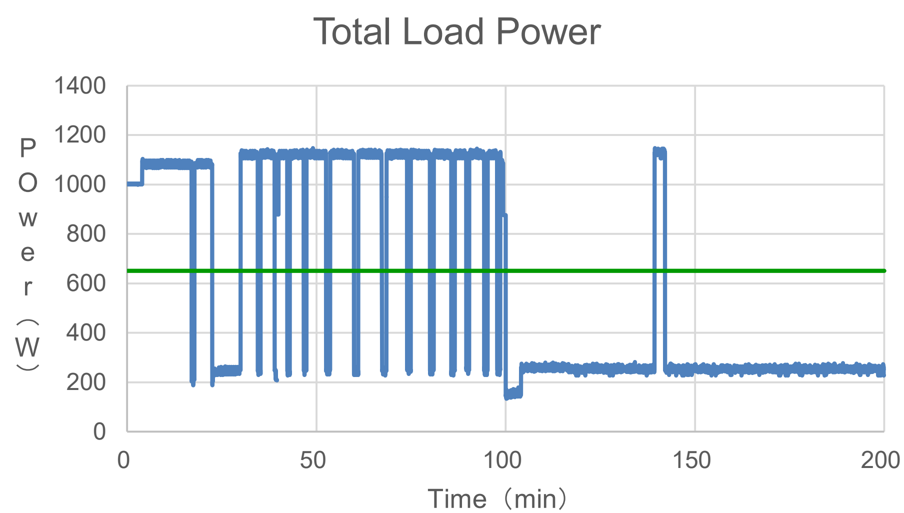
Experimental Study

- Loads, PV power generation, and battery SOC



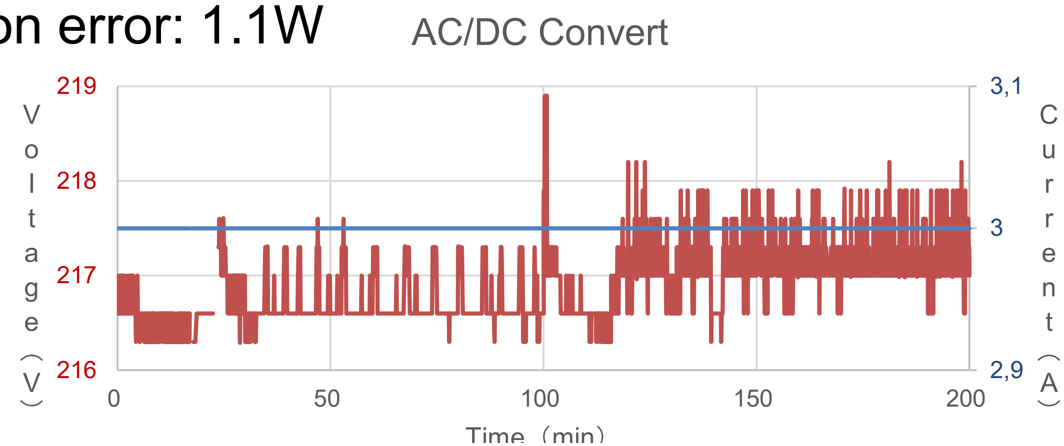


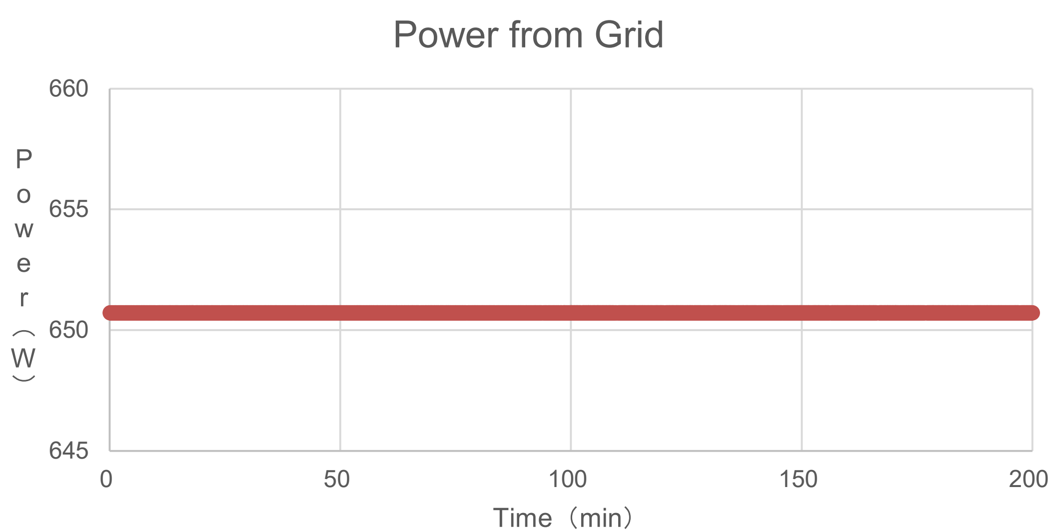




Preliminary results: Experiment

- Control results
  - Average power from grid: 650.7W
  - Standard deviation error: 1.1W





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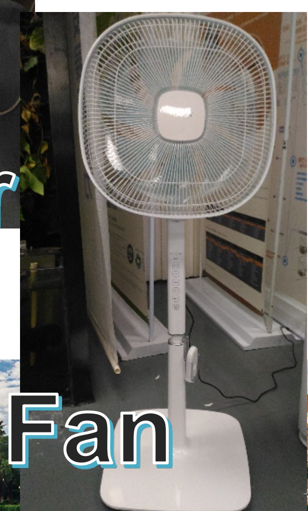
DEPARTMENT OF BUIL

Demonstration Buildings 1

- Low Carbon City located in Shenzhen, south China
  - Four- story
  - Floor area: 658 m^2

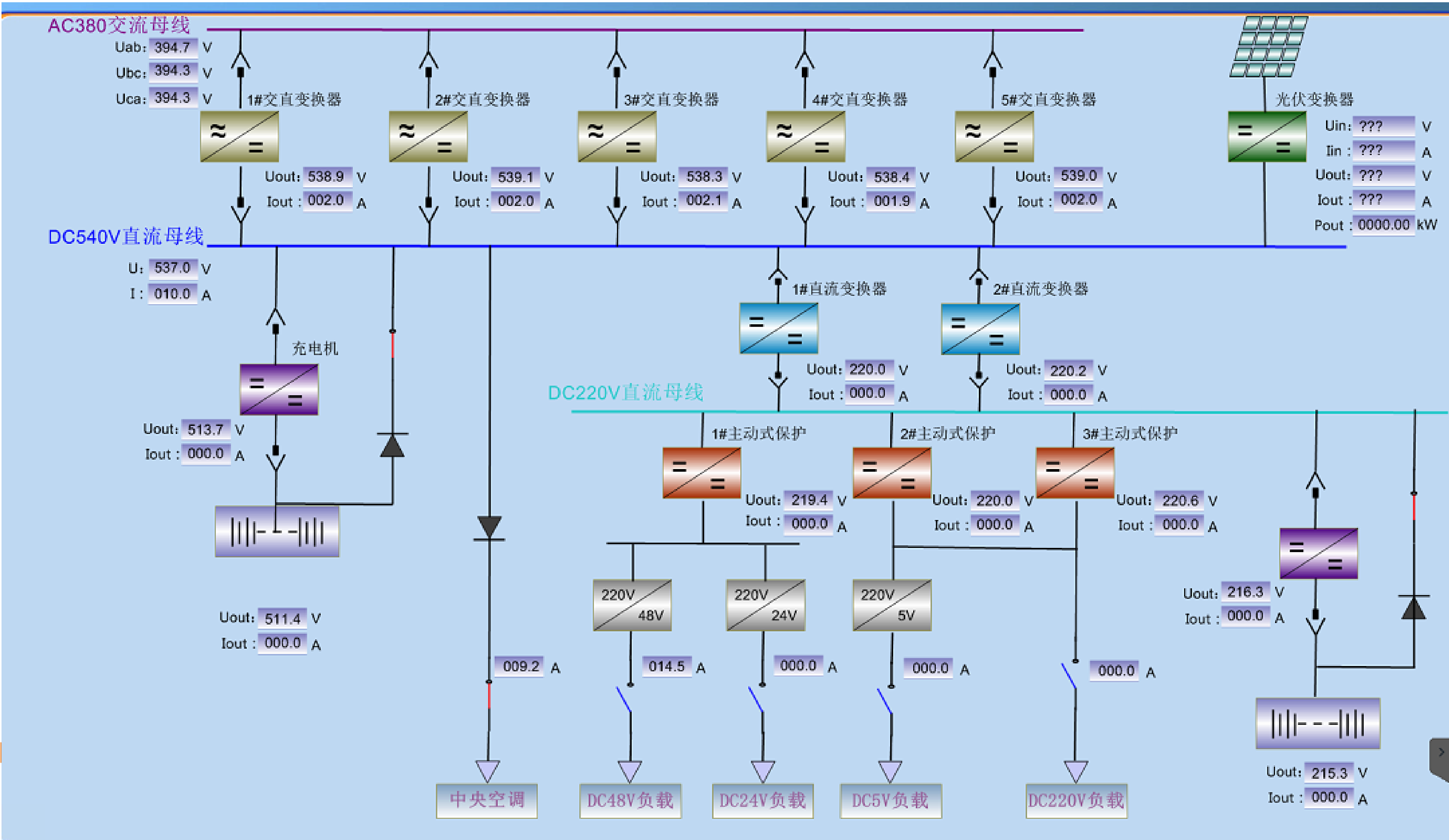
Preliminary results: Demonstration

- Facilities



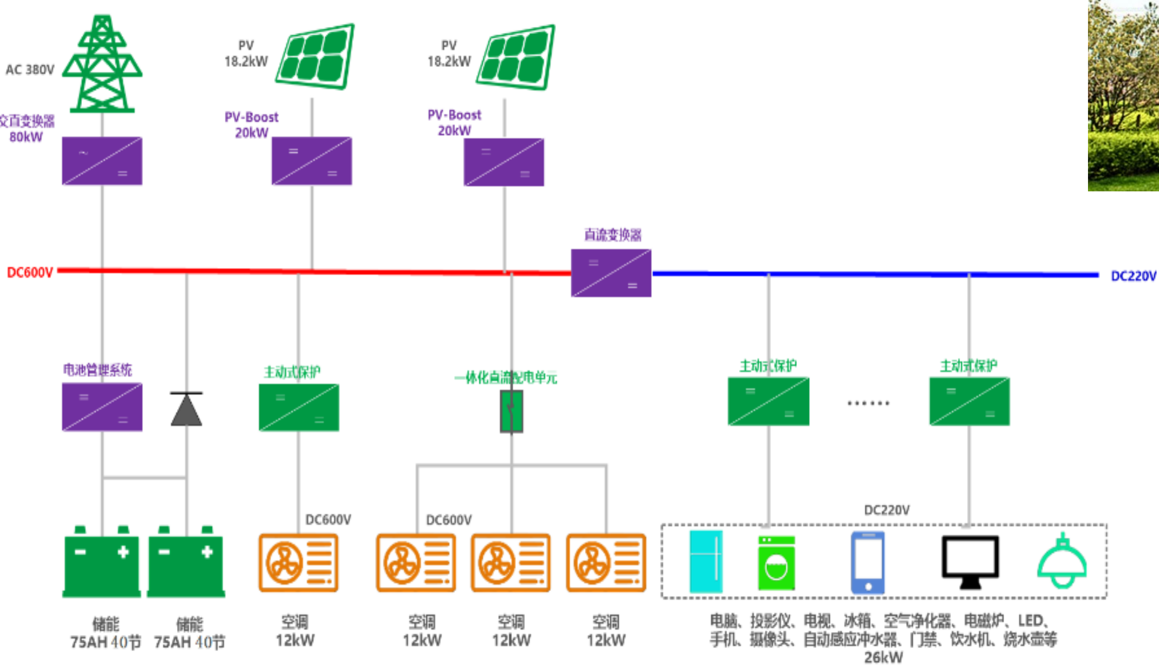
Preliminary results: Demonstration

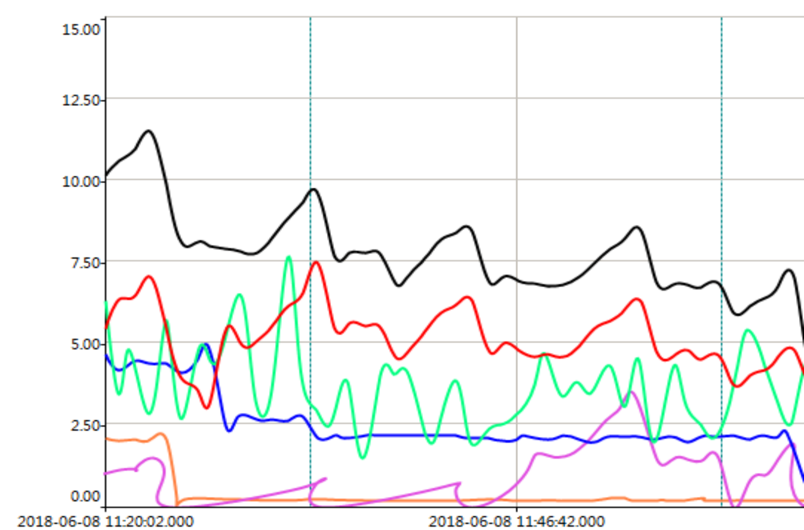
- System structure



Demonstration Buildings 2

- Office building Guochen, Nanjing
  - $2400m^2$ floor area
  - Designed building load 74kW
  - Equipped PV panel: 40kW





Demonstration Buildings 3

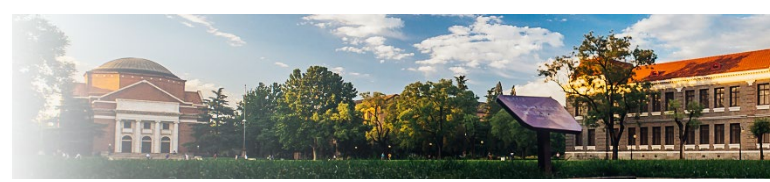
- Future Tower, Shenzhen
  - $4347m^2$ floor area, 6 floors
  - Designed building load 250kW
  - Equipped PV panel: 260kW

Summary

- China Energy Situations
  - Total energy consumption: High
  - Energy consumption per GDP: High
  - Building energy consumption per m^2 and capita: Low
- China Future Energy Roadmap
  - Energy Consumption Limitation:
    - Electricity:10 Trillion kWh/year
    - Fuel burning: 1.9 billion TCE/year
  - Future energy technologies
    - District Heating: Utilize low-grade waste heat
    - Flexible Electricity System

Summary

- DC supply + Distributed Storage in buildings
  - Reduce investment cost of power plant and grid
  - Reduce running cost of power generation
  - Accept renewable energy without curtailment
  - Benefits for building owners
    - Save electricity bill by utilizing time-of-use tariffs
    - Save initial cost of power system by capacity cut
    - Save building space because of small size of DC components
    - Improve power quality, reliability and safety
    - Reduce power line loss or save line costs



Thank you!
Q&A

Fulin Wang
Tsinghua University
flwang@Tsinghua.edu.cn

Building Energy Research Centre, Tsinghua University

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DEPARTMENT OF BUILDING SCIENCE, TSINGHUA UNIVERSITY