Building Energy Benchmarking between the U.S. and China: An Overview of the CERC-BEE Building Energy Monitoring Project

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U.S.–China Clean Energy Research Center
中美清洁能源研究中心

BERKELEY LAB

清華大學
Tsinghua University

Outline

- Project overview
  Tianzhen Hong, 10 minutes
- Monitoring systems overview
  Wei Feng, 5 minutes
- Building energy data analysis
  Le Yang, 30 minutes
- Q & A
  10-15 minutes

US-China Clean Energy Research Center (CERC)

- Founded in November 2009 by President Barack Obama and President Jintao Hu
- A five-year research program with $150 million fund contributed equally from both governments and private sectors
- Research in three areas
  - Building energy efficiency (BEE)
  - Clean coal
  - Clean vehicles
- CERC-BEE led by
  - US: Department of Energy, LBNL
  - China: MoHURD, MOST, Tsinghua University

CERC-BEE Phase 1 Research Topics and Projects

EXECUTIVE COMMITTEE ON CERC-BEE (MOHURD and U.S. DOE)

Center for Building Energy Efficiency (MOHURD) and LBNL

- **Crosscutting Activities**
  - Data Analysis
  - Tools
  - Commercial-ization Pilots
- ***A* Monitoring & Simulation**
  - ***A1 Real-time Monitoring 建筑能耗监测***
  - ***A2 Simulation***
  - ***A3* Building Benchmarking**
- ***B* Building Envelope**
  - ***B1 Window* Systems**
  - ***B2* Building Insulation System**
  - ***B3* Cool Roofs and Urban Heat Islands**
  - ***B4* Natural Ventilation**
- ***C* Building Equipment**
  - ***C1* Lighting**
  - ***C2* HVAC**
  - ***C3* Solar Integration**
  - ***C4* Monitoring and Control**
- ***D* Whole Building**
  - ***D1* Case Studies of Low Energy Buildings**
  - ***D2* Building Integration Research**
- ***E* Commercialization Research**
  - ***E1* Policy Analysis**
  - ***E2* Building Codes & Certification**
  - ***E3* Market Research**

Research Teams

- **Research Teams**
  - **LBNL – Tianzhen Hong, Wei Feng**
  - **ORNL – Piljae Im, Mahabir Bhandari**
  - **Tsinghua University – Jianjun Xia, Le Yang, et al.**
  - **IAB partners**

Research Background (1)

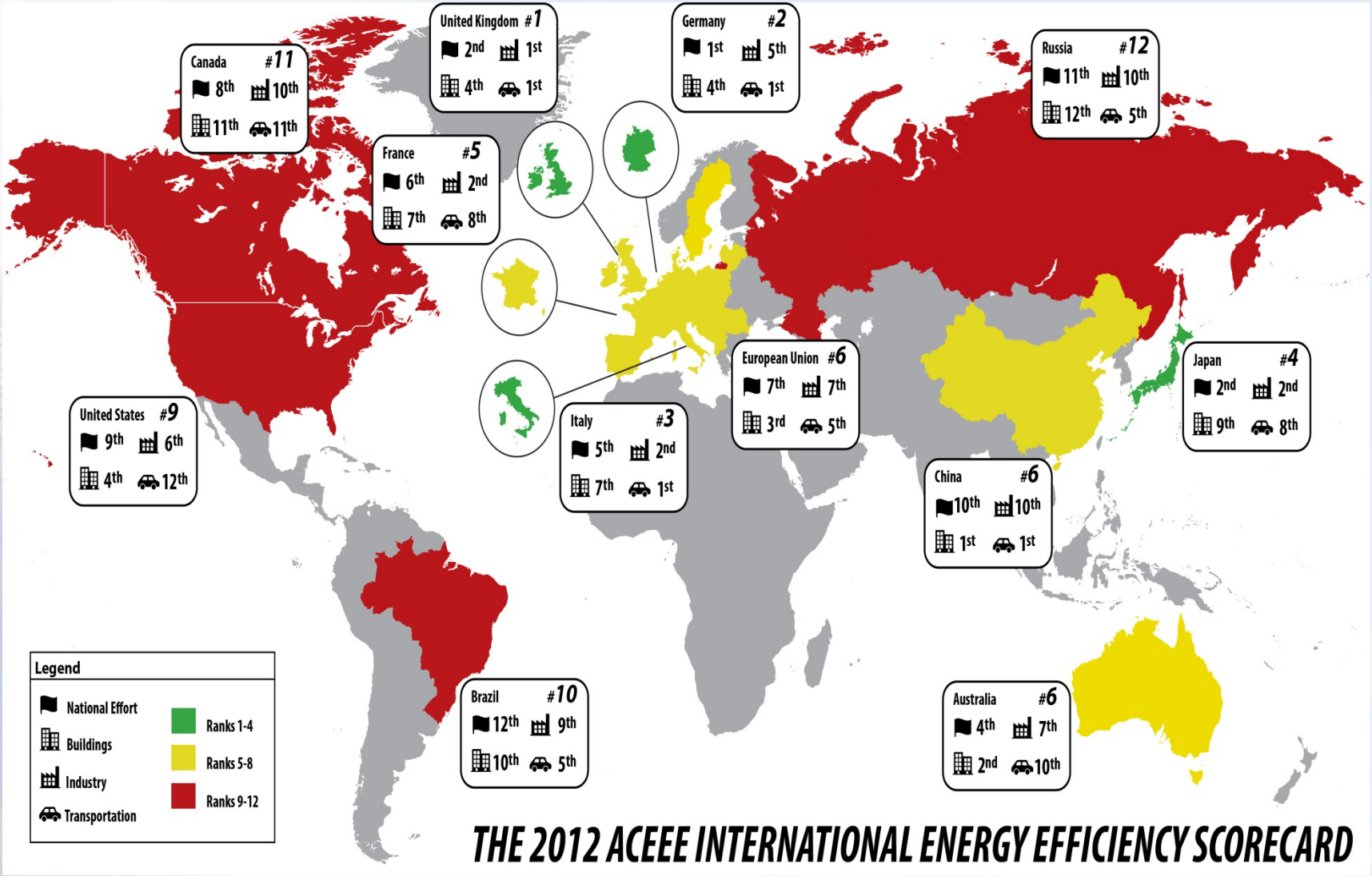
- Buildings consume a significant portion of primary energy in both countries: US 41%, China 28%

- Very different energy use styles

US: High efficiency / High consumption
China: Low efficiency / Low consumption
Energy Use = Consumption / Efficiency

- Opportunities for U.S. and China collaboration

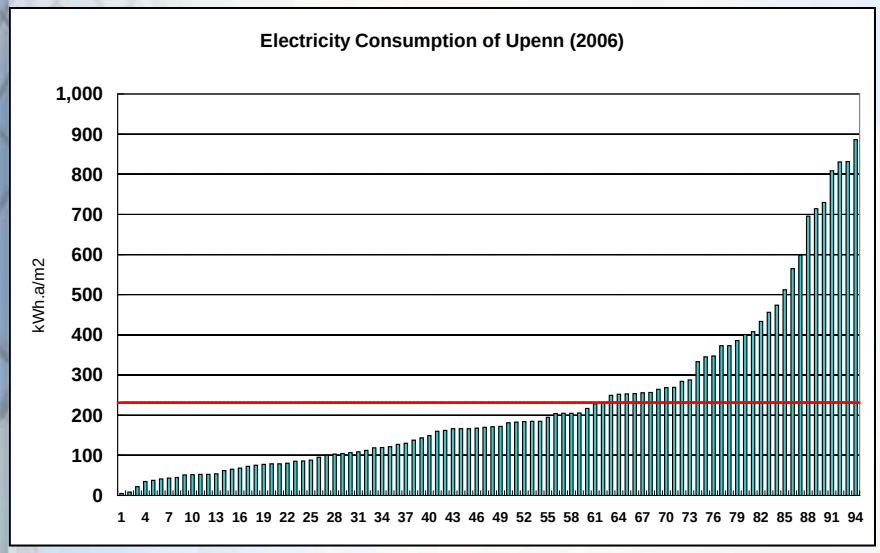
The cooperation in building energy efficiency between China and US creates a significant opportunity for sustainable development in both countries. A strategic, long-term, and in-depth research partnership is crucial and benefits both countries.

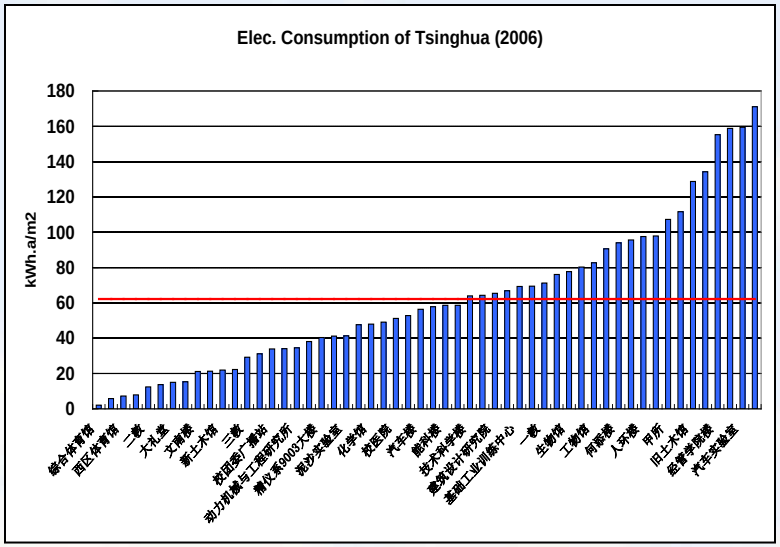


THE 2012 ACEEE INTERNATIONAL ENERGY EFFICIENCY SCORECARD

Research Background (2)

- Why some buildings consume so much more energy than others with similar functions?
  - Design?
  - Climate?
  - Operations and controls
  - Occupant behavior
  - Maintenance





Benefit of Energy Monitoring & Analysis Systems

- Reduce energy waste
- Improve operations for energy savings and longer equipment life
- Identify retrofit opportunity
- Improve comfort for better worker productivity
- Demonstrated energy savings of 15 to 30%!

Industry Adoption

Commercial products available but

- Limited use
  - Data analysis
  - Visualization
  - Customization
  - Lack actionable information
- Lack industry standards
  - Proprietary
  - Very poor interoperability
  - Incomplete data collection
- Separated from BAS/BMS/EMCS

Technical Tasks

- Task 1 - Review existing real time energy monitoring platforms (Joint)
- Task 2 - Develop a standard platform for data collection based on the data models of the proposed ISO Standard 12655 (China)
- Task 3 – Select a few office buildings in both countries with existing or new energy monitoring systems to collect detailed energy use data (Joint)
- Task 4 - Develop methods for data filtering and data mining (analysis and visualization) to help decision making of different levels of users – building owners, operators, facility managers, occupants, and investors. (Joint)
- Task 5 - Use the standard platform and the collected data to compare energy use of buildings in both countries to identity and better understand the key drivers of the differences. (Joint)

Research Findings

- Need a standard data model and platform to collect, process, analyze, and exchange building performance data
  - Different definitions of energy use and boundary
  - Difficult to exchange data
  - No standards
- Buildings in the U.S. and China are very different
  - Design, operation, maintenance, occupant behavior
  - U.S.: more stringent comfort standards – temperature, ventilation, lighting, hot-water use; higher internal loads and operating hours
  - China: lighting energy use is higher, seasonal HVAC operation, more operators, more natural ventilation, much less outdoor air, wider range of space temperature
- Good data is everything, but in practice:
  - Lack long period of time-interval data
  - Data quality is BAD!
  - Value of good data is not recognized
  - Afraid of BIG Data!

Research Outcomes

- A standard data model to represent energy use in buildings
  - ISO Standard 12655
  - China national standard
- A sourcebook of 10 office buildings in the U.S. and China
  - Detailed description of building, data point, and monitoring system
  - Energy analysis of each building
  - Energy benchmarking among all buildings
- A database of building performance, 4 bldgs completed, more to come
  - Detailed end use data
  - Time-interval data at 1-hour or 15-minute
  - Full documentation
  - Uploaded to a web portal
- Publications
  - An article under review – Building Research and Information
  - Another journal article under preparation
  - A few conference papers

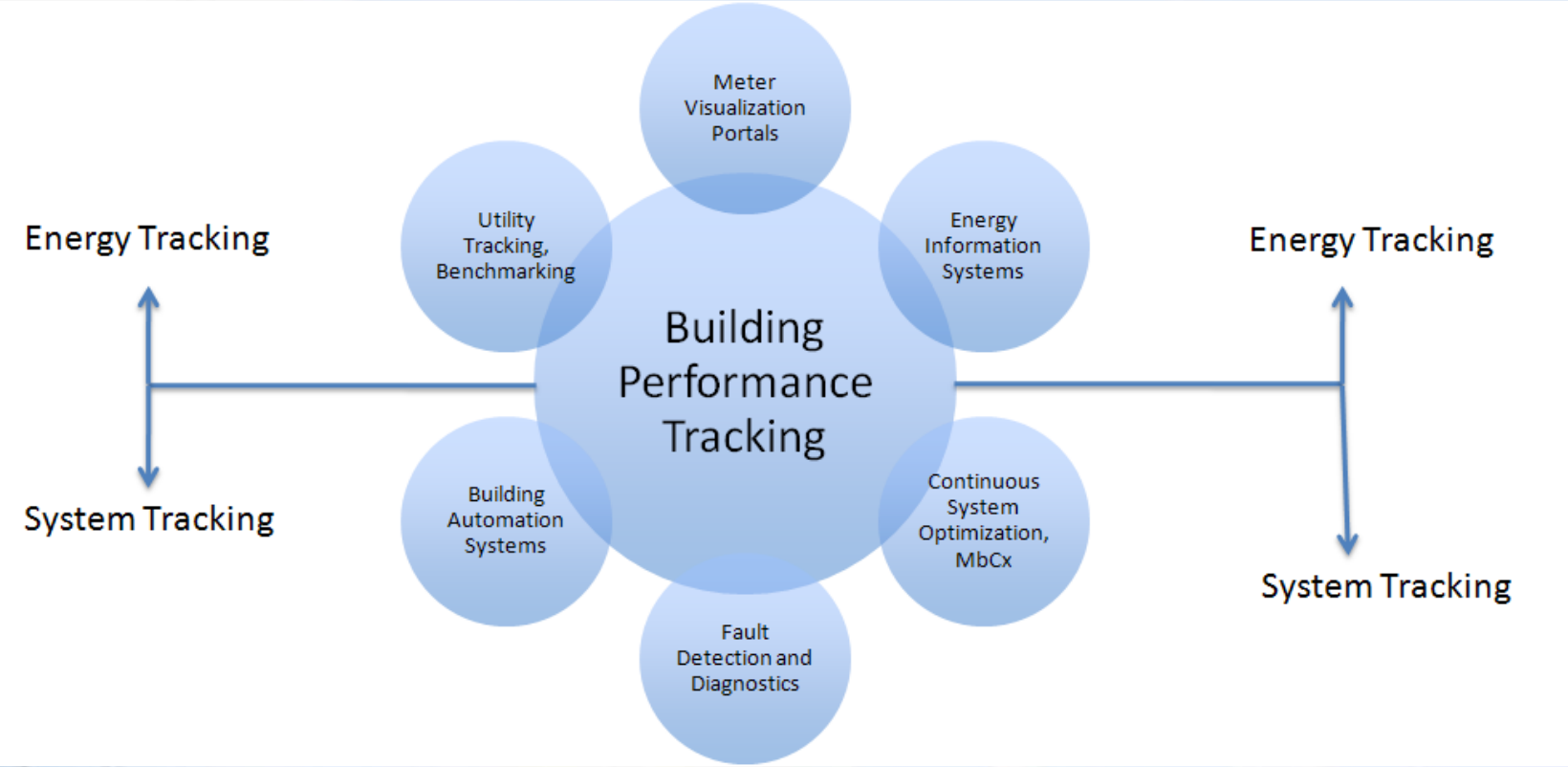
Research Collaboration

- Strong collaboration between U.S.-China research teams
  - Bi-weekly conference calls
  - Two team meetings per year
  - Exchanged students
  - Public workshops and seminars
- International activities
  - IEA ECBCS Annex 53: Total energy use in buildings – analysis and evaluation methods
  - Workshops, e.g. VTT real-time monitoring, UCL-LBNL energy epidemiology
- Coordination with USDOE/LBNL activities
  - Building Performance Database
  - Energy Information System
  - Big data initiative

Acknowledgement

- CERC-BEE
- Research teams
- LBNL researchers
  - Building 90 Core Team
  - Commercial Building Group
  - Building management teams

Energy monitoring systems



Building performance tracking systems (provided by Jessica Granderson at LBNL)

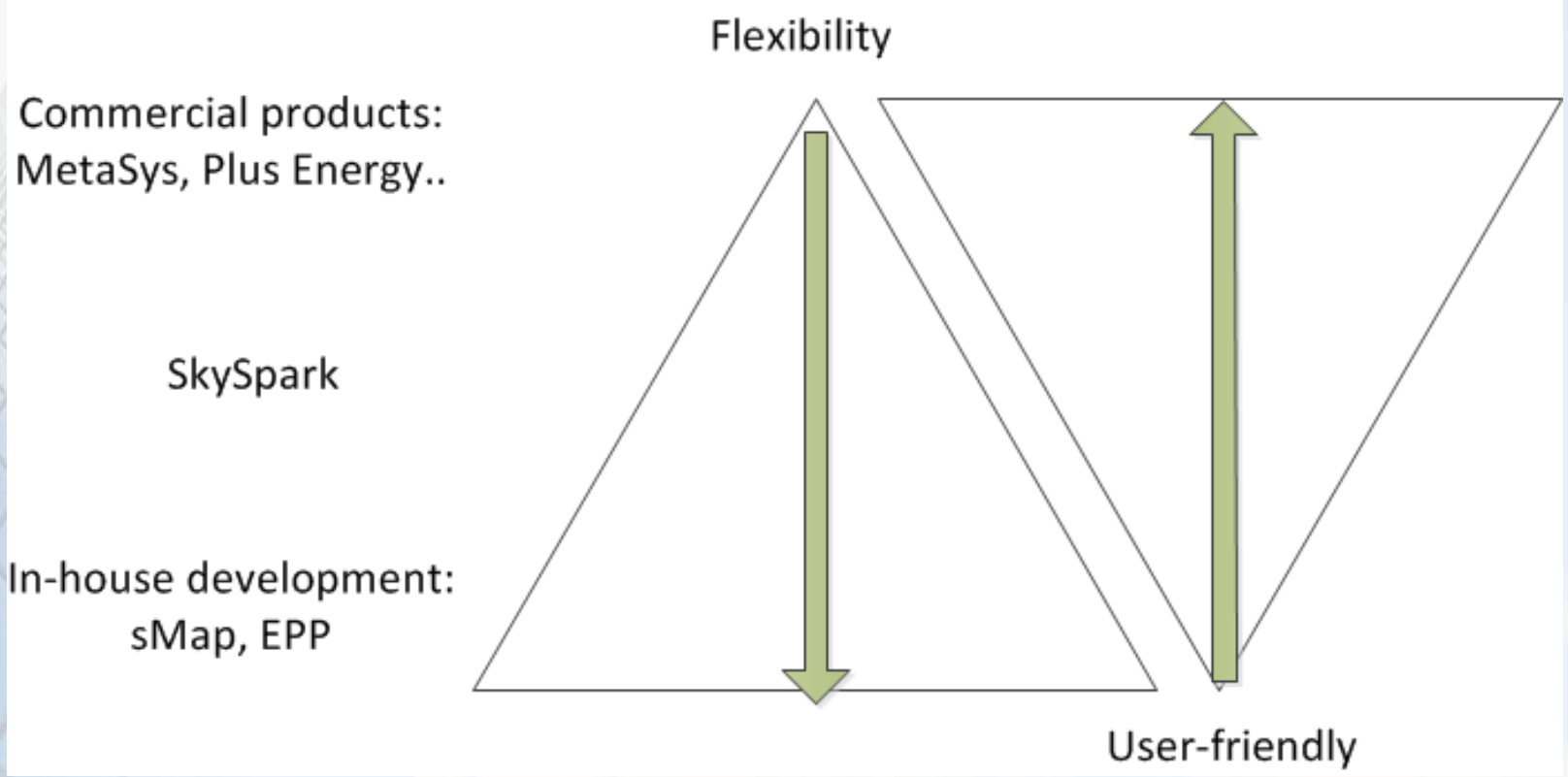
Granderson, J. (2012). Monitoring-based commissioning: Continuous performance investigation and evaluation. Presented at Lawrence Berkeley National Laboratory, Berkeley, CA.

Granderson, J., Piette, M.A., Rosenblum, B., Hu, L., et al. (2011). *Energy information handbook applications for energy efficient building operations*. Lawrence Berkeley National Laboratory, Technical Report, LBNL-5272E.

Energy Monitoring Systems

System	Developer	Database	Availability	API	GUI	Flexibility
iSagy	Persagy, China	SQL server	Commercial	n/a	Web	Medium
Pulse Energy	Pulse Energy, U.S.		Commercial	n/a	Web	Limited
EPP	LBNL, U.S.	SQL server	Public	internal	Web	Good
SkySpark	SkyFoundry, U.S.	"Folio"	Commercial	Yes	Web/standalone	Good
ION	Schneider Electric, France		Commercial	n/a	Web/standalone	Limited
sMAP	UC-Berkeley, U.S.		Public	internal	Web	Good
Metasys	Johnson Control, U.S.		Commercial	n/a	Web	Limited

Energy Monitoring System



Energy monitoring systems

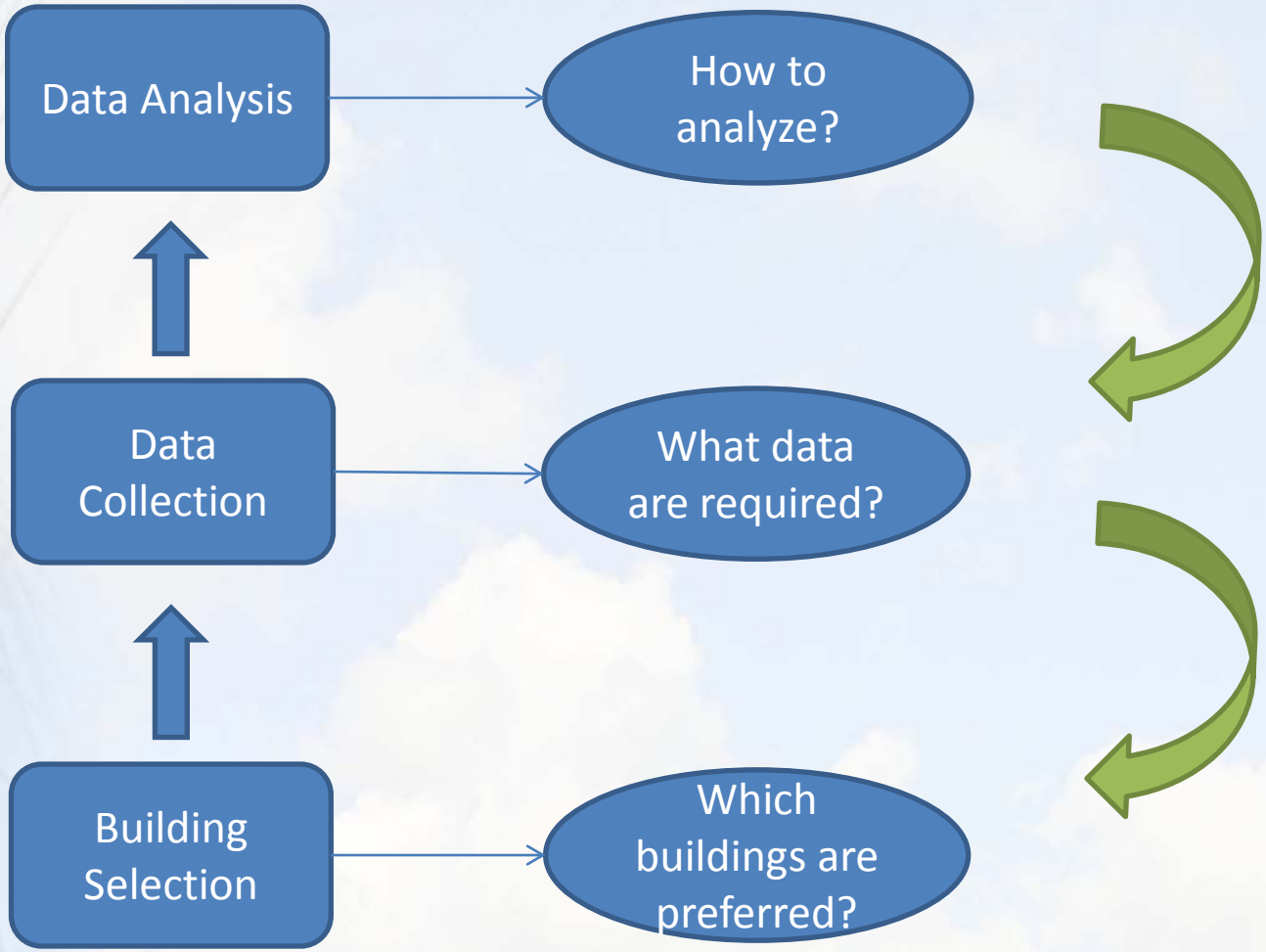
System	Technical features												Analysis features												Fault detection		
	Including hardware for acquisition	Automatic data acquisition	Manual data entry	Automatic data processing	Platform independent	CSV-Import	CSV-Export	Interfaces to BMS	Automatic chart generation	Interactive charts	Stand-alone software	Web frontend	Interpolation if arbitrary measure intervals	Virtual sensors	Definition of any reference values	Comfort analysis	Statistical analysis	Real-time diagnosis	Climate correction	Report system	Tools for benchmarking	Prediction of energy savings	Prediction of cost savings	Analyze building subsystems	Data integrity validation	Check by value ranges	Email notification
iSagy	■	■	■	■	■	■	■		■	■		■	■	■	■	■	■	■		■	■			■	■	■	
Pulse Energy		■	■	■	■		■	■	■	■	■	■		■			■			■				■			■
EPP		■		■	■		■	■	■		■	■			■					■	■			■			
SkySpark		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			■	■	■	■
sMAP		■		■	■	■	■	■	■	■	■	■	■	■			■	■	■	■	■			■	■	■	■
ION	■	■	■	■	■		■	■				■															

Characteristics of building energy information system

- EIS definition: Software, data acq. hardware, and communication systems to collect, analyze and display building energy information
- Almost all systems have database, data acquisition module, and GUI
- Some systems have additional functions such as: energy analysis, financial analysis, anomaly detection and so on.
- However, there is no consistent data storage structure which combines building energy information data with building indoor and outdoor conditions and system operation performance data

Building Energy Data Analysis

Building Energy Data Analysis Methods Overview



Analysis Methods

Three Levels of Data Analysis

(1) Energy Profiling

- Total use & end-uses
- Annual, monthly, weekly and daily energy use patterns
- Working day vs. non-working day, base-to-peak load ratio, etc.

(2) Energy Benchmarking

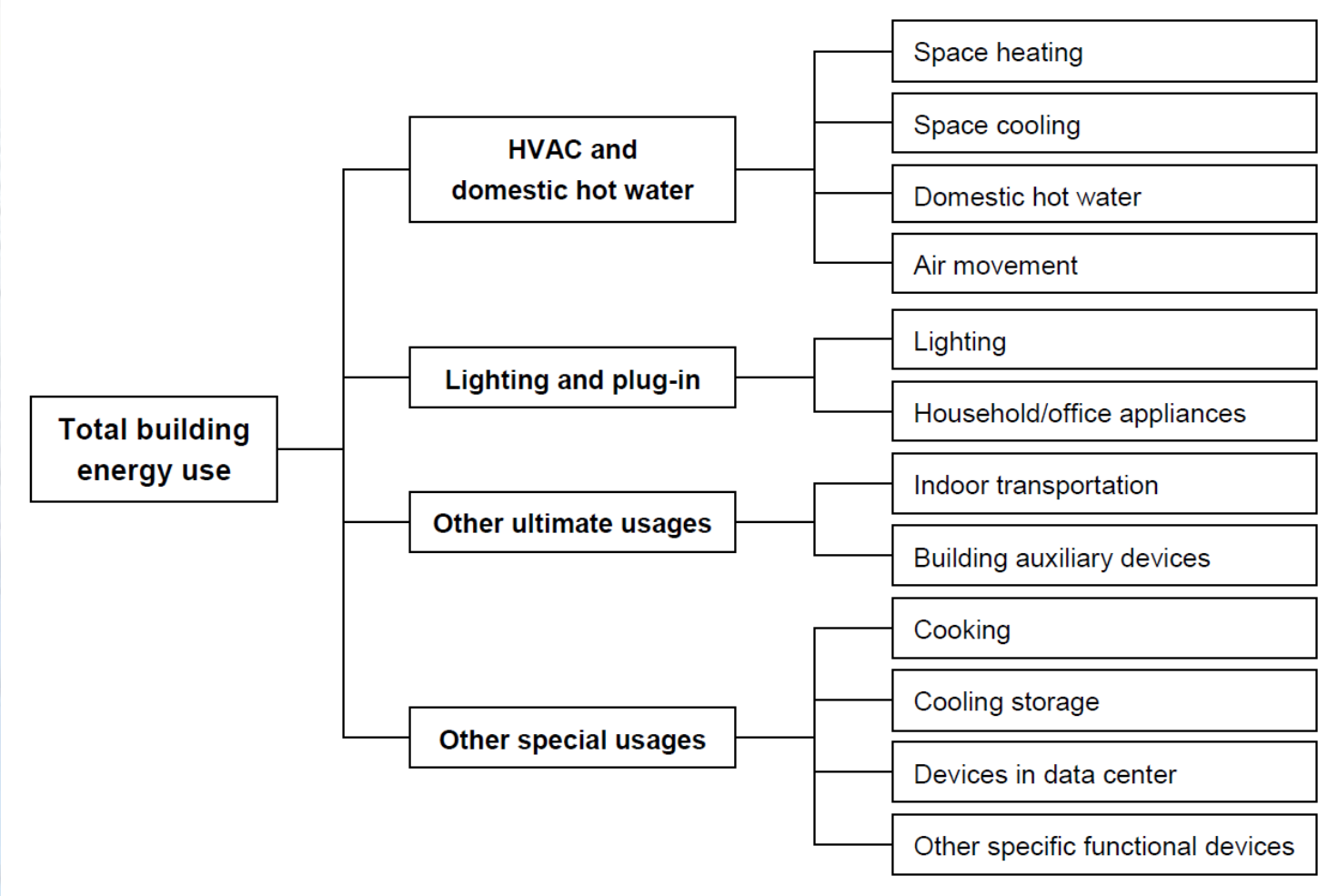
- Case study buildings
- Typical buildings – average level of same-type buildings
- Standard energy data model (next page)

(3) Energy Diagnostics

- Performance of systems and components (e.g. COP, WTF, EER)

Analysis Methods

Energy Use Data Model – ISO 12655



ISO 12655:
Energy Performance of Buildings — Presentation of measured energy use of buildings

Analysis Methods

Required data

(1) Building information →

(2) Monitored data

(i) Energy use – total & end-uses

lighting, plug-loads, elevators,

data center, kitchen, DHW,

HVAC equipment – chillers, boilers, DX units, pumps, fans, etc.

(ii) HVAC operating conditions

water/air flow rates,

supply/return temperature, etc.

(iii) Environmental conditions

indoor & outdoor air temperature and humidity,

wind speed and direction,

solar radiation, etc.

- **At least one year's data, with at least one-hour time interval.**

Category	Item name	Descriptions
Basic Information	Name	
	Location	Merced, CA
	Year of construction	2005
	Climate zone	ASHRAE Climate zone 3B
	Type	Office and Library
	number of floor	4 floors (3 for office wing)
	Floor area (m2)	16,000 m^2 (7,000 m^2 for office)
	Conditioned area (m2)	16,000 m^2 (7,000 m^2 for office)
	Operation hours	M-F 7:00am - 6:00pm (for office) 94.5 hours per week (for library)
	Max. Occupancy	seating capacity of 1100 + 9 librarians, 14 staff, 45 student assistants (68 staff)
Building Envelope	Exterior wall assembly	Cast concrete
	Roof assembly	Cast concrete
	WWR	20% (Need to check)
	Window	DL clear (Need to check)
	Shading devices	Interior blinds
Lighting System	Interior general lighting	T-8
	Interior task lighting	Fluorescent tube
	Exterior lighting	None
	Control system	ALC
	Operation hours	M-F 7:00am - 6:00pm (for office)
	Lighting Power	0.4 W/ft2 for actual usage average
HVAC	Cooling system	Campus District
	Heating system	Campus District
	Air system	AHU + VAV
	Room set-point	68F – 76F
	Zone	N/A
	Control system	Carrier ALC
	Operation hours	M-F 7:00am - 6:00pm (for office)
Internal Equipment & others	Plug load equipment	Office equipment
	Plug load power	N/A
	Transportation systems	2 elevators shared by office and library
	DHW	District heating and HX
	Energy generation	Campus site PV generation
Control & Monitoring	EMS	Carrier ALC
	Energy Monitoring system	LBNL EPP (Energy Performance Platform)

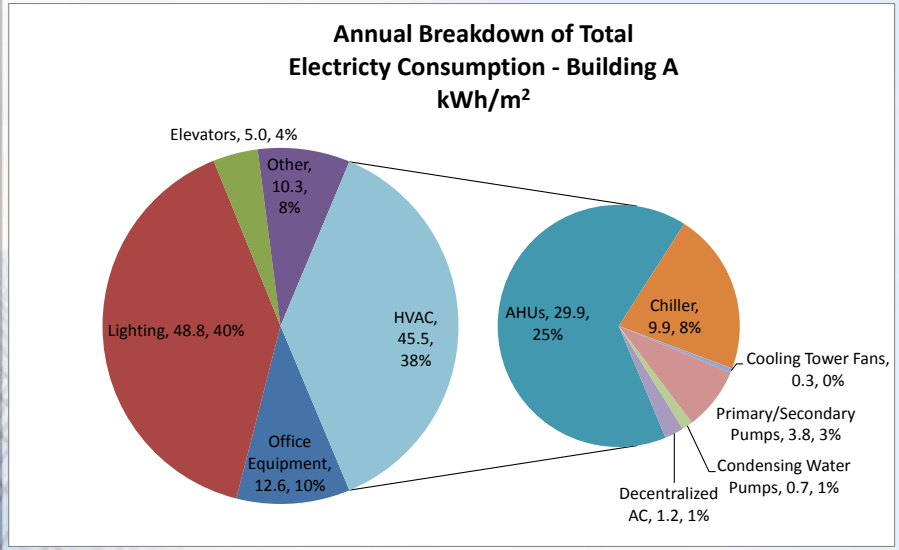
Case Study

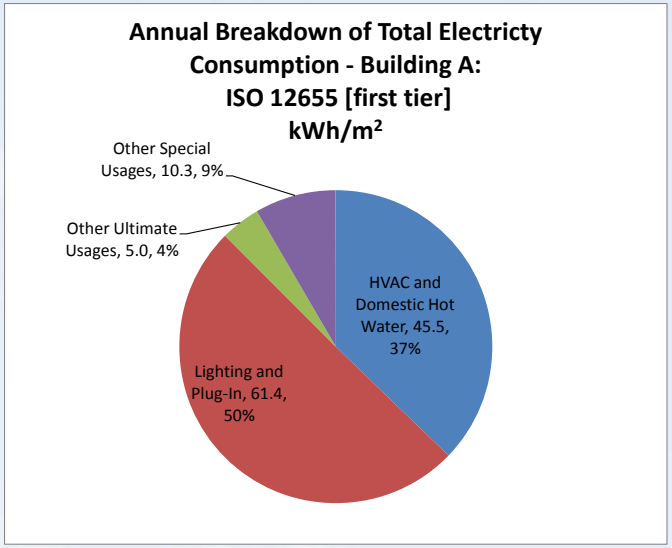
Summary of the four office buildings

Name	Building A	Building B	Building C	Building D
Location	Beijing, China	Beijing, China	Merced, California, U.S.	Berkeley, California, U.S.
Climate zone	Zone 4B, HDD18°C: 2,918, CDD10°C: 2,286	Zone 4B, HDD18°C: 2,918, CDD10°C: 2,286	Zone 3B, HDD18°C: 1,495, CDD10°C: 2,657	Zone 3C, HDD18°C: 1,612, CDD10°C: 1,614
Year of construction	1989	1987	2005	1960
Floor area (m²)	54,490	39,211	16,000 (7,000 for the office wing)	8,316
Typical operation hours	M-F 7 a.m.-6 p.m.	M-F 6 a.m.-6 p.m.	M-F 7 a.m.-6 p.m. (for office)	M-F 7 a.m.- 6 p.m.
HVAC	Water-cooled chiller, district heating, VAV + CAV systems	Decentralized AC for cooling, district heating	District cooling, district heating, VAV systems	Local electric cooling and gas-boiler heating Centralized and packaged DX systems
Monitoring Platform	iSagy	iSagy	EPP	Pulse Energy
Interval of archived data	1 hour	1 hour	15 min	15 min
Photo				

Case Study - Energy Profiling

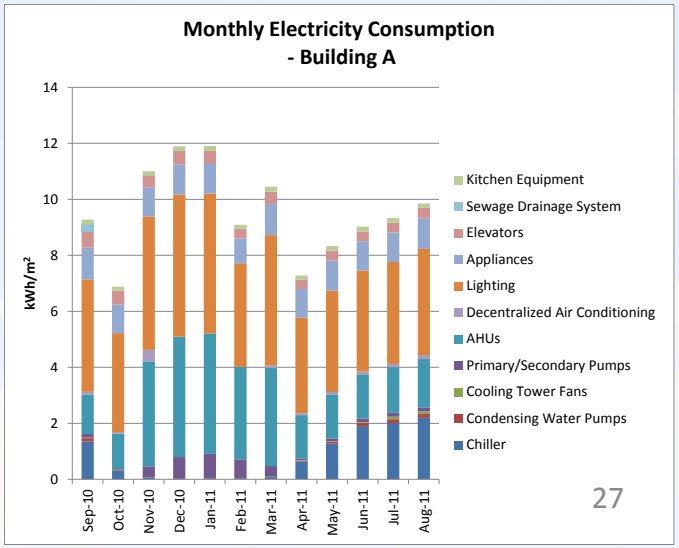
Building A





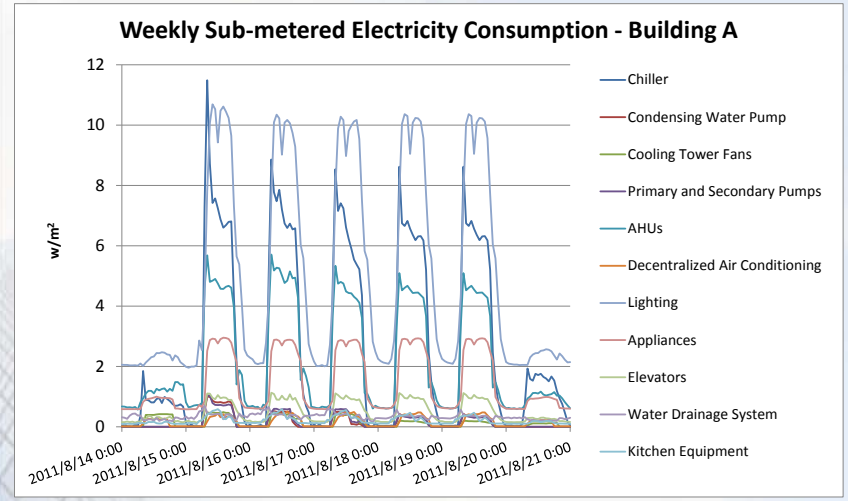
1 | 2
3

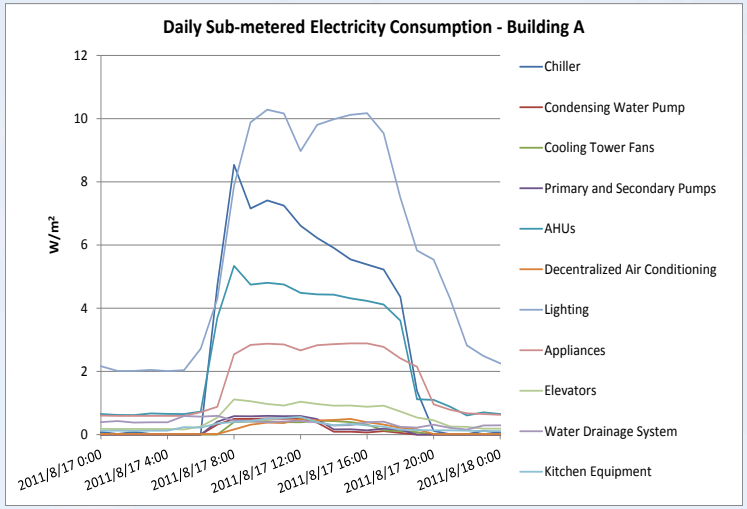
- Detailed sub-metering end-uses
- Only electricity, no gas
- Space heating source energy not included
- Space heating related equipment included
  – AHUs, pumps
- Increase during heating season
  – Nov.15 ~ Mar.15



Case Study - Energy Profiling

Building A





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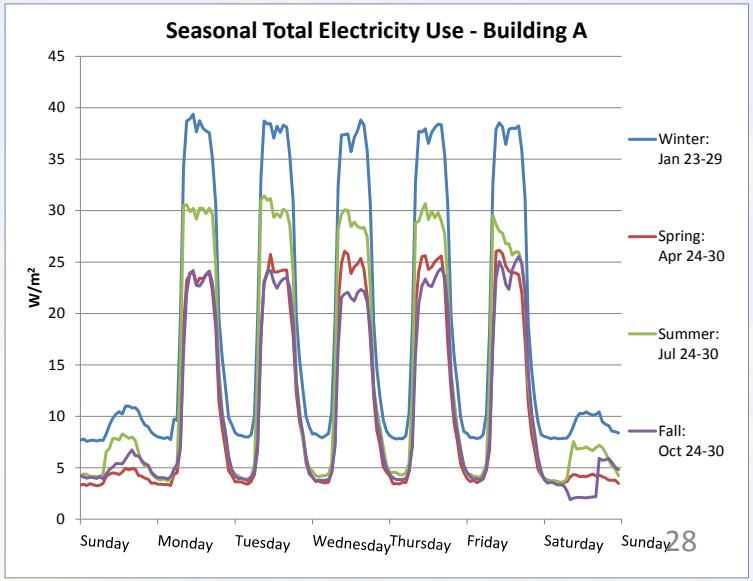
- Weekday > Weekend
- Daytime > Night
- Start-up peak for HVAC in the morning
- Drop during lunch time – energy saving occupant behavior
- Winter > summer > Spring/Fall



Case Study - Benchmarking

Total Electricity

- A & B ≈ typical Chinese building
- C & D < typical U.S. building

HVAC

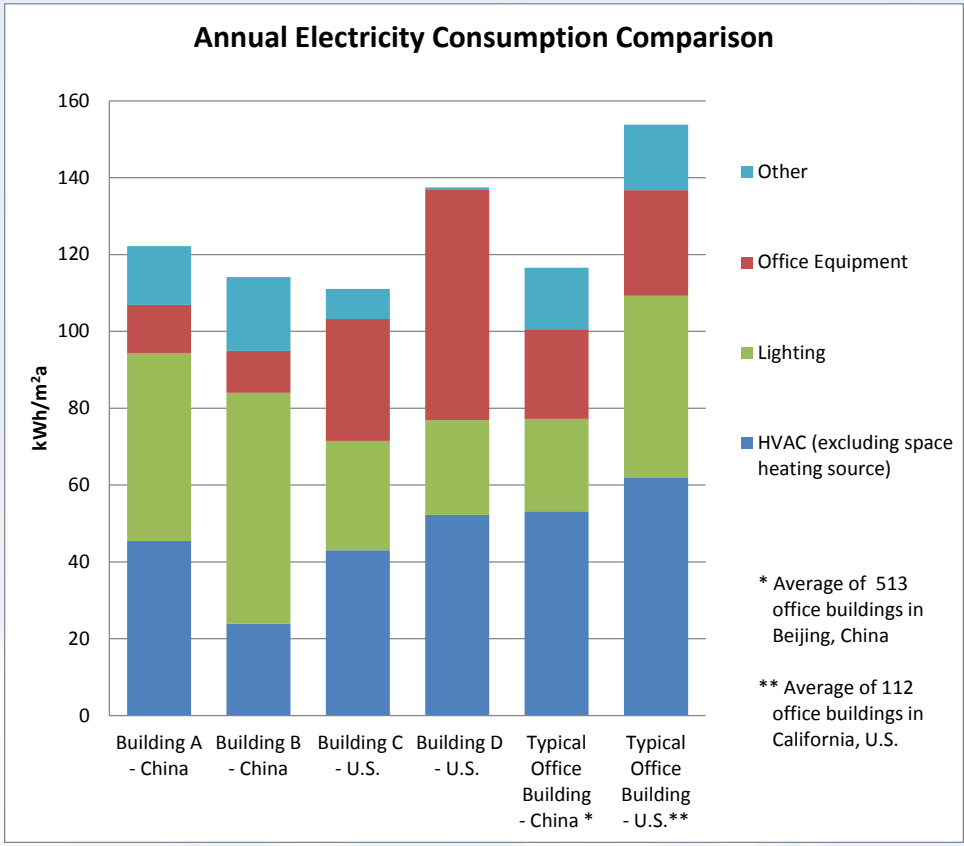
- B is min. (decentralized HVAC is more efficient)
- D is max. (old envelop; comfort standard; ventilation standard)

Lighting

- A & B > C & D (type of lights; natural light; occupant sensors)
- Typical Chinese building < Typical U.S. buildings (large variation of surveyed buildings)

Office Equipment

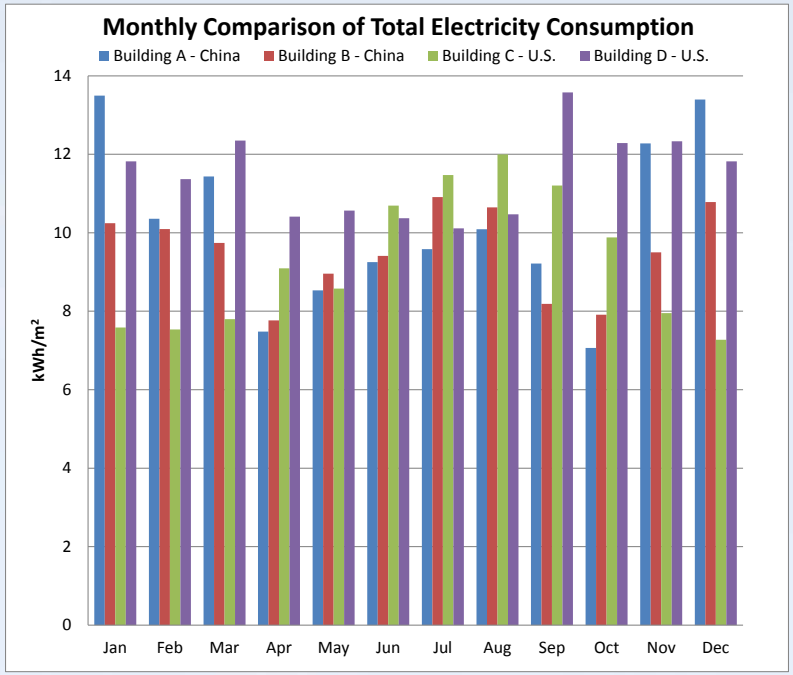
- D is max. (more PCs standby at night; more personal fans, task lights, etc.)



Data source:
*Annual report on China's building energy development;
**California Commercial End-use Survey (CEUS).

Case Study - Benchmarking

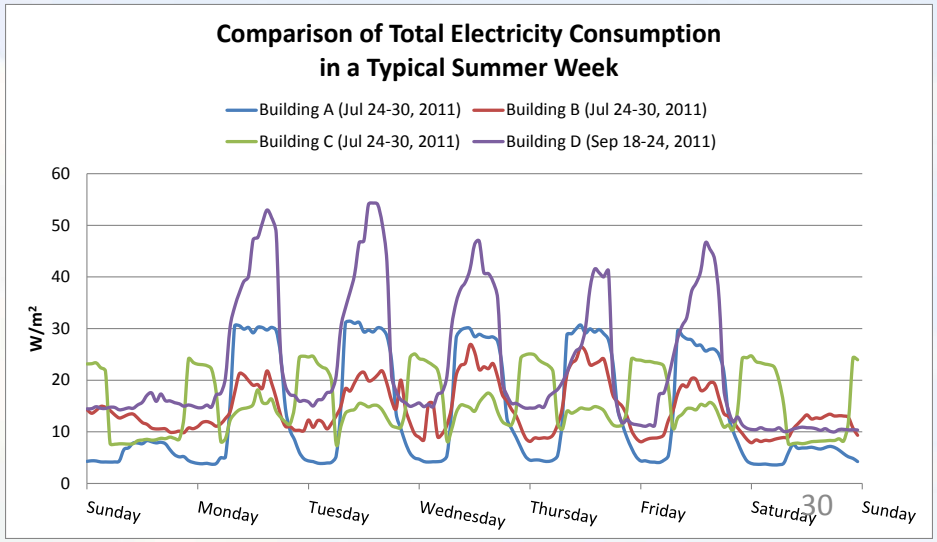
- The discrepancy is much larger in winter than in summer
- A & B consume less than C in summer, but more in winter – HVAC increase
- D is always high; highest in Sep



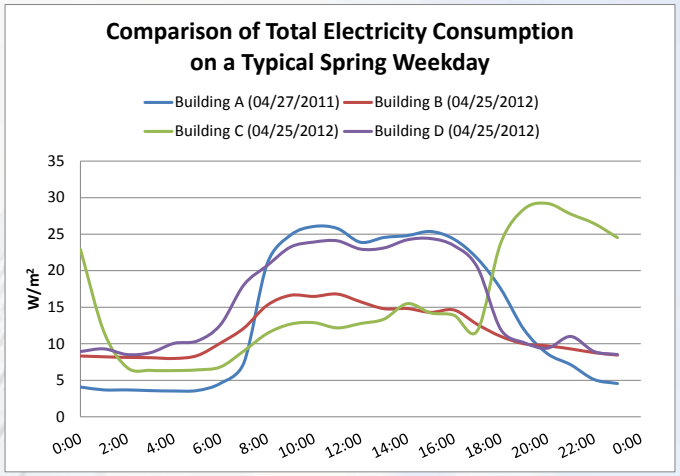
- C peaks at night – chilled water storage system
- Weekday-weekend load ratio:

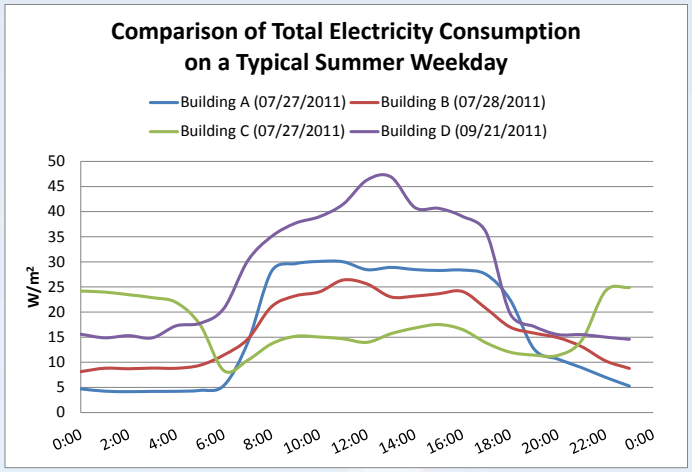
  A > D > B

Building	A	B	C	D
Average weekday-weekend energy use ratio	2.94	1.36	1.24	2.06



Case Study - Benchmarking





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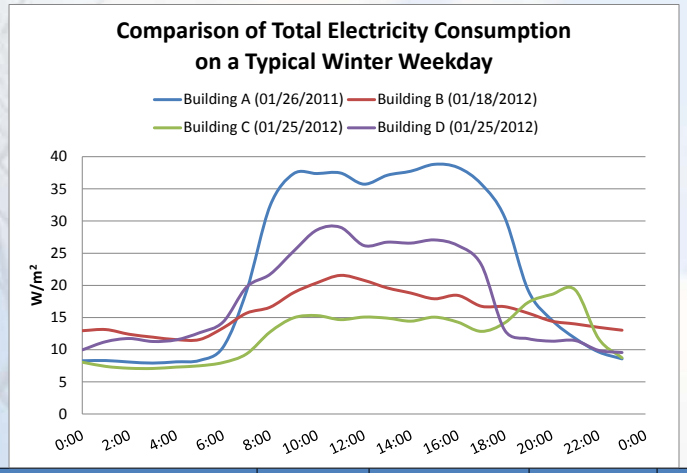
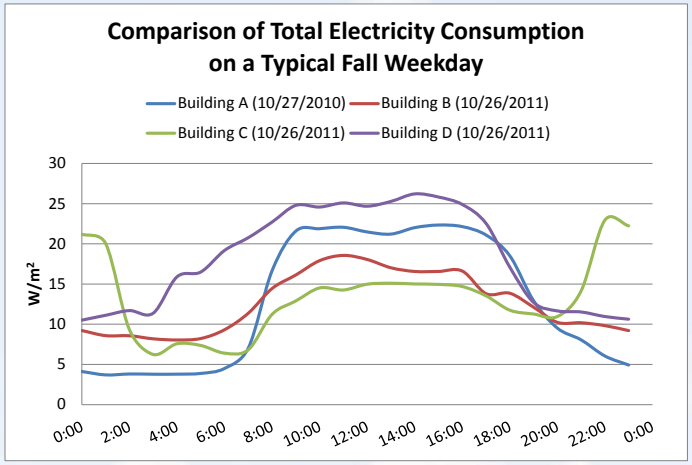




Peak- base load ratio (peak: 7 am – 7 pm Base: 7 pm – 7 am)	Spring	Summer	Fall	Winter
Building A	5.35	5.33	4.47	4.20
Building B	1.94	2.22	2.04	1.68
Building D	2.54	2.65	2.11	2.44

- A & D are always higher during daytime; A is lower at night
- A has a decline at noon
- Peak-base load ratio: A > D > B

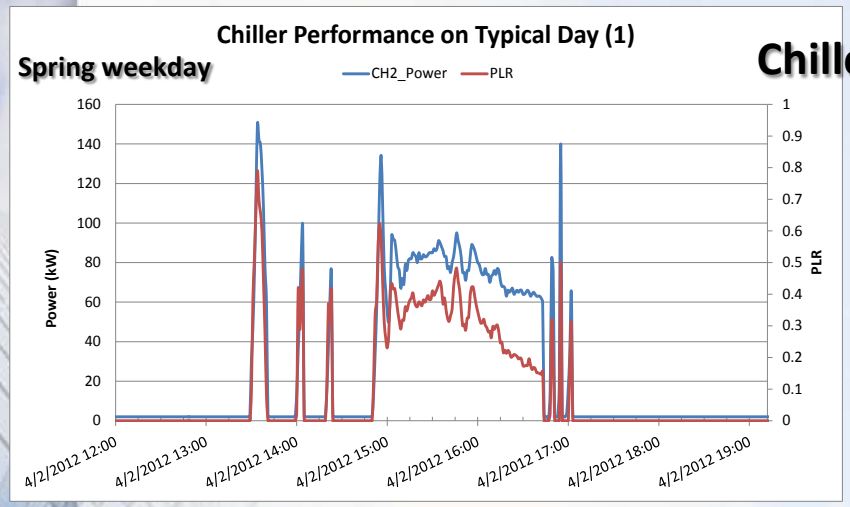
Case Study – Benchmarking

Even though total energy use intensities of these buildings are similar, the end-uses are quite different.

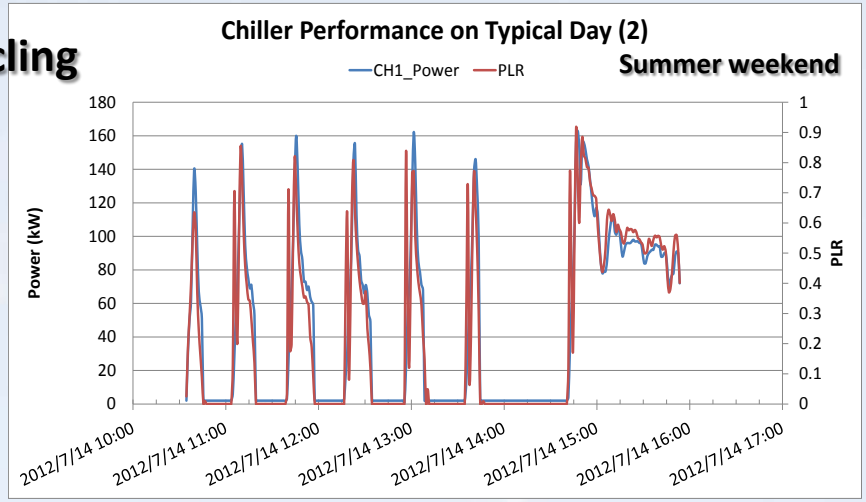
Energy saving potential:

- Building A & B – lighting; heating related equipment
- Building C & D – office equipment (plug-loads)
- Learn from Building B – decentralized HVAC may be more efficient
- Learn from Building A – high peak-base load ratio (maybe good operation and management, energy-saving occupant behavior)

Case Study – Energy Diagnostics



Chiller cycling



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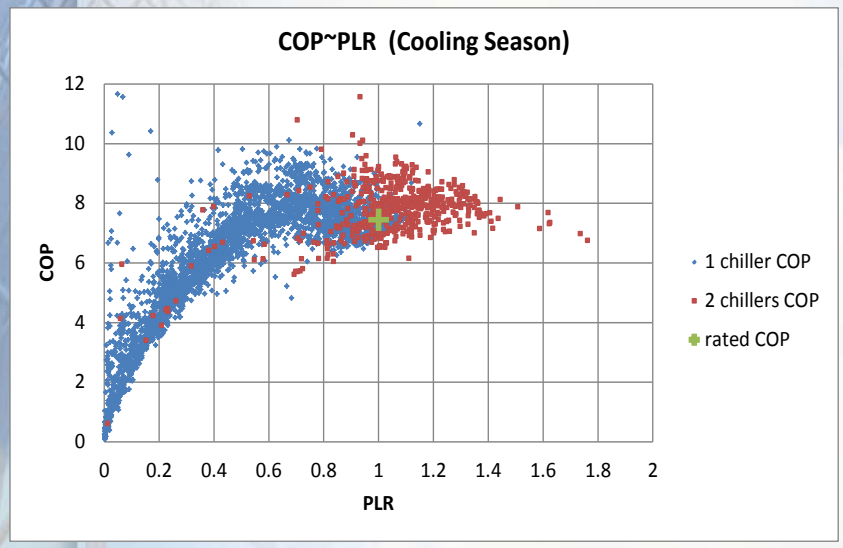
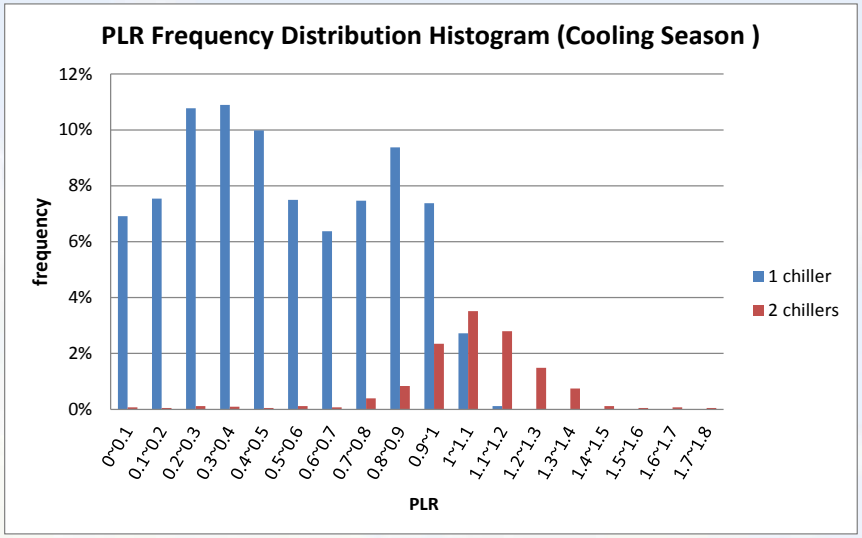
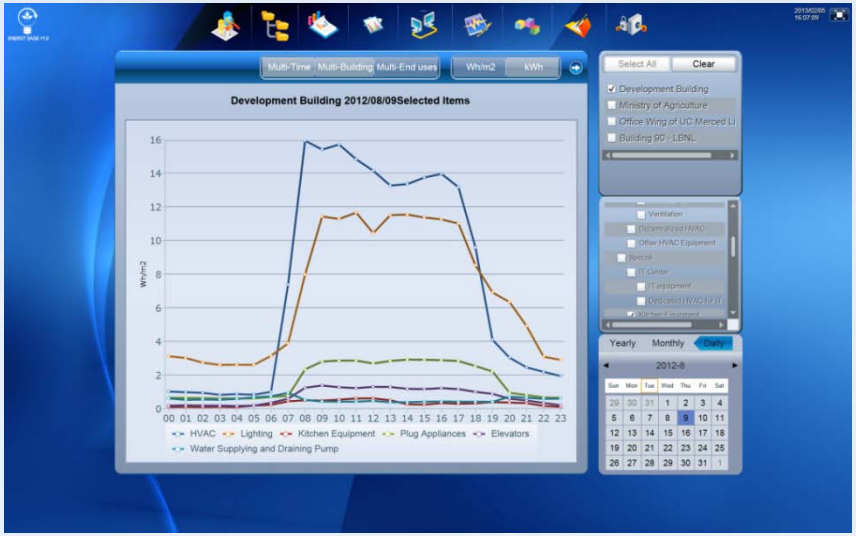




$$Part\ Load\ Ratio\ (PLR) = \frac{actual\ cooling\ load}{rated\ cooling\ capacity\ of\ one\ chiller}$$

iSagy Portal – Screenshot



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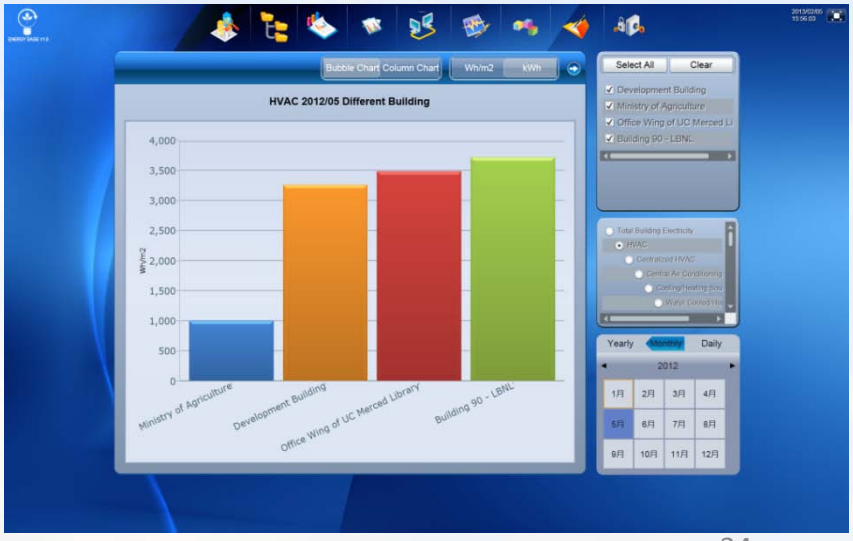

Challenges

- **Building Selection**
  - Lack of data – detailed end-uses at short interval, gas, environmental and HVAC operating conditions
  - Data sharing – communication with building owners, facility managers
- **Data collection and clean-up**
  - Download/export data
  - Naming of data points
  - Data time interval
  - Data quality – missing & invalid data
  - Data clean-up – considering weather, working/non-working day
- **Analysis issues**
  - Mixed end-uses – standard data model vs. various sub-metering structures
  - Mixed-use building – floor area ratio
  - District cooling/heating system – cooling/heating load ratio
  - Normalization of energy use – floor area, number of occupants, operating hours, CDD/HDD, etc.
  - Typical buildings – only annual data, only major sub-categories, accuracy and typicality

Summary

Project highlights

- Three types of data – power, operating, environmental
- Sub-metered data
- Short time-interval data
- ISO Standard data model

Recommendations for future work

- Complete understanding of the building characteristics: design and operation
- Good communication with building owners and facility managers
- **Install well-designed EMS during construction**
- U.S. buildings – need detailed end-uses; better data quality
- Chinese buildings – add HVAC operating & environmental conditions, district heating energy; smaller time-interval data

Questions?