Microsoft Research

Microsoft Research Asia
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ALPS:
Activity-Level
Power Monitoring System

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Energy issue

Unaware of how energy is spent

A master power meter

Energy monitoring systems

- Break down energy to provide more understandable feedback to users
- *"translating energy data into meaningful information"*

ALPS: Activity-Level Power Monitoring

Watching TV
200 Watts

Cooking
500 Watts

Reading
100 Watts

Closing the gap

low level energy data from power meters

high level energy-consuming activities

Outline

- System overview
- Experimentation
- Evaluation
- Energy Feedback
- Conclusion

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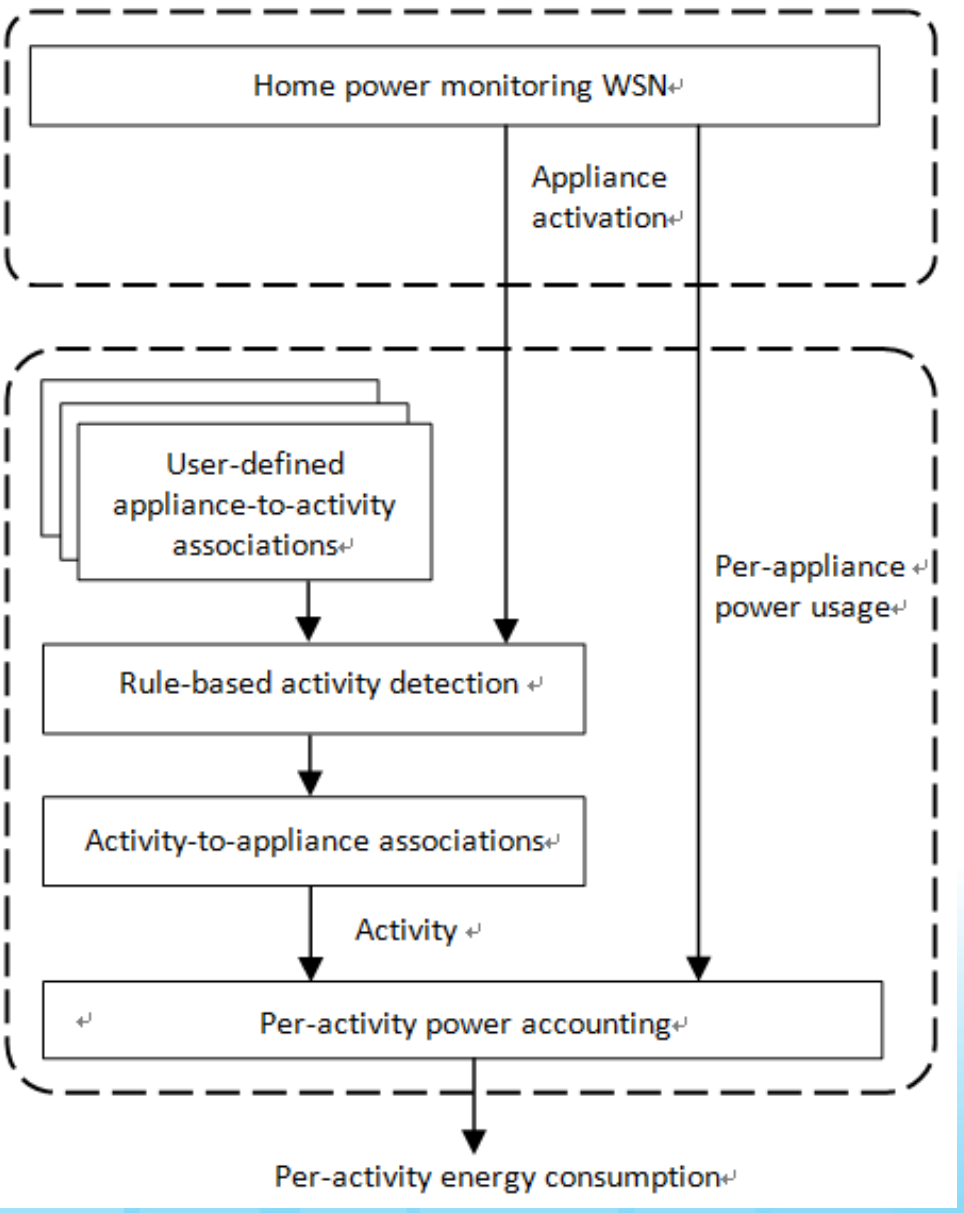
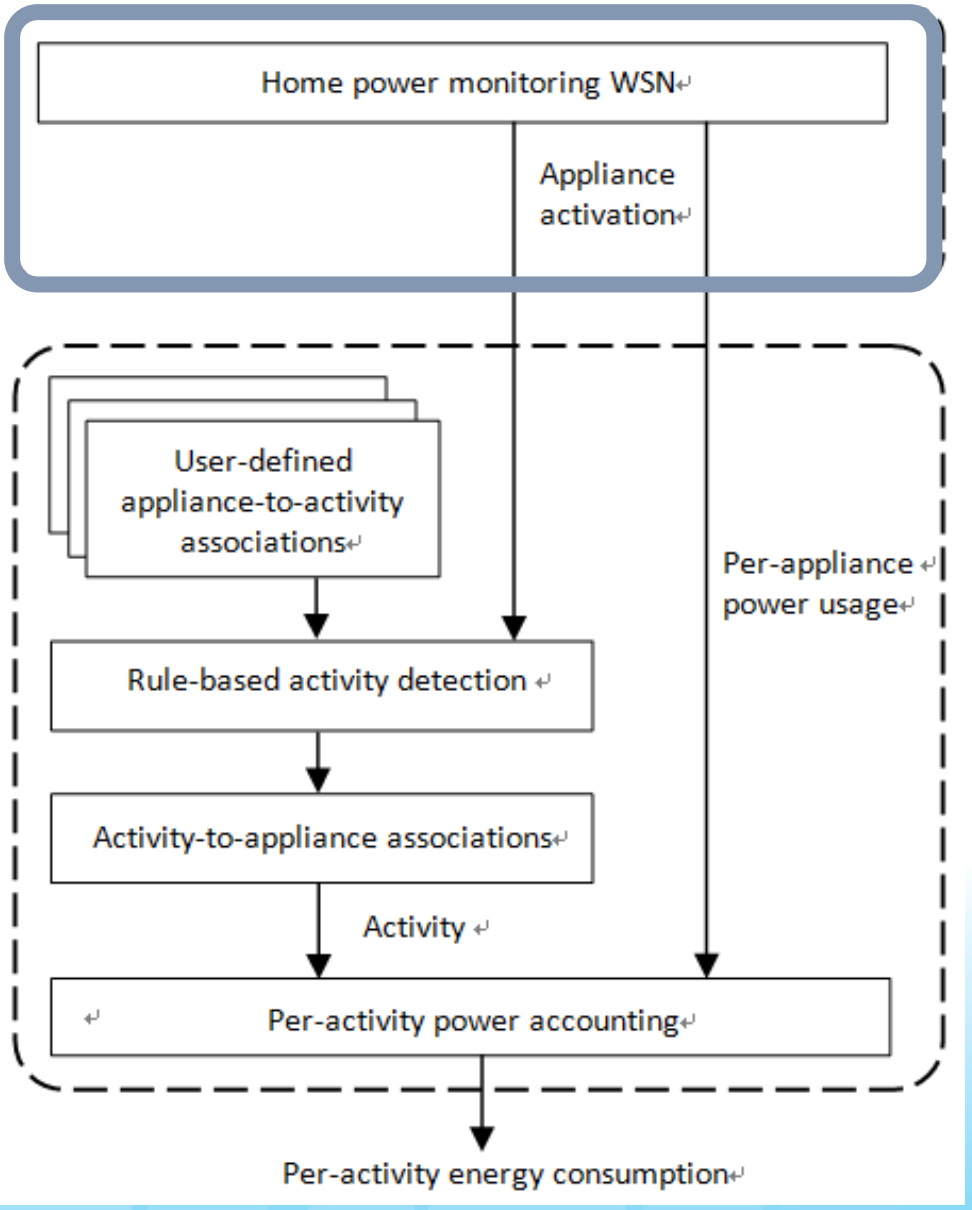
System Overview



Data Collection Module

Data Analysis Module

Data collection module



Data Collection Module

Data Analysis Module

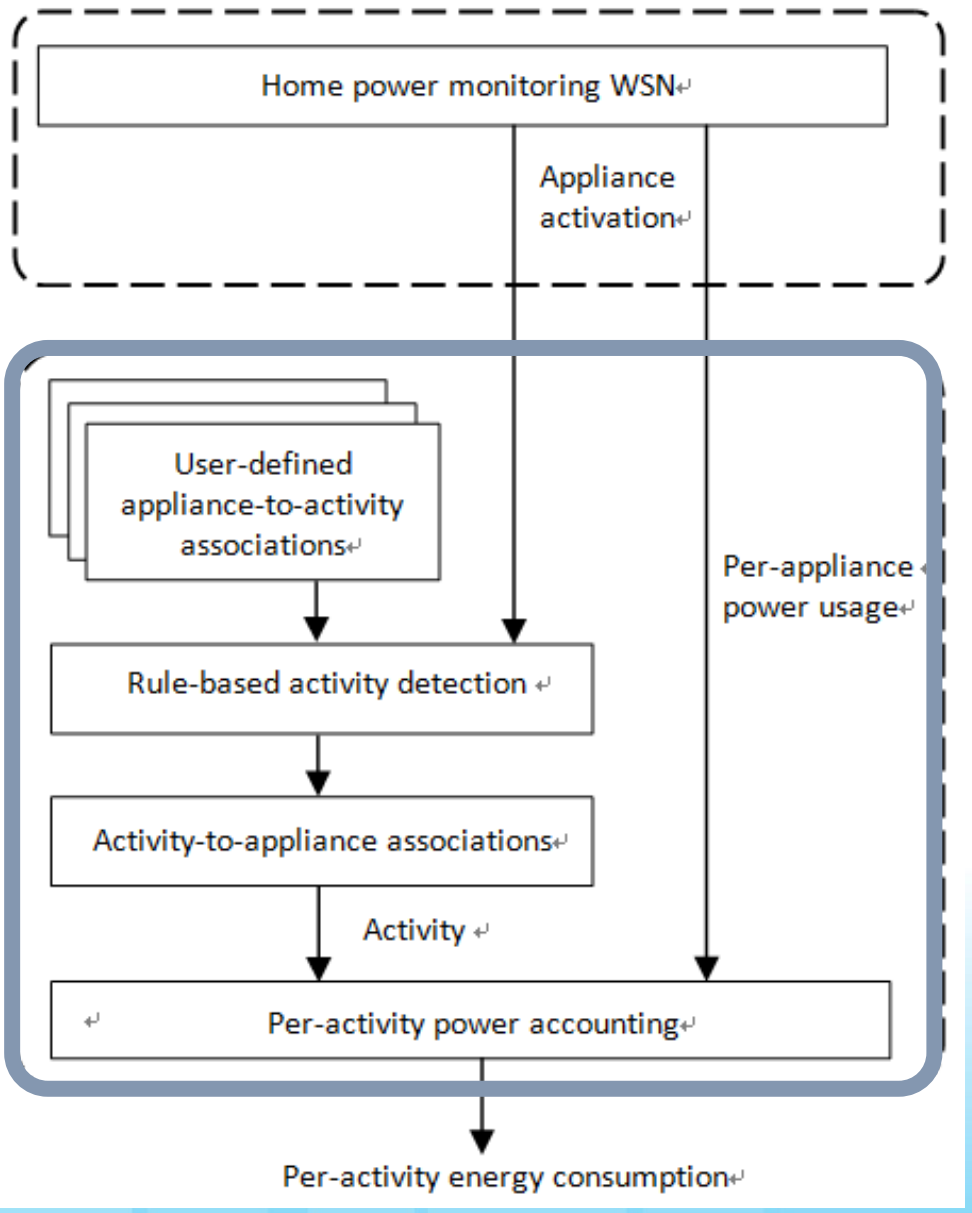
Data collection module

- Home power-monitoring WSN

(ACme power meter)

Light sensor (Taroko)

Data analysis module

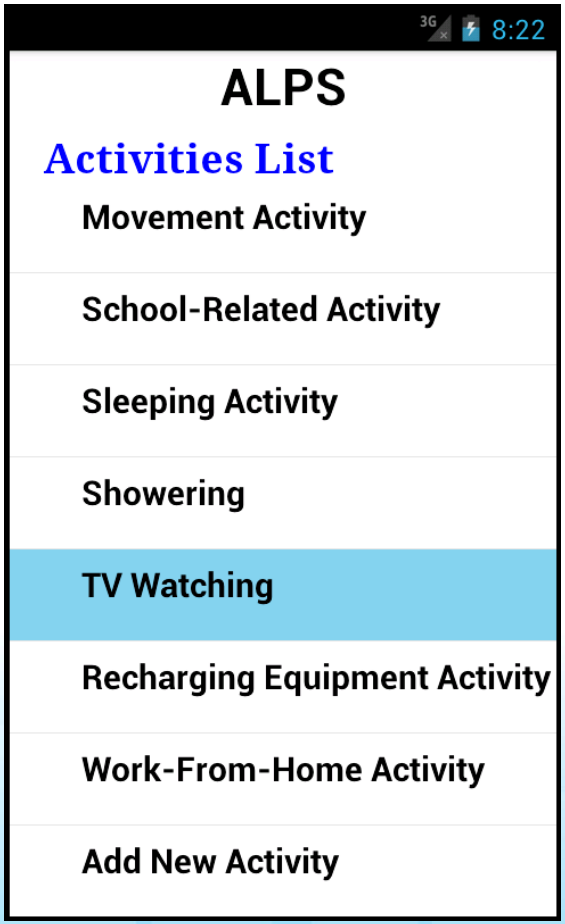


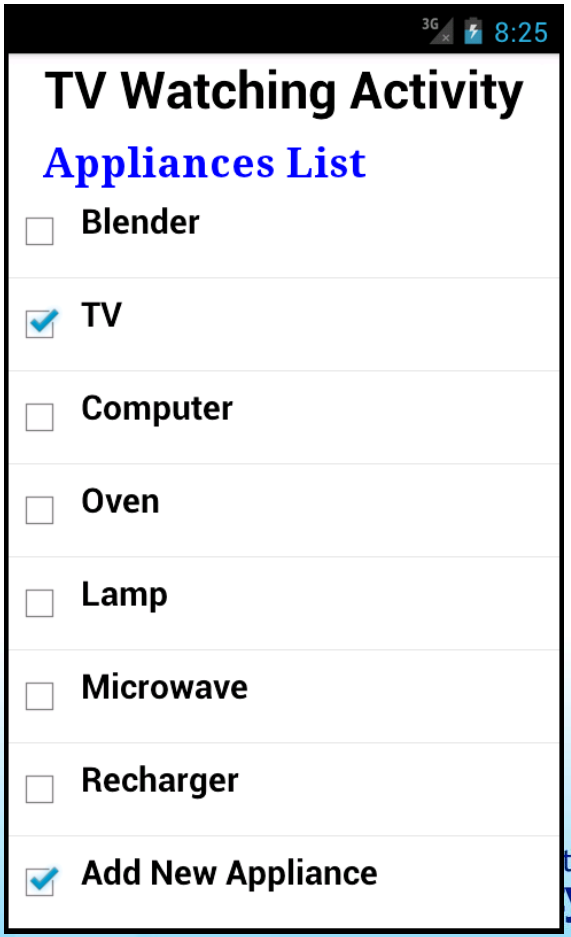
Data Collection Module

Data Analysis Module

1. User-defined activity-to-appliance associations

- Each household labels their own activity-to-appliance associations





1. User-defined activity-to-appliance associations

- Label only **Primary appliances**
- **Secondary appliances** do **not** need to be labeled
- TV watching: {TV}

TV watching

Primary appliance

Secondary appliance

… …

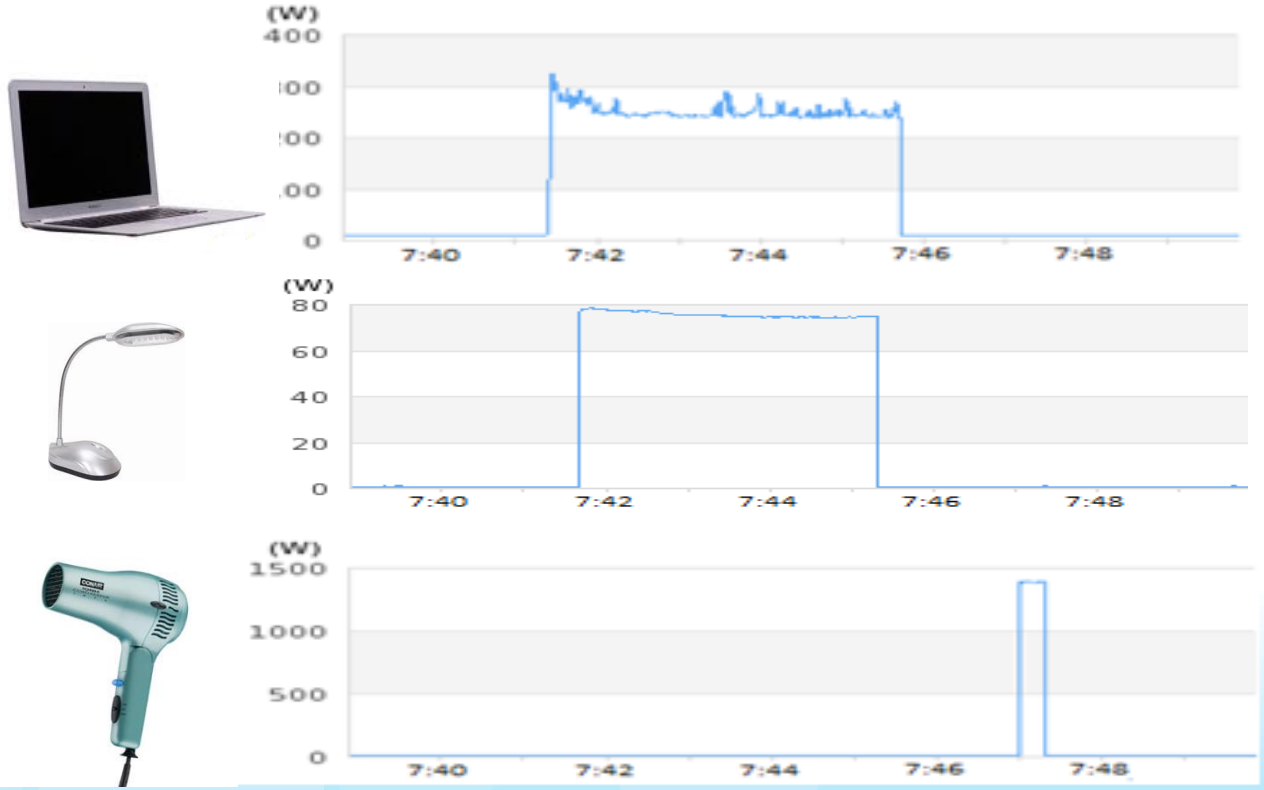
2. Rule-based activity detection

- **Lookup table** generate based on user-defined appliance-to-activity associations
- Cooking activity: {oven, rice cooker, microwave}

Appliance activation (1/0 = on/off)			Activities
Oven	Rice cooker	Microwave	
0	0	0	No-cooking
0	0	1	Cooking
0	1	0	Cooking
0	1	1	Cooking
1	0	0	Cooking
1	0	1	Cooking
1	1	0	Cooking
1	1	1	Cooking

3. Activity-to-appliance associations

- Determine the **full set of** operating appliances when an activity occurs

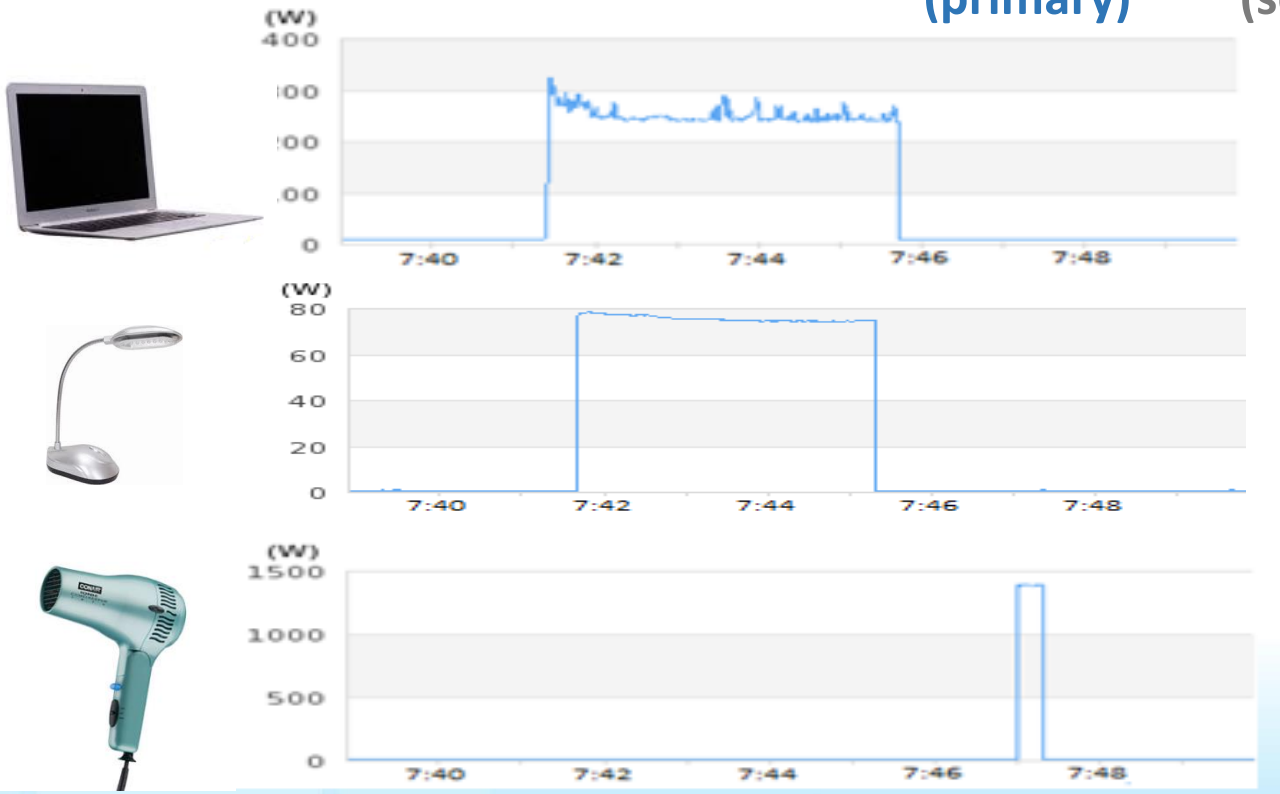


Computer-related activity

Showering activity

3. Activity-to-appliance associations

- Computer-related activity: { **notebook**, **lamp** }
  (primary) **(secondary)**



Computer-related activity Showering activity

4. Per-activity Power Accounting

1) Activity duration resolution
   - Determine activity duration from *rule-based activity detection* time series data

2) Power accounting
   - From *activity duration* and *activity-to-appliance associations*, calculate activity power consumption

4. Per-activity Power Accounting

1) Activity duration resolution

- Determines the duration of an activity from activity time series data
- Apply sliding window to find boundaries(start/end time) of activity

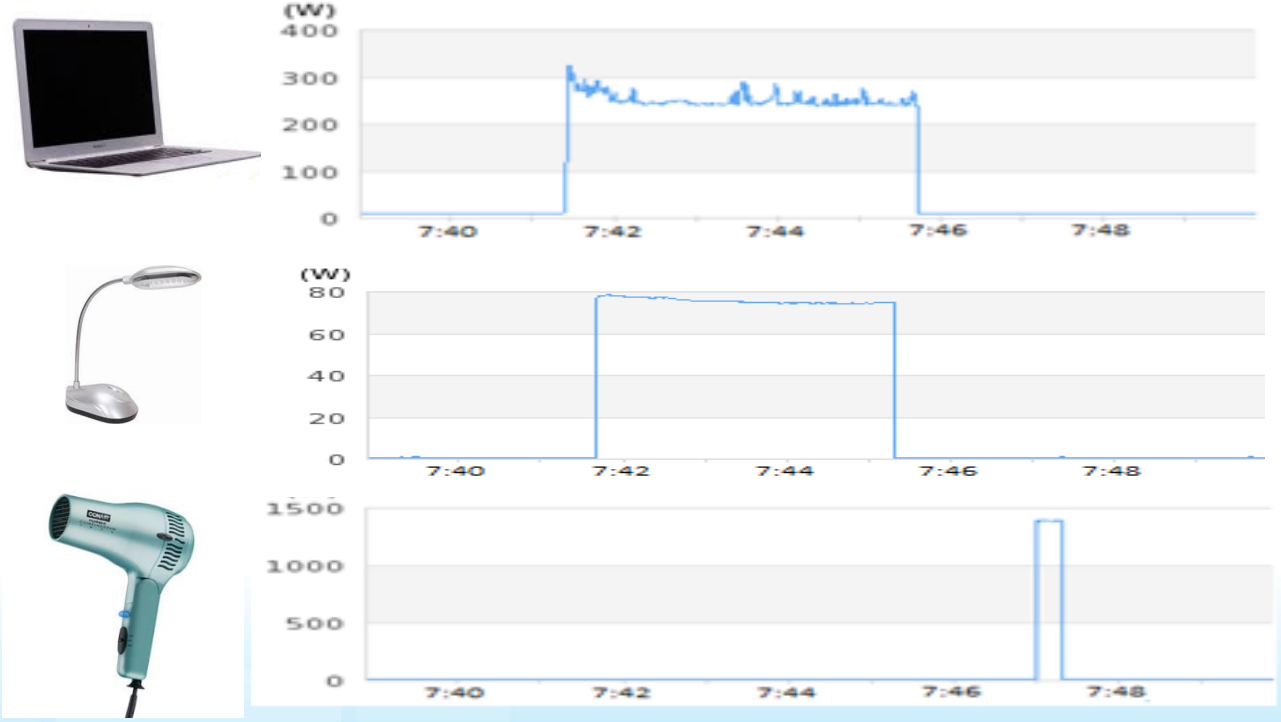
(a) Activity time series

(b) Activity duration

4. Per-activity Power Accounting

2) Power accounting

- Aggregate power consumption of associated appliances

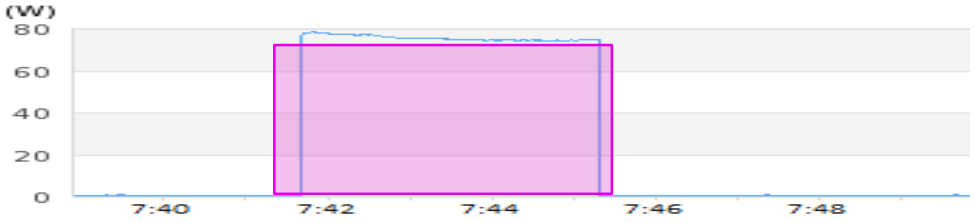


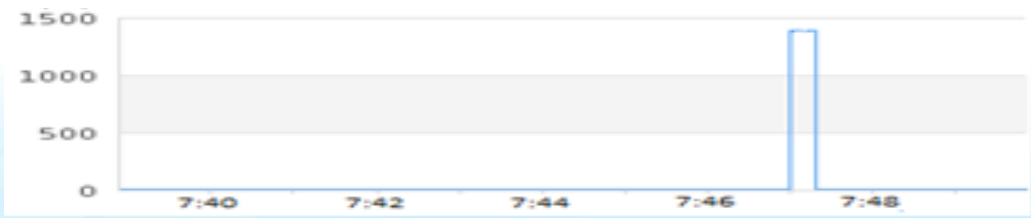
Computer-related activity Showering activity

4. Per-activity Power Accounting

2) Power accounting

- Aggregate power consumption of associated appliances
- Computer-related activity power consumption



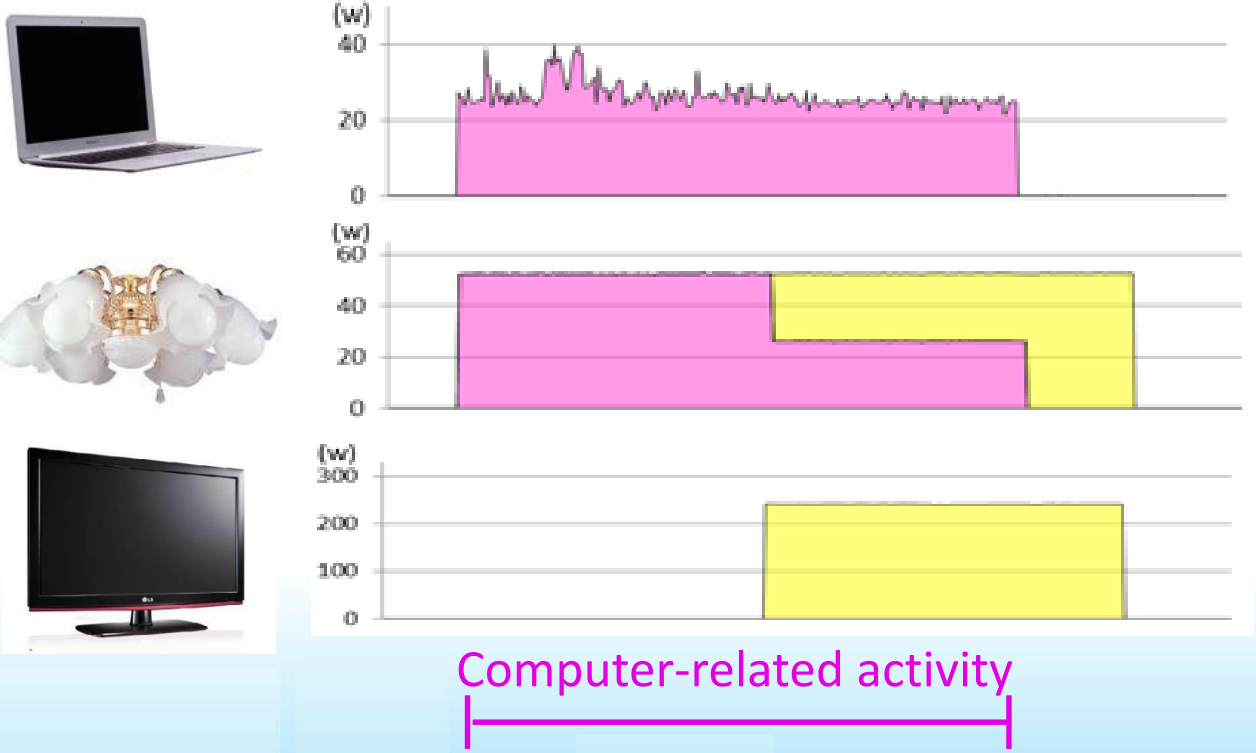


Computer-related activity Showering activity

4. Per-activity Power Accounting

2) Power accounting

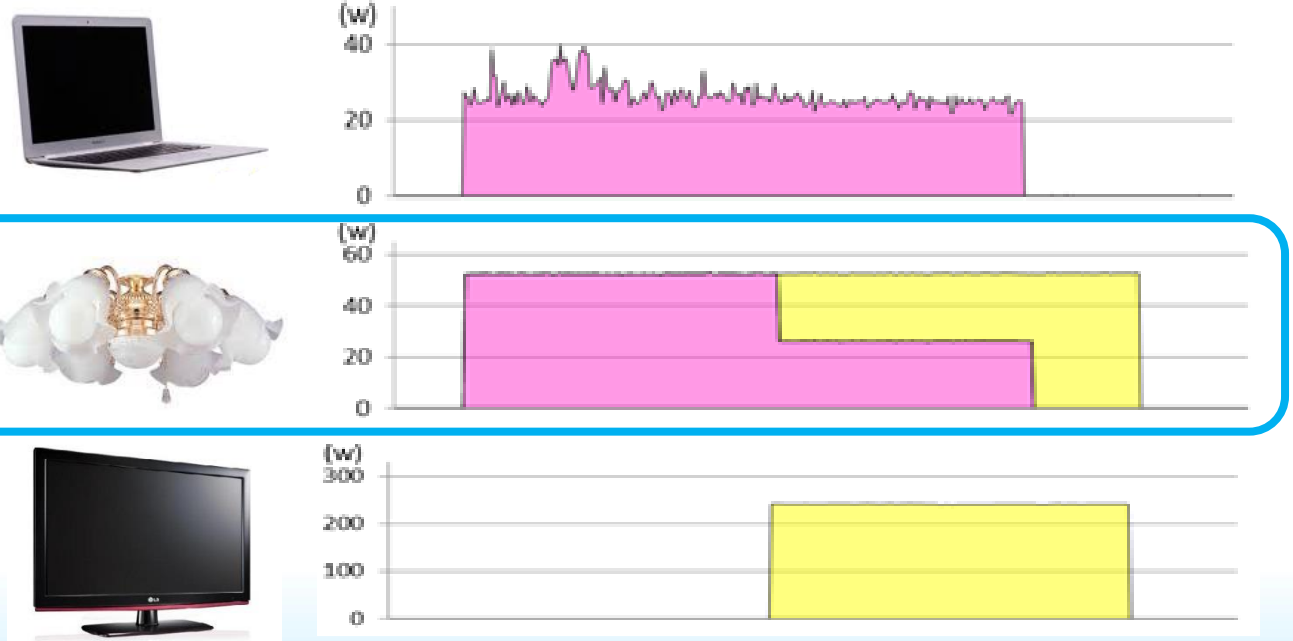
- For **shared appliances**, energy is split equally between activities



4. Per-activity Power Accounting

2) Power accounting

- **Ceiling light** is shared between “Computer-related activity” and “TV watching activity”



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Experimentation

- Real-world deployments in 3 homes
- 4 week duration
- Install 57 sensors
- Total 1,296 activities collected
- Ground truth:
  - Users label ground truth for evaluation purposes

Experimentation

	Home #1	Home #2	Home #3
Household size	1 man	3 men 1 woman	2 men 2 women
# of rooms	2 rooms	8 rooms	10 rooms
# appliances monitored	9	15	30








Experimentation

- Activity list

Home #1	Home #2	Home #3
5 activities	6 activities	9 activities





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Evaluation

- Evaluation metrics
  - Activity recognition accuracy
  - Activity duration error
  - Activity power accounting error

Activity recognition accuracy

- Accuracy of ***rule-based activity-appliance detection*** in estimating user activity

	# of activities	Average F-measure (%)
Home #1	220	91.32
Home #2	286	96.01
Home #3	763	91.58
AVG	-	92.97

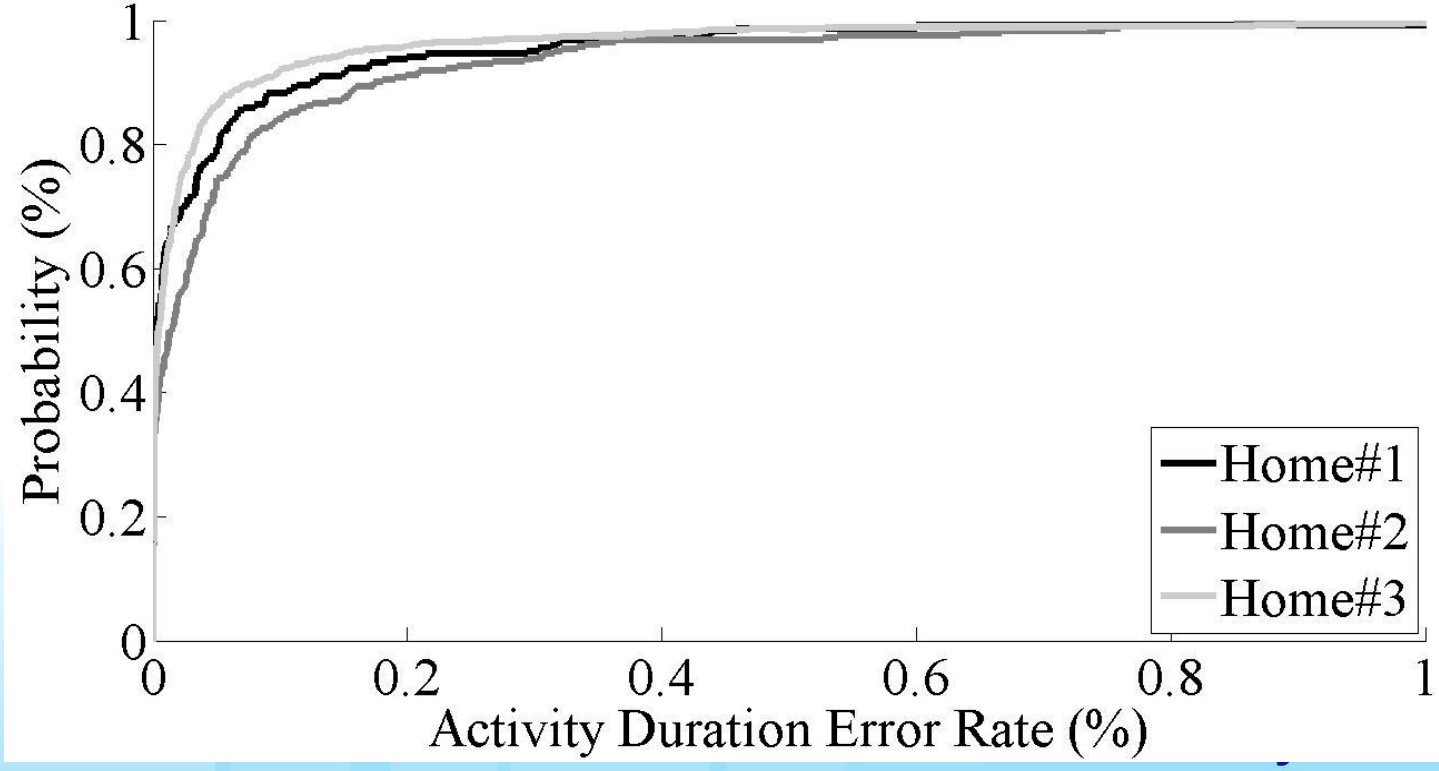
Activity recognition accuracy

- Detail of home #3

activity	# of activities	F-measure(%)
computer-related activity	65	95.20
cooking activity	106	91.89
eating activity	81	92.36
non-showering bathroom activities	311	90.94
recharging equipment activity	36	87.82
school-related activity	12	99.81
showering activity	63	82.34
TV watching	74	95.81
working activity	15	88.10
AVG.	-	91.58

Activity duration error

- Error in estimating the duration of an activity
- 80% of activities have error rate under 5.18%(home #1), 7.32%(home #2) and 3.06%(home #3)

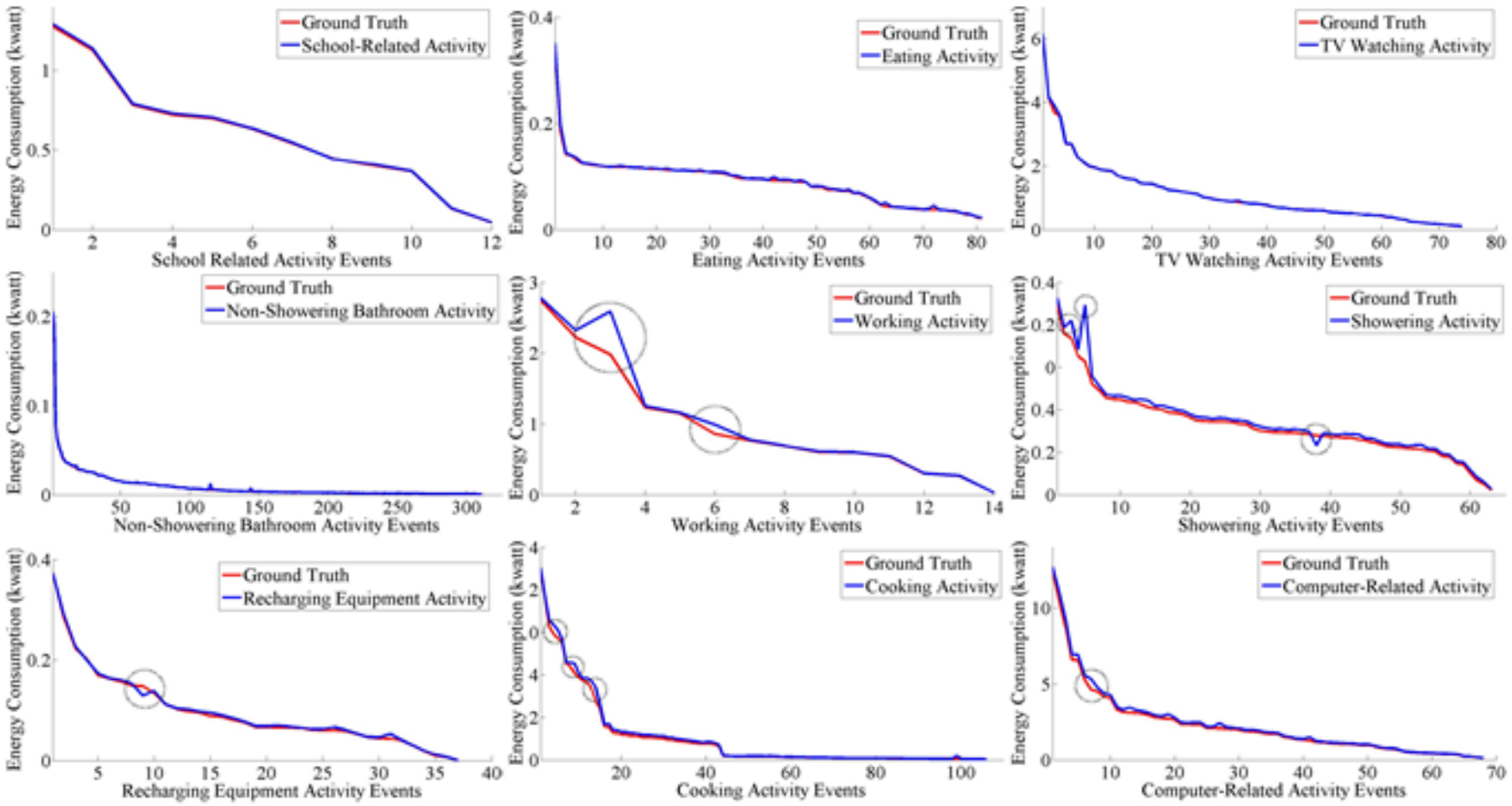


Activity power accounting accuracy

	Average Accuracy (%)
Home #1	94.79
Home #2	96.50
Home #3	95.73
AVG	95.55

Activity power accounting accuracy

- System estimated vs. ground truth power consumption for home #3

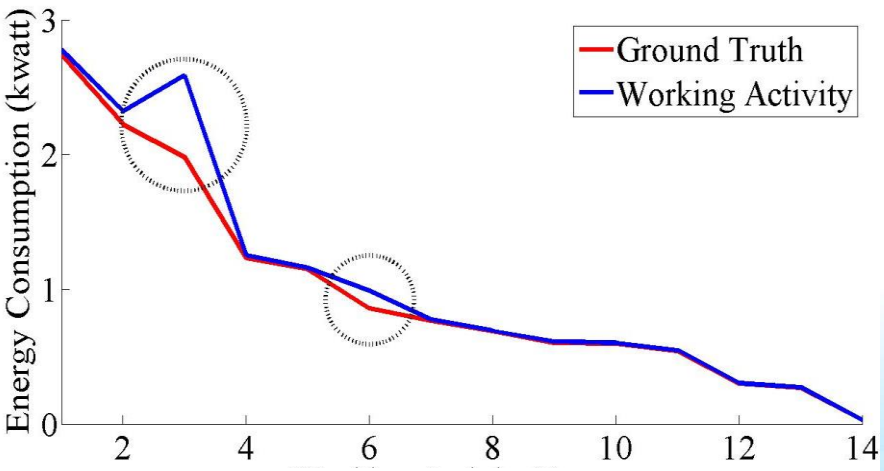


Activity power accounting accuracy

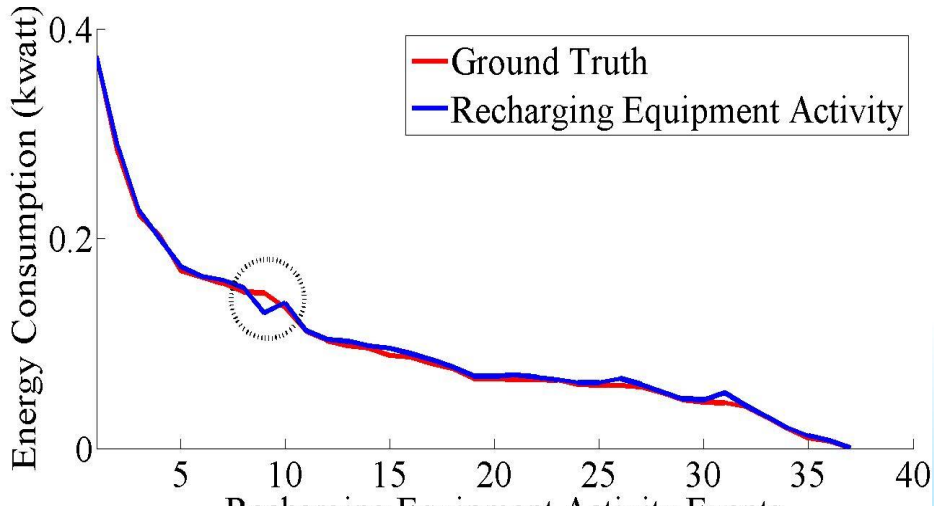
- Inaccuracies due to:

(1) the detected activity durations have large estimation errors

(2) human errors in labeling activity-appliance ground truth



(1)



(2)

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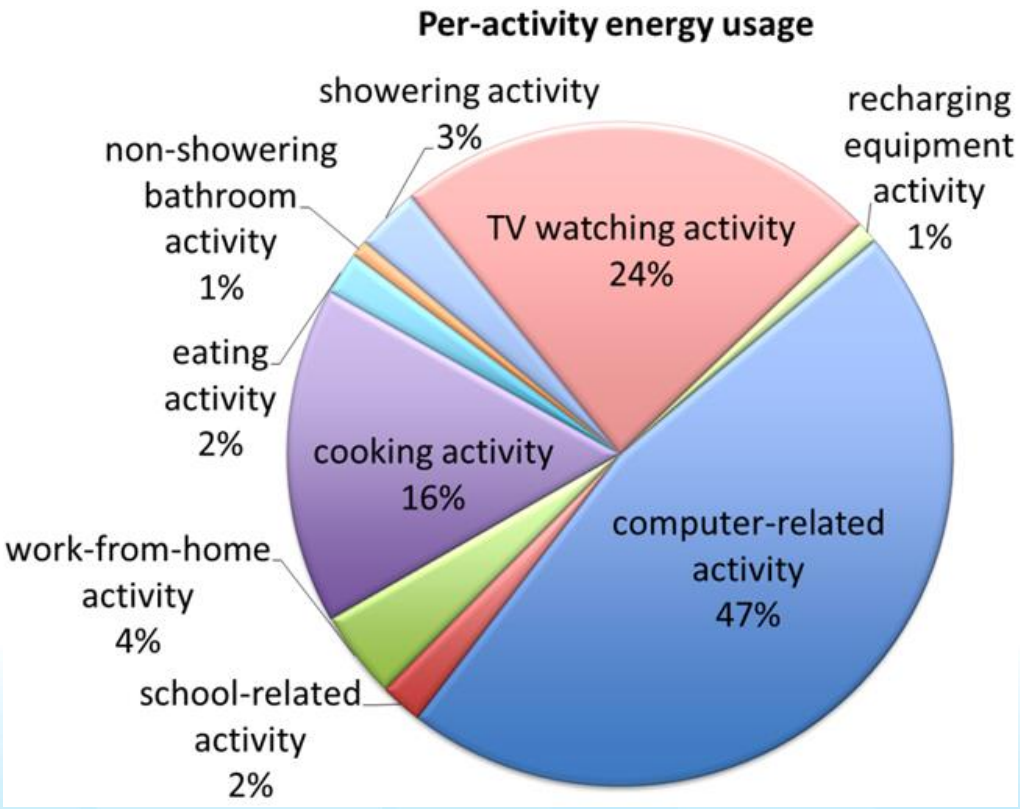
Energy feedback

- Per-activity energy usage in home #3:

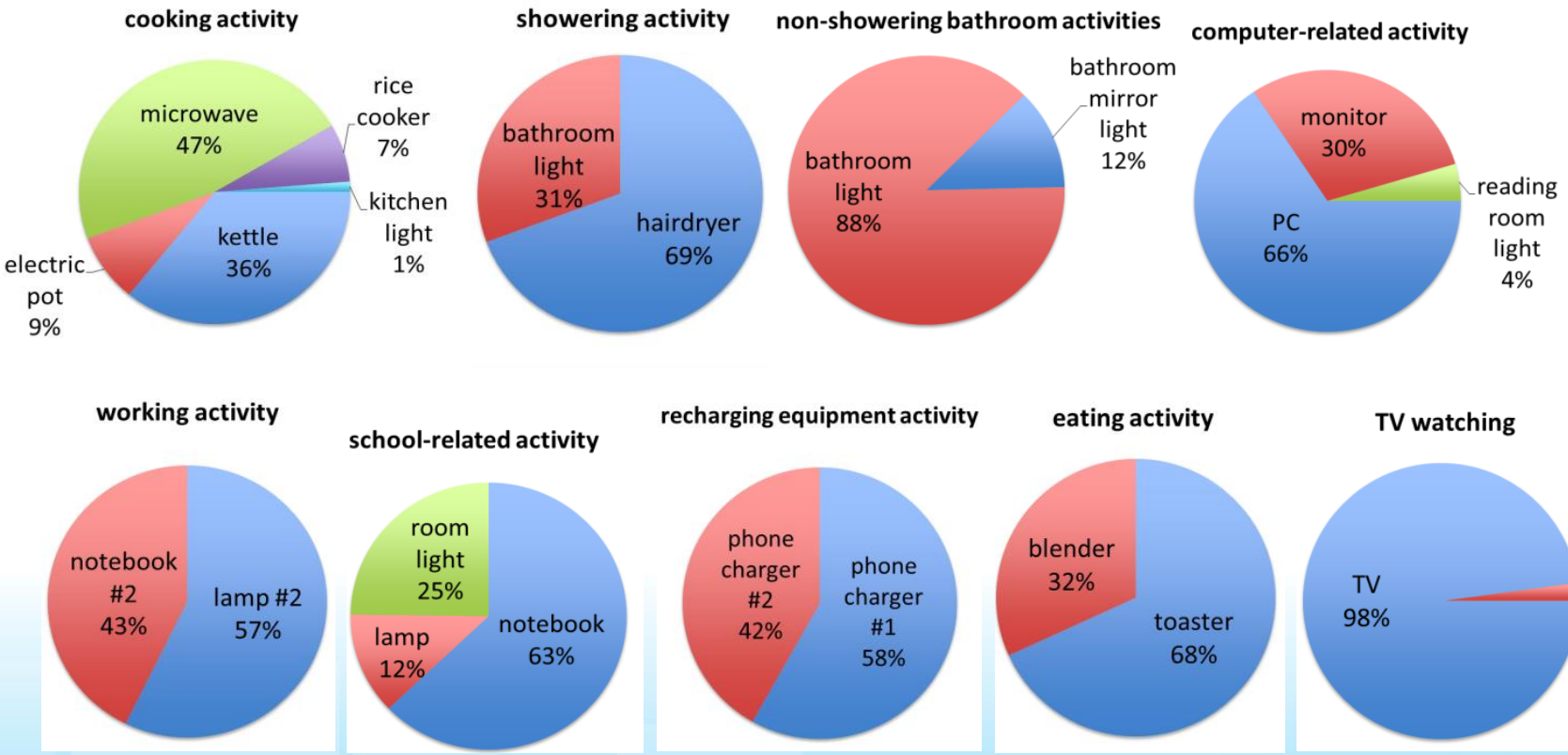


Participant A:

"We really ought to switch to shut-down mode when using the computer. I though [the computer] would just take up a little bit of energy when we just leave it there, but apparently not."

Energy feedback

- Energy breakdown of activities in home #3



Showering activity

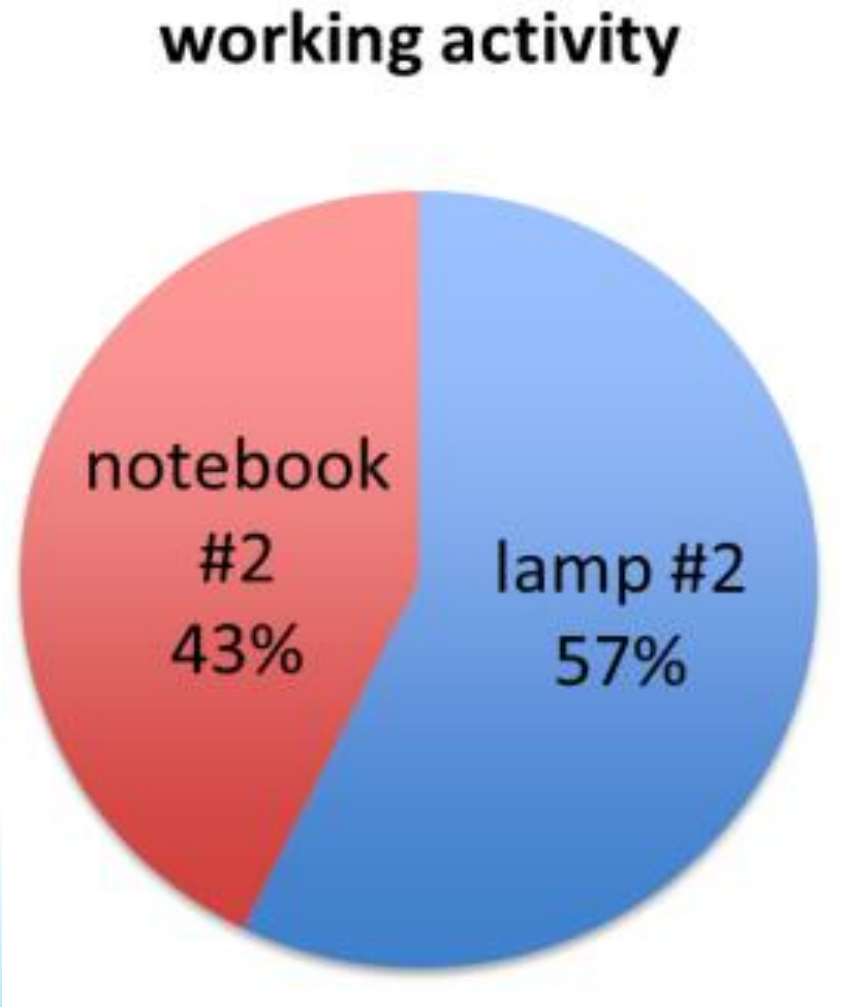
- Hairdryer consumes ~70%
- Participant A:

  "This information helps me focus on quickly drying my hair instead of reducing the bathroom light usage, which helps me save more energy."

Work-from-home activity

- Lamp consumes ~60%
- Participant B:

  "I ought to start switching off the lamp as soon as I leave the desk, [and change to] a more energy-efficient LED lamp"



Conclusion

- ALPS *bridges the semantic gap* between low-level power meter data and high-level everyday human activities
- Achieves 92.97% accuracy in activity-recognition and 95.55% accuracy in activity-level energy monitoring
- Future studies can use system output to design effective feedback mechanisms for motivating people to change their energy-consuming behaviors.

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Thank you!

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