ZonePAC

Zone Power Estimation and Control via HVAC Metering and Occupant Feedback

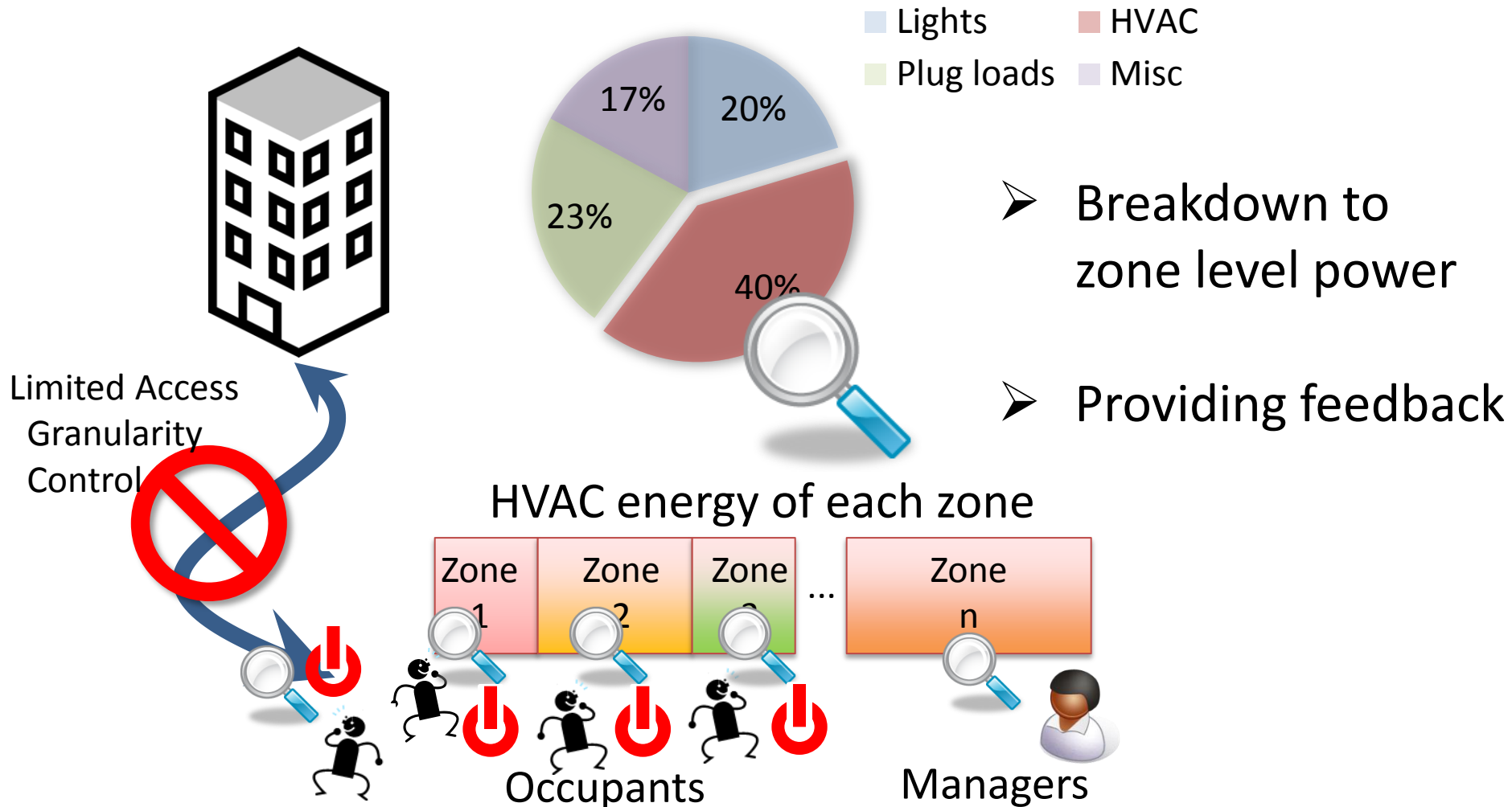Bharathan Balaji*, Hidetoshi Teraoka*

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Zone Power Estimation

Commercial Buildings Energy Breakdown [*1]

Legend: Lights, HVAC, Plug loads, Misc

Pie chart: 20% (Lights), 40% (HVAC), 23% (Plug loads), 17% (Misc)

➢ Breakdown to zone level power

➢ Providing feedback

HVAC energy of each zone

Zone 1 | Zone 2 | Zone 3 | ... | Zone n

Occupants

Managers

Limited Access
Granularity
Control

*1 Building Energy Data Book - http://buildingsdatabook.eren.doe.gov
*2 The effectiveness of feedback on energy consumption. S. Darby. DEFRA 2006.
*3 J. Schein, S.T. Bushby, N.S. Castro, J.M. House, A rule-based fault detection method for air handling units, Energy and Buildings 38 (12) (2006) 1485–1492.

Outline

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- Approach and Methodology

- Implementation

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- Conclusion

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Feedback Saves Energy Consumption

Occupants

> Providing direct feedback on energy consumption can save 5-15% [1] (Mostly for home)

Facility Managers

> Detecting anomalies using continuous commissioning can save 2-25% of HVAC energy consumption [2]

[1] The effectiveness of feedback on energy consumption. S. Darby. DEFRA 2006.
[2] E. Mills and P. Mathew. Monitoring Based Commissioning: Benchmarking Analysis of 24 UC/CSU/IOU Projects. Technical report, Ernest Orlando Lawrence Berkeley

Breakdown of Energy Consumption
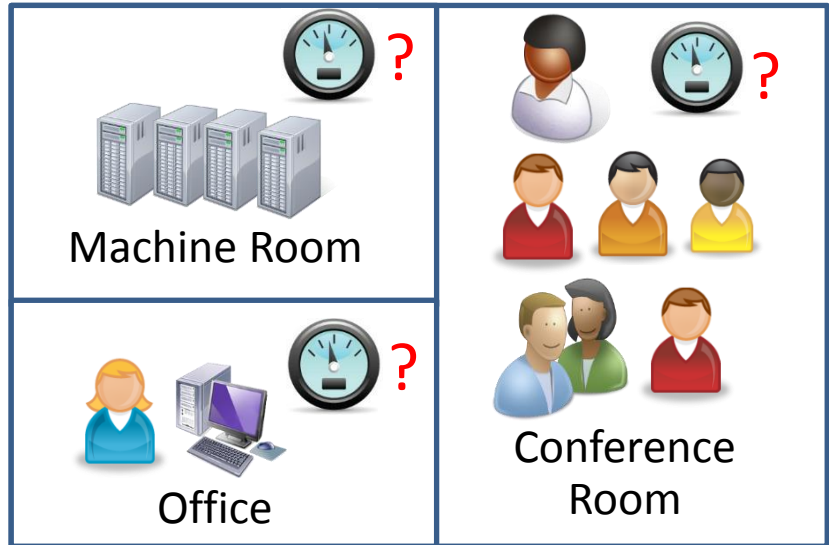
Power Meter

Energy Consumption of entire building[1]

Breakdown of Plug Load[3]

Breakdown of HVAC power consumption

Modern HVAC divides building into multiple zones

➢ Many zones

➢ Different type of power
   Thermal Power
   Electrical Power

Machine Room ?

Office ?

Conference Room ?

• Installing submeter for HVAC zone power is expensive

[1] The Energy Dashboard: Improving the Visibility of Energy Consumption at a Campus-Wide Scale – Y Agarwal, T Weng and R Gupta. Buildsys 2010
[2] Building Energy Data Book - http://buildingsdatabook.eren.doe.gov
[3] X. Jiang, S. Dawson-Haggerty, P. Dutta, and D. Culler. Design and Implementation of a High-Fidelity AC Metering Network. ACM IPSN, 2009
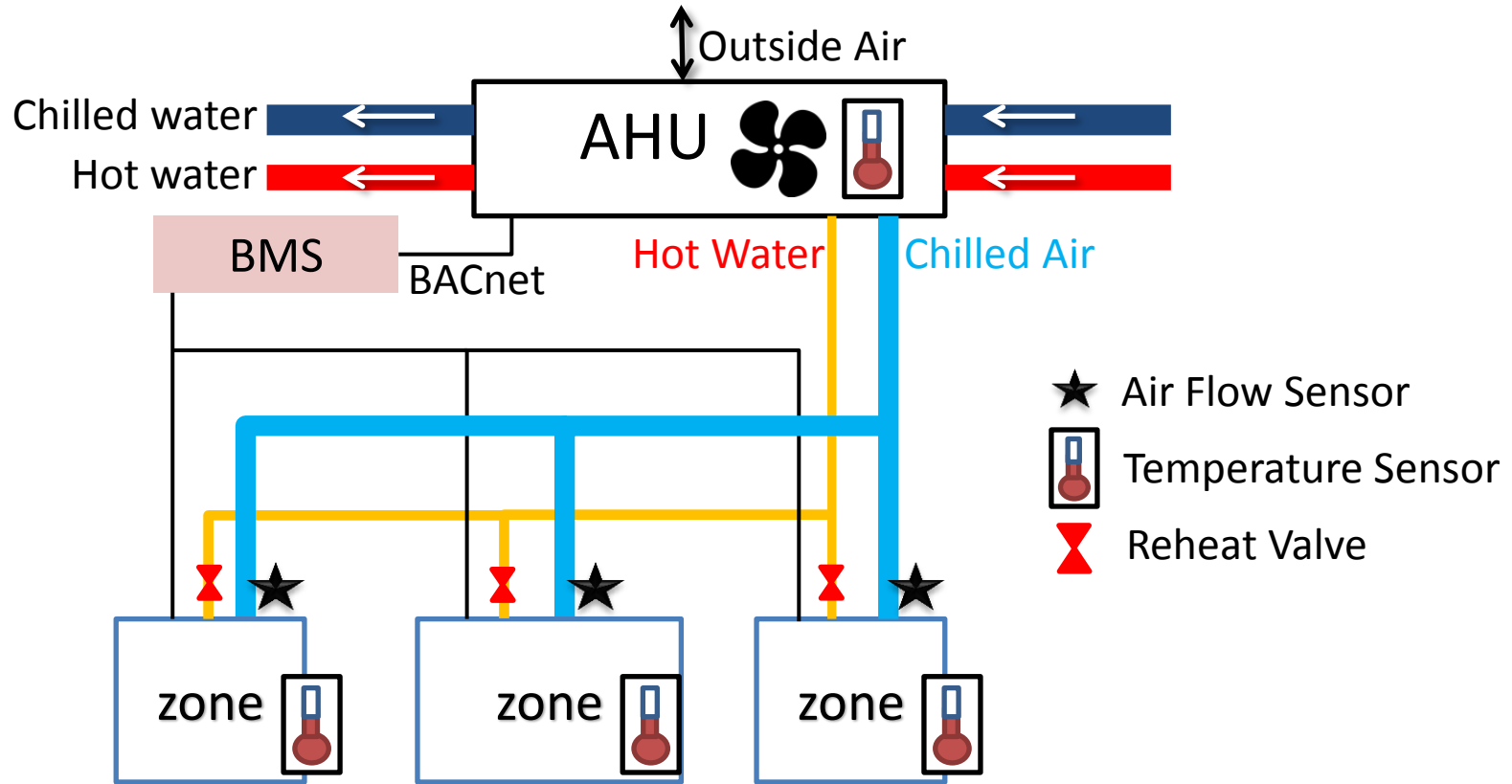
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Zone Power Estimation

- Estimating zone level power using existing sensors
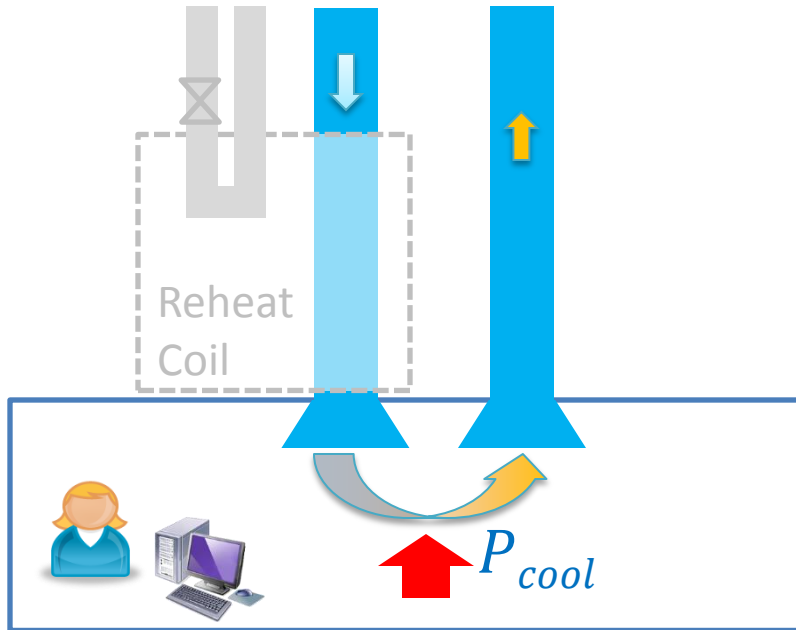- Deployment in UCSD CSE Building
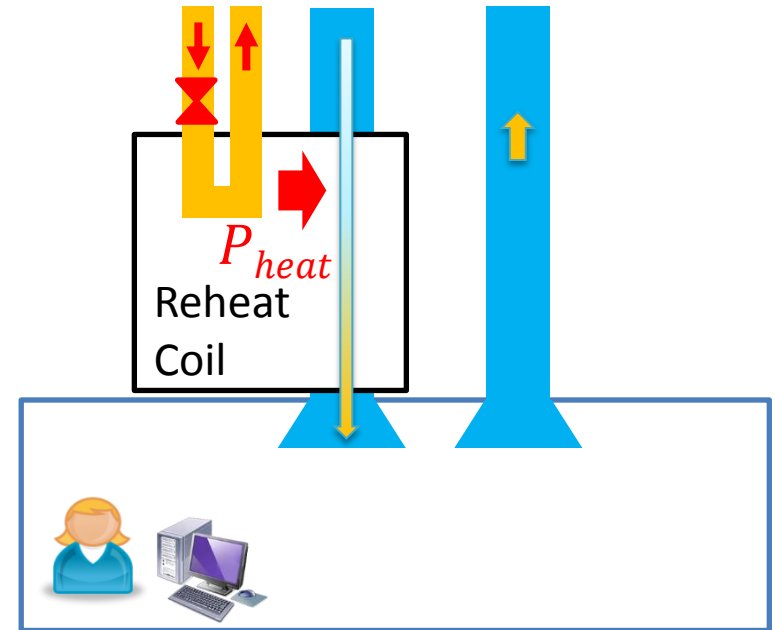
HVAC System of CSE Building

- Centralized VAV type HVAC System
- ~145,000 sqft with 1 AHU and 237 zones
- Managed by BMS via BACnet protocol
- ~17 sensors in each zone (~4,700 BACnet datapoints)

BMS: Building Management System , AHU: Air Handling Unit , VAV: Variable Air Volume

HVAC Power consists of 3 Parts

Cooling Thermal Power

Heating Thermal Power

Reheat Coil

P_{heat}
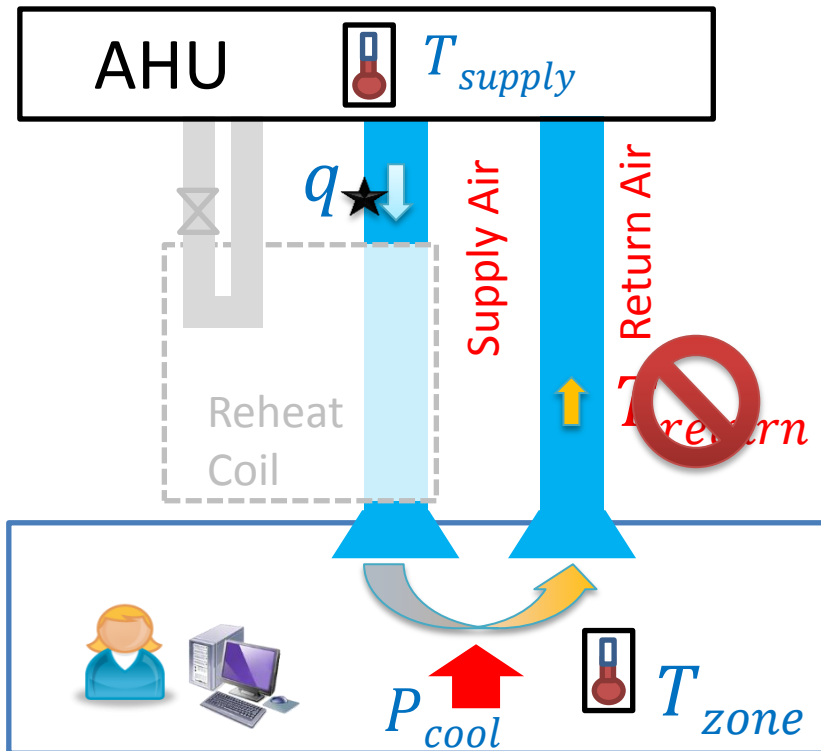
Reheat Coil

P_{cool}

Electrical Power

AHU

$P_{electric}$

Cooling Thermal Power Estimation

➤ Heat transfer equation

➤ Known: q , T_{supply}, T_{zone}

➤ Assumption: T_{return} ➡ T_{zone}

$$P_{cool} = \rho * C * q * (T_{zone} - Tsupply)$$

AHU T_{supply}

q ★

Supply Air

Return Air

Reheat Coil

T_{return}

P_{cool} T_{zone}

T_{supply} :Supply air temp
T_{zone} :Zone temp
T_{return} :Return Air Temp
q :Air flow rate
ρ :density of air
C :Specific heat of air

★ Air Flow Sensor

Temperature Sensor

Heating Thermal Power Estimation

➢ Known: P_{max} , H

➢ No information about hot water

➢ P_{heat} is proportional to reheat valve position

$$P_{heat} = H * P_{max}$$

Hot Water

Reheat Valve

P_{heat}

Reheat Coil
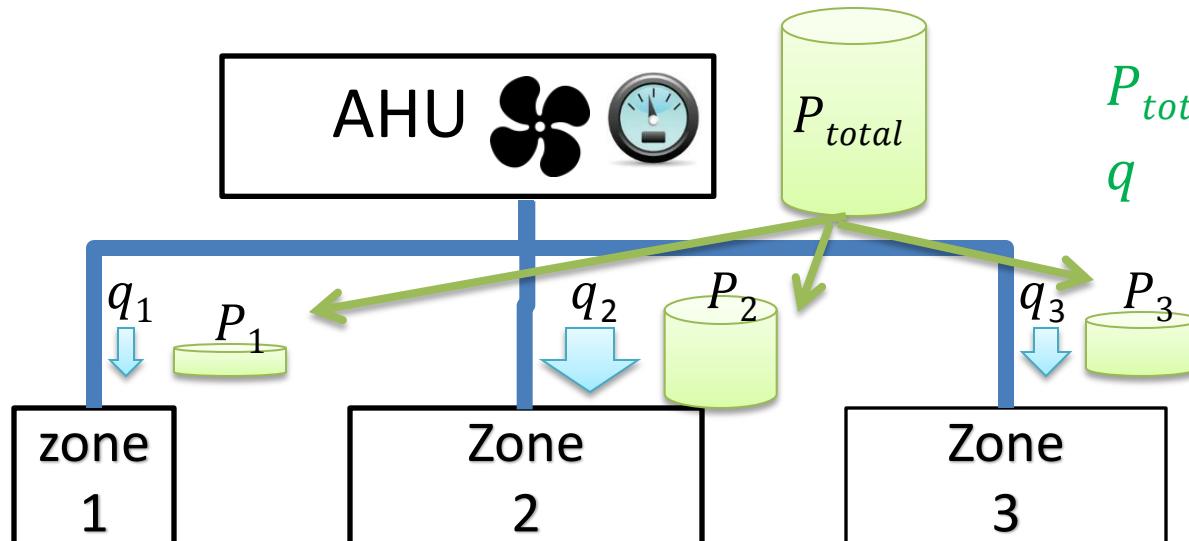
Supply Air

Return Air
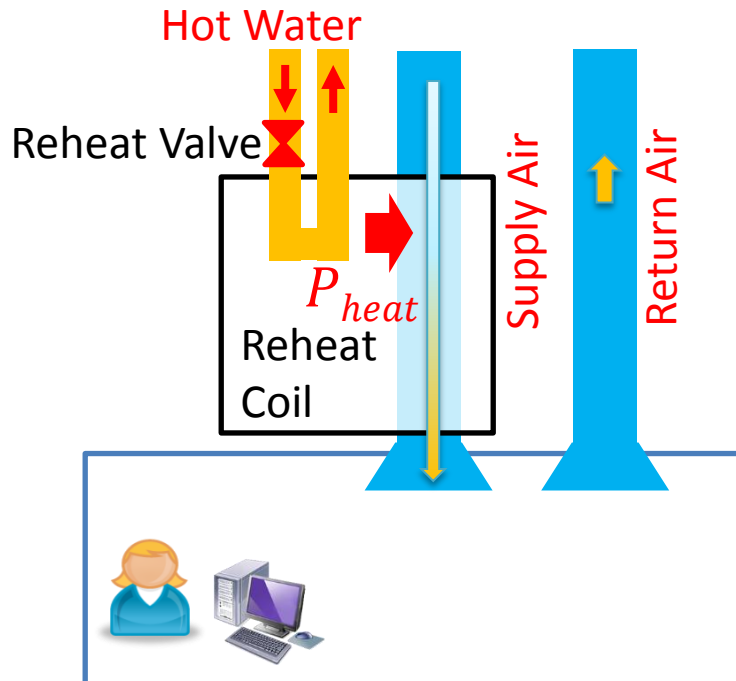
P_{max} : Heating capacity

H :Reheat valve position

Electrical Power Estimation

- Electrical Power

  ➢ Dominated by fans in AHU

  ➢ Known: P_{total}, q

  ➢ Power of fans are proportional to q^3

  ➢ Distribute total power to each zone depends on airflow

  $$P_{electric} = q^3 * P_{total}/\sum q^3$$
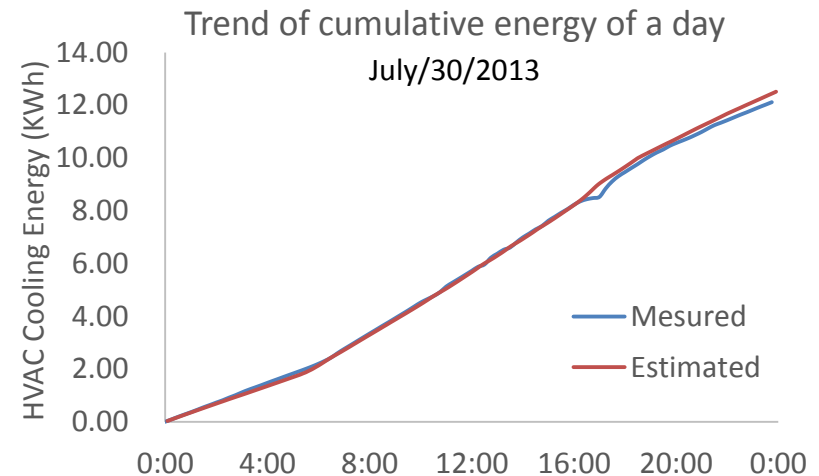

P_{total} : Total electrical power

q : Air flow rate

Evaluation of Accuracy

Compare with measured building level thermal power
(Measured from chilled/hot water main loop)

- ## Cooling Thermal Power
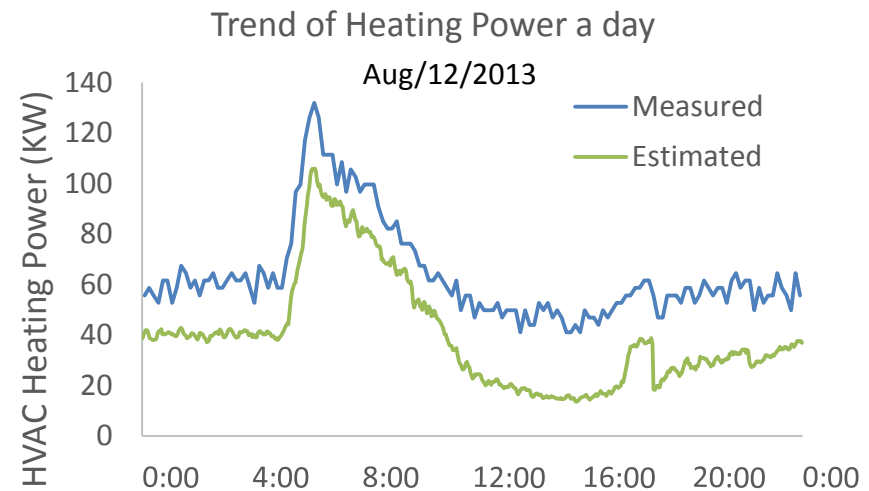
  ➢Average error is ~5%

- ## Heating Thermal Power
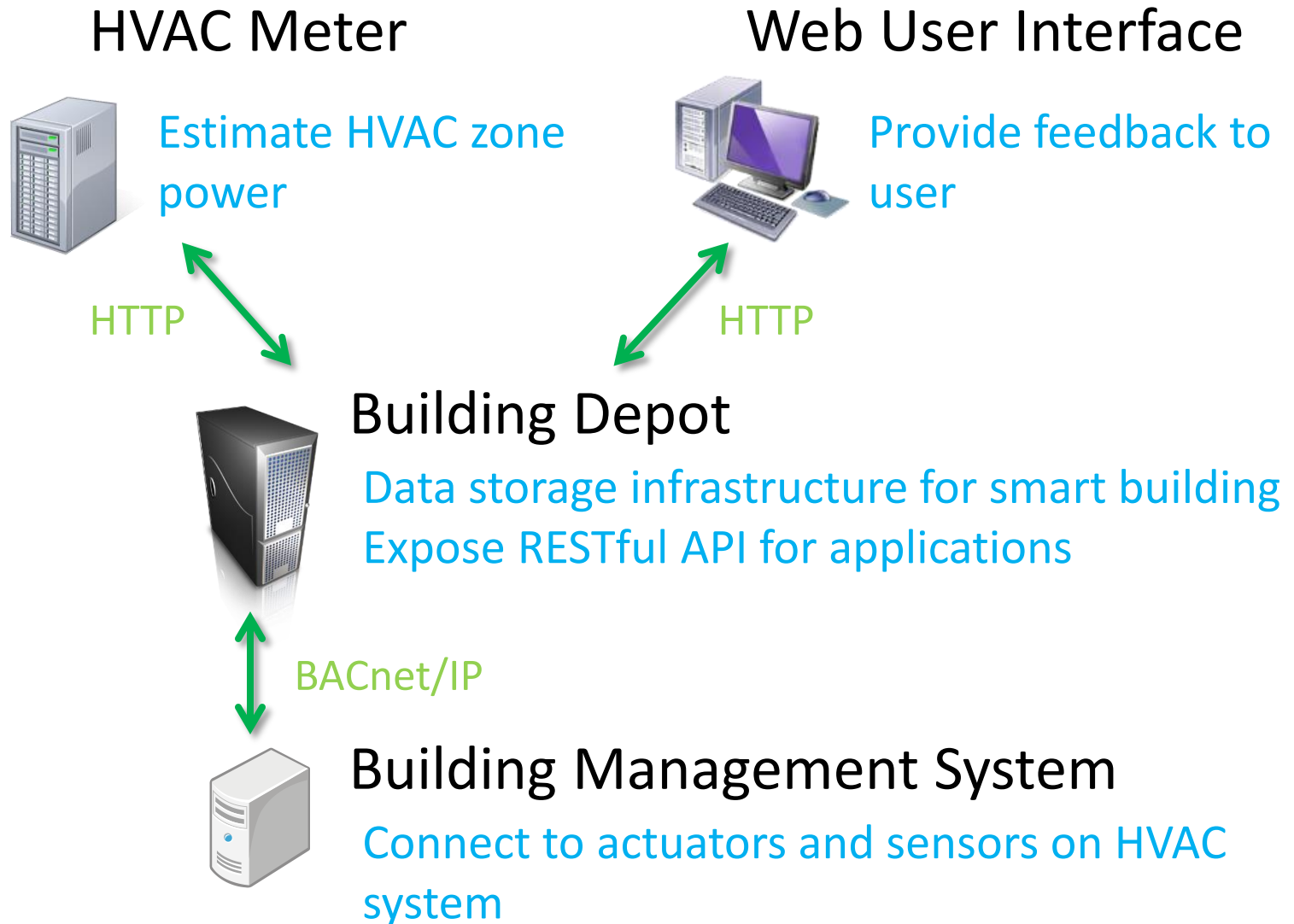
  ➢Average error is ~50%

  ➢Reason: Losses

  ➢Captures the trends

Trend of cumulative energy of a day

July/30/2013

Trend of Heating Power a day

Aug/12/2013

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Software Architecture

HVAC Meter

Estimate HVAC zone power

Web User Interface

Provide feedback to user

HTTP

HTTP

Building Depot

Data storage infrastructure for smart building
Expose RESTful API for applications

BACnet/IP

Building Management System

Connect to actuators and sensors on HVAC system

1. BuildingDepot: An Extensible and Distributed Architecture for Building Data Storage, Access and Sharing. Y. Agarwal, R. Gupta, D. Komaki, and T. Weng. In BuildSys 2012
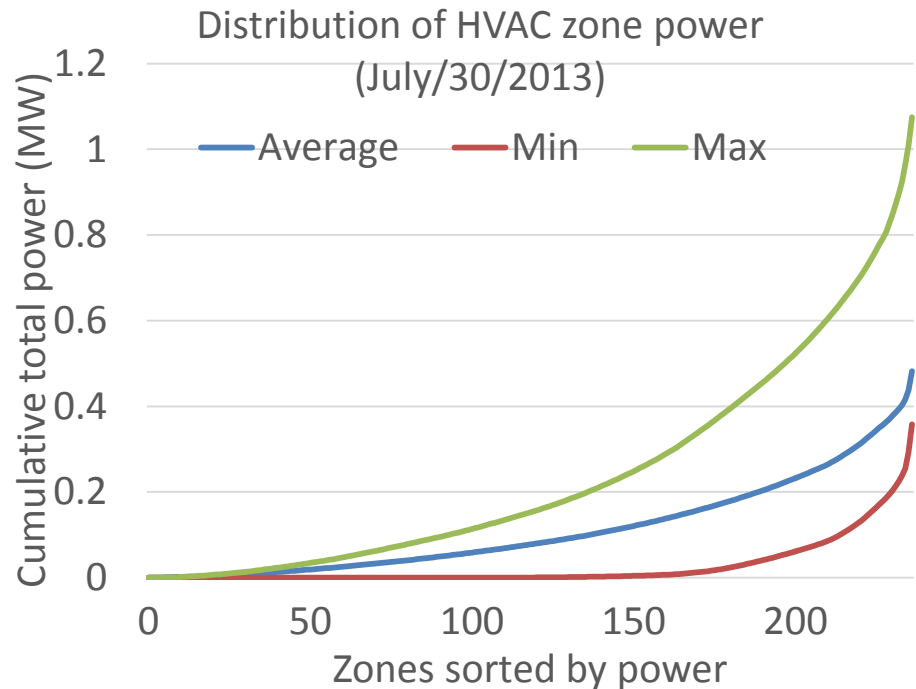
Web User Interface
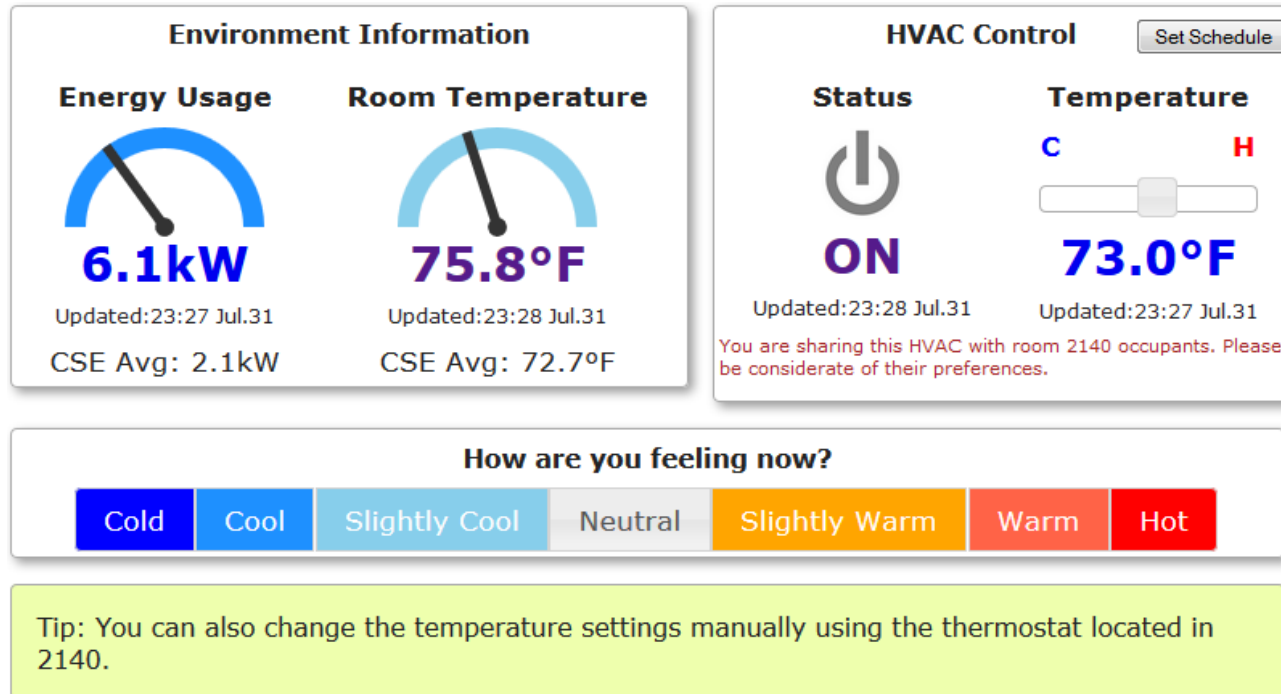
- Real-time information of estimated energy consumption and actual HVAC status
- Control of temperature and status
- Historical trend, thermal feedback interface, etc

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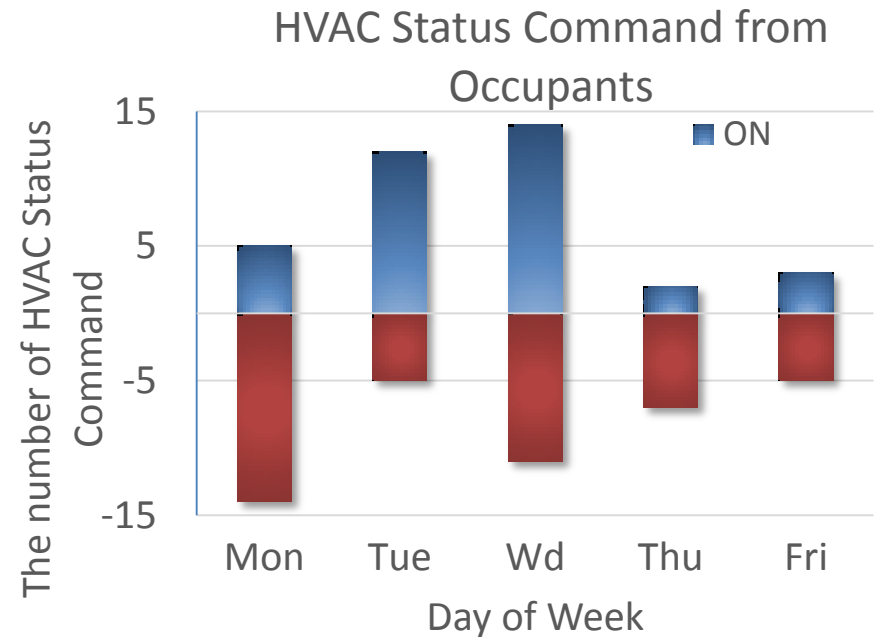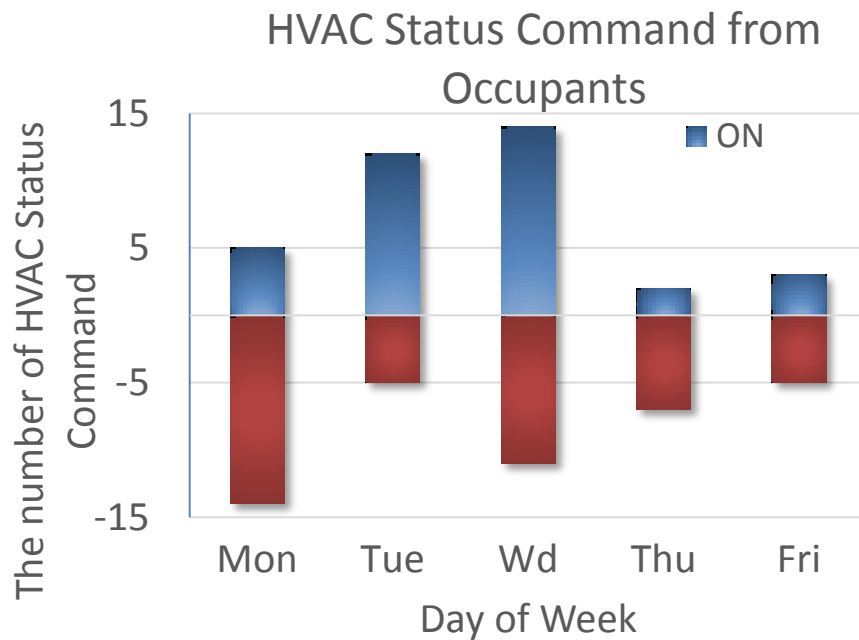- Conclusion

Analysis based on Zone Power Estimation

- ## 17% of zones consume 50% HVAC power

- ## Common spaces have high energy intensity

Distribution of HVAC zone power (July/30/2013)

Cumulative total power (MW)

— Average   — Min   — Max

Zones sorted by power

- ## Manual analysis of energy intensive zones:

  - ➤ Faulty sensors and misconfigured settings

  - ➤ Thermostats miscalibrated

  - ➤ Slider adjust in max or min position

  - ➤ Improper usage: space heaters, servers, etc.

Results of Feedback Experiment

- 65 users across 51 zones for 10 days (in Summer)
- User Feedback
  - ➢140 feedback inputs and 130 setting changes

➢~5% energy savings after providing control

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Conclusion

- Zone level HVAC power can be estimated using existing sensors

- Deploy ZonePAC in real commercial building and confirm the effect

- Feedback on zone level HVAC power consumption is useful for both occupants and managers

Thank You!

- Questions?