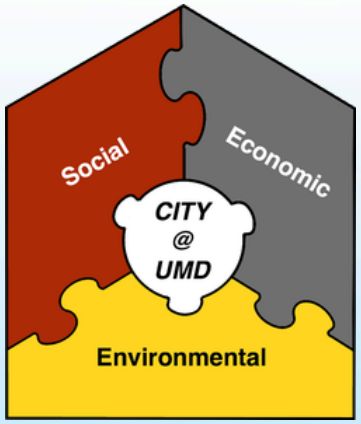

Yang-Seon Kim
University of Maryland
seonkim1221@gmail.com

Technical Paper Session 8 - Control and Monitoring for Improved Building Energy Efficiency

"Improvement of building energy simulation accuracy with occupancy schedules derived from hourly building electricity consumption," **Kim,Y.S.**, Srebric, J., accepted, **ASHRAE transactions 121 (1),** 2015.

Learning Objectives

- Demonstrate that a system with improved control accuracy has better energy efficiency
- Describe the relationship of energy-saving and control accuracy at different load conditions
- Define correlation between number of occupants and the building electricity consumption
- Provide a methodology to derive the occupancy rates by using plug-load consumption and significant improvement of the energy simulation accuracy
- Describe a method to detect energy anomalies using the recursive least squares (RLS) estimation and cumulative sum (CUSUM) change detection
- Apply the anomaly detection method to the energy balance load data from large commercial buildings

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- ASHRAE Graduate Grant-In-Aid
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Contents

- Introduction
- Research Objective
- Research Methodology
- Building Case Study
- Results
- Conclusions

Building Energy Consumption

Commercial buildings representing 46% of building energy consumption and 19% of U.S. total energy consumption

Energy End Uses	USA (%)
HVAC	49
Lighting	22
Equipment	13
DHW	4
Refrigeration	3
Others	9

EIA (Energy Information Administration), Figure 1.0 Energy Flow, 2011

Motivation

What is Building Energy Modeling?

- Energy modeling is the use of computer-based simulations to assess energy consumption

Why's the accuracy of a building energy simulation important?

- Building energy simulation tools are currently widely used to analyze or forecast building energy consumption in order to facilitate the design and operation of energy efficient buildings
- Simulation tools are used extensively across diverse disciplines because they enable experimentation with parameters that would otherwise be infeasible

Influence of Occupants on the Building

Occupant presence/absence

: How much is energy consumed during an occupied or un-occupied time period?

:How does building energy consumption change depending on the number of occupants?

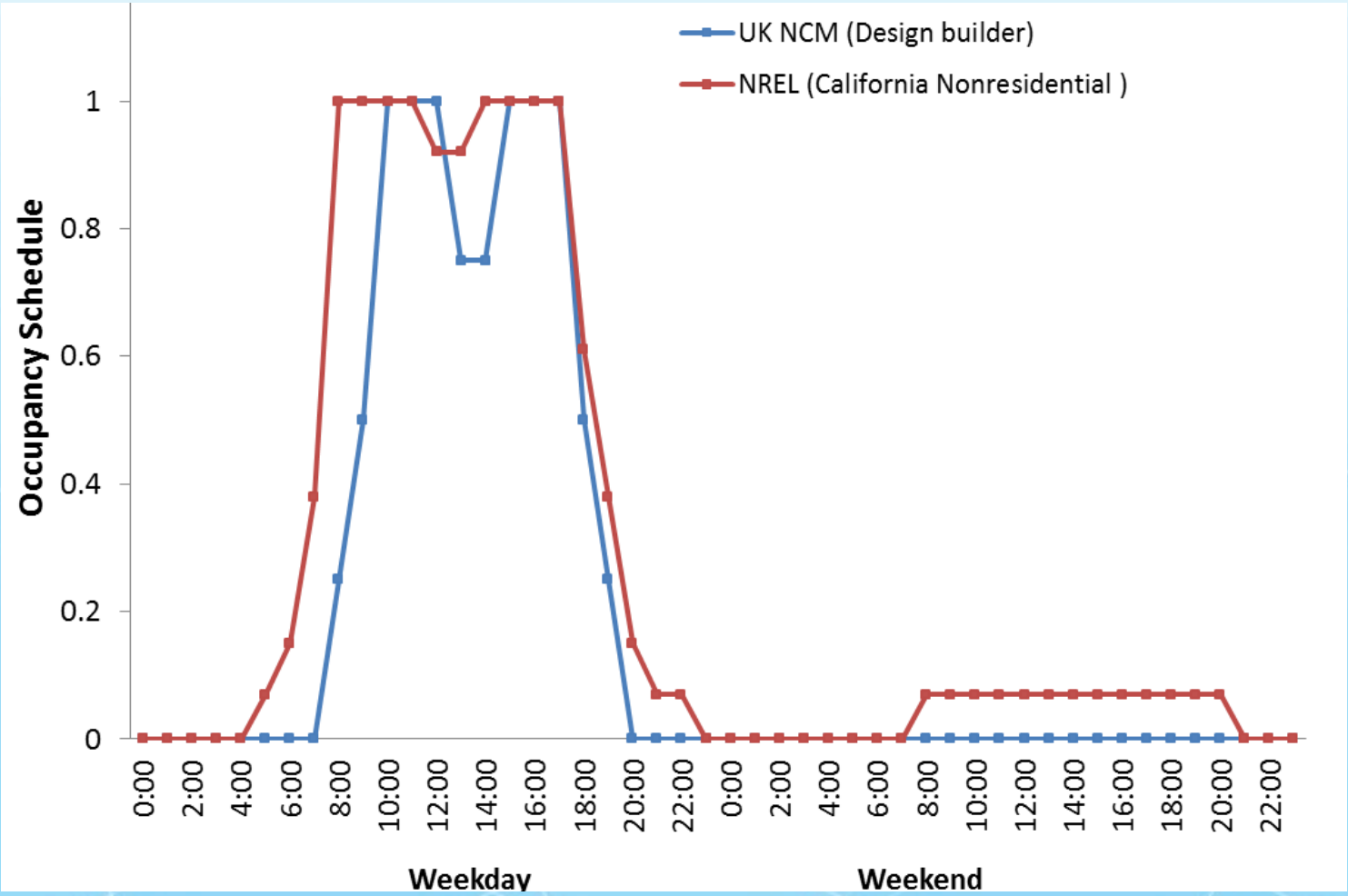
Occupant Behavior

: How does building energy consumption change with occupants' behavior?

Summary of Occupant's Effect in Building Studies

Categories	Conclusions
Occupant presence / absence	*14-28 % of the building energy (electricity and HVAC) was used during the unoccupied time period on the weekends [Y. Angarwal et al., O.T. Masoso et al., C. Martani et al., B. VonNeida et al] *Number of occupants has a 63-69% correlation with electricity consumption for campus building [C. Martani et al.]
Occupant behavior	*Potentially, 4-38% of the building energy (electricity and HVAC) can be saved with occupants' behaviors [R. Yang et al., T. Hong et al., J.F. Nicol et al., H.B. Rijial et al.]

Occupancy Schedule in Building Energy Simulation (Office Type Buildings)

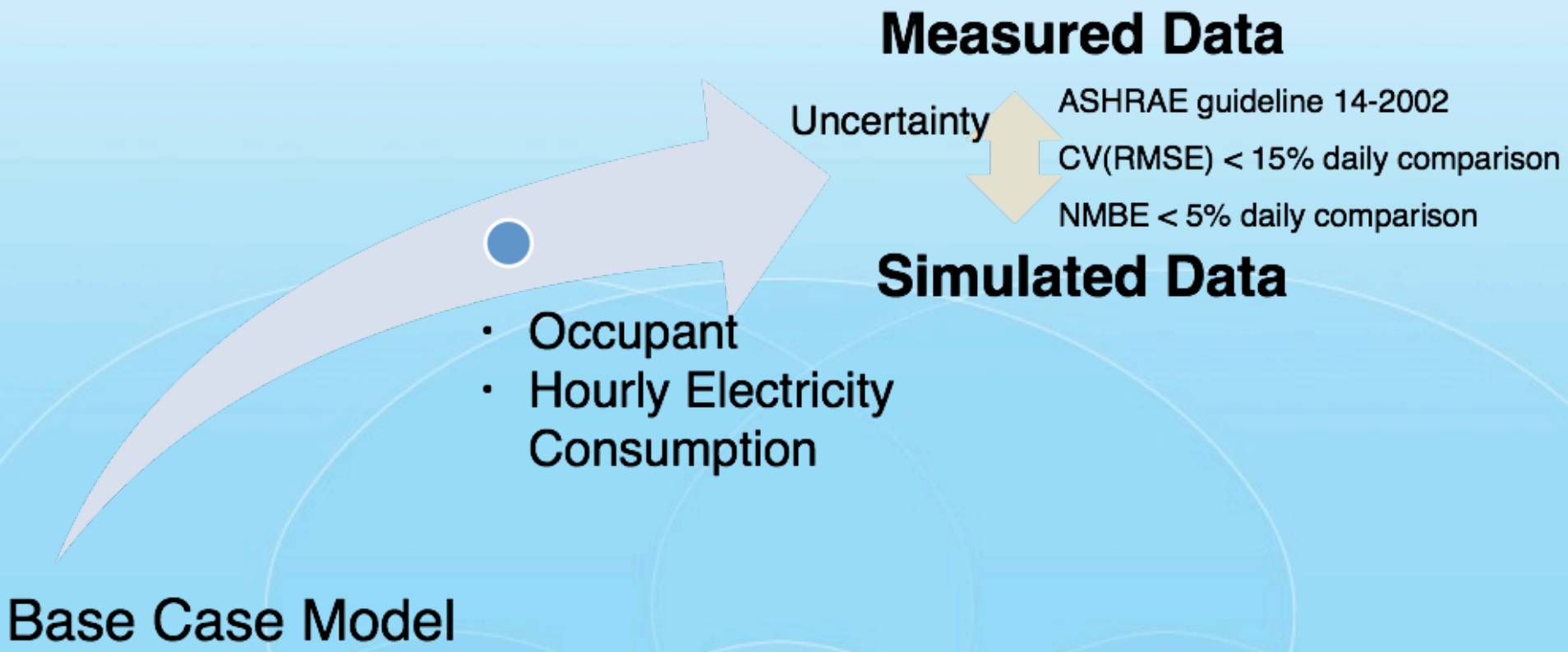


Occupancy schedules in building energy simulations cause a difference between the actual data and simulation results (CVRMSE = 48 % -> 14% improvements)

Research Hypothesis

Building electricity consumption patterns can be used to derive occupancy schedules and improve the accuracy of energy simulation results

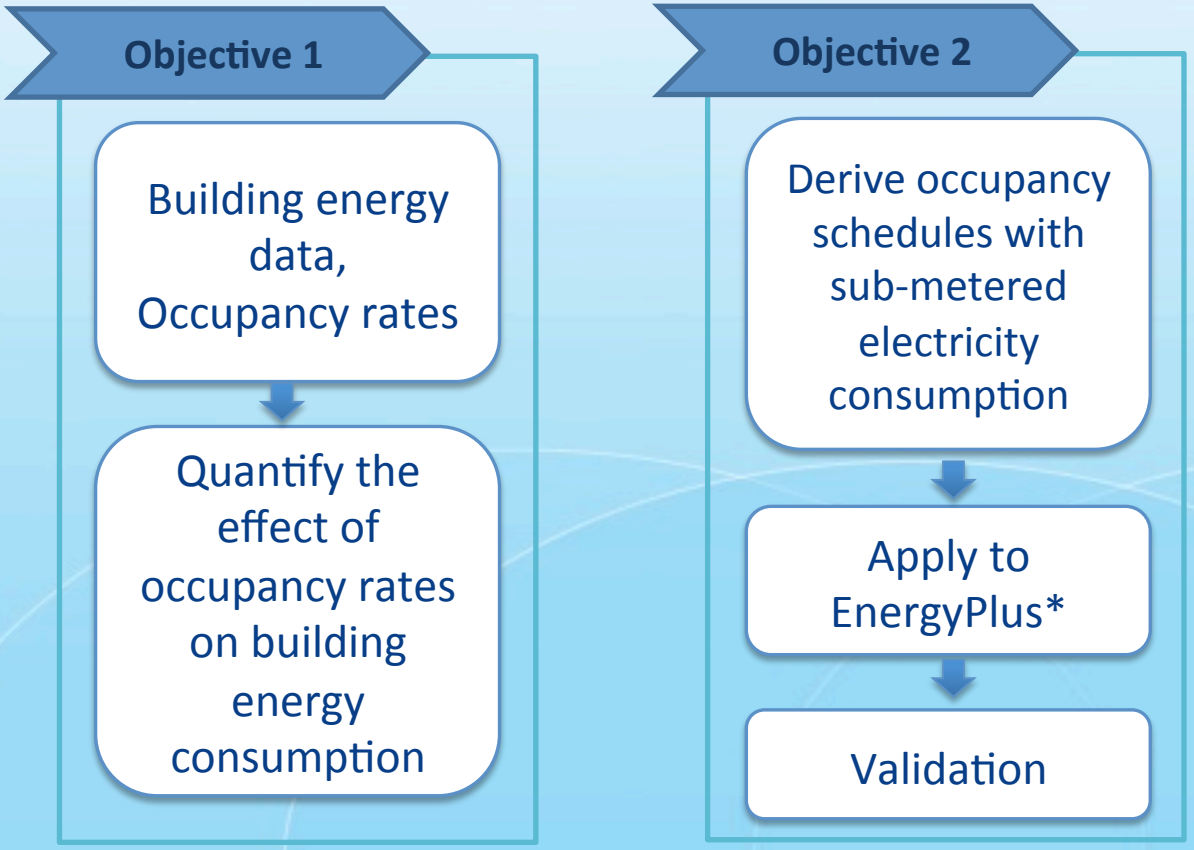
Improve the Simulation Accuracy with Two Parameters



Research Objectives

1. Quantify the effect of occupancy rates on the electricity consumption in office and campus buildings
2. Develop and validate a methodology to derive occupancy schedules from sub-metered electricity (plug-load end use) consumption for energy simulations

Research Hypothesis & Objectives

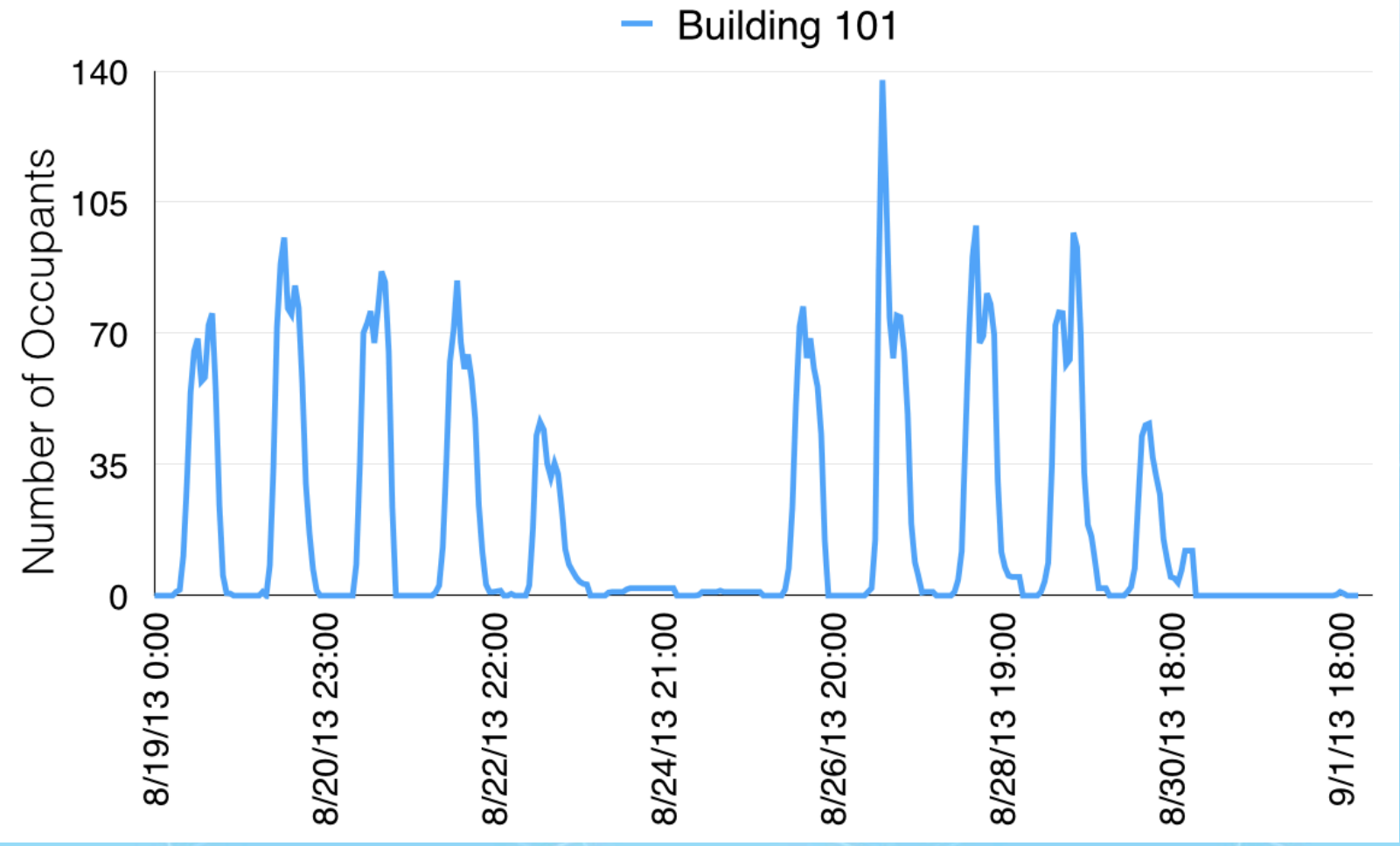


Building and people counter Information

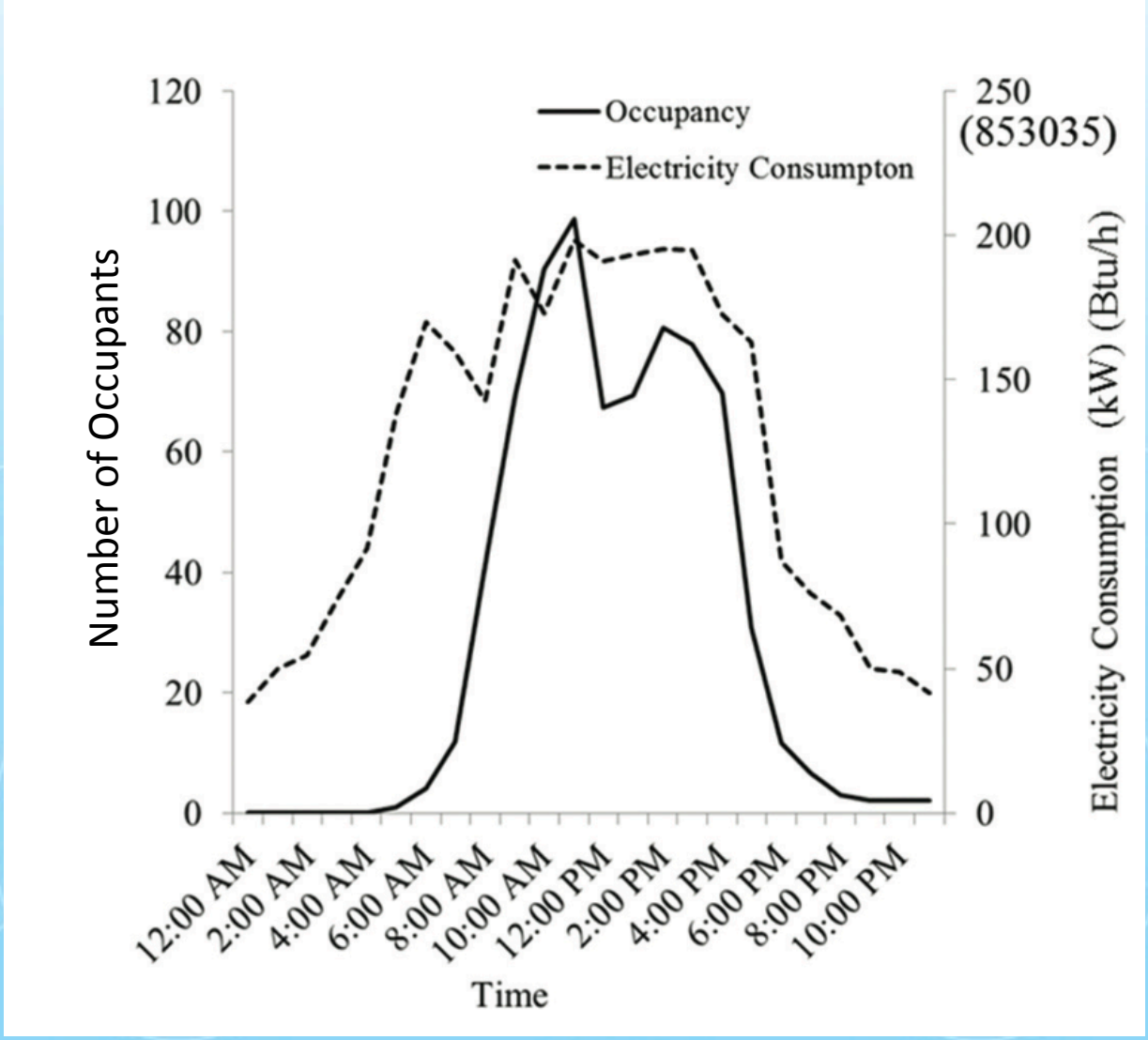
Office Building in Philadelphia,
66,088(ft2)
Open Offices: 40%,
Common Areas: 60%

3D advanced stereo vision tracking people counters

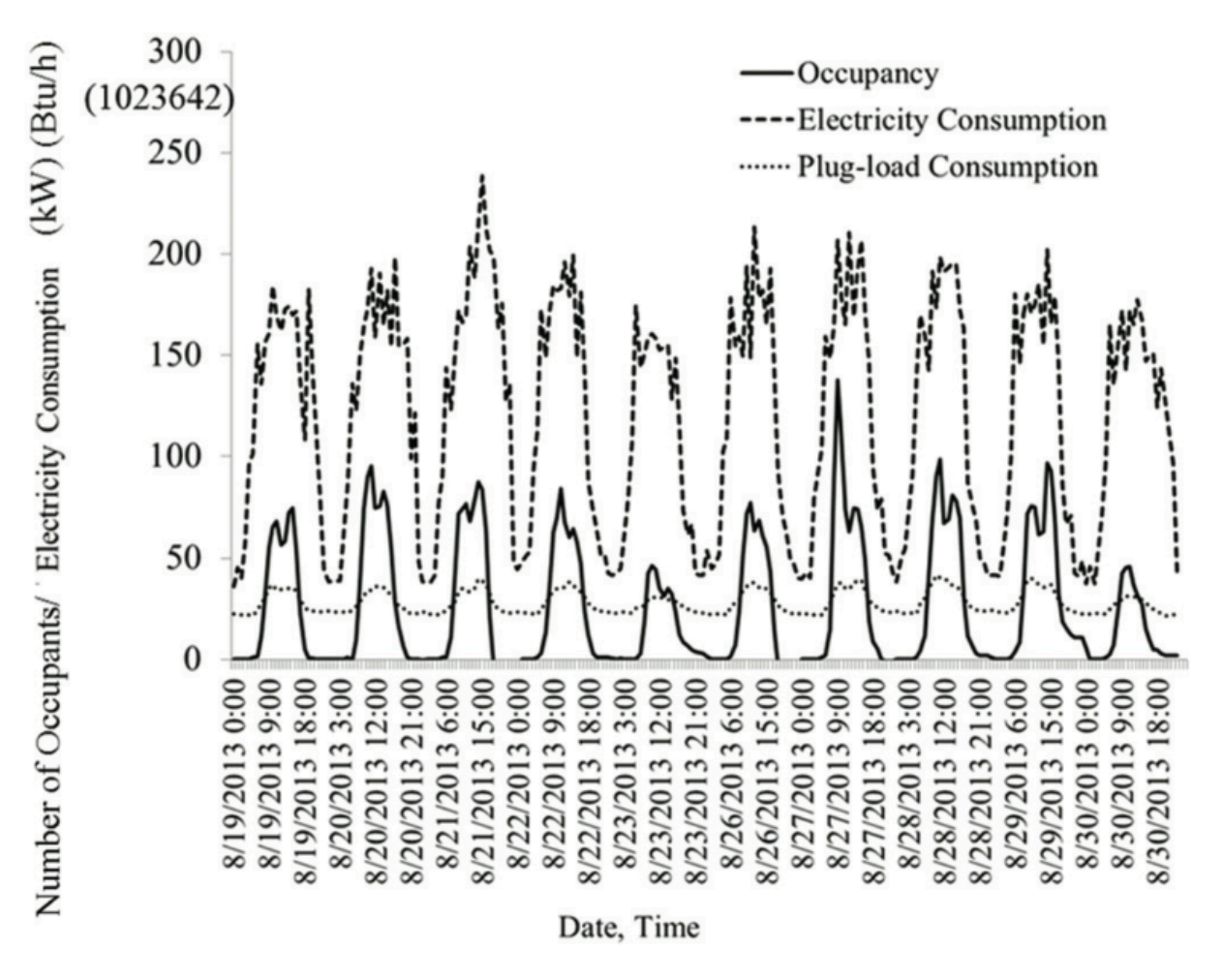
People Counter Installation



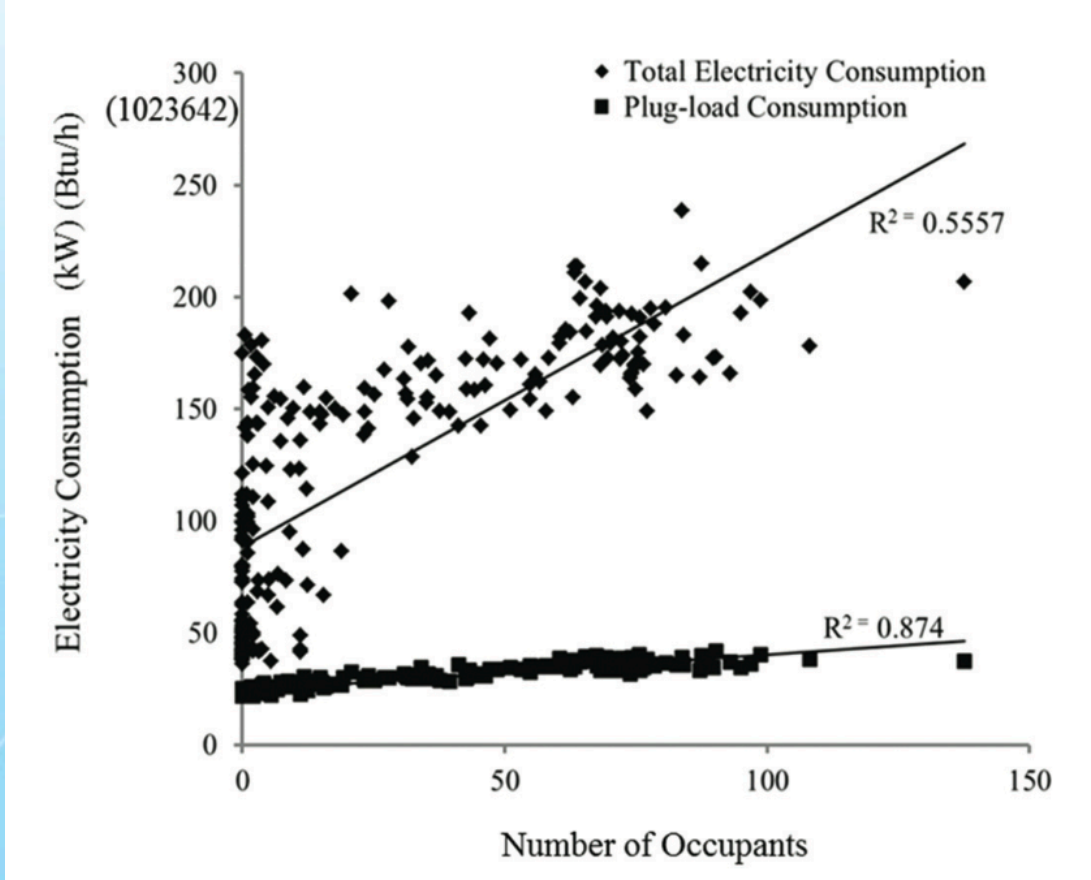
Number of Occupants and Electricity Consumption in Building 101



Number of Occupants and Electricity Consumption in Building 101

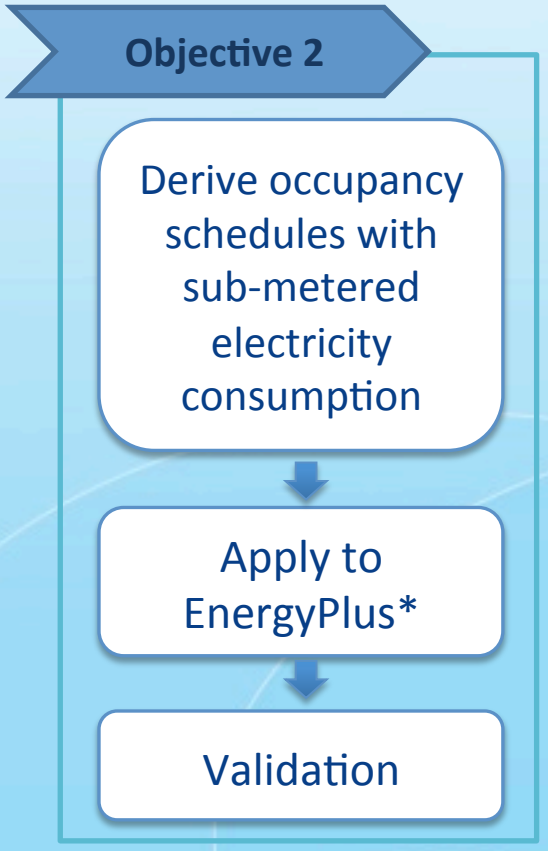


Number of Occupants and Electricity Consumption in Building 101



Building	Total Electricity Consumption	Plug-load Consumption
R^2 (%)	56	87
Baseline(kW)	88.69	23.93
Coefficient	1.323	0.16

Develop and Validate a Methodology



Develop and validate a methodology to derive occupancy schedules from sub-metered electricity consumption for energy simulations

Case Study with Office Building

Case study with Building 101

Regression analysis with occupancy and plug-load consumption

↓

Occupancy = C1 + C2 * Plug-load

↓

Plug-load = C3 + C4 * Occupancy

↓

	August, 1- 18	August, 19-30
Action	Derive an equation for occupancy and plug –load consumption	Calculate occupancy rates

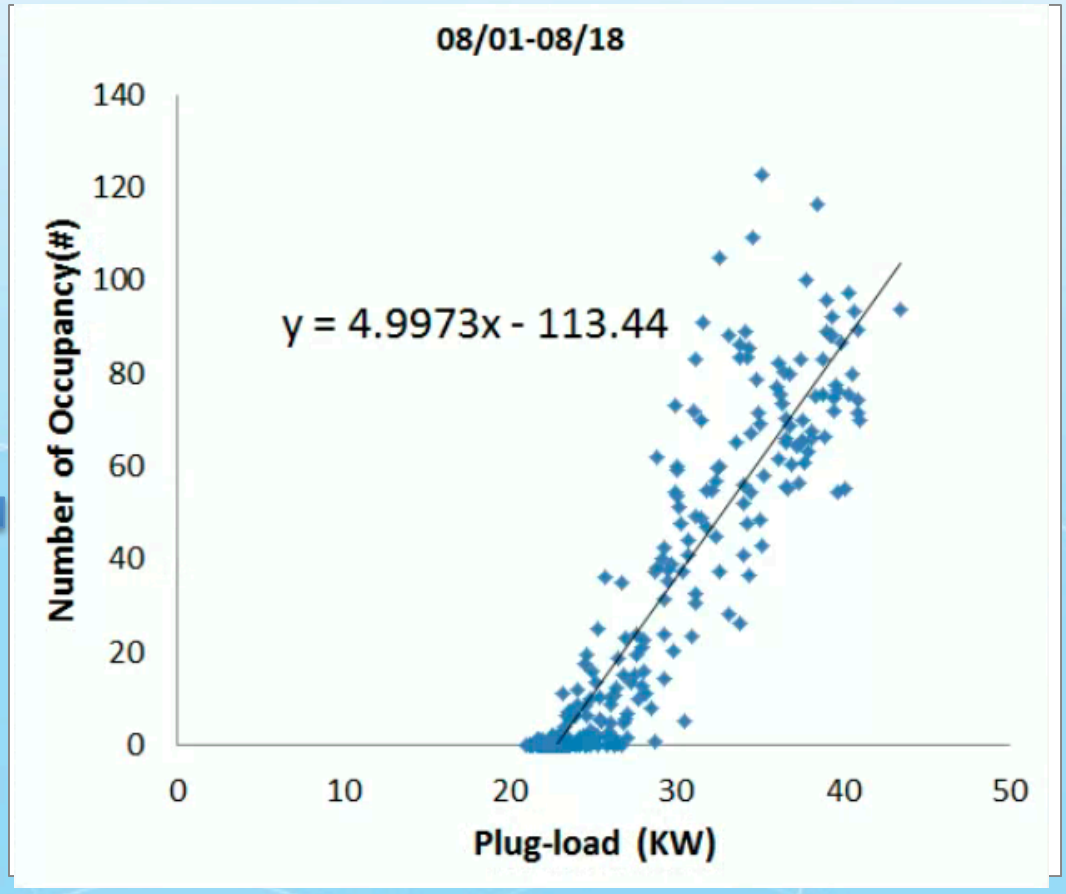
↓

Apply to the energy simulation

Demonstrate Building Energy Simulation

Objective 2

- Derive occupancy schedules from electricity consumption
- Apply to the EnergyPlus
- Validation



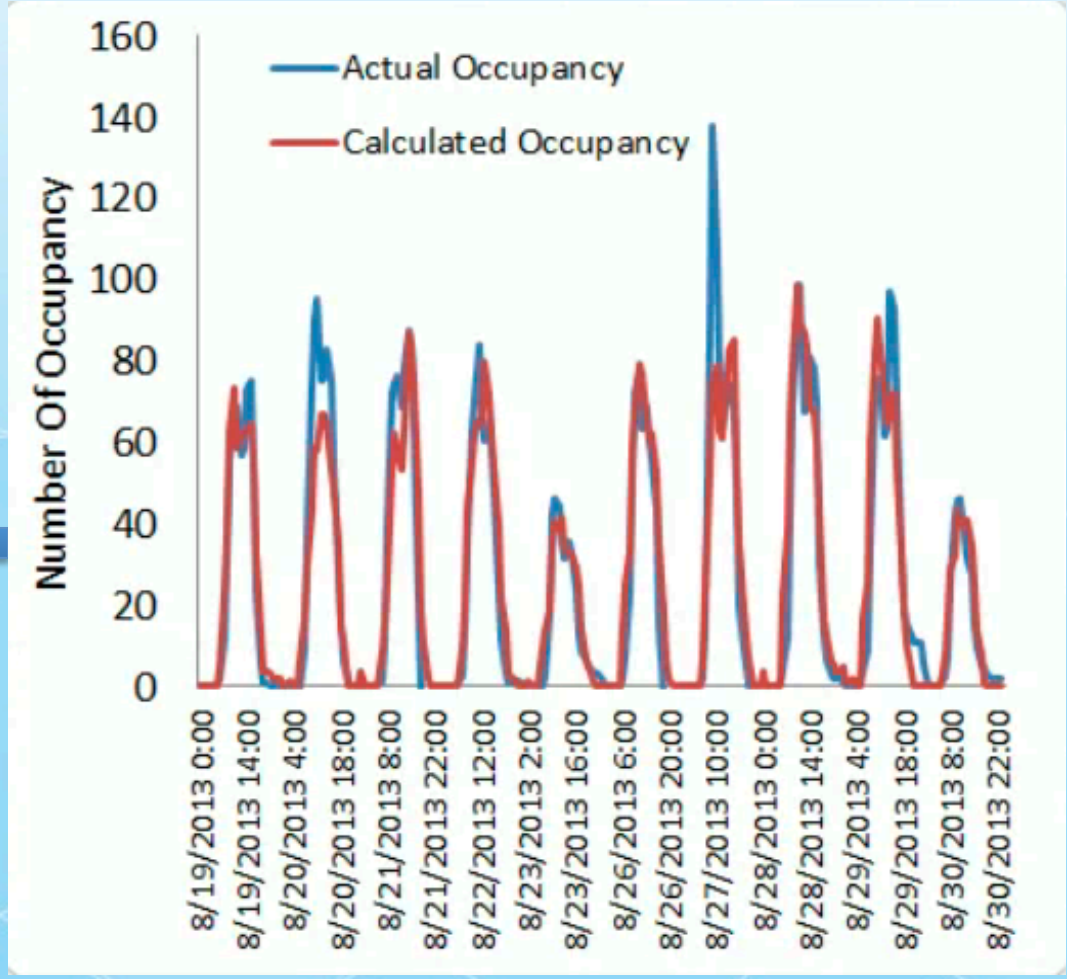
Demonstrate Building Energy Simulation

Objective 2

Derive occupancy schedules from electricity consumption

Apply to the EnergyPlus

Validation



Demonstrate Building Energy Simulation

Input parameters	Case 1	Case 2	Case 3	Case 4
Occupancy Schedule	Default	Averaged occupancy schedule	Actual occupancy schedule	**Calculated occupancy schedule**
Plug-load Consumption	Default	Averaged schedule	**Plug-load consumption equation**	**Plug-load consumption equation**

Default : Default schedules from Designbuilder
Averaged schedules : averaged occupancy schedule from actual occupancy schedule
Actual occupancy schedule: actual occupancy schedule
Calculated occupancy schedule: calculated occupancy schedule from hourly plug-load consumption

Demonstrate Building Energy Simulation

- **CV (RMSE)** = Coefficient of Variation of the Root Mean Squared Error

$$100 \times \frac{\sum((y_i - \hat{y}_i)^2 / (n-p))^{0.5}}{\bar{y}}$$

- **NMBE** = Normalized Mean Bias Error

$$100 \times \frac{\sum(y_i - \hat{y}_i)}{(n-p) \times \bar{y}}$$

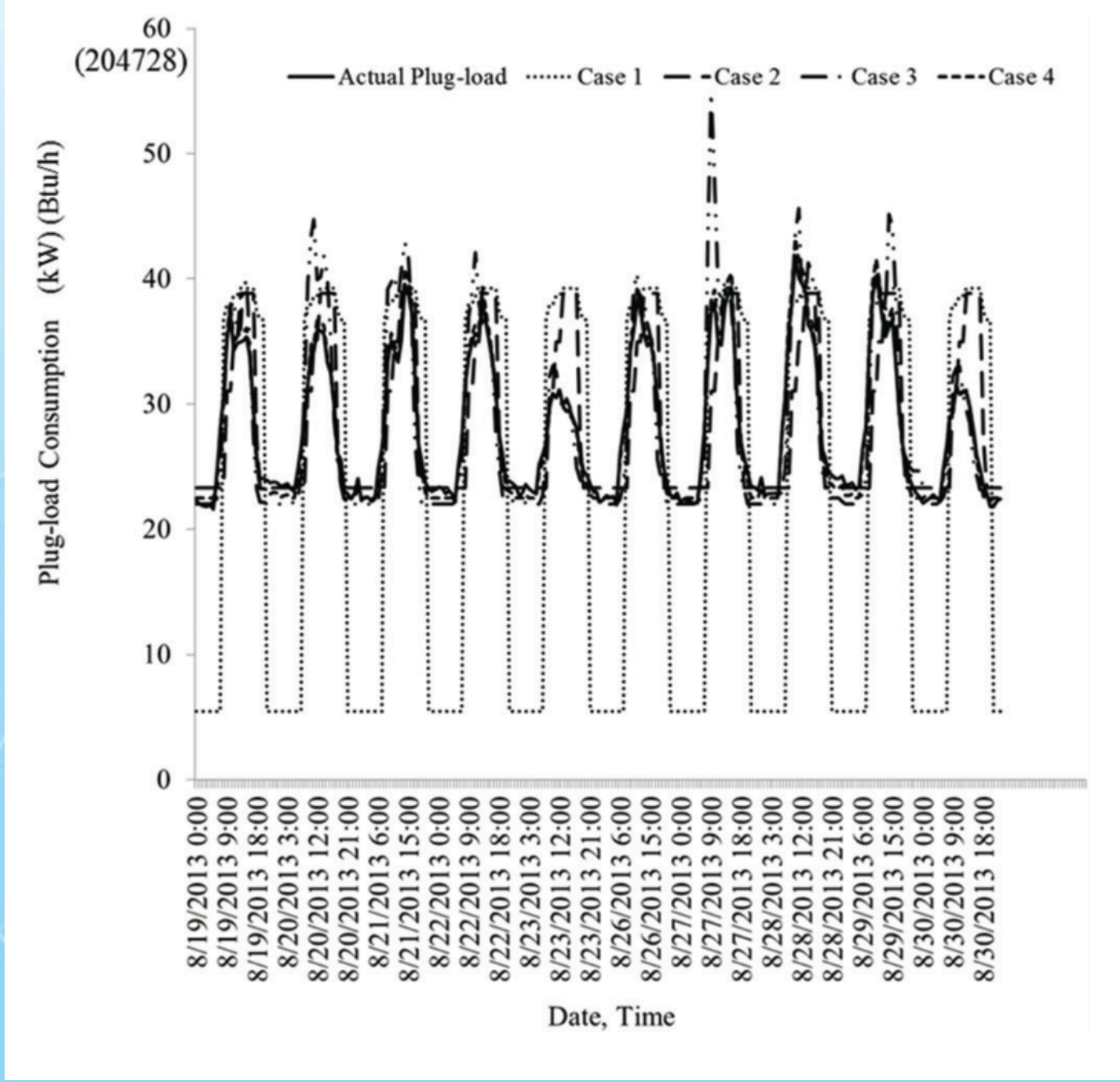
- **ASHRAE guideline 14-2002,**

	CV (RMSE)	NMBE
Daily Level Comparison	< 15%	< 5%
Hourly Level Comparison	< 30%	< 10%

Building Energy Simulation Result

Input parameters	Case 1	Case 2	Case 3	Case 4
Occupancy Schedule	Default	Averaged occupancy schedule	Actual occupancy schedule	Calculated occupancy schedule
Plug-load Consumption	Default	Averaged schedule	Plug-load consumption equation	Plug-load consumption equation
CV (RMSE)*	48%	14%	10%	**4%**
NMBE	21%	21%	7%	**3%**

Building Energy Simulation Result



Conclusions

- Coefficient of determinations between occupancy and **plug loads** are high (87%) compared to the coefficient of determinations between occupancy and total electricity consumption (56%)

- **Hourly electricity consumption** can be used as an occupancy indicator for building energy simulations

- Accurate building energy simulations require the occupancy rates directly associated with the use of electricity

- The accuracy of the building energy simulations is increased with the **derived occupancy schedules** and **electricity consumption equations (CVRMSE <15% , NMBE < 5%)**

Bibliography

– ASHRAE. 2015. Improvement of building energy simulation accuracy with occupancy schedules derived from hourly building electricity consumption, ASHRAE Transactions 121(1).

Questions?

Yang-Seon Kim
seonkim1221@gmail.com