Evidence-Based Approach to Calibration of Whole Building Energy Model

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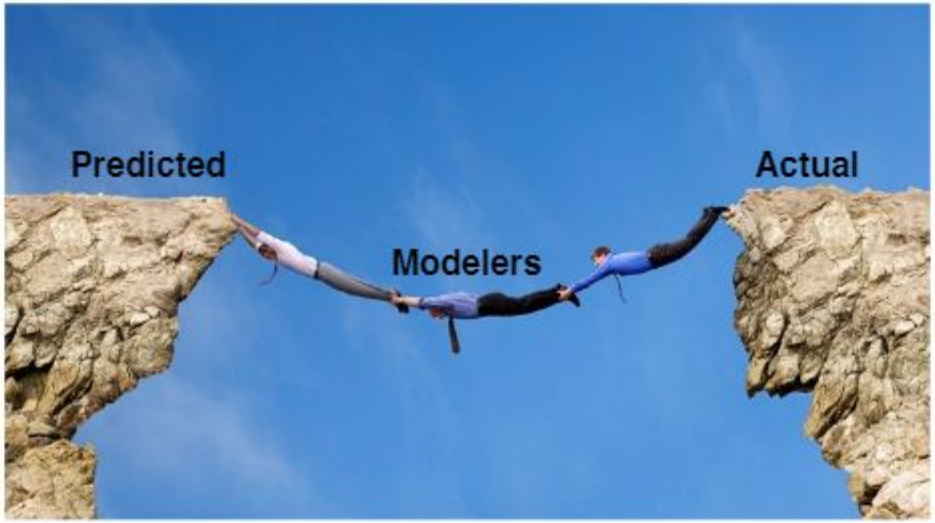
Introduction

Background

- Originally intended for use during the design phase, building energy models (BEM) are increasingly used throughout a building's life-cycle
  - Support an energy auditor's recommendation for cost effective energy conservation measures (ECMs)
  - Measurement & Verification (M&V)
  - Coupling simulation with the building's control system and through continuous calibration, use the model to find an optimal control and response strategy

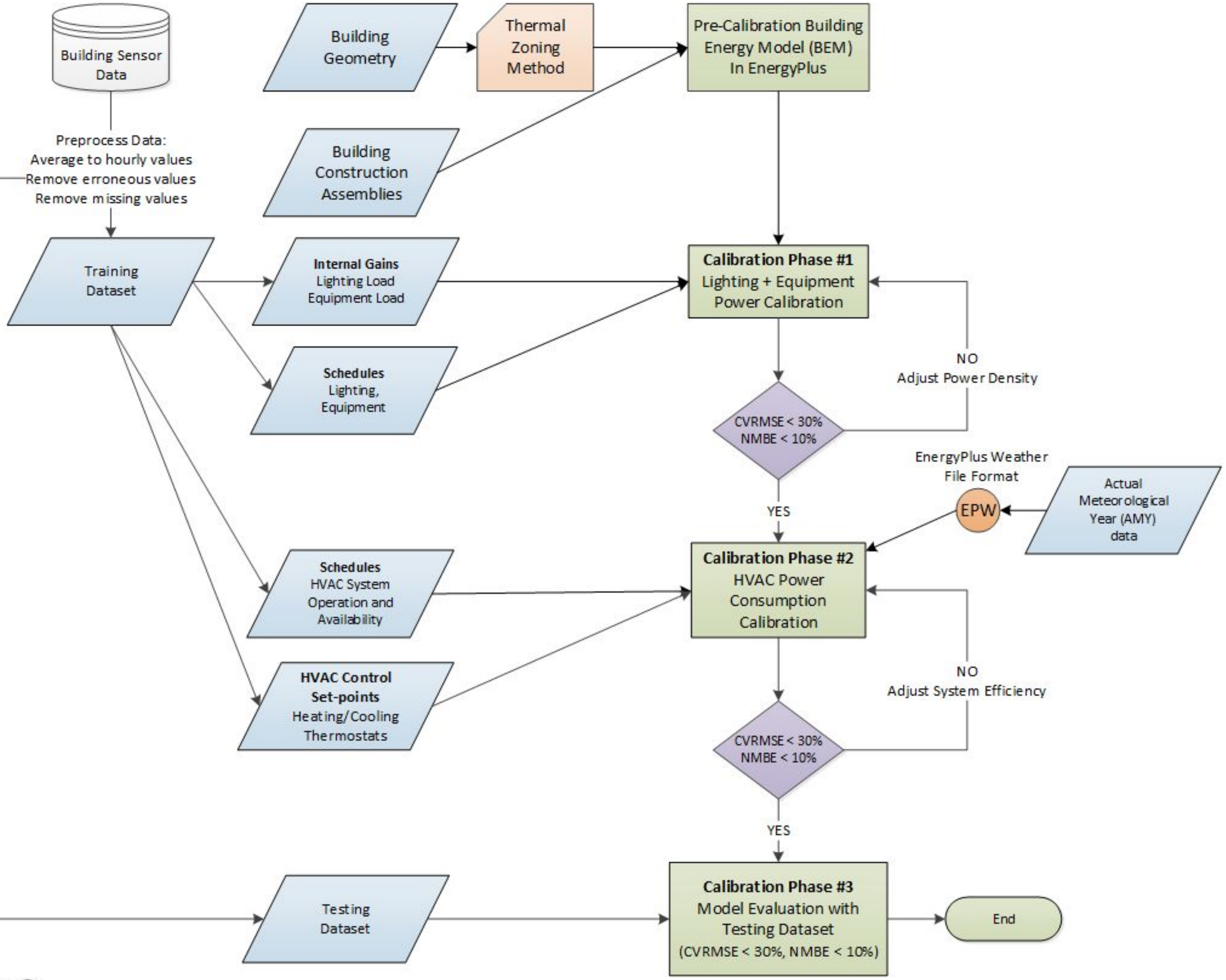
Background

- To ensure its reliability, model calibration has been recognized as an integral component to the overall analysis
- Bridge the gap between predicted and actual performance through measurements



Method

Overview



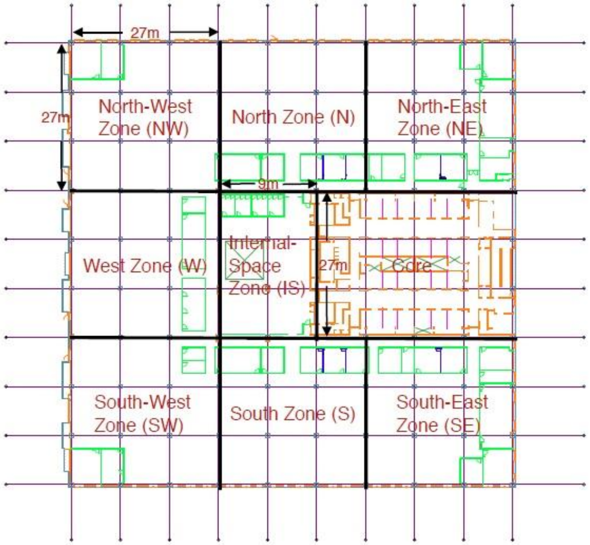
Building Sensor Data
Preprocess Data:
Average to hourly values
Remove erroneous values
Remove missing values
Training Dataset
Building Geometry
Thermal Zoning Method
Pre-Calibration Building Energy Model (BEM) In EnergyPlus
Building Construction Assemblies
Internal Gains
Lighting Load
Equipment Load
Schedules
Lighting,
Equipment
Calibration Phase #1
Lighting + Equipment Power Calibration
CVRMSE < 30%
NMBE < 10%
NO
Adjust Power Density
YES
EnergyPlus Weather File Format
EPW
Actual Meteorological Year (AMY) data
Schedules
HVAC System Operation and Availability
HVAC Control Set-points
Heating/Cooling Thermostats
Calibration Phase #2
HVAC Power Consumption Calibration
NO
Adjust System Efficiency
CVRMSE < 30%
NMBE < 10%
YES
Testing Dataset
Calibration Phase #3
Model Evaluation with Testing Dataset
(CVRMSE < 30%, NMBE < 10%)
End

Model Evaluation

- CVRMSE (30%) and NMBE (10%) satisfies thresholds for hourly calibration data set by ASHRAE Guideline 14 (2002)
- Evaluate performance on a hold-out test dataset that was not used for the calibration
- Hourly time series plot comparing measured and simulated results

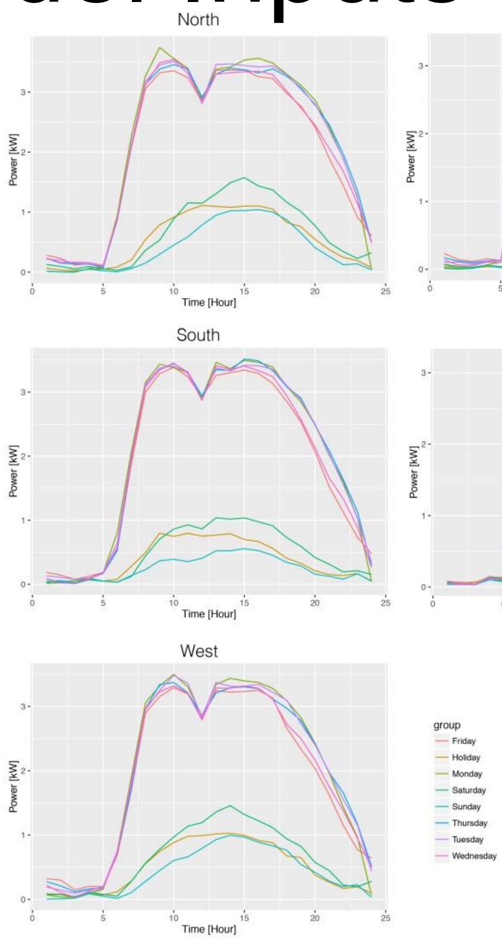
Case Study

Building Description



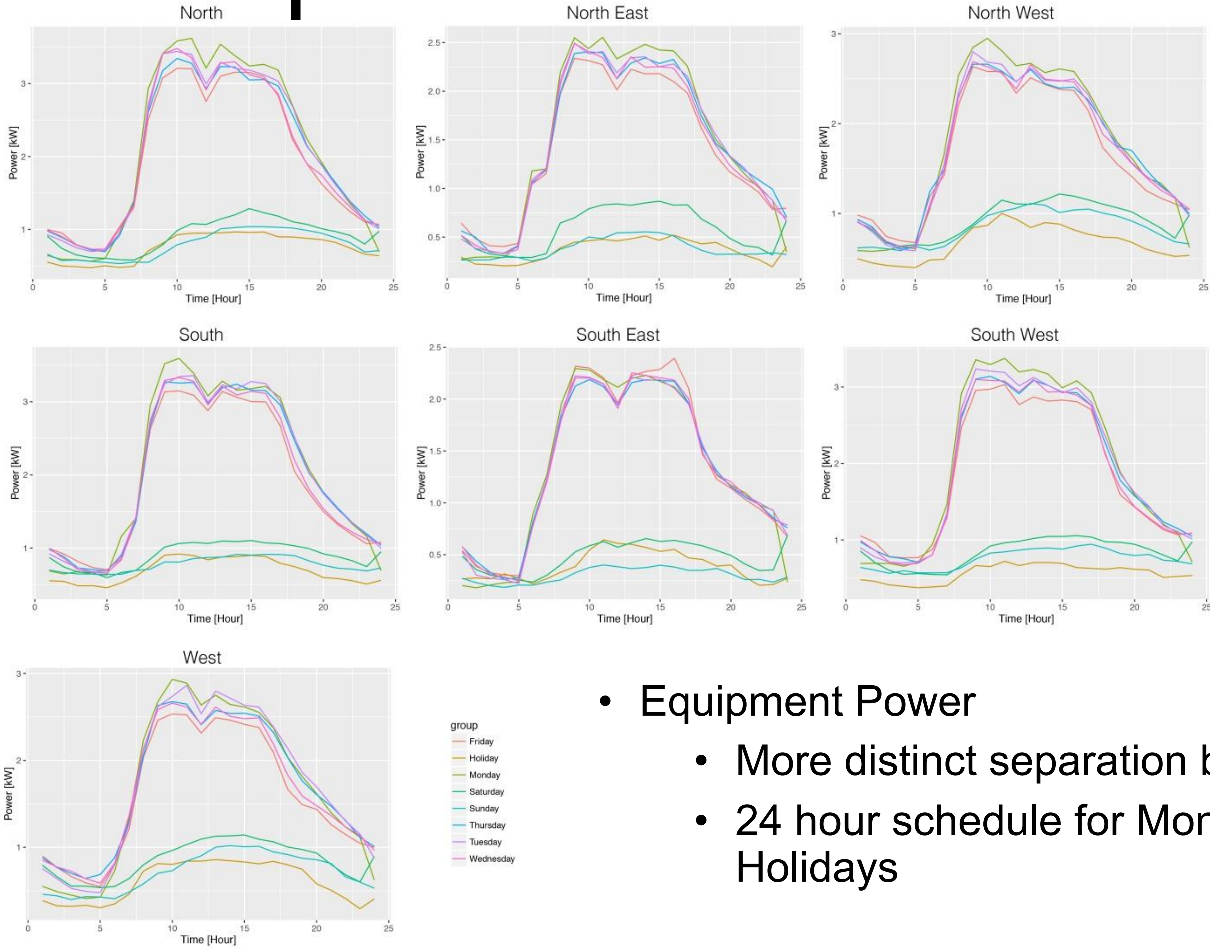
- 9th floor of an office building located in Japan
- Each zone (except core) installed with sensors that measure zone temperature, lighting power as well as plug and process power
- Data collection: 24th Jul 2015 to 24th Feb 2016 (1-min)
- Test data: Aug 2015 (summer), Nov 2015 (autumn) and Feb 2016 (winter)

Model Inputs



- Lighting Power
  - 4 distinct trends
  - 24 hour schedule for weekdays, Saturday, Sunday and Holidays

Model Inputs



- Equipment Power
  - More distinct separation between weekdays
  - 24 hour schedule for Monday to Sunday and Holidays

Model Inputs

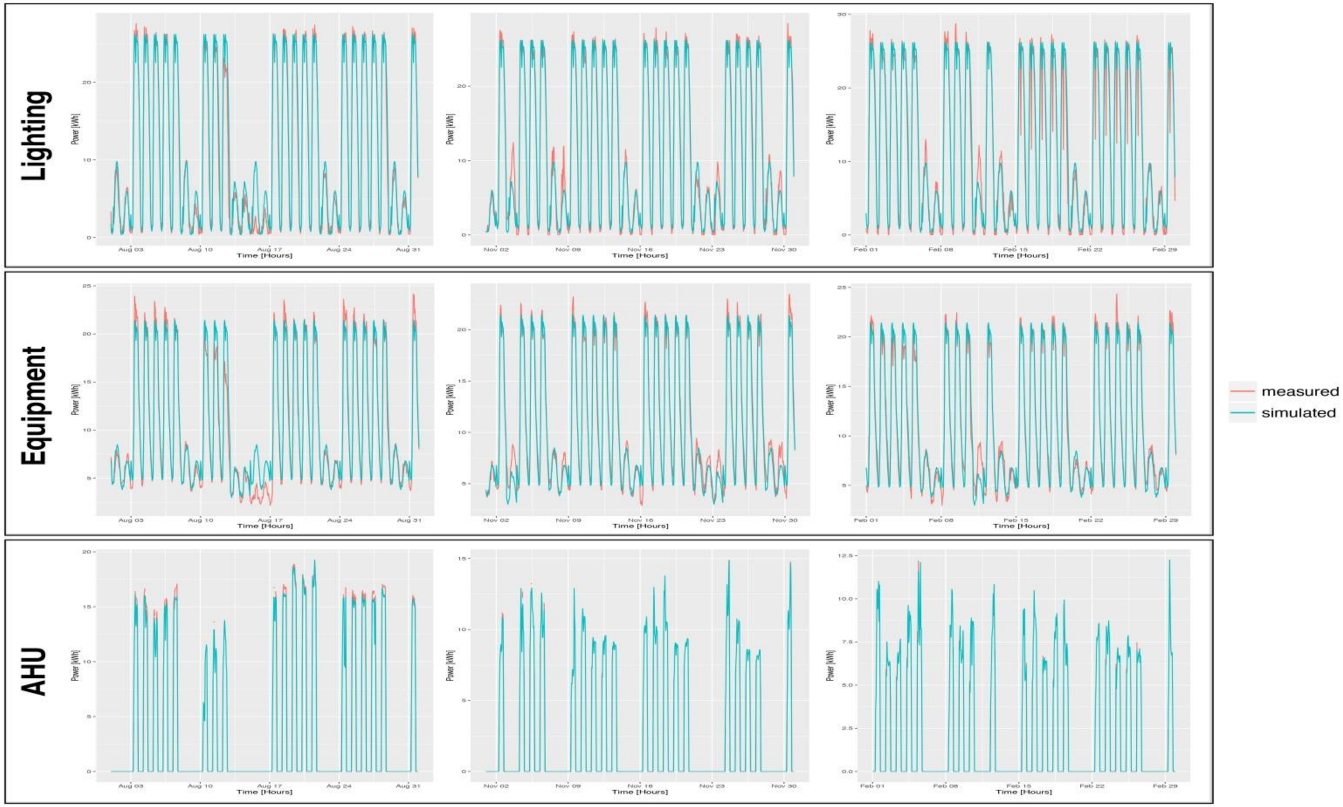
Parameter	Method used to compute parameter value
Fan Total Efficiency	Average fan efficiency computed from air flow measurements, fan power measurements and pressure rise from manufacturer's specification
Pressure Rise (Pa)	Manufacturer's specification
Maximum Flow Rate (m3/s)	Maximum airflow rate that was measured
Fan Power Minimum Air Flow Fraction	Ratio of minimum measured airflow rate to maximum measured airflow rate
Motor Efficiency	Given value of 1 since motor inefficiencies are accounted for in measurements of airflow and power
Coefficients of Fan Power Curve (Equation 4)	Least square regression using measurements of air flowrate and fan power consumption. The independent variable (f_{flow}) is derived from measured air flowrate as the ratio of air flowrate to the maximum airflow rate. The dependent variable (f_{pl}) was derived from measured fan power consumption as the ratio of fan power to the maximum fan power.

$$f_{flow} = \frac{\dot{m}}{\dot{m}_{design}}$$

$$f_{pl} = c_1 + c_2 \cdot f_{flow} + c_3 \cdot f_{flow}^2 + c_4 . f_{flow}^3$$

$$\dot{Q}_{tot} = f_{pl} \cdot \dot{m}_{design} \cdot \frac{\Delta P}{e_{tot} \cdot \rho_{air}}$$

Results



Component	CVRMSE (%)	NMBE (%)
Lighting Energy Consumption	14.01	1.47
Equipment Energy Consumption	10.68	-0.005
AHU Energy Consumption	11.48	-2.35

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Thank you