A New Hybrid Approach to Energy Modeling

DOE BENEFIT FOA
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Outline

- **Project Overview**
- **Method**
- **Technical Detail**
  - Inverse heat balance equation
  - Implementation in EnergyPlus
- **Next Steps**
- **Discussion**

Project Overview

- **A two-year project: 10/1/2014 – 9/30/2016**
- **Objective:**
  - Develop a new hybrid modeling approach to more accurately predicting energy performance for existing buildings
  - Calculate highly unknown inputs (internal mass and air infiltration) with easily measurable data (air temperature) as new input to EnergyPlus models
  - Improve accuracy of simulated results for existing buildings to support energy retrofit analysis

Technical Scope

- **Phase 1 FY15**
  - Development, implementation, and validation of the hybrid modeling covering internal thermal mass component
- **Phase 2 FY16**
  - Complete the development and implementation of hybrid modeling to include the air infiltration component
  - Validate the hybrid modeling using simulated and measured data from FLEXLAB

Hybrid Modeling Approach

Development Process

1. Development of zone heat balance inverse equations
2. Implementation in a custom version of EnergyPlus 8.3
3. Validation of codes

Simulation Process

1. Input: Measured Zone Air Temperature
2. Calculate temperature capacitance multiplier using hybrid modeling
3. Use the temperature capacitance multiplier in normal EnergyPlus modeling

Validation of Hybrid Approach: Internal Mass (1)

- **Method**
  - Use simulation results
  - Compare zone temperature and energy

Input of: **InternalMass object**	**vs**	Input of: **ZoneCapacitanceMultiplier:ResearchSpecial**

- **Simulation**
  - Use of DOE reference models: Small office
  - Four climate zones: 1A Miami, 3C San Francisco, 5A Chicago, 8A Fairbanks
  - Two vintages: Pre 1980 and 2004

Validation of Hybrid Approach: Internal Mass (2)

- **InternalMass Object**
  - Construction: Internal furnishings, Material: Std Wood 6 inch
  - Thickness 0.15 m, Density 540 kg/m3, Specific heat: 1210 J/kg-K

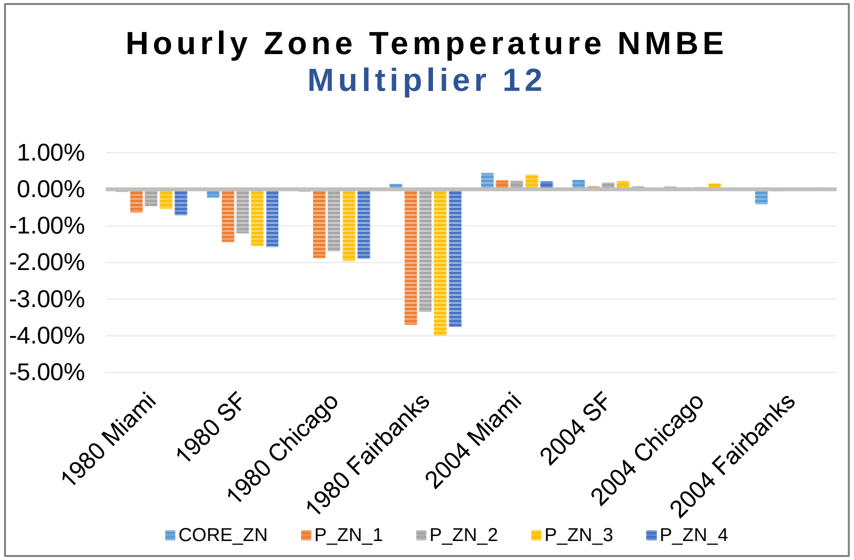
Zones	Core	Perimeter1	Perimeter 2	Perimeter 3	Perimeter 4
Zone Area[m2]	150	113	67	113	67
Surface Area [m2]	299	227	135	227	135

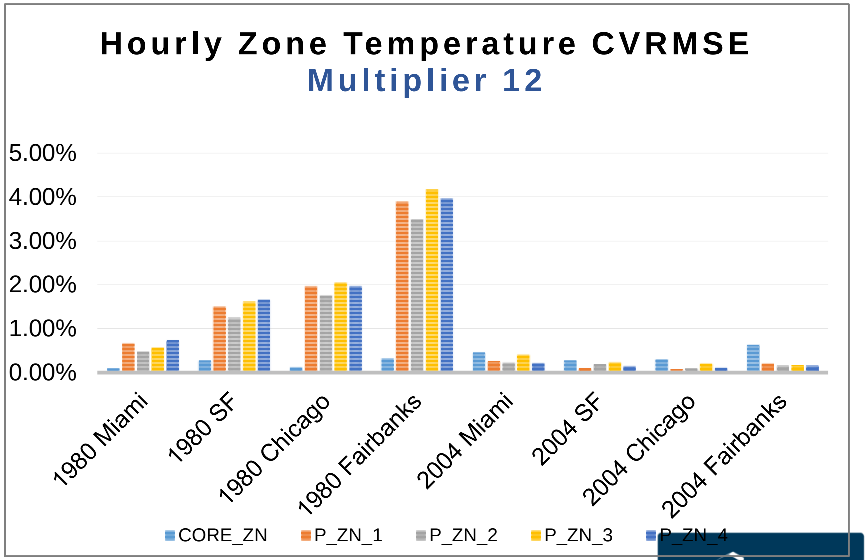
- **ZoneCapacitanceMultiplier:ResearchSpecial Object**
  - Temperature Capacity Multiplier

Note: Multiplier represents the relative capacitance of the air compared to an empty zone

Validation of Hybrid Approach: Internal Mass (3)

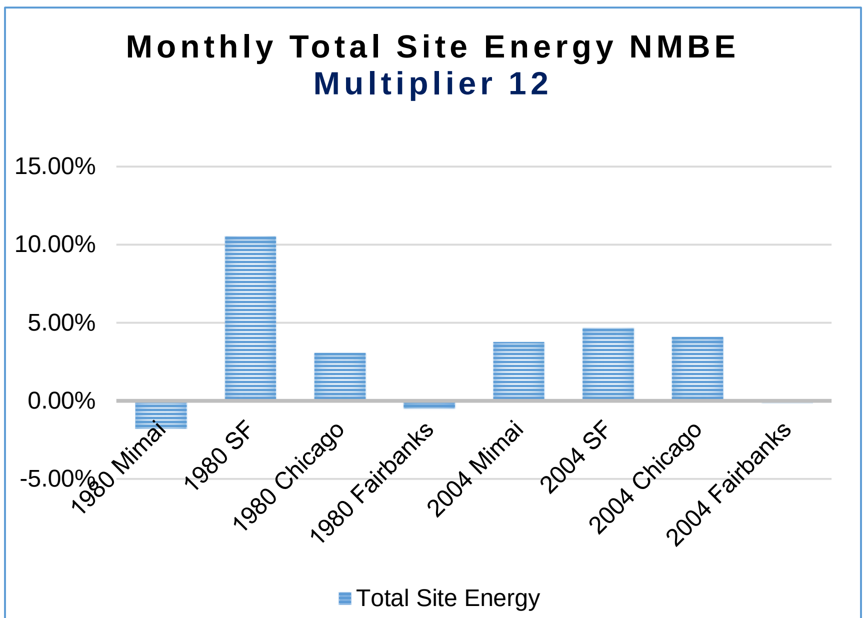
- **Validation Method**
  - Find the best multiplier based on results of the hourly zone air temperature in free-floating mode
  - A multiplier of 12 is found best meeting ASHRAE 14 Guideline: NMBE 15% and CVRMSE 30%

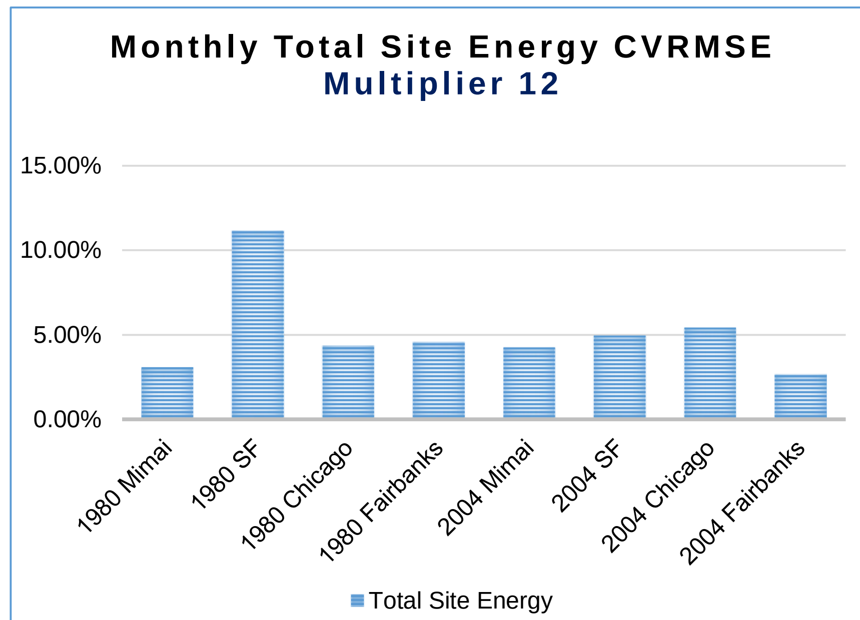




Monthly Energy Results (multiplier 12)

- **Validation Method**
  - A multiplier of 12 is found meeting ASHRAE 14 Guideline: Monthly NMBE 5% and CVRMSE 15%





Algorithm: Inverse Zone Heat Balance Equation (1)

- Use of the analytical solution algorithm

$$T_z^t = \left(T_z^{t-\delta t} - \frac{\sum_j Q_j + \sum_i h_i A_i T_{si} + \sum_i \dot{m}_i C_p T_{zi} + q C_p T_o + \dot{m}_{sys} C_p T_{sup}^t}{\sum_i h_i A_i + \sum_i \dot{m}_i C_p + q C_p + \dot{m}_{sys} C_p}\right) \times exp^{\left(-\frac{\sum_i h_i A_i + \sum_i \dot{m}_i C_p q C_p + \dot{m}_{sys} C_p}{C_z^t}\delta t\right)} + \frac{\sum_j Q_j + \sum_i h_i A_i T_{si} + \sum_i \dot{m}_i C_p T_{zi} + q C_p T_o + \dot{m}_{sys} C_p T_{sup}^t}{\sum_i h_i A_i + \sum_i \dot{m}_i C_p + q C_p + \dot{m}_{sys} C_p}$$

- Hybrid modeling approach
  - uses T_z^t and $T_z^{t-\delta t}$ from measured zone air temperature
  - then, derives C_z^t heat capacity of zone air that includes the internal mass

$$C_z^t = -\frac{\left(\sum_i h_i A_i + \sum_i \dot{m}_i C_p q C_p + \dot{m}_{sys} C_p\right)\delta t}{ln\left[\frac{T_z^t - \frac{\sum_j Q_j + \sum_i h_i A_i T_{si} + \sum_i \dot{m}_i C_p T_{zi} + q C_p T_o + \dot{m}_{sys} C_p T_{sup}^t}{\sum_i h_i A_i + \sum_i \dot{m}_i C_p + q C_p + \dot{m}_{sys} C_p}}{T_z^{t-\delta t} - \frac{\sum_j Q_j + \sum_i h_i A_i T_{si} + \sum_i \dot{m}_i C_p T_{zi} + q C_p T_o + \dot{m}_{sys} C_p T_{sup}^t}{\sum_i h_i A_i + \sum_i \dot{m}_i C_p + q C_p + \dot{m}_{sys} C_p}}\right]}$$

Algorithm: Inverse Zone Heat Balance Equation (2)

- Zone temperature capacity multiplier is represented:

$C_z = V\rho_{air}C_pC_T$	= heat capacity of air per volume including internal thermal mass and zone air
V	= Zone volume
ρ_{air}	= zone air density
C_p	= zone air specific heat
C_T	= sensible heat capacity multiplier

- Calculates C_T^t for each timestep if:
  1. Not in warmup and not in sizing calculation,
  2. For timesteps measured temperatures are provided, and
  3. When HVAC is off (otherwise HVAC energy is required)
- Finally calculates **average** $\boldsymbol{C_T}$, zone sensible temperature capacity multiplier for each zone
  - $\boldsymbol{C_T}$ is constant throughout the simulation

Implementation in EnergyPlus

- **Based on EnergyPlus 8.3**
- **Development of New Feature Proposal: Internal review**
- **IDD Object (New):**
  - \ group Hybrid Model

    HybridModel:Zone
- **IDD Object(s) (Revised):**
  - Zone to allow different multiplier for each zone
- **Proposed Report Variables:**
  - Variable: Zone Sensible Temperature Capacity Multiplier

HybridModel:Zone

```
HybridModel:Zone,
       \memo Zones with measured air temperature data and a range of dates.
       \memo A range of dates may differ from zones.
  A1 , \field Name
       \required-field
       \type alpha
  A2 , \field Zone Name
       \required-field
       \type object-list
       \object-list Zone Names
  A3 , \field Calculate Zone Internal Thermal Mass
       \note Use measured temperature data to calculate zone temperature capacity
      multiplier
      \type choice
       \key No
       \key Yes
  A4 , \field Calculate Zone Air Infiltration Rate
       \note Use measured temperature data to calculate zone air infiltration air
      flow rate
      \type choice
       \key No
       \key Yes
  A5 , \field Zone Measured Air Temperature Schedule Name
       \required-field
       \type object-list
       \object-list ScheduleNames
      \note from Schedule:File
  N1 , \field Begin Month
       \required-field
       \minimum 1
       \maximum 12
       \type integer
  N2 , \field Begin Day of Month
       \required-field
       \minimum 1
       \maximum 31
       \type integer
  N3 , \field End Month
       \required-field
       \minimum 1
       \maximum 12
       \type integer
  N4 ; \field End Day of Month
       \required-field
       \minimum 1
       \maximum 31
       \type integer
```

Zone,

```
Zone,
  N10; \field Temperature Capacity Multiplier
       \type real
       \default 1.0
       \note Optional, if blank, the input from the
       \note ZoneCapacitanceMultiplier:ResearchSpecial will be used.
       \note If Hybrid Model is used, this field is calculated and can be
      \note reported.
```

Implementation in EnergyPlus

- **New code created:**

HybridModel.cc & hh:	HybridModel:Zone Reading inputs and processing data

- **Code updates in:**

SimulationManager.cc	HybridModel:Zone object inputs and processing data
ZoneTempPredictorCorrector.cc	Inverse heat balance algorithm
HeatBalanceManager.cc	Zone objects revision
DisplacementVentMgr.cc	Zone specific multipliers
DataHeatBalFanSys.cc	Zone specific multipliers

ZoneTempPredictorCorrector.cc

```
// Solve for zone air power capacity
{ auto const SELECT_CASE_var(ZoneAirSolutionAlgo);
if (SELECT_CASE_var == Use3rdOrder) {
    AirCapHM = -(TempIndCoefHM - ZTMeasured)*(6 * TempDepCoefHM + 11 * ZTMeasured) /
      (18 * ZTM1(ZoneNum) - 9 * ZTM2(ZoneNum) + 2 * ZTM3(ZoneNum));// Inverse equation
}
else if (SELECT_CASE_var == UseAnalyticalSolution) {
    if (TempDepCoefHM == 0.0) { // B=0
        AirCapHM = TempIndCoefHM / (ZoneT1Measured - ZTMeasured); // Inverse equation
    }
    else {
        AirCapHM = TempDepCoefHM / std::log((TempIndCoefHM - TempDepCoefHM *
       ZoneT1Measured) / (TempIndCoefHM - TempDepCoefHM * ZTMeasured)); // Inverse
       equation
    }
}
else if (SELECT_CASE_var == UseEulerMethod) {
    AirCapHM = (TempDepCoefHM * ZTMeasured - TempIndCoefHM) / (ZoneT1Measured -
      ZTMeasured); // Inverse equation
}}
```

Input: Measured Zone Air Temperature

- The zone air temperatures will be recorded using portable data loggers
- Temperature interval data at 10-minute
- Specific measured period for **individual zones**, greater than one week
- Input in **CSV** for **Schedule:file** object

Validation of Codes

1. Input different multipliers per zone
2. Run simulation
3. Get zone mean air temperature
4. Create CSV file with the temperature
5. Use the CSV file for measured temperature input
6. Run the hybrid model simulation
7. Calculate multipliers for each zone

Building	Location	Vintage	Zones				
			CORE_ZN	PERIMETER_ZN_1	PERIMETER_ZN_2	PERIMETER_ZN_3	PERIMETER_ZN_4
			Multiplier Input				
			2	5	10	15	20
			Multiplier Calculation				
Small Office	Miami	1980	1.98	4.99	10.00	14.94	19.91
Small Office	SF	1980	2.00	4.99	9.93	14.95	19.93
Small Office	Chicago	1980	2.01	4.99	9.98	14.96	19.95
Small Office	Fairbanks	1980	2.03	5.03	10.00	14.90	19.94
Small Office	Miami	2004	2.00	4.96	9.92	14.73	19.66
Small Office	SF	2004	1.90	4.98	9.46	14.81	19.87
Small Office	Chicago	2004	1.99	4.92	10.14	14.84	19.67
Small Office	Fairbanks	2004	2.02	4.96	9.93	14.78	19.75

Compare

Input multipliers ≈ Calculated multipliers

Summary

- Current energy models require internal mass input, which is difficult to obtain in reality
- Internal mass can be represented with zone sensible temperature capacity multiplier
- Multipliers can be calculated using zone measured air temperature by solving the inverse zone heat balance equations
- Code implemented and tested in a custom version of EnergyPlus 8.3

Comments on NFP

- **NFP was sent to the team for review on May 28**
- **Received comments from:**
  - Mike Witte

    Naming, changes to IDD objects, well-mixed air model
  - Lixing Gu

    Naming, fixed multiplier? Moisture multiplier?
  - Edwin Lee

    Representation of internal mass: included in zone air heat balance and radiant exchange with zone interior surfaces, but does not interact with solar radiation.

Next Steps

- **Air infiltration** component
  - Development of algorithms
  - Implementation in the custom version EnergyPlus
  - Validation of algorithms with reference models
- Demonstration and validation in the **FLEXlab**
  - Multiple design experiments for internal mass and infiltration
  - Cross validate experiment data vs hybrid model simulation results
- Fine tune the hybrid modeling algorithms
- Refine the new feature proposal
- Implementation and testing in EnergyPlus release

Questions & Discussion