**Hybrid Model: Zone Infiltration and People Count**

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Original: October 6, 2018

# Justification for Feature Update:

The proposed new feature improves the current HybridModel object which utilizes inverse modeling algorithms based on the zone heat, moisture, and contaminant balance equations. The current HybridModel feature use easily measurable zone air temperature to solve zone internal thermal mass or air infiltration rate assuming the HVAC system is in free-floating mode. The new HybridModel feature allows additional parameters such as zone air humidity ratio and CO2 concentration as the input of the inverse modeling algorithms to solve highly uncertain parameters like air infiltration and people count. Depending on the availability of zone supply air parameters (i.e., supply air flow rate, supply air temperature, supply air humidity ratio, and supply air CO2 concentration) measurements, the new HybridModel feature can solve air infiltration and people count for both HVAC-off mode and HVAC-on mode. The hybrid approach keeps the virtue of the physics-based model and taking advantage of more measured buildings data which is available nowadays due to the wide use of low-cost sensors and the needs of better controls in existing buildings.

This new feature proposal provides technical details of the new HybridModel object its implementation in EnergyPlus. The proposed feature will improve simulation usability and accuracy for existing buildings, which supports more accurate analysis of energy retrofits.

# 1. Overview

**1.1 Infiltration**

EnergyPlus uses the object, ZoneInfiltration:DesignFlowRate, to represent the infiltration caused by the opening and closing of exterior doors, cracks around windows, and even in very small amount through building elements. Users define the infiltration design air flow rate, an infiltration schedule, and temperature and wind correction coefficients. The source code module, ZoneEquipmentManager, contains the simplified infiltration algorithm as shown in Equation (1).

|  |  |
| --- | --- |
| *Infiltration* = (*Idesign*) (*Fschedule*) [*A*+*B*|(*Tzone* −*Todb*)|+*C* (*WindSpeed*)+*D*(*Windspeed*2 )] | (1) |

Where:

*A* = Constant term coefficient;

*B* = Temperature term coefficient;

*C* = Velocity term coefficient;

*D* = Velocity squared coefficient.

The simple method has an empirical correlation that modifies the infiltration as a function of wind speed and temperature difference across the envelope. The difficulty in using this equation is determining valid coefficients for each building type in each location. The simplified infiltration models consider the wind speed on zone altitude, and the variation in infiltration heat loss based on the wind velocity. These coefficients vary and provide very different results that cause great uncertainty in determining which numbers to use. EnergyPlus allows users to input these coefficients, however it is not easy to identify correct ones for typical modeling practices.

The infiltration hybrid model derives the time-step zone infiltration air flow rates, using the inverse zone heat balance equation, moisture balance equation, or contaminant balance equation, which consider all complexities of design flow rate, coefficients and climate conditions.

**1.2 People Count**

In EnergyPlus, people count and people activity level is represented by People and corresponding schedule objects. Users set the number of people calculation method, people activity level, sensible and fraction heat fractions, and CO2 generation rate in the People object. Each People object can be assigned to a zone or a zone list. A set of people related schedule objects are used to define the temporal number of people rules. In typical simulation setting, the People object is usually set to have fixed schedules. In reality, occupancy schedule is highly uncertain. Using the typical settings for the People object can cause loss of model authenticity.

The new hybrid model algorithm calculates the time-step zone people count by inversely solving the zone sensible heat balance equation, moisture balance equation, or contaminant balance equation.

**1.3 Zone Balance Equations**

The hybrid model algorithms are built upon the physics-based zone heat, moisture, and contaminant balance equations reformulated to solve a partially inverse problem. The basis for the zone air system integration is to formulate balance equations for the zone air and solve the resulting ordinary differential equations. It should be noted that the hybrid algorithms to be developed are generic and can be adopted by EnergyPlus and other building energy simulation programs.

Equation (1) below indicates zone heat balance relationships. It assumes that the sum of zone loads and air system output equals the change in energy stored in the zone. The infiltration airflow rate, changes for different conditions depending on outdoor temperature, wind speed, and HVAC system operations. The energy provided from systems to the zone is represented as .

|  |  |
| --- | --- |
|  | (2) |

Where:

|  |  |
| --- | --- |
|  | = sum of the convective internal loads |
|  | = convective heat transfer from the zone surfaces |
|  | = zone surface temperature |
|  | = heat transfer due to interzone air mixing |
|  | = zone air temperature |
|  | = heat transfer due to outside air infiltration |
|  | = outdoor air temperature |
|  | = infiltration mass flow rate |
|  | = infiltration air flow rate |
|  | = energy stored in zone air including the internal thermal mass of the zone air node |
|  | = heat capacity of air per volume including internal thermal mass and zone air |
|  | = Zone volume |
|  | = air density |
|  | = zone air specific heat |
|  | = sensible heat capacity multiplier |
|  | = air system energy provided to the zone to meet heating and cooling loads |
|  | = air system supply air temperature |

The sum of zone loads and the provided air system energy equals the change in energy stored in the zone. Typically, the capacitance would be that of the zone air only. The internal thermal masses, assumed to be in equilibrium with the zone air, are included in this term. EnergyPlus provides algorithms to solve the zone air energy and moisture balance equations defined in the ZoneAirHeatBalanceAlgorithm object. The algorithms use the finite difference approximation or analytical solution to calculate the derivative term with respect to time.

EnergyPlus provides three different heat balance solution algorithms to solve the zone air energy balance equations. These are defined in the Algorithm field in the ZoneAirHeatBalanceAlgorithm object: 3rdOrderBackwardDifference, EulerMethod and AnalyticalSolution. The first two methods to solve Equation use the finite difference approximation while the third uses an analytical solution. The hybrid modeling approach uses the 3rdOrderBackwardDifference to inversely solve the air infiltration. EnergyPlus Code for these balance algorithms are referenced to the ZoneTempPredictorCorrector module.

Similarly, EnergyPlus solves zone humidity ratio and CO2 concentration with the predictor-corrector approach. Equations (2) and (3) are the balance equations for moisture and CO2 concentration, respectively. The definitions of the terms in the equations can be in the Chapter 2 – Integrated Solution Manager of EnergyPlus Engineering References.

|  |  |
| --- | --- |
|  | (3) |
|  | (4) |

# 2. Approach

This section provides technical details of solving the air infiltration rate and people count with the zone balance equations.

**2.1 Infiltration Inverse Models**

An air infiltration term is present in all three balance equations. Therefore, there are three ways to solve it. This section provides theoretical basis of the inverse algorithms to solve the air infiltration. The infiltration hybrid modeling approach derives the infiltration mass flow rate, by reformulating the zone air heat balance equation, zone air moisture balance equation, or zone air contaminant balance equation. *3rdOrderBackwardDifference* method is used to solve the differential equations because *AnalyticalSolution* cannot be realized in a mathematical form when deriving the infiltration mass flow rate.

*2.1.1 Solving Infiltration with Temperature*

Equation (2) can be re-written as:

*2.1.2 Solving Infiltration with Humidity Ratio*

*2.1.3 Solving Infiltration with CO2 Concentration*

**2.2 People Count Inverse Models**

There are three ways to solve zone people count since the all three balance equations have a people-related term. This section provides theoretical basis of the inverse algorithms to solve the air infiltration.

*2.2.1 Solving People Count with Temperature*

*2.2.2 Solving People Count with Humidity Ratio*

*2.2.3 Solving People Count with CO2 Concentration*

The infiltration hybrid modeling approach derives the infiltration mass flow rate, by reformulating the zone air heat balance algorithm. For the inverse modeling of the heat balance algorithm for the infiltration hybrid modeling, 3rdOrderBackwardDifference method is used. The inverse model to derive the internal mass flow, using the AnalyticalSolution cannot be realized in a mathematical form when deriving the infiltration mass flow rate. The time-series zone air temperature, using the 3rd order method is shown in Equation (6).

|  |  |
| --- | --- |
|  | (6) |

Equation (7) shows the inverse algorithm for infiltration hybrid modeling method to derive the zone infiltration mass flow rate using the measured air temperature.

|  |  |
| --- | --- |
|  | (7) |

The infiltration air flow rate, is calculate from the derived infiltration mass flow rate, , in Equation (8):

|  |  |
| --- | --- |
|  | (8) |

For the infiltration mode of the hybrid model simulation, the calculation is only done when the zone air temperature difference between the current and previous timestep is less than 0.1°C and the zone air and outdoor air temperature difference is greater than 5°C as depicted

(c) Assumptions

The current hybrid model implementation applies to periods when HVAC systems are off, i.e. spaces are in free floating mode. However, this is not a limitation of the hybrid modeling but rather based on the assumption that measured energy delivered by HVAC systems is not easily available. If the hybrid mode simulation is used when HVAC system operates, it requires data of the supply air temperature and supply air volume to derive .

The challenge of the hybrid model algorithm lies when both infiltration and internal mass parameters are unknown. From previous validation study using the DOE reference models, the IM multiplier of 8 reflects a typical office internal mass environment. It is recommended to use an IM multiplier of 3 to 6 for light offices, 6 – 10 for typical offices, and 10 – 15 for heavy mass office configurations. For the use of hybrid model when internal mass and infiltration inputs cannot be estimated, the default input of the IM multiplier of 8 is used to derive infiltration air flow rate. Once the hybrid simulation for the infiltration mode is done, the derived infiltration is used in the hybrid modeling internal mass mode to correct the IM multiplier. This newly calculated multiplier represents the real internal mass configuration.

# IDD Object (New):

None

# IDD Object(s) (Revised):

We propose to revise the current HybridModel:Zone. The revised object defines inputs for the new hybrid modeling algorithms for individual zones.

HybridModel:Zone,

\memo Zones with measured air temperature data and a range of dates.

\memo If the range of temperature measurement dates includes a leap day, the weather data should include a leap day.

A1 , \field Name

\required-field

\type alpha

A2 , \field Zone Name

\required-field

\type object-list

\object-list ZoneNames

A3 , \field Calculate Zone Internal Thermal Mass

\note Use measured data (temperature, humidity ratio, or CO2 concentration) to calculate zone temperature capacity multiplier.

\note At leat one measured parameter should be provided to calculate the thermal mass.

\type choice

\key No

\key Yes

\default No

A4 , \field Calculate Zone Air Infiltration Rate

\note Use measured temperature data (temperature, humidity ratio, or CO2 concentration) to calculate zone air infiltration air flow rate.

\note At leat one measured parameter should be provided to calculate the thermal mass.

\type choice

\key No

\key Yes

\default No

A5 , \field Calculate Zone People Count

\note Use measured humidity ratio data (temperature, humidity ratio, or CO2 concentration) to calculate zone people count.

\note At leat one measured parameter should be provided to calculate the thermal mass.

\type choice

\key No

\key Yes

\default No

A6 , \field Zone Measured Air Temperature Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A7 , \field Zone Measured Air Humidity Ratio Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A8 , \field Zone Measured Air CO2 Concentration Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A9 , \field Zone Input People Activity Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A10 , \field Zone Input People Sensivle Heat Fraction Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A11 , \field Zone Input People Radiant Heat Fraction Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A12 , \field Zone Input People CO2 Generation Rate Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A13 , \field Zone Input Supply Air Temperature Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A14 , \field Zone Input Supply Air Mass Flow Rate Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A15 , \field Zone Input Supply Air Humidity Ratio Schedule Name

\type object-list

\object-list ScheduleNames

\note from Schedule:File

A16 , \field Zone Input Supply Air CO2 Concentration Schedule Name

\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

# Simulation Process:

The hybrid modeling feature uses a new flag, “Hybrid Modeling Flag” in the sizing and primary simulation in the simulation manager. “Hybrid Modeling Flag” is triggered by inputs in the new object, “HybridModel:Zone”. The flag triggers the hybrid model simulation that calculates the zone temperature capacitance multipliers or infiltration air flow rates depending on the user’s input in the object, and the zone air temperature data input in the Schedule:File objects. The simulation steps will be as follows depending on the inputs of the HybridModel:Zone object.

When the “Calculate Zone Air Infiltration Rate” flag and the “Calculate Zone Internal Thermal Mass” flag are both set to YES:

1. Hybrid model simulation for infiltration using the default IM multiplier of 8
2. Hybrid model simulation for IM multiplier using the calculated infiltration output
3. Normal energy simulation with the calculated IM multiplier and infiltration

When the “Calculate Zone Air Infiltration Rate” flag is set to YES and the “Calculate Zone Internal Thermal Mass” flag is set to NO:

1. Hybrid model simulation for infiltration using user’s IM multiplier input
2. Normal energy simulation with the calculated infiltration

When the “Calculate Zone Air Infiltration Rate” flag is set to NO and the “Calculate Zone Internal Thermal Mass” flag is set to YES:

1. Hybrid model simulation for IM multiplier using user’s infiltration input
2. Normal energy simulation with the calculated IM multiplier

# Output Description (new):

Variable: Zone Temperature Capacity Multiplier

Units: N/A

Variable reference: Zone( Loop ). HMMultiplierAverage

Index type key: Zone

Variable type key: Average

Keyed value: Zone( Loop ).Name

Variable: Infiltration Air Change per Hour

Units: N/A

Variable reference: Zone( Loop ). InfilOAAirChangeRateHM

Index type key: Zone

Variable type key: Average

Keyed value: Zone( Loop ).Name

# IO Ref (draft):

To be provided for the different mode of the hybrid modeling simulation.

# Testing/Validation/Data Source(s):

The testing and validation of the hybrid model were done using a custom version of EnergyPlus 8.5 in which the hybrid modeling features were implemented. Details of the testing and validation are available in the technical reports (Lee and Hong 2016; Lee and Hong 2015).

# EngRef (draft):

To be provided based on the overview of the hybrid algorithm described above.

# Example File

# E-mail comments:

# Conference Call Conclusions:

# Other Conference Call Topics (not in scope of current proposal):

# Transition changes:

# Other documents:

# Reference:

Lee, Sang Hoon, and Tianzhen Hong. 2015. *Validation Report for the Hybrid Modeling Approach Part 1: Internal Thermal Mass*.

Lee, Sang Hoon, and Tianzhen Hong. 2016. *Validation of the Hybrid Modeling Using Measured Data from the FLEXLAB Experiment*.