Algorithms for Modeling Multiple Air Handling Units Serving the Same Zone in EnergyPlus

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Abstract

A new zone air balance method has been developed for EnergyPlus to allow the simulation of more than one air handling unit (AHU) serving the same zone. The new method allows each zone to be served by one or more AHUs and one or more zone HVAC units. The zone air mass flow balance allocates return air flows to multiple AHUs while accounting for zone exhaust flows, infiltration, and interzone mixing. At the same time, each AHU must balance supply and return flow with available outdoor air. Infiltration and interzone mixing flows may be automatically adjusted. The method can model various applications which previously could not be modeled or required awkward workarounds including pressurized systems (hospital), transfer air (food service), dedicated outdoor air systems in parallel with multi-zone VAV systems (school), and systems with no return (warehouse). This paper documents new algorithms at the heart of the EnergyPlus HVAC simulation. Modeling multiple air handlers serving the same zone(s) is a significant new capability for a widely used building energy modeling tool.

Introduction

EnergyPlus (U.S. Department of Energy, 2019) is an open-source whole building energy modeling tool originally released in 2001. From its inception, it has been limited to one air handling unit (AHU) per zone plus any number of zone HVAC units. This single-AHU limitation and a general inability to control return air flow frustrated users for a variety of applications which previously could not be modeled or required awkward workarounds including pressurized systems (hospital), transfer air (food service), dedicated outdoor air systems (DOAS) in parallel with multi-zone VAV systems (school), and systems with no return (warehouse).

DOAS systems have been promoted by Stanley Mumma since the 1990s “as a way to improve energy efficiency while meeting tighter ventilation requirements” (Manuel 2003). In Mumma’s many publications on the benefits of DOAS systems, several system configurations are suggested, including DOAS in parallel with FCU (fan coil units or other similar zone units), DOAS in parallel with radiant or chilled beam, and DOAS in parallel with VAV (Mumma 2003 and 2010). Of these, EnergyPlus could model all of them except DOAS in parallel with VAV. Two prior development efforts sought to overcome this

limitation. In 2010, a single-zone dedicated outdoor air (DOAS) model was added to EnergyPlus version 5.0.0 (Chae and Strand, 2010). This model allowed the user to add a DOAS system to a multi-zone AHU by breaking it into multiple single-zone DOAS units. In 2011, a special air terminal unit was added to EnergyPlus version 7.0.0 to allow a DOAS to be modeled using one side of a dual-duct AHU while using the other side of the dual-duct system as a recirculating VAV system (Miller and Sekhar 2010). These capabilities improved the ability to model DOAS systems, but each came with limitations, and neither one was straightforward for users to implement.

To meet this need, as well as other applications, in 2017 (version 8.8.0) a new zone air balance method was developed to allow the simulation of more than one AHU serving the same zone. Some improvements were added to the method in early 2019 (for version 9.1.0). This paper describes the original air balance method, the new method and some example results comparing the original method (with workarounds) against the new method. References to specific EnergyPlus syntax are provided for clarity.

Original single-AHU method

The original zone air balance method assumed that each zone would have only one (or no) return air node. This imposed a limit of one AHU serving any given zone, along with any number of zone HVAC units (e.g. fan coil).

Default method

The default single-AHU zone air balance method looks only at HVAC and exhaust fan flows, ignoring infiltration and zone-to-zone (mixing) flows. The method sums all inlet flows, less all zone HVAC exhaust flows, less zone exhaust fan flows and sends the remainder to the AHU return.

$$\dot{m}_{\text{return}} = \sum_{i=1}^m \dot{m}_{\text{inlet},i} - \sum_{j=1}^n \dot{m}_{\text{exhaust},j} \quad (1)$$

Any incoming flow from infiltration and mixing is assumed to exfiltrate without impacting HVAC system flows. Also, all zone exhaust fan flow rates on a given AHU are assumed to be replaced by outdoor air from the AHU mixing box.

Optional zone air mass balance

The optional zone air mass balance method starts with the default air balance, then looks at infiltration and mixing flow rates. It will adjust infiltration and mixing flow rates

as needed to balance the HVAC system flows. (*Reference ZoneAirMassFlowConservation.*)

Optional specified return flow

There is an optional method to schedule the return flow from a zone or set it to track the flows of some other HVAC system node(s) in the model. This may be used to model a pressurized system, for example, by setting the return flow to be zero or some fraction. If used in combination with the zone air mass balance feature, the pressurized system flow can reduce infiltration or increase mixing to an adjacent zone. (*Reference ZoneHVAC:EquipmentConnections "Zone Return Air Node 1 Flow Rate Basis Node or NodeList Name."*)

New multiple-AHU method design

Requirements

The new method was designed to meet the following requirements:

- *Allocate Multiple Return Flows* - The original zone air balance methods described above all assume a single return air path (return node) leaving a given zone. With multiple AHUs in a given zone, the new method requires logic to allocate the net total return flow to each available return node.
- *Allocate Exhaust Flows* - With multiple AHUs the exhaust fan makeup air must be allocated to each AHU. Does one AHU provide all of the makeup air, or do multiple AHUs share the task?
- *Work with Zone Air Mass Balance* - The new method must still work with the zone air mass balance option.

Figure 1 shows an example system diagram for two AHUs serving two zones.

New user inputs

The following new user inputs were added to support the new multi-AHU method.

- *Multiple return nodes* - The new method allows more than one return air node (outlet) to be specified in each zone. It also removes the previous requirement that a return path be defined for every AHU, even if it was a dedicated outdoor air system (DOAS) with no physical return path. So, if a zone is served by N AHUs, it may have N or fewer return nodes. (*Reference ZoneHVAC:EquipmentConnections "Zone Return Air Node or NodeList Name."*)
- *Return air flow controls* - The new method requires options to give the user control over how much return flow goes to each AHU in order to specify balanced or pressurized systems. The existing scheduled and node-based return flow controls remain available for the first return node in a zone. More directly, there is a new input to specify the design return air flow relative to the supply flow for each AHU. This defaults to 1.0, but may be set to 0.9 for example to model a pressurized system, or zero for a DOAS. (*Reference AirLoopHVAC "Design Return Air Flow Fraction of Supply Air Flow."*)

- *Return air heat gains* - Lights, refrigerated cases, and air flow windows can all add a heat gain or loss to return air. These gains may now be assigned to a specific return air node. (*Reference Lights "Return Air Heat Gain Node Name," Refrigeration:Case "Under Case HVAC Return Air Node Name," and WindowProperty:AirflowControl "Airflow Return Air Node Name."*)
- *Air terminal sizing* - With multiple AHUs serving a single zone, new inputs have been added to allow each AHU terminal unit to serve a specified fraction of the zone sensible cooling and heating loads and the zone outdoor air requirement. For example, consider a zone served by two AHUs: a DOAS and a VAV with reheat. The DOAS may be sized to meet 100% of the outdoor air requirement and none of the sensible loads, while the VAV may be sized to meet 100% of the sensible loads but no outdoor air. New optional air terminal sizing inputs allow the user to specify these fractions which are applied when sizing the terminal units and AHUs. (*Reference DesignSpecification:AirTerminal:Sizing.*)

Figure 1. Example system schematic for two zones with two AHUs. System A is recirculating only, System B is outdoor air only, Zone 1 has an exhaust fan.

New multiple-AHU zone air balance algorithm

The new multiple-AHU zone air balance method uses the following algorithm to solve for the return air flow rate to each AHU from each zone. (*Reference EnergyPlus functions CalcZoneAirMass and CalcZoneReturnFlows.*) The flow chart in Figure 2 provides a visual overview of the following steps.

Step 1 – Calculate expected return air flow for the zone

Sum all inlet node flows and subtract all exhaust node flows (same as the old method):

$$\dot{m}_{zone,expected} = \sum_{i=1}^m \dot{m}_{inlet,i} - \sum_{j=1}^n \dot{m}_{exhaust,j} \quad (2)$$

Step 2 – Set initial return node flows

Set each return node flow rate based on the matching inlet node flow rate and the design air loop return fraction.

If the available outdoor air flow rate for the corresponding AHU is greater than zero:

$$\dot{m}_{return,i} = ReturnFrac \times \dot{m}_{inlet,i} \quad (3)$$

If the available outdoor air flow rate for the corresponding AHU is zero, tag this return node as “fixed” (cannot be adjusted later) and set return equal to supply:

$$\dot{m}_{return,i} = \dot{m}_{inlet,i} \quad (4)$$

Subscript i matches the inlet node and return node which are on the same AHU (which is not necessarily the order that the nodes are listed in the input).

If return flow basis nodes are specified for return node 1, tag this return node as “fixed” and set the flow rate based on other node flow(s), also applying the zone return flow schedule fraction:

$$\dot{m}_{return,1} = ZoneSch \times \sum_{i=1}^k \dot{m}_{basis,i} \quad (5)$$

Step 3 - Allocate unbalanced exhaust air flows to each air loop

If the initial total zone return flow exceeds the expected zone return flow, then adjust the return flow proportionately across all return nodes (except those which have been tagged as “fixed”).

$$\dot{m}_{zone,initial} = \sum_{i=1}^l \dot{m}_{return,i} \quad (6)$$

$$IF \dot{m}_{zone,initial} > \dot{m}_{zone,expected} THEN \quad (7)$$

Sum the return flow for nodes which are not tagged as “fixed”:

$$\dot{m}_{zone,variable} = \sum_{i=1}^l \dot{m}_{return,variable,i} \quad (8)$$

Calculate the flow adjustment factor:

$$AdjFactor = \left(1 - \frac{\dot{m}_{zone,initial} - \dot{m}_{zone,expected}}{\dot{m}_{zone,variable}} \right) \quad (9)$$

Adjust the return flow for all variable flow nodes:

$$\dot{m}_{return,i} = AdjFactor \times \dot{m}_{return,i} \quad (10)$$

Calculate the final zone total return flow, summing all return nodes:

$$\dot{m}_{zone,final} = \sum_{i=1}^l \dot{m}_{return,i} \quad (11)$$

Step 4 - Adjust infiltration and mixing flows for zone air mass balance

If the optional zone air mass balance method is active, then adjust infiltration and mixing flow rates as needed to balance the HVAC system flows. (*Reference ZoneAirMassFlowConservation.*)

Step 5 - Balance each air loop

When the optional zone air mass balance method is not active, the air loops check for any zones with excess exhaust flow that is greater than the available supply flows (without accounting for infiltration or mixing flows). If there is any excess exhaust flow, the air loop returns are adjusted proportionally to the available outdoor air from each air loop serving those zones.

Step 6 - Iterate until converged or limit reached

If the optional zone air mass balance method is active, several iterations may be necessary to balance the infiltration and mixing flows.

Step 7 – Check zone and air loop balances

Conservation of mass is checked for each zone and each air loop and a warning is reported for any imbalance.

Figure 2. Zone air balance flow chart
(for standard case without automatic adjustment of infiltration and mixing flows).

Calculation example

For the system shown in Figure 1, assume the inlet (supply) and exhaust flow rates shown in Table 1 and the system flows shown in Table 2. The optional zone air mass balance is not active. The results of each step are shown in Table 3.

Table 1. Example Calculation Zone Assumptions

	Zone 1	Zone 2
System A Inlets	1.00	2.00
System B Inlets	0.25	0.50
Exhaust	0.25	0.00

Table 2. Example Calculation System Assumptions

	System A	System B
Design Return Fraction	1.00	1.00
Outdoor Air	0.00	0.75

Table 3. Example Calculation

	Zone 1	Zone 2
Step 1		
Total Inlets	1.25	2.50
Total Exhaust	0.25	0.00
Expected Total Return	1.00	2.50
Step 2		
Return A	1.00	2.00
Return B	0.25	0.50
Initial Total Return	1.25	2.50
Step 3		
Total > Expected?	1.25 > 1.00	2.50 = 2.50
AdjFactor	$(1 - (1.25 - 1.0)/0.25) = 0.0$	n/a
Return A	1.00 "fixed"	2.00
Return B	$0.0 \times 0.5 = 0.0$	0.50
Final Total Return	1.00	2.50
Step 4		
	n/a	n/a
Step 5		
Total Supply	3.00	0.75
Total Exhaust	0.00	0.25
Total Return	3.00	0.50
Imbalance	0.00 ok	0.00 ok

Simulation example

DOAS with parallel VAV AHU

The example case is a five-zone building similar to the one illustrated in Figure 1. The building is served by two air handlers:

- System A is a 100% recirculating VAV system serving the space conditioning load.
- System B is a dedicated outdoor air system (DOAS) with 100% outdoor air and no return path.
- Zone 1 has an exhaust fan.

Old method – Single AHU with multiple outdoor air units

Prior to the new multiple-AHU capabilities, the only way to model this configuration was to use a VAV AHU plus multiple zone outdoor air units. The system schematic for the first two zones are shown in Figure 3. System A is the VAV AHU serving five zones. (*Reference AirLoopHVAC, AirTerminal:SingleDuct:VAV:Reheat.*) System B (the DOAS) is divided into five outdoor air units, one for each zone. (*Reference ZoneHVAC:OutdoorAirUnit.*) These units are similar to a fancoil unit, with a fan, cooling coil, and heating coil in each zone, greatly increasing the number of components to be input and simulated. This method is awkward to set up, especially for a large building, and it does not correctly model the part-load operation of the DOAS coils.

New method – Two AHUs

With the new multiple-AHU capabilities, the system is modeled with two AHUs similar to Figure 1. System A is the VAV AHU serving five zones. (*Reference AirLoopHVAC, AirTerminal:SingleDuct:VAV:Reheat.*) System B is the DOAS AHU serving five zones. (*Reference AirLoopHVAC, AirTerminal:SingleDuct:VAV:NoReheat.*) If the DOAS AHU does not collect air for heat recovery, then the return side of the loop may be omitted. This method allows more efficient and intuitive input using the same number of coils and other components as the actual system design.

Simulation results

Key simulation results are summarized in Table 4 with yellow highlights indicating values which are significantly different (i.e. incorrect) using the old method. The key difference in the two simulations comes from the oversized chiller and boiler using the old method. This also results in oversized pumps which significantly increases the pump power which then increases the required cooling electricity to offset the added pump power. EnergyPlus v9.1.0 was used for these results. The new method results in a slight reduction in simulation elapsed time.

Conclusion

The new multiple-AHU zone air balance method in EnergyPlus has increased the range of applications which can be modeled while simplifying input requirements and adding flexibility. The method can be used to model various applications including pressurized systems

(hospital), transfer air (food service), dedicated outdoor air systems in parallel with multi-zone VAV systems (school), and systems with no return (warehouse). The new method also avoids sizing and other control pitfalls, providing greater confidence in the simulation results.

Figure 3. System schematic for single AHU with multiple single-zone outdoor air units.

Table 4. Simulation results comparing new method vs. old. Yellow highlights indicate significant differences.

	Old	New
Heating Gas [GJ]	59.1	59.6
Cooling Electricity [GJ]	24.2	18.8
Fan Electricity [GJ]	10.5	10.5
Pump Electricity [GJ]	9.2	2.1
Total Site Energy [GJ]	102.9	91.0
Chiller Capacity [kW]	34.2	29.0
Boiler Capacity [kW]	40.9	26.6
Elapsed Time [mm:ss]	04:31	04:11

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Nomenclature

<i>AdjFactor</i>	Flow adjustment factor
<i>m</i>	Mass flow rate [kg/s]
<i>ReturnFrac</i>	Loop design return fraction
<i>ZoneSch</i>	Zone return schedule fraction

Subscripts

<i>basis</i>	Return flow basis node
<i>exhaust</i>	Exhaust node (flow leaving the zone)
<i>expected</i>	Expected zone return flow
<i>final</i>	Final flow rate after adjustments
<i>initial</i>	Initial flow rate before adjustments
<i>inlet</i>	Inlet node (flow entering the zone)
<i>variable</i>	Return node not tagged as “fixed”
<i>return</i>	Return node (to an AHU)
<i>zone</i>	Total zone return flow
<i>i, j</i>	Summation indices
<i>k</i>	Number of return flow basis nodes
<i>l</i>	Number of return nodes
<i>m</i>	Number of inlet nodes
<i>n</i>	Number of exhaust nodes

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