COMPARISON OF ENERGYPLUS AND DOE-2 DETAILED WINDOW HEAT TRANSFER MODELS

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ABSTRACT

Two commonly used building energy simulation engines, EnergyPlus and DOE-2, can differ significantly in their calculations of window heating load. In this paper, the authors identify the issues in the window heat transfer algorithms used in detailed window models, and provide suggested changes to make the calculations more accurate. We estimate that up to 82% of the observed differences can be resolved through the suggested changes.

The methodology employed for this investigation involved programming the algorithms from the respective simulation engines in the Engineering Equation Solver (EES) so that the impact of each proposed change could be investigated and quantified independently.

INTRODUCTION

Window heat transfer represents a significant portion of the overall heating load in buildings. This is especially true for the tens of millions of older homes with single pane windows. When assessing these buildings for energy savings potential through retrofits, it is important to be able to accurately predict the heat transfer through the windows. For single pane windows, the predicted heat transfer is more sensitive to the convection and radiation boundary conditions than it is for multiple-pane, less-conductive window types.

Two commonly used building energy simulation engines, EnergyPlus (version 6.0.0.023) (U.S. Department of Energy, 2010) and DOE-2 (version 2.2-47h2) (James J. Hirsch & Associates, 2010), both offer a number of ways to model window heat transfer. A comparison of each window model is presented in Table 1.

The inputs for many of the more detailed models are not often available in most applications of energy modeling. Therefore, it is desirable to have a model – such as the EnergyPlus detailed model with simple inputs – that can provide a detailed level of analysis given a limited, but readily-available set of inputs [e.g., the information provided on an NRFC (National Fenestration Rating Council) energy performance label].

Although the EnergyPlus detailed model with simple inputs is not explicitly available in DOE-2, it is possible to use the same methodology to create a near-equivalent model using the WINDOW software (LBNL, 2012) input method for the DOE-2 detailed model. This simple input methodology is thoroughly described in Arasteh et al. (2009).

Kruis et al. (2012) compared results between EnergyPlus and DOE-2 [each using the detailed model with the simple input methodology described by Arasteh et al. (2009)] and found significant differences in the calculation of the window boundary conditions (i.e., exterior convection, interior convection, and interior radiation) causing up to 41% difference in the predicted net window heating load (including impacts of solar gains). The differences found in the boundary condition algorithms are described and quantified in this paper.

INTERIOR CONVECTION

Interior convection is modeled as natural convection for both EnergyPlus and DOE-2.

EnergyPlus

EnergyPlus uses the ISO (2003) correlation to calculate the interior convection coefficient:

$$h_{c,int} = \frac{\text{Nu} \cdot \lambda}{H} \tag{1}$$

where

$$\text{Nu} = \begin{cases} 0.56 \cdot \left(\text{Ra}_H \cdot \sin\left(\frac{\phi}{2}\right) \right)^{1/4} & \text{Ra}_H \leq \text{Ra}_{cv} \\[2ex] 0.13 \cdot (\text{Ra}_H^{1/3} - \text{Ra}_{cv}^{1/3}) \\ \quad + 0.56 \cdot \left(\text{Ra}_{cv} \cdot \sin(\frac{\phi}{2}) \right)^{1/4} & \text{Ra}_H > \text{Ra}_{cv} \end{cases} \tag{2}$$

$$\text{Ra}_{cv} = 2.5 \times 10^5 \cdot \left(\frac{e^{0.72 \cdot \frac{\phi}{2}}}{\sin\left(\frac{\phi}{2}\right)} \right)^{1/5} \tag{3}$$

$$\text{Ra}_H = \frac{\rho^2 \cdot H^3 \cdot g \cdot c_P \cdot |T_{win} - T_{in}|}{T_{m,f} \cdot \mu \cdot \lambda} \tag{4}$$

$$T_{m,f} = T_{in} + \frac{T_{win} - T_{in}}{4} \tag{5}$$

*Table 1: Comparison of window models available in EnergyPlus and DOE-2. Rows that are **bold** are the models that are used for the analysis in this report.*

Simulation Engine	Model	Input	Inputs	Deficiencies
EnergyPlus DOE-2	Detailed Detailed	Detailed Detailed	• Layer-by-layer construction with average spectral properties[*] • WINDOW software output	• Input requires in-depth knowledge of glazing system
EnergyPlus **DOE-2**	**Detailed** **Detailed**	**Simple** **Simple**[†]	NFRC rating metrics: • solar heat gain coefficient • U-factor • visible transmittance	• Less control over spectral properties than detailed models • Radiation/convection effects between panes are not explicitly calculated at each timestep
DOE-2	Simple	Simple[‡]	• Shading coefficient • window conductance • visible transmittance	• Less control over spectral properties than detailed models • Radiation/convection effects between panes are not explicitly calculated at each timestep • Input does not correspond directly with NFRC rating metrics • Model does not account for variations in optical properties at off-normal solar incidence • Interior convection and radiation heat transfer coefficients are constant

[*]EnergyPlus also has the capability to use full spectral properties.
[†] This model is not explicitly available in DOE-2 (see explanation in introduction).
[‡]The calculation methodology in this model is significantly different than the other more detailed models. Not all of the issues discussed in this paper apply to this model.

$$\lambda = 2.873 \times 10^{-3} \left[\frac{\text{W}}{\text{m} \cdot \text{K}} \right] + 7.76 \times 10^{-5} \left[\frac{\text{W}}{\text{m} \cdot \text{K}^2} \right] \cdot T_{m,f} \quad (6)$$

$$\mu = 3.723 \times 10^{-6} \, [\text{Pa} \cdot \text{s}] + 4.94 \times 10^{-8} \left[\frac{\text{Pa} \cdot \text{s}}{\text{K}} \right] \cdot T_{m,f} \quad (7)$$

DOE-2

The DOE-2 detailed model uses a correlation from the fenestration chapter of the 1993 ASHRAE Handbook (ASHRAE, 1993, ch. 27):

$$h_{c,int} = 1.77 \left[\frac{\text{W}}{\text{m}^2 \cdot \text{K}^{5/4}} \right] \cdot \Delta T^{1/4} \quad (8)$$

The resulting interior convection coefficient is then adjusted to account for non-vertical window tilts.

Curcija and Goss

In the 1997 ASHRAE Handbook (ASHRAE, 1997), Eq. (8) was replaced by a new correlation from Curcija and Goss (1995):

$$h_{c,int} = 1.46 \left[\frac{\text{W}}{\text{m}^{7/4} \cdot \text{K}^{5/4}} \right] \cdot \left(\frac{\Delta T}{H} \right)^{1/4}, \quad (9)$$

which has a dependence on the height of the window.

Results

The results show that it is important to incorporate a dependence on the height of the window into the interior convection algorithm, which the current DOE-2 algorithm does not do.

The 1997 ASHRAE Handbook correlation gives very good agreement with the ISO correlation for most building applications, i.e., vertical windows with convection in the sub-critical flow regime ($\text{Ra}_H \leq \text{Ra}_{cv}$). However, ISO provides the most complete correlation – accounting for window tilt, second-order temperature dependencies and multiple buoyant flow regimes.

Comparisons of all three correlations are shown in Figure 1.

<u>EXTERIOR CONVECTION</u>

Exterior convection has both a natural (buoyancy-driven) component and a forced (wind-driven) component. EnergyPlus and DOE-2 use the same algorithm for the natural convection, but there are differences in the calculation of forced convection.

For exterior building surfaces, the forced convection coefficient varies with the wind speed near the surface. In EnergyPlus and DOE-2, the wind speed near each surface is calculated from the weather station wind speed using an assumed height-varying velocity profile, the shape of which depends on the characteristics of the local terrain. *(In DOE-2, this near-surface wind speed is used to cal-*
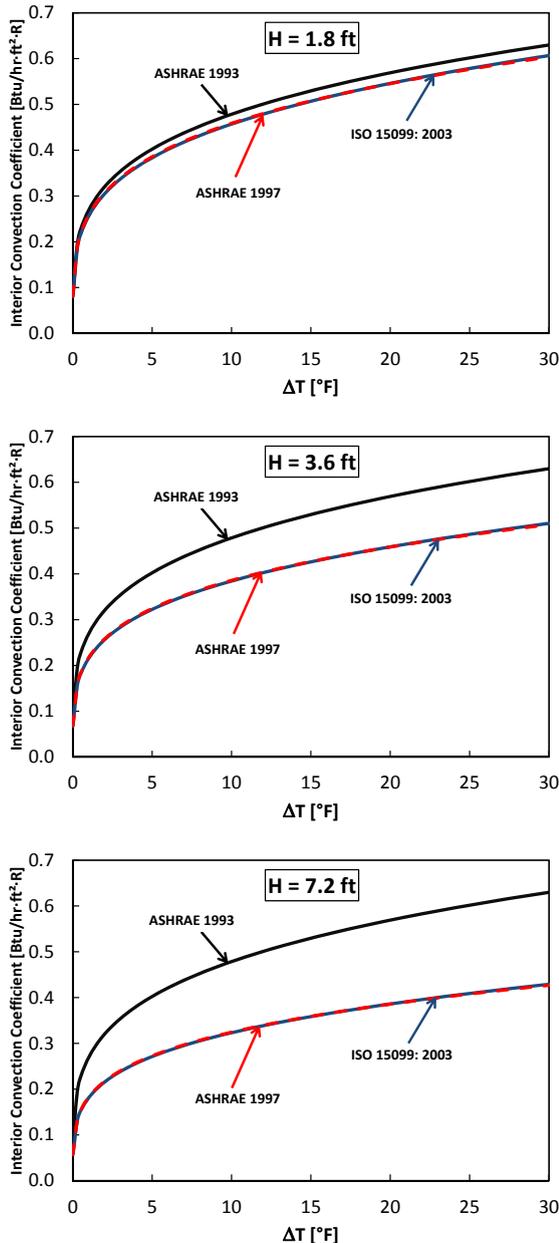
Figure 1: Comparison of three interior convection heat transfer coefficient correlations for windows. EnergyPlus models use ISO 15099: 2003, and the DOE-2 detailed model uses ASHRAE 1993.

culate the forced convection coefficient for every surface except windows using the detailed model, which use the weather station wind speed.)

EnergyPlus and DOE-2 both reference the MoWiTT (Mobile Window Thermal Test facility) correlation for exterior forced convection put forth by Yazdanian and Klems (1994). However, in the MoWiTT correlation, the forced exterior convection coefficient is a function of the wind speed measured at 10 meters (and not the wind speed near the surface where the exterior convection was measured). Therefore, *the MoWiTT correlation, as described by Yazdanian and Klems, is not appropriate for use with the near-surface wind speeds calculated by the simulation engines.*

The MoWiTT correlation can be adjusted to apply appropriately with the use of near-surface wind speeds.

MoWiTT Background

The original MoWiTT correlation for exterior forced convection is:

$$h_{c,ext,f} = a \cdot V^b \qquad (10)$$

where a and b are constants defined in Table 2, and V is the measured wind speed at the MoWiTT test site, 10 meters above the ground.

Table 2: MoWiTT forced convection regression coefficients (from Yazdanian and Klems (1994))

	a	b
SI Units:	$\left[\dfrac{\mathrm{W}}{\mathrm{m^2 \cdot K \cdot (m/s)}^b}\right]$	$[-]$
Windward	2.38 ± 0.036	0.89 ± 0.009
Leeward	2.86 ± 0.098	0.617 ± 0.017
IP Units:	$\left[\dfrac{\mathrm{Btu}}{\mathrm{hr \cdot ft^2 \cdot R \cdot (mph)}^b}\right]$	$[-]$
Windward	0.203 ± 0.005	0.89 ± 0.01
Leeward [†]	0.335 ± 0.016	0.59 ± 0.017

[†]The leeward values in IP units appear to be incorrect based on unit conversion inconsistency in the source document (Yazdanian and Klems, 1994). They are presented for reference only and are not used elsewhere in this document.

Based on the location of the MoWiTT facility on the University of Nevada, Reno campus, and the description and the photograph in Yazdanian and Klems' publication:

- the terrain is assumed to be classified as "urban, industrial or forest area" in Tables 3 and 5 ($\alpha_M = 0.22$, and $TP2_M = 0.25$)

- the weather station height, $z_{M,ws}$, is 10 m (32.8 ft),

- the window centroid height, $z_{M,win\,c}$, (used to define the wind speed near the window in EnergyPlus) is assumed to be 2 m (6.6 ft), and

- the space height, $z_{M,sp\,ht}$, (used to define the wind speed near the window in DOE-2) is assumed to be 3.2 m (10.5 ft).

With this information and the definitions of near-surface wind speeds used by each simulation engine, we will develop a simulation engine specific regression coefficient, a^*, that will apply appropriately for use with near-surface wind speeds.

EnergyPlus

EnergyPlus calculates the near-surface wind speeds at the height of the surface centroid (z_{surf}):

$$V_{surf} = V_{ws} \cdot \left(\frac{\delta_{ws}}{z_{ws}} \right)^{\alpha_{ws}} \cdot \left(\frac{z_{surf}}{\delta_{local}} \right)^{\alpha_{local}} \quad (11)$$

Values for the terrain parameters δ_{ws}, δ_{local}, α_{ws} and α_{local} are given in Table 3.

Table 3: EnergyPlus terrain correction parameters [from U.S. Department of Energy (2010)]

Terrain Description	δ [m]	α
Ocean or large body of water	210	0.10
Flat terrain with isolated obstacles	270	0.14
Rural area with low buildings	370	0.22
Urban, industrial or forest area	370	0.22
Cities	460	0.33

The window-centroid wind speed in the MoWiTT situation (see Figure 2) can be estimated using Eq. (11):

$$V_{M,win\,c} = V_{M,ws} \cdot \left(\frac{\delta_{M,ws}}{z_{M,ws}} \right)^{\alpha_{M,ws}} \cdot \left(\frac{z_{M,win\,c}}{\delta_{M,local}} \right)^{\alpha_{M,local}} \quad (12)$$
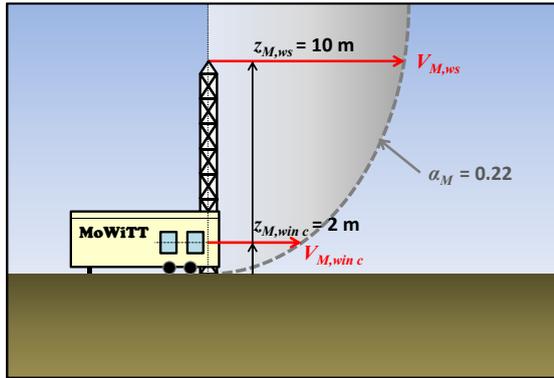

Figure 2: EnergyPlus wind speed adjustment for the MoWiTT facility (near-window wind speed defined at the window-centroid height)

Since the weather station and the MoWiTT facility were on the same site the terrain around both is characterized identically (i.e., $\delta_{M,ws} = \delta_{M,local}$ and $\alpha_{M,ws} = \alpha_{M,local} = \alpha_M$) giving us:

$$V_{M,win\,c} = V_{M,ws} \cdot \left(\frac{z_{M,win\,c}}{z_{M,ws}} \right)^{\alpha_M}$$
$$= V_{M,ws} \cdot \left(\frac{2\text{ m}}{10\text{ m}} \right)^{0.22} \quad (13)$$
$$= V_{M,ws} \cdot 0.702$$

Next, we use Eq. (10) and introduce the new regression coefficient, a^*, to relate the forced convection coefficient, $h_{c,ext,f}$, to the window-centroid wind speed:

$$h_{c,ext,f} = a \cdot V^b = a \cdot V_{M,ws}^b = a^* \cdot V_{M,win\,c}^b \quad (14)$$

The window-centroid wind speed correction from Eq. (13) is substituted to give:

$$a \cdot V_{M,ws}^b = a^* \cdot (V_{M,ws} \cdot 0.702)^b \quad (15)$$

Eq. (15) simplifies to solve for a^*:

$$a^* = \frac{a}{0.702^b} \quad (16)$$

Eq. (16) has been evaluated for both windward and leeward window positions to provide the proposed regression coefficients in Table 4.

Table 4: EnergyPlus adjusted forced convection regression coefficients (for use with window-centroid height local wind speeds)

	a^*	b
SI Units:	$\left[\frac{\text{W}}{\text{m}^2 \cdot \text{K} \cdot (\text{m/s})^b} \right]$	[−]
Windward	3.26	0.89
Leeward	3.55	0.617

DOE-2

DOE-2 calculates the near-surface wind speeds at the height of the space, $z_{sp\,ht}$, to which the surface belongs:

$$V_{sp\,ht} =$$
$$V_{ws} \cdot \frac{TP1_{local}}{TP1_{ws}} \cdot \left(\frac{z_{sp\,ht}}{32.8\text{ ft}} \right)^{TP2_{local}} \cdot \left(\frac{32.8\text{ ft}}{z_{ws}} \right)^{TP2_{ws}} \quad (17)$$

Values for the terrain parameters $TP1_{ws}$, $TP1_{local}$, $TP2_{ws}$ and $TP2_{local}$ are given in Table 5.

The window-space wind speed in the MoWiTT situation (see Figure 3) can be estimated using Eq. (17):

$$V_{M,sp\,ht} =$$
$$V_{M,ws} \cdot \frac{TP1_{M,local}}{TP1_{M,ws}} \cdot \left(\frac{z_{M,sp\,ht}}{32.8\text{ ft}} \right)^{TP2_{M,local}} \cdot \left(\frac{32.8\text{ ft}}{z_{M,ws}} \right)^{TP2_{M,ws}}$$
$$(18)$$

Table 5: DOE-2 terrain correction parameters [from James J. Hirsch & Associates (2010)]

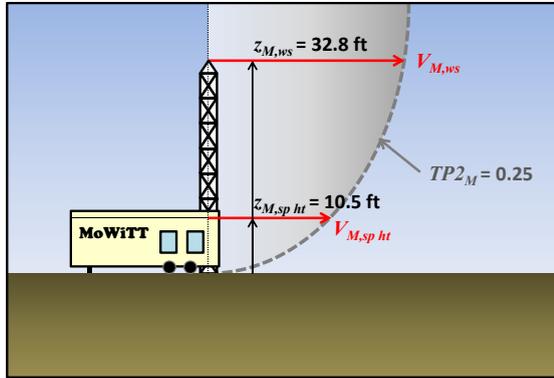| Terrain Description	$TP1$	$TP2$
Ocean or large body of water	1.30	0.10
Flat terrain with isolated obstacles	1.00	0.15
Rural area with low buildings	0.85	0.20
Urban, industrial or forest area	0.67	0.25
Cities	0.47	0.35

Figure 3: DOE-2 wind speed adjustment for the MoWiTT facility (near-window wind speed defined at the window-space height)

Since the weather station and the MoWiTT facility were on the same site the terrain around both is characterized identically (i.e., $TP1_{M,ws} = TP1_{M,local}$ and $TP2_{M,ws} = TP2_{M,local} = TP2_M$) giving us:

$$
\begin{aligned}
V_{M,sp\,ht} &= V_{M,ws} \cdot \left(\frac{z_{M,sp\,ht}}{z_{M,ws}} \right)^{TP2_M} \\
&= V_{M,ws} \cdot \left(\frac{10.5\ \text{ft}}{32.8\ \text{ft}} \right)^{0.25} \quad (19) \\
&= V_{M,ws} \cdot 0.752
\end{aligned}
$$

Next, we use Eq. (10) and introduce the new regression coefficient, a^*, to relate the forced convection coefficient, $h_{c,ext,f}$, to the window-space wind speed:

$$
h_{c,ext,f} = a \cdot V^b = a \cdot V_{M,ws}^b = a^* \cdot V_{M,sp\,ht}^b \quad (20)
$$

The window-space wind speed correction from Eq. (19) is substituted to give:

$$
a \cdot V_{M,ws}^b = a^* \cdot (V_{M,ws} \cdot 0.752)^b \quad (21)
$$

Eq. (21) simplifies to solve for a^*:

$$
a^* = \frac{a}{0.752^b} \quad (22)
$$

Eq. (22) has been evaluated for both windward and leeward window positions with the SI-unit values of a (converted to $\text{Btu}/\left[\text{hr} \cdot \text{ft}^2 \cdot \text{R} \cdot (\text{knots})^b\right]$) in Table 2 to give the proposed changes to the regression coefficients in Table 6.

Table 6: DOE-2 adjusted forced convection regression coefficients [for use with window-space height local wind speeds (in knots)]

	a^*	b
IP Units:	$\left[\dfrac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{R} \cdot (\text{knots})^b} \right]$	$[-]$
Windward	0.299	0.89
Leeward	0.399	0.617

Note that the derived values of a^* are similar to the values of a used in the DOE-2 source code (Table 7). The values in the source code may result from a similar (though undocumented) adjustment to the MoWiTT correlation perhaps with different assumptions.

Table 7: DOE-2 source code forced convection regression coefficients

	a^*	b
IP Units:	$\left[\dfrac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{R} \cdot (\text{knots})^b} \right]$	$[-]$
Windward	0.289	0.89
Leeward	0.391	0.614

Results

The adjusted forced convection heat transfer coefficients resulting from using the near-surface wind speed in the DOE-2 detailed model and applying the adjusted MoWiTT correlation to both simulation engines can be seen in Figure 4.

INTERIOR RADIATION

The interior radiation algorithms in EnergyPlus and DOE-2 use fundamentally different heat balance methodologies, and it is not practical to change DOE-2 to calculate the surface temperatures required to perform similar radiative exchange calculations to those of EnergyPlus.

EnergyPlus

EnergyPlus takes a physically fundamental approach to estimating heat radiated between windows and other surfaces in a zone (each at their own calculated interior temperature). EnergyPlus employs a radiation matrix method called "Script F" from Hottel and Sarofim (1967) to estimate the net radiation exchange for each surface within the zone. This method requires the calculation of the interior temperature of each surface in the zone.
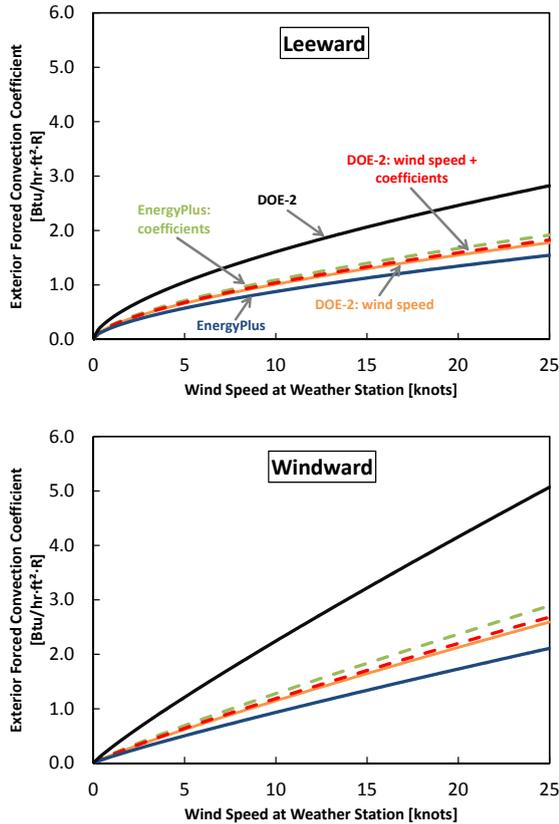
Figure 4: Exterior forced convection heat transfer coefficient for EnergyPlus and DOE-2 detailed models (z_{win} = 5.2 ft, z_{space} = 8 ft, z_{ws} = 32.8 ft weather station: "flat terrain with isolated obstacles", local terrain: "urban, industrial or forested area")

DOE-2

In the DOE-2 detailed model, interior radiation is modeled under the assumption that each window radiates to other surfaces all at the same temperature as the air in the zone:

$$Q_{IR} = \varepsilon_{win} \cdot \sigma \cdot A_{win} \cdot \left(T_{win}^4 - T_{in}^4\right) \qquad (23)$$

EXTERIOR RADIATION

There are no differences in the calculated exterior radiation between EnergyPlus and DOE-2 window models. In both models, surfaces exchange radiation with the ground, the air, and the sky with view factors determining the relative contribution of each component to total heat transfer.

ESTIMATED IMPACTS

The impacts of the different calculations of the boundary conditions described in the previous sections were es-

timated using a simplified test case.

Test Case Description

In the test case, annual window heat loss was calculated for a building with a simple geometry:

- A single zone the shape of a cube: 8 ft × 8 ft × 8 ft

- One single-pane window, 15% of the area of a single wall: 3.6 ft high × 2.7 ft wide = 9.6 ft^2

All of the opaque surfaces (walls, floor, and ceiling) of the room were modeled as adiabatic, massless surfaces. This simplified the heat balance of the wall surfaces to have only radiation or convection heat transfer components (i.e., there is no conduction component). The indoor temperature was controlled at 71°F.

Window heat loss was simulated using Chicago TMY3 (NREL, 2010) weather (with solar radiation values set to zero) and terrain characterized as "urban, industrial or forest area" for the purposes of wind speed adjustment calculations. The heat loss calculated represents only the outward heat loss through the window. (Kruis et al. (2012) found that the difference between EnergyPlus and DOE-2 window heating loads has little dependence on transmitted and absorbed solar radiation.)

EES Methodology

The algorithms, as they were found in the EnergyPlus and DOE-2 source code, were re-programmed into Engineering Equation Solver (EES) (F-Chart Software, 2010). The impact of possible changes to the simulation engine algorithms were then evaluated in EES rather than modifying and recompiling the executable programs for EnergyPlus and DOE-2.

Results

Simulating the annual window heat loss in EES using the algorithms as they appear in the source code of EnergyPlus and DOE-2 shows an estimated 18.3% difference as seen in Figure 5 (note: the percent difference in annual net window heating load, including the impacts of solar gain, is approximately twice as large). The updates and fixes to the identified issues eliminate all but 3.3% of the difference. Based on modeling in EES, the remaining difference appears to be related to the fundamentally different interior radiation algorithms.

CONCLUSIONS

Four issues were identified in the detailed window models in EnergyPlus and DOE-2 related to the calculation of the window heat transfer boundary conditions. The following changes are proposed to address issues identified in the source code of the simulation engines. Impacts on the difference between EnergyPlus and DOE-2 (detailed model) window heat loss, based on EES representation of
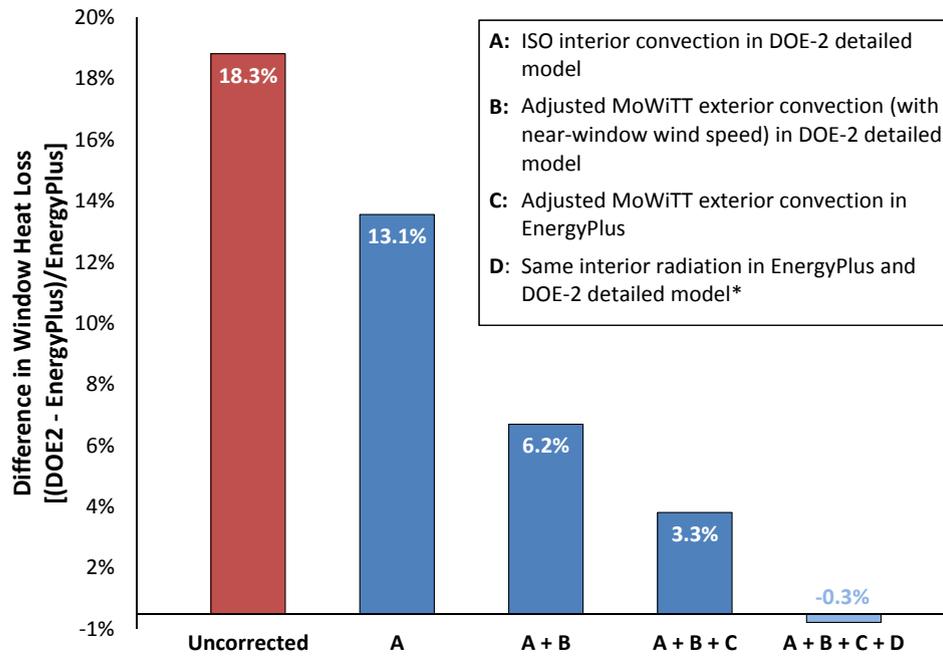
*These results show the impact of using EnergyPlus-like zone radiation exchange in EnergyPlus and DOE-2 (modeled in EES) . It is not deemed practical to add a radiative exchange algorithm to DOE-2.

Figure 5: Estimated cumulative impacts of source code changes plus use of an EnergyPlus-like interior radiation algorithm in EnergyPlus and DOE-2 (on single-pane window heat loss modeled in EES for the simplified test case with Chicago TMY3 weather file without solar).

window heat transfer algorithms, are shown in parentheses.

A: The interior convection algorithm in DOE-2 is out of date and should be updated to incorporate a dependence on the height of the window. (Window heat loss is reduced, resulting in a 28% reduction of the simulation engine difference.)

B: The exterior forced convection coefficient in DOE-2 should be calculated using (1) the near-surface wind speed for detailed window models (as it is for other surfaces), not the weather station wind speed and (2) adjusted MoWiTT regression coefficients that are appropriate for use with near-surface wind speeds. (Window heat loss is reduced, resulting in a 38% reduction of the simulation engine difference.)

C: The exterior forced convection coefficient in EnergyPlus should be calculated using adjusted MoWiTT regression coefficients that are appropriate for use with near-surface wind speeds. (Window heat loss is increased, resulting in a 16% reduction of the simulation engine difference.)

D: The interior radiation algorithms in EnergyPlus and

DOE-2 are fundamentally different. Reconciling interior radiation would require changes to the fundamental heat balance methodologies used by the simulation engines and is beyond the scope of this work. (However, in the EES model, if an EnergyPlus-like interior radiation algorithm is used in DOE-2, window heat loss is reduced resulting in an 18% reduction of the simulation engine difference.)

There were no issues identified related to the transmitted/absorbed solar radiation or the exterior radiation algorithms.

Implementing the proposed changes will improve the accuracy, and therefore the consistency, of window heating load calculations in EnergyPlus and DOE-2. (The combination of all of the proposed changes addresses 82% of the original simulation engine difference. The remaining 18% of the difference is likely related to fundamental differences between interior radiation algorithms.)

ACKNOWLEDGMENTS

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NOMENCLATURE

a	MoWiTT convection regression coefficient (multiplier)
a^*	Adjusted MoWiTT convection regression coefficent (multiplier)
A_{win}	Window area
α	Wind boundary layer exponent
b	MoWiTT convection regression coefficient (exponent)
c_P	Specific heat of air
δ	Wind boundary layer thickness
ΔT	Absolute value of temperature difference
EES	Engineering Equation Solver
ε_{win}	Emissivity of the window
g	Gravitational constant
H	Height (dimension)
$h_{c,ext,f}$	Exterior forced convection heat transfer coefficient
$h_{c,int}$	Interior convection heat transfer coefficient
λ	Thermal conductivity of air
local	Subscript denoting "local terrain"
M	Subscript denoting "MoWiTT test conditions"
MoWiTT	Mobile Window Thermal Test facility
μ	Dynamic viscosity
NFRC	National Fenestration Rating Council
Nu	Nusselt number
ϕ	Surface tilt
Q_{IR}	Radiation heat transfer rate
Ra_H	Rayleigh number (height based)
Ra_{cv}	Critical value of Rayleigh number
ρ	Density of air
σ	Stephan-Boltzmann constant
T_{in}	Indoor air temperature
$T_{m,f}$	Indoor mean air film temperature
$TP1$	DOE-2 terrain parameter #1
$TP2$	DOE-2 terrain parameter #2
T_{win}	Window surface temperature
V	Wind speed
$V_{sp\,ht}$	Wind speed at the space to which a surface belongs
V_{surf}	Wind speed at a surface
$V_{win\,c}$	Wind speed at a window centroid
ws	Subscript denoting "weather station"
z	Height (relative to the ground)
$z_{sp\,ht}$	Height of the space to which a surface belongs (relative to the ground)
z_{surf}	Height of the centroid of a surface (relative to the ground)
$z_{win\,c}$	Height of the centroid of a window (relative to the ground)