

**COMPARISON OF DOE-2.1E WITH ENERGYPLUS AND TRNSYS FOR
GROUND COUPLED RESIDENTIAL BUILDINGS IN HOT AND HUMID
CLIMATES**

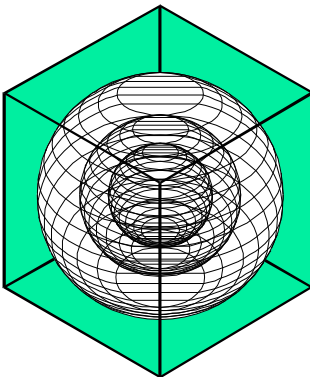
STAGE 4

“Fully Loaded IECC Compliant Slab-on-grade Houses in the Four U.S. Climates”

A Report

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NOMENCLATURE

IGain	daily internal gain per dwelling unit (Btu/day)
CFA	conditioned floor area (ft ²)
N _{br}	number of bedrooms
SLA	specific leakage area (unitless)
L	effective leakage area (ft ²)
R _{eff}	effective resistance of the slab (hr-ft ² -°F/Btu)
A	area of the slab (ft ²)
F2	perimeter conduction factor (Btu/hr-°F-ft)
P _{exp}	exposed perimeter (ft)
U _{eff}	effective U-value of the slab (Btu/hr-ft ² -°F)
R _{us}	actual slab resistance (hr-ft ² -°F/Btu)
R _{slab}	resistance of 4in concrete (hr-ft ² -°F/Btu)
R _{carpet}	resistance of the carpet (hr-ft ² -°F/Btu)
R _{film}	resistance of the inside air film (hr-ft ² -°F/Btu)
R _{soil}	resistance of the soil (hr-ft ² -°F/Btu)
R _{fic}	resistance of the fictitious insulation layer (hr-ft ² -°F/Btu)
GI	ground isolated
EP	modeled with <i>EnergyPlus</i>
D2	modeled with <i>DOE-2</i>
TR	modeled with <i>TRNSYS</i>
GCW	ground coupled with Winkelmann's slab-on-grade model
GCS	ground coupled with <i>Slab</i> model
-eit-	ground coupled by external iteration of <i>EnergyPlus</i> and <i>Slab</i>
-iit-	ground coupled by a single internal iteration of <i>EnergyPlus</i> and <i>Slab</i>
-wtEv	evapotranspiration flag of <i>Slab</i> is on
-wotEv	evapotranspiration flag of <i>Slab</i> is off
GCT	ground coupled with <i>TRNSYS</i> slab-on-grade model
GCTh	hourly <i>TRNSYS</i> slab/soil interface temperatures entered into <i>EnergyPlus</i>
GCTm	monthly <i>TRNSYS</i> slab/soil interface temperatures entered into <i>EnergyPlus</i>
Q _{slab/zair}	heat transfer between the slab and the zone air
Q _{soil/slab}	heat transfer between the soil and the slab
Q _{fm} (s)	monthly average floor heat flux(es)
T _{am} (s)	monthly average outside air temperature(s)
T _g (s)	monthly average deep ground temperature(s) calculated by <i>DOE-2</i> using Kasuda approach
T _{slab/soil} (s)	monthly average interface temperature(s) between the soil and the slab
T _{zair}	zone air temperatures
U _{effective}	effective conductivity of the underground surface
Q _{mod}	floor heat flux at 78°F steady state zone air temperature
Q _{LOADS}	floor heat flux at 70°F steady state zone air temperature
T _{mod}	78°F constant zone air temperature
T _{LOADS}	the 70°F default constant zone air temperature that <i>DOE-2</i> LOADS uses

1. ORGANIZATION OF THE REPORT

This report consists of two sections. The first section is the introduction to the significance of the topic. The second section is a comparative analysis between DOE-2, EnergyPlus and TRNSYS programs for slab-on-grade heat transfer in empty sealed boxes in four U.S. climates.

2. INTRODUCTION

Ground coupled heat transfer (GCHT) through concrete floor slabs can be a significant component of the total load for heating or cooling in low-rise residential buildings. For a contemporary code or above code house, ground-coupled heat losses may account for 30%–50% of the total heat loss [1]. Ground coupling is still considered a hard-to-model phenomenon in building energy simulation since it involves three-dimensional thermal conduction, moisture transport, longtime constants and heat storage properties of the ground [2]. Over the years, many researchers worked on the development of slab-on-grade models. Some used simplified methods for slab-on-grade load calculations [3-5]; whereas others developed more detailed models [6]. For an uninsulated slab-on-grade building, the range of disagreement among simulation tools is estimated to be 25%-60% or higher for simplified models versus detailed models [2].

This study compared *EnergyPlus* and *DOE-2.1e* (*DOE-2*) GCHT for slab-on-grade low-rise residential buildings. *DOE-2* has been used for more than three decades in design studies, analysis of retrofit opportunities and developing and testing standards [7]. In 1996, the U.S.D.O.E.¹ initiated support for the development of *EnergyPlus*, which was a new program based on the best features of *DOE-2* and BLAST [8]. The shift from *DOE-2* to *EnergyPlus* raised questions in the simulation community on the differences between these two simulation programs [9-11]. Ground coupled heat transfer is an area that *EnergyPlus* differs significantly from *DOE-2*. *EnergyPlus* calculates z-transfer function coefficients to compute the unsteady ground coupled surface temperatures [12]; whereas *DOE-2* sets the temperatures of the ground coupled surfaces as steady [13]. The slab-on-grade GCHT models of *DOE-2* and *EnergyPlus* have been compared separately with other programs in order to maintain consistency among the results of current simulation tools for identical cases [2, 14-17]. *EnergyPlus* and *DOE-2* have been compared with each other based on thermal loads, HVAC systems and fuel-fired furnaces using the test cases defined in ANSI²/ASHRAE Standard 140-2007³, which were “effectively decoupled thermally from the ground” [17, 18]. This study extends the previous studies by comparing *EnergyPlus* and *DOE-2* slab-on-grade heat transfer based on the results obtained from IECC⁴ [19] compliant residential buildings in four climates of the U.S. In these comparisons, the *TRNSYS* slab-on-grade model is used as the truth standard for slab-on-grade heat transfer modeling. The reliabilities of the *DOE-2* and *EnergyPlus* slab-on-grade models are then discussed and recommendations are made for the building energy modelers.

This study is divided in two sections. In Section I, empty, adiabatic, ground coupled sealed boxes were modeled using *DOE-2*, *EnergyPlus* and *TRNSYS* programs in order to isolate the slab-on-grade heat transfer from other building load components and compare it between these three programs. In these comparisons, the *TRNSYS* slab-on-grade model was assumed to be the truth standard for slab-on-grade heat transfer modeling. The results of the *DOE-2* and *EnergyPlus* slab-on-grade models were then evaluated based on the closeness of their results to those of the *TRNSYS* slab-on-grade model.

In Section II, load components were added to the sealed boxes modeled in Section I to convert them into fully loaded IECC⁴ [19] compliant houses. The effect of slab-on-grade heat transfer on thermal loads of these houses was then quantified and compared between the *DOE-2*, *EnergyPlus* and *TRNSYS* programs. The findings of this section provided the code users an insight to estimate and understand the thermal load

differences they will obtain if *EnergyPlus* replaces *DOE-2* in energy code compliance calculations of low-rise slab-on-grade residential buildings.

This report includes the results of the second section (Section II) of this study.

1. MODELING OF THE FULLY LOADED IECC COMPLIANT HOUSES

The sealed boxes modeled in section I were added the following features to obtain fully loaded IECC compliant houses located in Austin, TX; Phoenix, AZ; Chicago, IL and Columbia Falls, MT.

- 1) An unconditioned attic
- 2) Standard ceiling and exterior walls
- 3) Windows, doors and shades
- 4) Lights and equipment
- 5) Infiltration

The resulting fully loaded IECC compliant houses are shown in Figure 1.

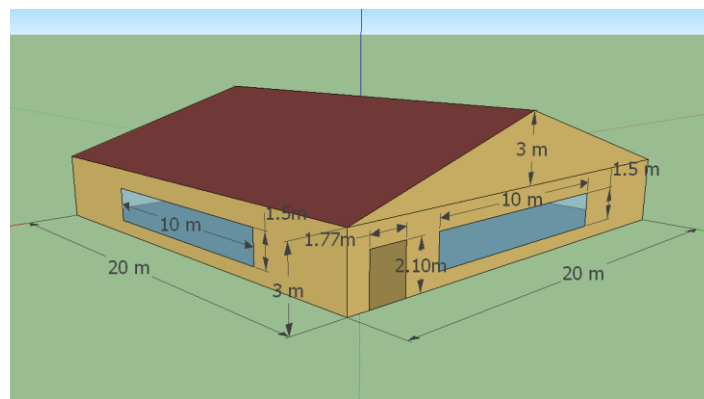


Figure 1. The slab-on-grade fully loaded IECC compliant house.

3.1. Unconditioned Attic

A 3m high unconditioned attic with a gable roof was added to the top of the sealed box turning the ceiling of the sealed box into an interior surface. The features of the roof construction are listed in Table 1.

3.2. Standard ceiling and exterior walls

The adiabatic ceiling and the exterior walls were turned into standard heat transfer surfaces that allow conduction heat transfer.

3.3. Windows, doors and shades

Four windows and a door were added to the exterior walls as described in Table 1. The windows were designed in Window 5.2.17a (Window 5) and imported into *DOE-2*, *EnergyPlus* and *TRNSYS* separately. To do this, *DOE-2* and *EnergyPlus* reports were generated from Window 5 program and then copied into the window dataset files of *DOE-2*, *EnergyPlus* and *TRNSYS* programs. *DOE-2*, *EnergyPlus* and

TRNSYS read the window information from their window dataset files to model the required windows. All windows had interior shades. As required by IECC 2009, from 30th of April until 31st of October, the shading ratio was set to 70%, while at all other times it was set to 85%.

3.4. Lights and equipment

In the IECC⁴ [19], the overall daily average internal gain of a residential building is calculated by Equation 5.

$$\text{IGain} = 17,900 + 23.8 \times \text{CFA} + 4104 \times \text{Nbr} \dots\dots\dots (\text{Equation 5})$$

The fully loaded houses were assumed to have five bedrooms. In Equation 1, the N_{br} value was, therefore, taken as “5.” The total conditioned floor areas (CFA) of the houses were 400m² (4305.6 ft²). When these CFA and N_{br} values were substituted into Equation 5, the internal gains of the houses were calculated to be 140,893.6 Btu/day which corresponded to 5870.5 Btu/hr (1,720.5 Watts). This value was then divided into two and assigned for the lights (860.2 Watts) and the equipment (860.2 Watts) equally. The radiant fraction of the heat generated by the lights was set to 0.71. The remaining 0.29 was then assigned as the fraction of the heat convected to the zone air. The radiant fraction of the heat generated by the equipment was 0.7. The lights and the equipment were always on all through the year to provide an average constant internal load.

3.5. Infiltration

In the IECC⁴ [19], the infiltration requirement of a residential building is defined in terms of Specific Leakage Area (SLA) and the SLA value is required to be 0.00036 assuming no energy recovery. The SLA value is calculated by Equation 6.

$$\text{SLA} = L / \text{CFA} \dots\dots\dots (\text{Equation 6})$$

Substituting the overall conditioned floor areas of the modeled houses (4305.6 ft²) into Equation 6, 1.55 ft² (1,440 cm²) was obtained for the effective leakage area (L) of the main living space of the houses. The IECC also requires a vented aperture of 1 ft² surface area per 300 ft² of the roof area. Since the roof areas of the modeled houses were 4305.6 ft², the effective leakage area (L) of their attics were calculated to be 14.35 ft² (13,333cm²). The final “L” values obtained for the main living space and the attic were then directly entered into *EnergyPlus* and *TRNSYS* as inputs using Sherman Grimsrud Infiltration Model. In *DOE-2*, the “L” values were entered relative to total floor area using the Sherman Grimsrud Infiltration Model in order to model the same infiltration condition.

1. RESULTS AND DISCUSSION

The results of the study are discussed in two sections: 1) The Sealed Boxes and 2) The Fully Loaded Houses. The first section presents the results obtained for the adiabatic, ground coupled sealed boxes and compares the three slab-on-grade models by isolating the ground coupling effect. The second section presents the results obtained for the fully loaded IECC compliant houses and quantifies the significance of the discrepancies in slab-on-grade heat transfer modeling relative to the fully loaded building energy requirement. This report includes the results obtained for the fully loaded IECC compliant houses. The abbreviations used in this section are explained in the nomenclature section of this paper and the generation of the results from the program outputs is described below.

The *DOE-2* thermal loads presented in this study were obtained from the System Monthly Loads Summary (SS-A) reports of *DOE-2* after “SUM” was assigned to the test houses as the “system-type”.

Similarly, the thermal loads of the *EnergyPlus* houses were obtained from the “Zone/Sys Sensible Heating Energy” and “Zone/Sys Sensible Cooling Energy” reports of *EnergyPlus* after the “Ideal Loads Air System” was assigned to the test houses. The *DOE-2* monthly average floor heat fluxes were obtained by modifying the “underground floor conduction gain” values reported by *DOE-2*. This modification was necessary due to the load calculation and reporting differences between *DOE-2* and *EnergyPlus*. In *DOE-2*, thermal loads are calculated in the LOADS subroutine based on a constant zone air temperature throughout the year [22]. The thermal loads calculated in the LOADS subroutine are then transferred into the SYSTEMS subroutine of *DOE-2* where the variations in the zone air temperatures are taken into account [22]. The output for floor conduction heat gain is available only from the LOADS subroutine of *DOE-2*. The values obtained from the LOADS subroutine of *DOE-2*, therefore, had to be multiplied by correction factors to obtain floor heat gain/loss values for the varying zone air temperatures. The resulting *DOE-2* values then became comparable with *EnergyPlus* values. The *EnergyPlus* results were generated by subtracting the “Opaque Surface Inside Face Conduction Loss” values from the “Opaque Surface Inside Face Conduction Gain” values for the ground coupled floor.

4.1. Results for the fully loaded IECC compliant houses

Building thermal load is an important parameter that affects both the magnitude and the direction of the estimated heat flux through the floor. Building load affects the zone air temperatures (T_{zairS}). The zone air temperatures (T_{zairS}) then affect the inside surface temperatures of the floor (T_{is}), which is one of the primary parameters of conductive heat transfer through the floor. *DOE-2*, *EnergyPlus* and *TRNSYS* programs are known to have calculation differences for both aboveground and belowground load components, which result in different annual thermal load estimations for identical conditions [7, 17].

In this part of the study, an unconditioned attic, wall and ceiling heat transfer, windows, doors and shades, lights and equipment and infiltration were added to the sealed boxes. These components were added following the requirements of IECC 2009. As a result, four energy code compliant fully loaded houses located in hot-humid (Austin), hot-dry (Phoenix), temperate (Chicago) and cold (Columbia Falls) climates were obtained. First, these houses were modeled with an adiabatic floor that did not allow conductive heat transfer through the floor and the differences in the thermal load estimates of *DOE-2*, *EnergyPlus* and *TRNSYS* programs were quantified excluding the effect of ground coupling. Second, the adiabatic floors of these houses were converted into standard heat transfer surfaces exposed to the ground and differences between the results of these programs were quantified including the effect of slab-on-grade heat transfer.

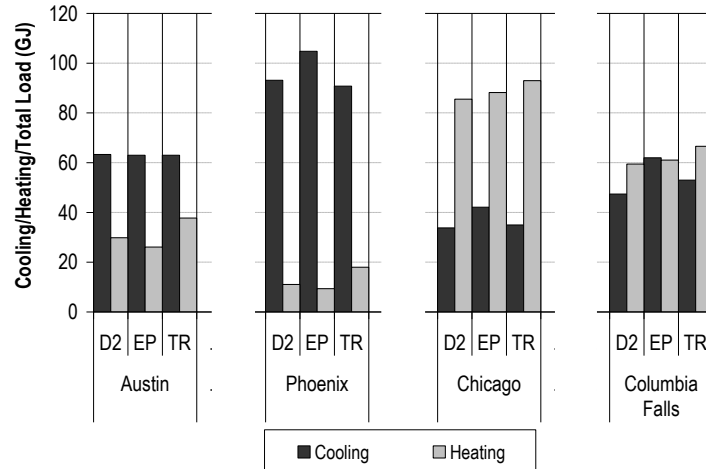


Figure 2. The cooling and heating loads of the ground isolated fully loaded IECC compliant houses.

Figure 2 shows the thermal loads of the fully loaded houses modeled in *DOE-2*, *EnergyPlus* and *TRNSYS* programs in the ground isolated condition. For these houses, the *EnergyPlus* results differed from the *DOE-2* results by 0%-31% in cooling load and 3%-15% in heating load (Figure 2). The magnitude of the difference between the load estimates of the *DOE-2* and *EnergyPlus* programs was not proportional to the magnitude of the load. Thus, the percentage difference between the results of the programs varied from climate to climate. For instance, the heating load estimates of *EnergyPlus* differed from those of *DOE-2* more in hot climates (13%-15%) than in temperate and cold climates (3%). Similarly, the cooling load estimates of *EnergyPlus* program differed from those of *DOE-2* more in temperate and cold climates (25%-31%) than in hot climates (0%-13%).

Based on this fact, our findings were compared with the findings of the studies conducted in similar climates. In an earlier study, Henninger and Witte [17] had compared the results of *DOE-2* and *EnergyPlus* programs in “cold clear winters and hot dry summers” using the 13 ground isolated test cases of ASHRAE Standard 140. They had found that *EnergyPlus* results varied from those of *DOE-2* by 7%-32% in cooling load and by 4%-13% in heating load. Our findings for the cooling load variation in hot-dry summers (13%) and the heating load variation in cold winters (3%) were within the range presented by Henninger and Witte [17].

In the ground isolated condition, one of the primary reasons for the differences in thermal load estimates of *DOE-2* and *EnergyPlus* programs was the different window solar heat gains calculated by these programs from identical Window 5 inputs. *EnergyPlus* showed generally higher (11%-15%) total solar incidents on windows than *DOE-2* did with an exception of the Austin house, which was under an overcast sky most of the year (See the first columns in Figure 3). These total solar incidents included direct and diffuse solar incidents. The direct solar incidents on windows were very similar (within 1%) in the *DOE-2* and *EnergyPlus* programs (Figure 4). The diffuse solar incident on windows, however, showed 6%-33% variation from *DOE-2* to *EnergyPlus* (Figure 4).

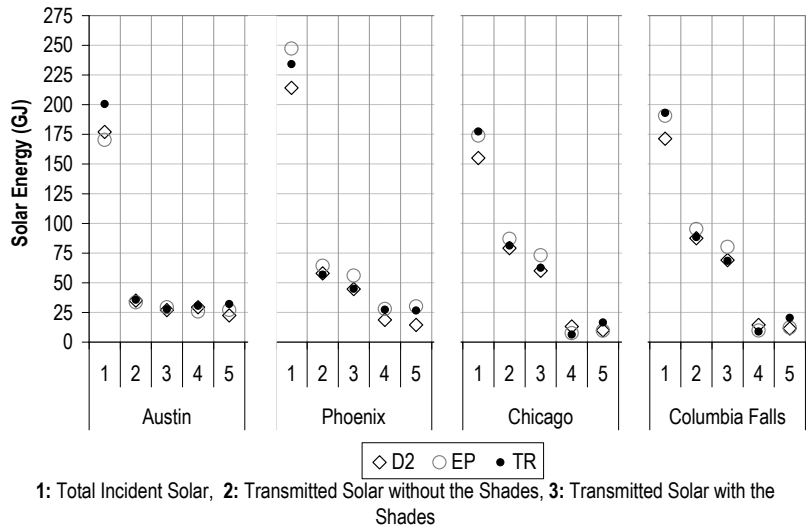


Figure 3. The total incident, transmitted and absorbed solar gains of the fully loaded IECC compliant houses.

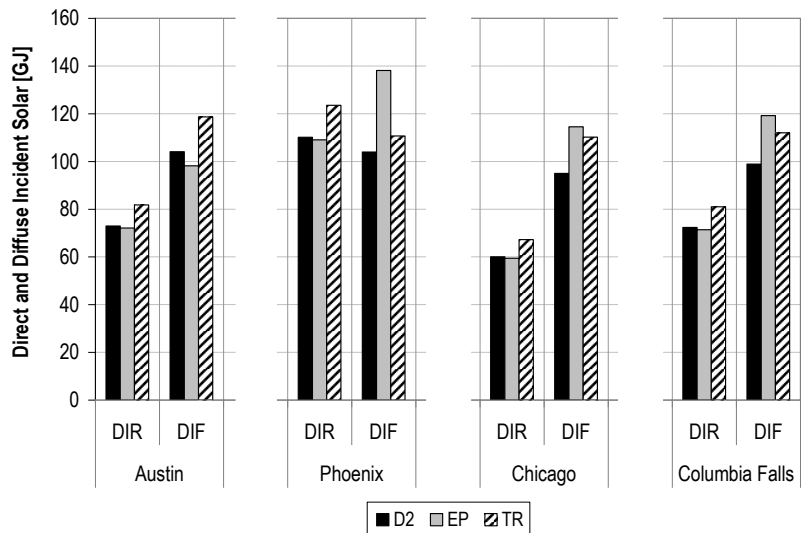


Figure 4. The direct and diffuse incident solar on windows in the fully loaded IECC compliant houses.

For the calculation of the solar incidents on windows, *DOE-2* read both the direct and the diffuse horizontal solar radiation values from the weather file and modified them considering the tilt of the surface, sun's position, cloud cover and the fraction of the hour that the sun was up [22]. *EnergyPlus*, however, calculated each of the direct and diffuse horizontal solar incidents rather than importing them from the weather file. For the calculation of direct horizontal solar incident, *EnergyPlus* used ASHRAE's Clear Sky model which uses the extraterrestrial radiant flux values and the relative mass of the atmosphere [23]. For the calculation of the diffuse horizontal solar incident, *EnergyPlus* then used an anisotropic sky radiance distribution model based on the measurements of Perez et al. [24]. This model

included three superimposed distributions: 1) an isotropic distribution that covers the entire sky dome, 2) a circumsolar brightening centered at the position of the sun and 3) a horizon brightening.

The transmitted solar gains through the glazing layers were 9%-11% higher in *EnergyPlus* than in *DOE-2* in all climates except in the hot-humid climate in Austin (See the second columns in Figure 3). The solar energy absorbed by the glazing layers and transferred to the zone were 12%-50% higher in *EnergyPlus* than in *DOE-2* (See the fourth columns in Figure 3). The introduction of interior shades to these windows further increased the discrepancies between the solar gains calculated by these programs in all climates. For instance, *EnergyPlus* interior shades absorbed a user defined percentage (in this case 1% to minimize difference between programs) of the solar energy transmitted through the glazing. They then transferred this heat by convection into the zone air and into the air gap between the shade and the adjacent glass. These shades also transferred heat back into the zone air by IR radiation and reflected some of the IR radiation back onto the adjacent glazing layers. The introduction of these shades with 80% transmittance finally resulted in 12%-16% decrease in annual transmitted solar gains and 5%-28% increase in annual absorbed solar gains in *EnergyPlus* (See the third and fifth columns in Figure 3). In *DOE-2*, however, the interior shades with 80% transmittance reduced both the transmitted and the absorbed annual solar gains by 20% (See the third and fifth columns in Figure 3). These findings explained the generally higher cooling loads in *EnergyPlus* when compared to those in *DOE-2* in the ground isolated condition (Figure 2).

The solar incidents on windows calculated by *TRNSYS* were similar to those calculated by *EnergyPlus* within 5% except in the Austin house (see the first columns in Figure 3). The absorbed solar gains in *TRNSYS* were also within 19% of those in *EnergyPlus* and showed very high (up to 51%) differences from those in *DOE-2* (See the fourth columns in Figure 3). The transmitted solar gains in *TRNSYS* were, however, generally lower (6%-12%) than those in *EnergyPlus* and were within 3% of those in *DOE-2* (See the third columns in Figure 3). Since the magnitudes of the transmitted solar gains were higher than the absorbed solar gains in all three programs, *TRNSYS* showed closer overall window heat gains to *DOE-2* than to *EnergyPlus* in all houses. This explained the close cooling loads of the *DOE-2* and *TRNSYS* models in all climates. These discrepancies between *DOE-2*, *EnergyPlus* and *TRNSYS* programs in window heat gains showed that the simulation community needs a validated and standardized window heat transfer model in order to provide consistency in residential code compliance calculations.

TRNSYS calculated 1°C-5°C lower zone air temperatures than *EnergyPlus* did all year for the unconditioned empty houses before load components were introduced. This suggested that the opaque building envelopes of the *TRNSYS* houses gained less heat in summer and lost more heat in winter when compared to those of the *EnergyPlus* houses. Thus, the introduction of identical heat gains into these building envelopes resulted in lower cooling loads and higher heat gains in *TRNSYS* than it did in *EnergyPlus*. This finding further explained the 5-12 GJ higher heating loads and 7-14 GJ lower cooling loads of the *TRNSYS* houses when compared to the *EnergyPlus* houses

Another important discrepancy between *DOE-2* and *EnergyPlus* programs occurred in the modeling of air infiltration. Figure 5 presents the annual average air changes per hour and the resulting sensible heat gains and losses in the four fully loaded houses modeled in this study. These values showed that infiltration primarily caused heat losses in the fully loaded houses and these heat losses were higher in temperate and cold climates than they were in hot climates. In temperate and cold climates, identical

infiltration inputs resulted in 4% higher annual average air changes in *EnergyPlus* than in *DOE-2*. These higher air changes then resulted in 9-10 GJ higher sensible heat losses in temperate and cold climates (Figure 5), which became an important factor that explained the 3% higher heating loads in *EnergyPlus* than in *DOE-2* in these climates (Figure 2). The different air changes obtained from *DOE-2* and *EnergyPlus* with identical infiltration inputs were attributed to the different local wind speeds and zone air temperatures calculated by these programs.

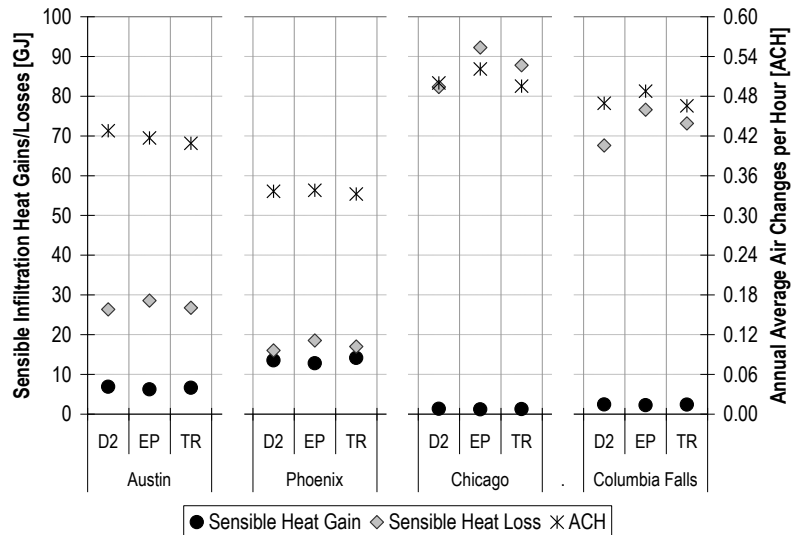


Figure 5. The sensible infiltration heat gains and losses in the fully loaded IECC compliant houses.

Figure 6 shows the heating and cooling loads of the fully loaded *DOE-2*, *EnergyPlus* and *TRNSYS* houses after they were coupled with the ground. The load calculation discrepancies identified between *DOE-2*, *EnergyPlus* and *TRNSYS* programs for the ground isolated houses were also the primary reasons for the thermal load variations between the *D2-GCW* and *EP-GCW* models (the first and second columns in Figure 6) and between the *TR-GCT* and *EP-GCT* models (the eighth and ninth columns in Figure 6). Our comparisons were then isolated from these discrepancies by inserting the slab-soil interface temperatures calculated by each slab-on-grade model into *EnergyPlus* and comparing them in *EnergyPlus* (See columns 2-8 in Figure 6).

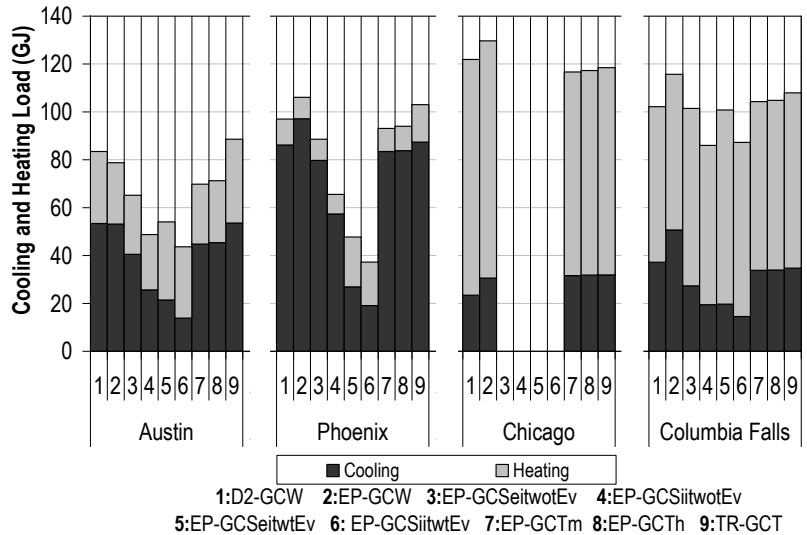


Figure 6. The cooling and heating loads of the slab-on-grade fully loaded IECC compliant houses.

It was found that the *EnergyPlus* total thermal loads for the fully loaded code compliant houses varied by 14%-51% when compared to the averages depending on the selected slab-on-grade model. Among these slab-on-grade models, the *EnergyPlus* model with the hourly *TRNSYS* slab-soil interface temperatures (*EP-GCTh*) represented the most detailed slab-on-grade heat transfer calculations. Using the *TRNSYS* slab-soil interface temperatures in *EnergyPlus* monthly (*EP-GCTm*) instead of hourly (*EP-GCTh*) caused 0%-2% variation in total building load (See the 7th and 8th columns in Figure 6). This finding showed that the slab-soil interface temperatures did not show significant hourly variations in fully loaded houses with zone air temperatures varying between 20°C (68°F) and 25.55°C (78°F). Monthly coupling of above-ground and belowground heat transfer calculations can; therefore, make reasonable enough building load estimates.

Among the studied slab-on-grade models, the *EP-GCS* models without evapotranspiration that iterated externally until the zone air temperatures converged to 0.0001°C (*EP-GCSeitwotEv*) exhibited the closest results to those calculated by the detailed *EP-GCTh* models. These models exhibited only 3%-9% lower total building loads than the *EP-GCTh* models did (See the third and the eighth columns in Figure 6). They also showed cooling and heating loads within 19% and 13% of those of the *EP-GCTh* models respectively. When the *EP-GCS* models iterated internally for once (*EP-GCSiitwotEv*) as recommended in *EnergyPlus* manuals; however, the zone air temperatures did not converge and the estimated total building load became significantly (18%-32%) lower than those calculated by the *EP-GCTh* models for the same houses. This convergence problem was attributed to the zone air temperatures of the fully loaded houses that varied between 20°C (68°F) and 25.55°C (78°F) throughout the year. These findings showed that the current internally iterated *EP-GCS* model needs to be improved before it is used for the modeling of low-rise slab-on-grade houses. The improved model needs to allow for multiple iterations between *EnergyPlus* and *Slab* programs until the zone air temperatures converge. The cooling and heating loads of all studied houses showed only 1% variation between the convergence tolerances of 0.0001°C and 0.1°C for zone air temperatures. It was also found that assigning a high resistance insulation layer under the concrete slab in the first *EnergyPlus* run and removing it in the later runs decreased the number of iterations needed for convergence. With this method, 0.1°C convergence

tolerance that resulted in load estimates within 1% of the fully converged (within 0.0001°C) values was met at the end of the 4th iteration, the latest.

Evaporative transpiration (evapotranspiration) increased the difference between the total thermal load estimates of the *EP-GCS* and *EP-GCTh* models. By considering the evapotranspiration from the soil around the building, the externally iterated *EP-GCS* models (*EP-GCSeitwtEv*) showed 4%-49% lower thermal loads and the internally iterated *EP-GCS* models (*EP-GCSiitwtEv*) showed 17%-60% lower total thermal loads when compared to the *EP-GCTh* models. Evapotranspiration affected both the cooling and heating loads of the fully loaded houses dramatically with a higher impact in hot climates. It decreased the cooling loads by 25%-67% and increased the heating loads by 9%-135% in the fully loaded houses in all studied U.S. climates.

The *EnergyPlus* models with Winkelmann's slab-soil interface temperatures (*EP-GCW*) calculated 10%-13% higher total building loads than the *EP-GCTh* models. The *EP-GCW* models appeared to make better estimates for heating loads (within 16%) than they did for the cooling loads (within 49%) of the slab-on-grade fully loaded houses. The overestimation of cooling loads in the *EP-GCW* model was attributed partly to the fact that Winkelmann's slab-on-grade model was based on earlier calculations of Huang et al. [20] that assumed constant zone air temperatures all year.

5. SUMMARY AND CONCLUSIONS

Early studies have shown that the current energy modeling tools calculate dissimilar results for the slab-on-grade heat transfer. This study quantifies the discrepancies between *DOE-2* and *EnergyPlus* slab-on-grade heat transfer for International Energy Conservation Code (IECC) compliant low-rise 20m x 20m x 3m residential buildings with unconditioned attics in four U.S. climates (hot-humid, hot-dry, cold, and temperate). For the modeling of the slab-on-grade heat transfer, Winkelmann's slab-on-grade model was used with *DOE-2* and the *Slab* model was used with *EnergyPlus*. The reliabilities of these models were then discussed by comparing their results with those of a more detailed *TRNSYS* slab-on-grade model.

The study included two steps. In the first step, the effect of ground coupling was isolated by modeling empty slab-on-grade sealed boxes at 23°C constant zone air temperature in four U.S. climates with the IECC required insulation configurations. The ground temperatures calculated by Winkelmann's (*GCW*), *Slab* (*GCS*) and *TRNSYS* (*GCT*) slab-on-grade models were entered into *EnergyPlus* and the resulting ground coupling loads were compared. At the second step, load components (i.e. wall heat transfer, ceiling heat transfer to/from an unconditioned attic, windows, doors, shades, lights, equipment and infiltration) were added to these boxes to convert them into fully loaded IECC compliant houses. Discrepancies between the results of the obtained models were then quantified and explained both for the ground isolated and the ground coupled conditions. This report includes the results obtained for the fully loaded IECC compliant houses modeled in hot-humid, hot-dry, temperate and cold climates.

For the ground isolated fully loaded houses, *EnergyPlus* results differed from those of *DOE-2* by 0%-31% in cooling load and by 3%-15% in heating load. These differences were caused primarily by the 11%-15% higher window solar incidents and 8%-15% higher sensible infiltration heat losses that *EnergyPlus* calculated from identical window 5 inputs and leakage areas respectively.

For the slab-on-grade fully loaded houses, the *GCW* models calculated 10%-13% higher total building loads than the *GCT* models did. This result was attributed to the fact that the *GCW* model was based on the results of a 2-D finite difference program that assumed constant zone air temperatures all year. For the same houses, the currently used internally iterated *GCS* models calculated significantly (18%-32%)

lower total building loads than those calculated by the *GCT* models. When *EnergyPlus* was iterated with *Slab* externally until the zone air temperatures converged within 0.0001°C, however, very close (within 9%) total thermal loads were obtained with the *GCS* models to those calculated by the *GCT* models. This finding showed that, the convergence of zone air temperatures is significant for the accuracy of the results in the *GCS* models. The 0.1°C convergence tolerance for zone air temperatures was found to be sufficient in these models to make thermal load estimations within 1% of the fully converged (within 0.0001°C) values. Besides the convergence problem, three other problems were observed with the current *Slab* model. First, the introduction of evaporative transpiration decreased the total thermal load estimates significantly resulting in 17%-60% lower thermal loads than those of the *GCT* models. Second, the *Slab* program could not model the vertical R-10 insulation with depths less than 1 m, which was required by IECC for temperate climates. Third, in a few test runs, the *Slab* program made internal adjustments on the slab thicknesses to meet an internal convergence tolerance value, which resulted in inconsistent thicknesses in the aboveground and belowground models of *EnergyPlus*.

It was concluded that the *Slab* model makes closer estimates to the *TRNSYS* slab-on-grade model than Winkelmann's slab-on-grade model does if: 1) the zone air temperatures are converged and 2) evaporative transpiration is ignored. The *Slab* model, however, has significant limitations, convergence problems and inconsistent internal adjustments. Thus, an improvement is needed in this model before it is used in residential energy code compliance calculations in order to avoid erroneous results.

6. ACKNOWLEDGEMENT

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