

ENERGYPLUS VS DOE-2: THE EFFECT OF GROUND COUPLING ON HEATING AND COOLING ENERGY CONSUMPTION OF A SLAB-ON-GRADE CODE HOUSE IN A COLD CLIMATE

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ABSTRACT

For low-rise buildings, the heat loss through the ground coupled floor is a significant load component. Studies showed that the current simulation tools give dissimilar results for the ground coupled heat transfer (GCHT) in slab-on-grade constructions. This paper extends the previous comparative work by comparing EnergyPlus and DOE-2.1e results for GCHT based on a slab-on-grade code house in a cold climate. Three GCHT models were used in the study. These models were Winkelmann's (2002) model in DOE-2.1e, Winkelmann's model in EnergyPlus and EnergyPlus with its GCHT calculator utility, *Slab*.

INTRODUCTION

Ground-coupled heat transfer (GCHT) through concrete floor slabs is a significant component of the total load for heating or cooling in low-rise buildings like residential buildings. For a contemporary code or above house, ground-coupled heat loss may account for 30–50% of the total heat loss (Zhong and Braun 2007; Deru 2003; Claesson and Hagentoft 1991; Labs et al. 1988). Comparative studies on GCHT models of current simulation tools showed high degree of variation in their results for slab-on-grade constructions (Neymark et al. 2008; 2009). For uninsulated slab-on-grade constructions, the range of disagreement among simulation tools is estimated to be 25%-60% or higher for simplified models versus detailed models. Early studies showed that typical slab-on-grade floor heat loss ranged from 15% to 45% of the annual heating load depending on the simulation model, climate, thermal properties of the building and the presence of insulation (Neymark et al. 2008; 2009).

EnergyPlus (EPlus) and DOE-2.1e, which is referred as DOE-2 in this study, are the two frequently used building energy simulation tools that calculate GCHT in slab-on-grade buildings. DOE-2 is a well known simulation tool that has been used for over 30 years in various areas such as building design studies, analysis

of retrofit opportunities and developing and testing standards (Crawley et al. 2005). The simulation community is familiar with this program and its results. With the introduction of EPlus, DOE-2 is no longer maintained by the Department of Energy (DOE) (Huang et al. 2006). The shift from DOE-2 to EPlus raised questions in the simulation community on the differences between these two simulation programs (Huang et al. 2006; Andolsun and Culp 2008). There is a growing interest towards the differences between the ground coupled heat transfer models of EPlus and DOE-2 (Xiaona et al. 2008).

This study compares EPlus with DOE-2 in terms of ground coupled heat transfer based on the results obtained for a slab-on-grade code house in a cold climate. The effect of ground coupling on the HVAC electricity consumption of the house is determined for different loading conditions both in DOE-2 and EPlus.

METHODOLOGY

This study included three sets of simulations. The first set simulated a base-case house in Montana with no load component other than exterior walls. The second set identified the individual and combined effects of the building load components on HVAC electricity use. The third set identified the effect of ground coupling on the HVAC electricity use of the test cases simulated in the previous simulation sets.

Simulation Set 1

Simulation Set 1 included only the base-case (Case 1) house. The Case 1 house was modeled as a ground isolated sealed box both in DOE-2 and EPlus. This section describes the simulation of the Case 1 house in terms of building envelope and system simulation.

Building Envelope

A 20m x 20m x 3m building with a 3m high unconditioned attic was modeled in DOE-2.1e and EnergyPlus 5.0.0.031. The slab was modeled as an

adiabatic surface both in EPlus and in DOE-2 in order to decouple the building from the ground. The ceiling facing the unconditioned attic was also adiabatic. The walls had no windows or doors. There were no internal loads such as lights, equipment or people in the house. The only load was due to exterior walls that had a U-value of $0.34 \text{ W/m}^2\text{-K}$ ($0.06 \text{ Btu/hr.ft}^2\text{-F}$). From the outside towards the inside, the exterior walls had 0.076m face brick (BK), 0.013m plywood (PW), 0.102m soft wood (WD) wall frame filled with 0.171m mineral wool (IN) with 25% framing ratio, and 0.013m gypsum board (GP) as an interior finish. The roof consisted of a 0.254m soft wood (WD) frame covered with 0.013m plywood (PW) and shingle (AR) respectively. The thermal resistance value of the shingle roof covering was $0.078 \text{ m}^2\text{-K/W}$ ($0.44 \text{ hr-ft}^2\text{-}^\circ\text{F/Btu}$). The ceiling had insulation inside the wood frame on the attic side. The Ceiling studs were 0.254m soft wood which framed 0.43m mineral wool (IN). Table 1 gives the details on the layers of the building envelope.

Table 1. Material Properties of the Envelope Constructions.

	Conductivity		Density		Specific heat	
	W/m-K	Btu/hr-ft-°F	kg/m ³	Lb/ft ³	J/kg-K	Btu/Lb-°F
BK	1.31	0.757	2083	130	920	0.22
PW	0.115	0.066	545	34	1213	0.29
WD	0.115	0.066	513	32	1381	0.33
IN	0.043	0.025	96	6	837	0.20
GP	0.16	0.093	801	50	837	0.20
AR	-	-	1121	70	1464	0.35

System Simulation

The house had a direct expansion (DX) cooling system with heat pump both in EPlus and in DOE-2. This system controlled only the occupied zone. The attic zone was unconditioned. In EPlus, a DX cooling coil (DXCC), a DX heating coil (DXHC), a supply fan (SF) and a supplementary heating coil (SHC) were connected to build the main air loop side of the system. Figure 1 shows the schematic diagram of the DX cooling system with heat pump modeled in EPlus. In DOE-2, the RESYS system was assigned as the equivalent system.

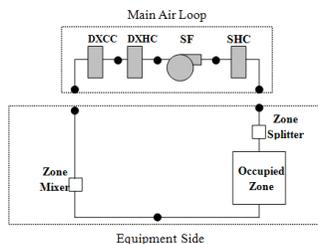


Figure 1. Diagram of the DX Cooling System with Heat Pump in EPlus.

Both in DOE-2 and EPlus, the systems were autosized for the peak heating and cooling days to maintain zone air temperatures within 20°C heating set point and 25.5°C cooling set point. Since EPlus does not model throttling ranges (Huang et al. 2006); the throttling range in DOE-2 was set to its minimum value (0.1°C) in all cases.

Both in EPlus and in DOE-2, the cooling (minimum) and heating (maximum) design supply air temperatures were 12.8°C and 48.9°C respectively. The DX Cooling system with Heat Pump simulated in EPlus controlled humidity both at the system and zone level. The zone cooling and heating design supply air humidity ratios, the central heating and cooling design supply air humidity ratios were all set to $0.008 \text{ kg-H}_2\text{O/kg-Air}$ in EPlus. The RESYS system modeled in DOE-2 did not allow for humidity control. Both in EPlus and in DOE-2, the system neither had preheating nor precooling. Both in EPlus and in DOE-2, the supply fan had 1.5 inH₂O (373.6 Pa) pressure rise, 0.9 motor efficiency and 0.7 overall fan efficiency. The fan motor was inside the air stream both in EPlus and in DOE-2. The performances of the cooling and heating coils were defined with reverse units in EPlus and DOE-2. In EPlus, the rated coefficient of performance (COP) was used to define the performances of the cooling (4.05) and the heating coils (3.88). In DOE-2, electric input ratio (EIR) was used to define the performances of the cooling (0.25) and heating (0.26) coils. Both in DOE-2 and in EPlus, supplementary heating was electric and it was available any time when the outside dry bulb temperature fell below 20°C .

Simulation Set 2

Simulation Set 2 included the Case 2, Case 3, Case 4, Case 5 and Case 6 houses. With this simulation set, the individual and combined effects of four major load components on the total HVAC electricity consumption of the house were identified. The load components included in the study were:

- 1- windows and doors,
- 2- heat transfer through the ceiling,
- 3- lights and equipment,
- 4- infiltration.

Case 2

Windows and doors with U-value of $1.99 \text{ W/m}^2\text{-K}$ ($0.35 \text{ Btu/hr.ft}^2\text{-}^\circ\text{F}$) were added to the base-case house with 25% window-to-wall ratio both in DOE-2 and EPlus to model the Case 2 house. The windows were designed in Window 5.2.17a (Window 5). For these windows, DOE-2 and EPlus reports were generated in Window 5. These reports were then copied into the window dataset files of DOE-2 and EPlus. DOE-2 and EPlus read the

window information from their window dataset files to model the windows. The modeled windows had two panes of low emissivity glass with 7.4 mm argon gas layer between the panes. All windows had shades. From 30th of April until 31st of October, shading ratio was 70%, while all other times it was 85%. In DOE-2, the shades were movable interior shades. In EPlus they had the features listed in Table 2.

Table 2. Features of the shades used in EPlus.

Solar Transmittance	0.075
Solar Reflectance	0.7
Visible Transmittance	0.032
Visible Reflectance	0.5
Thermal Hemispherical Emissivity	0.15
Thermal Transmittance	0.41
Thickness (m)	0.0004
Conductivity (W/m-K)	0.1
Shade to Glass Distance (m)	0.05
Top Opening Multiplier	0.1
Bottom Opening Multiplier	0.1
Left-Side Opening Multiplier	0
Right-Side Opening Multiplier	0
Airflow Permeability	0.3

Case 3

860 Watts of lights and 860 Watts of equipment were added to the base-case house both in EPlus and in DOE-2 to model the Case 3 house. The radiant fraction of the heat generated by lights was 0.71 both in EPlus and in DOE-2. The remaining 0.29 was the fraction of the heat convected to the zone air. The radiant fraction of the heat generated by equipment was also 0.7 both in EPlus and in DOE-2. The lights and equipment was always on all through the year.

Case 4

Infiltration was added to the base-case building to model the Case 4 house. Both in DOE-2 and in EPlus, the Sherman and Grimsrud (1980) method was used to simulate infiltration in the house. In EPlus, the effective leakage area was 13,333 cm² in the attic and 1,440 cm² in the occupied space at 4 Pa. The building was one story high and there were no obstructions or local shielding around the building. The stack coefficient was therefore set to 0.000145 and the wind coefficient was 0.000319. In DOE-2, the leakage area is entered as the ratio between the effective leakage area and the total floor area (FRAC-LEAK-AREA). FRAC-LEAK-AREA was 0.0033 for the attic and 0.0004 for the occupied space.

Case 5

The adiabatic ceiling of the base-case house was

replaced with a standard heat transfer surface that had a U-value of 0.15 W/m²-K (0.026 Btu/hr.ft².°F) to model the Case 5 house.

Case 6

The base-case building was converted into a fully occupied house (Case 6) by adding all of the four major load components.

Simulation Set 3

In this simulation set, the test houses modeled in the previous simulation sets were coupled with the ground. The effect of ground coupling on the HVAC electricity consumption was identified for different loading conditions. In order to allow for ground coupled heat transfer, the adiabatic floor was replaced by a standard floor. The floor construction of the house included a carpeted slab with 1.2m (4ft) foundation depth and it consisted of a 0.102m (4") heavy-weight concrete with R-value of 0.078 m²-K/W (0.44 hr-ft²-°F). As required by the code (IECC 2009), 4ft deep exterior insulation with an R-value of 10 ft².°F. hr/Btu was added to the floor construction. In Simulation Set 3, the common GCHT models of EPlus and DOE-2 were used to model the heat flow through the ground coupled floors. Winkelmann's (2002) method was used in DOE-2 (DOE-2 GCW). EPlus was used with its GCHT calculator utility, *Slab* (EPlus GCS). In order to compare Winkelmann's method with *Slab*, Winkelmann's method was also used in EPlus (EPlus GCW).

Winkelmann's Method

Winkelmann's (2002) method was used in the same way in DOE-2 (DOE-2 GCW) and in EPlus (EPlus GCW). In this method, it is assumed that the heat transfer mainly occurs in the exposed perimeter of the floor slab since this region has relatively short heat flow paths to the outside air. Instead of using the U-value of the floor, an effective U-value is entered for the slab that represents the heat flow through the exposed perimeter. A new construction is also assigned for the floor that will have an overall U-value equal to the entered effective U-value. This new construction properly accounts for the thermal mass of the floor construction when custom weighting factors are specified. The new floor construction consists of three layers: I- underground surface plus air film (R_{us}), II- 0.3m (1 ft) of soil (R_{soil}) and III- fictitious insulating layer (R_{fic}). Figure 4 shows the layers of the floor construction assigned in DOE-2 GCW and EPlus GCW models. Underneath the fictitious insulating layer, the system faces the ground temperatures provided from the weather file. For the Montana house, the perimeter

conduction factor was taken as 0.64 W/m-K (0.37 Btu/hr-°F-ft), which was the value given by Winkelmann (2002) for carpeted slab-on-grade floors that have R-10 exterior insulation and 1.2m (4ft) foundation depth.

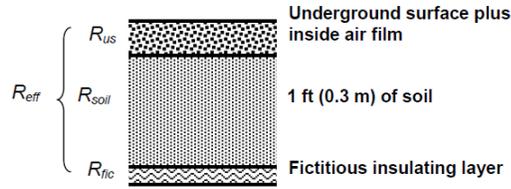


Figure 2. The floor construction assigned in the DOE-2 GCW and EPlus GCW (Winkelmann, 2002; p:20).

The effective resistance (R_{eff}) of the slab was then calculated as 7.71 m²-K/W (43.73 hr-ft²-°F/Btu) from Formula 1.

$$R_{eff} = A/(F2 * P_{exp}) \dots\dots\dots(\text{Formula 1})$$

Effective U-value of the slab then became 0.13 W/m²-K (0.023 Btu/hr-ft²-°F) from Formula 2.

$$U_{eff} = 1/R_{eff} \dots\dots\dots(\text{Formula 2})$$

Assuming that the air film resistance is 0.136m²-K/W (0.77 hr-ft²-°F/Btu), the actual slab resistance (R_{us}) was calculated as 0.213m²-K/W (1.21 hr-ft²-°F/Btu) from Formula 3.

$$R_{us} = R_{slab} + R_{film} \dots\dots\dots(\text{Formula 3})$$

The resistance of the soil was assumed as 0.176m²-K/W (1 hr-ft²-°F/Btu). Using Formula 4, the resistance of the fictitious layer (R_{fic}) under the soil was then calculated as 7.32 m²-K/W (41.52 hr-ft²-°F/Btu).

$$R_{eff} = R_{us} + R_{soil} + R_{fic} \dots\dots(\text{Formula 4})$$

Slab

EPlus iterated with its GCHT calculator utility, *Slab*, to model the heat transfer through the ground coupled floor in the EPlus houses (EPlus GCS). First, the main EPlus input file was run to obtain monthly average zone air temperatures. These temperatures were then entered into *Slab* input file and *Slab* was run. The monthly average ground temperatures calculated by *Slab* were entered back to the main EPlus input file and EPlus was rerun with the new ground temperatures. EPlus continued to iterate with *Slab* until the difference between the monthly average zone air temperatures calculated by the last two EPlus runs was 0.0001°C or lower.

Current sources describe three different methods of using the ground coupled heat transfer model of EPlus (U.S.D.O.E. 2002-2003). They differ only in the initial EPlus run. One of these methods suggests assigning

18°C for the ground temperatures in the initial run. The other method suggests assigning a high insulation layer underneath the slab in the initial run. The last method includes simulating the slab as an interior surface in the initial run. In this study, preliminary runs were made using all three methods. It was observed that the second method where a high insulation layer is added underneath the slab in the first EPlus run needed less iteration to achieve a convergence tolerance of 0.0001°C. For all ground coupled houses, a high insulation layer was assigned underneath the slab in the initial EPlus run. The insulation layer that had a thermal resistance of 500 m²-K/W (2837.2 hr.ft².°F/Btu) was removed in the later runs and the iteration continued.

The same carpeted 0.102m (4”) concrete floor was modeled both in EPlus and in *Slab*. In the EPlus model, the floor slab had two layers: 1- 0.102m (4”) heavy-weight concrete with resistance value of 0.078 m²-K/W (0.44 hr-ft²-°F), 2- carpet with a resistance of 0.3 m²-K/W (1.702 hr-ft²-°F). Surface albedo was 0.158 without snow and 0.379 with snow. Surface emissivity was 0.9 both with and without snow. Surface roughness was 0.75 without snow and 0.03 with snow. Downward indoor convection coefficient was 6.13 W/m²-K (1.08 Btu/hr-ft²-°F) and upward indoor convection coefficient was 9.26 W/m²-K (1.63 Btu/hr-ft²-°F). The physical properties of slab modeled in EPlus GCS were identical to those defined in DOE-2. For the soil, typical properties recommended by EPlus were used. Slab material density was 2243 kg/m³ (140 lb/ft³) and soil density was 1200 kg/m³ (74 lb/ft³). Specific heat of the slab and soil were 837 J/kg-K (0.20 Btu/lb-°F) and 1200 J/kg-K (0.29 Btu/lb-°F) respectively. Conductivity of the slab and soil were 1.31 W/m-K (0.76 Btu/hr-ft-°F) and 1 W/m-K (0.58 Btu/hr-ft-°F) respectively. The lower boundary temperature assigned in *Slab* was 10°C (50°F). The distance from the edge of slab to the domain edge was 15m and the depth of region below the slab was 15m. The same slab thickness (0.1m) was assigned in EPlus and in *Slab*; however, *Slab* increased the slab thickness by 20% while running and reset it to 0.12m (4.8”) in order to maintain computational stability. *Slab* also did not allow for properly inputting the 1.2m (4ft) deep vertical floor insulation. The closest available insulation depth (0.1m) was entered for the vertical floor insulation instead of 1.2m.

RESULTS

DOE-2 results were obtained from Building Energy Performance Summary (BEP) Reports. EPlus results were obtained from “Electricity:HVAC”, “Cooling:Electricity” and “Heating:Electricity” output variables.

Cooling Electricity

The DOE-2 and EPlus results for the annual cooling electricity consumption of the test houses are given in Figure 3 and 4. The ground isolated test houses showed higher (24%-88%) cooling electricity consumption in EPlus than in DOE-2. For the ground isolated fully occupied house, EPlus calculated 25% higher cooling electricity consumption than DOE-2 did.

Ground coupling decreased the cooling electricity consumption in all loading conditions in all models. The decreases in cooling electricity consumption with ground coupling were higher in EPlus GCS (38%-100%) than in DOE-2 GCW (19%-95%) and in EPlus GCW (15%-91%). The highest reduction in cooling electricity consumption with ground coupling (100%) was observed in the base-case (Case 1) house and in the house with standard ceiling (Case 5) modeled with EPlus GCS. In the fully occupied house, cooling electricity decreased significantly more in EPlus GCS (38%) compared to EPlus GCW (15%) and DOE-2 GCW (19%). The ground coupled fully occupied house showed 4% lower cooling electricity consumption in EPlus GCS than it did in DOE-2 GCW.

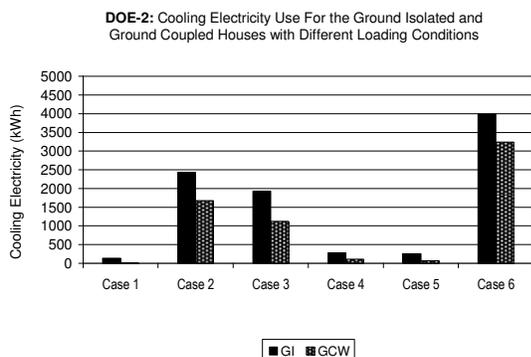
Heating Electricity

Figure 5 and 6 show the annual heating electricity consumptions of the DOE-2 and EPlus test houses. The ground isolated test houses showed lower (15%-27%) heating electricity consumption in EPlus than in DOE-2. For the ground isolated fully occupied code house, EPlus (6997 kWh) calculated 27% lower heating electricity consumption than DOE-2 (9542 kWh) did. Ground coupling increased (7%-267%) the heating

electricity consumption of all DOE-2 houses. In EPlus GCS, heating electricity consumption increased (4%-42%) with ground coupling in all houses except in the Case 2 and Case 5 houses. In EPlus GCW, heating electricity consumption increased (8%-116%) in all test houses. With ground coupling in the fully occupied house, heating electricity consumption increased more in EPlus GCW (8%) than it did in DOE-2 GCW (7%) and EPlus GCS (5%). For the ground coupled fully occupied house, EPlus GCS showed 28% lower heating electricity consumption than DOE-2 GCW did.

Total HVAC Electricity

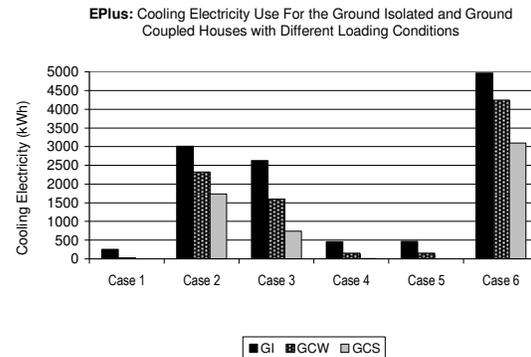
The annual total HVAC electricity consumptions of the test houses are given in Figure 7 and 8. Except for the Case 2 and Case 3 houses, all of the ground isolated EPlus test houses used less (9%-19%) total HVAC electricity than the DOE-2 houses did. For the ground isolated Case 2 and Case 3 houses, EPlus calculated 5% and 33% higher total HVAC electricity consumption than DOE-2 did respectively. DOE-2 and EPlus showed dissimilar variation in total HVAC electricity consumption when the test houses were coupled with the ground. In DOE-2 GCW, the total HVAC electricity consumption increased (9%-41%) in the Case 1, Case 4 and Case 5 houses and decreased (1%-16%) in the Case 2, Case 3 and Case 6 houses with ground coupling. In EPlus GCW, the total HVAC electricity consumption decreased (2%-28%) in the Case 2, Case3 and Case 6 houses and increased (7%-43%) in the Case 1, Case 4 and Case 5 houses with ground coupling. In EPlus GCS, ground coupling decreased (0.28%-64%) the total HVAC electricity



	GI	GCW	Δ_w
Case 1. Base-case	136	7	-129
Case 2. Case 1 with Windows, doors & shades	2430	1671	-759
Case 3. Case 1 with Lights & equipment	1931	1124	-807
Case 4. Case 1 with Infiltration	280	108	-172
Case 5. Case 1 with Standard Ceiling	252	67	-185
Case 6. Fully Occupied	3987	3242	-745

$\Delta_w = GCW-GI$, Units are in kWh.

Figure 3 Annual Cooling Electricity Consumption of Each Test Case House in DOE-2.



	GI	GCW	GCS	Δ_w	Δ_s
Case 1. Base-case	256	22	0	-234	-256
Case 2. Case 1 with Windows, doors & shades	3008	2320	1731	-688	-1277
Case 3. Case 1 with Lights & equipment	2633	1599	741	-1034	-1892
Case 4. Case 1 with Infiltration	457	152	8	-305	-449
Case 5. Case 1 with Standard Ceiling	467	154	0	-313	-467
Case 6. Fully Occupied	4971	4242	3098	-729	-1873

$\Delta_w = GCW-GI$, $\Delta_s = GCS-GI$, Units are in kWh.

Figure 4 Annual Cooling Electricity Consumption of Each Test Case House in EPlus.

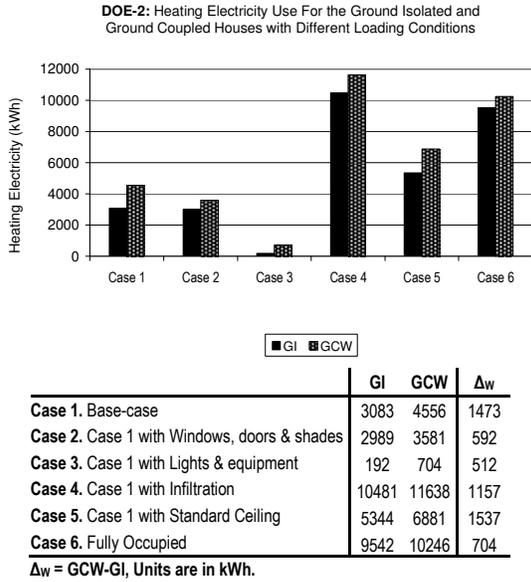


Figure 5 Annual Heating Electricity Consumption of Each Test Case House in DOE-2.

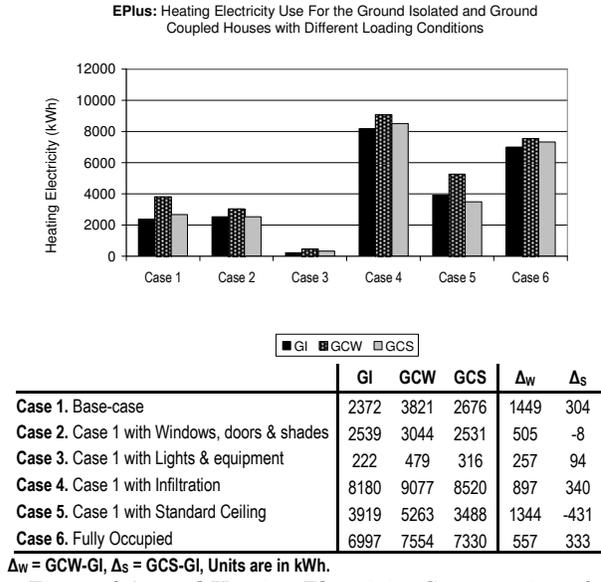


Figure 6 Annual Heating Electricity Consumption of Each Test Case House in EPlus.

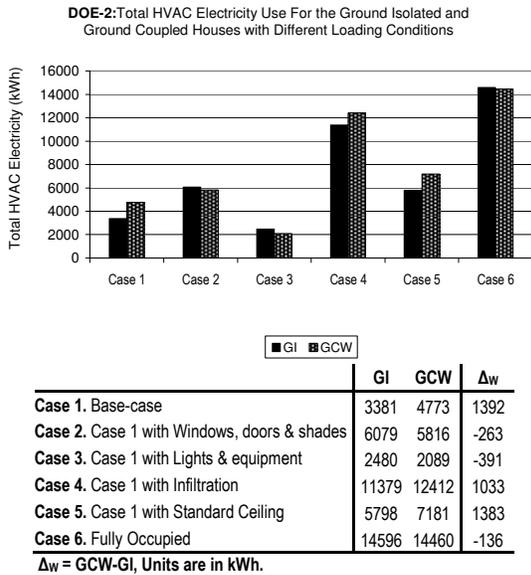


Figure 7 Annual Total HVAC Electricity Consumption of Each Test Case House in DOE-2.

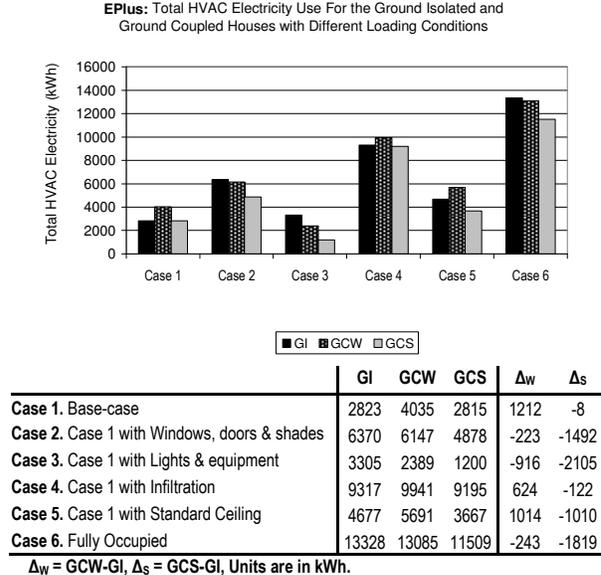


Figure 8 Annual Total HVAC Electricity Consumption of Each Test Case House in EPlus.

consumption in all loading conditions. In the fully occupied code house, ground coupling decreased the total HVAC electricity consumption by 14% in EPlus GCS, 2% in EPlus GCW and 1% in DOE-2 GCW. For the ground coupled fully occupied house, EPlus and DOE-2 were in close agreement for cooling but heating dominated the annual energy use of the house. Consequently, the total HVAC electricity use of the fully occupied ground coupled code house was 14% lower in EPlus GCS than in DOE-2 GCW.

Overview of EPlus Results

The total HVAC electricity consumption of the fully occupied house showed higher dependency on ground coupling in EPlus GCS compared to the other models. Figure 9 shows the monthly average ground temperatures that the EPlus GCS and EPlus GCW floors were exposed to. In EPlus GCW, the ground temperatures from the weather file were directly used. In EPlus GCS, Slab calculated the ground temperatures separately for each case.

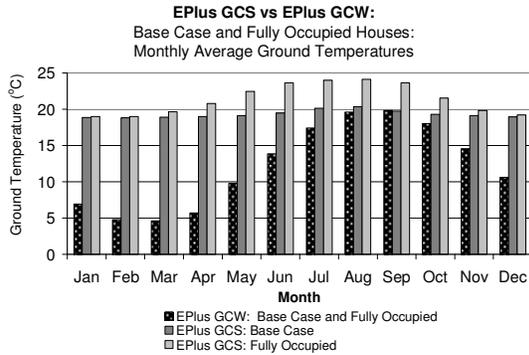


Figure 9 The Monthly Average Ground Temperatures of the Ground Coupled Base-case and Fully Occupied Houses in EPlus GCS and EPlus GCW.

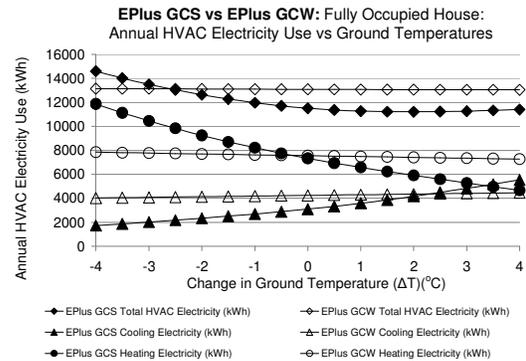


Figure 11 The Variation in Annual HVAC Electricity Consumption of the Ground Coupled Fully Occupied House in EPlus with Changing Ground Temperatures.

In order to investigate the relationship between the ground temperatures and the overall HVAC electricity consumption, a further analysis was done in EPlus. A constant value (ΔT) was added to and subtracted from the 12 ground temperatures of the base-case and fully occupied houses. The variation in HVAC electricity use with varying ΔT was recorded. Figure 10 and 11 show the results when ΔT varied between -4°C and 4°C with increments of 0.25°C .

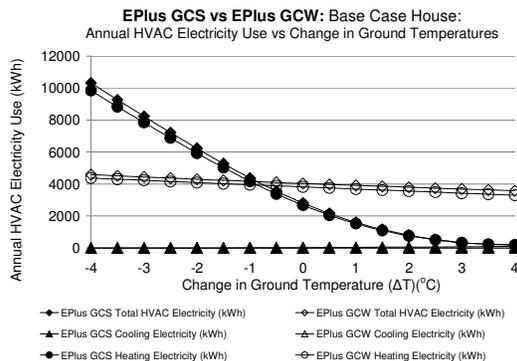


Figure 10 The Variation in Annual HVAC Electricity Consumption of the Ground Coupled Base-case House in EPlus with Changing Ground Temperatures.

In the ground coupled base-case house, 8°C ($\pm 4^{\circ}\text{C}$) variation in the monthly average ground temperatures lead to higher variation in total HVAC electricity use in EPlus GCS (10128 kWh) compared to EPlus GCW (1006 kWh). In the ground coupled fully occupied house, 8°C ($\pm 4^{\circ}\text{C}$) variation in the monthly average ground temperatures resulted in higher variation in total HVAC electricity use in EPlus GCS (3204 kWh) compared to EPlus GCW (103 kWh). These results showed that for the same R-value and depth of floor insulation required by IECC 2009, *Slab* calculates much higher heat transfer through the ground coupled floor than the Winkelmann's (2002) model does.

SUMMARY

This study extends the previous studies on current ground coupled heat transfer (GCHT) models by comparing EnergyPlus 5.0.0.031 (EPlus) and DOE-2.1e (DOE-2) results in terms of GCHT for an all electric slab-on-grade code (IECC 2009) house in a cold climate. The ground isolated and ground coupled cases of the code house were modeled with each and all of the load components in the house. In order to model the heat flow through the ground coupled floor, DOE-2 was used with Winkelmann's (2002) method and EPlus was used with its GCHT calculator utility, *Slab* (EPlus GCS). Winkelmann's method was also used with EPlus (EPlus GCW) to compare with *Slab*.

The ground isolated EPlus houses used more cooling electricity and less heating electricity than the ground isolated DOE-2 houses did. For the ground isolated fully occupied house, EPlus calculated 25% higher cooling and 27% lower heating electricity consumption than DOE-2 did. Ground coupling increased the heating and decreased the cooling electricity consumptions of the test houses both in EPlus and DOE-2. Compared to DOE-2, EPlus showed higher variation in heating, cooling and total HVAC electricity consumption with ground coupling in the fully occupied house. In the fully occupied house, cooling electricity consumption decreased by 38% in EPlus (GCS) and by 19% in DOE-2. Ground coupling increased the heating electricity consumption of the fully occupied house by 8% in EPlus (GCW) and by 7% in DOE-2. The total HVAC electricity consumption of the fully occupied house decreased by 14% in EPlus GCS, 2% in EPlus GCW and 1% in DOE-2 with ground coupling.

This paper has shown that the GCHT models of EPlus and DOE-2 have significant dissimilarities. The same code compliant floor allowed for higher heat losses in

EPlus than it did in DOE-2. These discrepancies underlined that GCHT modeling tool choice is significant in determining the code requirements for low-rise residential buildings.

NOMENCLATURE

R_{eff} : effective resistance of the slab (hr-ft²-°F/Btu)
 A : area of the slab (ft²)
 F_2 : perimeter conduction factor (Btu/hr-°F-ft)
 P_{exp} : exposed perimeter (ft)
 U_{eff} : effective U-value of the slab (Btu/hr-ft²-°F)
 R_{us} : actual slab resistance (hr-ft²-°F/Btu)
 R_{slab} : resistance of 4" concrete (hr-ft²-°F/Btu)
 R_{film} : resistance of the inside air film (hr-ft²-°F/Btu)
 R_{soil} : resistance of the soil (hr-ft²-°F/Btu)
 R_{fic} : resistance of the fictitious insulating layer (hr-ft²-°F/Btu).

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REFERENCES

- Andolsun, S., Culp, C.H. 2008. A Comparison of EnergyPlus with DOE-2 Based on Multiple Cases from a Sealed Box to a Residential Building. In Proceedings of: Sixteenth Symposium on Improving Building Systems in Hot and Humid Climates. Plano, Texas, USA. December 15-16, 2008.
- Classon, J., Hagentoft, C-E. 1991. Heat Loss to the Ground from a Building- I. General Theory. *Building and Environment*. 26(2):195-208.
- Crawley, D.B., Hand, J.W., Kummert, M. and Griffith, B. 2005. Contrasting the Capabilities of Building Energy Performance Simulation Programs. A Joint Report. Version 1.0.
- Deru, M. 2003. A model for ground-coupled heat and moisture transfer from buildings, NREL/TP-550-33954, Golden, Colorado, USA: National Renewable Energy Laboratory. www.nrel.gov/docs/fy03osti/33954.pdf.
- Huang, J., Bourassa, N., Buhl, F., Erdem, E., Hitchcock, R. 2006. Using EnergyPlus for California Title-24 Compliance Calculations. *Proceedings of SimBuild 2006*, 2-4 August 2006, MIT, Cambridge, Massachusetts. IBPSA-USA.
- Labs, K., Carmody, J., Sterling, R., Shen, L., Huang, Y.J., Parker, D. 1988. *Building Foundation Design Handbook*, ORNL/Sub/86-72143/1, May, 1988.
- Neymark, J., Judkoff, R., Beausoleil-Morrison, I., Ben-Nakhi, A., Crowley, M., Deru, M., Henninger, R., Ribberink, H., Thornton, J., Wijsman, A., Witte, M. 2008. International Energy Agency Building Energy Simulation Test and Diagnostic Method (IEA BESTEST) In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-on-Grade Construction, NREL/TP-550-43388. Golden, Colorado, USA: National Renewable Energy Laboratory. www.nrel.gov/docs/fy08osti/43388.pdf.
- Neymark, J., Judkoff, R., Beausoleil-Morrison, I., Ben-Nakhi, A., Crowley, M., Deru, M., Henninger, R., Ribberink, H., Thornton, J., Wijsman, A., Witte, M. 2009. IEA BESTEST In-Depth Diagnostic Cases for Ground Coupled Heat Transfer Related to Slab-on-grade Construction. Eleventh International IBPSA Conference, Glasgow, Scotland. July 27-30, 2009.
- U.S.D.O.E. 2002-2003. Lecture 24: Ground Heat Transfer. Retrieved June 02, 2010, from <http://apps1.eere.energy.gov/buildings/energyplus/cfm/training.cfm>.
- Winkelmann, F. 2002. Underground Surfaces: How to get a Better Underground Surface Heat Transfer Calculation in DOE-2.1E. *Building Energy Simulation User News*. 23(6):19-26.
- Xiaona, X., Yi, J., Jianjun, Xia. 2008. A New Approach to Compute Heat Transfer of Ground-Coupled Envelope in Building Thermal Simulation Software. *Energy and Buildings*. 40: 476-485.
- Zhong, Z., Braun, J.E. 2007. A simple method for estimating heat transfer in slab-on-ground floors. *Building and Environment*. 42:1071-1080.