Energy and Buildings 43 (2011) 1663–1675

Contents lists available at ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

EnergyPlus vs. *DOE-2.1e*: The effect of ground-coupling on energy use of a code house with basement in a hot-humid climate

Simge Andolsun[a,*], Charles H. Culp[a], Jeff Haberl[a], Michael J. Witte[b]

[a] College of Architecture, Texas A&M University, 053 WERC, 3137 TAMU, College Station, TX 77843-3137, USA
[b] GARD Analytics Inc., 115 S. Wilke Road, Ste 105, Arlington Heights, IL 60005, USA

ARTICLE INFO

Article history:
Received 17 November 2010
Received in revised form 27 January 2011
Accepted 14 March 2011

Keywords:
BESTEST
EnergyPlus
DOE-2
Ground coupling
Basement
Crawlspace

ABSTRACT

For low-rise buildings, the heat losses or gains through the ground coupled building envelope can be a significant load component. Studies have shown that current simulation tools give dissimilar results for the ground coupled heat transfer (GCHT) with basements. This paper quantifies and explains the differences between *EnergyPlus* and *DOE-2.1e* (*DOE-2*) basement GCHTs based on their results for an all electric code house in a hot and humid climate zone. The code house was modeled with two basement configurations i.e. a conditioned basement and an unconditioned crawlspace. *DOE-2* was used with Winkelmann's basement model and *EnergyPlus* was used with its GCHT calculator utility, Basement. The results revealed that the ground isolated *EnergyPlus* houses used 3–23% more cooling, 12–29% less heating and 3–7% lower overall HVAC electricity use when compared to the ground isolated *DOE-2* houses. Ground coupling added up to three times more heat loss in *EnergyPlus* than in *DOE-2*. This increased the overall energy use difference between these two programs from 3–7% (ground isolated) to 14–25% (ground coupled). These results showed that a truth standard is required for basement heat transfer calculations of low-rise buildings.

1. Introduction

Ground coupled heat transfer (GCHT) through underground concrete walls and floors can be a significant component of the total load for heating or cooling in low-rise residential buildings. It is estimated that an uninsulated basement can contribute up to 60% of heat loss in a house well-insulated above grade [1]. Ground coupling is still considered a hard-to-model phenomenon in building energy simulation since it involves three-dimensional thermal conduction, moisture transport, long time constants and heat storage properties of the ground [2]. Comparative studies on ground coupled heat transfer models of current simulation tools showed remarkable variation for basements. The disagreement among the simulation tools with respect to the average values was estimated to be 87% for ground coupling heating load [3], 138% for ground coupling cooling load [3] and 11–23% for the annual total heating load [4].

This study compared *EnergyPlus* and *DOE-2.1e* (*DOE-2*) ground coupled heat transfer for basements of low-rise residential buildings. *DOE-2* has been used for more than three decades for building design and code compliance studies, analysis of retrofit opportunities and developing and testing standards [5]. In 1996, United States Department of Energy (DOE) initiated support for the development of *EnergyPlus*, which was a new program based on the best features of *DOE-2* and BLAST [6]. The shift from *DOE-2* to *EnergyPlus* raised questions in the simulation community on the differences between these two simulation programs [7–9]. Ground coupled heat transfer is an area that *EnergyPlus* calculations significantly differ from those of *DOE-2*. *EnergyPlus* calculates z-transfer function coefficients to compute the unsteady ground temperatures for underground surfaces [10]; whereas *DOE-2* sets a single steady ground temperature for each month [11]. *DOE-2* basement GCHT has been compared with that of BLAST-3.0, SERIRES/SUNCODE, SERIRES-1.2, ESP, S3PAS, TRNSYS, TASE, DEROB-LTH and CLIM2000 in order to maintain consistency among the results of simulation tools for identical cases [3,4]. *EnergyPlus* and *DOE-2* have been compared with each other based on thermal loads, HVAC systems and fuel fired furnaces [12] using the test cases defined in American National Standards Institute (ANSI)/American Society of Heating Refrigerating and Air-conditioning Engineers (ASHRAE) Standard 140-2007 [13], which effectively isolates the test cases from the ground. This study extends the previous studies by quantifying the differences between the basement models of *EnergyPlus* and *DOE-2* based on the results obtained for a code house with a basement in Austin, Texas.

---

* Corresponding author. Tel.: +1 979 862 6415; fax: +1 979 862 2457.
E-mail addresses: andolsun@tamu.edu, simgeandolsun@gmail.com (S. Andolsun).

0378-7788/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2011.03.009

Nomenclature

IGain	daily internal gain (Btu/day per dwelling unit)
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 underground wall/floor (h ft^2 F/Btu)
A	area of the underground wall/floor (ft^2)
F2	perimeter conduction factor (Btu/h F ft)
P_{exp}	exposed perimeter (ft)
U_{eff}	effective *U*-value of the underground wall/floor (Btu/h ft^2 F)
R_{ub}	actual resistance of the underground wall/floor (h ft^2 F/Btu)
R_w	resistance of 8 in. concrete wall (h ft^2 F/Btu)
R_{film}	resistance of the inside air film (h ft^2 F/Btu)
R_{soil}	resistance of the soil (h ft^2 F/Btu)
R_{fic}	resistance of the fictitious insulation layer (h ft^2 F/Btu)
EPlus	*EnergyPlus*
DOE-2	*DOE-2.1e*
T_z	zone air temperatures (°C)
T_{gf}	outside surface temperatures of the ground coupled floor (°C)
T_{if}	inside surface temperatures of the ground coupled floor (°C)
T_{gw}	outside surface temperatures of the ground coupled wall (°C)
T_{iw}	inside surface temperatures of the ground coupled wall (°C)
ΔT	temperature difference between the outside and the inside surface of the underground wall/floor: $T_{gw} - T_{iw}$ (°C) for the wall and $T_{gf} - T_{if}$ (°C) for the floor

2. Current state of research

2.1. Basement models of DOE-2 and EnergyPlus

DOE-2 and *EnergyPlus* select from multiple basement models. This study covers the models commonly used for compliance with International Energy Conservation Code (IECC). These models are:

1) Winkelmann's [14] model
2) Basement

2.1.1. Winkelmann's model

In 1988, Huang et al. [15] calculated perimeter conductance per perimeter foot values for slab-on-grade floors, basements and crawl spaces using a two-dimensional finite difference program and presented their findings with their paper published in The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Transactions. In 2002, Winkelmann [14] revised the work of Huang et al. [15] in the Building Energy Simulation User News and described how to use their findings in a *DOE-2* model. The basement model referred to as "Winkelmann's basement model" in this paper is based on these descriptions from Winkelmann [14].

In Winkelmann's [14] method, it is assumed that the heat transfer mainly occurs in the exposed perimeter of the underground surface since this region has relatively short heat flow paths to the outside air. To model this heat flow from the exposed perimeter, an effective resistance value (R_{eff}) is assigned to the underground construction. This R_{eff} value is calculated using the area to perimeter ratio and the perimeter conduction factor of Huang et al. [15] for that specific location and amount of insulation. The inverse of the R_{eff} value is also assigned as the effective *U*-value (U_{eff}) of the underground construction. The construction of the underground surface is then redefined such that its overall resistance value will be equal to the calculated R_{eff} value. The new underground floor construction consists of three layers as shown in Fig. 1.

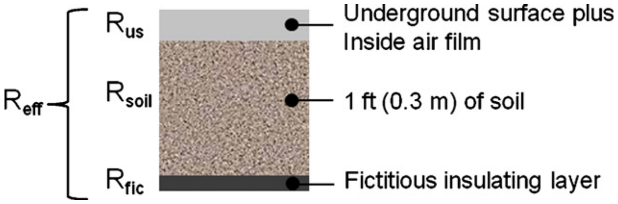

Fig. 1. Underground construction layers of the Winkelmann's [14] basement model.

This new construction accounts for the thermal mass of the neighboring ground when custom weighting factors are specified in *DOE-2*. Underneath the fictitious insulating layer, the system is exposed to the ground temperatures provided from the weather file. These temperatures are the monthly average outside air temperatures delayed by 3 months.

2.1.2. Basement model

Basement is a preprocessor program of *EnergyPlus* that calculates monthly ground temperatures for underground walls and floors of basements using a 3-D numerical analysis [16]. *Basement* was originally developed by Cogil [16] in 1998 based on the earlier findings of Bahnfleth [17] in 1989. Cogil's [16] model was then further modified and integrated with *EnergyPlus* by Clements [18] in 2004.

In 1989, Bahnfleth [17] conducted a parametric study for slab-on-grade GCHT using a detailed three-dimensional finite difference model. He found that not the perimeter length (P_{exp}) but the area to perimeter ratio (A/P) was a proper scaling factor to correlate the average heat flux for L-shaped and rectangular floors. He also estimated that the perimeter heat loss method (F2 method) which correlates GCHT with perimeter length (P_{exp}) may be in error by 50% due to this erroneous scaling. Bahnfleth's study [17] also showed that the thermal conductivity of the soil, ground surface boundary conditions and shading of adjacent soil are important parameters for ground coupled heat transfer. Based on his findings, Bahnfleth developed a new GCHT model for slab-on-grade constructions.

The mathematical basis of this new model was a boundary value problem on the three-dimensional heat conduction equation [17]. The adopted boundaries were interior slab surface, far-field soil, deep ground and ground surface. This boundary value problem was solved in Cartesian coordinates by a Fortran program that implemented the Patankar-Spalding [19] finite difference technique. An irregular grid of 10,000 cells discretized the three-dimensional domain of the model. The minimum grid spacing was 4 in. (0.1 m) near the ground surface and slab boundaries. The user inputs were domain dimensions and grid spacings, weather data file (TMY), soil and slab properties, ground surface properties, slab shape and size, deep ground boundary condition, evaporative loss at ground surface and building height for shadowing calculations.

In 1998, Cogil [16] developed a numerical model to predict basement heat loss based on the slab-on-grade model of Bahnfleth [17], which formed the basis of the *Basement* preprocessor of *EnergyPlus*. Similar to the slab-on-grade model of Bahnfleth, Cogil's basement model treated the GCHT calculation problem as a boundary value problem on three-dimensional heat conduction equation. This model, however, had a few significant differences from Bahnfleth's slab-on-grade model [16–18]: