Modeling of slab-on-grade heat transfer in EnergyPlus simulation program

Modelagem da transferência de calor da laje de piso no programa de simulação EnergyPlus

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Abstract

The heat flow through the floor and the ground of a single-story slab-on-grade building is one of the most influential aspects in its thermal and energy performance. However, there are still many uncertainties and only few studies on the subject. This study compares different modeling alternatives of the parameters related to the heat transfer between the floor and the ground, and their influence in the thermal performance of a naturally ventilated single-story house located in São Carlos, Brazil, using the programs EnergyPlus (8.5.0) and Slab (.75). The comparison between the modeling alternatives indicated wide variation in the results. When compared with Slab, the KusudaAchenbach method of the object Ground Domain presented the largest variation, with a difference of 55.2 % in the number of degree-hours of discomfort. It was observed that even the way of using Slab - for example, with or without the convergence procedure - could cause significant differences in the results. The thermal conductivity of the soil was a parameter of great impact, resulting in differences of up to 57.5 % in discomfort. Such results provide indications of the variability and impact of the different modeling options for this type of heat transfer in EnergyPlus.

Keywords: Thermal comfort. Computer simulation. EnergyPlus. Slab-on-grade. Slab preprocessor. Object Ground Domain.

Resumo

O fluxo de calor entre o piso e o solo de uma edificação térrea é um dos aspectos mais influentes em seu desempenho térmico e energético. No entanto, há ainda um grande número de incertezas e poucos estudos nessa área. Neste trabalho comparam-se diferentes alternativas de modelagem nos programas EnergyPlus (8.5.0) e Slab (.75) dos parâmetros relacionados à transferência de calor entre o piso e o solo, e sua influência no desempenho térmico de uma edificação térrea naturalmente ventilada, localizada em São Carlos, Brasil. A comparação das alternativas de modelagem indicou grande variação nos resultados. Quando comparado ao Slab, o método KusudaAchenbach do objeto Ground Domain apresentou a maior variação, com diferença de 55,2 % no número de horas de desconforto. Observou-se que mesmo a forma de uso do Slab pode causar diferenças significativas nos resultados; por exemplo, a adoção ou não do procedimento de convergência. A condutividade térmica do solo foi um parâmetro de grande impacto, que implicou diferenças de até 57,5 % no desconforto. Tais resultados fornecem indicações da variabilidade e do impacto de uso das diferentes opções de modelagem desse fluxo de calor no EnergyPlus.

Palavras-chave: *Conforto térmico. Simulação computacional. EnergyPlus. Fundação em laje. Pré-processador Slab. Objeto Ground Domain.*

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Introduction

The heat flow between the floor and the ground of a slab-on-grade single-story building is one of the most influential aspects in its thermal and energy performance. The heat transfer can be calculated in EnergyPlus (DEPARTMENT…, 2016a), with the aid of the Slab preprocessor (DEPARTMENT…, 2016b), to generate more accurate results (DEPARTMENT…, 2016d). EnergyPlus is a program validated by ASHRAE 140 (ASMERICAN…, 2014) and used worldwide to assess the thermal energy performance of buildings. The calculation method used by Slab is based on the works of Bahnfleth (1989) and Clements (2004). The Brazilian "Whole-Building Energy Efficiency Labeling Program for Residential Buildings" (INSTITUTO…, 2012) also indicates the need to use Slab in simulations of the slab-on-grade type when using EnergyPlus. Recently, a new object with the same functions as Slab was incorporated (Site: Ground Domain: Slab) in EnergyPlus 8.2. It calculates by using two methods, defined by the user: FiniteDifference (XING, 2014) and KusudaAchenbach (KUSUDA; ARCHENBACH, 1965).

Both alternatives (Slab and Site: Ground Domain: Slab) calculate the temperature of the interface between the ground and the building's floor, which must be entered in EnergyPlus to proceed with the simulation of the building. Silva, Almeida and Ghisi (2017) pointed out that ground temperature[1] is one of the most influential variables in EnergyPlus simulations, when performing a sensitivity analysis for a residential building located in Florianópolis/Brazil. Those authors also indicated this input variable as the most uncertain in the thermal performance results. However, there is a series of questions regarding the modeling in Slab and its input data, and the same is true for the object Site: Ground Domain: Slab (GDomain). Below, some studies on the subject are presented, which focus especially on slab-on-grade buildings.

Batista, Lamberts and Güths (2011), when calibrating the simulation data with experimental data from a single-story residential building located in Florianópolis/Brazil, saw that the best correlation for indoor air temperatures was found using the measured values of the ground temperatures, followed by a case using Slab.

Andolsun *et al.* (2012) quantified the differences among the slab-on-grade heat transfer models in the DOE-2, EnergyPlus/Slab and TRNSYS simulation programs for low-rise residential buildings in four climates of the US. The simulation with the TRNSYS program was considered the most accurate and correct model, and was therefore used as reference for comparison with the other models. When comparing the EnergyPlus/Slab and TRNSYS models, the results differed according to the way the ground was modeled. The TRNSYS results were sufficiently close to the simulations in EnergyPlus when Slab was run externally and with convergence temperatures. However, EnergyPlus with Slab running internally, and without convergence, presented heat load results 18 %-32 % lower than TRNSYS.

Another example that compared different alternatives for modeling slab-on-grade heat transfer in thermal performance simulation programs is the study by Larsen (2011), who verified which model of the SIMEDIF and EnergyPlus programs best represented the data from a slab-on-grade prototype measurement. The SIMEDIF program models the slab-on-grade heat transfer considering the ground temperature at a depth of 2m equal to the average outside air temperature, and the floor consisting of slab material and a 1m layer of soil. In EnergyPlus, three modeling options were adopted: the measured ground temperature, the modeling of slab-on-grade equal to the SIMEDIF program, and the Slab preprocessor. The SIMEDIF program presented the best results, with an average difference of 0.6 °C for the internal temperature and 0.2 °C for the floor surface temperature. The EnergyPlus models yielded similar indoor temperatures, with an average difference of about 1°C in relation to the measured data. However, the floor surface temperatures given by the EnergyPlus models did not accurately represent the measured data. The EnergyPlus modeling of slab-on-grade equal to SIMEDIF was the model that best represented the measured data.

The above-mentioned references show that there is a lack of studies on this theme, especially in Brazil, where there is usually no thermal insulation on floors, many of the buildings are naturally ventilated, and most do not have artificial conditioning. In this context, the aim of this paper is to assess the impact of different modeling alternatives for heat transfer between the floor and the ground in EnergyPlus, evaluating the thermal performance of naturally ventilated slab-on-grade single-story houses in Brazil. The study focuses

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[1] The term ground temperature in this paper refers to the temperature of the interface between the building floor and the ground.

especially on the Slab preprocessor and its various operation options, as well as on comparing it to other modeling options.

Modeling Slab-on-grade heat transfer in EnergyPlus

To calculate the heat exchanges between the slab-on-grade building and the ground, the monthly temperature variation data for the external surface of the floor is necessary (surface in contact with the ground). Currently, EnergyPlus provides two ways of performing calculations for this temperature: the Slab preprocessor and the object Site: Ground Domain: Slab (GDomain). In addition, there is a simplified way, which is to directly enter this temperature information in the object Site: Ground Temperature: Building Surface (GT:BSurface). The Manual Auxiliary Program (DEPARTMENT..., 2016d) indicates considering this value around 2 ºC below the mean indoor air temperature for artificially conditioned commercial buildings in the USA. Papst (1999) and Venâncio (2007) suggest the use of monthly mean air temperatures from weather files as reference.

The site: Ground Domain, Slab object (GDomain)

The object GDomain allows modeling multiple floors in contact with the ground, including different thermal zones. GDomain is in the object class Site: Ground Temperature, as part of EnergyPlus. When added, it is automatically used by the program. “It uses an implicit finite difference formulation to solve for the ground temperatures” (DEPARTMENT…, 2016c).

As a basis for calculation, this object uses a definition for Undisturbed Ground Temperature, which can be based on three different models. The first, FiniteDifference, is based on the work by Xing (2014). The second model, KusudaAchenbach, was developed by Kusuda and Achenbach (1965). And the third, Xing, developed by Xing (2014), is the most complex one, requiring a greater number of input variables (MAZZAFERRO; MELO; LAMBERTS, 2015).

The Slab preprocessor program

Slab is an auxiliary program linked to EnergyPlus. Its calculation algorithm was originally developed by Bahnfleth (1989), and then modified by Clements (2004). Its numerical method is based on an operation of finite tridimensional differences, providing a well-detailed solution with great flexibility. Slab’s input data refer to the EPW weather files, to the characteristics of the building and the soil, and to the operating conditions of the program itself. The Auxiliary Programs Manual (DEPARTMENT…, 2016d) and the EnergyPlus University Course Teaching Material (GARD…, 2003) present a description of the data (inputs and outputs) and basic instructions.

With the ground temperature provided by Slab, it is possible to simulate the building in EnergyPlus by entering this information in the object “Site:BuildingSurfaceGroundTemperature”. There are two ways to run Slab. In the first, Slab runs individually and its output (ground temperature) is an input in EnergyPlus, which is then run (“slab operating externally”, Figure 1). The second option makes the simulation process easier, running Slab internally in EnergyPlus (“slab operating internally”, Figure 1). In this case, all Slab input data are entered in the input file in EnergyPlus (*.idf) itself, and the above-mentioned process becomes automatic.

However, regardless of the choice to run Slab internally or externally to EnergyPlus, a previous simulation in EnergyPlus, denominated *preliminary simulation*, is always necessary. Figure 1 (“preliminary simulation”) illustrates this procedure. Its purpose is to obtain a first estimate for the building's indoor air temperature (monthly means), since it is an input for Slab. At the beginning of the simulation, there is no such data, especially for buildings in free-float conditions. The Auxiliary Programs Manual (DEPARTMENT…, 2016d) recommends that in such simulation, a layer with high insulation on the floor be added.

After the preliminary simulation and the first run of the duo EnergyPlus/Slab, EnergyPlus may produce an indoor air temperature for the building (monthly means) that is very different from the temperature considered as input in Slab. To adjust this data, it is necessary to adopt the convergence procedure (Figure 2) described by Andolsun *et al.* (2012). To perform it, it is necessary to carry out consecutive simulations with iteration between the results given by Slab and by EnergyPlus. Those authors consider that the convergence is obtained when the difference in the monthly mean indoor air temperatures in the thermal zone between the last two simulations is of $\leq$0.0001 °C.

Another aspect to be highlighted about Slab is that it provides three monthly temperature series for the ground surface underneath the floor: the average temperature for the core, for the perimeter and the weighted average for the surface area. The temperatures can be applied in EnergyPlus in two ways. If the user selects the average temperature, a uniform distribution of heat transfer on the entire floor surface is assumed. If the core and perimeter temperatures are used, it is assumed that the heat transfer in the core is different from the one in the perimeter, leading to the adoption of independent ground temperature values for each surface.

Research method

The method consisted of tests with various modeling options for a naturally ventilated slab-on-grade single-story building in the EnergyPlus (version 8.5.0) and Slab (version .75) programs.

Building geometry and construction

The simulated building model was based on a social housing project usually employed by a major Brazilian housing funding agency (MARQUES, 2013). The original project is a slab-on-grade single-story isolated house. The building has two bedrooms, a kitchen, a living room and a bathroom, with a total area of 37.1 m². The simulated model considered only the external walls, resulting in one thermal zone composed of all the rooms (Figure 3). The roof consists of a non-ventilated attic, which was also simulated as a thermal zone, exchanging heat with the interior of the building through the roof slab. The windows are positioned as in the original project, and their areas were also maintained the same. The dimensions of the windows are 1.2 x 1.0m (living room), 1.2 x 1.0m (bedrooms), 0.50 x 0.50m (bathroom) and 1.2 x 1.0m (kitchen).

Table 1 presents the constructive characteristics and the thermophysical properties of the building's elements. The choice was based on information given by the Brazilian funding agency previously mentioned (Caixa Econômica Federal, with data from Marques (2013)), and it reflects what is usually employed in this type of building. There is no thermal insulation on the floor, which is common for all types of single-story houses in Brazil, not just social housing projects.

Figure 1 - **Scheme for Slab running internally or externally to EP and preliminary simulation**

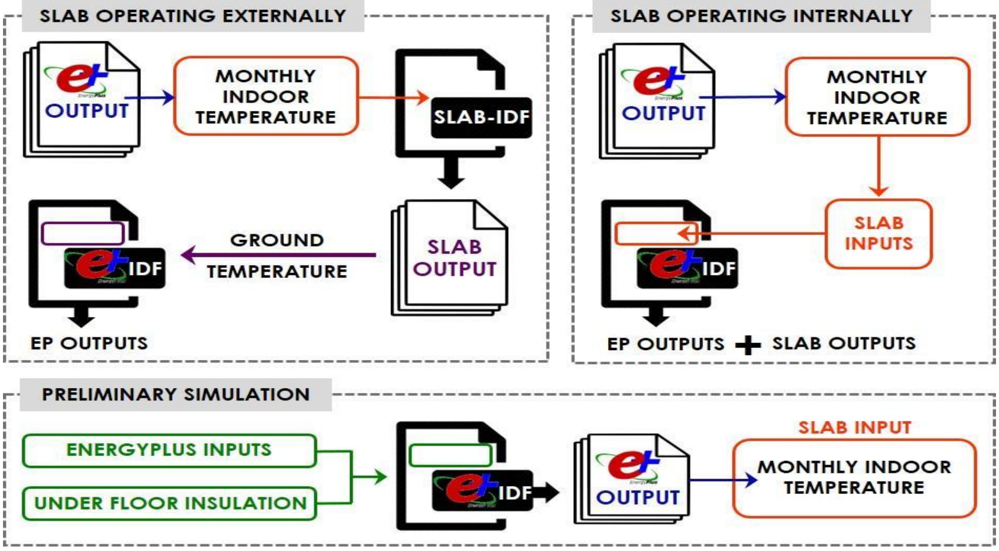


Figure 2 - **Convergence Procedure**

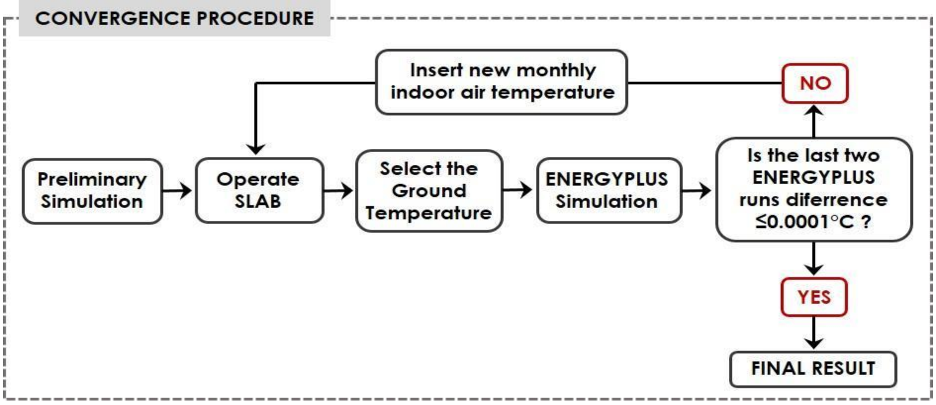
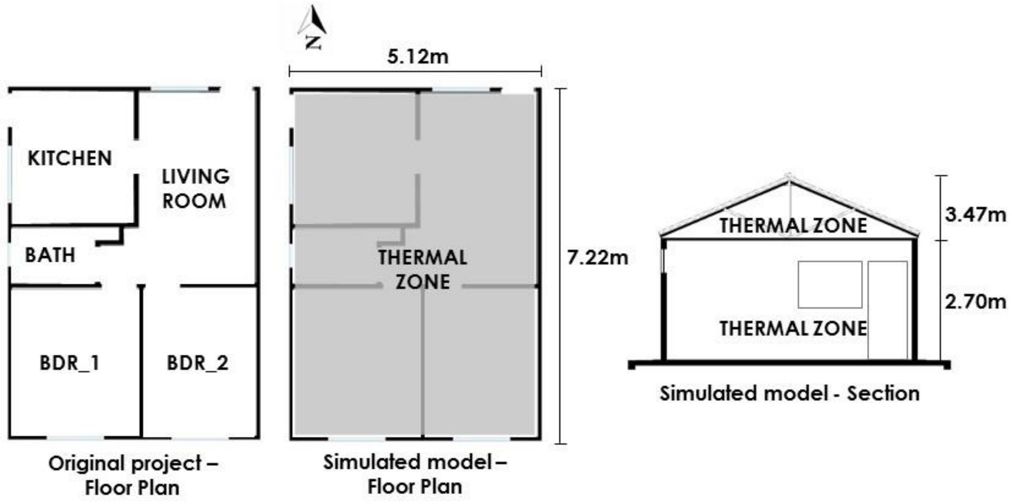


Figure 3 - **original project and simulated model**



Original project – Floor Plan

Simulated model – Floor Plan

Simulated model - Section

Table 1 - **Constructive characteristics and thermophysical properties of the building's elements**

Opaque elements of the building	U-value[1] (W/m^{2}K)	R-value (m^2.K/W)	C-value (kJ/m^{2}K)	Solar Absorptance[2]
External walls Plaster (2.5 cm) + 14cm perforated concrete block + plaster (2.5cm)	2.76	-	266	0.30
Roof Ceramic tile (1cm) + non-ventilated attic + pre-molded ceramic slab (12cm)	1.78	-	189	0.75
Floor[3] Gravel (3cm) + concrete (8cm) + plaster (2.5cm) + ceramic tiles (0.4cm)	-	0.32	279	-

Translucent areas		
Glass	Color	Clear
	Thickness	4 mm

Note: [1]material properties, transmittance (U-value) and heat capacity (C-value) calculations were conducted according to the Brazilian Standard "Thermal performance of buildings Part 2: Calculation method for thermal transmittance, heat capacity, thermal delay and buildings' elements factors and components" NBR 15220-2 (ABNT, 2005a).

[2]the envelope's absorptance was determined according to paint absorptance measurements conducted by Dornelles (2008). The color selected was ice white.

[3]for the floor, the thermal resistance value is presented instead of transmittance due to the difference in the external surface resistance.

Internal gains

The internal loads due to internal heat sources (occupants, artificial lighting and equipment), and their use patterns, were defined as recommended by the "Whole-Building Energy Efficiency Labeling Program for Residential Buildings" (INSTITUTO…, 2012). The values are presented in Table 2.

Climate

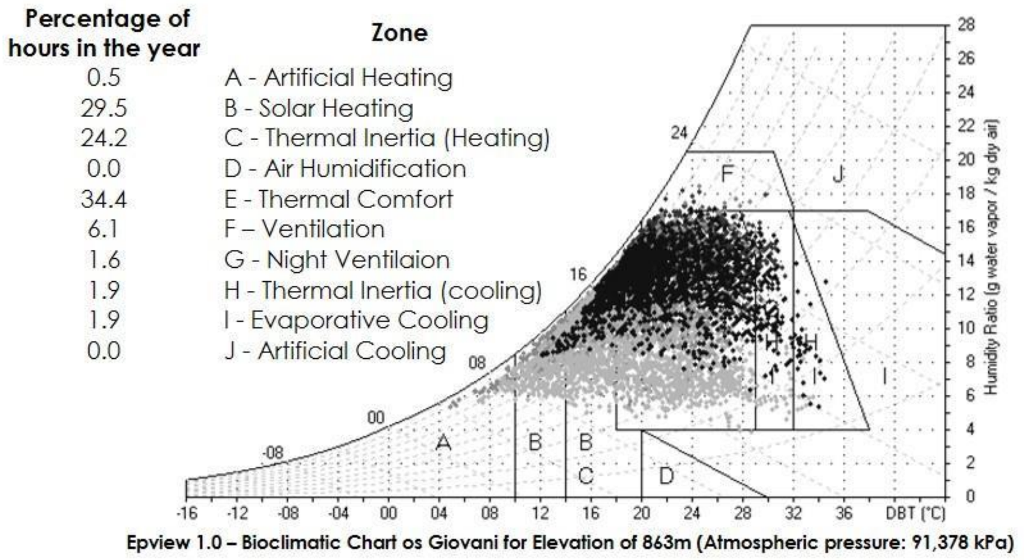
The chosen location is the city of São Carlos, with latitude 22°01'03''S, altitude of 863m, and situated in climate zone 4, according to the Brazilian Standard NBR 15220-3 (ABNT, 2005b). The EPW file used was developed by Roriz (2012). Figure 4 represents Givoni's (1992) climatic diagram generated by the EPview program (RORIZ; RORIZ, 2015) using the above-mentioned weather file. The diagram shows that during most of the year (34.4 %) the city is within the comfort zone. It is also possible to see that there is a predominance of cold over heat, with 29.5 % of the year located in the solar heating zone, and 24.2 % in the thermal-inertia zone (heating).

Table 2 - **Total daily internal gains**

Total internal gains corresponding to a 24-hour period		
Heat Sources	**Week days**	**Weekends**
Occupation	2490 W/m²	3360 W/m²
Lighting	45 W/m²	57 W/m²
Equipment	36 W/m²	

Note: the Brazilian "Whole-Building Energy Efficiency Labeling Program for Residential Buildings" (INSTITUTO..., 2012) presents different patterns for occupation, equipment and natural lighting for each room (living room, bedroom and kitchen). These gains are irregularly distributed during the day. On this table, only the total sum is presented for a 24-hour period.

Figure 4 - **Givoni's (1992) bioclimatic diagram for the city of São Carlos/Brazil**



Natural ventilation modeling

The building was considered naturally ventilated by the use of windows, as is common for residential buildings with these dimensions in the chosen location. Ventilation was modeled using the Airflow Network module in EnergyPlus. For the wind pressure coefficients for each façade, the values automatically calculated by EnergyPlus for rectangular geometries were adopted. The main input data adopted in the simulations for the Airflow Network module are presented in Table 3. Using temperature as the control for window opening, ventilation was allowed when the indoor air temperature was higher than the external air temperature (Tint >Text), and when the indoor air temperature was higher than the control temperature (Tint >Tsetpoint). The ventilation schedule was defined according to the users' occupation pattern (see Internal Gains section) as well as to previous studies about window operation conducted for the same climate, which indicate the need for nocturnal ventilation (MARIN; CASATEJADA; CHVATAL, 2016). The percentage of window opening considered was 100 %, in accordance with what is proposed by the Brazilian Standard NBR 15220 (ABNT, 2005b) for climate zone 4. The standard recommends the use of medium openings for ventilation in this zone, with an effective opening area between 15 % and 25 % of the floor area.

Input data and simulation variations

The simulations are divided into three groups, as indicated in Table 4. In the first group, tests were run to evaluate the operation of Slab and other modeling alternatives for the heat exchanges between the building and the ground. In the second group, the objective was to evaluate the influence of certain input data from Slab on the output data. In the third group, tests were performed varying specifically one type of input data from Slab: the thermophysical properties of the soil.

Table 3 - **Input data for Airflow Network**

Parameter	Variable
Control type for window opening	By temperature
Control setpoint	20°C[1]
Wind pressure coefficient type	Surface Average Calculation
Ventilation schedule	18h - 6h/12h - 13h (Sep. to Apr.)
Effective window opening percentage	100 %

Note: [1]defined according to the "Whole-Building Energy Efficiency Labeling Program for Residential Buildings" (INSTITUTO..., 2012).

Table 4 - **Groups and sub-groups of simulations and their variations**

Simulation groups	Sub-groups	Variations	Observations
Slab operation and other alternatives	1. Slab Activation	Slab run internally in EnergyPlus and externally to EnergyPlus, with the same input data	In both cases, Slab was run only once. These two variations were compared with each other.
	2. Slab use	(A) With Slab. With floor insulation layer in the preliminary simulation by EnergyPlus[1] (B)Without Slab. With GT:BSurface. (C)Without Slab. With GDomainFD. (D)Without Slab. With GDomainKA.	From these simulations onward, Slab was always internally run in EnergyPlus. In the case With Slab, the convergence procedure was adopted. The three use alternatives for Slab are presented in the section "Modeling Slab-On-Grade Heat Transfer in EnergyPlus". The temperature of the ground and floor interface, using the object GT:BSurface, is the same as the mean outdoor air temperature from the weather file.
	3. Convergence procedure and ground temperature in preliminary simulation in EnergyPlus[1]	(A) With Slab. With floor insulation layer in the preliminary simulation in EnergyPlus [1] (B) With Slab. Without floor insulation layer and ground temperature of 18°C, in preliminary simulation by EnergyPlus [1] (C) With Slab. Without floor insulation layer and ground temperature of 25°C, in preliminary simulation by EnergyPlus [1]	The convergence procedure was tested by comparing the results from Slab after the first run, and after reaching convergence.
Influence of Slab's input data	4. Daily temperature amplitude	(A) Amplitude = 0	Each of these alterations was made separately. In the case of sub-group 6, two floor surfaces were created in EnergyPlus (core and perimeter). The perimeter dimensions correspond to a 1.5m wide strip around the building's perimeter (CLEMENTS, 2004). The remaining area corresponds to the core.
	5. Evapotranspiration	(A) No evapotranspiration	
	6. Entering Temperature generated by Slab in EnergyPlus	(A) Entering different temperatures in EnergyPlus, for the floor core and perimeter	
	7. Horizontal domain dimension	(A) 7.5m (B) 30m	
	8. Iteration time	(A) 5 years (B) 20 years	
Influence of the thermophysical properties of the soil	9. Conductivity (k), specific heat (c_p) and ground density (ρ) (humid, intermediate and dry soil)	(A) dry soil k: 0.5 W/m.K ρ: 1200 kg/m^3 c_p: 1200 J/kg.K (B) humid soil k: 2 W/m.K ρ: 1700 kg/m^3 c_p: 1700 J/kg.K	Values measured by Kersten (1949) and provided by Bahnfleth (1989).

Note: [1]the preliminary simulation is defined in the section "Modeling Slab-On-Grade Heat Transfer in EnergyPlus".

Each of these groups was divided into a series of sub-groups. Tables 5 to 11 list all input data for Slab (Tables 6 to 11) as well as the data for the object GDomain (Table 5), identifying to which sub-group they belong. From sub-groups 4 to 9, the results of the considered variations were compared to a case designated as “reference”. The reference case was considered as the most indicated, according to the literature and the Auxiliary Programs Manual and EnergyPlus University Course Teaching Material (GARD…, 2003; DEPARTMENT…, 2016d). The choice of what would be altered was also based on those references. All simulations followed the procedures outlined in the section “Modeling Slab-On-Grade Heat Transfer in EnergyPlus”, unless otherwise stated. Table 6 also presents some additional details about the simulation procedure.

Table 5 – **GDomain object input data (described in Table 4)**

Input data for object GDomain	
Input Fields	**Adopted Values**
Name	GDomain
Ground Domain Depth (m)	15[1]
Aspect Ratio	1.41
Perimeter Offset (m)	10
Soil Thermal Conductivity (W/m.K)	1[1]
Soil Density (kg/m³)	1200[1]
Soil Specific Heat (J/kg.K)	1200[1]
Soil Moisture Content Volume Fraction (%)	30
Soil Moisture Content Volume Fraction at Saturation (%)	50
Type of Undisturbed Ground Temperature Object	Site:GroundTemperature: Undisturbed:FiniteDifference (sub-group 2, variation C) Site:GroundTemperature: Undisturbed: KusudaAchenbach (sub-group 2, variation D)
Name of Undisturbed Ground Temperature Object	GDomainFD (sub-group 2, variation C) GDomainKA (sub-group 2, variation D)
Evapotranspiration Ground Cover Parameter	1.5
Slab Boundary Condition Model Name	GroundCoupledOSCM
Slab Location	OnGrade
Slab Material Name	
Horizontal Insulation	No
Horizontal Insulation Material Name	
Horizontal Insulation Extents	Full
Perimeter Insulation Width	
Vertical Insulation	No
Vertical Insulation Material Name	
Vertical Insulation Depth	
Simulation Timestep	Hourly
GroundTemperature: Shallow	
Input Field	**Adopted Values**
January – December Surface Ground Temperature (°C)	Monthly mean outdoor air temperature from the weather file
Site:GroundTemperature:Undisturbed: FiniteDifference (when it is Case C from sub-group 2, variation C)	
Input Fields	**Adopted Values**
Name	GDomainFD
Soil thermal conductivity	1[1]
Soil density	1200[1]
Soil specific heat	1200[1]
Soil moisture content volume fraction (%)	30
Soil moisture content volume fraction at saturation (%)	50
Evapotranspiration ground cover parameter	1.5
Site:GroundTemperature:Undisturbed: KusudaAchenbach (sub-group 2, variation D)	
Input Fields	**Adopted Values**
Name	GDomainKA
Soil thermal conductivity	1[1]
Soil density	1200[1]
Soil specific heat	1200[1]
Average Soil Surface Temperature (°C)	
Average Amplitude of Surface Temperature (Δ°C)	
Phase shift of Minimum Surface Temperature (days)	
SurfaceProperty:OtherSideConditionsModel	
Input Fields	**Adopted Values**
Name	GroundCoupledOSCM
Type of modeling	GroundCoupledSurface

Note: [1] in this case, default values from GDomain were not used, as they differ from Slab. Therefore, both Slab and GDomain were run with the same value for this parameter.

Table 6 - **Slab input data from Class Ground Heat Transfer: Slab: Materials and additional details about the simulation procedure for the reference case and further simulations (described in Table 4)**

Preliminary simulation		
Reference Case and sub-groups 1, 2, 3 (variation A) and 4 to 9. According to the procedure described in the section The Slab Preprocessor Program. With an insulation layer underneath the floor (on the ground and floor interface). Composed of glass wool (thickness of 20cm) with conductivity of 0.045 W/m.K, density of 100 kg/m³ and specific heat of 700 J/kg.K. Monthly mean ground temperature is the same as external air. **SUB-GROUP 3 (VARIATIONS B, and C).** As described in the section “Modeling Slab-On-Grade Heat Transfer in EnergyPlus), but with the preliminary simulation with the monthly mean ground temperature equal to 18 or 25 degrees, and not considering the insulation layer.		
Convergence procedure		
Reference Case and sub-groups 2 (VARIATION A), 3 (VARIATIONS A, B and C) to 9. Adopting such procedure, as described in the section “Modeling Slab-On-Grade Heat Transfer in EnergyPlus”.		
Input parameters for Slab		
I) Ground Heat Transfer: Slab: Materials:	**Adopted value**	**Observations**
NMAT: Number of materials	2	Number of different materials used on slab-on-grade.
ALBEDO: Surface Albedo: No Snow	0.16	Indicates the surface's potential of solar reflectance. Varies from 0 to 1. The default value was used.
ALBEDO: Surface Albedo: Snow	0.40	
EPSLW: Surface Emissivity: No Snow	0.94	Indicates the capacity to emit and absorb thermal radiation. Varies from 0 to 1. The default value was used.
EPSLW: Surface Emissivity: Snow	0.86	
Z0: Surface Roughness: No Snow (cm)	0.75	It is used to determine the heat transfer coefficient by convection between the ground surface and the air. The default value was used.
Z0: Surface Roughness: Snow (cm)	0.25	
HIN: Indoor Conv. Downward Flow (W/m².K)	6.13	Defines the heat transfer coefficient by convection and by radiation combined between the upper surface of the floor and the air in the thermal zone. Default value for Slab taken from the ASHRAE Handbook of Fundamentals (AMERICAN…, 2005).
HIN: Indoor Conv. Upward (W/m².K)	9.26	

Note: [1]When not otherwise stated, the input data were used in all simulations (the reference one and all sub-groups).

Table 7 - **Slab input data from Class Ground Heat Transfer: Slab: MatlProps**

II) Ground Heat Transfer: Slab: MatlProps	**Adopted value and observations**
RHO: Slab Material density (kg/m³)	Data referring to the thermophysical properties of the floor. 2007 kg/m³ The properties were taken from the Brazilian standard "Thermal performance of buildings Part 2: Calculation method for thermal transmittance, heat capacity, thermal delay and factors and components of building elements” NBR 15220-2 (ABNT, 2005a)
RHO: Soil Density (kg/m³)[1]	**Reference Case and all sub-groups, except 9(B).** 1200 kg/m³. This value corresponds to the default value and also to the value measured by Kersten (1949) and provided by Bahnfleth (1989). **Sub-Group 9(B).** 1700 kg/m³
CP: Slab CP (J/kg K)	Data referring to the thermophysical properties of the floor 1000 J/kg K The properties were taken from the Brazilian standard "Thermal performance of buildings Part 2: Calculation method for thermal transmittance, heat capacity, thermal delay and factors and components of building elements" NBR 15220-2 (ABNT, 2005a)
CP: Soil CP (J/kg K)	**Reference Case and all sub-groups, except 9(B).** 1200 J/kg K. This value corresponds to the default value and also to the value measured by Kersten (1949) and provided by Bahnfleth (1989). **Sub-Group 9(B).** 1700 J/kg K
TCON: Slab k (W/m.K)	Data referring to the thermophysical properties of the floor 0.429 W/m.K The properties were taken from the Brazilian standard "Thermal performance of buildings Part 2: Calculation method for thermal transmittance, heat capacity, thermal delay and factors and components of building elements" NBR 15220-2 (ABNT, 2005a)
TCON: Soil k (W/m.K)	**Reference Case and all sub-groups, except 9**. 1 W/m.K. This value corresponds to the default value and also to the value measured by Kersten (1949) and provided by Bahnfleth (1989). **Sub-Group 9. (A)** 0.5 W/m.K **(B)** 2 W/m.K

Note: [1]as recommended by the Auxiliary program (DEPARTMENT…, 2016d).

Table 8 - **Slab input data from Class Ground Heat Transfer: Slab: BoundConds**

III) Ground Heat Transfer: Slab: BoundConds	Adopted value and observations
EVTR: Is surface evapotranspiration modeled	**Reference Case and all sub-groups, except 5.** TRUE [1] **Sub-Group 5.** FALSE
FIXBC: lower boundary at a fixed temperature[1]	FALSE There is no temperature value for the lower boundary.
TDEEPin (ºC)[1]	BLANK because the previous field was defined as “FALSE”.
USRHflag: is the ground surface h specified by the use[1]	FALSE There is no coefficient value.
	BLANK because the previous field was defined as “FALSE”.

Note: [1]as recommended by the Auxiliary program (DEPARTMENT..., 2016d).

Table 9 - **Slab input data from Class Ground Heat Transfer: Slab: BldgProps**

IV) Ground Heat Transfer: Slab: BldgProps	Adopted value and observations
IYRS: Number of years to iterate[1]	**Reference Case and all sub-groups, except 8.** 10 years (default Value) **Sub-Group 8(A)** 5 years **(B)** 20 years
Shape: Slab shape	Zero (rectangular floors, only available option). Default value
HBLDG: Building height (m)	Data referring to the building's geometry. 3.47m
TIN (January – December) Indoor Average Temperature Setpoint (ºC)	Generated in the previous simulation with EnergyPlus. See simulation procedure in the section The Slab Preprocessor Program.
TINAmp: Daily Indoor sine wave variation amplitude	**Sub-groups 1 to 4.** Amplitude = 0 (default value) **Reference Case and sub-groups 5 to 8.** Annual average indoor air temperature amplitude given by the previous iteration with EnergyPlus (see simulation procedure in the section the “Modeling slab-on-grade heat transfer in EnergyPlus”
ConvTol: Convergence Tolerance	Slab's default values 0.1

Note: [1]as recommended by the Auxiliary program (DEPARTMENT..., 2016d).

Table 10 - **Slab input data from Class Ground Heat Transfer: Slab: Insulation**

V) Ground Heat Transfer: Slab: Insulation	Adopted value and observations
RINS: R value of under slab insulation	A value of zero is entered because there is no type of insulation in the building's floor composition.
DINS: Width of strip of under slab insulation	
RVINS: R value of vertical insulation	
ZVINS: Depth of vertical insulation	
IVINS: Flag is there vertical insulation	

Table 11 - **Slab input data from Class Ground Heat Transfer: Slab: EquivalentSlab**

VI) Ground Heat Transfer: Slab: EquivalentSlab	Adopted value	Observations
APRatio: The area to perimeter ratio for this slab	1.5m	Data referring to the building's geometry.
SLABDEPTH: Thickness of slab on grade (m)	0.139m	
CLEARANCE: Distance from edge of slab to domain edge (m)[1]	15m	**Reference Case and all sub-groups, except 7.** 15m **Sub-Group 7. (A)** 7.5m **(B)** 30m
ZCLEARANCE: Distance from bottom of slab to domain bottom (m)[1]	15m	Slab's Default value

Note: [1]as recommended by the Auxiliary program (DEPARTMENT..., 2016d).

Form of analysis of the results

The output data used were indoor air temperature and operative temperatures (hourly), given by EnergyPlus, and ground temperature right beneath the floor (monthly means), given by Slab. The impact that the modeling possibilities explored in the simulations had on the hourly indoor air temperature was closely examined. As well as that, the study investigated how that impact reflected on the comfort evaluation of the house, by adopting the comfort limits given by the adaptive approach in Standard 55 (AMERICAN…, 2013), which are specific to naturally ventilated rooms. The temperatures corresponding to those limits are a function of the outside air temperature, given by the weather file. As indicated in the Standard, the limits adopted corresponded to 80 % acceptability by users. Figure 5 presents the external air temperature, the comfort temperature and the upper and lower limits, as a function of the hours in a year, for the city of São Carlos, Brazil, given by the EPW weather file provided by Roriz (2012).

With the comfort range established, the total annual degree-hours of discomfort by heat and by cold were obtained. Each degree-hour corresponds to the discomfort caused when the operative temperature[2] is below the lower limit (cold) or above the upper limit (heat) by 1˚C during one hour. The annual levels are the sum of the degree-hours that occurred over the hours for a year (RORIZ; CHVATAL; CAVALCANTI, 2009).

Results and discussion

This section shows the results of the simulations. The sub-groups are described in Table 4 in Research Method and the results are divided into the following items:

(a) internal or external Slab activation on EnergyPlus (simulations from sub-group 1);

(b) with or without using Slab, with or without convergence procedure (simulations from sub-groups 2 and 3);

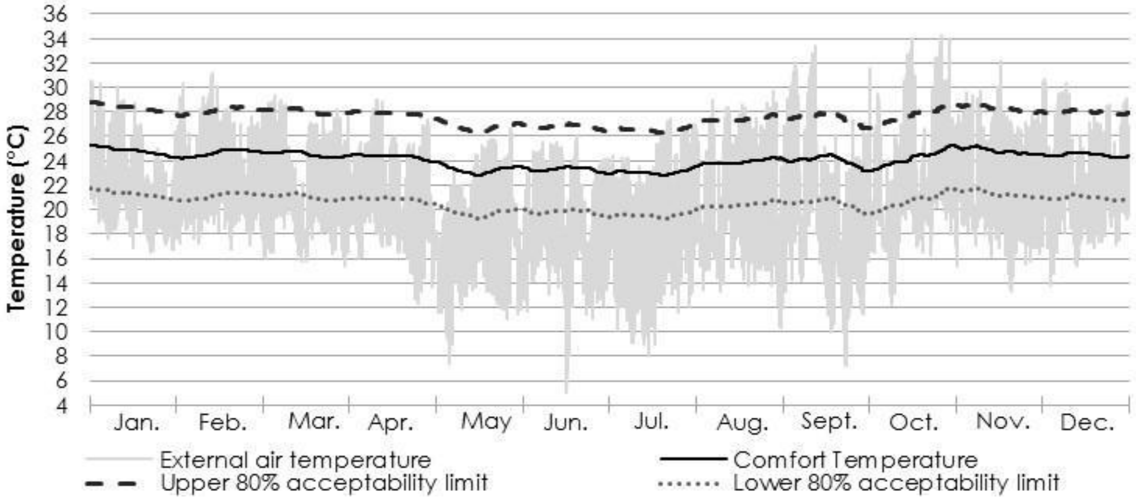
(c) influence of Slab’s input data (simulations from sub-groups 4 to 8); and

(d) influence of the thermophysical properties of the soil (simulations from sub-group 9).

Internal or External Slab activation on EnergyPlus

Simulations were performed with both types of activation using the same input data, according to the procedure indicated in the “Modeling Slab-On-Grade Heat Transfer in EnergyPlus” section and the input data described in Research Method. Both simulations presented all the output variables with identical values. This indicates that when Slab is internally activated, it works correctly. Besides, since it was only run once when externally activated, this confirms that the same occurred when it was internally activated, that is, no iterations were performed searching convergence. After this result, Slab was internally activated in EnergyPlus in all the simulations.

Figure 5 - **Upper and lower limits of the comfort zone, comfort temperature and hourly external air temperature for São Carlos - Brazil**



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[2] “The uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation plus convection as in the actual nonuniform environment” (AMERICAN…, 2013).

With or without using Slab, with or without Convergence Procedure

As presented in Research Method (simulations sub-group 2), the following situations were analyzed, regarding the scenarios with and without Slab:

(a) (2A) Slab. Adopting the convergence procedure and the preliminary simulation run with the insulation layer on the floor;

(b) (2B) GT:BSurface. Without Slab, with the ground and floor interface temperatures the same as the monthly mean air temperature in the weather file;

(c) (2C) GDomainFD. Without Slab, adopting the FiniteDifference calculation method;

(d) (2D) GDomainKA. Without Slab, adopting the KusudaAchenbach calculation method.

The results are presented in Figure 6. It indicates the number of hours in a year in which the difference between the hourly indoor air temperatures in cases 2B, 2C and 2D and in Slab case 2A are found within the limits defined on the x-axis. The positive values correspond to indoor air temperatures in cases 2B, 2C and 2D higher than those in the Slab case, and the negative values indicate the opposite. The results show that without Slab there is a considerable impact on the hourly indoor air temperature, which increases for the most part of a year in all three alternatives. Case GT:BSurface presents differences smaller than or equal to +0.5 °C in 63.8 % of the time. As for case GDomainFD, as well as GDomainKA, the differences are slightly higher, and their distributions are very similar to each other. There are values above +1.25 °C in 14 % and 24.0 % of the annual hours, respectively, with the maximum value reaching + 3.06 °C, in the GDomainKA case.

When opting to use Slab, Andolsun *et al.* (2012) state that, in order to obtain more accurate results, convergence of the internal air temperature is necessary. The final converged result is more correct, since it refers to the same monthly mean ground- and indoor air temperature combinations in both calculation algorithms: EnergyPlus and Slab. Before the convergence procedure, a preliminary simulation is run to obtain the first indoor air temperature estimate, which is an input data in Slab. The convergence procedure and the preliminary simulation are described in the section "Modeling Slab-On-Grade Heat Transfer in EnergyPlus".

Hence, the second test refers to the verification of the impact of adopting the convergence procedure, also considering different modeling alternatives in EnergyPlus from the preliminary simulation. Six cases were compared (detailed in Research Method, simulations sub-group 3):

(a) (3A) Slab. With convergence and preliminary simulation considering one floor insulation layer. 7 iterations were required;

(b) (3B) $T_{18\,°C.}$ With convergence and preliminary simulation without floor insulation and ground temperature equal to 18 °C, which is the minimum value allowed by EnergyPlus. 6 iterations were required;

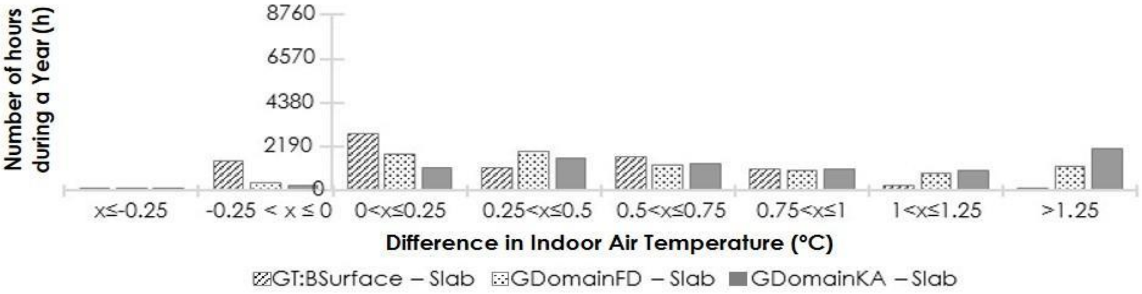
(c) (3C) $T_{25\,°C.}$ With convergence and preliminary simulation without floor insulation and ground temperature equal to 25 °C, which is the maximum value allowed by EnergyPlus. 7 iterations were required;

(d) (3D) 1stSlab. Same as case 3A, but the simulation was finished after the first run in EnergyPlus/Slab;

(e) (3E) 1st$T_{18\,°C.}$ Same as case 3B, but the simulation was finished after the first run in EnergyPlus/Slab; and

(f) (3F) 1st$T_{25\,°C.}$ Same as case 3C, but the simulation was finished after the first run in EnergyPlus/Slab.

Figure 6 - **Hourly indoor air temperature difference for the tests with Slab or other alternatives**



As expected, cases 3A, 3B and 3C, at the end of the convergence procedure resulted in the same final indoor and ground temperature combination. Several iterations were required to achieve very similar convergences between them. Andolsun *et al.* (2012), on the other hand, indicated a significant reduction in the amount of iterations when adopting a case similar to A (with an insulation layer in the preliminary simulation). This is possibly due to the initial interior temperature values adopted to enter in the first run in EnergyPlus/Slab, which were already close to their final result.

The impact of not adopting the convergence procedure (comparison between cases 3A, 3D, 3E and 3F), is presented in Figure 7. This difference ranges from 0 °C to +0.3 °C in 83.11 % of the annual hours, for case 3D (preliminary simulation with insulation). In case 3E (1st$T_{18\,°C}$), the difference ranges between -0.1 °C and +0.1 °C for 95.74 % of the annual hours. And in case 3F (1st$T_{25°C}$), it is greater than +0.5 °C in 24.97 % of the period. That is, if the convergence procedure is not adopted when using Slab for a building with these characteristics, the preliminary simulation with 25 °C is the one that presents the greatest difference, followed by case 3D (1st Slab) and the case with 18 °C.

This indoor temperature difference is a consequence of the difference for ground temperature adopted in EnergyPlus, as presented in Table 12. The results show that it is in the case of 25 ºC (1st $T_{25\,°C}$) - in comparison with the cases of 18 ºC (1st$T_{18\,°C}$) and 1stSlab case - that the greatest differences occur between the ground temperature used in EnergyPlus for these simulations and the temperature that would be the most correct. These results confirm what had previously been observed: on the floor without insulation, differences in the ground temperature directly impact the indoor temperature. The differences in the cases without convergence are smaller when the first simulation is run (1st iteration) and the ground temperature is closer to the final one. In this specific case, this corresponded to the preliminary simulation of 18 °C. However, this varies according to the climate and building characteristics, and it is not possible to predict the best solution. Since there is no thermal insulation on the floor, which is common in Brazilian slab-on-grade buildings, differences in the average ground temperature directly influence the internal environment.

Figure 7 - **Hourly indoor air temperature difference for the convergence procedure tests**

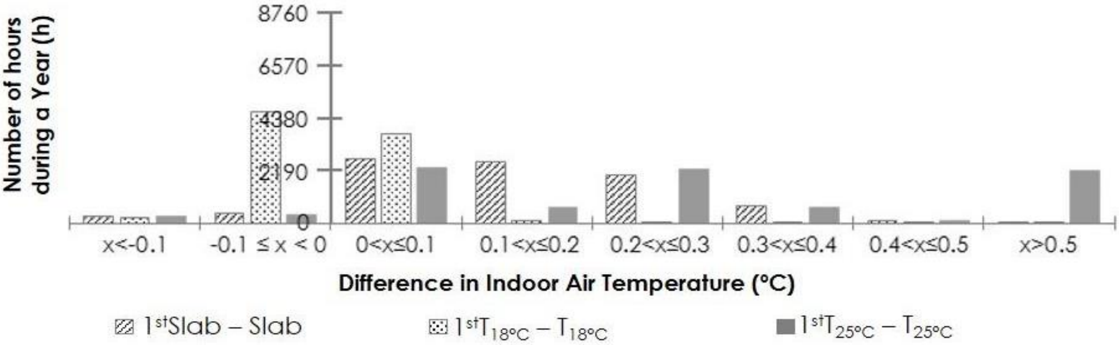


Table 12 - **Comparative table of the ground temperature used in cases A, B, C, D, E and F of sub-group 3 in the test for convergence procedure and initial temperature**

Month	Temperature Difference (°C)					
	(a) Slab	(b) $T_{18°C}$ – (a) Slab	(c) $T_{25°C}$ – (a) Slab	(d) 1stSlab – (a) Slab	(e) 1st$T_{18°C}$ – (b) $T_{18°C}$	(f) 1st$T_{25°C}$ – (c) $T_{25°C}$
Jan.	22.1	0	0	+0.56	-0.16	+0.72
Feb.	22.9	0	0	+0.59	-0.23	+0.7
Mar.	22.1	0	0	+0.53	-0.18	+0.71
Apr.	21.3	0	0	+0.44	-0.13	+0.76
May	19.3	0	0	+0.32	+0.05	+0.9
June	20.2	0	0	+0.54	+0.13	+1.71
July	20.4	0	0	+0.74	+0.2	+1.91
Aug.	22.3	0	0	+1.1	+0.01	+1.7
Sept.	20.6	0	0	+0.65	+0.09	+1.09
Oct.	22.5	0	0	+0.72	-0.04	+0.87
Nov.	22.2	0	0	+0.65	-0.1	+0.78
Dec.	22.5	0	0	+0.64	-0.13	+0.77

Finally, the impact of the above-mentioned hourly temperature differences on the comfort assessment of the building was verified. Table 13 shows the degree-hours of discomfort by cold, by heat and the total discomfort, as well as their increase (+) or decrease (-) percentages in relation to case 2A (Slab). The other options reflect the previously observed internal temperature behavior: cases GDomainKA and GDomainFD present the greatest impact (decreases of 55.2 % and 44.0 % on total discomfort in relation to Slab). Cases GT:BSurface and $1^{st}T_{25\ °C}$ present an intermediate difference (decreasing total discomfort by 26.2 % and 26.9 %). Case $1^{st}T_{18\ °C}$ presents the smallest alteration (-0.2 %).

These results demonstrate the considerable impact of the studied alternatives both on the indoor temperature and on the comfort evaluation, indicating not only the importance of using Slab but also the convergence procedure. The considerable differences observed between the object GDomain and Slab, indicate the need to better understand both methods. In addition, a comparison to real measured data would show which method would be more adequate for the building type in question.

Influence of Slab input data

Although the importance of using Slab in slab-on-grade simulations has been confirmed, there are still many uncertainties related to its input data, especially in Brazil, where there are no studies pertaining such issues. To evaluate the impact of some of these input data, selected as relevant, eight cases were simulated. Their detailed description can be found in Research Method. In all cases, the convergence procedure was adopted.

(a) (4A) Zero amplitude. Annual daily average amplitude equal to zero;

(b) (5A) Evapotranspiration. With evapotranspiration deactivated;

(c) (6A) Slab temperature. With two ground temperatures, for the core and for the perimeter;

(d) (7A) Horizontal domain. With the horizontal domain dimensions considered 7.5m;

(e) (7B) Horizontal domain. Within the horizontal domain dimensions considered 30 m;

(f) (8A)Years to iterate. With the amount of iteration years considered 5 years;

(g) (8B)Years to iterate. With the amount of iteration years considered 20 years; and

(h) Reference case - where none of the above-mentioned input data were altered, referring to cases 4 to 8.

The alteration that presented the largest difference in relation to the reference case was the one with evapotranspiration deactivated (Figure 8). It varied between -1.13 ºC and +1.78 ºC with 50.7 % of the differences above 0.3 °C. As for the comfort evaluation (Table 14), this was the parameter with the greatest impact, with 23.8 % less degree-hours of total discomfort in a year. This result corroborates the results obtained by Bahnfleth (1989), who conducted a study comparing activated and deactivated evapotranspiration in different climate conditions. He found that the greater differences between using evapotranspiration or not occurred in dry and hot climates.

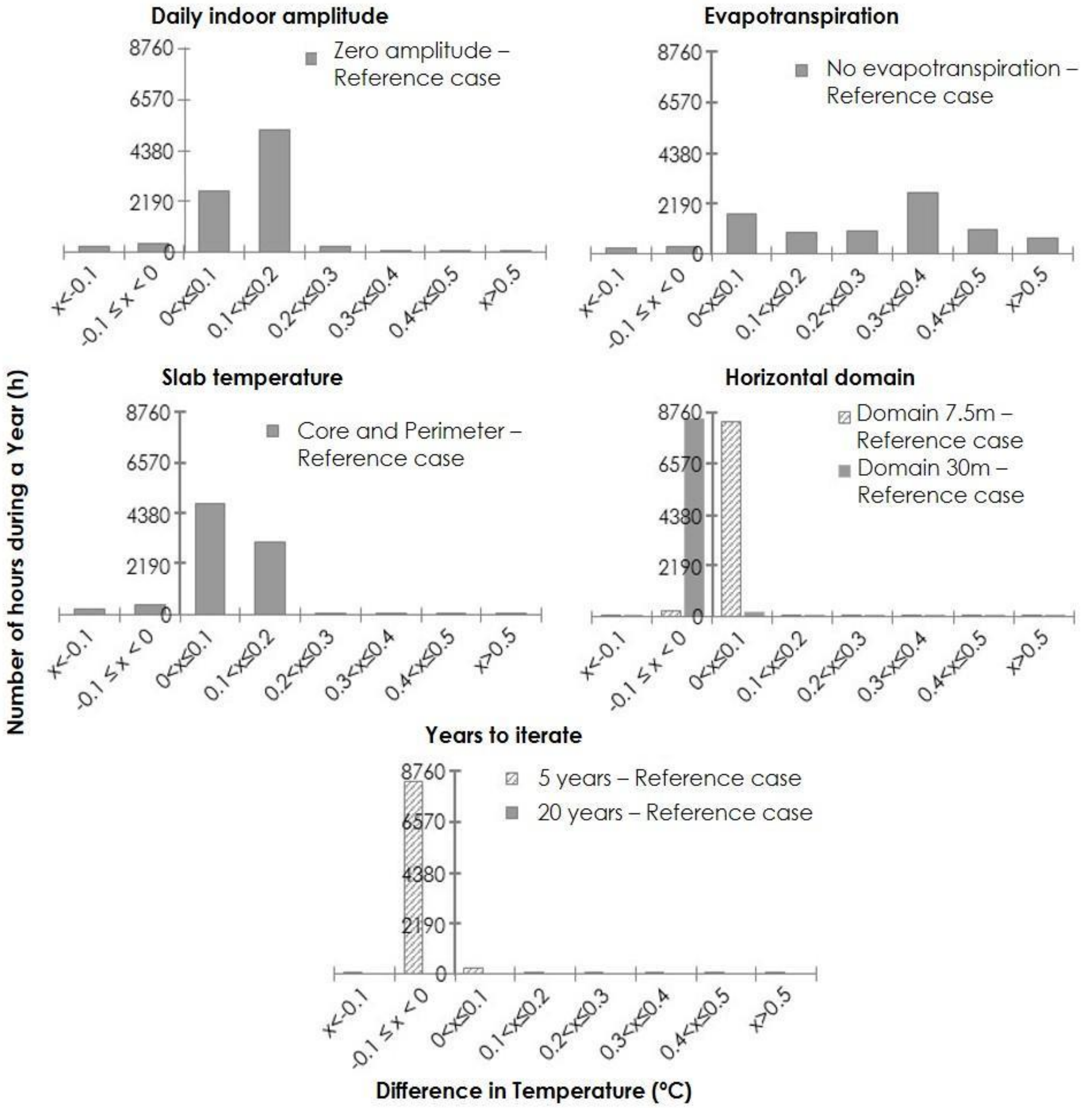
The other alterations (zero amplitude, slab temperature, horizontal domain and years to iterate) presented medium to low impact. The difference between these cases and the reference case ranged between -0.1 °C and +0.2 °C for 62.6 % to 99.7 % of the year, with a maximum value of -2.37 °C in the Slab temperature case.

As for the amplitude, the EnergyPlus manual informs that this data has little influence. This was, in fact, observed in this building, whose annual average amplitude is equal to 5.86 °C. In the comfort evaluation, this case presented an 11 % decrease in total discomfort.

Table 13 - **Hours of discomfort during a year**

Cases	By cold (°Ch)	By heat (°Ch)	By cold - Difference from Slab case (%)	By heat - Difference from Slab case (%)	Total (°Ch)	Total - Difference from Slab case (%)
Slab	4195.8	6.2	---	---	4202.0	---
GT:BSurface	3043.2	57.8	-27.4	+823.3	3101.0	-26.2
GDomainFD	2234.1	115.9	-46.7	+1751.2	2350.1	-44
GDomainKA	1731.1	151.1	-58.7	+2313.9	1882.3	-55.2
1^{st}Slab	3586.6	10.8	-14.5	+72.5	3597.5	-14.3
$1^{st}T_{18°C}$	4186.5	5.9	-0.2	-5.7	4192.4	-0.2
$1^{st}T_{25°C}$	3061.0	12.1	-27.0	+93.2	3073.1	-26.8

Figure 8 - **Hourly indoor air temperature difference for the test of the influence of Slab input parameters**



With regard to Slab temperature, Clements (2004) informs that the use of the core and perimeter temperatures yields better heat transfer results, than when average temperature is used. The most detailed simulation produced an evaluation with 6.7 % discomfort for this building.

The horizontal domain test was performed to verify the impact of this aspect, since the information found in the literature regarded only the vertical domain (BAHNFLETH, 1989; BAHNFLETH; PEDERSEN, 1990). This aspect presented an impact of less than 0.5 % on the discomfort evaluation.

In relation to iteration time, when it was equal to 20 years, the difference was always zero. For a 5-year period, the influence on the degree-hours of discomfort was also very low, at +0.5 %. This shows that a period of 10 or more years is satisfactory for the convergence calculations, according to what is suggested in the Auxiliary Programs Manual (DEPARTMENT…, 2016d), and also that increasing the number of years adopted has no effect on the results.

Influence of the thermophysical properties of the soil

The values referring to the thermal properties of the soil are among the input data that generate most doubts during a simulation. The lack of information about this aspect in Brazil is compounded by the difficulty to determine the properties that vary with time, location, roof type and soil composition.

Table 14 - **Hours of discomfort during a year**

Cases	By cold (°Ch)	By heat (°Ch)	By cold – Difference from Reference Case (%)	By heat - Difference from Reference Case (%)	Total (°Ch)	Total - Difference from Reference Case (%)
Case 4A (Zero amplitude)	4195.8	6.2	-11.1	+32.2	4202.0	-11
Case 5A (No evapotranspiration)	3586.6	10.8	-24	+61.1	3597.5	-23.8
Case 6A (Core and Perimeter)	4398.3	6.2	-6.8	+32.2	4404.6	-6.7
Case 7A (Horizontal domain 7.5m)	4705.1	4.3	-0.3	+2.3	4709.4	-0.3
Case 7B (Horizontal domain 30m)	4726.9	4.2	+0.1	0.0	4731.2	+0.1
Case 8A (Years to iterate 5 years)	4743.9	4.1	+0.5	-2.4	4748.0	+0.5
Case 8B (Years to iterate 20 years)	4719.9	4.2	0.0	0.0	4724.1	0.0
Reference Case	4719.9	4.2	---	---	4724.1	---

To verify the impact of the properties of the soil, three sets of values selected from Bahnfleth (1989) were used. These sets of values represent the soil in conditions of high, medium and low conductivity, given that the soil with low conductivity is dry and the one with high conductivity is humid. Thus, the following cases were compared:

(a) (9A) Dry soil. Low k. k = 0.5 W/m K, ρ: 1200 kg/m³ and c_p: 1200 J/kg.K;

(b) (9B) Humid soil. High k. k = 2 W/m K, ρ: 1700 kg/m³ and c_p: 1700 J/kg.K; and

(c) Reference case - Medium k. With average conductivity of k = 1 W/m K, ρ: 1200 kg/m³ and c_p: 1200 J/kg.K.

More detailed information about these cases can be found in Research Method. All cases were simulated using the convergence procedure. The average conductivity value was adopted as reference solely to serve a comparison parameter; it is not considered the most correct. The thermophysical properties of the soil are variable over time and space, and the most adequate procedure would be to measure its properties in loco. The purpose of this test was to verify whether, in the Slab model, variations measured from this value would cause an impact on the interior temperature.

The differences in indoor air temperatures are shown in Figure 9. In the Dry Soil (low k) case, for 35.11 % of the year the temperature was 1°C higher than in the case with medium k, with a maximum difference of 1.7 °C. The Humid Soil (High k) presented a maximum difference of +1.8 °C, and 93.12 % of the time with differences between 0 °C and -0.4°C.

The observed impact reflected significantly on discomfort (Table 15). The Dry Soil (Low k) case presented 58.6 % less discomfort by cold in relation to the Medium k, 92.3 % more discomfort by heat and 57.5 % less total discomfort in a year. The Humid Soil (High k) also had high impact, with 25 % more total discomfort (always presenting inferior temperatures).

Conclusions

This study investigated different modeling alternatives for the parameters related to the heat transfer between the floor and the ground, with an emphasis on the Slab program linked to EnergyPlus. The method consisted of computer simulations of a naturally ventilated single-story slab-on-grade house located in São Carlos, Brazil.

The results indicated that not using Slab generates a very significant difference in the performance evaluation. Directly entering the ground temperature, with the adopted value equal to the air temperature in the weather file, resulted in a 26.2 % reduction in the total degree-hours of discomfort. As for adopting the object Site: Ground Domain, there was an even greater impact on total discomfort, with differences of -44 % for the FiniteDifference method and -55.2 % for the KusudaAchenbach method. The simulations also demonstrated the need for the convergence procedure should Slab be used. This procedure considers several iterations between Slab and EnergyPlus, which are currently not performed automatically. Using the iteration only once resulted in a reduction of the total annual degree-hours of discomfort, when considering the comfort evaluation for the studied building.

As for the input data for Slab, the thermophysical properties of the soil were the data that had the most influence. The building was evaluated as being 57.5 % less uncomfortable with the dry soil, and 25 % more uncomfortable with the humid soil, in relation to an intermediate humidity level. The literature indicates the difficulties pertaining these parameters, since they vary during the year and should preferably be taken from measurements.

Figure 9 - **Hourly indoor air temperature for the influence of the thermophysical properties of the soil**

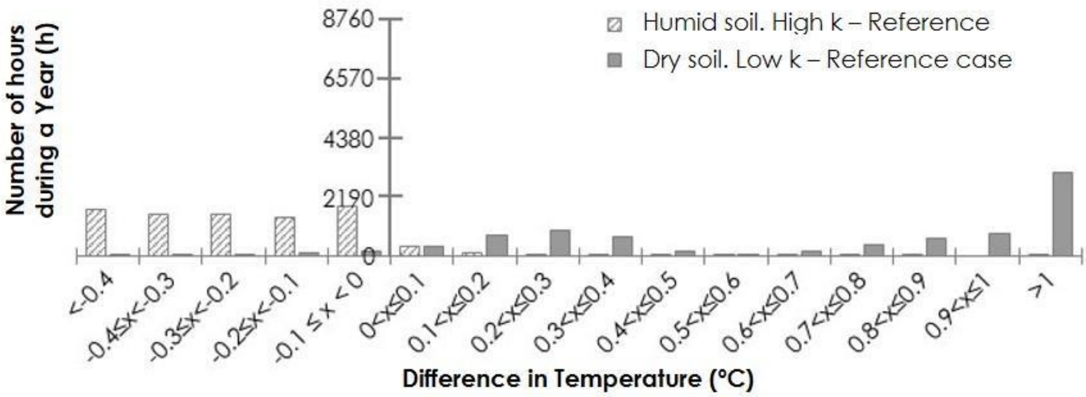


Table 15 - **Hours of discomfort during a year**

Cases	By cold (°Ch)	By heat (°Ch)	By cold - Difference from the recommended case (%)	By heat - Difference from the recommended case (%)	Total (°Ch)	Total - Difference from the recommended case (%)
Reference Case (Average k)	4719.9	4.2	---	---	4724.1	---
Case 9B (High k)	5908.2	0.9	+25.1%	-366.6%	5909.2	+25.0%
Case 9A (Low k)	1950.4	54.9	-58.6%	+92.3%	2005.3	-57.5%

The study also indicated the relevance of evapotranspiration, annual average amplitude and separate modeling for core and perimeter. Not considering these aspects caused a reduction in the total annual discomfort of 23.8 %, 11 % and 6.7 %, respectively. The other input data that were assessed (horizontal domain dimension and number of iteration years) presented an impact smaller than-or equal to 0.5 % on the total discomfort.

These conclusions indicate a great need to better understand the theme of the study and, by means of comparison with real measured data, to determine the calculation process that best represents reality, since there are uncertainties in several input data. This issue is especially relevant in the case of Brazilian houses, which are usually not artificially conditioned and have no thermal insulation on the floor, being subject to significant heat flows through this element. There is need of further studies on this theme in order to achieve simulations that produce results that are closer to reality.

References

AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR CONDITIONING ENGINEERS. **ASHRAE Handbook of Fundamentals:** thermal and water vapor transmission data. 2005.

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR CONDITIONING ENGINEERS. **ANSI/ASHRAE Standard 140-2001:** standard method of test for the evaluation of building energy analysis computer programs. Atlanta, 2014.

AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR CONDITIONING ENGINEERS. **ANSI/ASHRAE Standard 55:** thermal environmental conditions for human occupancy. Atlanta, 2013.

ANDOLSUN, S. *et al.* EnergyPlus vs DOE-2.1e: the effect of ground coupling on cooling/heating energy requirements of slab-on-grade code houses in four climates of the US. **Energy and Buildings**, v. 52, p. 189–206, sep. 2012.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 15220-2:** desempenho térmico de edificações: Parte 2: métodos de cálculo da transmitância térmica, da capacidade térmica, do atraso térmico e do fator solar de elementos e componentes de edificações. Rio de Janeiro, 2005a.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 15220-3:** desempenho térmico de edificações: parte 3: zoneamento bioclimático brasileiro e estratégias de condicionamento térmico passivo para habitações de interesse social. Rio de Janeiro, 2005b.

BAHNFLETH, W. P. **Three-Dimensional Modelling of Heat Transfer From Slab Floors**. University of Illinois, Urbana, 1989.

BAHNFLETH, W. P.; PEDERSEN, C. O. A Three-Dimensional Numerical Study of Slab-on-Grade Heat Transfer. **ASHRAE Transactions**, St. Louis, v. 96, n. 2, p. 61-72, 1990.

BATISTA, J. O.; LAMBERTS, R.; GÜTHS, S. Influências dos Algoritmos de Condução e Convecção Sobre os Resultados de Simulações do Comportamento Térmico de Edificações. **Ambiente Construído**, Porto Alegre, v. 11, n. 4, p. 79–97, out./dez. 2011.

CLEMENTS, E. **Three Dimensional Foundation Heat Transfer Modules for Whole-Building Energy Analysis**. Pennsylvania: The Pennsylvania State University, 2004.

DEPARTMENT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY. **EnergyPlus.** Version 8.5.0**.** US, 2016a. Available at: <https://energyplus.net/downloads>. Accessed: Oct. 15 2016.

DEPARTMENT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY. **Engineering Reference**. US. Documentation, EnergyPlus^{TM} Version 8.5, 2016c.

DEPARTMENT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY. **Ground Heat Transfer in EnergyPlus**. Documentation, EnergyPlus^{TM} Version 8.5 **- Auxiliary Programs**, p. 103–142, 2016d.

DEPARTMENT OF ENERGY EFFICIENCY AND RENEWABLE ENERGY. **Slab.** Version .75. US, 2016b. Available at: <https://energyplus.net/downloads>. Accessed: Oct. 15 2016.

DORNELLES, K. A. **Absortância Solar de Superfícies Opacas**: métodos de determinação e base de dados para tintas acrílica e PVA. Campinas, 2008. Tese (Doutorado em Engenharia Civil) – Faculdade de Engenharia Civil, Arquitetura e Urbanismo, Universidade Estadual de Campinas, Campinas, 2008.

GARD ANALYTICS. **Lecture 24** : ground heat transfer EnergyPlus. University Course Teaching Material, 2003.

GIVONI, B. Comfort, Climate Analysis and Building Design Guidelines. **Energy and Buildings**, v. 18, n. 1, p. 11–23, 1992.

INSTITUTO NACIONAL DE METROLOGIA, NORMALIZAÇÃO E QUALIDADE INDUSTRIAL. **RTQ-R:** Regulamento Técnico da Qualidade para o Nível de Eficiência Energética de Edificações Residenciais, Rio de Janeiro, 2012.

KERSTEN, M. S. **Thermal Properties of Soils**. Minnesota: University of Minnesota Institute of Technology, 1949. Engineering Experiment Station Bulletin, nº. 28.

KUSUDA, T.; ARCHENBACH, P. Earth Temperature and Thermal Diffusivity at Selected Stations in the United States. **ASHRAE Transaction**, v. 71, n. 1, p. 61–75, 1965.

LARSEN, S. F. Modelización de la Transferencia de Calor al Suelo en los Programas de Simulación Térmica de Edificios EnergyPlus y SIMEDIF. **Avances en Energías Renovables y Medio Ambiente**, v. 15, p. 27–34, 2011.

MARIN, H. F.; CASATEJADA, M. P.; CHVATAL, K. M. S. Impacto da Temperatura de Controle na Operação das Janelas e no Conforto Térmico Para Uma Habitação de Interesse Social Naturalmente Ventilada em São Carlos – SP. In: ENCONTRO NACIONAL DE TECNOLOGIA DO AMBIENTE CONSTRUÍDO, 16., São Paulo, 2016. **Anais...** São Paulo, 2016.

MARQUES, T. H. T. **Influência Propriedades Térmicas Envolvente Opaca no Desempenho Habitações Interesse Social em São Carlos, SP**. Dissertação (Mestrado em Arquitetura e Urbanismo) – Instituto de Arquitetura e Urbanismo, Universidade de São Paulo, São Carlos, 2013.

MAZZAFERRO, L.; MELO, A. P.; LAMBERTS, R. **Manual de Simulação Computacional de Edifícios Com o Uso do Objeto Ground Domain no Programa EnergyPlus.** Florianópolis, 2015.

PAPST, A. L. **Uso de Inércia Térmica no Clima Subtropical Estudo de Caso em Florianópolis - SC.** Florianópolis, 1999. Dissertação (Mestrado em Engenharia Civil) – Escola de Engenharia, Universidade Federal de Santa Catarina, Florianópolis, 1999.

RORIZ, V. F. **Arquivos EnergyPlus Weather Data**. 2012. Available in: <http://www.roriz.eng.br/epw_9.html>. Accessed: 15 out. 2016. In Portuguese.

RORIZ, M.; CHVATAL, K. M. S.; CAVALCANTI, F. S. Sistemas Construtivos de Baixa Resistência Térmica Podem Proporcionar Mais Conforto. In: ENCONTRO NACIONAL, 10.; ENCONTRO LATINO AMERICANO DE CONFORTO NO AMBIENTE CONSTRUÍDO, 6., Natal, 2009. **Anais...** Natal, 2009.

RORIZ, V. F.; RORIZ, M. **EPvieW.** São Carlos: [s.n.], 2015.

SILVA, A. S.; ALMEIDA, L. S. S.; GHISI, E. Análise de Incertezas Físicas em Simulação Computacional de Edificações Residenciais. **Ambiente Construído**, Porto Alegre, v. 17, n. 1, p. 289–303, jan./mar. 2017.

VENÂNCIO, R. **A Influência de Decisões Arquitetônicas na Eficiência Energética do Campus / UFRN.** Dissertação (Mestrado em Engenharia Civil) – Escola de Engenharia, Universidade Federal do Rio Grande do Sul, Natal, 2007.

XING, L. U. **Estimations of Undisturbed Ground Temperatures Using Numerical and Analytical Modeling**. Stillwater: Oklahoma State University, 2014.

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