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Ener-Habitat: A cloud computing numerical tool to evaluate the thermal performance of walls/roofs.

Guillermo Barrios, Guadalupe Huelsz, Jorge Rojas

Instituto de Energías Renovables, Universidad Nacional Autónoma de México, A.P. 34 Temixco Centro, 62580, Temixco, Mor. Mexico

Abstract

Ener-Habitat is a cloud computing numerical tool designed to evaluate the thermal performance of building envelope walls/roofs. It solves the time dependent heat transfer equation in one or two dimensions with convective boundary on the inside and periodic outdoor temperature, solar radiation, and convective boundary condition on the outside. All the needed data is introduced through a Graphical User Interface. First, the user defines if the evaluation is for a constructive system (CS) composed by only homogeneous layers or for a CS that contains one no-homogeneous layer. A homogeneous layer is composed by only one material and has no air cavities in it. A no-homogeneous layer is composed by two or more materials or has air cavities in it. The user selects a city of Mexico where the evaluation is performed, the time period (typical day of month or annual evaluation), the type of CS (wall or roof) and the condition in which the CS is evaluated (air-conditioned or non-air conditioned). If the user selected a CS composed by homogeneous layers, Ener-Habitat can compare up to five CS at once and it last a couple of minutes, for CS with a no-homogeneous layer, the numerical analysis takes some hours, and the user can evaluate only one CS at once. Up to now, Ener-Habitat can evaluate three types of no-homogeneous layers. The materials and dimensions of the layers, and the solar absorptance of the outdoor surface must be defined. When the CS is evaluated considering an air-conditioned room, with constant indoor temperature at the comfort temperature, the reported parameter is the energy per unit area per selected period needed to keep the room at the comfort temperature and the best CS configuration is the one with the lowest value. When the CS is evaluated considering a non-air-conditioned room, one of the reported parameters is the heat transfer through the CS per unit area per the selected period. In this case, the best CS configuration is the one with the lowest value. Three examples are presented, the first two include homogenous layers and the last one a constructive system with one no homogeneous layer.

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1. Introduction

The envelope of a building plays an important role in the heat transfer between the exterior and the interior spaces. For climates with a big difference between the maximum and minimum temperature in a day and a large insolation, like most places in México, the best constructive system for the envelope cannot be chosen taking into account only the thermal resistance according to a steady-state (time independent) heat transfer analysis [1]. Instead, a time dependent heat transfer analysis must be carried out in order to select the constructive system that contributes the most to thermal comfort conditions inside the building without the use of air-conditioning systems, or when using it, consuming the minimum energy. A constructive system has different thermal performance depending on the condition of the room where it is used: air-conditioned or non-air-conditioned [1].

In México, most of the energy used in air-conditioning is for cooling [2], thus the official standards NOM-008-ENER-2001 [3] and NOM-020-ENER-2011 [4], for non-residential and residential buildings respectively, aim to save energy for cooling and restrict the energy gains in the building taking into account for the walls and roofs of the envelope only their thermal resistance. This comes from assuming a steady state heat transfer, which is a good approximation for the temperate or polar zones, where the insolation is low and the daily temperature oscillation during the day is small [5], then the heat storage capacity of the constructive system is not relevant. In climates like the Mexican, a time dependent heat transfer analysis must be carried out where the heat storage capacity or thermal mass become relevant. For this analysis three thermal properties of any material of the envelope must be specified, the thermal conductivity, the density and the specific heat [1].

The time dependent heat transfer through a wall or roof of the envelope requires the numerical solution of the corresponding equations. The selection of the constructive system to save energy and to be in comfort if not using air-conditioning is very important. A numerical tool, like Energy Plus or TRANSYS, for thermal building simulations can be used, but this kind of software requires expert users with great knowledge of heat transfer. Ener-Habitat was developed to evaluate the thermal performance of the constructive systems (CS) walls or roofs of the envelope of a building for the climates for México's cities and requires the user to know only the materials and orientation of the wall or roof to evaluate. In this work, the cloud computing numerical tool Ener-Habitat is presented. The evaluation of three CS used in the two conditions, in air-conditioned and in non-air-conditioned rooms are shown as examples.

Nomenclature

A	the solar absorptivity of the outdoor surface
α_j	thermal diffusivity of the material of the j -th layer
c_a	specific heat of air
C_j	thermal storage capacity or heat capacity of the material of the j -th layer
c_j	specific heat of the material of the j -th layer
d	distance from the indoor surface where there is no heat transfer
h_i	indoor surface heat transfer coefficient
h_o	outdoor surface heat transfer coefficient
k_j	thermal conductivity of the j -th layer

ρ_a	density of air
ρ_j	density of the material of the j -th layer
T	temperature
t	time
T_i	air indoor temperature
T_o	temperature of the outdoor air
T_{sa}	sol-air temperature
T_{wi}	temperature of the indoor surface
T_{wo}	temperature of the outdoor surface
x	spatial coordinate transverse to the wall/roof
y	spatial coordinate parallel to the wall/roof

For homogeneous layers in a constructive system (CS), the time dependent heat transfer can be assumed one dimensional, then the heat transfer equation is [6]

$$\frac{\partial T}{\partial t} - \alpha_j \frac{\partial^2 T_j}{\partial x^2} = 0, \tag{1}$$

where T is the temperature as a function of time t , α_j is the thermal diffusivity of the material j , and x is the position. The thermal diffusivity is defined as the ratio of the thermal conductivity and the thermal storage capacity or heat capacity, per unit of volume, of the material $C_j = \rho_j c_j$.

By continuity in the heat transfer between layer

$$-k \frac{dT}{dx} = -k \frac{dT}{dx} \tag{2}$$

at the outdoor and indoor surfaces, the following boundary conditions are applied

$$-k \frac{dT}{dx} \Big|_{wo} = ho(Tsa - Two) \quad -k \frac{dT}{dx} \Big|_{wi} = hi(Twi - Ti) \tag{3}$$

where Tsa and Two are the solar-air and the outdoor surface temperatures of the CS, Ti and Twi are the indoor air and indoor surface temperatures, ho and hi are the outdoor and indoor film coefficients. When the room is air-conditioned, the temperature of the air inside is kept constant at the neutrality temperature Tc [7]. When the indoor air temperature of the room is not controlled, it is a function only of the heat transfer through the CS

$$d\rho_a c_a \left(\frac{\partial Ti}{\partial t} \right) = hi(Twi - Ti) \tag{4}$$

where ρ_a and c_a are the density and the specific heat capacity of the air. It is assumed that at a distance d from the indoor surface there is no heat transfer, *i. e.* an adiabatic condition.

In order to solve a constructive system with one no-homogeneous layer, the two-dimensional time dependent heat transfer equation must be solved

$$\frac{\partial T}{\partial t} - \alpha_j \left(\frac{\partial^2 T_j}{\partial x^2} + \frac{\partial^2 T_j}{\partial y^2} \right) = 0, \quad (5)$$

where x and y are the directions in the two dimensional plane. All previous boundary conditions apply for the two dimensional model by just adapting the boundary condition to the appropriate surface changing the direction of the corresponding derivative.

Ener-Habitat solves numerically the time-dependent heat transfer equation using an implicit method [6] with the described boundary conditions during a typical day of a desired month from a specific Mexican city under periodic conditions. The film coefficients h_o and h_i are considered constant and were taken from the Mexican official standards NOM-008-ENER-2001 [3] and NOM-ENER-020-2011 [4]. The typical day for a place is calculated with the average of the maximum and minimum temperatures for a typical year of each month, solar radiation and the time when they occur. The typical year is obtained from Meteornorm [8]. Ener-Habitat has a database with the climatic data for more than 40 Mexican cities.

The comparison for the CS for a non-air-conditioned room is carried out considering the energy transferred to the indoor through a unit area [9]

$$Q = \sum \frac{h_i(T_i - T_{wi})}{\Delta t} \quad \text{if} \quad T_i > T_{wi} \quad (6)$$

where the summatory is taken during a day, and Δt is the time step for the numerical simulation. When evaluating a CS with air-conditioning, the comparison is carried out by considering the total thermal energy consumed in a unit area needed to keep the indoor air temperature at the desired value. The total energy is calculated with

$$E = E_h + E_c, \quad (7)$$

where E_h and E_c are the energy consumed for heating and the one for cooling, respectively and are calculated by

$$E_h = \sum \frac{h_i(T_c - T_{wi})}{\Delta t} \quad \text{if} \quad T_{wi} < T_c, \quad E_c = \sum \frac{h_i(T_{wi} - T_c)}{\Delta t} \quad \text{if} \quad T_{wi} > T_c. \quad (8)$$

2. Use of Ener-Habitat

Ener-Habitat has been developed with the idea to be as simple as possible to help architects and other building designers to choose a suitable CS configuration for Mexican climates and does not require the user to be an expert on heat transfer. Ener-Habitat is available for free through the webpage <http://www.enerhabitat.unam.mx> previous registration. Firefox and Chrome are the browsers recommended in order to have full functionality.

Once logged in, first the user must define if the CS is homogeneous or has one no-homogeneous layer. All CS can be composed by up to seven layers. If a homogeneous layers is selected, the user defines the city where the CS is evaluated, the time period (specific month or annual evaluation), the condition at the indoor (air-conditioned or non-air-conditioned room), the location of the CS (wall or roof), and the number of CS to compare. Then, the user must define each CS with the material and width of each layer

and the solar absorptivity of the outdoor layer. Each CS can be composed by up to seven layers, where at most one layer can be non-homogeneous. Ener-Habitat contains a material database for the most common materials used in Mexico. This database keeps the thermal properties of the materials: thermal conductivity, density and specific heat, all in the International Unit System (IUS). Each user has also a private database where he can save the name and the three thermal properties in the IUS. Also, a list for the value of the solar absorptivity is provided with the values of the most common envelope finishes.

If a CS with one no-homogeneous layer is selected, then the user defines the city where is evaluated, the condition at the indoor (air-conditioned or non-air-conditioned room), and the location (wall or roof). In this case, the time period should be a specific month and only one CS can be evaluated in each simulation. This restriction is because the thermal evaluation of one CS with one no-homogeneous layer takes about six hours.

Once all layers of all CS have been defined, Ener-Habitat performs the numeric calculations to solve the periodic time-dependent heat transfer equations, along with the appropriate boundary conditions, and then shows the results.

2.1. Example: Evaluation of three homogeneous roofs for air-conditioned rooms

Once logged, the first step consists in selecting the desired kind of CS, in this case, homogeneous layers, as shown in Figure 1.

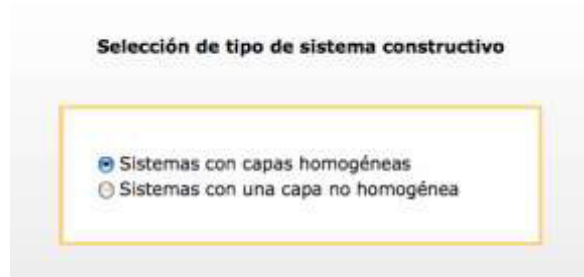


Fig. 1. Selection of the kind of constructive system: homogeneous layers (sistemas con capas homogéneas).

Next, the selection of the place: Temixco, period: May, condition: air-conditioned room, location of the CS: roof, and the number of constructive systems to evaluate.

Selección de los parámetros de simulación

Lugar: Temixco

Periodo: Mayo

Condición: Con aire acondicionado

Ubicación: Techo

Número de sistemas constructivos: 3

Fig. 2. Selection of place (lugar), the period (periodo), the condition of air-conditioned room (condición), location of the constructive system: roof (ubicación:techo), and the number of CS to evaluate (número de sistemas constructivos).

The inclination and orientation must be defined, as shown in Figure 3. The user can select only from eight predefined orientations, the same applies if the constructive system were a wall.

Definición de la inclinación y la orientación

Techo

Inclinación: 0 [°]

Orientación: Norte

- Norte
- Noreste
- Este
- Sureste
- Sur
- Suroeste
- Oeste
- Noroeste

Fig. 3. Definition of the inclination (inclinación) and orientation (orientación) of the constructive system.

The definition of each CS starts by selecting the number of layers corresponding to the first CS, as shown in Figure 4. Each material layer must be selected from the database or defined, as shown in Figure 5.

Definición de número de capas del sistema constructivo

Techo 1

Número de capas: 1

Fig. 4. Selection of the number of layers (número de capas) for the first CS (techo 1).

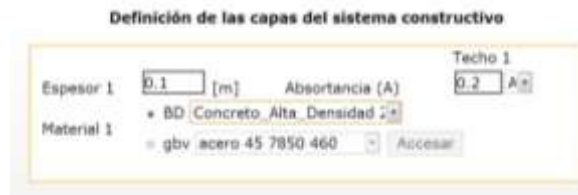


Fig. 5. Definition of the layers for the first constructive system, thickness (espesor) of 0.1m, absorptivity (absortancia) of 0.2, and material from the database (BD): high density concrete (concreto alta densidad).

This process is repeated for each constructive system. The next one was defined with one EPS layer (poliestireno expandido) of 0.1m and absorptivity 0.2. The last constructive system was defined with two layers, an EPS outdoor layer of 0.02m with absorptivity 0.2 and a second layer of 0.08m of high density concrete.

Once defined the three CS for the roofs, Ener-Habitat solves numerically the three cases with the appropriate boundary conditions and in about few minutes presents a results page. For the air-conditioned room and evaluation for a specific month, Ener-Habitat presents three plots, the thermal energy consumed by the air-conditioned system per day per unit area of the roof for cooling (enfriamiento), for heating (calentamiento), and the total energy, for each CS. In Figure 6 is presented the plot for the total energy for the three CS defined. As can be seen, the best one for an air-conditioned room in Temixco in May is the 0.1m of EPS (S.C. 2).

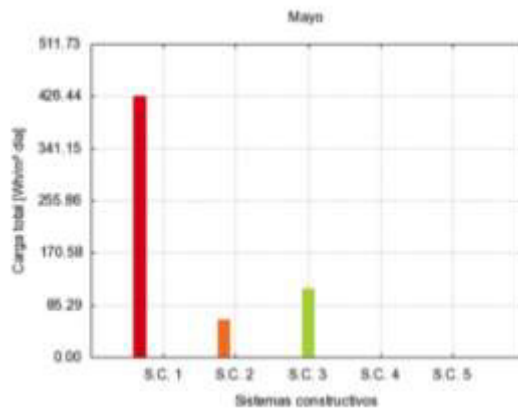


Fig. 6. Total energy (carga total) consumed in a day for the three constructive systems evaluated in Temixco during May.

In the results page, below the plots, two tables are presented with all the simulation conditions previously defined, as shown in Figure 7. This table allows changing all the parameters except the number of CS. If a change is made, the user can press the run button (Correr programa) in order to perform again the simulation with the new parameters shown in the tables

For an annual evaluation, the period (periodo) option shown in Figure 2 must be selected or it also can be changed in the table of results shown in Figure 7. For this case, the results page shows six plots. The first three correspond to the thermal energy consumed by the air-conditioned per year per unit area for cooling, for heating, and the total, for the defined CS.

The screenshot shows a software interface with a table of simulation parameters. The table has several columns, including 'Material', 'Thickness', and 'U-value'. There are three rows of material data, each with a 'Material' column containing a name and a 'Thickness' column with a numerical value. The interface also includes a search bar and some navigation buttons.

Fig. 7. Tables with the simulation parameters.

2.2. Example: Evaluation of three homogeneous roofs for non-air-conditioned rooms

The process can be initiated from the selection page shown in Figure 2, but also by selecting non-air-conditioned in the condition option from the table in the results page shown in Figure 7. As an example, the from the results page the condition is change to non-air-conditioning condition, from the examples of section 2.1. For a specific month evaluation with no-air-conditioning, the result page shows the two plots presented in Figure 11. One shows the outdoor temperature, together with the indoor air temperature for each CS defined, as well as the comfort zone. The second plot shows the energy transferred (energía transferida) inside the CS per unit area per day. For an annual evaluation, the results page shows two plots, the energy transferred per unit area per year and the energy transferred per unit area per day for each month of the year. As can be seen from Figure 11 and 12, for the specific month and annual evaluation the best configuration, with less energy transferred through the CS is the third one (S.C.3).



Fig. 11. Temperatures and energy transferred through the constructive system per day per unit area for three constructive systems in Temixco during May.

2.3. Example: Evaluation of one roof with one no-homogeneous layer for non- air-conditioned rooms

After the user has logged in, the constructive system with one no homogeneous layer (sistema con una capa no homogénea) must be selected in the selection of the kind of constructive system page (Figure 1). Next, the selection of the place, period (only one month at a time), the condition of air-conditioned room and the location of the constructive system: roof. Now the period can be only one specific month and only one constructive system.



Fig. 12. Energy transferred per unit area per year and energy transferred per unit area per month for the three constructive systems in Temixco during May.

The numbers of layers must be specified, and then, Ener-Habitat displays different kinds of non-homogeneous CS available for roofs or walls, depending on the choice made in the corresponding step. For roofs four types can be selected and the corresponding scheme is displayed when selecting. Once selected the desired type of CS, the geometric parameters must be defined. In this example case, a symmetric block with three air blocks, as shown in Figure 13, was selected. Also the material(s) should be defined in this step.

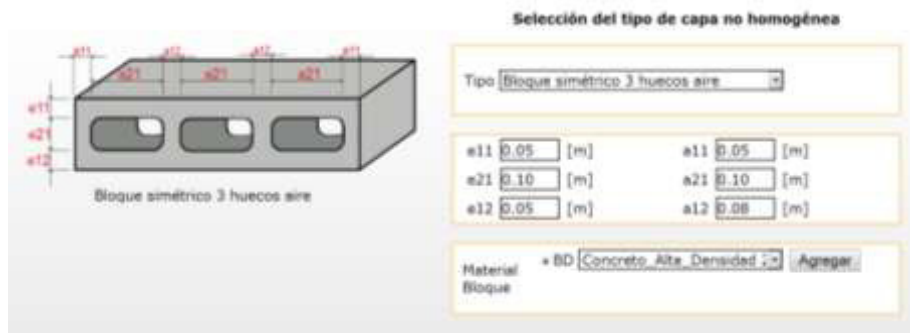


Fig. 13. Selection of the type (tipo) of non-homogeneous layer, geometric parameters and material (material bloque), symmetric block with three air cavities and $e11=0.05m$, $e21=0.10m$, $e12=0.05m$, $a11=0.05$, $a21=0.10m$, $a12=0.08m$ and made of high density concrete.

Once the non-homogeneous layer was defined in geometry and material(s), the position of this layers is selected and the others homogeneous layers are defined, as can be seen in Figure 14. If a roof was selected, it is evaluated as a horizontal plane, so there is no need to define neither the inclination nor the orientation. If the constructive system is defined as a wall, then the user can only specify the orientation. Next Ener-Habitat solves numerically the equations for the constructive system with one non-homogeneous layer. This may take up to six hours, meanwhile Ener-Habitat displays a notice that it is still solving the thermal evaluation. When Ener-Habitat finishes the process, sends an email notifying the availability of the results. The results are the same than for homogeneous layers for non-air-conditioned

room or for air-conditioned room, but only presenting results for the corresponding month and only one constructive system.

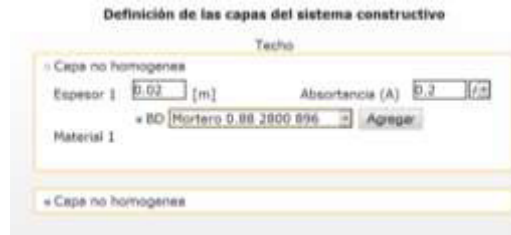


Fig. 14. Position of the non-homogeneous layer and definition of the rest of the homogeneous layers. A mortar layer of 0.02m with absorptivity 0.2 is placed first and then the no-homogeneous layer previously defined.

3. Concluding remarks

Ener-Habitat evaluates constructive systems of the envelope of a building composed by homogeneous layers or by at most one no-homogeneous layer. In order to evaluate the CS, it solves the time dependent heat transfer equation with the appropriate boundary conditions. The CS can be evaluated considering an air-conditioned room or a non-air-conditioned room. It has been previously proven the differences in the performance of a constructive systems for these two conditions in a Mexican climate [1]. The thermal evaluation is carried out using the total thermal load for air-conditioned rooms and the energy transferred through the CS for non-air-conditioned rooms [9].

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