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Research Paper

Implementation of the equivalent-homogeneous-layers-set method in whole-building simulations: Experimental validation

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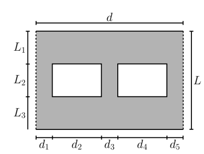
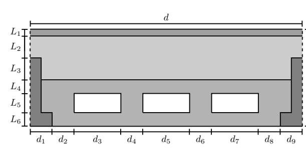
HIGHLIGHTS

- Implementation of the equivalent-homogeneous-layer-set EHLS method into EnergyPlus.
- EHLS method gives a thermal equivalent for constructive system air-cavities-inside.
- EHLS validated with measurements from test-hut with hollow-blocks in walls and roof.

GRAPHICAL ABSTRACT



Wall constructive system



Roof constructive system

Test-huts built

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ABSTRACT

This work presents the experimental validation of the equivalent-homogeneous-layers-set method (EHLS) implemented in EnergyPlus, a whole-building energy simulation program. The EHLS method generates a constructive system that is thermally equivalent, under time-dependent heat transfer, to a wall/roof constructive system that has air-cavities inside. The equivalent constructive system is a set of homogeneous layers, some of them with time-dependent equivalent thermal conductivity. The EHLS method takes into account the heat transfer through the constructive system by two-dimensional conduction, natural convection inside the air-cavities and radiation between the air-cavity surfaces. To validate the EHLS method implemented in EnergyPlus, a whole year of experimental results were taken from a non-air-conditioned test-hut constructed with concrete hollow-block walls and the roof comprised of concrete hollow-blocks and T-beams. The numerical results show a good agreement with the experimental ones. The differences between EnergyPlus simulation results and experimental results are of the same order of magnitude as the differences between EnergyPlus simulation and experimental results from two adjacent test-huts made of homogenous constructive systems over the same time-period and reported previously.

1. Introduction

Constructive systems of the building envelope that have air-cavities inside are common in many countries [1–4]. Time-dependent heat transfer through these complex building envelopes are difficult to simulate due to two or three-dimensional conduction heat transfer, the natural convection of the air inside the cavities and the radiation heat transfer between air-cavity surfaces. A review of studies addressing these problems was presented in [5].

A method to account for the time-dependent heat transfer through constructive systems with air-cavities inside has recently

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been proposed by Huelsz et al. [5]. This method can be implemented in whole-building simulation programs and was named the equivalent-homogeneous-layer-set (EHLS) method. The EHLS method provides an equivalent wall/roof composed of a set of homogeneous layers that considers the two-dimensional conduction, the natural convection of the air inside the cavities and the radiation heat transfer between air-cavity surfaces. These authors presented the EHLS method and applied it to a wall composed of hollow-blocks. Convection and radiation inside the air-cavities were taken into account by using temperature dependent heat transfer coefficients and a radiative correction factor. The thermal behavior of the EHLS wall is similar to that of the actual hollow-block wall. The authors showed that the EHLS method results were in agreement with results of an experimentally validated two-dimensional numerical model. Discrepancies were up to 3.4% for the energy transferred through the wall in a non-air-conditioned room, and up to 6% for the total thermal load in the case of an air-conditioned room. Using the appropriate convective and radiative coefficients and a radiative correction factor, the EHLS method can be extended to other constructive systems for walls or rooves that have air-cavities inside.

The objective of this work is to implement the EHLS method in a whole-building energy simulation program, namely EnergyPlus [6], and validate the simulation results with experimental results from a non-air-conditioned test-hut with concrete hollow-block walls and hollow-blocks-and-T-beams roof.

The experiments that validate the implementation of the EHLS method in the whole-building simulation scenario are presented in Section 2. Section 3 describes the procedure for the implementation of the EHLS method in EnergyPlus. The comparison between numerical simulation results and experimental results is made in Section 4. Conclusions are presented in Section 5.

2. Experiments

The experimental data for this study were obtained from April 2010 to March 2011 in one of the three one-room test-huts, shown in Fig. 1, built in Torreón, Coahuila, Mexico (24.5°N, 103.24°W) by Meccano de México. The experimental data from the other two test-huts, were used to compare the thermal performance of two envelope constructive systems for walls and rooves of monolithic concrete buildings. This type of constructive systems is composed of homogeneous layers and its thermal simulation in EnergyPlus is direct [7]. The test-hut used for the present study was constructed with concrete hollow-block walls and hollow-blocks-and-T-beams roof. Its interior dimensions were 2.8 m by 2.8 m on its square base and 2.7 m high. The Northeast wall had a door, with a small window above it. Outdoor and indoor surface temperatures were measured using thermocouples at the center of each wall and roof of the test cell. The thermocouples were glued to the surfaces with a thermally conductive cement. The maximum uncertainty associated to the thermocouples was 0.2 °C. Also climatic conditions were recorded, both surface temperatures and climatic conditions were logged each ten minutes.

The solid section of the hollow-blocks comprising the walls was made of concrete with thermal conductivity of 1.3 W/m °C, specific heat of 866 J/kg °C and density of 2120 kg/m^3 [8]. The length of each block was $d = 0.380$ m, its width was $L = 0.125$ m, and its height was 0.185 m. Each block had two hollow cavities as shown in Fig. 2. The width and length of each air-cavity were $L_2 = 0.055$ m and $d_2 = d_4 = 0.135$ m, respectively. The thickness of the solid front and back was $L_1 = L_3 = 0.035$ m. The fractional area of the in-cavity heat flow path was $a_a = (d_2 + d_4)/d = 0.71$; the fractional area of the framing heat flow path was $a_c = (d_1 + d_3 + d_5)/d = 0.29$. The outdoor surface of the walls were painted white and had a solar absorptance of 0.25.

The solid section of the hollow-blocks in the roof was made of the same concrete as the walls. The T-beams had thermal conductivity of 2.0 W/m °C, specific heat of 950 J/kg °C, and density of 2800 kg/m^3. Each block was 0.510 m long at the base and 0.560 m long at the top, 0.200 m wide and 0.100 m high, and had three air cavities (Fig. 2) that were 0.103 m long ($d_3 = d_5 = d_7$) and 0.040 m high (L_5). The thickness of the solid top and of the solid bottom of the block was $L_4 = L_6 = 0.030$ m and $d_2 = d_4 = d_6 = d_8 = 0.05$ m, respectively. The T-beams were 0.150 m high ($L_3 + L_4 + L_5 + L_6$), 0.100 m long at the base ($d_1 + d_9$) and 0.050 m long at the top. The axes distance, i.e. the distance from the center of one T-beam to the center of the next T-beam was $d = 0.609$ m. The fractional area of the in-cavity heat flow path was $a_a = (d_3 + d_5 + d_7)/d = 0.507$, the fractional area of the framing heat flow path of the blocks was $a_{cb} = (d_2 + d_4 + d_6 + d_8)/d = 0.329$, and the fractional area of the framing heat flow path of the T-beams was $a_{cT} = (d_1 + d_9)/d = 0.164$. The T-beams were reinforced with three longitudinal, 6 mm diameter, pre-stressed steel rods that were not included in the analysis. A concrete layer of 0.10 m covered the

Fig. 1. Test-huts built in Torreón, Coahuila, Mexico.