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ENHANCING ENERGY ACCESS BY EARTH-AIR HEAT EXCHANGER FOR BUILDINGS' THERMAL COMFORT BY THE CONSTRUCTAL DESIGN

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Harnessing soil low-depth thermal energy to support mechanical systems for buildings' thermal comfort has been considered one pathway for reducing the buildings' energy demand (avoid) and adding renewable energy to buildings. The literature addressed those issues in many ways. However, this work introduces two key novelties: (1) the optimization of the duct's configuration and (2) a strategy for the optimal use of the duct assembly to attend to the time-variable energy demand throughout the year. Both are based on the minimization of entropy generation. The irreversibility mechanisms relate to heat transfer and fluid flow in the EAHE and the coupled building-environment-soil-EAHE thermodynamic system.

This approach was carried out by numerically solving the mathematical model (3-D, transient, heat-conduction finite volume with an upwind scheme and heat convection inside the ducts by known convective correlations) developed considering a solid parallelepiped domain on the ground (W×L×H), crossed parallel to its central horizontal axis by several channels of rectangular section (w×L×h), positioned in arrangements of variable geometry.

The design degrees of freedom are the number of ducts, their dimensions, and the spacing among them while meeting prescribed thermal comfort temperatures for each season. Results show that if the energy access of the EAHE is enhanced or optimized for a date in the year, it may not be helpful in other seasons, thus showing that the greater access of the ground thermal energy throughout the year requires a compromise in the EAHE design.

Keywords: Built environment; Passive air conditioning; Entropy generation; Constructal design.

1. INTRODUCTION

Earth-Air Heat Exchangers (EAHE) have been addressed in the literature in many instances (*e.g.*, a review [1], modeling, simulation, and measurement [2, 3], and constructal design [4]). The metrics underlying those designs consider the potential thermal benefit for thermal comfort and the energy expenditure of blowing air through the ducts. Another design challenge is determining under which conditions a design shall be compared since the access of the thermal potential varies in space and time. Therefore, one shall understand the demand's thermal profile, the soil's thermal behavior, the soil-air heat transfer, and the design of duct geometry by minimizing the entropy generation [5].

2. PHYSICAL AND MATHEMATICAL MODELING

The gas-solid heat exchanger was modeled as a parallelepiped solid domain on the ground with dimensions $10\text{m}\times 100\text{m}\times 10\text{m}$ crossed parallel to its central horizontal axis by several channels of rectangular section

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($w \times 100m \times h$) positioned in variable geometry arrangements. The mathematical model considered mass and energy conservation and entropy balance. The degrees of freedom of the project are as shown in Fig. 1(a, b, c), the number of ducts, their dimensions, and the spacing between them. Meanwhile, the volumes of the solid parallelepiped domain (the gray color in Fig. 1) and all channels of the rectangular cross-section are kept constant (air flow occurs perpendicular to the paper sheet).

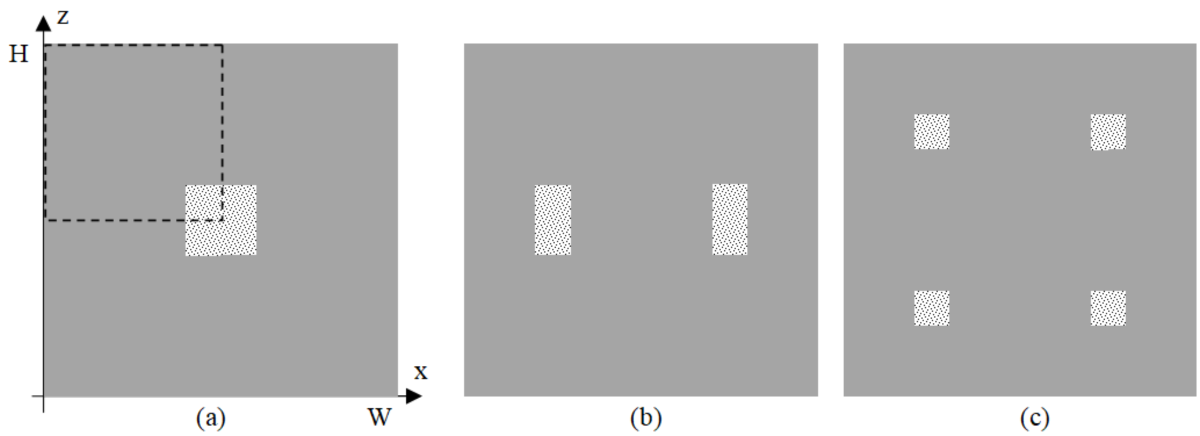

Fig. 1 – Arrangements of variable geometry are considered in the numerical simulations of the airflow passing throughout the parallelepiped solid domain (heat sink).

3. RESULTS

A particular demand for ambient air ($\dot{m} = 0.24$ kg) was initially considered, whose temperature must be reduced by 5°C, from 26°C to 21°C, for thermal conditioning purposes in a building when the ground temperature is approximately 18°C.The numerical results obtained based on the mathematical model $w = h = 2$ m indicate that, over long periods, the temperature of the soil at the contact surface with the air in the channels varies very little, while the air flows through the channels in a manner similar to a permanent process (see Fig. 2).

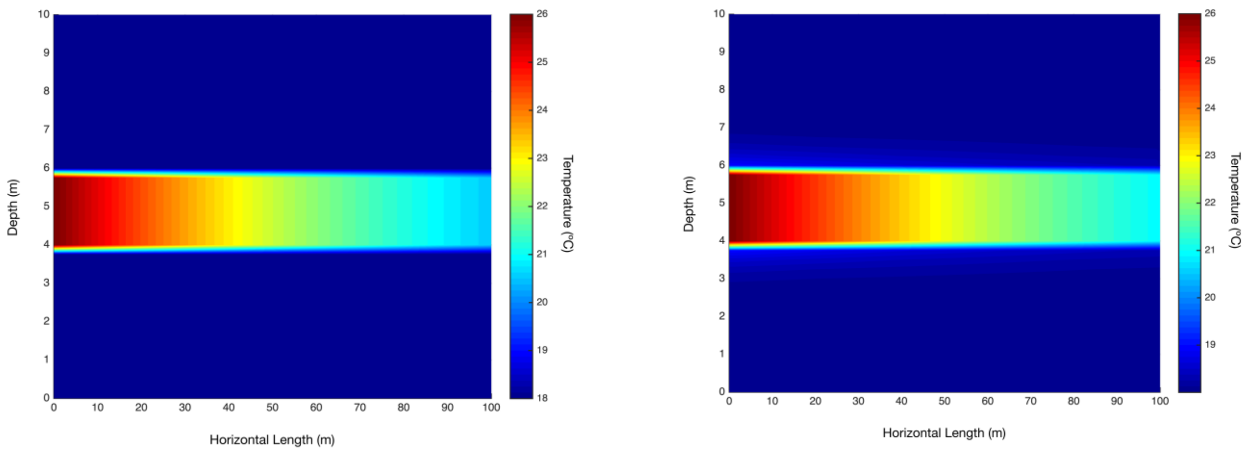

Fig. 2 – Temperature distribution in the middle of the solid domain and the flowing gas after 1 hour (a) of operation is very similar to that after 10 hours (b) of operation.

Based on these first results, for intermittent use for short periods of this type of gas-solid heat exchanger, the processes in the solid and gas are studied separately. Then, for minimal irreversibility, the optimal hydraulic diameter of the channels is determined based on the following formulae $D_{h,opt} = 4\dot{m}/(\pi\mu\rho\,\mathrm{Re}_{opt})$, where μ and ρ are respectively the dynamic viscosity and air density, and $\mathrm{Re}_{opt} = 2.023\,\mathrm{Pr}^{-0.7}\,\mathrm{Be}^{0.36}$ [5].

The number of channels to be implemented should be determined considering the thermal regimes that occur most frequently throughout the year and the possibility of meeting the demands for thermal conditioning purposes in a building using various combinations of one or more existing channels simultaneously. In this work, we seek the best of these combinations by minimizing entropy generation [5]:

$$\tilde{S} = \dot{S}'_{gen} / \dot{S}'_{gen,min} = 0.856\times(\mathrm{Re}/\mathrm{Re}_{opt})^{-0.8} + 0.144\times(\mathrm{Re}/\mathrm{Re}_{opt})^{4.8}. \tag{1}$$

4. **DISCUSSION AND CONCLUSIONS**

Although the problem is just optimizing the operation of the gas-solid heat exchanger when harnessing thermal energy from the ground, we are looking for its optimal functioning to satisfy the variable demand throughout the year. Once the channel geometry was optimized for a given regime, the question of how the already built channel systems would be operated in any other regime remains. In this work, the answer is given by minimizing the entropy generation.

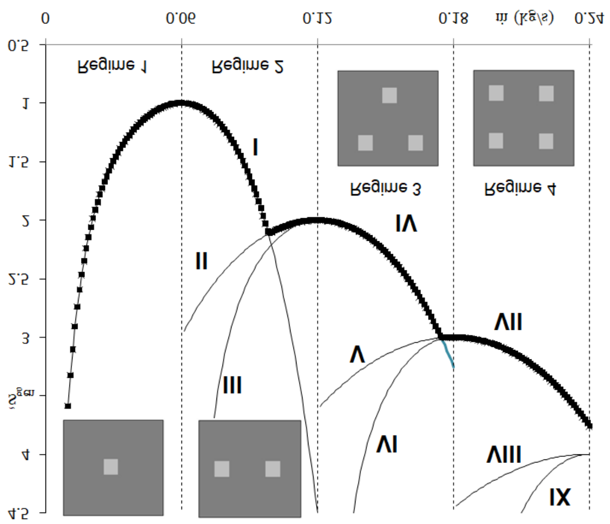

Fig. 3 – Dimensionless minimal entropy generation for different operating regimes that aim to reduce the variable air mass flow temperature by 5°C.

In Fig. 3, the black square markers indicate the sequence of operations leading to minimum entropy generation. For example, in Regime 2, where up to two of the channels initially optimized for airflow can be used, operation with minimum entropy generation occurs by initially passing all the airflow through a single channel (line **I**) while for $0.06 \le \dot{m} \le 0.098$ dividing the total airflow equally between the two operating channels (line **II**).

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