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ScienceDirect

Procedia Environmental Sciences 38 (2017) 68 – 76

Procedia Environmental Sciences

International Conference on Sustainable Synergies from Buildings to the Urban Scale, SBE16

Numerical Study of Solar Chimney Operation in a Two story Building

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Abstract

In the present study a CFD model is developed for the examination of natural ventilation in a two store building with a solar chimney. The steady-state transport equations for the vector and scalar quantities (velocity vectors, turbulence, energy and spectral intensity of radiation) are solved numerically by a FV numerical method. The turbulent nature of the flow is simulated by the two equation k-ω high Reynolds model while for the incident radiation is used the Discrete Ordinates (DO) model. The model efficiently renders the buoyancy effects inside the building, through density variation caused by temperature raise. The radiation modelling takes into account the thermal and optical spectral properties of materials. The developed numerical model was validated against published works for relative flows. Three modifications of the basic 2D geometry were examined in order to exploit the functionality design of a solar chimney. The better performance was achieved with the simpler design which has single openings connecting the solar chimney and the ventilated rooms, while the ventilation rate was compared with analytical models. 2D simulations' results can be used safely as indication about the solar chimney qualitative performance while they underestimate the mass flow rate in comparison with equivalent 3D approaches. The solar chimney operates better at morning and afternoon, while the worst operation is observed at the noon of June, as far it concerns the ventilation of the whole building

Peer-review under responsibility of the organizing committee of SBE16.

Keywords: CFD; buoyant forces; mixed heat transfer; solar chimney; passive systems

1. Introduction

The building's ventilation with the lower possible cost has been the subject of extended studies for many researchers, and one of the most used practices is the natural ventilation. The available techniques for natural

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Peer-review under responsibility of the organizing committee of SBE16.
doi:10.1016/j.proenv.2017.03.079

ventilation are distinguished in those that are driven by the pressure difference and those that are driven by buoyancy. In the second category are reported techniques like the stack ventilation (or chimney effect), cool tower (cooling through evaporation) or combination of them. Many designs are proposed for solar chimneys in the literature and practice and many parameters, related to their performance, have been investigated.

The behavior and the performance of solar chimneys have been studied mainly with experimental and analytical tools. Various geometries and parameters have been studied in experimental setups. In some cases the experimental devices were used for the validation of analytical or/and numerical models. In [1] a mathematical tool is developed in order to determine the tilt that maximizes natural air flow inside a solar chimney. The analytical tool is validated through measurements in experimental setup and CFD calculations. In similar work [2] a FEM-based numerical code is used along with an analytical tool in order to study the effect of inclination angle on the solar chimney performance. It is shown that an optimum air flow rate value can be achieved for chimney inclination between 45^o and 70^o for latitude of 28.4^o N. The developed model was validated against published experimental work [3].

Purely numerical studies can also be found. A finite difference – control volume numerical method is used in order to study laminar flow inside a solar chimney without modelling directly the radiation [4]. The study proved that the surface radiation modifies the flow and temperature fields, affects the Nusselt number and the volume flow rate and improves the ventilation performance. A finite volume method is used for investigation of a 2D geometry simplified system of solar-wind tower [5]. The effect of inclination angle and of glazing with low-emissivity are investigated numerically [6] showing that an angle of 67.5^o was optimum giving 11% greater efficiency than the vertical chimney and 10% higher efficiency was obtained using a low-emissivity wall surface. The radiation is still not simulated and the emissivity value is taken into account through the absorber surface temperature.

In the present study, 2D and 3D steady-state CFD models for the examination of a solar chimney operation are developed using a finite volume source code. The models are initially validated through a 2D simulation against experimental data available in literature. The studied building is consisted of two stores with side openings. The air enters the house through the side openings and leaves it through the solar chimney top due to buoyant developing forces. In this approach, the radiative transport equation (RTE) is being solved, simulating efficiently the radiation absorption and transmittance at opaque and transparent elements of the envelope with the DO model

2. Mathematical & Numerical Model

The transport phenomena developed inside the examined building (air and solid materials) are described by the Navier-Stokes equations [7]. The flow is assumed to be uncompressible, steady state and turbulent. For continuity and momentum equations are solved the time-averaged Navier-Stokes. The effect of thermal buoyancy is modelled through the addition of a source term in the momentum equation. In the energy Conservation equation a source term, S_h, is added in order to incorporate the effect of radiation in the energy balance and it is obtained from the solution of the radiative transport equation. Inside the solid materials the above equation is reduced to heat transfer conductivity equation. The flow inside the two stores and in the solar chimney is turbulent. The effect of turbulence is implemented via the standard high Re k-ε model [8]. The Discrete Ordinates (DO) model was used for the simulation of solar incident radiation [9]. The RTE equation is coupled with the energy equation through a volumetric source term given by the following equation [10]:

$$S_h = -\frac{\partial q_{r_i}}{\partial x_i} = \alpha_\lambda \left(4\pi I_{b\lambda}\left(\vec{r}\right) - \int_{4\pi} I\left(\vec{r},\vec{s}\right) d\Omega \right) \quad (1)$$

The spectral absorption coefficient, α_λ, is computed from the absorptivity, according to the media thickness, d:

$$\alpha_\lambda = d^{-1} \ln\left(\left(1-a\right)^{-1}\right) \quad (2)$$

The transport equations are solved using the method of finite volume. The coupling of continuity and pressure is achieved through the SIMPLEC algorithm. The grid, used for the simulations, was a multi-block hybrid mesh,