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Thermal and fluid Dynamic Performance of wavy Wall Systems applied for architectural Design of Building in Saudi Arabia

Ali Alzaed[1] and Ashraf Balabel[2]

[1] *Faculty of Engineering, Taif University, Al-Haweiah, Taif, Saudi Arabia.*

[2] *Faculty of Engineering, Taif University, Al-Haweiah, Taif, Saudi Arabia.*

Abstract

For the purposes of thermal comfort in buildings, a new innovation architectural design using wavy wall systems applied for thermal insulation in building in Saudi Arabia has been developed [1]. In the present paper, numerical investigations of the thermal and dynamic performance of such wavy wall system are carried out. The numerical simulation is carried out using CFD code developed by the present authors. The system of the governing equations being solved consists of the set of Navier-Stokes equations and energy equation in its primitive forms. The governing equations are descretized over a regular grid system using the control volume approach. The performance of the wavy wall system is investigated by considering different wave ratios and different Reynolds number and showing the effects of such geometrical parameters and inlet flow conditions on the thermal behavior of the wavy wall system. The numerical results obtained showed that the proposed architectural building design, in general, improves the thermal characteristics of the building by reducing the air temperature flowing over it. This can lead to saving energy consumption without using any of traditional insulation materials. Moreover, the effect of wave ratio is clearly obtained in such a way that by decreasing the wave ratio the temperature in the wave trough is decreased. However, the separation zone of the flow can be increased by increasing the wave ratio.

Keywords: Energy saving; Building designs, Numerical simulation, Thermal insulation, Wavy walls.

INTRODUCTION

It is well known that the great consumption of electrical energy worldwide is concentrated in building sectors in order to achieve the thermal comfort conditions [2]. Consequently, the increase demand for the electrical energy in building sectors can be clearly observed in Saudi Arabia, see Figure 1.

The electricity consumption in Saudi Arabia should continue to increase at a very fast rate. At the moment, more than half a million barrels of oil per day is used directly for power generation

According to ministry of water and electricity in Saudi Arabia, there are some important regulations for building insulation system applied for new buildings in order to reduce electric consumption and, consequently, saving energy used for heating or cooling purposes [3, 4, and 5]. It is well known that, the addition of external or internal insulation to solid walled buildings tends to be very expensive. Therefore, it is important to underestimate the costs associated with the necessary levels of care in details. Moreover, the traditional insulation materials exhibit major disadvantages when it used for the thermal building insulations [6].

Instead of searching on the thermal performance of either the traditional insulation materials or the new insulation materials, in our previous paper [1], a new architectural building design is introduced. Moreover, the proposed design was modeled and simulated using CFD code developed by the present authors. The capability of the proposed design in improving the thermal characteristics of the building was investigated numerically.

In the present paper, further investigations for the proposed design of the wavy wall system applied for new building instead of using thermal insulation material, are performed.

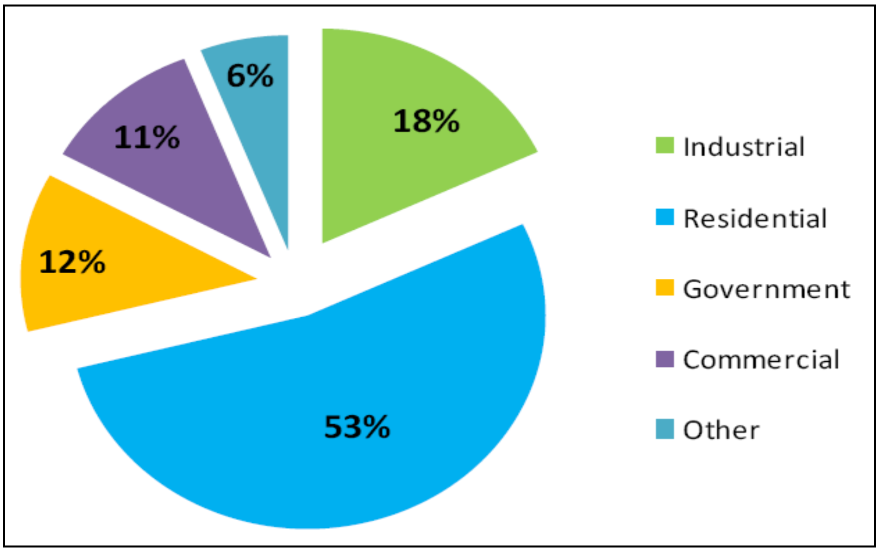

Figure 1: Electricity consumption in different sectors in Saudi Arabia (2008)

PHYSICAL AND COMPUTATIONAL MODEL

The physical domain to be investigated is shown in figure 2 below. It can be seen that the building front seems like a wavy form with specified wavelength and wave amplitude. The dynamics of air flowing on such wavy wall can be changed, and consequently, its temperature. In our previous research [1], it is found that the temperature decreases at the wave trough enabling the air to become much cooler than the inlet air flow at the wave crest. This phenomenon can be used in building design by letting the buildings opening located directly to the wave trough. The cooled air is attracted inside the building by the effects of pressure difference between wave trough and the atmospheric pressure inside the building. Therefore, numerical investigations of the effects of the geometrical parameters of the wavy wall system are required.

Figure 2: Illustration for some wavy wall building design (dubaisession.com).

In our investigation, the computational model is shown in figure 3. The main geometrical parameters that can affect the fluid dynamics and the thermal performance of the proposed model are the wavelength and the wave amplitude.

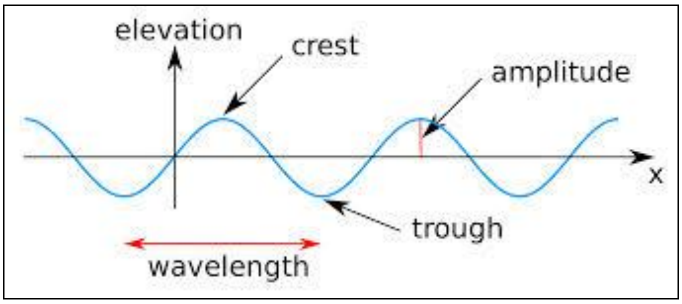

Figure 3. The computational model for wavy walls building.

In the previous figure, the wave number (***k***), and the wave ratio (***wr***), can be defined as:

$$k = \frac{2\pi}{\lambda}, \qquad wr = \frac{2\pi a}{\lambda}$$

where, $\boldsymbol{\lambda}$ is the wavelength and ***a*** is the wave amplitude.

Three different values for the wave number and the wave ratio are considered in the present paper; namely, ***k*** =2.5, 25, and 250 which are corresponding to the wave ratios ***wr*** =0.04, 0.4, and 4, respectively.

GOVERNING EQUATIONS AND NUMERICAL METHOD

The system of governing equations for the case under consideration can be summarized as below. It consists of the conservation equations of mass, momentum and energy at each point of the flow field. These equations can be written in the primitive variables formulation as follows:

$$\nabla \cdot \mathrm{u} = 0 \tag{1}$$

$$\rho\left(\frac{\partial \mathrm{u}}{\partial t} + \nabla \cdot (\mathrm{uu})\right) = \nabla p + \mu \nabla^2 \mathrm{u} \tag{2}$$

where ρ, u, p, μ are the density, velocity vector, pressure and viscosity of the fluid. The fact that there is no pressure transport equation necessitates the consideration of the continuity equation as a means to obtain the correct pressure field. This is done by a proper coupling between the pressure and velocity field through the Poisson equation for pressure:

$$\nabla^2 p = -\nabla \cdot \rho\left(\frac{\partial \mathrm{u}}{\partial t} + \nabla \cdot (\mathrm{uu})\right) \tag{3}$$

The Poisson equation is solved by means of the Successive Over-Relaxation method.

The energy equation can be written as:

$$\frac{\partial(\rho T)}{\partial t} + \nabla \cdot (\rho u T) = \nabla \cdot (q / C_p) \tag{4}$$

where T is the temperature, q is the heat flux and C_p is the specific heat constant. The numerical method employed here to solve the above equations is based on a general method for prediction of heat and mass transfer, fluid flow, and related processes [7]. This method has been developed and proved its generality and capability in a wide range of possible applications.

RESULTS AND DISCUSSION

In this section, some numerical results are illustrated and discussed in details. The figures presented compare the axial velocity profiles for the three wave ratios considered; namely, ***wr***=0.04, 0.4 and 4. The inlet velocity and temperature of the air flow is considered to be constant for the three cases. The wave amplitude is considered to be constant for the three cases considered resulting in the corresponding wave number ***k***=2.5, 25 and 250, respectively.

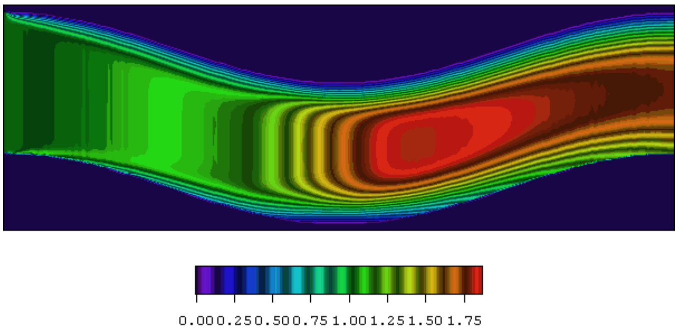

Figure 4: The axial velocity profiles for ***wr***=0.04

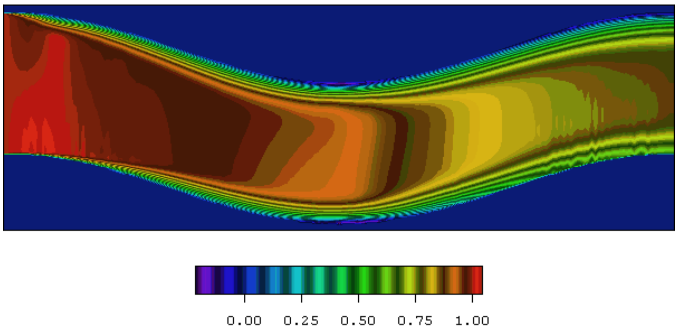

Figure 5: The axial velocity profiles for ***wr***=0.4

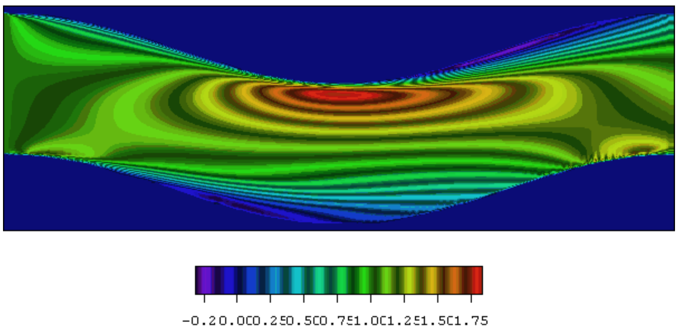

Figure 6: The axial velocity profiles for ***wr***=4

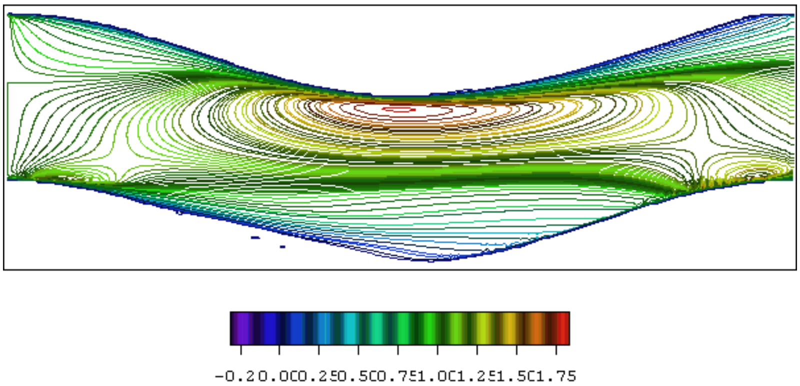

Figure 7: The axial velocity contours for ***wr***=4

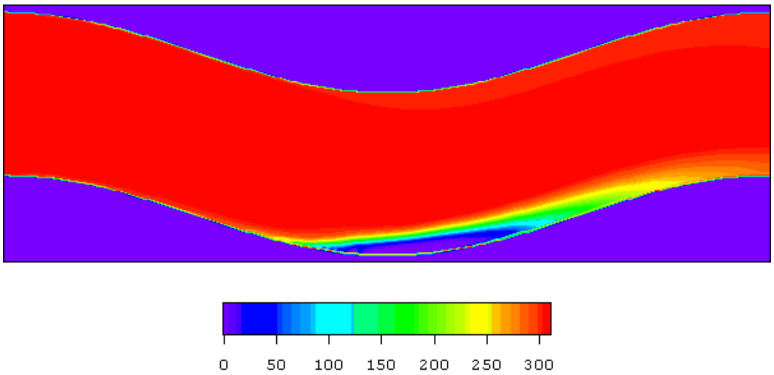

Figure 8: The temperature profiles for ***wr***=0.04

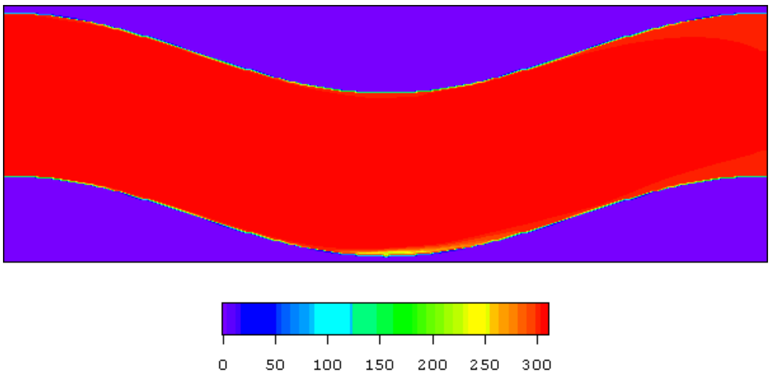

Figure 9: The temperature profiles for ***wr***=0.4

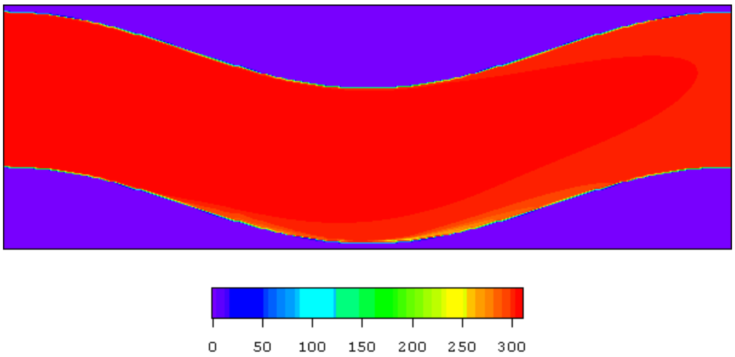

Figure 10: The temperature profiles for ***wr***=4

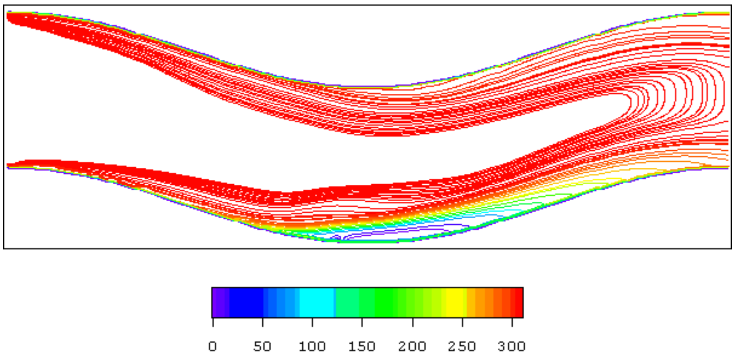

Figure 11: The temperature contours for ***wr***=0.04

The previous figures illustrate the axial velocity profiles and the temperature distribution for the different waves considered. The obtained results show that, by increasing the wave ratio, large separation zone can be observed revealing, especially, in the trough of the wave, as it can be seen for figure 6 and figure 7. However, by decreasing the wave ration, low temperature can be obtained in the wave trough as it can be seen from figure 8 and figure 11. According to the required function of the wavy wall system in obtaining low temperature in the wave trough and consequently thermal comfort inside the buildings, therefore the smallest wave ratio is preferred in such cases. For the purposes of natural ventilation, the largest wave ratio can be chosen.

CONCLUSION

In the present paper, numerical investigations of wavy wall system applied in the buildings fronts instead of thermal insulation are performed. The numerical simulation is carried out using CFD software prepared by the present authors. The obtained results showed that the smallest wave ratio results the lowest temperature in the wave trough. However, the largest wave ratio produces the largest separation zone. According to the purpose of the building front, the designed wave ratio can be chosen For natural ventilation purposes, the largest wave ratio is proffered. However, for the thermal comfort purposes inside buildings, the smallest wave ratio is chosen.

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