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An Innovation Architectural Design Using Wavy Wall Systems Applied for Thermal Insulation of Building in Saudi Arabia

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Abstract

Buildings are responsible for nearly about 40 percent of the world's total energy consumption and about 36 percent of world carbon dioxide emissions. Application of the effective thermal insulation in building in Saudi Arabia is one of the important issues from the aspect of energy economy. The implementation of traditional thermal building insulation materials and solutions of today have the drawback that it result in thick building envelopes due to the increasingly demanding of thermal insulation requirements. In the present paper, an innovation design for building in Saudi Arabia is applied in order to improve its thermal characteristics. This technique is related to the field of architectural engineering instead of using traditional thermal materials. In order to approve the effectiveness of the proposed technique, numerical simulation of the proposed design using CFD code. The obtained results showed that the proposed architectural building design 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.

Keywords

Energy Saving, Building Designs, Numerical Simulation, Thermal Insulation, Wavy Walls

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1. Introduction

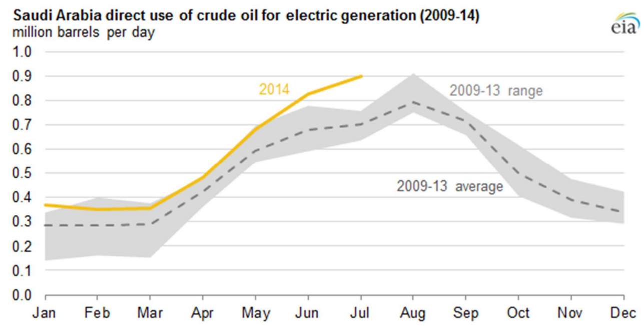

Figure 1. The direct use of crude oil in Saudi Arabia for electric generation.

According to the recent reports overall the world, there is an increase of global demand for electrical energy due to the increase of population or industrial development. Building sectors are considered as the largest consumer of electrical energy in heating and cooling purposes especially in tropical countries, e.g. Saudi Arabia (Aktacir, et al. 2010). The electricity consumption in Saudi Arabia s hould 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, see Fig. 1.

Moreover, there is a recently large increase in temperature over all the Saudi Arabia zones, as seen from Fig. 2. This temperature distribution is expected to increase fast in the upcoming years due to the global warming process. Therefore, most of governments impose mandatory the thermal

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insulation of building in order to reduce electric consumption and, consequently, saving energy used for heating or cooling purposes, see (AlTurki, and Zaki, 1991, A. Bolatturk, 2006).

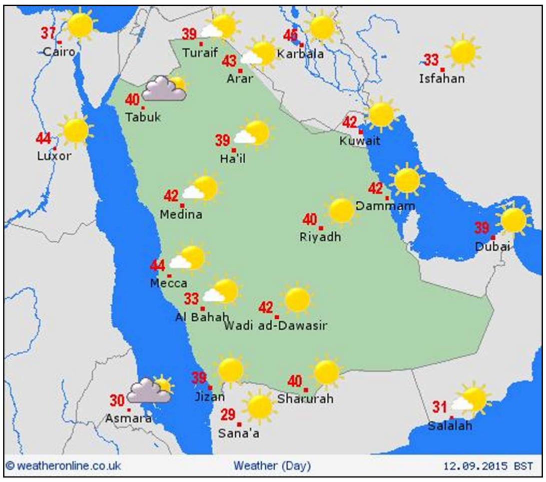

Figure 2. The Temperature distribution over Saudi Arabia Zones, 12 Sep. 2015.

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, see for more details (Hasan, 1999, Al-Homoud, 2005, Papadopoulos and Giama, 2007, Papadopoulos, 2005).

Instead of searching on the thermal performance of either the traditional insulation materials or the new insulation materials founded by researchers, in the present paper, a new architectural building design is introduced. Moreover, the proposed design is 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 is investigated numerically.

2. Physical and Computational Model

Figure 3. Illustration for some wavy wall building design (dubaisession.com).

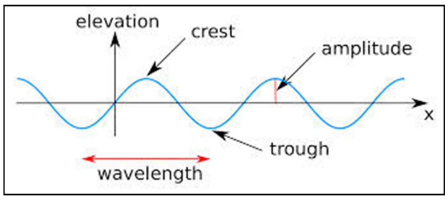

Figure 4. The computational model for wavy walls building.

The proposed building design is based on constructing the building with wavy walls that periodically repeated. Some examples for such design can be seen in Fig. 3. The computational model for the wavy wall building is shown in Fig. 4. The basic idea of the proposed design is related to the fluid dynamics of the flowing air stream when it moves over the periodically waves. According to the CFD associated dynamics, the air stream can exhibit flow separation in the trough of the wave due to the increase of the pressure gradient starting from the crest of the wave. Therefore, a decrease in the air temperature is obtained in the trough of the wave. Accordingly, the required windows are located in the front of the building in the trough region of the wavy walls. As the air leaving the wave trough, it is accelerated due to the wave form and then we can use the crest of the wave for the ventilation purposes if required.

3. Governing Equations and Numerical Method

The governing equations for incompressible flow are mathematically expressed by the conservation equations of the mass and momentum at each point of the flow field. These equations can be written in the primitive variables formulation in form of continuity equation and Navier-Stokes equations, respectively, as follows:

$$\nabla \cdot \mathrm{u} = 0 \qquad (1)$$

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

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:

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

The Poisson equation is solved by means of the Successive Over-Relaxation method. The energy equation can be written as:

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

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, (Patankar, 1980). This method has been developed and proved its generality and capability in a wide range of possible applications; see for more details (Balabel, 2011, 2012, 2013). The software used for solving the present problem is developed by the authors and has been tested and validated through wide range of applications (Balabel, 2015).

4. Results and Discussion

In the following sections, sample of the obtained results are presented and the associated dynamics are discussed. Figure 5 shows the axial velocity distribution over the wavy wall starting from the left side to the right one. It can be clearly seen the existence of the separation region in the wave trough and the upper part of the wave starting from the center point. The axial velocity contours can be seen in Fig. 6, which shows the separation zones. The velocity vector plot is shown in Fig. 7, where the previous velocity characteristics are approved clearly.

Samples of the important figures are shown in Figs. 8, 9, where the temperature distribution and contours over the wavy walls are illustrated. The previous figures showed that the temperature reaches about the half of the initial temperature in the trough region and a low value at the crest of the exit section. This implies that configuration of the wavy walls can lead to a highly reduction in the temperature of the streaming air, especially in the wave trough. The above results proved the capability of the proposed design in building insulation systems.

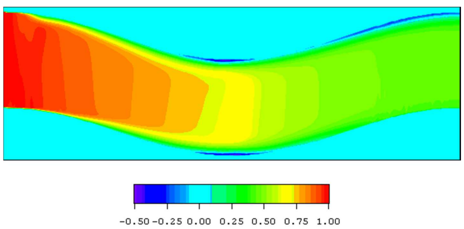

Figure 5. The axial velocity distribution over the wavy wall.

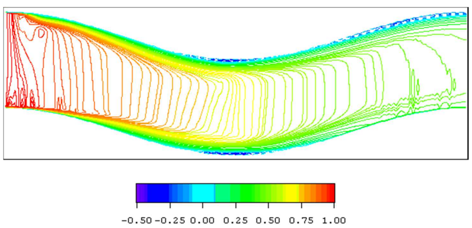

Figure 6. The axial velocity contours over the wavy wall.

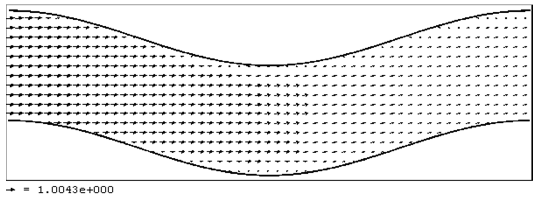

Figure 7. The velocity vectors over the wavy wall.

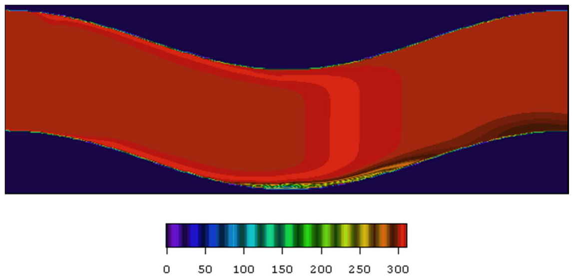

Figure 8. The teperature distribution over the wavy wall.

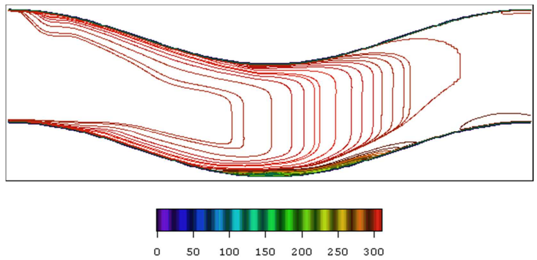

Figure 9. The temperature contours over the wavy wall.

5. Conclusions

In the present paper, an innovation architectural building design is proposed and tested for the thermal insulation purposes. The proposed design is based on the wavy wall systems applied for the front walls of the building. The test of the proposed design is carried out by performing the computational fluid dynamics of the governing equations by using an accurate numerical method. The results obtained proved the capability of the proposed design to reduce the streaming air temperature without any traditional insulation materials.

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