# Numerical Analysis of Natural Ventilation System in a Studio Apartment in Bangladesh

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**Abstract.** The study of temperature and air flow for natural ventilation system has been investigated numerically. A finite element model for studio apartment was developed with the aim of achieving detail energy allocation in the real buildings during the transient process in the walls and internal air. A tool of computational fluid dynamics (CFD) is employed to assist the process. In the tropical regions most of the energy is consumed by the heating, cooling and ventilation appliances. Therefore, the optimize ventilation system will be a suitable and valid option for the saving of energy from the household sector to increase cooling performance and ensuring thermal comfort as well. A mathematical exploration is carried out on full scale dwelling and small scale model and indication is given on the relevance of such a comparison. Calculations are carried out with household heat sources for calm and windy period, but without any human. As expected, for windy periods, the wind is the main driving force behind the internal air flow. However, in calm periods for unsteady flow the internal airflow looks like more complexes through observation.

## INTRODUCTION

Consumption of energy is an acute proclaims and has become a great anxiety during the last eras. In developed countries buildings are responsible for one-third of all energy consumption [1]; atmospheric pollution and global warming are increasing due to increase of fossil-based energy. The energy requirement has increased at a rate of 2 % per year for the past 25 years and it will increase continuously at the same rate if current energy patterns persist, according to the International Energy Agency (IEA). Energy is used for heating and cooling purposes in most of the building, and approximately 51% of energy consumption in residential buildings in London [2].Whereas in Bangladesh, the consumption patterns was given below: Domestic (47.21%), Industry (36.56%) and Commercial (9.49%) [3] and it is increasing day by day. One of the ways of saving costs of energy is the use of natural ventilation, which supplies and removes air to the building without using engineering systems. Natural ventilation has significant role to decrease operating costs to condition buildings while maintaining acceptable indoor air quality [4-5]. While introducing a natural ventilation system, the inside air quality must be considered. For decreasing the energy use in buildings and keeping a healthy indoor environment an alternative energy efficient solution is Natural ventilation [8-9]. Tamami Kusuda, showed about the heat transfer in buildings [10]. David Park, solve the heat transfer and air flow in a room numerically [11]. There are mainly two types of natural ventilation: cross ventilation and single-sided ventilation, and occur by wind and buoyancy forces, respectively. The buoyancy forces are induced from gradients of density occurring due to temperature gradients. The airflow and thermal conditions in the building can be altered by heat sources such as fires, electronic components, electrical heaters, and even from people. Usually cross ventilation is used for cooling purposes, which depends on outsider wind to transport the cool air into an inlet (window, door, etc.) and to transport the insider warm air through an outlet (window, door, etc.). Single-sided ventilation involves a room with one opening. The differences between the indoor and the outdoor temperatures create a pressure difference, and for these reason the air is ventilated through an opening. It is a greater challenge to design a naturally ventilated building than designing a mechanically ventilated building because natural ventilation affects by weather, which changes continuously. On the other hand, for a mechanically ventilated building, ambient conditions outside the building are not as important. Without any openings, the room can be maintained at comfortable thermal conditions. However for a naturally ventilated building, fluctuating ambient temperature, humidity, wind speed, and wind direction must be considered [12-13]. When designing a naturally ventilated building layout of the building also must be measured. The size and position of inlet, heat sources, or obstacles are important issues that affect the airflow inside the building. Experimental investigation is suitable to study practical airflow patterns, but it is costly and lengthy. Moreover, it is not easy to study of the airflow patterns in a building in details. An alternative way to model natural ventilation in a building is CFD, which is a numerical analysis to solve the Navier-Stokes equations and calculate the airflow within the building. In compare to experimental investigation, CFD is cost-effective and easy to investigate on the flow due to geometry change. So it is easy to use the powerful tool CFD to model natural ventilation.

## MATHEMATICAL MODEL

The problem is solved using a set of equation for compressible, unsteady fluid flow with standard k-ε model. The equation for a general variable $\phi$ has the well-known form,

$$\rho\frac{\partial}{\partial t}(\phi)+\rho\frac{\partial}{\partial x_i}(u_i\phi)=\frac{\partial}{\partial x_i}(\Gamma\frac{\partial}{\partial x_i}\phi)+S_\phi \quad (1)$$

Where, the variable $\phi$ substitutes velocity components $u, v, w$ temperature $T$ and kinetic energy of turbulence $k$ and its rate of dissipation $\varepsilon$ . The equations for $k-\varepsilon$ model of turbulence are as follows,

$$\rho\frac{\partial}{\partial x_i}(u_i k)=\frac{\partial}{\partial x_i}(\frac{\mu_{ef}}{\sigma_k}\frac{\partial k}{\partial x_i})+P+P_B-\rho_e \quad (2)$$

$$\rho\frac{\partial}{\partial x_i}(u_i\varepsilon)=\frac{\partial}{\partial x_i}(\frac{\mu_{ef}}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x_i})+C_1(\frac{\varepsilon}{k})(P+C_3P_B)-C_3(\frac{\rho\varepsilon^2}{k}) \quad (3)$$

The major heat balance equation for this problem is,

$$\nabla(-k.\nabla T)+\rho C_p.v.\nabla T+\rho C_p.\frac{\partial}{\partial t}T=Q \quad (4)$$

Where, k means heat conductivity, T is the room temperature, $\rho$ is density, $C_p$ is specific heat, $v$ is speed, t is time, Q is heat source.

## MODEL DETAIL

In the present study, a typical flat studio is modelled and simulated using three dimensional CFD and Heat Transfer. The net length is 7.5m, width is 5m and height is 3m of the apartment. There is 1 kitchen, 1 bathroom and 1 living room as shown in **FIGURE 1(a)**.The studio apartment space is filled with air and one burner in kitchen, one refrigerator and one Television in living room as heat sources as shown in **FIGURE 1(b)**.The studio apartment is employed with three doors, two windows in living room and one in kitchen of typical size and a vent in bathroom as shown in **FIGURE 1(b)**. Every room has an open door to an interior circulation area, which in our model is considered as an open boundary, like as [14]. High resolution second order accurate advection scheme was used to discretize the equations for the flow, turbulent kinetic energy, and turbulence eddy dissipation. Kajtar et al [15], simulated different cases using FLOVENT by employing k-ε turbulence model. The CFD module is the platform for simulating devices and systems that involve sophisticated fluid flow and heat transfer models. Initially, 0 (zero) velocity is used inside the flat. Here inlets are taken in kitchen, bathroom and living room (north side window).

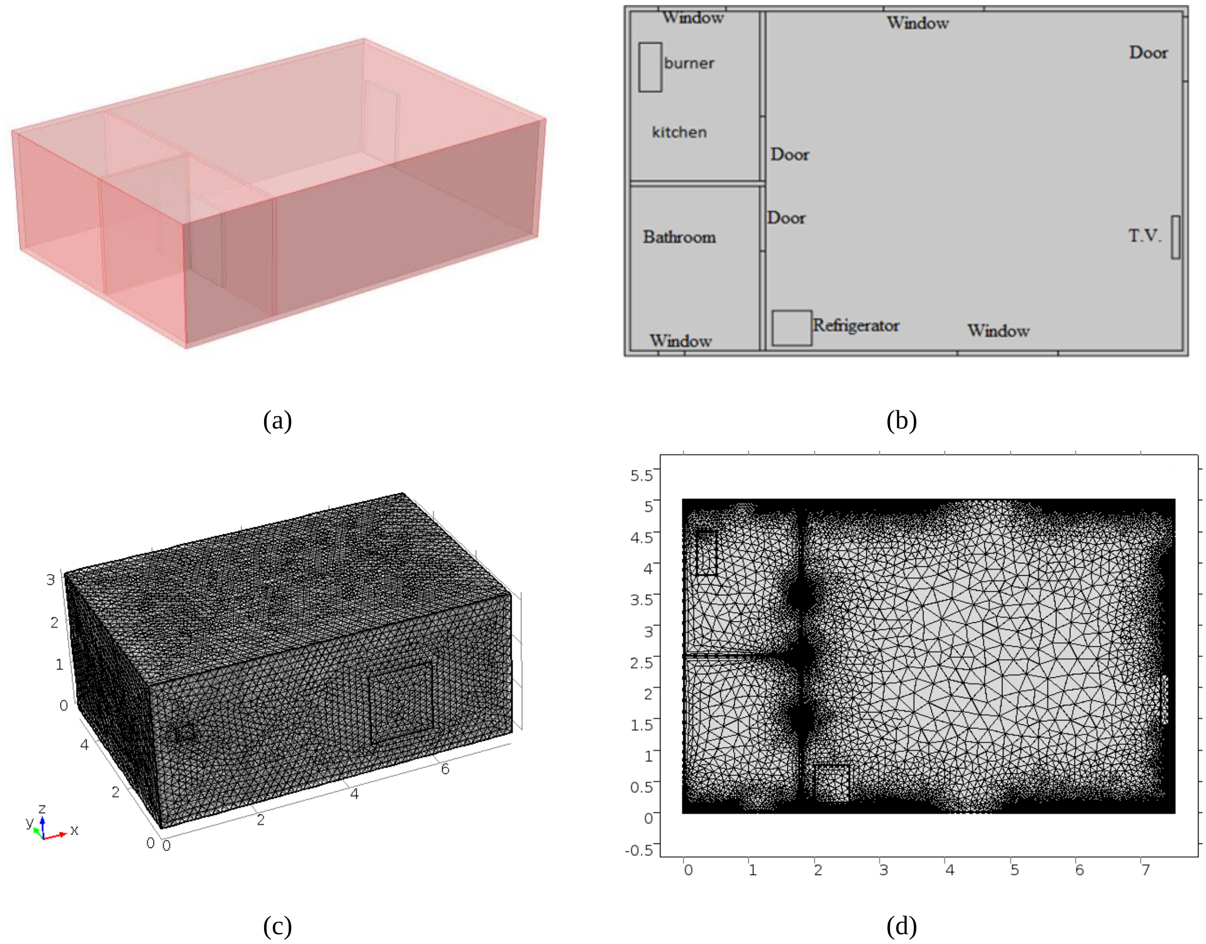
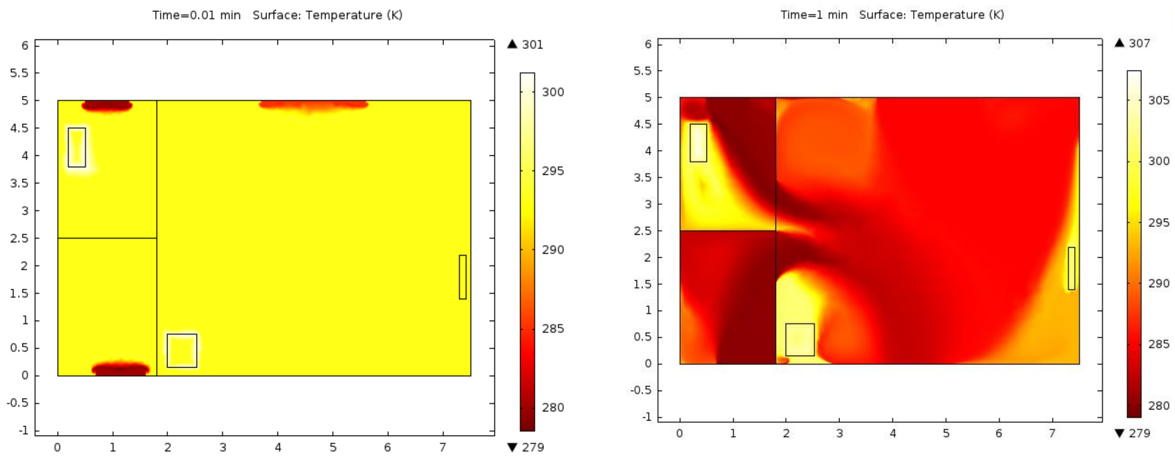



**FIGURE 1. (a)** 3D Geometry of Studio Apartment model, (b) 2D Geometry of Studio Apartment model with details, (c) 3D meshing of Studio Apartment model and (d) 2D meshing of Studio Apartment model

Then, a complete combustion occurs in presence of air inside the flat. There are two outlets; one is living room's Southside window and other is living room's door. Both outlets are open during the simulation. The buoyancy driven air flow resulting from temperature difference between the gas combustion and the surrounding air was also accounted in the simulations. An unstructured triangular shape grid is adopted for the entire domain as shown in **FIGURE 1** (c) and (d) for different cross-sectional plains. An appropriated attention is given in the combustion zone where gradient of the flow variables are expected to be significant. Since the combustion is modeled and heat is convicting into the space due to burning, a very smooth grid transition from finer to coarser was maintained so that the information can be transmitted with reasonable accuracy. The study does not take into account radiation, humidity and external pressure. For simplicity, velocity and temperature are assumed according to the climate condition of Bangladesh. In future, further study will be performed using radiation, humidity, pressure and acoustic with different positions and places.

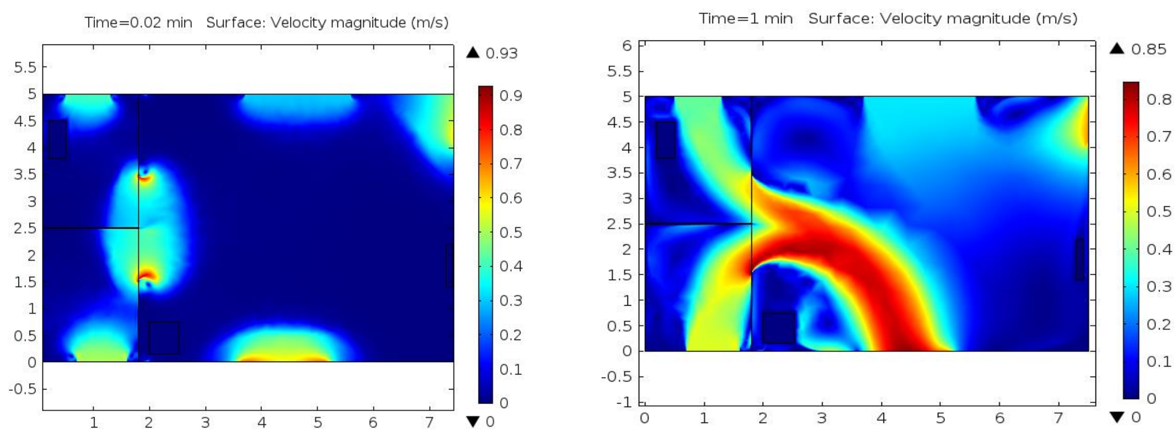
## RESULT AND DISCUSSION

In this work natural ventilation of the studio apartment is simulated. Numerical analysis based on finite element method is used to solve three dimensional unsteady flows in enclosed space and resulting temperature distribution and air velocity field with different heat sources. In the following figure, it is visible that the cold air is pushed to the exterior face. According to the present position of the inlets, the temperature inside the flat will not be equally distributed. Analysis shows strong influence of natural ventilation and room geometry on thermal comfort. According to the ANSI/ASHRAE Standard 62-2001 [16] the mean values of temperature and air flow velocity obtained in this study are satisfactory for indoor air quality and thermal comfort. **FIGURE 2 (a)** and **(b)** describe the temperature effect in an apartment due to natural air flow for different times. Velocity magnitude is shown for 0.02 minute and 1 minute in **FIGURE 3 (a)** and **(b)**. In **FIGURE 4 (a)** to **(d)**, the pressure distributions are depicted to show the internal Temperature distribution of different times for isotherm is shown in **FIGURE 5 (a)** and **(b).**




(a) (b)

**FIGURE 2**. (a) Temperature distribution at time t=0.01 min and (b) Temperature distribution at time t=01 min




(a) (b)

**FIGURE 3**. (a) Velocity profile at time t=0.02 min and (b) Velocity profile at time t=01 min

From the examined figure it can be explained that small volume of air follows the ventilation air flow while large volume of air may behave differently and settle. Internal re-circulation of such volumes into the convective heat source may increase air exposures in the breathing zone. The continuous settling of volumes during transport in the main flow direction leads to an accumulation of particles that are brought into the breathing zone by the convective heat sources. The exposures are increased by distance from supply wall with displacement ventilation. Due to the fact that the air is not distributed equally some volumes of air in the room will remain colder. Ventilation system performance was indicated well accepting result [17] for indoor air velocity profile for incidence angle of 0º. In

**TABLE1**, inlet and outlet wind velocity are shown for two cases $A_1$ ($U_\infty$ = 1 m/s) and $A_2$ ($U_\infty$ = 3 m/s) to validate our numerical data only for velocity profile.

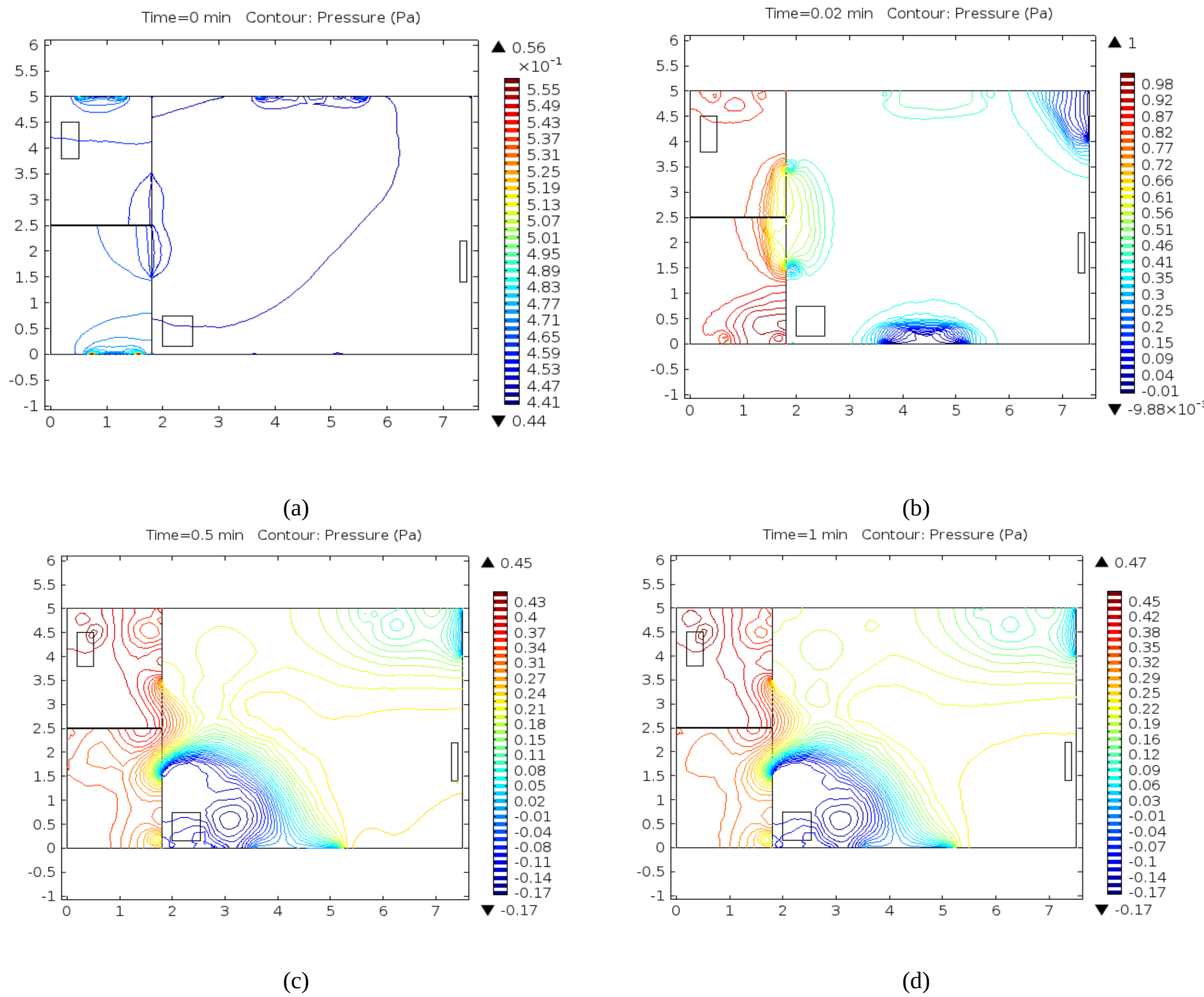
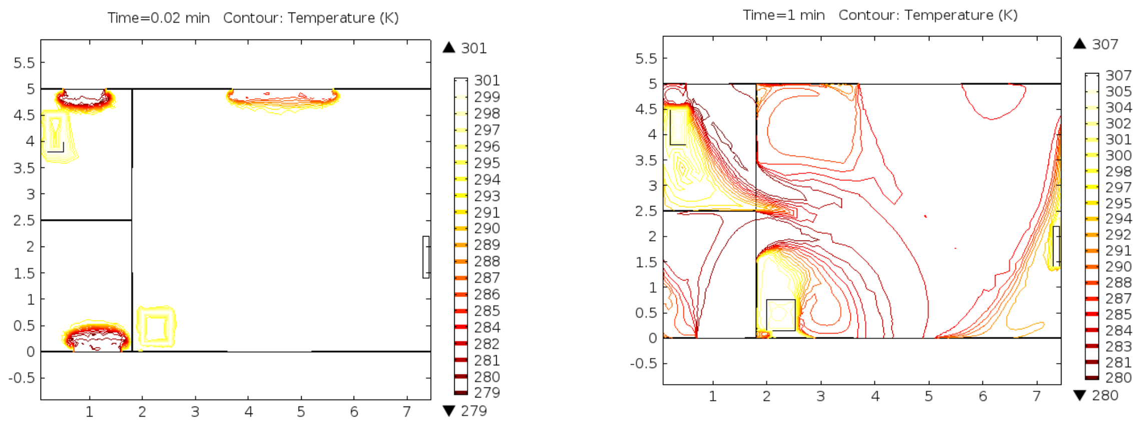



**FIGURE 4**. (a) Pressure distribution at time t=0 min, (b) Pressure distribution at time t=0.02 min, (c) Pressure distribution at time t=0.5 min and (d) Pressure distribution at time t=01 min.

**TABLE 1**

| Case | [17] (inlet wind)/(outlet wind) | Result (inlet wind)/(outlet wind) |
|---|---|---|
| $A_1$ | 3.53/3.85 | 3.53/4.01 |
| $A_2$ | 3.61/3.63 | 3.61/3.73 |




(a) (b)

**FIGURE 5**. (a) Isothermal Contour at time t=0.05 min and (b) Isothermal Contour at time t=01 min

## CONCLUSION

Ventilation system performance was investigated with respect to a studio apartment room and can continue with multiple scenarios was examined here. The results of the analyses provided the information about the internal air movement inside the studied studio apartment and sensible areas which are not reached by the outer air. This area may cause the form of problems regarding inhabitants comfort. Comfort and indoor air quality are dependent on many factors, including thermal regulation, control of internal and external sources of pollutants, supply of acceptable air, removal of unacceptable air, occupants' activities and preferences, and proper operation and maintenance of building systems. The lack of ventilation in some area inside the studio may create condition for a very unwanted phenomenon. Though the result of the study is satisfactory with respect to ASHRAE Standard [17], results obtained through this study could not explain all the conditions and possibilities due to not considering all the factors. At Dhaka in Bangladesh, the average air velocity and temperature are 1.12 m/s and 25 °C respectively [6-7]. Using this natural resources, depending on mechanical system can be reduced in Bangladesh.

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