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Numerical simulation of heat transfer in a desktop computer with heat-generating components[☆]

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Abstract

The heat transfer analysis of considering heat-generating components with different locations of two side-wall fans in a three-dimensional desktop computer was investigated in this paper. Herein, the well-known computational fluid dynamics (CFD) code of PHOENICS was employed to simulate the dissipative heat transfer in a ventilated enclosure. The SIMPLEST algorithm with the hybrid scheme was utilized to simulate these flows. The parameters are focused on the inlet Reynolds number and the locations of two fans on one of the side-wall boards. The calculating results show that the heat transfer efficiency of mode 4 is better than the other three modes due to the directly dissipative heat by forcing fans right on the vicinity of the high heat-generating components. The present findings not only set up a numerical heat transfer analysis of desktop computer but also provide a basis for further simulation of the associated heat transfer for more complicated situations.

Keywords: Desktop computer; Computational fluid dynamics; Heat transfer

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1. Introduction

The new wave of computer technology making a crucial impact on modern world and desktop computer is widely employed in state-of-the-art industry. Thus, the heat transfer problems with heat-

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generating components such as central processing unit (CPU), hard disk (HDD), and adaptive cards have been getting more and more significant since they are indispensable in our daily lives. The geometric configuration of the heat sources and the cooling fans must be selected so as to generate an air flow rate which minimizes the average and the maximum temperature rise inside the enclosure itself. In this paper, numerical heat transfer analysis is endeavored to the complex flow field with components in desktop computer. The associated heat transfer problem about PCB (Printed Circuit Board) in computer was solved numerically using FLOTHERM software package by Lee and Mahalingam [1]. In the same time, Linton and Agonafer [2] had performed an approximate temperature distribution of the PC heat transfer flow field with a single fan by utilizing PHOENICS. The finite volume technique together with staggered grid distribution and SIMPLEST algorithm was also employed. Moreover, Ronald and Dereje [3] investigated the effect of course and detailed CFD modeling of a finned heat sink on system. Furthermore, a numerical heat transfer simulation about PowerPC620 with processors was made using FLOTHERM by Wong and Lee [4]. Recently, Chang and Webb [5] using finite element technique analyzed and obtained the minimum air flow rate for a desktop computer by means of CFD modeling. Khan and Mahadevan [6] had shown that chassis with additional block can enhance the mixing of generating heat and cooling air by impinging effect. Moreover, Yu and Webb [7] carried out the CFD calculation by ICEPAK for a desktop computer system in order to realize the heat transfer effect with different locations of heat sources.

2. Physical model and governing equations

The basic numerical simulation mode 1 without side-wall fans is schematically shown in Fig. 1. The mode 2 is added two side-wall fans on one side board in addition to mode 1. The different locations of the two fans consist of the mode 2, mode 3, and mode 4 as illustrated in Fig. 2. The working fluid is air and flows through the enclosure with two fans on one side-wall board. The other walls are all adiabatic. A PCB was placed near the side opposite to the board with two fans. Three-dimensional steady turbulent flow with neglecting buoyancy effect is presented and the fluid

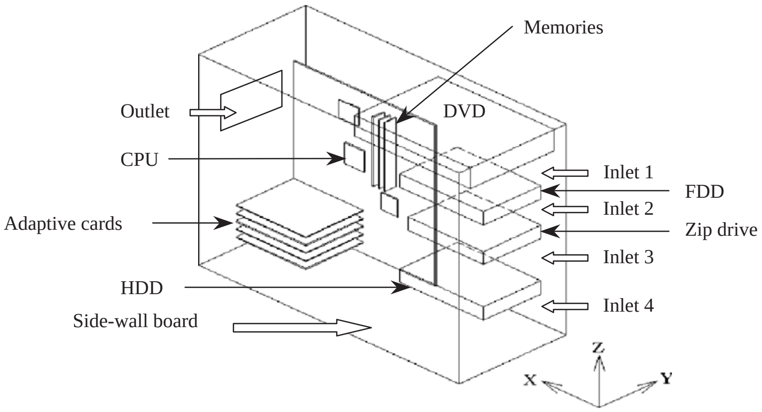
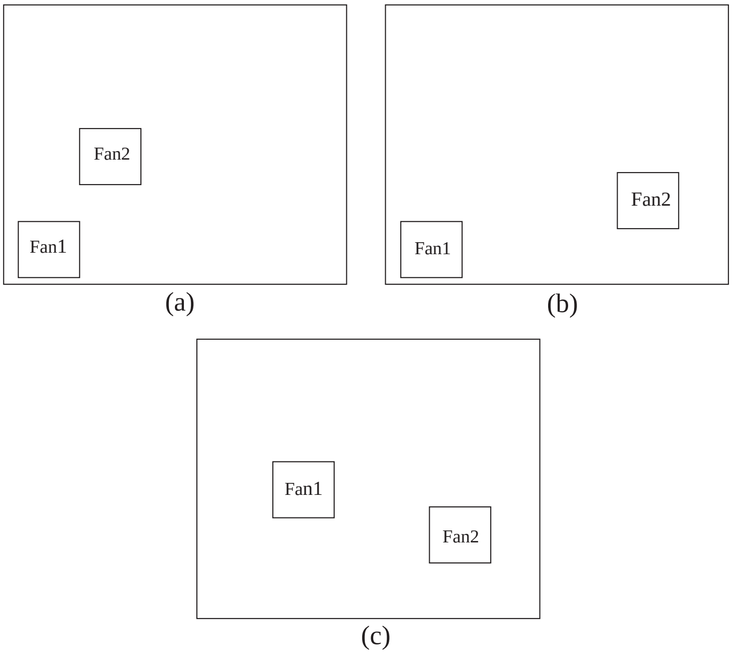


Fig. 1. Simulation case of mode 1 without side-wall fans.



(a) (b)

(c)

Fig. 2. Different locations of side-wall fans. (a) Side-wall board of mode 2 with fan 1 location in the vicinity of cards and fan 2 of CPU. (b) Side-wall board of mode 3 with fan 1 location in the vicinity of cards and fan 2 of HDD. (c) Side-wall board of mode 4 with fan 1 location in the vicinity of CPU and fan 2 of HDD.

is incompressible and all materials are isotropic. Herein, forced convection resulted in the heat transfer.

In this study, the well-known CFD program PHOENICS was employed to simulate the thermal behavior inside an enclosure. This program is base on structured mesh and a finite volume formulation to discretize the Navier-Stokes equations. The grid distributions are non-uniform and refines in the vicinity of high power components. The widely used two-equation κ–ε turbulent model adopting the eddy viscosity (μ_t) concept together with wall function [8,9] were employed to close the closure problem after long-time average of the Navier-Stoke equations. The special treatment of staggered grids technique was utilized in these numerical calculations in order to avoid absurd wave-like solutions of pressure and velocity fields. Thereby, continuity equation, three components of Navier-Stokes equations, energy equation, turbulent kinematic energy (κ) equation and turbulent energy dissipation rate (ε) equation are coupled and solved together. The hybrid scheme and SIMPLEST algorithm [10] which originates from the SIMPLE series developed by Spalding and Patankar [11,12] have also been carried out to get the final solutions. The main high power heat-generating components include CPU, HDD, and adaptive cards. A distinction is made for individual component inside desktop computer as follows:

CPU produces heat of 80 W
HDD produces heat of 20 W
DVD, FDD, Zip drive produce 10 W respectively
Memories produce total heat of 18 W

5 adaptive cards produce total heat of 50 W
2 chips produce heat of 10 W respectively

3. Results and discussions

The thermal behavior of a ventilated enclosure depends on the geometric configuration of the heat sources and the cooling fans. Forced convection by adding fans on side-wall board of desktop computer case can largely enhance heat transfer rather than free convection. In validating the present numerical simulation, a comparison between numerical data [7] and our calculating results was performed as indicated in Fig. 3. It shows in agreement with the numerical data in literature.

The Reynolds number and the different locations of two fans on side-wall board are the main parameters in our present investigation. In order to analyze the thermal behavior within desktop computer, and in particular, to obtain the character of fluid flowing several tests were performed varying systematically the above parameters. Subsequently, three different Reynolds numbers and four modes of different locations of two fans are implemented in this study. For the different Reynolds number conditions, the flow patterns are very similar to each other. Yet, with various modes, the flow structures are apparently different due to the varied locations of side-wall fans. Particularly, the velocity distribution of the flow field of mode 1 is more uniform than those of the other three modes because the mode 1 is the case without side-wall fans likewise the other three modes. Fig. 4 gives the velocity distribution of mode 4 for Re=24,000. The ambient cooling air enters the case through fans and inlet in front of the desktop computer and removes parts of the heat generated by components inside. The cooling air-stream of fan 2 is destroyed by directly impinging on more huge volume of HDD compared with CPU. Meanwhile, the flow structure in the vicinity of CPU becomes very complex and enhances the convection/mixing effect so as to reduce the generating heat. In this way, the large amount of heat generated by high power CPU is fluently taken away.

3.1. Temperature distribution

Fig. 5 illustrates the temperature contour of the flow field for the two fans on side-wall of mode 4. It is evident that the local high temperature area is located in the vicinity of heat-generating components, such as CPU, chips, memories, adaptive cards, etc. However, a component's temperature rise is dominated by its own power and the bypass air of convective effect. Therefore, the side-wall fans play a significant role for improving the convective capability, in particular, when fans are located in the neighborhood of

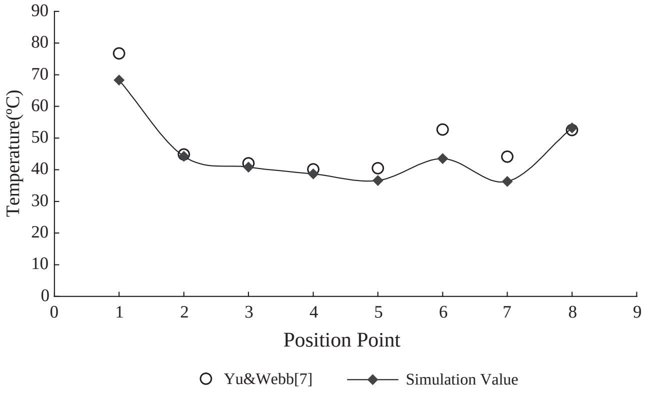


Fig. 3. Comparison of data between present calculation and Yu and Webb [7].

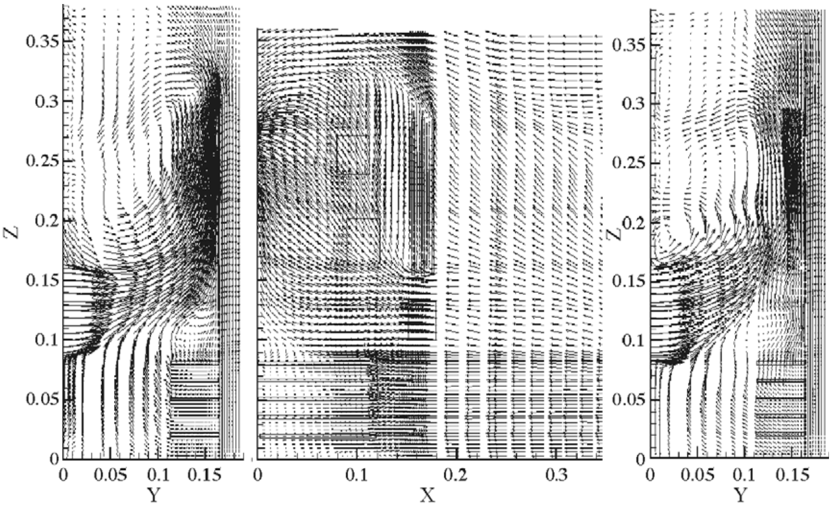


Fig. 4. Velocity distribution of mode 4 with *Re*=24,000.

high power components, such as CPU, HDD, adaptive cards. The heat removed by the bypassed air of fans is transferred to the external ambient by convection through the outlet. The temperature rise of high power components, however, is dominated by the deficiency of ventilated air. Therefore, in this situation, all components inside that rely on forced convection to dissipate heat. The calculating results

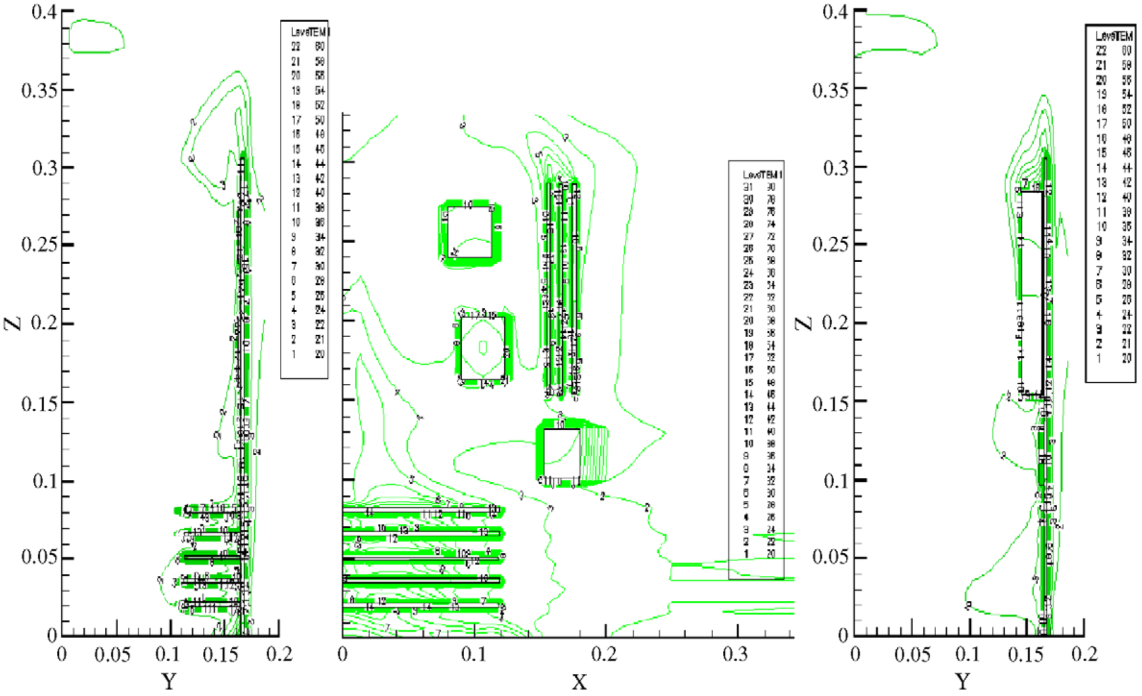


Fig. 5. Temperature distribution of mode 4 with *Re*=24,000.

show that adding cooling-fans in the neighborhood of high heat-generating components can apparently improve the heat transfer efficiency in the ventilated box. Obviously, these preliminary investigations provide a fundamental tool for the thermal design of casings containing electronic boards and high power components even though the flow pattern in a casing is very complex.

3.2. Heat transfer of heat-generating components

The Nusselt number is one of the most important parameter in convective heat transfer problems. Convection intensity is determined by the value of Nusselt number. The average Nusselt number of component is calculated in order to realize the heat transfer phenomenon around the heat source. As we know the heat transfer by convection is $q=hA\Delta T$, where h is convective coefficient, A is the contact area and ΔT is the difference of temperature. The heat exchange between fluid and solid boundary:

$$\frac{q}{A} = h(T_\mathrm{w} - T_\infty) = -k_\mathrm{f}\left(\frac{\partial T}{\partial y}\right)_{y=0} \tag{1}$$

where k_f is the conductance coefficient of fluid, T_∞ is the inlet temperature.

The definition of Nusselt number:

$$Nu = \frac{hL}{k_\mathrm{f}} = \frac{\left[\dfrac{\partial(T_\mathrm{w} - T)}{\partial y}\right]_{y=0} L}{(T_\mathrm{w} - T_\infty)} \tag{2}$$

The Nusselt number of mode 1 without side-wall fans is apparently lower than that with side-wall fans of mode 2, mode 3, and mode 4. Thereby, we can conclude that side-wall fans will efficiently promote the heat transfer in desktop computer. Moreover, the CPU is the most important and also max heat-generating component in the computer. In the vicinity of CPU (about Z=0.183 m), the convection heat transfer is less efficient than that on the other area in the enclosed PC case. Therefore, heat is somewhat difficult to convect to the surrounding fluid of air owing to the high heat-generating rate. Among the four testing cases in this paper, mode 4 with fan 1 and fan 2 on the top of CPU and HDD respectively always make the

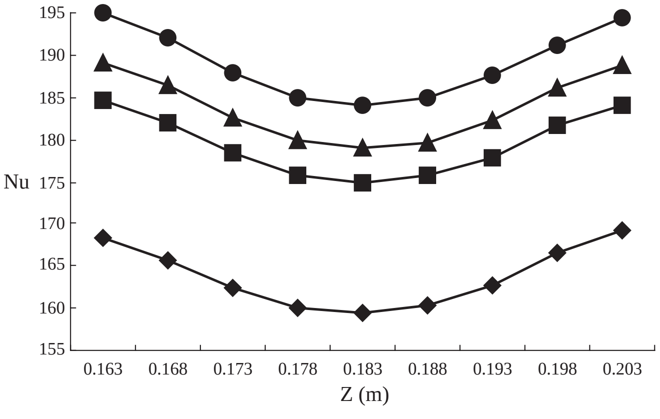


Fig. 6. The local Nusselt number of CPU in different modes with Re=24,000.

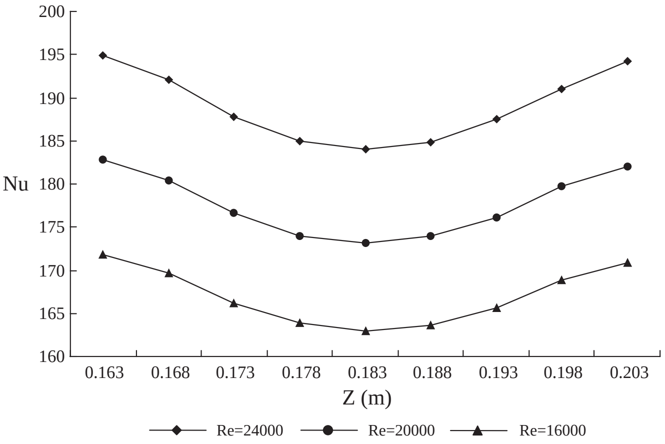


Fig. 7. The local Nusselt number of CPU in mode 4 with different *Re*.

best performance. The configuration of mode 4 causes the optimum cooling condition inside the casing (minimum high power component temperature rise). The heat transfer effect was improved obviously by forced convection by means of fans and led to higher Nusselt number as illustrated in Fig. 6. Meanwhile, higher Reynolds number based on inlet velocity will enhance the effect of heat transfer. The location of CPU is always the high heat spot area due to large amount of heat generation compared with other components. The calculating results show the trend and the effect of Reynolds number as shown in Fig. 7.

4. Conclusions

The geometric configuration of the heat sources and the cooling fans must be selected so as to generate an air flow rate which minimizes the average and the maximum temperature rise inside the enclosure itself. Therefore, numerical analysis and practical simulations for desktop computer with heat-generating components and fans were discussed in this paper. The locations of side-wall fans and Reynolds number play an important role in such complex heat transfer flow field. Among the four modes, the Nusselt number in the enclosure at Reynolds number 24,000 is always higher than those at Reynolds number 20,000 and 16,000. On the other hand, a manifestly improved performance of heat transfer can be obtained by setting the side-wall fans near the main heat-generating components.

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