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Study of Wyee-Tee Duck Design at Various Protrusion and Guide Vane Location Using CFD

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ABSTRACT

The design of the air ducting system in a HVAC system is crucial as it serve its main function of delivering desired air properties at optimum efficiency. However, air flow deficiency in the duct system can caused major issues in an HVAC system; building discomfort, high energy costs, increased noise levels, bad air quality, vibration, etc. One of the main factors in air flow efficiency is the fluid resistance which consist of; friction losses and dynamic losses. Numerous studies have been made to reduce effect of resistance especially at junctions and elbows of a duct system. The objective of this study is to investigate the characteristic of the wye tee duct with protrusion and guide vane installed using CFD method. A variance of the wye tee duct is introduced by installing protrusion and guide vane at various configuration. The flow characteristic is studied using CFD and the best efficiency of the configuration is observed. Simulation study shows that vane protrusion height H=0.05 m and guide vane position L=0.3 gave the best efficiency improvement at 22.29% at main duct section and 2.4% at the branch duct section. This study concludes that it is possible to further increase the wye-tee duct design efficiency with protrusion design and guide vane installation in the section.

Keywords:
Duct; HVAC; CFD

1. Introduction

Heating, ventilation and air conditioning system are one of the most important system in the construction of buildings. Energy is one of the main concerns in HVAC system due to sustainability issues, thus efforts have been made to reduce energy consumption in buildings without sacrificing the air quality and thermal comfort [1-2]. According to Wang and Lavan [3], HVAC system functions includes; heating and cooling, air quality control (dehumidifying and humidifying, purifying and cleaning) and air ventilation. Indoor air quality such as humidity can cause bad consequences to occupant health such as dry skins and irritating nasal passages [4]. All these functions are realized thru the air handling unit, the duct system and the air diffuser outlet. The duct system is used in transferring and distributing the air to the various rooms inside a building. Friction and turbulence are an important factor affecting air flow rate in the duct system. In the case of solar chimney for ventilation and cooling application, a bad duct design can affect the air flow significantly [5]. With the emergence of earth air pipe system for cooling, the system relies on efficient design of ducts to allow

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natural air flow to occur based on temperature difference [6]. Thus, it is very important to address these factors and mitigate its negative effects to increase air flow efficiency and ultimately reducing operational cost [7].

2. Factors Affecting Duct System Efficiency

By decreasing the fluid resistance in the ducting system in the aspect dynamic losses, previous researchers design innovative ideas to optimize the geometric structure of the duct. Gao *et al.,* [8] proposed a resistance reduction method using a protrusion structure from the perspective of biomimetic structure. The protrusion structure is applied to a tee; the shape of the protrusion is an arc at the tee junction, then centre of the circle is on the centreline of the duct tee, and the width of the arc surface is 4D. Study on the relationship between traditional tee and tee with protrusion in the aspect of resistance coefficient have been done. Relative to the performance of traditional tee, the resistance of the tee with protrusion was reduced by 36% in main flow direction and 21% in the branch flow.

Before Gao *et al.,* [9], studies on guide vane inside the duct have been on going with the purpose of reducing drag effect. As early as 1966, investigation on the effect of different guide vane on the resistance of the elbow duct segment has been done by Ito and Imai [10]. His study shows that an optimized guide vane position is not necessarily in the centre of the duct. Haskew and Sharif [11] studied the resistance reduction effect of a guide vane on an 80° elbow of a circular duct, it shows that wrong positioning of the guide-vane could substantially increases fluid resistance. However, the method of positioning the guide vane in the elbow is different with the guide vane in the tee and yet study on the subject is scarce. Computational fluid dynamics (CFD) method is a great tool to study large HVAC system to reduce cost as well as time [12]. The method has been widely used in HVAC related investigation which have been showed reliable and able to study the flow dynamics in a much more detail as demonstrated by some investigators [2, 13]. Thus, a number of simulation work was done by Gao *et al.,* [8] to corelate the reasonable position of the tee guide vane, arc shape optimization of the tee with the guide vane, effects of the flow ratio and the aspect ratio on the resistance reduction rate and analyses of the tee resistance characteristic under different flow velocities and aspect ratios of the duct.

These past studies have showed the advantage of installing guide vanes at sections of the duct system. Coupled with findings made by Gao *et al.,* [14] on biomimetic tee design, it is interesting to study the effect of the guide vanes on the improved tee design in terms of its flow behaviour and drag coefficient improvement.

3. Model Description

3.1 Design of Wyee-Tee Duct

In this study, a wye-tee duct model is configured to transfer air with the inlet volume flow rate at 0.5 m^3/s, and both the branch as well as main outlet volume flow rate of 0.25 m^3/s. The ratio of air flow rate between outlet duct and inlet duct is half. The area for the inlet and outlet is same both for branch and main section. The radius of the duct turning part is also same with the width of the duct. Figure 1 shows the design and important dimension of the wyee-tee junction used in this study.

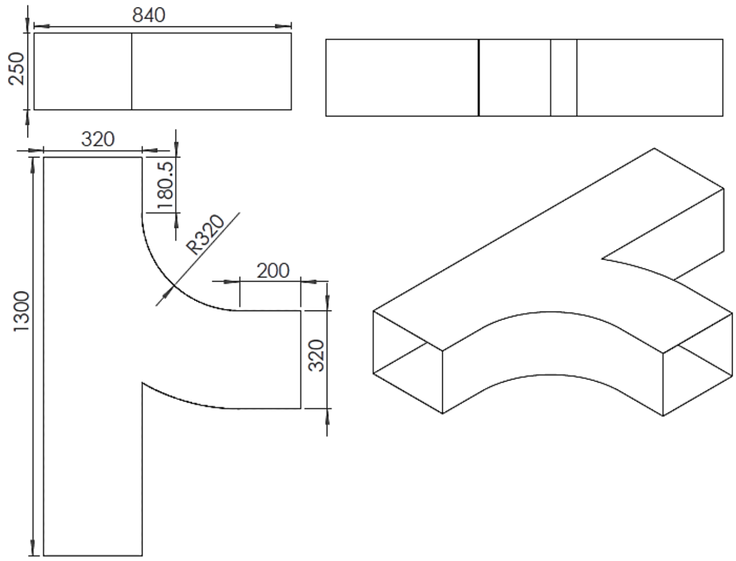


Fig. 1. Wyee-tee duct

Based on ASHRAE [4], the theoretical resistance coefficient for the branch outlet duct is set at 1.28 and the theoretical resistance coefficient for the main outlet duct is 0.24. A variance of the wyee-tee duct with protrusion design and guide vane position were designed as shown in Figure 2 and Figure 3. A number of design variance with different protrusion height at the top of the wyee-tee duct were first simulated to investigate its effect on resistance coefficient calculated using Eq. (1) [4]. The height of the protrusion is represented in term of ratios; radius of protrusion divides the height of wye tee duct as shown in Eq. (2). The ratio identified are; h=0.025, h=0.05, h=0.075, h=0.1, h=0.111, h=0.125. Then, the best protrusion ratio identified is installed with a guide vane at multiple position to identify the best position for the vane. The position of guide vane is also determined in term of ratio using Eq. (3) and the value identified are; L=0.1, L=0.2, L=0.3, L=0.4, L=0.5, L=0.6 and L=0.7.

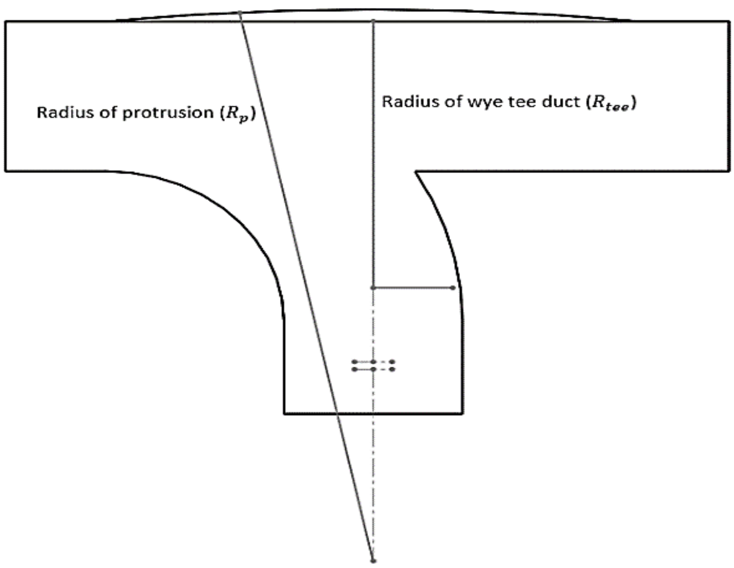


Fig. 2. Protrusion design showing protrusion ratio, H_p

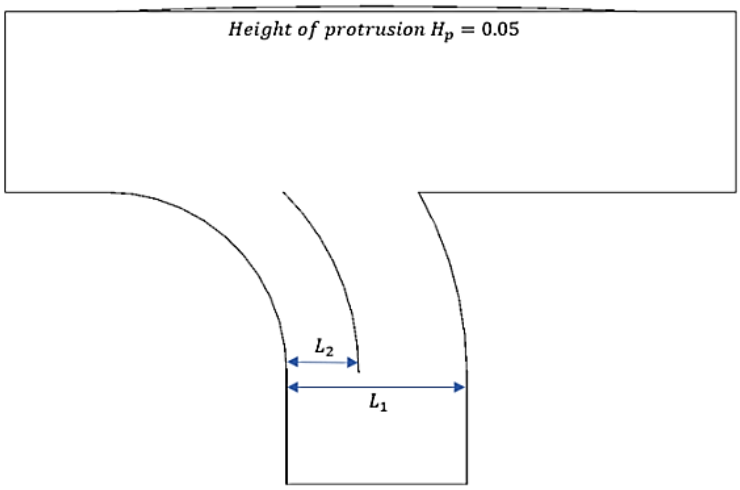


Fig. 3. Guide vane location, *L*

$$P_t = P_v + P_s + P_l \quad (1)$$

$$H_p = \frac{R_{tee}}{R_p} \quad (2)$$

$$L = \frac{L_2}{L_1} \quad (3)$$

3.2 Governing Equation

The simulation work was done using SolidWorks flow simulation. SolidWorks Flow Simulation is a heat transfer and fluid flow analysis software fully integrated into SolidWorks. The software simulates the wye tee duct model based on the time-dependent Reynolds-averaged 3D Navier-Stokes equation using the k-e turbulence model. A flow simulation consists of partial derivative equation (PDE) which is used to calculate the fluid flow behaviour. The general equation of the PDE is written in Eq. (4) for reference:

$$A\frac{\partial^2 y}{\partial x^2} + B\frac{\partial^2 y}{\partial x^2} + B\frac{\partial^2 y}{\partial x^2} + C\frac{\partial^2 y}{\partial x^2} + D\frac{\partial^2 y}{\partial x^2} + E\frac{\partial^2 y}{\partial x^2} + E\emptyset + G = 0 \quad (4)$$

The PED equation is actually sum up of three types of conservation which is conservation of mass, conservation of angular momentum, conservation of energy.

Conservation of mass

$$\frac{\partial p}{\partial t} + \frac{\partial}{\partial t_j}(pu_i) = 0 \quad (5)$$

Conservation of angular momentum

$$\frac{\partial(pu_i)}{\partial t} + \frac{\partial}{\partial t_j}\left(pu_i u_j\right) + \frac{\partial p}{\partial x_i} = \frac{\partial}{\partial x_j}\left(\tau_{ij}\tau_{ij}{}^R\right) + S_i \;\; i = 1,2,3 \quad (6)$$

Conservation of energy

$$\frac{\partial pH}{\partial t} + \frac{\partial pu_i H}{\partial x_i} = \frac{\partial}{\partial x_i}\left(u_j\left(\tau_{ij}\tau_{ij}{}^{R}\right)q_i\right) + \frac{\partial p}{\partial t} - \tau_{ij}{}^{R}\frac{\partial u_i}{\partial x_j} + p\epsilon + S_i u_i + Q_H \quad (7)$$

3.3 Grid Independence Test

Grid independence test was done to find out the optimum mesh density to be used in the computational work. There are five levels of mesh density used as shown as shown in Table 1.

Table 1
Mesh Density

	Level 1	Level 2	Level 3	Level 4	Level 5
Total Cell	3104	23030	142844	172514	176384
Fluid Cell	3104	23030	142844	172514	176384
Solid Cell	2320	12118	64182	64102	66132
Partial Cell	1796	7830	31434	31274	33044

The simulation was run, and results were expressed in resistant coefficient as shown in Figure 4 and Figure 5. It shows that grid independence was achieved at level 4. Thus, subsequent simulation works were done using level 4 mesh density.

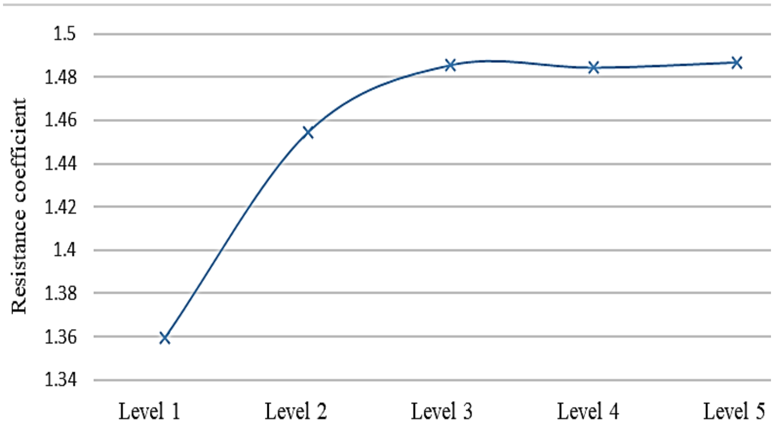


Fig. 4. Mesh density vs Resistance coefficient, C_b

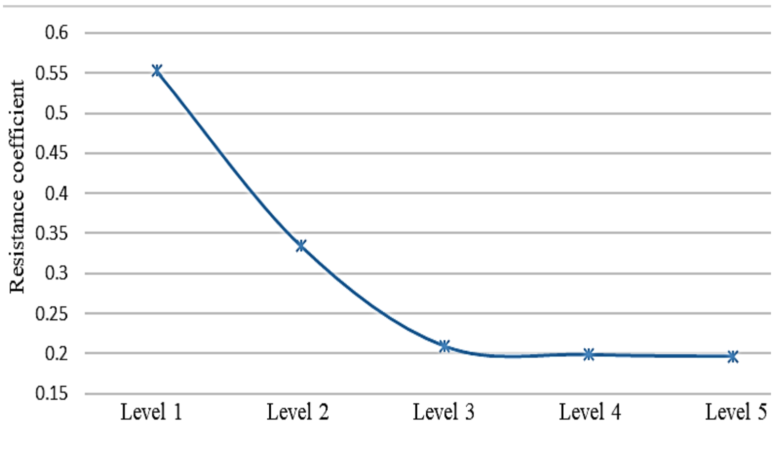
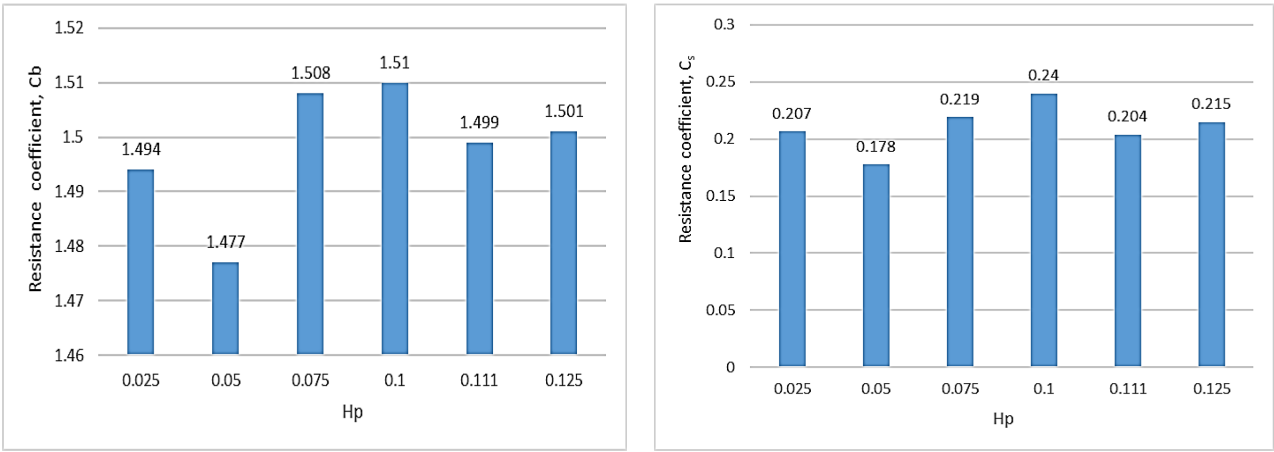


Fig. 5. Mesh density vs Resistance coefficient, C_s

4. Result and Discussion

4.1 Effect of Protrusion Ratio on Resistance Coefficient

Simulation work on multiple protrusion ratio were done and the corresponding resistance coefficient were calculated both at the main and section branch as shown in Figure 6. The best protrusion ratio is, H_p = 0.05 while the worst protrusion height is 0.1. The original duct simulation calculated the resistance coefficient in the main section as 0.19663 while the best protrusion duct with protrusion height 0.05, yield 0.178. These results show an increase of efficiency by 9.47 %. Meanwhile, the resistance coefficient in the branch section is 1.48692 for the original duct while the 0.05 protrusion duct resistance coefficient is calculated at 1.477. The efficiency of the air flow rate was increased by 0.67 %.



(a) (b)

Fig. 6. Height of protrusion, Hp vs Resistance coefficient, (a) Cb and (b) Cs

The air flow velocity at the top part of the duct will decreases when the air flow passes through the tee section, which means air velocity was dissipated. For the standard wye tee duct (as shown in Figure 7), there is an air velocity lost observe which is represented by the yellow colour gradient. A wyee-tee duct with protrusion (as shown in Figure 8) however shows better flow with lesser air velocity dissipation along the upper wall. The maximum velocity for the original wye tee duct is 6.928 m/s and minimum velocity is 0.378 m/s. Whereas, the maximum velocity for the protrusion tee duct is 6.970 m/s and minimum velocity is 0.470m/s. These result shows that both maximum and minimum velocity were increased in protrusion wyee-tee duct thank to the protrusion design.

With the best protrusion ratio identified at H_p = 0.05, the following simulation were done by positioning the guide vane at different location in the branch. Simulated resistance coefficient (as presented in Figure 9) shows that the best guide vane position for the branch section is 0.1 with resistance coefficient 1.4314 but the friction coefficient in the main section is relatively high at 0.1883. Looking at alternative guide vane position, guide vane position L = 0.3 gave the best friction reduction as both the branch and main friction were relatively low value. The guide vane position L = 0.3 have the lowest resistance coefficient for the main section which is 0.1528 and the third lowest resistance coefficient for the branch duct section which is 1.4512. For the main section, the efficiency of the air flow rate was increased by 22.29 % compared with the original wye tee duct. Whereas in the branch section, the optimize guide vane position compared to a standard wye tee duct decrease the resistance coefficient from 1.48692 to 1.4512 which translate to increase of air flow efficiency by 2.40 %.

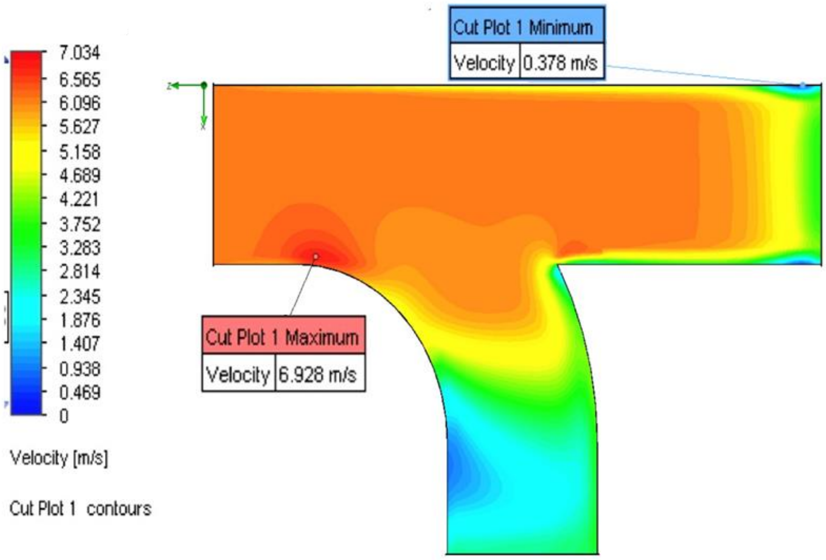


Fig. 7. Air velocity variance in standard wyee-tee duct

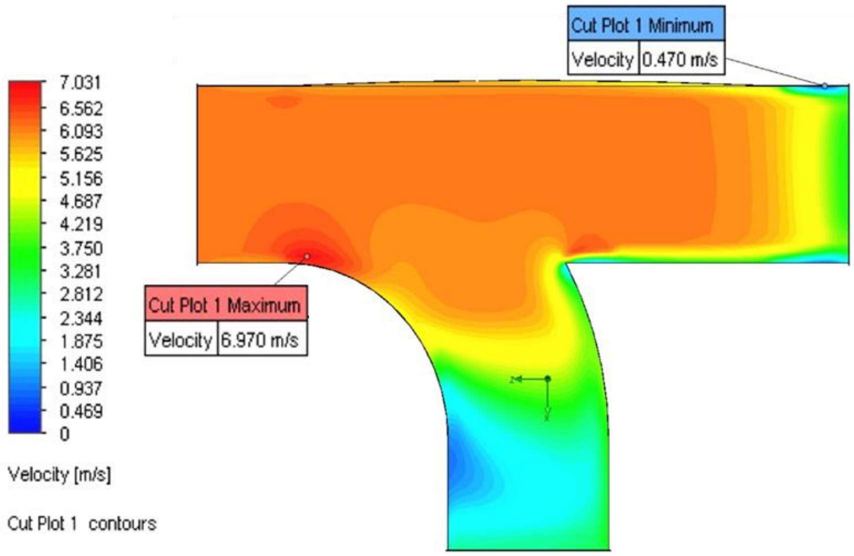
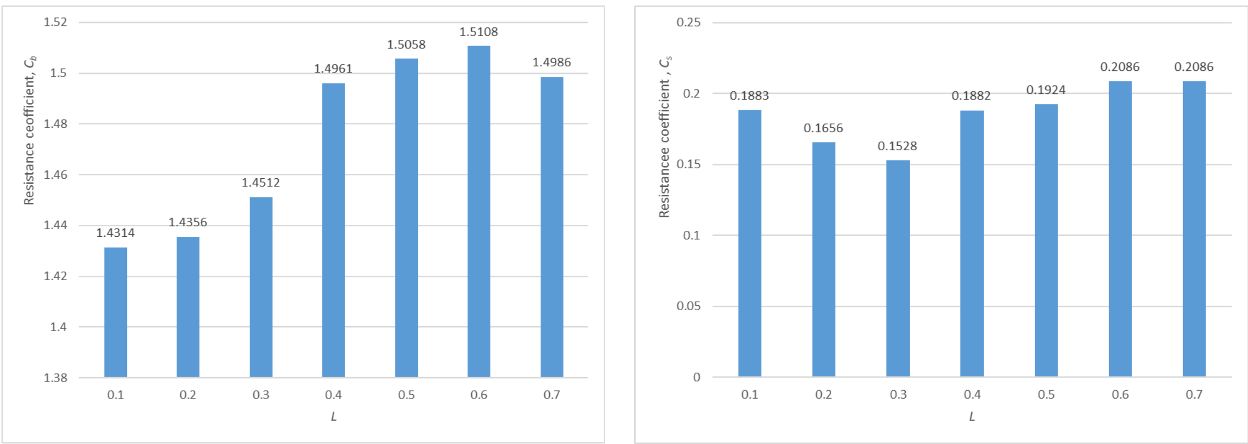


Fig. 8. Air velocity variance in wyee-tee duct with protrusion design



(a) (b)

Fig. 9. Guide vane position, L vs resistance coefficient; (a) C_b and (b) C_s

Comparing the air velocity gradient between the standard wyee tee duct and the protrusion with guide vane duct shows better air flow and lesser air velocity dissipation as shown in Figure 10 and Figure 11. The insertion of guide vane on a wyee tee section divides large vortex into smaller one and function as a guiding mechanism [15]. Similar finding was also reported by Gao *et al.,* [14], the energy dissipation in a wyee tee junction installed with a guide vane shows significant reduction in energy dissipation at the outer wall compared to a standard design. The guide vane also improves the air flow homogeneity at the outlet of the branch duct reducing the effect of excessive friction at the duct wall and reducing the overall friction coefficient.

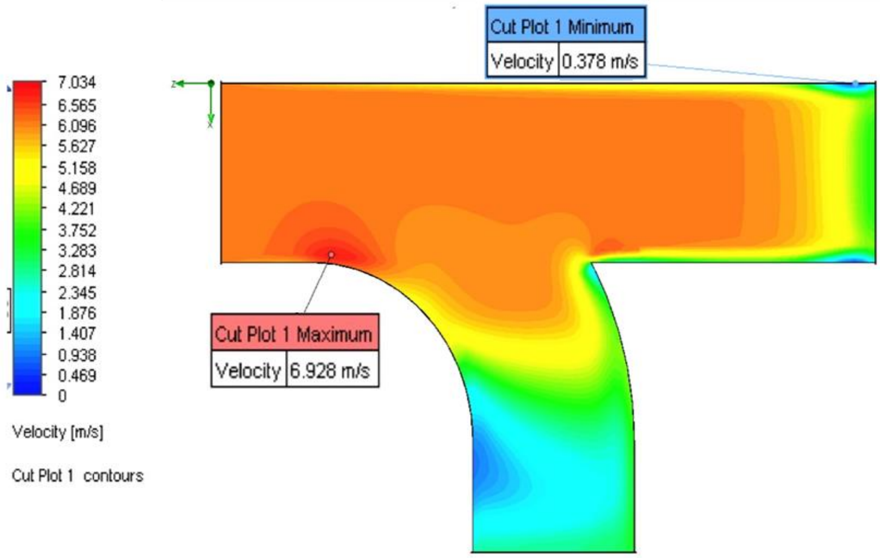


Fig. 10. Air velocity variance in traditional wyee-tee duct

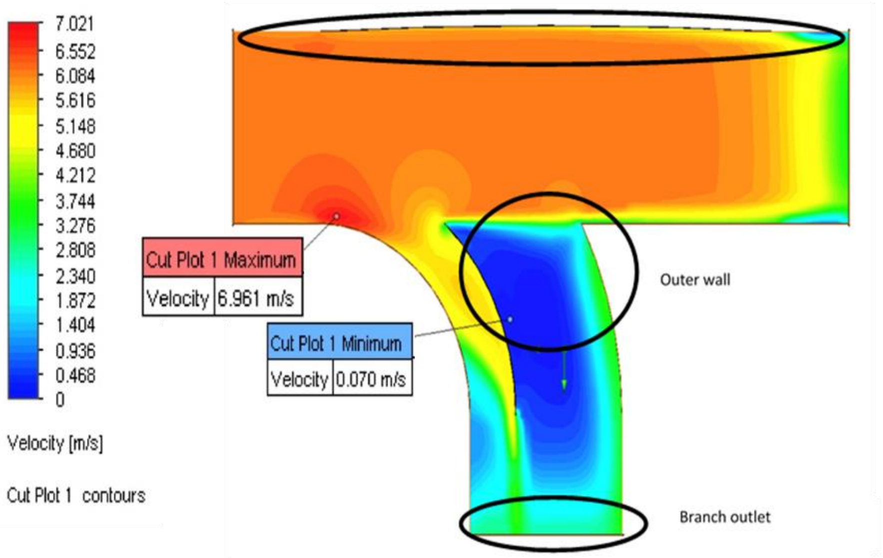


Fig. 11. Air velocity variance in wyee-tee duct with protrusion and guide vane at optimum location

5. Conclusions

As a conclusion, this study has shown through simulation work that the resistance coefficient in a wyee-tee duct design can be improved by adding a protrusion design coupled with a guide vane position at the branch section of the duct. Simulation work at different duct position reveals that at a constant designated flow rate, there exist and optimum location that reduces resistance coefficients. In the current work, it is found that positioning the guide vane at L = 0.3 yields an increase of 22.9 % at the main duct and 2.4 % in the branch duct compared to a traditional wyee-tee duct design.

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