COMPUTATIONAL STUDY OF AIR VENTILATION IN HIGH TENSION ELECTRICAL CABLE TUNNEL

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FACULTY OF ENGINEERING
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KUALA LUMPUR

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RESEARCH REPORT SUBMITTED IN FULFILMENT OF THE REQUIREMENTS FOR THE MASTERS DEGREE OF MECHANICAL ENGINEERING

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Name of Degree: Master Mechanical Engineering

COMPUTATIONAL STUDY OF AIR VENTILATION IN HIGH TENSION ELECTRICAL CABLE TUNNEL

Field of Study: Mechanical Engineering – Computational Fluid Dynamics

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COMPUTATIONAL STUDY OF AIR VENTILATION IN HIGH TENSION ELECTRICAL CABLE TUNNEL

ABSTRACT

The chive concern in this project is the study and develop a ventilation system for a High Tension Electrical Cable Tunnel. This is because the cables in the tunnels generates heat up to about 60^0C. These cables are laid in a trefoil configuration with 6 circuits running in an 80-metre-long with 3 metre diameter tunnel. To analyse the effects of air velocity and air flow on the surrounding of the interior of the tunnel a model of the tunnel was created using Solid works, CAD software. The parameters of the analysis were the Velocity and air flow which was determined from Air Change Per-Hour ("AC/Hr"). Using the assumption of Air Change Per-Hour with the volume of the tunnel designed, the velocities and air flow in tunnel were determined. the velocities obtained were used in the ANSYS Computational Fluid Dynamics software to determine the temperature at the mid of the tunnel at various ambient temperature and velocities to determine the best velocity and air flow for the tunnel ventilation system. The main emphasis was given for the ambient temperature of 33^0C which the average temperature of the area is where the tunnel is proposed to be built. All the results are presented in the Conclusion and Recommendation in this report.

ANALISIS PENYALURAN UDARA BAGI TEROWONG KABEL BAWAH TANAH MENGUNAKAN PENGIRAAN DINAMIK BENDALIR

ABSTRAK

Keprihatinan chive dalam projek ini ialah mengkaji dan membangunkan sistem pengudaraan untuk Terowong Tegangan Elektrik Tinggi. Ini kerana kabel di dalam terowong menghasilkan haba hingga kira-kira 60^0C. Kabel-kabel ini diletakkan dalam konfigurasi trefoil dengan 6 litar yang berjalan di dalam terowong bersaiz 80 meter panjang dengan 3 meter diameter. Untuk menganalisis kesan halaju udara dan aliran udara di sekeliling pedalaman terowong, sebuah model terowong dibuat dengan menggunakan perisian “Solidworks”. Parameter analisis adalah aliran Velocity dan udara yang ditentukan dari Air Change Per-Hour. Menggunakan asumsi Air Change Per-Hour dengan volum terowong yang direka, halaju dan aliran udara dalam terowong ditentukan. halaju yang diperoleh digunakan dalam perisian “ANSYS Computational Fluid Dynamics” untuk menentukan suhu pada pertengahan terowong pada pelbagai suhu dan halaju ambien untuk menentukan halaju dan aliran udara yang terbaik untuk sistem pengudaraan terowong. Penekanan utama diberikan untuk suhu sekitar 33^0C di mana terowong dicadangkan untuk dibina. Semua keputusan dibentangkan dalam Kesimpulan dan Cadangan dalam laporan ini.

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I would like to say thanks to ***University of Malaya*** for giving an opportunity to do a research which can improvise my technical career in future.

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LIST OF SYMBOLS AND ABBREVIATIONS

XLPE : Cross-Linked Polyethylene Cable

CAD : Computer Aided Design

CAD : Computational Fluid Dynamics

HV : High Voltage

UHV : Ultra High Voltage

Q : Flow Rate

Vi : Inlet Velocity

Vol : Volume

k V : Kilo Volt

AC/Hr : Air Change Per-Hour

$\Delta\theta_s$: Difference in surface Temperature

K_A : Thermal Conductivity

CFM : Cubic Feet Per-Minute

Ft^3 : Cubic Feet

A : Cross Section Area of Tunnel

De : Diameter of Cable

n : no of conductor within cable

λ_1 : Ratio of Losses in Metallic Sheet

λ_2 : Ratio of Losses in Armor to Conductor

T_1 : Thermal Resistance Between Conductor and Sheet

T_2 : Thermal Resistance Between Metallic Sheet and

T_3 : Thermal Resistance of outer covering

h : Heat Dissipation Coefficient

d_a : Metallic Sheet Outer Diameter

W_d : Dielectric Losses

U_o : Voltage from Phase to Ground

C : Capacitance

Di : Conductor Outer

ε : Insulation Emissivity

CHAPTER 1: INTRODUCTION

1.1 Introduction

Globally, cities are very active in the process to upgrade their living standard and technology capabilities. Disregard, developed or developing countries, the demand for utilities such as power, tele/network communication, water, steam and sewerage is persistently increasing and requiring upgradation. This necessity has led to increasing number of utility tunnels in the subsurface environment mainly at urban cities. These tunnels are commonly found in template climate countries especially in very cold countries where burial under frost ground is not feasible. Nowadays, these tunnels are becoming preference and favorite for majority service providers in tropical climate countries in-order to avoid disruption caused by repeating construction, repair and upgrading of cables and pipes in direct burial where it will impact on the quality of utility line and cost. Moreover, this method is also undoubtedly a best way for maintenance and for future upgradation.

In building these tunnels, one of the most important factor to be taken into consideration prior to construction will be ventilation system. This will be the challenge for the design engineers especially when the tunnel transmits High Tension cables and auxiliary equipment which required to be maintained at certain temperature. The ventilation or cooling system must be designed by considering both peak energy demand and ambient temperature. The system also must be able to achieve suitable airflow by either natural or forced ventilation to eliminate heat emission by the power cables. Not neglecting the human factor, the air flow design must be in way to allow permanent human presence in the tunnel or for maintenance purpose only depending on the purpose/requirement.

Figure 1.1: Sample of utility tunnel, **(**http: www.xinhuanet.com)

1.2 Problem Statement

Without a proper ventilation system, the cables maybe prone to malfunction due to heat. It is due the XLPE cable insulation loses its dielectric capacity for higher temperatures. Higher conductor temperature worsens dielectric insulation quality of high voltage cables which generally operates at nominal current while higher surrounding temperature and dielectric losses will lead to electrical breakdown and early ageing of the cable. Thus, it is necessary for an optimum airflow in the tunnel in-order to ensure the cables are not affected by temperature in the tunnel and for safe human movement in the tunnel for monitoring, maintenance and upgradation. This research project is a computational fluid dynamics (CFD) study and analysis on requirement by company ‘X’ to route an 18 number of 1 core (trefoil) XLPE 132 KV 1200mmSq Cu in the ventilated cable tunnel for a new development project with steady state heat transfer condition. The total length 80-meter (m) tunnel with circular and rectangular man-holes will be constructed and simulated in CFD analysis for steady state condition. Different air flow configuration will be simulated to investigate the best temperature condition during full load.

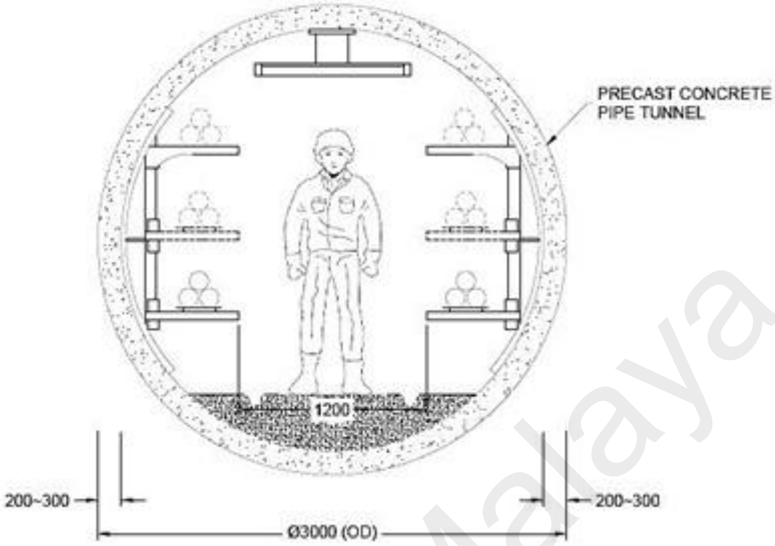


Figure 1.2: Underground Cable tunnel with 6 x 3c x 1200mmsq XLPE 132 KV Cable

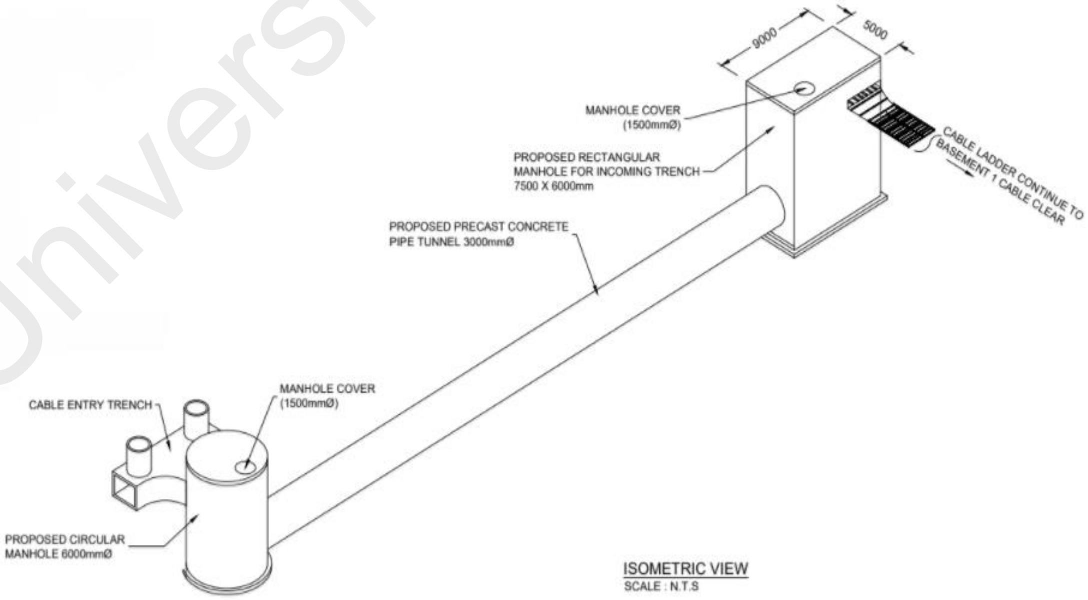


Figure1.3: Underground Cable Tunnel Model

1.3 Objective

To design, simulate and analyze underground cable tunnel with considering ambient temperature, air change per hour (ACPH), and volume to determine an efficient airflow to maintain the temperature in tunnel at safe operational level to facilitate competent person to monitor and conduct maintenance.

i. To design cable tunnel to accommodate cables with desired dimension
ii. To simulate in ANSYS computational fluid dynamics with various air flow
iii. To analyze the steady state condition of simulation results
iv. To calculate suitable air flow
v. To discuss and recommend suitable air flow for underground cable tunnel

1.4 Scopes

The scope of this research project to design an underground cable tunnel with desired parameters, then configure three ambient temperature base on meteorological data from relevant authority with four inlet velocity to determine best air flow to remove the heat emitted from cable.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The aim of tunnel air ventilation system is to ensure safety levels are at maximum during fire and service situation. In service situation the system must guarantee that the tunnel is at suitable condition of comfort and safe for the users. To ensure safe and comfortable ventilation, the system must be designed appropriately prior to the construction, so that structural precaution can be taken more easily which will lead well defined operation and maintenance methodologies.

The purpose of this study is to conduct numerical simulation study to determine required air flow in a High-Tension cable tunnel during full load to allow human presence. Different air flow configurations were simulated to investigate best temperature condition in the tunnel during full load.

The studies for this research is majorly done using '*Computational Fluid Dynamics*'(CFD) simulation software to analyze cable tunnel ventilation which has very minimal previous studies or research reports.

2.2 Ventilation Systems

There five types of tunnel ventilation system or combination of any of these 5

1. Natural ventilation
2. Longitudinal Ventilation
3. Semi-Transverse Ventilation
4. Full Transverse Ventilation
5. Single Point Extraction

2.2.1 Natural Ventilation

Natural ventilation depends on natural circumstances which ventilates tunnel with piston effect. The air in tunnel will never be idle or still, as there will be continuous air flow due to piston effect, wind and natural factors. Natural ventilated tunnels are mostly dependent on atmospheric condition to retain airflow and accommodate satisfactory environment. The lead factors which affects the environment are change in pressure due to differences in elevation, ambient air temperature and wind effects at the boundary of the tunnel or facility. (Igor Maevski, 2017)

There are also external factors which contributes to differences in portal pressure which are, portal entrance and exit pressure losses, Stack (chimney) effect where air will flow from lower portal to higher portal or other way around, due to differences between inside, outside and chimney’s air particles weight and wind effects at the portal. These effects will combine and creates a net external force to act on the tunnel air volume. (Igor Maevski, 2017)

The ventilation system concepts for underground tunnel, design criteria and technical issues, emphasizing their corresponding importance for safe and comfortable operation. (Igor Maevski, 2017)

2.2.2 Longitudinal Ventilation

The longitudinal ventilation in its plainest form which consists of the fresh air introduced into the inlet port and into the exhaust vent expelled from the outlet port. This is shown in Figure 3. Pollution levels rise across the tunnel as it is the direction of airflow and vehicles continue to produce emissions as they move from one side to the other. In fact, tunnels in the urban areas of Australia are usually classified at the beginning of the tunnel and then uphill to the exit, as they generally cross a relatively flat terrain. The relatively high engine load on the uphill road tends to produce higher exhaust gases near the end of the tunnel. The design of a longitudinal ventilation system depends on the limitation of pollution allowed in the tunnel. It is controlled by ensuring that the amount of fresh air entering the tunnel on the inlet portal dilutes the pollutants sufficiently. This amount of air can be induced by vehicles and is sometimes called the "piston effect". For longer tunnels, airflow can be integrated by fans if the traffic speed is insufficient to generate sufficient flow of the portal to keep the polluting values below the permitted limit (Roads and Maritime Services, 2014)

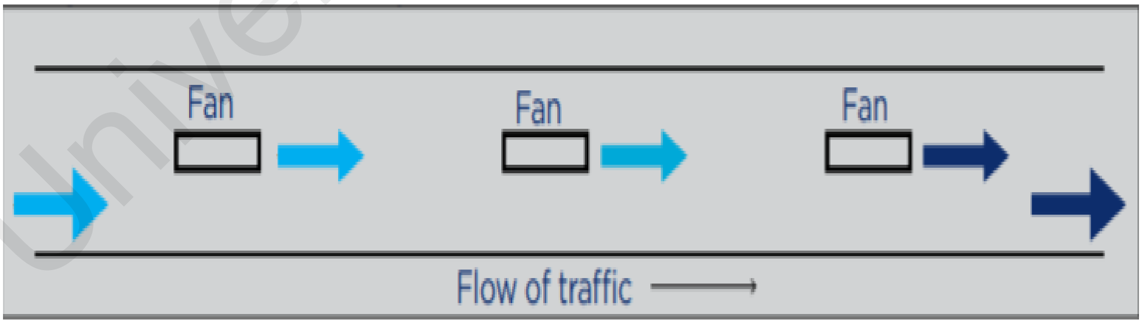


Figure 2.1: Longitudinal Ventilation System (Roads and Maritime Services, 2014)

2.2.3 Semi Transverse Ventilation

Semi-transverse ventilation uses mechanical fans for air movement. The system designed to have its own plenum or ductwork either above or below tunnel in-order to allow uniform distribution of air along the tunnel. This operation is either can be either for intake or to exhaust air from tunnel. The ducts or plenum is located either above ceiling or hanged/suspended below tunnel roof/structural slab. The figure 2.2 shows the sample of supply and exhaust system of semi transverse Ventilation. The design of this system is subject to the requirement and environment as in some tunnels, it is installed where the intake would be for half of the tunnel and exhaust will be for the other half of the tunnel. In another situation the intake fans will be mounted at the end both side of the while exhaust fans would have installed above ceiling where air will be extracted by ducts or plenum. (Aberham Berhanu ,2016)

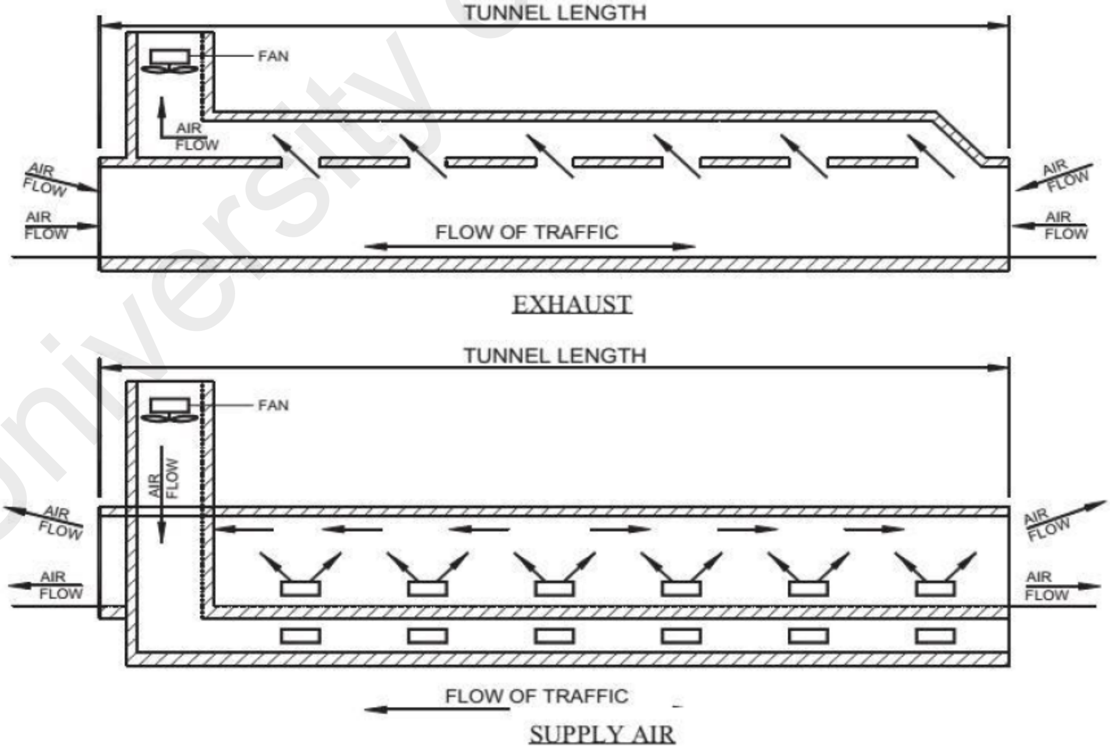


Figure 2.2: Semi Transverse Ventilation (Aberham Berhanu ,2016)

2.2.4 Full Transverse Ventilation

Full transverse ventilation portrays the same characteristics as semi transverse ventilation. The difference between both will be, semi transverse ventilation used for short tunnel while full transverse ventilation is highly recommended for long (in distance) tunnels. This is due to the longer tunnel will produce higher contaminants. Having supply and exhaust ducts will allow pressure difference between the road way and the ceiling. Therefore, the air circulation in the tunnel will be more frequent. (Aberham Berhanu ,2016)

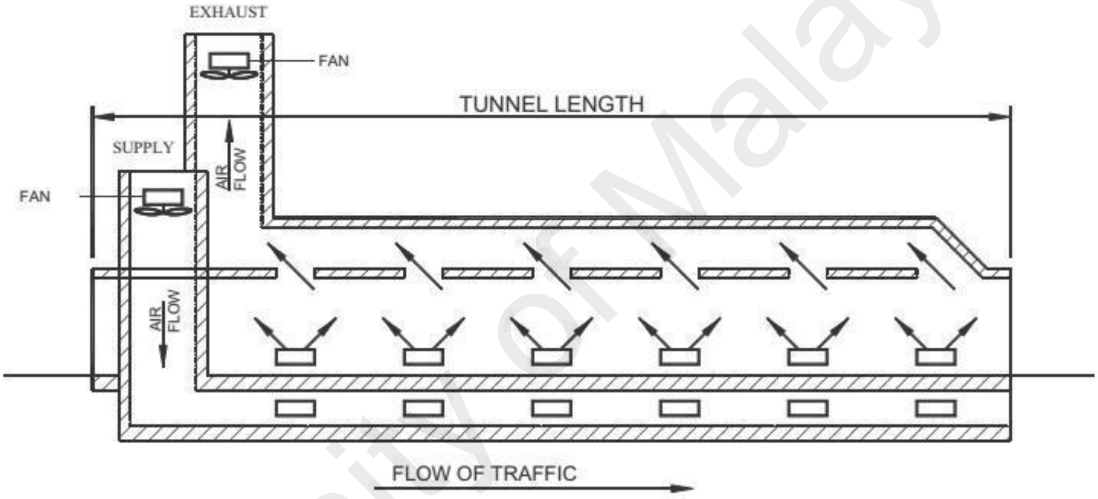


Figure 2.3: Fully Transverse Ventilation (Aberham Berhanu ,2016)

2.2.5 Single Point Extraction

With a semi and full transverse ventilation system, there can be a single point suction used to increase the airflow in case of a fire in the tunnel. The system works by increasing the size of the opening to allow the smoke to be extracted out during emergency. This can be done by mechanically opening louvers or by a part of the ceiling Material that changes from solid to gaseous during a fire and offers a larger opening. These methods are quite expensive and are therefore seldom used. Newer tunnels achieve the same result. Simply by a larger suction opening in a certain interval, which is connected to the fan through the pipeline. (Highway and rail transit tunnel inspection Manual, 2005 Edition)

2.3 Previous Study

After doing some research on previous studies, it is found that underground cable tunnel system implementation is an upcoming practice in urban area. The followings will be brief studies on underground cable tunnel especially regarding ventilation system.

In an extension project to connect 400KV network with three 400KV substation, Dubai Electricity and Water Authority have preferred underground cable tunnel to avoid limitation on the ground and visual sight of the cables. This tunnel is connecting through two tunnels of 4Km and 11.5 Km. The ultimate challenge they faced was to design the tunnel's cooling system which transmit 2 x 1500 MVA through 2 circuits where outside ambient temperature may reach up to 50ºC during summer since they are in Desert climate. The concern over possible high demand of energy and peak ambient temperature might occur together, the technical experts have proposed on natural ventilation system supported with forced ventilation system during critical period. The combination of both system is said to be efficient due to desert climate. Designing these systems said to be one of the toughest due to ambient temperature, environment constraints, restriction ventilation shaft size, noise of the fans, surrounding urban architecture and etc. (Saeed Al Jallaf and Olivier Moreau, 2014)

Therefore, Computational modal with power cable were created to tackle the deigning issue by taking into consideration of all the constraint including surface temperature of the cable and the peak ambient temperature. Upon developing computational model to calculate the ambient and air velocity, All the required services to transmit through were included and studied to optimize the position, number, size of the shaft and all the related auxiliary equipment. Once the first part of tunnel start operation in 2013, the temperature were recorded and stated to be below ambient temperature despite heat release by two circuits (Saeed Al jallaf and Olivier Moreau, 2014)

In April 1985, the public utilities board of Singapore (PUB) awarded a design and build contract to a reputable company to construct a cable tunnel from Pulau Seraya to main land Singapore. The immersed cable tunnel is 2,600m long in which 18000 has floor level and 23 meters below sea level. The cable loading which required to transmit through the tunnel will 7 number of 500MVA @ 0.5KVA cables. The technical specialist has come with idea to associate a cable two piped cooling water circuit. These cooling pipes were supplied with cold water from Pulau Seraya cooling towers. This pipe was highly monitored and designed for 50% of total cooling requirement. (O.P.Jensen & Devar Abi Zadeh ,2018)

Moreover, six axial flow, vertical mounted, two speeds, two stage contra rotating, reversible fans also were located in the Pulau Seraya. These fans operate in two areas. Each for an area and each area is operated by combination of system to suit the ventilation operation system. To assure this, a heat transfer model was developed to check the operation of this combination system on feasibility to maintain the temperature less 40ºC when any combination of power circuits is under full load and heat emission from the cable to its environment. (O.P.Jensen & Devar Abi Zadeh ,2018)

The study or experiment on the modal have resulted that only average temperature will emitted around the tunnel at multiple surfaces of the tunnel cross section including cable and air temperature. (O.P.Jensen & Devar Abi Zadeh ,2018)

In London, 400KV XLPE cable system was developed due to increasing power demand by Mega Polis, A 20KM underground tunnel with 3 m inner diameter were constructed below 30 meter from ground level which will give way to for straight route without any limitation as on the ground. (Scott Sadler Simon Sutton & Horst Memmer Johannes Kaumanns ,2004).

The tunnel is equipped with forced air cooling system which will also increase the transmission capacity of the cable. The monitoring system is design in such a way where, temperature will be monitored all over in the tunnel and cable screen will optimize the cable’s load status at all time in-order to ensure continuous transmission capacity of 1600MVA for each circuit. Adding to that, two more additional detectors were also installed as an additional precautionary method. (Scott Sadler Simon Sutton & Horst Memmer Johannes Kaumanns ,2004).

The air cooling system also designed to deliver air very fast with a speed 6m/s. Assuming the air inlet is at 20ºC, the cooling system in the tunnel will allow a maximum load of 1600MVA for one cable in operation. If two more cables in operation the admissible load will reduced to 1200MVA per cable. (Scott Sadler Simon Sutton & Horst Memmer Johannes Kaumanns ,2004).

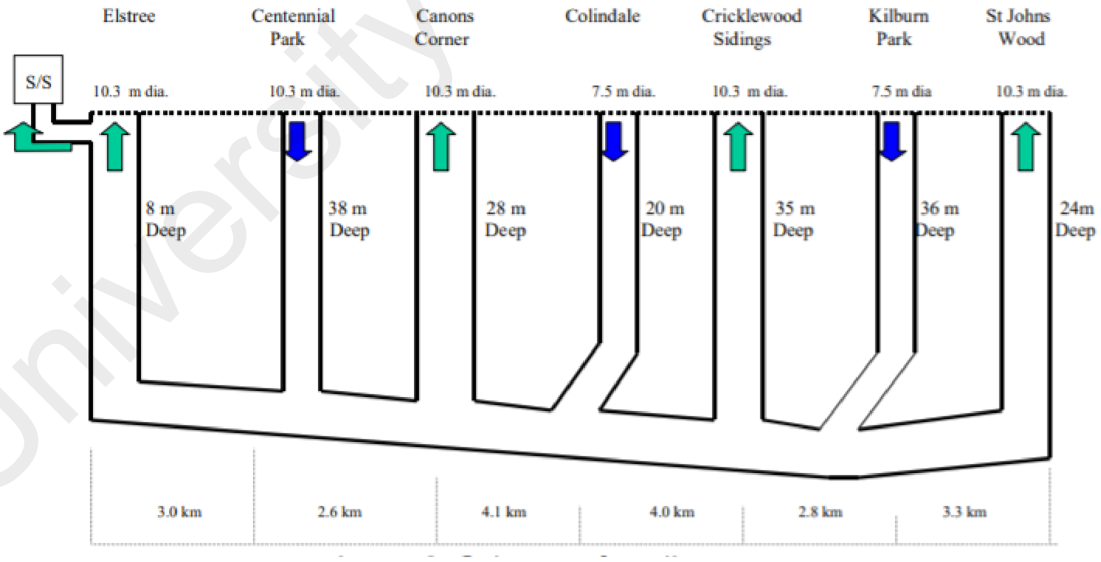


Figure 2.4: Schematic of XLPE Cable Tunnel Cooling System (Scott Sadler Simon Sutton & Horst Memmer Johannes Kaumanns ,2004).

In a report on Cable Tunnel Design Manual by UK Power Network, a tunnel builder essentially to comply with requirement of air ventilation policy which created by UK Power Network. The builder to utilize “CRATER” tool which derived from the Cigre Electrical Technical Paper 143, in where it is indicated that, the tunnel ventilation outlet temperatures shall not exceed 44 ºC based on maximum design inlet temperature of 28ºC. The ventilation in tunnel specifically the air flow in the tunnel shall be able to control temperature in the tunnel which will be contributed by cable size, load, current density, number of circuits and tunnel diameter. They body also have recommended a minimum 2m/s inlet velocity to avoid layering of methane or other poisonous gases. The air supplied must be dry cool to allow smooth passage through the tunnel and to avoid moisture. They also specified the ductworks along the along tunnel shall also comply to the Engineering Association Specification DW/1444 air system metal duct and for the internal ducts it shall be fabricated from hot dipped galvanized sheet metal.

When it’s about fan, they have only mentioned about required temperature compliance which is about 50ºC as the fan model, types and system varies base on the design requirement. They also stressed that, there must be one duty and one standby for emergency mode. Apart from that, the tunnel ventilation system must also to be equipped with automated monitoring system using distributed Temperature sensors (DTS) and Tunnel Ventilation & Management System (TVCMS) to control air flow and temperature. This is to enable, efficient future maintenance by UK Power Network. The essential compliance to above policies will minimize fatality/casualty during maintenance or passage through tunnel. (Mark Dunk 2015)

CHAPTER 3: METHODOLOGY

3.1 Introduction

The primary purpose of this chapter is to present the philosophical assumption underpinning this project and to determine the strategy and techniques for air flow analysis in tunnel.

The analysis strategy is adopted to perform calculations on ventilation velocities based on the air change per hour and to conduct multiple cases of Computational Fluid Dynamics analysis on to the model.

This chapter is divided into two sections. In the first, the calculations. The next section is about the computational fluid dynamic (CFD) software ANSYS – Fluent analysis method. It describes the parameters which are varied to produce the best possible airflow to achieve desired temperature.

3.2 Data Collection and Design Calculation

The following steady state heat transfer analysis related to the cooling of high voltage power cable in an underground tunnel. The design calculation of air flow based on the requirement and data provided by company “X” as mentioned in chapter one. The length of the tunnel, diameter of manhole, height of the manholes, number of cable in the tunnel and the construction material are the primary data for this study. The details of the predetermined data are tabulated in the table 3.1. Using these specifications mathematical model and mathematical calculations were developed base on Heat Transfer Equations. Multiple value of air change per hour (AC/HR) were substituted in the equation to calculate the suitable air flow.

Table 3.1: Parameter of Study

No	Specifications	
1	Manhole Diameter	1.5 meters
2	Tunnel Length	80 meters
3	Tunnel Height	8.5 meters
4	Tunnel Diameter	3 meters
5	Number of cables	18 x 1C
6	Number of circuits	6 (trefoil arrangement)
7	Cable Type	132KV 1C XLPE 1200mmsq CU
8	Cable Diameter	193mm
9	Ambient Temperature	30ºC to 35ºC (meteorological data)
10	Cable Maximum Temperature	90ºC
11	$\Delta\theta$ (Assumption)	60ºC

3.2.1 Thermal Properties and Calculations

The cable's surplus temperature is given as $\Delta\theta_{s.}$ This temperature is the deferential temperature between ambient temperature and cable surface temperature. $\Delta\theta_s$ is calculated iteratively using the following equations

3.2.1.1 Calculation

λ_1 = ratio of losses in metallic sheath to conductor = 0.04575/10.89337

λ_1 = 0.0041998

λ_2 = ratio of losses in armor to conductor

in this case, with no armor installed, λ_2 = 0.

T_1 = Thermal Resistance between one conductor and sheath $T_1 = \frac{\rho_T}{2\pi}\ln\left[1+\frac{2t_1}{d_c}\right]$

Thermal resistivity for XLPE, ρ_T = 3.5 K.m/W

Thickness of layer between conductor and metallic sheath, t_1 = 0.0247m

Conductor Diameter, d_c = 0.0434m

T_1 = 0.4233 K.m/W

T_2 = Thermal Resistance between metallic sheath and armor

In this case, with no armor installed, T_2 = 0.

T_3 = Thermal resistance of outer covering (serving)

$$T_3 = \frac{\rho_T}{2\pi}\ln\left[1+\frac{2t_3}{d_a}\right]$$

Thermal resistivity for XLPE, ρ_T = 3.5 K.m/W

Thickness of XLPE jacket, t_3 = 0.00725m

Metallic sheath outer diameter, d_a = 0.09636m

T_3 = 0.07808 K.m/W

Heat dissipation coefficient, h

$$h = \frac{Z}{\left(D_e^*\right)^g} + E$$

For three cables in trefoil, installed on non-continuous brackets, ladder supports or cleats with D_e^* not greater than 0.15m (case under study = 0.11086m).

Z = 0.96

E = 1.25

g = 0.20

D_e^* = 0.11086m

h = 2.740446

Dielectric losses, $W_d = CU_o^2\tan\delta = 1.061\text{x}10^{-3}$ W/m

Voltage from phase to ground, U_o = 76,210 V

$\tan\delta = 0.001$

Capacitance, $C = \dfrac{\varepsilon}{18\ln\left(\dfrac{D_i}{d_c}\right)}10^{-9} = 1.8275\times10^{-10}$ F/m

Insulation outer diameter, D_i Conductor outer diameter, d_c = 0.0434m

Insulation emissivity, ε = 2.5

Calculating K_A

$$K_A = \frac{\pi D_e^* h}{(1+\lambda_1+\lambda_2)}\left[\frac{T_1}{n} + T_2\ (1+\lambda_1) + T_3\ (1+\lambda_1+\lambda_2)\right]$$

$D_e^* = 110.86\text{mm} = 0.11086\text{m}$

n = 1 (single conductor within cable)

$\lambda_1 = 0.0041998$

$\lambda_2 = 0$

$T_1 = 0.4233$ K.m/W

$T_2 = 0$ K.m/W

$T_3 = 0.07808$ K.m/W

h = 2.740446

$K_A = 0.476844549$

Calculating $\Delta\theta_d$,

$$\Delta\theta_d = W_d\left[\left(\frac{1}{1+\lambda_1+\lambda_2}-\frac{1}{2}\right)T_1-\frac{n\,\lambda_2\,T_2}{1+\lambda_1+\lambda_2}\right]$$

$W_d = 1.061\text{x}10^{-3}$ W/m

$\lambda_1 = 0.0041998$

$\lambda_2 = 0$

$T_1 = 0.4233$ K.m/W

$T_2 = 0$

$\Delta\theta_d = 2.227\text{x}10^{-4}\ {}^{o}\text{C}$

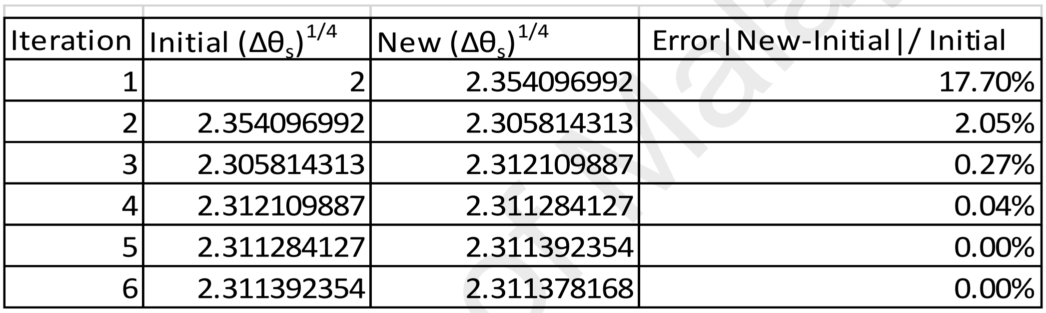
Surface Temperature,

$$(\Delta\theta_s)_{n+1}^{1/4} = \left[\frac{\Delta\theta + \Delta\theta_d}{1 + K_A (\Delta\theta_s)_n^{1/4}} \right]^{0.25}$$

Since, $\Delta\theta_d = 0.0002227$ and $\Delta\theta = 60$, $K_A = 0.476844549$

Iteration to stop when, $(\Delta\theta_s)_{n+1}^{1/4} - (\Delta\theta_s)_n^{1/4} \leq 0.001$

Table 3.2: Temperature Iteration



Iteration	Initial $(\Delta\theta_s)^{1/4}$	New $(\Delta\theta_s)^{1/4}$	Error|New-Initial|/ Initial
1	2	2.354096992	17.70%
2	2.354096992	2.305814313	2.05%
3	2.305814313	2.312109887	0.27%
4	2.312109887	2.311284127	0.04%
5	2.311284127	2.311392354	0.00%
6	2.311392354	2.311378168	0.00%

The iteration stopped with:

$$(\Delta\theta_s)^{1/4} = 2.311284127$$

$$\Delta\theta_s = 28.54^{o}C$$

results with:

$$\theta_s = 28.54 + 30.0 = 58.54^{o}C \text{ @ } \mathbf{60}^{o}\mathrm{C}$$

Referring to the above calculation, the surface temperature of the cable is 58.54 °C with cable's maximum temperature 90°C and ambient temperature 33°C

3.2.2 Design Calculation

As mentioned in section 3.2, the design calculation is based on air change per hour (AC/Hr). In order calculate AC/Hr the volume of the tunnel was obtained from design drawing of the tunnel. The value of AC/Hr were calculated from value and then increased logically depending on the inlet velocity value obtained from calculation.

Air Change Per Hour Equation,

$$AC/Hr = \frac{60\ X\ CFM}{Vol}$$

The Volume obtained from design is,

Volume = 40057.85 ft^3

Then, substitute the volume and the AC/Hr in the equation below to obtain Q,Flow rate (CFM)

$$CFM = \frac{AC/HrX\ Vol}{60min}$$

The value of Flow rate (CFM), will be substituted in the equation below to find the value of V (velocity) m/s

$$CFM = V\ X\ A\ X\ 2118.88$$

$$V = \frac{CFM}{A\ X\ 2118.88}$$

The result/value obtained are tabulated in the table below

Table 3.3: Air Change, Flow rate, Velocity tabulation

AC/Hr	**Q (ft^3/min) or CFM**	**Velocity of Air at Inlet (m/s)**
5	3338.154	0.89
13	8679.200	2.32
22	14687.878	3.92
33	22031.817	5.88
44	29375.756	7.85
55	36719.695	9.81
66	44063.635	11.77

3.3 CAD and Computational Fluid Dynamics Analysis

CAD is the software utilized to create the model to desired parameter. Computational fluid dynamics is one of the branches of fluid mechanics that uses numerical methods and algorithms to solve and analyze problems that involve fluid flows. The above design of the cable tunnel which was derived from the specification and calculation was tested using CFD software to determine the suitable airflow. The optimum mesh was generated and used to simple wizard was used to set the governing parameters. Various cases were studied to produce an optimum air flow.

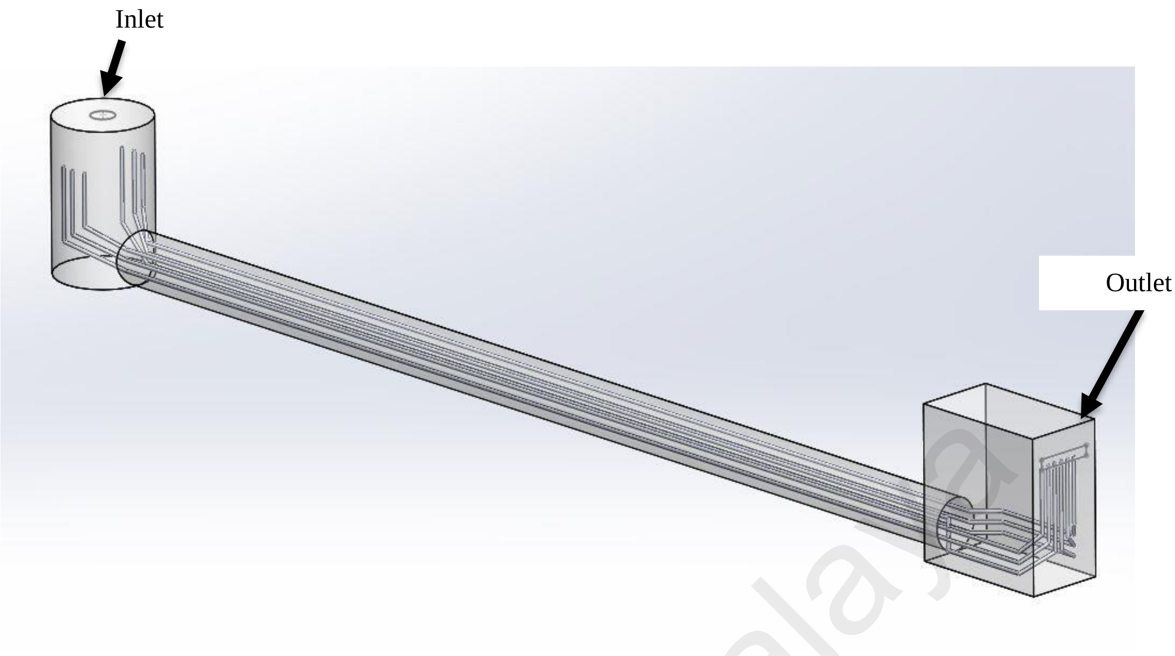


Figure 3.1: Boundary Condition of cable tunnel

Figure 3.2: Side view of the model with cable

3.3.1 Design Mesh

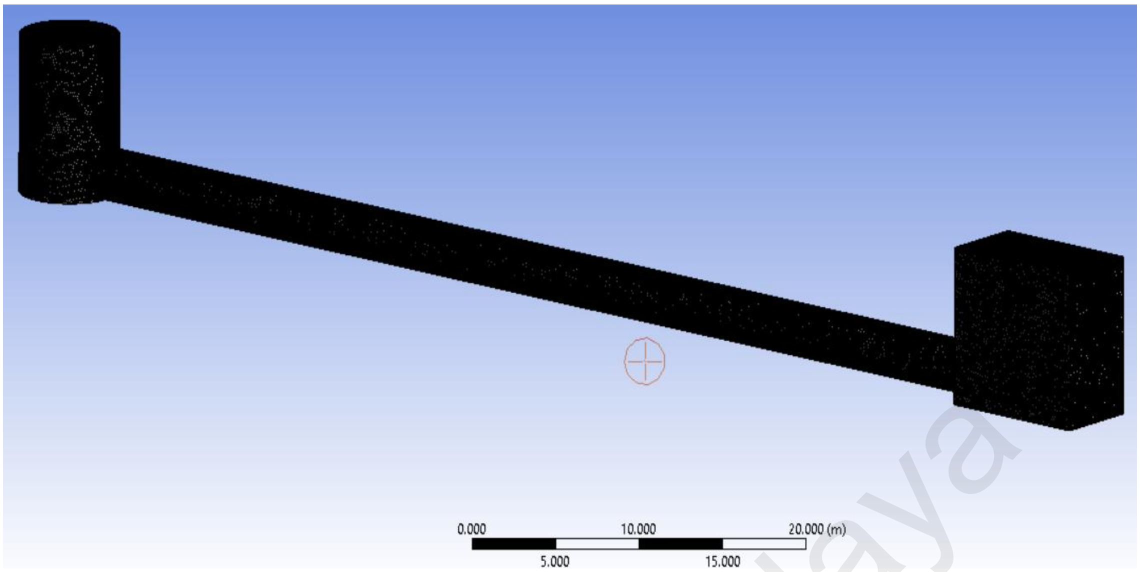


Figure 3.3: Mesh Model view 1

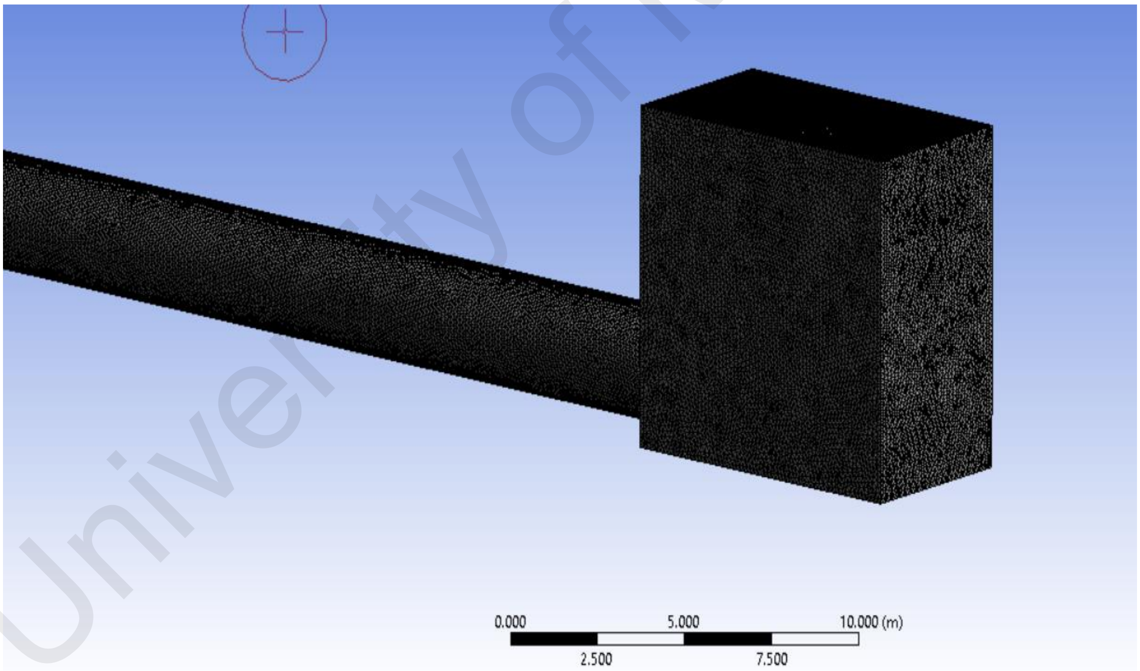


Figure 3.4: Mesh Model view 2

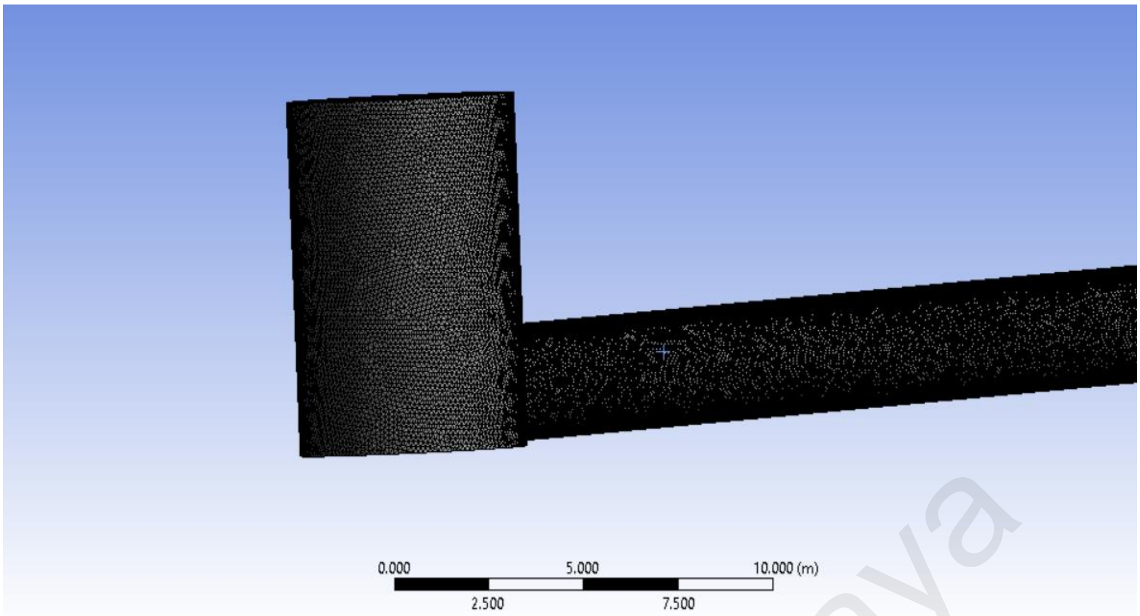


Figure 3.5: Mesh Model view 3

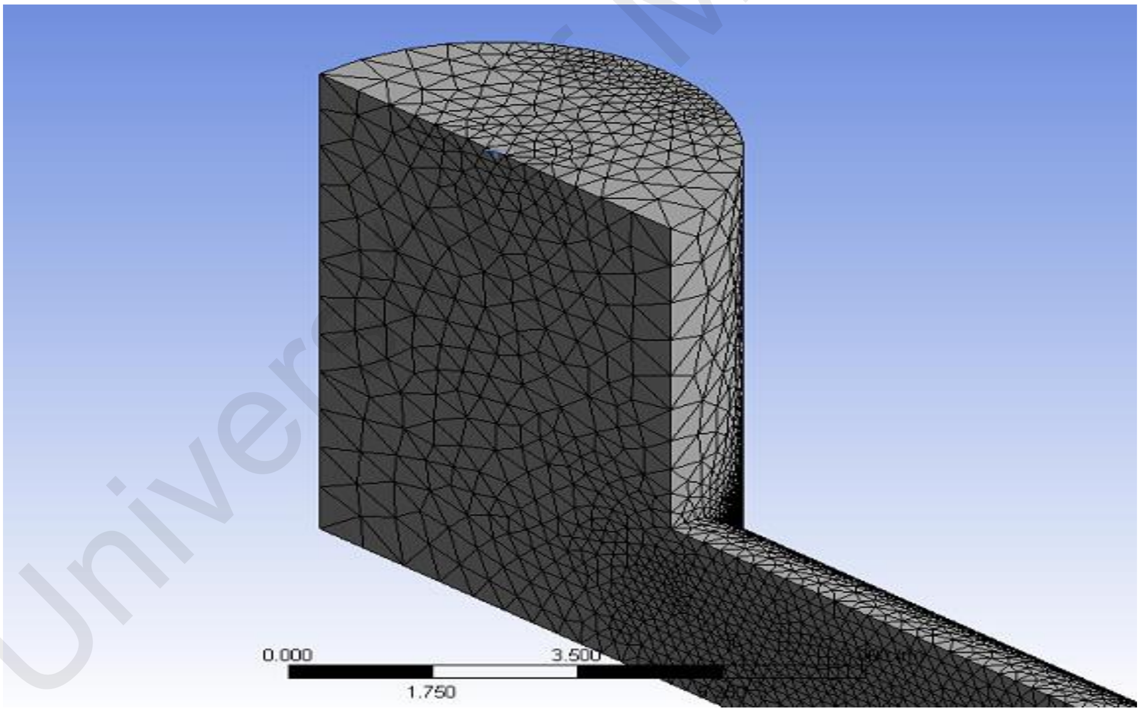


Figure 3.6: Mesh Section View 1

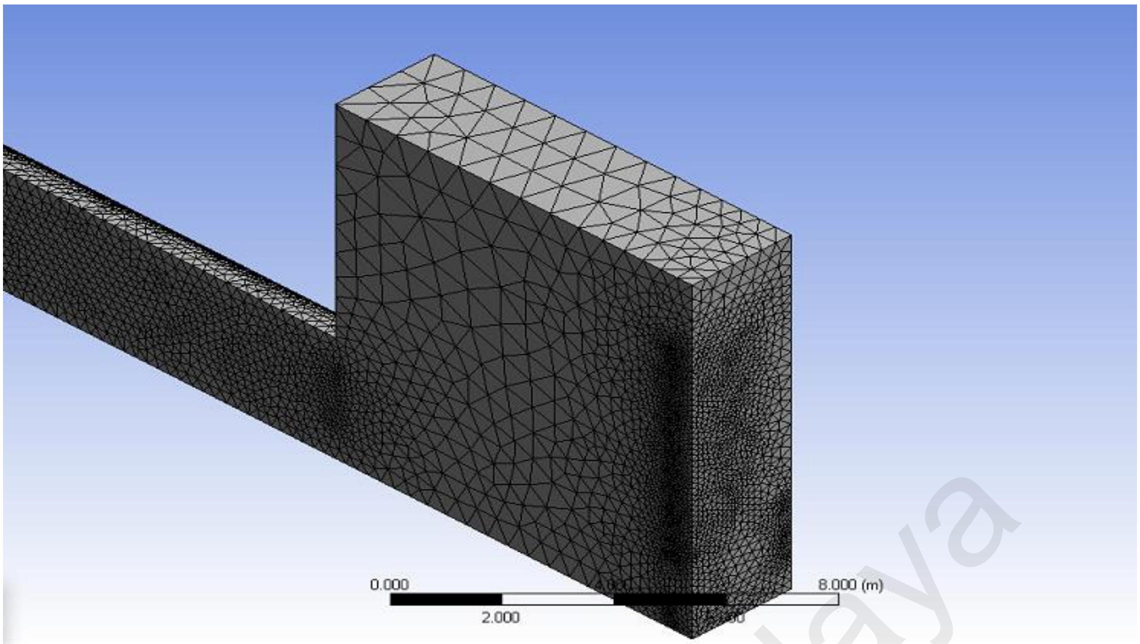


Figure 3.7: Mesh Section view 2

Upon creating the design in CAD, the designed will be meshed in CFD as per statistics in the table 3.4

Table 3.4: Mesh Statistics

Number of Nodes	308,365
Number of Elements	1531025
Min Size (m)	0.13
Max Size (m)	0.13

3.3.2 Analysis

In total three configuration with four velocities were documented in this report. In the first configuration, the ambient temperature is set to 30°C, and four different velocity which are 4m/s, 6m/s, 8m/s and 10m/s were flowed through inlet man-hole. These parameters were tested to find the tunnel mid-point temperature and to decide on the suitable are flow. The whole process will be repeated for ambient temperature 33°C and 35°C with the same 4 velocities. The result of the analysis is tabulated in the following chapter

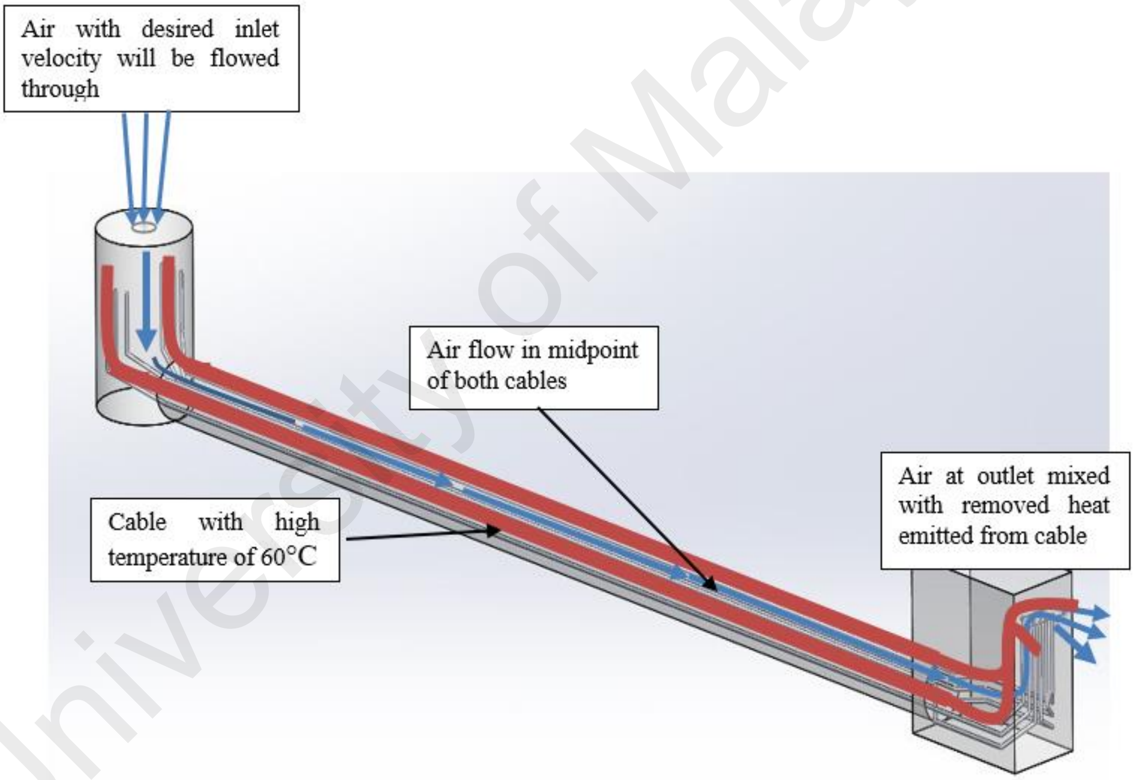


Figure 3.8: Model of Simulation

The above simulation model shows the heat generated by the cable is maximum temperature which is 60°C while air at inlet will remove the heat at mid-point to allow suitable environment for human's presence and to avoid cable malfunction due to heat. This concept will be simulated in CFD to obtain suitable velocity.

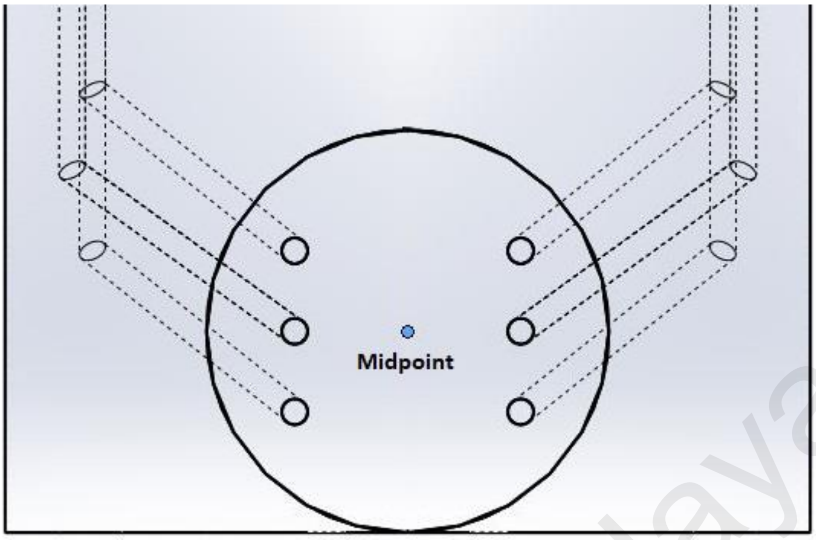


Figure 3.9: Mid-Point of temperature taken

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Introduction

Results from the analysis outlined in the previous chapter are presented here. These results include temperature, and velocity analysis of the high-tension cable tunnel. These results are utilized to determine the optimum air flow ventilation system which takes into account factors such as fan operating life, noise level and also size. Ultimately, the results will be utilized as a basis for recommendations for change in the design methodology of cable tunnel ventilation system to obtain desired temperature

4.2 Computational Fluid Dynamics Results

In total three configuration with four vital analyses for each were carried out. The results for all the analysis is presented in the following section.

4.2.1 Configuration 1: AMBIENT TEMPERATURE, 30°C

Results from the analysis of configuration one presented in Table 4.1. The results include the velocity of Air at inlet (m/s), flow rate $(\frac{ft^3}{min})$, temperature (°C) of Air at Midpoint and temperature difference (°C) The temperature chose for this analysis is lower to ambient temperature to indicate differences in air flow in different temperature

Table 4.1: Temperature difference with multiple velocity for Ambient temperature 30°C

No	**Velocity of Air at Inlet (m/s)**	**Diameter of Inlet(m)**	**Flow Rate of Air at Inlet $(\frac{ft^3}{min})$**	**Temperature of Air at Midpoint (°C)**	**Temperature Difference(°C)**
1	4	1.5	14687.878	32.12	2.12
2	6	1.5	22031.817	31.98	1.98
3	8	1.5	29375.756	31.93	1.93
4	10	1.5	36719.695	31.84	1.84

Temperature Contour at 30°C, V= 4 m/s, Max Temperature ,60°C

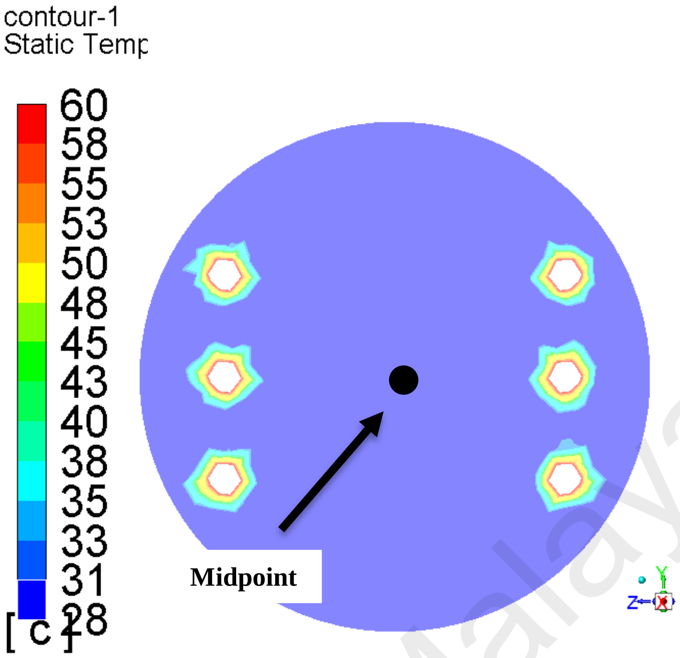


Figure 4.1: Temperature Contour at Cross-Section of tunnel, 4m/s -30°C

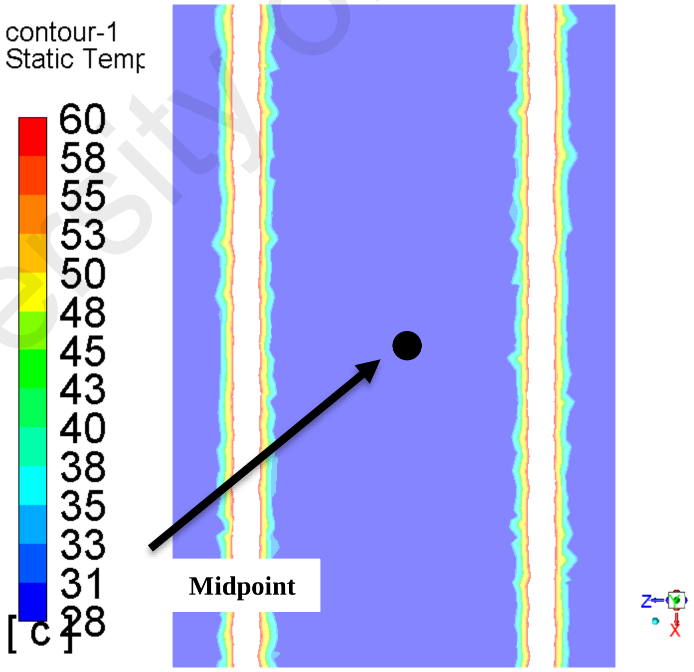


Figure 4.2: Temperature Contour at Top View of Tunnel, 4m/s - 30°C

Temperature Contour at 30°C, V= 6 m/s, Max Temperature ,60°C

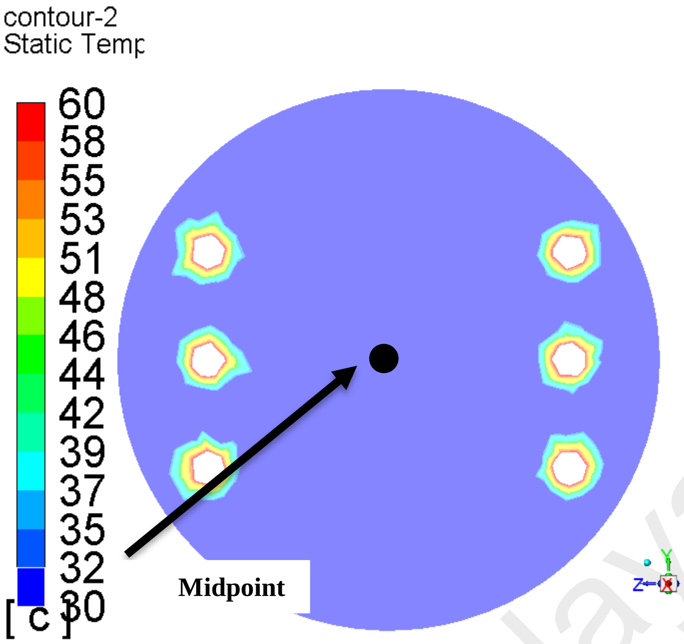


Figure 4.3: Temperature Contour at Cross-Section of tunnel, 6m/s - 30°C

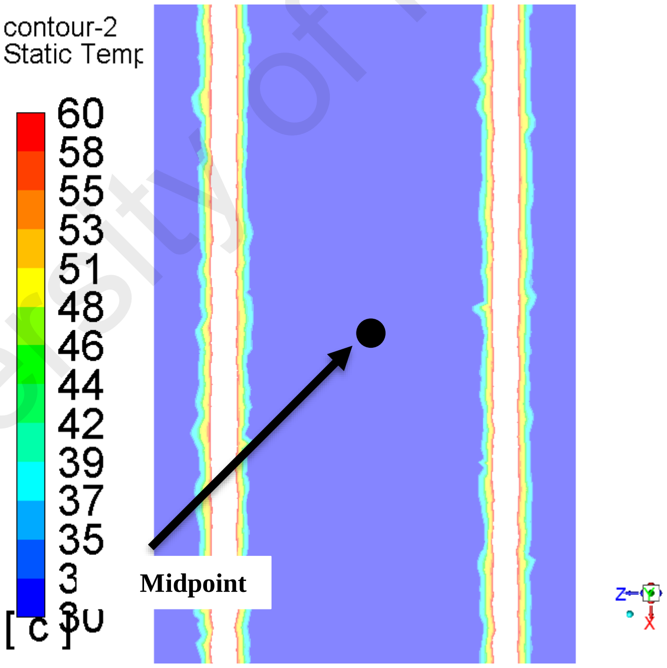


Figure 4.4: Temperature Contour at Top-View of tunnel, 6m/s - 30°C

Temperature Contour at 30°C , V= 8 m/s, Max Temperature ,60°C

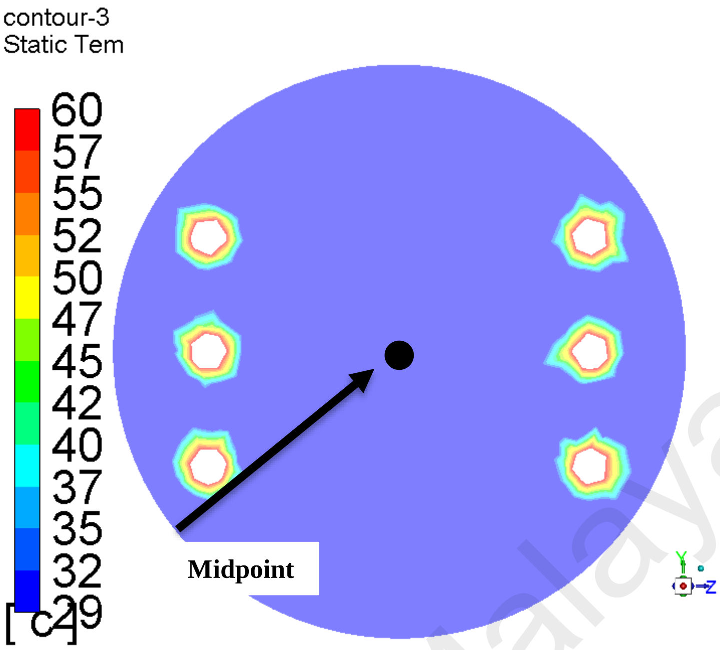


Figure 4.5: Temperature Contour at Cross-Section of tunnel, 8m/s - 30°C

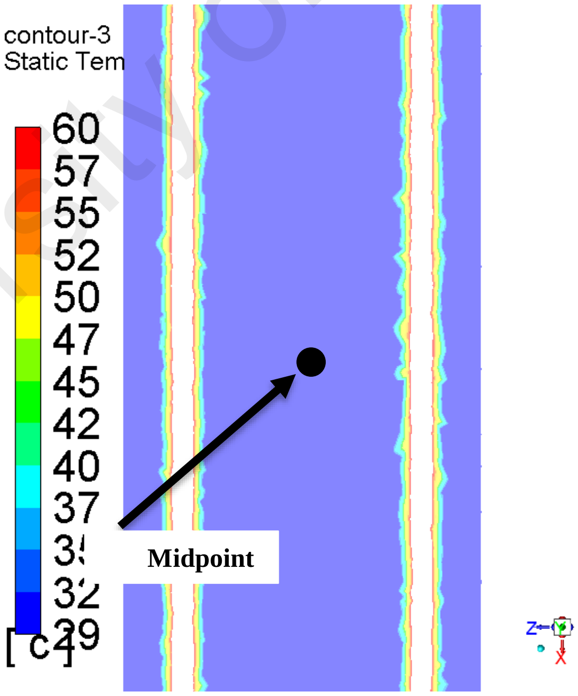


Figure 4.6: Temperature Contour at Top-View of tunnel, 8m/s - 30°C

Temperature Contour at 30°C , V= 10 m/s, Max Temperature ,60°C

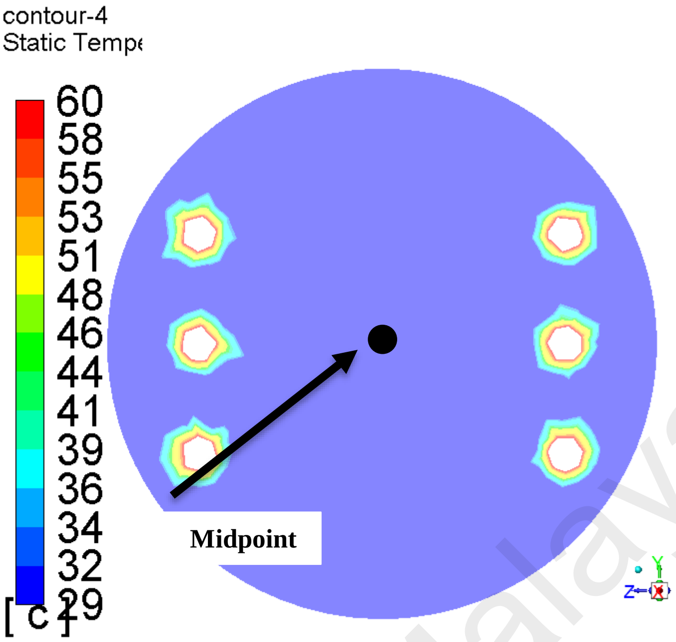


Figure 4.7: Temperature Contour at Cross-Section of tunnel, 10m/s - 30°C

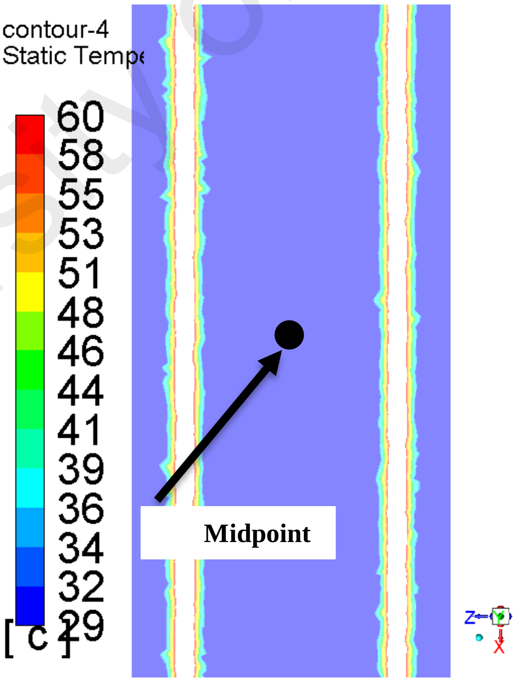


Figure 4.8: Temperature Contour at Top-View of tunnel, 10m/s - 30°C

4.2.2 Configuration 2: AMBIENT TEMPERATURE = 33°C

Results from the analysis of configuration one presented in Table 4.1. The results include the velocity of Air at inlet (m/s), flow rate $(\frac{ft^3}{min})$, temperature (°C) of Air at Midpoint and temperature difference (°C). This will be the ambient temperature base on meteorological data for the location of the project

Table 4.2: Temperature difference with multiple velocity for Ambient temperature 33°C

No	Velocity of Air at Inlet (m/s)	Diameter of Inlet(m)	Flow Rate of Air at Inlet $(\frac{ft^3}{min})$	Temperature of Air at Midpoint (°C)	Temperature Difference(°C)
1	4	1.5	14687.878	34.92	1.92
2	6	1.5	22031.817	34.88	1.88
3	8	1.5	29375.756	34.85	1.85
4	10	1.5	36719.695	34.78	1.78

Temperature Contour at 33°C , V= 4 m/s, Max Temperature ,60°C

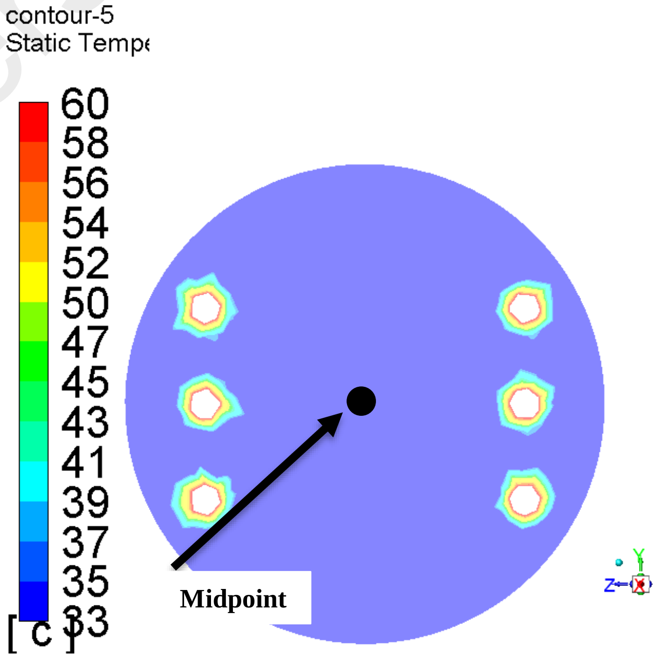


Figure 4.9: Temperature Contour at Cross-Section of tunnel, 4m/s - 33°C

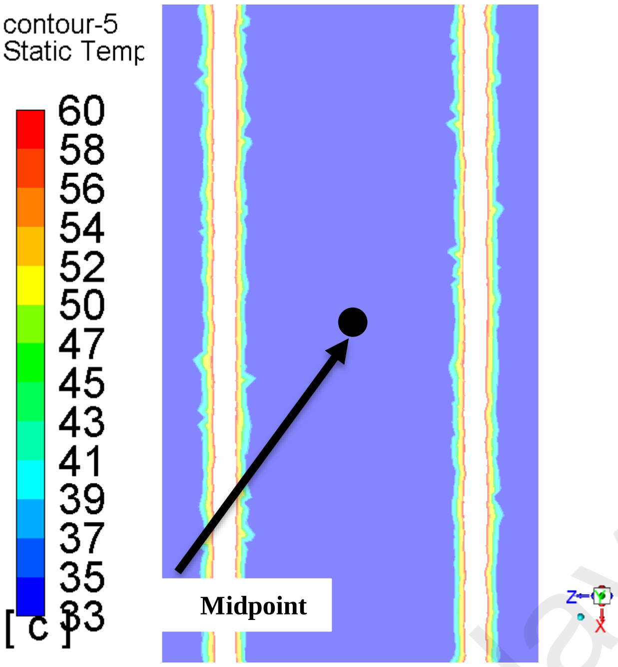


Figure 4.10: Temperature Contour at Top-View of tunnel, 4m/s - 33°C

Temperature Contour at 33°C , V= 6 m/s, Max Temperature ,60°C

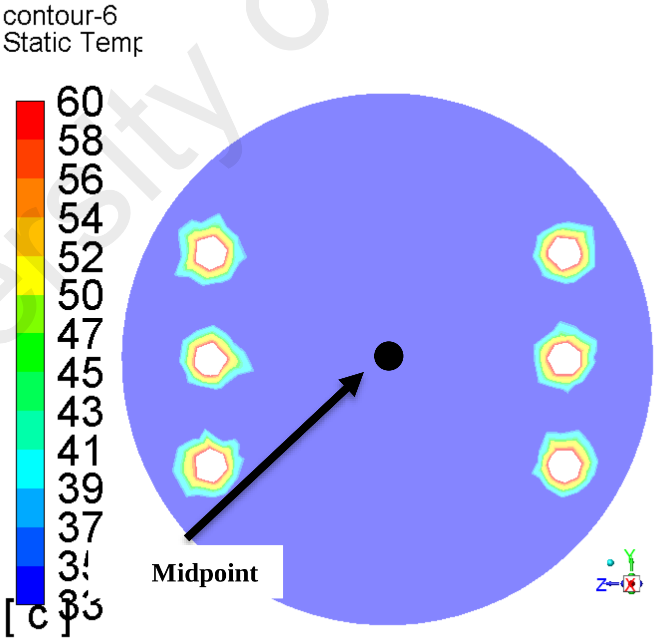


Figure 4.11: Temperature Contour at Cross-Section of tunnel, 6m/s - 33°C

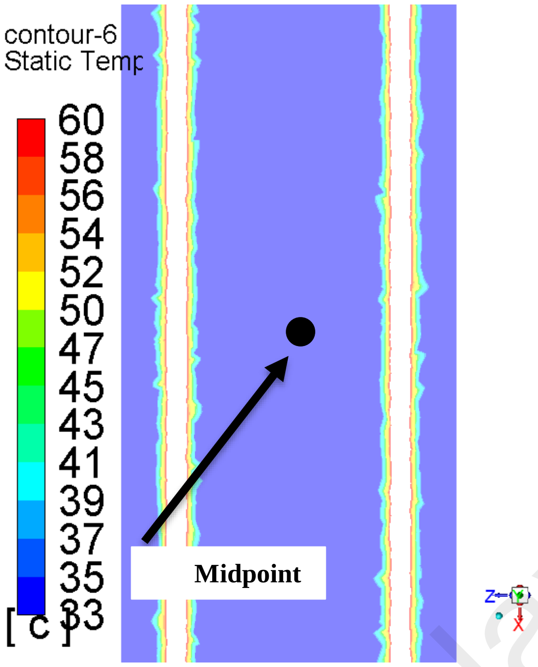


Figure 4.12: Temperature Contour at Top-View of tunnel, 6m/s - 33°C

Temperature Contour at 33°C, V= 8 m/s, Max Temperature ,60°C

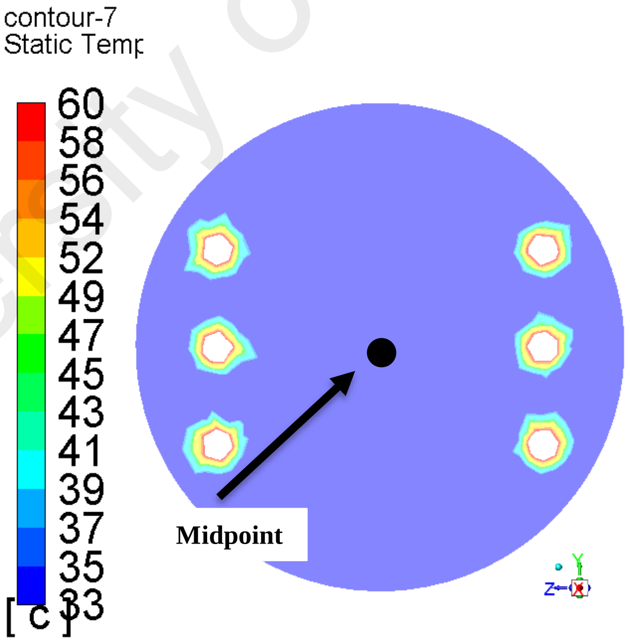


Figure 4.13: Temperature Contour at Cross-Section of tunnel, 8m/s - 33°C

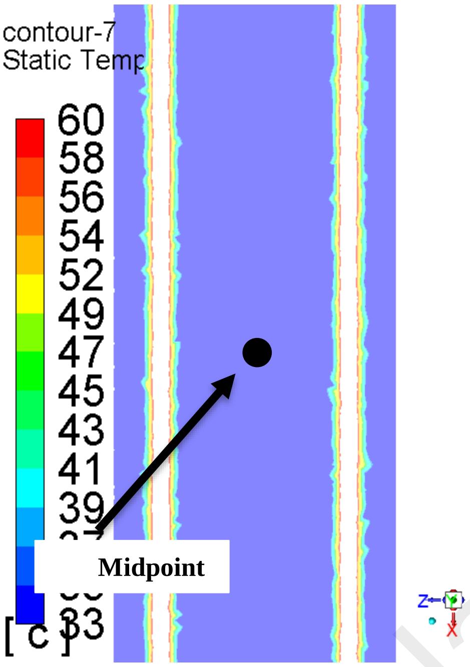


Figure 4.14: Temperature Contour at Top-View of tunnel, 8m/s - 33°C

Temperature Contour at 33°C , V= 10 m/s, Max Temperature ,60°C

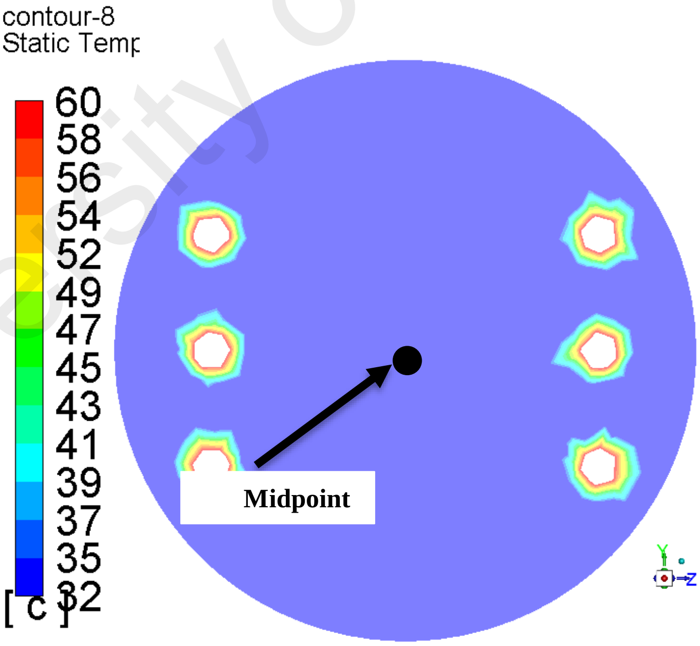


Figure 4.15: Temperature Contour at Cross-Section of tunnel, 10m/s - 33°C

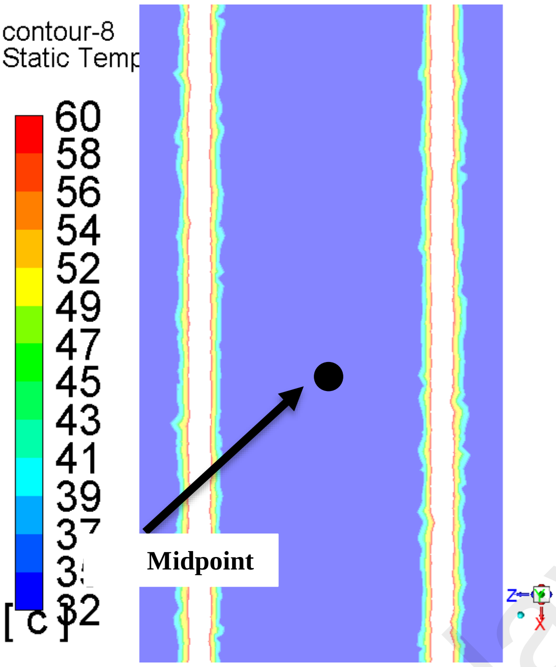


Figure 4.16: Temperature Contour at Top-View of tunnel, 10m/s - 33°C

4.2.3 Configuration 3: AMBIENT TEMPERATURE = 35°C

Results from the analysis of configuration one presented in Table 4.1. The results include the velocity of Air at inlet (m/s), flow rate $(\frac{ft^3}{min})$, temperature (°C) of Air at Midpoint and temperature difference (°C). The temperature chose for this analysis is higher to ambient temperature to indicate differences in air flow in different climate

Table 4.3: Temperature difference with multiple velocity for Ambient temperature 35°C

No	**Velocity of Air at Inlet (m/s)**	**Diameter of Inlet(m)**	**Flow Rate of Air at Inlet $(\frac{ft^3}{min})$**	**Temperature of Air at Midpoint (°C)**	**Temperature Difference(°C)**
1	4	1.5	14687.878	36.78	1.78
2	6	1.5	22031.817	36.70	1.70
3	8	1.5	29375.756	36.66	1.66
4	10	1.5	36719.695	36.58	1.58

Temperature Contour at 35°C, V= 4 m/s, Max Temperature ,60°C

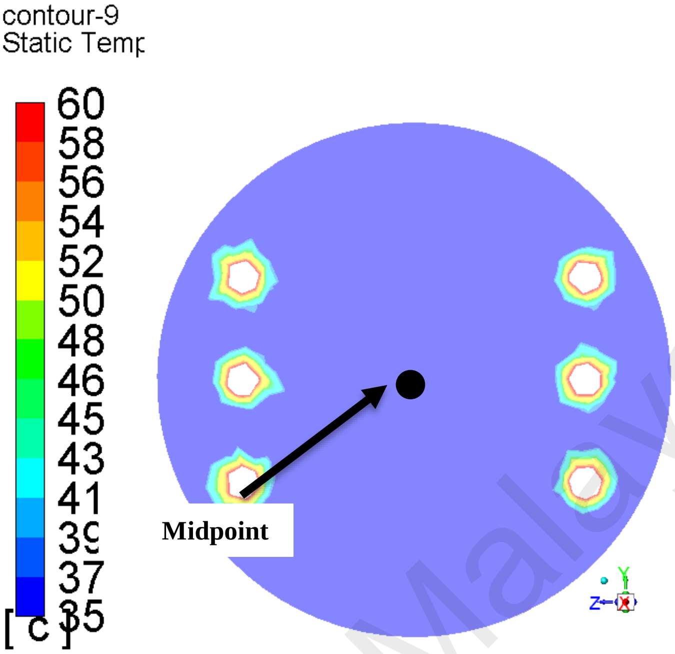


Figure 4.17: Temperature Contour at Cross-Section of tunnel, 4m/s - 35°C

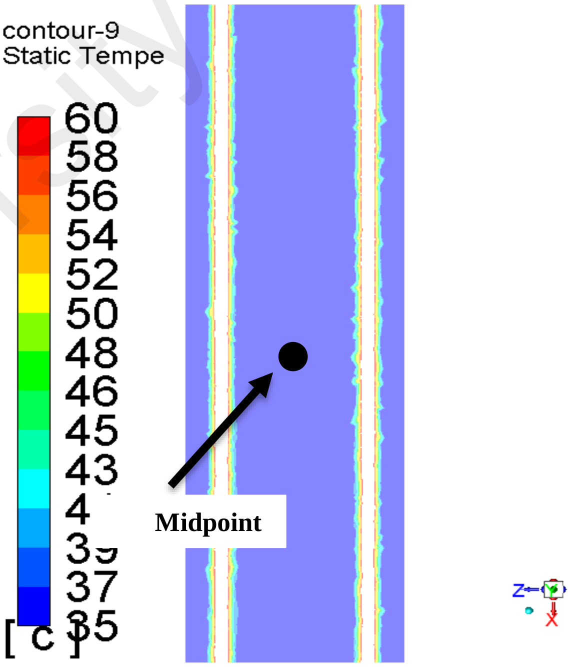


Figure 4.18: Temperature Contour at Top View of tunnel, 4m/s - 35°C

Temperature Contour at 35°C, V= 6 m/s, Max Temperature ,60°C

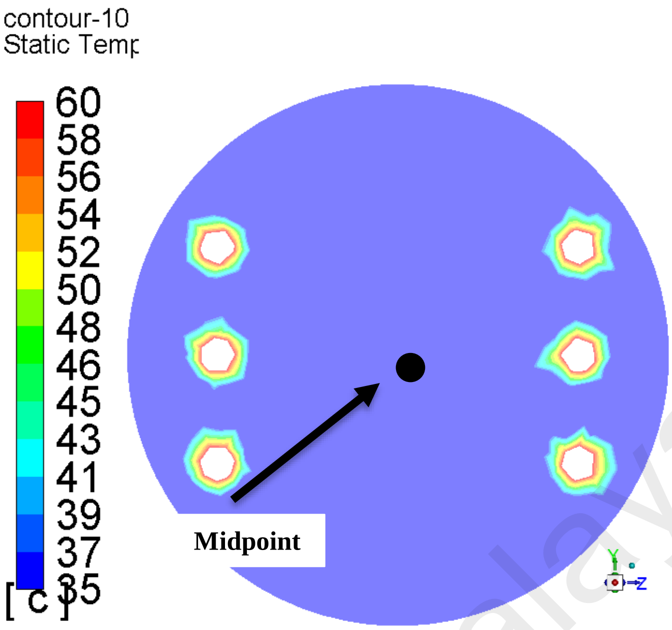


Figure 4.19: Temperature Contour at Cross-Section of tunnel, 6m/s - 35°C

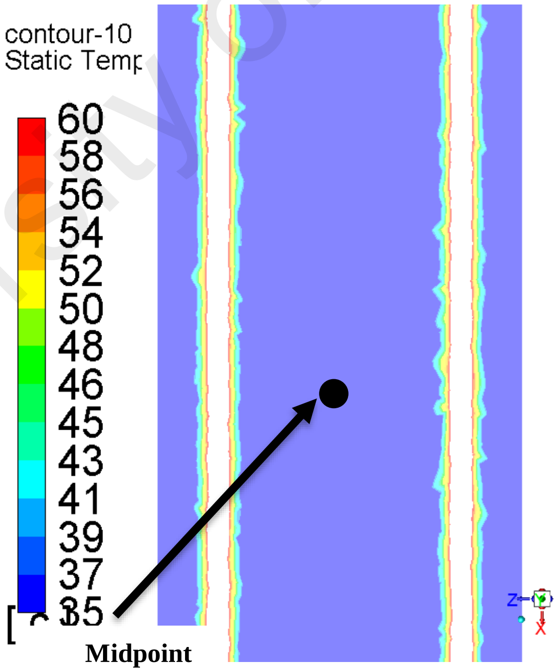


Figure 4.20: Temperature Contour at Top View of tunnel, 6m/s - 35°C

Temperature Contour at 35°C, V= 8m/s, Max Temperature ,60°C

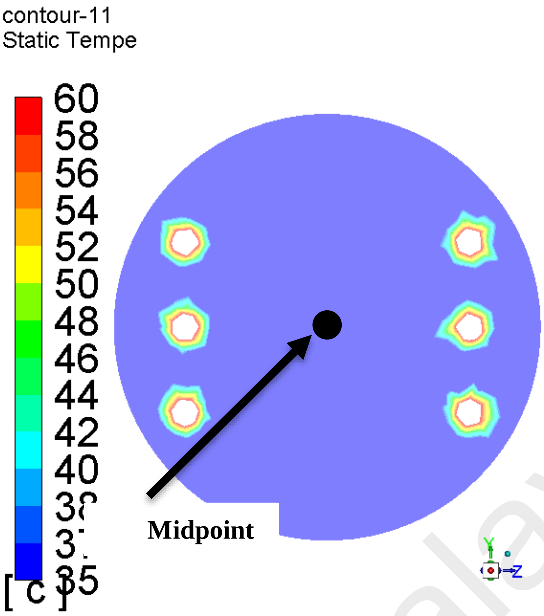


Figure 4.21: Temperature Contour at Cross-Section of tunnel, 8m/s - 35°C

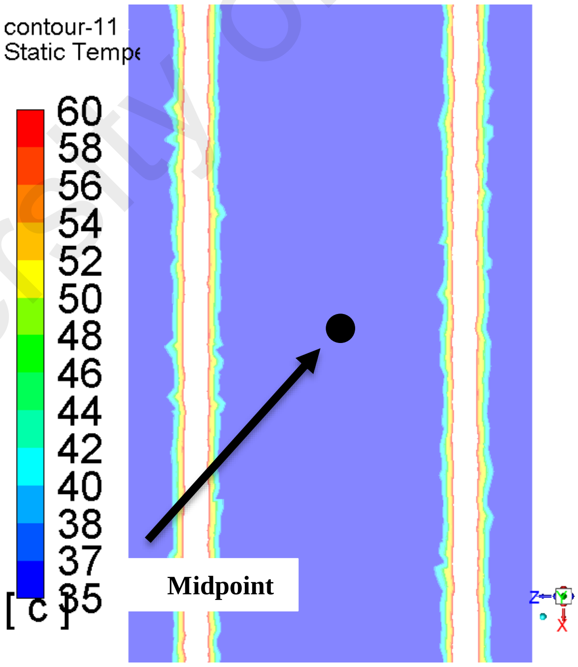


Figure 4.22: Temperature Contour at Top View of tunnel, 8m/s - 35°C

Temperature Contour at 35°C, V= 10m/s, Max Temperature ,60°C

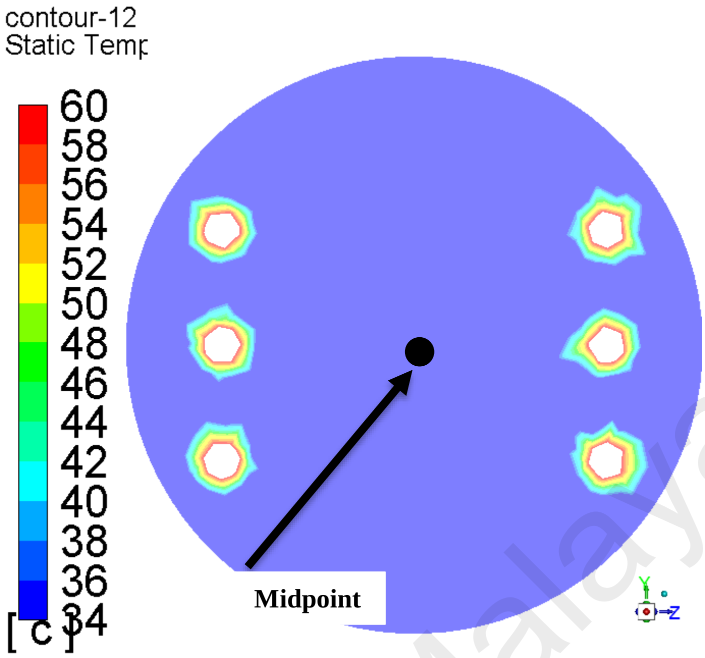


Figure 4.23: Temperature Contour at Cross-Section of tunnel, 10m/s - 35°C

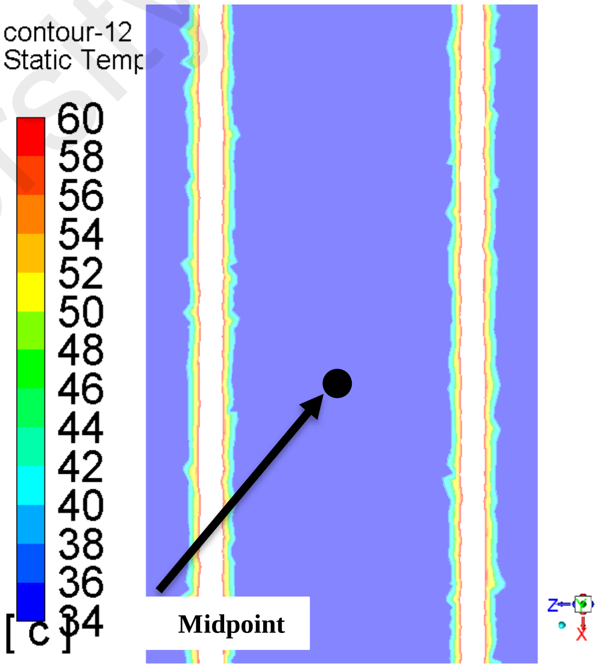


Figure 4.24: Temperature Contour at Top View of tunnel, 10m/s - 35°C

4.3 Discussion

Table 4.4: Meteorological Data

Station ID	**Station**	**Minimum (°C)**	**Maximum (°C)**
48603	Alor Setar	24.0	30.1
48642	Batu Embun	23.6	34.2
48670	Batu Pahat	24.7	30.0
48601	Bayan Lepas	24.0	29.9
96441	Bintulu	23.9	33.5
48602	Butterworth	25.4	31.6
48632	Cameron Highlands	16.2	22.4
48604	Chuping	23.5	30.2
48617	Gong Kedak	23.8	32.0
48625	Ipoh	24.8	32.8
96420	Kapit	24.3	35.2
96467	Keningau	23.2	33.5
48672	Kluang	24.0	33.2
48615	Kota Bharu	25.4	30.7

The proposed location for the cable tunnel construction is in Kluang area. The ambient temperature for Kluang is 33. 2°C.The reference temperature for this analysis will be 33°C while the other two-temperature analysis are for comparison

Base on previous chapters the results are tabulated as below

Table 4.5: Results Tabulation

Velocity of Air at Inlet (m/s)	**Q (ft^3/min) or CFM**	**AC/Hr**	**Average Mid-Point Temperature difference (°C)**
4	14687.878	22	1.96
6	22031.817	33	1.85
8	29375.756	44	1.81
10	36719.695	55	1.73

With referring results tabulation data, the temperature difference for 10m/s is found to be lowest based on simulation analysis. The temperature difference for Inlet velocity 6m/s and 8m/s does not vary much and the temperature difference for 4m/s inlet velocity is the second lowest after 10m/s.

Temperature for inlet velocity 10m/s has the lowest temperature differences due to high inlet velocity and its CFM is the highest among all three. So, it could the best way to remove the heat emitted by cable during full load, for inlet velocity 6m/s and 8m/s the differences in the CFM varies about 7343.939 ft^3/min but the temperature difference is very minimal. Even though the temperature difference is not the best for inlet velocity 4m/s, when relate with CFM, it would be a much efficient choice.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Based on the CFD simulation analysis and the result obtain in the chapter 4, the temperature, air change and the CFM plays a major role in determining a suitable inlet velocity for the underground cable tunnel. The simulation was carried for a total of three temperatures which are 30^0C, 33^0C and 35^0C. As per the location of the cable tunnel, the ambient temperature will be 33.2^0C. The primary temperature for the analysis was 33^0C.By considering the climate change and for comparison purpose the other two temperatures were analyzed.

As for the closure, the mid -point temperature of 33^0C which is closest to the actual location's ambient temperature can be achieved based on CFD analysis. This temperature is obtained with inlet velocity of 4m/s and CFM 14687.878. This velocity inlet and CFM will be more efficient comparing with other three despite minimal temperature difference because, the CFM for this temperature is low and this would be best cost-efficient selection. In adding to that, high air flow in tunnel will create less comfortable environment during maintenance or future upgradation. Adding to that, we also conclude that 4m/s inlet velocity can cool the environment of cable tunnel for the range of ambient temperature of 30^0C to 35^0C base on the CFD analysis.

5.2 Recommendation

With referring to the analysis for ambient temperature of 33^0C, the inlet velocity of 4m/s with 14639.98 @15,000 CFM can be utilized for any upcoming tunnels without exceeding the parameters analyzed in this study.

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