Kathmandu University Journal of Science, Engineering and Technology, Vol. 15, No. 2, August 2021

Kathmandu University
Journal of Science, Engineering and Technology

Study and optimization of existing ventilation system of public buses using computational fluid dynamics

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Abstract

Among all of the public transport, public buses are the major means of transportation for the people on daily basis. In both urban as well as in rural areas, a large number people travel through public bus regularly. Despite of this usage, public buses in developing countries like Nepal are equipped with minimum or zero facilities to the passengers. The maximum number of public buses, used for medium and short routes, are not air-conditioned and air has to be regulated naturally throughout the bus to provide the passengers with adequate thermal comfort. Furthermore, the operating buses are old, noisy and uncomfortable. With rising pollution in the environment, there is also a high chance of passenger compartment being contaminated with pollutants like particulate matters since there is frequent movement of people in peak hours. Therefore, as a solution to these problems, the research is being carried out. The study and optimization of the existing ventilation system of the buses enabling the efficient flow of air ensuring better thermal comfort for the passenger is accomplished. The bus operation region is accordance to Nepal city area and especially summer temperature is focused. The interior design of the bus is with reference to TATA star bus series and the manlike shape of the passengers are as per Body Mass Index (BMI) of Nepalese people and 3D designed in Solidworks. Through several number of design modifications and test using computational fluid dynamics, finally the design with the optimum result is selected and advised to be opted for efficient performance of ventilation in public buses. For the CFD simulations turbulence model of k-epsilon and tetrahedral mesh is applied in ANSYS. And with a mean observation, among all the roof vents orientations, the case with roof ventilation at the front and backside provides the optimum result among the optimized design with effective temperature of 305.53 K and mean velocity of 14.77 m/s.

Keywords: Ventilation System; Bus Compartment; Thermal Comfort; Computer Aided Design; Computational Fluid Dynamics

1. Introduction

Public buses have become an integral part in human movement in daily basis. It is a shared means of transportation in which anyone can travel through by paying the sets of fares. In context of Nepal, despite of the roads being crowded with public buses, majority of them are not air-conditioned with minimum or zero facilities offer to passengers. The condition of the passenger compartment is smelly, noisy and uncomfortable but also, they are obliged this means. During the work hours, large number of people transit form bus which causes the atmosphere inside the bus to worse due to lack of air circulation and poor ventilation system ultimately bringing air borne diseases which causes health hazards. Similar scenario can be found in all the developing countries in Africa and South Asian Region.

The pollution inside the compartment of bus can be reduced through the proper circulation of air. Thus, in a non-airconditioned bus, ventilation system plays a vital role. In a non-airconditioned bus, ventilation is to the dual requirements i.e., fresh breathing air as well as providing a cooling sensation. The ventilation has become necessary part for non-AC bus because due to increasing concern in Thermal Comfort. Thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation [1]. In a bus temperature affecting factors like number of passengers, ambience temperature and engine heat generation is directly related for Thermal Comfort. Analyzing these factors can make the good thermal condition of bus compartment [2]. The human response to the thermal environment can be found to depend mainly on six factors: Air Temperature, Mean Radiant Temperature, Air Velocity, Relative Humidity, Physical Activity, Clothing Thermal Resistance [3]. Among which thermal comfort air temperature, radiant temperature, air velocity and relative humidity are environmental factor since they are varying according to place, season and climate whereas physical activity and clothing resistance are personal factors determining thermal comfort.

The ventilation mechanism of a non-airconditioned bus is primarily the air flow through the windows due to relative motion between the bus and air around it. The air is circulated in the vehicle jointly due to the ram effect on account of the vehicle movement. Besides the windows and door, roof vents also allow air flow to the bus interior. And for the optimization of ventilation system in public bus, numerical CFD simulation in interior part of the bus with different conditions of ventilators placements is conducted.

2. Materials and method

The steady methodology is followed for research procedure. All the necessary subject matters ere literature reviewed. Five major steps are accomplished for the optimization of ventilation system.

2.1. Identification of Non-Air-Conditioned Bus

According to data by Department of Transport, a total of around 3 million of vehicles are registered in Nepal out of which around 75 thousand of them fall under the categories of bus [4]. These buses can be categorized into three categories: short, medium and long route buses. Here, it is a safe assumption that not air-conditioned

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Table 1: Maximum temperature at different stations.

Station	Temperature (°C)	Trend
Dadeldhura	29.7	↑
Dhangadi	41.2	↓
Dipayal	41.0	-
Jumla	30.3	-
Surkhet	36.9	-
Nepalgunj	42.2	↓
Dang	37.4	-
Jomsom	25.5	↓
Bhairahawa	40.0	-
Pokhara	34.5	↑
Lumle	27.5	↑
Simara	38.5	-
Kathmandu	33.3	↑
Jiri	28.0	↓
Janakpur	40.4	↑
Okhaldhunga	29.7	↑
Dhankuta	31.7	↓
Dharan	38.7	-
Biratnagar	38.0	-
Taplejung	29.7	↑

Table 2: Mean BMI Data

Sex	Body Mass Index (BMI)	Height (m)
Male	22.6	1.63
Female	22.8	1.51
Mean	22.7	1.57

buses are mostly used for medium and shorter routes as the longer routes' bus are majorly equipped with air-conditioning. Among the medium and shorter route, TATA Starbus is one of the most popular series of the buses in Nepalese market. Therefore, the selection of the bus for the analysis was Tata Starbus 24 D LP 410/36 [5].

2.2. Collection and Analysis of Data

After the selection of the bus for the analysis, the data for the design and dimension of the bus was collected. Furthermore, the data needed for the analysis was also collected from various sources and analyzed to properly set up the boundary conditions for the simulation. Also, data like average speed of the vehicle in Nepal i.e., 60 km/hr is assumed. For the ambient temperature data published by Department of Hydrology and Meteorology in year 2018-2019 is used [6] (Table 1).

The highest and lowest recorded maximum temperature out of the stations were Dhangadi at 41.2 °C and Jomsom at 25.5 °C. Here, for the analysis, the highest maximum temperature is selected as the outside temperature.

Now, for the temperature due to heat emission by human, the following calculation is done. According to the data by STEPS Survey Nepal 2019, the BMI and the height of the Nepalese are [7] given in Table 2.

Thus, the average weight of Nepalese can be calculated to be 55.88 kg. Similarly, it is known that a resting human emits 100 joules of heat per second under normal circumstances with specific heat capacity of human being 3.47 KJ/kg·K [8]. Now, assuming a passenger spends an average of fifteen minutes on a short route bus, the temperature increase can be calculated as:

Heat Generated (Q) = Mass of the body × Specific Heat Capacity × Increase in Temperature

Here, Increase in Temperature = 0.92 C ~ 1 °C

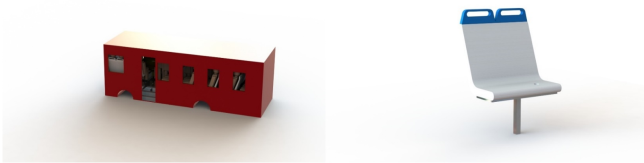

Figure 1: CAD design of bus and passenger seat (left to right).

Figure 2: Mannequin position: seated and standing (Left to Right).

Thus, the interior temperature of the bus is assumed to be ~42 °C.

2.3. Study and development of design

The 3D design of the bus is shown in Fig. 1. The design was done using SolidWorks 2019. The bus interior is designed to match the dimensions of TATA Starbus Series. The design consists of three major components: bus exterior, seats and manikins. Using the above components, a total of six were calculated and developed.

The bus consists of two compartments: driver and passenger. The compartments are of open-type i.e., no separation by wall. The driver compartment consists of a driver seat and four passenger seats. The passenger compartment consists of five two-seater arrangements on the left, six two-seater arrangements on the right and a five-seater arrangement in the back. Two sets of luggage carrier are also designed on either side of the bus just above the two-seater arrangement. Thus, while being full the bus can accommodate a total of thirty-two people along with the driver. Moreover, considering the ongoing trends an arrangement for eleven people have also been made in the bus while standing.

Along with that two mannequins are also designed, one mimicking standing and another mimicking seating position of the passengers inside the bus (Fig. 2). The detailed design of the assembly is given in the Appendix below.

2.4. CFD Simulation

The simulation for computational fluid dynamics was performed using Ansys 2018. CFX was selected as the tool for the simulation. With the design already done, all the designs were converted into a compatible file format (.STEP) and then analyzed using finite volume method. The volume extract is meshed into finite number of tetrahedral elements. Whole interior is defined as a fluid domain with three boundary condition defined as inlet, outlet and wall. The windows and doors are assigned as inlet, the back wall as outlet to study the flow and remaining faces as wall. The data from the analysis was studied under four major section, three being from passenger compartment: Left side namely A, right side namely B and aisle and one being the driver compartment, the analysis overall is performed for the major situation of bus being fully packed meaning all the seats are being seated and the aisle is also covered by standing passengers.

2.5. Selection and Standardization

After the completion of analysis, the datasets from the simulations were plotted using Microsoft Excel. Now, being based on

ASHRAE six condition for thermal comfort, the best possible outcome was selected. Additionally, every dataset was checked for variation and the selection was also done on the basis of least possible variation.

3. Results and discussion

The major research objective which are to analyze the velocity of the bus, interior temperature and turbulence model in the interior compartment of bus is performed accordingly. Different ventilation cases for fully packed (passenger seated as well as standing) bus are being analyzed as:

3.1. Case I (Existing Design Analysis)

The case depicts the condition where the bus is full with both standing and seated passenger and all windows are half open. The maximum temperature recorded among the measured region is 315.68 K in the Driver Compartment and the maximum velocity is 20.14 m/s in both A-Region a B-Region. The graphical representation of each section of the analysis is given in Fig. 3.

Here, it is observed that in A-region, the temperature distribution of upper, middle and lower plane is a flat curve. The temperature distribution of B-region is analogous to A-region in terms of upper, lower and middle section. Similarly, in case of driver compartment, it is observed that temperature of upper and middle plane too coincides and the temperature distribution curve of the lower plane is shifted a maximum of three degrees above the upper and middle plane. In case of the aisle, the temperature distribution of upper and upper stand-plane coincides and shifts about two degree above lower and middle plane which also coincides. The final figure above shows the velocity distribution at the above four regions with A and driver and B and aisle region having an intermingled curve with an increasing trend.

3.2. Case II (Optimized design analysis)

3.2.1. Front Roof Ventilation as Inlet

The case depicts the condition where the bus the bus has a roof ventilation in the driver compartment acting as inlet with all seated and standing passenger. The maximum temperature recorded among the measured region is 306.45 K in the Passenger Compartment: A-Region side and B-Region side and the maximum velocity is 23.21 m/s at A-Region. The graphical representation of each section of the analysis is shown in Fig. 4.

Here, it is observed that in A-region, the temperature distribution of upper, middle and lower plane is a smooth curve. The temperature of upper and lower curve lies in the same temperature region however the middle plane is having a distribution shift of around three degree upward. The temperature distribution of B-region is analogous to A-region. Similarly, in case of driver compartment, the upper and middle plane have a decreasing trend with maximum difference of three degree with each other and the lower plane has a steep increasing trend onwards second two. For the aisle, the temperature distribution of all the plane lie in the same temperature region and shows a decreasing trend. The final figure above shows the velocity distribution at the above four regions with all three having an intermingled curve with an increasing trend except for A-region.

3.2.2. Front Roof Ventilation as Outlet

The case depicts the condition where the bus the bus has a roof ventilation in the driver compartment with all seated and standing passenger. The maximum temperature recorded among the measured region is 308.9 K at Aisle and the maximum velocity is 23.21

Figure 3: Graphical representation of the parameters for operating condition.

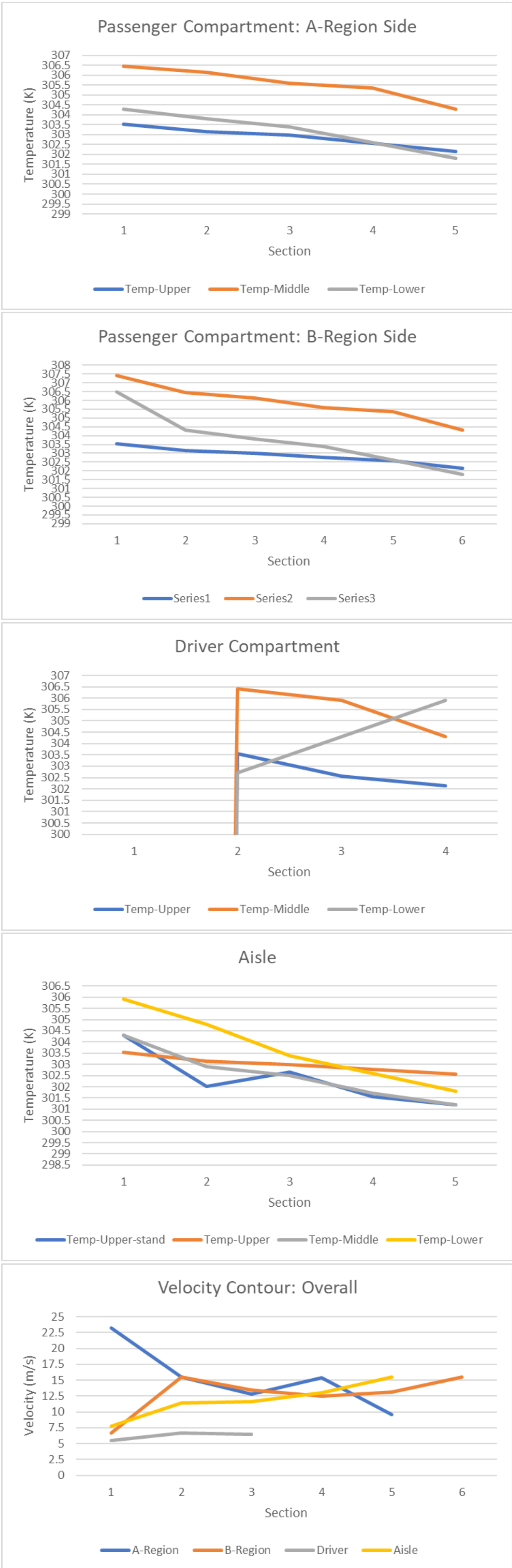

Figure 4: Graphical representation of the parameters for front roof ventilation as inlet.

m/s at Aisle. The graphical representation of each section of the analysis is shown in Fig. 5.

Here, it is observed that in A-region, the temperature distribution of upper and lower plane is intermingled with middle plane intersecting at section four. On the contrary, all the planes in B-region show a similar decreasing trend. Similarly, in case of driver compartment, all the plane shows a decreasing trend. For the aisle, the temperature distribution of all the region has a similar decreasing trend. The final figure above shows the velocity distribution at the above four regions with all four curves with a similar trend intersecting at section three and four.

3.2.3. Roof Ventilation Front and Back as Outlet

The case depicts the condition where the bus has roof ventilation in both driver and passenger compartment with all seated and standing passenger. The maximum temperature recorded among the measured region is 306.45 K at Aisle and the maximum velocity is 13.56 m/s at A-Region. The graphical representation of each section of the analysis is shown in Fig. 6.

Here, it is observed that in A-region, all the plane has a similar curve with a shift of one-two degree from each other. On the contrary, all the planes in B-region show a similar increasing trend. Similarly, in case of driver compartment, all the plane shows a decreasing trend. For the aisle, the temperature distribution of all the region has a similar decreasing trend. The final figure above shows the velocity distribution at the above four regions with all four-region showing an increasing trend intertwined to each other.

3.2.4. Roof Ventilation Front, Middle and Back as Outlet

The case depicts the condition where the has three roof ventilation with all seated and standing passenger. The maximum temperature recorded among the measured region is 307.01 K at Driver Compartment and the maximum velocity is 16.82 m/s at A-Region. The graphical representation of each section of the analysis is shown in Fig. 7.

Here, it is observed that in A-region, all the plane shows downward trend with curves intersecting at section two. The curve for upper and middle plane are similar while the curve for lower pane is a flat down. Similarly, all the planes in the region also shows a decreasing trend and like A-region, the upper and middle plane show a similar curve. In case of driver compartment, upper and middle plane shows a decreasing trend while upper curve is a up. For the aisle, the temperature distribution of all the region is intertwined to each other. The final figure above shows the velocity distribution at the above four regions with four showing an increasing trend.

3.2.5. Roof Ventilation Opening

The case depicts the condition where the bus has a single roof ventilation spanning from driver to passenger compartment with all seated and standing passenger. The maximum temperature recorded among the measured region is 299.8 K at Passenger Compartment: B-Region and the maximum velocity is 15.59 m/s at Aisle. The graphical representation of each section of the analysis is shown in Fig. 8.

Here, it is observed that in A-region, the upper and middle planes are intertwined to each other with lower curve on the rise. Similarly, the temperature distribution of B-region is analogous to A. In case of driver compartment, upper and middle plane are flat after section three while the lower curve is a down. For the aisle, the temperature distribution of all the plane is an increasing trend except for the lower plane. The final figure above shows the velocity distribution at the above four regions. In this case, three curves show similar downward trend except for lower plane.

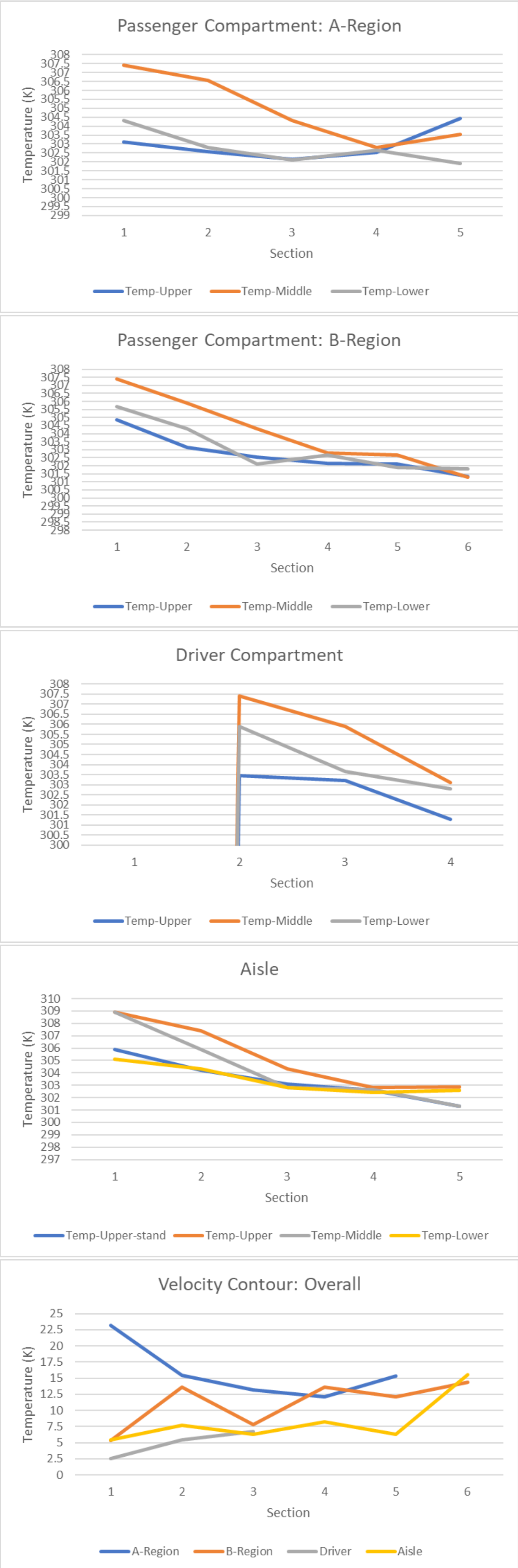

Figure 5: Graphical representation of the parameters for front roof ventilation as outlet.

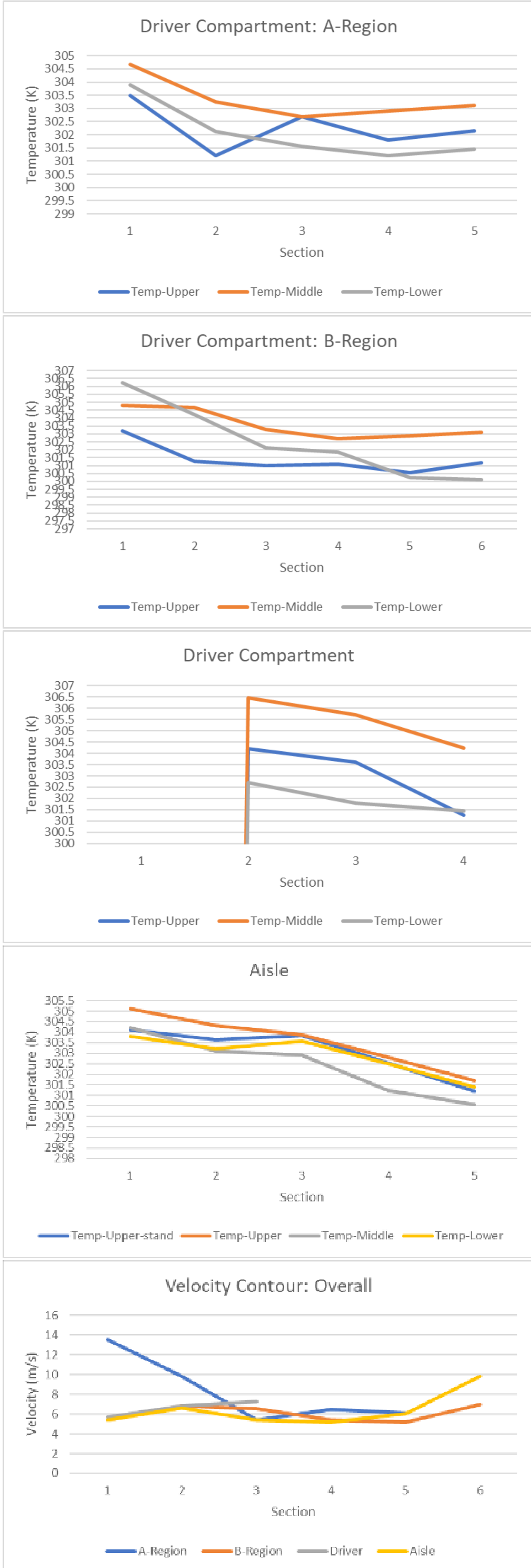

Figure 6: Graphical representation of the parameters for roof ventilation front and back as outlet.

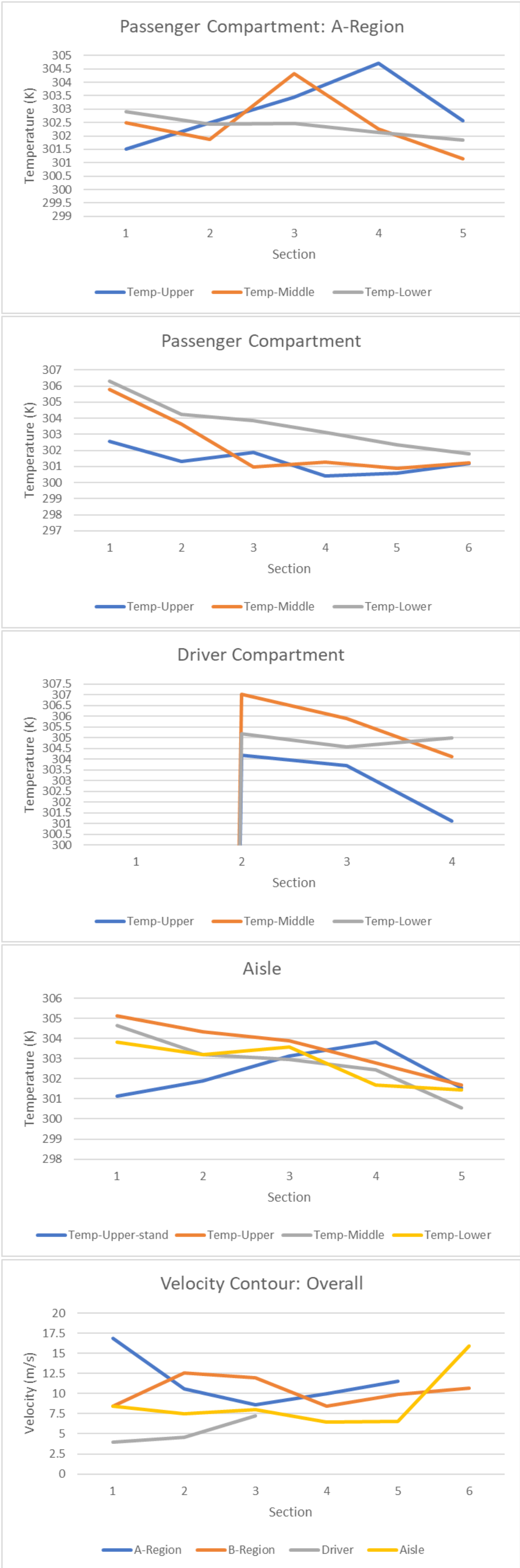

Figure 7: Graphical representation of the parameters for roof ventilation front, middle and back as outlet.

Figure 8: Graphical representation of the parameters for roof ventilation opening.

Table 3: Sample variance of the simulated cases.

Case	Variance
Operating Condition	8.37
Front Roof Ventilation as Inlet	2.41
Front Roof Ventilation as Outlet	3.65
Roof Ventilation Front and Back as Outlet	2.13
Roof Ventilation Front, Middle and Back as Outlet	2.39
Roof Ventilation Opening	0.16

The variance of the datasets of above cases are calculated and enlisted in Table 3.

Observing the data obtained, it is found that, the case with roof ventilation at the front and backside provides the optimum result among the optimized design with effective temperature of 305.53 K and mean velocity of 14.77 m/s. Similarly, it exhibits smallest variance of 2.77 among the other cases.

4. Conclusion

After the completion of the research, it is observed that with an appropriate ventilation system design, thermal comfort can be achieved for the passengers without the use of air-conditioning. From the study, it was found that roof ventilation has a direct effect in air flow inside the bus with optimum roof vent placement reducing the temperature inside the bus compartment up to 12 °C. However, the limitations of using only ventilation system still rises as people are directly in contact to harmful microparticles in the places where there is high amount of pollution. Moreover, the ventilation also creates drag decreasing the overall vehicular efficiency. Despite of the disadvantages, optimized ventilation system can be a great way of providing thermal comfort as the economy of the country hinders its ability to run air-conditioning vehicles everywhere on the road. Additionally, the tradition of non-air-conditioned vehicles are so deep rooted in the Nepalese routes that even replacement trials will not provide an immediate solution. Instead, the above demerits can be looked as further challenges and research can be done to solve the problem. Thus, optimized ventilation system is an optimum method for countering the current problem of inadequate thermal comfort experienced by the people traveling by bus in developing countries like Nepal.

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