Experimental Investigation of Air Circulation Using Duct System in a Non-AC Bus Coach

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Abstract. Public transport is the life line in many of the developing and under developed countries for the safe conveyance, i.e. also consider as economical. The major limitation in public transport (non-AC busses) Air Condition, is the lack of proper air circulation leading to suffocation and vomiting. The present research work emphasis on design and analysis of air flow duct system (non AC Busses) to increase the level of comfortance of the passengers, tools like solidworks software 2016 is used for 3D drawing, Hypermesh software 13.0 is for the discretization and ANSYS Fluent software 16.0 for the Computational Fluid Dynamic (CFD) analysis, from the experimental the airflow is found to be 10 m/s, and from the numerical analysis the airflow is found to be 9.8 m/s, by comparing the experimental and numerical results a negligible deviation of 2% is observed and it is within the limit.

Keywords: Air Circulation, Non-AC Bus, Passenger Comfort, Pollution.

1. Introduction
In most developing and developed countries, passengers travelling in public transport are common, especially in peak travel hours, difficult to provide seats for all passengers, so a high percentage of non-AC bus users across the country are standing in aisle. The analysis shows the air circulation for people standing in the aisle of non-AC buses is causing discomfort and suffocation [1], while majority of the airflow is concentrated on people sitting near the windows.

Suffocation is a general concept that includes many types of asphyxia, either due to the absence of air in the breathing area or due to obstruction of the external airways (smothering) or internal airways (Choking), or due to pressure on the chest or abdomen or the location of the body preventing respiratory movement (traumatic and positional asphyxia, respectively). Especially in sunny days have complain of headache, vomiting [2] etc.

Currently there is no system in non-ac buses that regulates or purifies air in order to help ease comfort of people standing in the coach, the only current alternative is to employ the use of AC buses but it is impossible to convert all non-AC buses to AC without increasing the cost of Journey.
substantially [3]. A simple and affordable solution to increase the uniform air flow that cools the entire bus is to impart duct system in non-AC buses. This results in improving the passenger the and hence improving passenger comfort and greatly reducing fatigue of travelling long distances [4-6]. When a bus is moving, there is air resistance pushing against wind and the air naturally wants to gush into the bus to equalize pressure [7]. This air pressure is utilized by using a duct that is placed in the optimal location using CFD analysis [8]. Therefore increasing the air supply enhances the breathing ability of the passenger thereby increasing the comfort level [9].

The blower as an auxiliary unit facilitates in proper air circulation for the passengers when the bus is stationary. The duct size and heating load in a Non AC bus coach is calculated based on the standards [10-15]. The present work focuses on the development is that it's aimed at meeting all the standards set by ISHRAE (Indian society of Heating, Refrigerating and Air conditioning manufactures association) and the use of natural resources, does not pollute like AC does.

Development of duct system for proper air circulation in a non-AC bus coach according to ISHRAE standards will improve the airflow in a non-AC bus by providing a proper duct system.

2. Materials & Methodology

In the present work the experimental investigation for a duct system is carried out. The model was fabricated using the Galvanized Iron (GI) sheets, pop rivets, neoprene gasket and a blower used to generate the air. The generalized expressions used to obtain the amount of air required to increase the passengers comfort and to reduce the cabin temperature has been discussed below, Table 1. Illustrates the material considered for the duct fabrication along with its descriptions.

| Table 1. Material with description |
|-----------------------------------|
| Material                        | Description/Specification |
| Pop Rivet                       | POP rivets are used to connect two pieces of material in a quick efficient manner with a hand riveter or pneumatic rivet gun. |
| Neoprene Gasket                 | Neoprene is a material made from synthetic rubber designed to be flexible, durable, resilient, and very resistant to compression and liquids such as water, oil, and other solvents. |
| Blower                          | A 14kw, High performance blower is used that is capable of producing 353CFM (Cubic feet per minute) and a maximum of 2500 RPM (Revolutions per minute). |
| Volume Control Damper (VCD)     | Automatically maintains a desired volume of airflow independent of pressure changes, used in Heating, Ventilation, coolers etc. |

The fabrication of duct was carried out using GI material. The mechanical properties of GI material considered in this present work have been tabulated in Table 2.

| Table 2. Material properties of GI |
|-----------------------------------|
| Grade | Modulus of Elasticity(E) | Bulk Modulus(G) | Poisson’s Ratio (μ) | Shear Modulus (τ) | Density (ρ) |
| IS 1079 | 200 GPa | 340 GPa | 0.29 | 80 GPa | 7.8 g/cc |

2.1 Process parameters.
The scaled model was considered and tested experimentally using a high speed blower and an anemometer to record flow rate at the outlet of ducts. The results were compared with the values obtained from the CFD analysis, Table 3. Illustrates the different inlet flow velocities of duct.

| Table 3. Experimental Input velocity |
|-----------------------------------|
| SI No. | Velocity (m/s) |
| 1 | 30 |
| 2 | 20 |
| 3 | 18 |
| 4 | 15 |
2.2 Generalized expression to obtain the quantity of air required for optimal passenger comfort.

Volume of air was measured in CFM (Cubic feet per minute) as shown in equation 1[15]. It is a measurement of the velocity at which air flows in/out of a space. The amount of air required to increase the passenger comfort is very much essential when dealing with HVAC (Heating Ventilation and Air Condition) or designing of ducts. Since, the obtained volume of air facilitates in designing the ducts and airflow control valves for better circulation of air.

The heat disipated in the bus =

\[ \sum (\text{Total heat dissipated by the passanger} + \text{Heat dissipated from the roof} + \text{Glass heat} + \text{Heat from the engine and infiltration load}) \]  

(1)

The Passenger Metabolic load is the amount of heat generated from the passenger is calculated by using the equation 2[15].

\[ Q_{\text{met}} = \text{Sum of (M} \times \text{BSA)} \]  

(2)

Where M is the passenger metabolic heat production rate and BSA (Body Surface Area) that was obtained using the equation 3[15]. Based on activity levels and occupation for a driver and a sitting passenger, the values can be considered as 85 W/m\(^2\) and 55 W/m\(^2\) [15]

\[ \text{BSA} = 0.202 \times W^{0.425} \times H^{0.725} \]  

(3)

Where,

- W = Weight of passenger in kg
- H = Height of passenger in m

W=60 Kg and H=1.5m considered for driver and passenger (Indian adult average height and weight is considered in this present work)

Infiltration is an unintended or accidental introduction of outside air into a non-AC bus, usually through windows in the bus envelope and through the use of doors for passage. It is obtained by using the equation 4 [15].

\[ \text{Air Infiltration Load} = \text{Amount of air leaked} = \frac{V}{2} \text{ m}^3/\text{hr}, \]  

Where,

- V = vehicle speed in km/h Assuming 72 kmph,
- Air volume leaked = 36 m\(^3\)/hr.

\[ = 36 \times \text{Air density} \times (\text{Enthalpy of Infiltered Air} - \text{Enthalpy of Cabin Air}) \]  

(4)

Sensible heat given for roof sheet load is the amount of heat generated due to roof top of the non-AC bus and is obtained using the equation 5[15].

\[ Q = A \times U \times \Delta t \]  

(5)

Where,

- A= Area m\(^2\),
- U = Heat transfer coefficient W/m\(^2\)K from equation 6 [12],
- \(\Delta t\) = Change in temperature K,

\[ U = \frac{1}{\frac{1}{h_1} + \frac{\Delta x}{k} + \frac{1}{h_2}} \]  

(6)

Where,

- \(h_1\) and \(h_2\) = convection heat transfer coefficient of outside and inside surface in W/m2K from equation 7[15],
- K= Thermal Conductivity in W/mK,
- \(\Delta x\) = Thickness in m,

\[ h=0.6+6.64\sqrt{v} \]  

(7)
Where, 
V is the velocity of the vehicle in m/s.
Sensible heat given for portion of glass load is defined as the amount of heat generated when the surface of the glass is exposed to direct sunlight. In the same manner the window glass of the non-AC busses generates huge amount of heat inside the bus cabin leading to passenger’s discomfort. The expression considered for obtaining the sensible heat is depicted in equation 8 [15][10].

$$Q = A \times U \Delta t + \text{Diffused radiation + Direct radiation}) \times \cos(i) \times A \times \tau$$  \hspace{1cm} (8)

Where,
\( i \) = Sun’s incidence angle on glass,
\( \tau \) = transmissivity of glass.

\( (U = 36.98 \text{ W/m}^2\text{K} \text{ from the expression} \text{ and} \ K = 0.756 \text{ W/mK for glass,} \Delta x = 0.04 \text{ m}) \)

Heat generated by blower motor is the heat from the engine during traveling is expressed in equation 9

\( = \text{Blower Wattage x Load factor / Efficiency} \)

Area of Duct required for a flow rate is given by

\[ \text{Area} = \frac{\text{CFM}}{\text{V}} \]  \hspace{1cm} (10)

3. Results and Discussion

3.1 Airflow calculation
The analytical results are obtained based on the following assumption, air flow is consider only from the duct system and the air entering from the windows are not consider in the present work. However to obtain the amount of heat generated in a bus, the following assumptions were considered, direct radiation from the glass, roof top, engine and heat from the passenger. Minimum amount of air required to travel in a non-AC bus with seating capacity (MiTR: Ashok Leyland make 28 seat school bus) of 28 passengers is obtained from the equation 1

Passenger metabolic load value is obtained using equation 2 i.e.,

\( Q_{\text{met}} = 2502.5 \text{W} \)

Air Infiltration value is obtained using equation 4 i.e.,

\( \text{Air infiltration} = 902.8 \text{ W} \)

Sensible heat given for Roof sheet load value is obtained using equation 5 i.e.,

\( Q = 320.76 \text{ W} \)

Sensible heat given for portion of glass load value is obtained using equation 8 i.e.,

\( Q = 3234.37 \text{ W} \)

Heat generated by blower motor from equation 9

\( Q = 202 \text{ W} \)

Total Heat load on a bus is \( = 2502.5 + 902.8 + 320.76 + 3234.37 + 202 \)

\( Q = 7162.43 \text{ W} \)

For a safer side considering at the peak hour and peak load condition 20% of additional value is considered for the calculation.

\( Q = 2.44 \text{ Tr (Tonnage)} \)

Total CFM required is \( = 2.44 \times 315 = 768.6 \approx 800 \text{ CFM} \)

Area = 1.33 feet\(^2\), or Area = 0.123 m\(^2\) from equation 10

Cross sectional area of duct required for the comfortable traveling in a non-AC bus is 1.33 ft\(^2\) or 0.123 m\(^2\), but in the present work a square duct of cross-sectional area 0.0056 m\(^2\) is considered.

3.2 Designing of Scaled Duct
For the conduction of the experiment a scaled model of a duct with a suitable scaling factor of 1:20 was considered for designing and fabrication. The tools such as solid works for drafting, Hyper-mesh for discretization and ANSYS Fluent for CFD analysis were considered in this present work. The main
duct with sub branch duct is shown in the Figure 1 and Figure 2 respectively (all dimensions are in millimeters) having the cross section 75mm x 75mm. the galvanized Iron material was considered to prevent the corrosion. The assembly of the duct was carried out with the help of rivets, gasket and VCD. The analytical work is conducted

![Figure 1. 3D Model of scaled duct](image1)

![Figure 2. Drawing of scaled duct with specification.](image2)

3.3 Discretization
The discretization was carried out for the scaled duct model, the tetrahedral elements is used for the CFD analysis, tetra mesh is preferred in CFD because these elements can fit better complex geometry and it shown in Figure 3 and Figure 4.

![Figure 3. Mesh Model of scaled Duct](image3)

![Figure 4. Discretization of scaled duct model](image4)

3.4 CFD analysis
Analysis was carried out using ANSYS Fluent software, duct model is subjected to varying inlet velocity, and the results are tabulated in Table 4. The boundary condition was applied to permit the flow of air to enter and exit the duct system. Incompressible flow velocity at inflow and outflow was considered in this present work. Air from the inlet of main duct passes through the symmetric sub braches as shown in Figure 5. The entire duct system is located below the bus roof with regulating unit for the uniform air circulation. The filters are provided for the air purification. These filters are
made up of spun fiberglass material or cloth enclosed in a cardboard frame.

![Figure 5. Analysis of scaled duct model](image)

![Figure 6. CFD results of scaled duct](image)

3.5: Results of CFD analysis summary

Table 4 shows the result of CFD analysis, the duct model is subjected to varying velocity, in this study analysis is carried out for velocity of 15, 18, 20 and 30 m/s. and the velocity at the outlet is noted at four different positions, i.e., branch 1 and 2 of outlet A and B.

| Blower Speed | Branch 1 Outlet A m/s | Branch 1 Outlet B m/s | Branch 2 Outlet A m/s | Branch 2 Outlet B m/s |
|--------------|------------------------|-----------------------|-----------------------|-----------------------|
| 30 m/s       | 9                      | 10                    | 12                    | 10                    |
| 20 m/s       | 8                      | 7                     | 10                    | 7                     |
| 18 m/s       | 8                      | 6                     | 8                     | 7                     |
| 15 m/s       | 6                      | 5                     | 7                     | 6                     |

3.6 Fabrication of scaled duct model

The scaled model of duct is fabricated and was assembled in the laboratory using pop rivet and gasket, to ensure leak-proof joint in the duct system and it is made up of GI (Galvanized Iron) sheet to avoid corrosion. The assembled duct is shown in Figure 7 and Figure 8. The material properties of GI sheet considered for the fabrication is depicted in Table 2. Figure 9 shows the duct system with uniform air circulation from the blower. The assembled duct model is fitted with volume control damper in the main duct, it ensures equivalent amount of airflow is happening on either side of duct i.e. sub branches. At the outlet of duct VCD is placed to control the amount of air required for a passenger comfort.
3.7 Experimental results of the fabricated scaled model

Table 4 shows the experimental results conducted with the varying velocity. The duct was subjected to 15, 18, 20 and 30 m/s of velocity at the inlet, and the outlet velocity measured at the branch 1, 2 of section A and B using anemometer.

| Blower Speed (m/s) | Branch 1 A (m/s) | Branch 1 B (m/s) | Branch 2 A (m/s) | Branch 2 B (m/s) |
|-------------------|-----------------|-----------------|-----------------|-----------------|
| 30                | 10              | 9               | 12              | 10.2            |
| 20                | 7.8             | 8.5             | 10.4            | 9               |
| 18                | 7.9             | 8               | 7.5             | 7.7             |
| 15                | 5.7             | 5.5             | 6.9             | 6.7             |

4. Conclusion:

From the present experimental and numerical investigation the following conclusions were drawn.

- The minimum amount of air required for the comfortable traveling in a non-AC bus using duct system was found to be 8594.91 W or 2.44 Tr (Tonnage).
- Design and Analysis was carried out to obtain the outlet velocities at various branches of the duct system.
- The numerical results (velocities) were validated for the fabricated scaled model and values are found to be well agreed with each other.
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