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A Review on Flow Analysis Inside a Tractor Cabin Selecting Vent Location and Glazing

Sai Rumde[1], Kunal Thakare[2], Rijul Kotian[3], Harsh Chavan[4]

[1-4]B.E. Students, Automobile Department, Saraswati College of Engineering, Navi Mumbai, MAHARASHTRA, INDIA

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Abstract - *Two types of methods were used such as PMV and PPD. PMV stands for Predicted mean vote and PPD stands for Predicted percentage of dissatisfied were used to evaluate thermal comfort, humidity, air velocity, and the temperature for calculating PMV were simulated Based on the temperature measurement positions proposed in SAE J1503 temperature and PMV measurement locations were used. Three locations were selected for the air conditioner vent and those were ceiling dashboard and side column. These locations were selected on the basis of the actual location of the air conditioner vent inside the tractor cabin. Lowest energy loss was observed when the air conditioner vent was positioned on the dashboard. It was observed, when vent was located at the front of the operator on the dashboard the average temperature was 22.2 °C, which showed a deflection of 3 °C lower than that at other locations. In addition, 0.53 was the observed average PMV value, which was less than 1 at other location. Most comfortable environment was observed inside the tractor cabin was generated when the air conditioner vent was located on the dashboard. This simulation showed a temperature difference of 2 °C or less from the measured temperature. The present study aims to investigate spectral solar radiation effect on the temperature distributions and air flow in a passenger compartment. A device named spectrophotometer is used in this case to achieve by measuring the transmittance and reflectance of the different glass for analyzing special characteristics of the windshield.*

Key Words: Thermal Comfort, Computational fluid dynamics (CFD), Tractor cabin, Vent position determination, predicted mean vote (PMV), Predicted Percentage of Dissatisfied (PPD), Glazing

1. INTRODUCTION

Based on people-related factors, such as age, gender, health status, clothing, and work intensity, and environmental factors such as season, weather and smell IEQ is assessed. Comfort factors are also controlled, such as lighting, noise, temperature, humidity, and air quality at an appropriate level to improve IEQ. Based on the conditions created by experience thermal environment of HVAC systems for tractors is being estimated, such as measuring the time required to reach a target temperature in a specific region inside a cabin. 'But this experience-based evaluation method was not suitable for evaluating actual thermal comfort because it does not consider the influences of an operator's radiation heat, radiation temperature, and amount of clothing. Predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) are commonly used methods for evaluating thermal comfort" [9]. They were developed by Fanger (1972) and established as standard through ISO 7730. Madsen et al. (1986); Nilsson et al. (1999); Nilsson and Homler (2004) proposed equivalent homogeneous temperature (EHT) as an evaluation method for human body parts; this method is being widely used. 4 air conditioner vents installed on which thermal flow analysis was performed on front of the vehicle. By using PMV, PPD, and EHT thermal comfort was evaluated according to the variations in the air conditioner vents. Han et al. (2001, 2010) "analyzed internal heat flow according to the temperature and physical properties of vehicle glass, the incident angle of the sun, and humidity, and they evaluated thermal comfort using the EHT method and virtual thermal comfort engineering method" [12]. Ivanescu et al. (2010) confirmed that solar radiation energy should be taken into consideration in evaluating the temperature change characteristics and thermal comfort of a vehicle during driving". When thermal comfort was evaluated using simulation models, at first heat flow analysis was performed; the thermal comfort is evaluated based on the heat flow analysis results. Thermal boundary condition for numerical analysis were applied on the basis of previous heat flow analysis work. Air flow was tested after selecting 4 different vents locations. As industries have been asked for decrease in the energy consumption. In the field of the heating, refrigeration, and air conditioning, energy consumption is so large that a further reduction is indispensable. The automobile industries are facing the issues of improving fuel economy with the utmost comfort and luxury in the automobiles. Glazing derives from the middle English for 'Glass', is a part of a wall or window made of glass. Glazing is when you paint a thin layer of minerals and glass onto a ceramic piece.

2. THEORY

There are ultrafine tungsten wires within the PVB interlayer and are so thin that they are invisible, but can clear the frozen windscreen in 2minutes. While this glazing helps with blocking infrared (IR) or reflecting capability to reduce the heat inside the cabin and helps in cooling the cabin atmosphere. This laminated glazing also provides security. While on higher preferences this glazing comes with active noise cancellation, controlled light transmission.

There are many types of glass materials available in the market mainly includes ingredient like silica with additives like MgO, AL2O3, B2O3. By using this additive in various amounts, we obtain product with different characteristics.

"Mainly the windshield is composed of:

72% of SiO2

14% of Na2O

10 % of CaO

4% of MgO" [4]

The glass which is being used is traditionally flat but then to obtain the windshield shape or curvature it is been heated and then using bending operations result is obtained. The heating is done of about 600 C.

There are different types of glass:

Laminated Safety Glass - The laminated windscreens glass is bonded with cellulose nitrate interlayer. It was observed that by adding the moisture content within the PVB layer the safety of LSG windshield was increased. Toughened Safety Glass – As there was trend of the increase in the glazing area and removing window frames. So, for this LSG was found to be weak enough to with stand the door slamming, while this led to security issues. While they introduced this TSG with high mechanical and thermal strength.

Colored Glass – The iron oxides provides a green colored layer over glass which helps in cooling the cabin faster. In today's era, the process of installing fixed glazing units into the vehicles is carried out in one of three automated processes which are – injection moulding, resin injection, or extrusion of profiles. This had helped in providing the glazing with maintaining the aesthetics as well as aerodynamics.

3. METHOD

Compared to automobiles, the heat input from the engine and transmission in agricultural tractors is higher. Therefore, in this study, the thermal load was replaced by the measured temperature as boundary condition. "The operating conditions for thermal load were applied i.e., the set outdoor temperature, the rated engine RPM, and the rated PTO RPM and the temperature in each part of the cabin was measured. The air conditioner operation was switched off and temperature was measured until all sensor values converged. The converged temperature value was set as the thermal environment boundary condition assuming that the converged temperature is continuously applied to the tractor cabin." [1] The input cold area is depended on the air volume and temperature set by the operator. The optimal location of the air conditioner vent was derived by evaluating thermal comfort while changing the location of the air conditioner vent in the flow analysis model for the agricultural tractor cabin. This method for evaluating thermal comfort was referred from SAE J1503, which provides a method for testing. This study shows the flow analysis performed inside a tractor cabin using the k-ε turbulence model in a commercial CFD analysis software called Star-CCM+. The Reynolds averaged Navier-Stokes equations formed the governing equations. From Equation. (1)– (3) (Anderson and Wendt, 1995), the continuity, momentum and energy equations were formed.

<Continuity equation>

$$\nabla \cdot (\rho \vec{v}) = 0 \quad (1)$$

<Momentum equation>

$$\nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\bar{\tau}) + \rho \vec{g} \quad (2)$$

<Energy equation>

$$\nabla \cdot (\vec{v}(\rho E + p)) = \nabla \cdot \left(k_{eff} \nabla T - \sum_i h_i \vec{J}_i + (\bar{\tau}_{eff} \cdot \vec{v}) \right) \quad (3)$$

where,

ρ = density(kg/m^3)
$\vec{v}$ = velocity(m/s)
p = static pressure(N/m^2)
$\bar{\tau}$ = stress tensor(N/m^2)
$\vec{g}$ = gravitational body force(N)
k_{eff} = thermal conductivity($\frac{W}{m}$ °C)
T = temperature(°C)
h_i = specific enthalpy(J/kg)
$\vec{J}_i$ = diffusion flux of species($\frac{mol}{m^2}$ s)
E = energy per unit mass(J/kg)
$\bar{\tau}_{eff}$ = effective stress tensor(N/m^2)

From Equations. (4) and (5), the equations for transport turbulence kinetic energy (k) and turbulent dissipation rate (ε) were formed respectively.

<k-ε turbulence model transport equations>

$$\nabla \cdot (\rho k \vec{v}) = \nabla \cdot \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \nabla k \right] + G_k + G_b - \rho\varepsilon - Y_M + S_k \quad (4)$$

$$\nabla \cdot (\rho \varepsilon \vec{v}) = \nabla \cdot \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \nabla \varepsilon \right] + \rho C_1 S \varepsilon - \rho C_2 \frac{\varepsilon^2}{k + \sqrt{\nu\varepsilon}} + C_{1\varepsilon} \frac{\varepsilon}{k} C_{3\varepsilon} G_b + S_\varepsilon \quad (5)$$

where

$C_1 = \max\left[0.43, \frac{\eta}{\eta+5}\right]$: constant (dimensionless)

$\eta = S\frac{k}{\varepsilon}$

$S = \sqrt{2S_{ij}S_{ij}}$: modulus of the mean rate – of – strain tensor (1/s)

$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$: turbulent viscosity (m^2/s)

$C_\mu = 0.09$: constant for an inertial sublayer in an equilibrium boundary layer (dimensionless)

$\sigma_k = 1.0$: turbulent Prandtl number for k (dimensionless)

$\sigma_\varepsilon = 1.2$: turbulent Prandtl number for ε (dimensionless)

$G_k = \mu_t S^2$: turbulent kinetic energy generated owing to mean velocity gradients (J/kg)

$G_b = \beta g_i \frac{\mu_t}{P_{rt}} \frac{\partial T}{\partial x_i}$: turbulent kinetic energy generated owing to buoyancy(J/kg)

$\beta = -\frac{1}{\rho}\left(\frac{\partial \rho}{\partial T}\right)_p$: coefficient of thermal expansion (1/°C)

g_i = component of the gravitational vector in the ith direction(m/s^2)

$P_{r_t} = 0.85$: turbulent Prandtl number for energy (dimensionless)

$Y_M = 2\rho\varepsilon M_t^2$: contribution of the fluctuating dilatation in compressible turbulence(W/m^3)

$M_t = \sqrt{\frac{k}{a^2}}$: turbulent Mach number (dimensionless)

$a = \sqrt{\gamma RT}$: speed of sound (m/s)

$C_{1\varepsilon} = 1.44$: constant (dimensionless)

$C_2 = 1.9$: constant (dimensionless)

$C_{3\varepsilon} = \tanh\left|\frac{v}{u}\right|$: constant (dimensionless)

S_k, S_ε: user-defined source terms (J/kg)

- 3.1 Predicted Mean vote (PMV)

For the evaluation of thermal comfort inside a tractor cabin, an index is used which is called PMV. It is a measure of human warmth in terms of quantity and is defined as follows: 0: thermal neutral state; −3: cold; −2: cool; −1: slightly cool; +1: slightly warm; +2: warm; +3: hot. Here, the value of PMV was obtained using six thermal environmental variables and the thermal load acting on human body from Eq. (6).

$$PMV = (0.303e^{-0.036M} + 0.028)\{(M-W) -3.05\times10^{-3}[5733-6.99(M-W)-P_a] -0.42[(M-W)-58.15] - 1.7\times10^{-5}M(5867-Pa) -0.0014M(34-t_a) - 3.96\times10^{-8}f_{cl}\left[(t_{cl}+273)^4 - (\bar{t}_r+273)^4\right] -f_{cl}h_c(t_{cl}-t_a)\} \quad (6)$$

where

$$t_{cl} = 35.7 - 0.028(M - W - I_{cl}\{3.96\times10^{-8}f_{cl}[(t_{cl}+273)^4 - (\bar{t}_r+273)^4] + f_{cl}h_c(t_{cl}-t_a)\}$$

$$h_c = \begin{cases} 2.38(t_{cl}-t_a)^{0.25} & \text{if } \frac{2.38(t_{cl}-t_a)^{0.25}}{\sqrt{v_{ar}}} > 12.1 \\ 12.1\sqrt{v_{ar}} & \text{if } \frac{2.38(t_{cl}-t_a)^{0.25}}{\sqrt{v_{ar}}} \le 12.1 \end{cases}$$

$$f_{cl} = \begin{cases} 1.00 + 1.290 I_{cl} & \text{if } I_{cl} \le 0.078 \quad m^2\cdot K/W \\ 1.05 + 0.645 I_{cl} & \text{if } I_{cl} > 0.078 \quad m^2\cdot K/W \end{cases}$$

M = Metabolic rate(W/m^2)

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W = Effective mechanical power(W/m^2)

I_{cl} = Clothing resistance(m^2 K/W)

f_{cl} = Clothing surface area factor (dimensionless)

t_a = Air temperature(°C)

$\bar{t}_r$ = Mean radiant temperature(°C)

v_{al} = Relative air velocity(m/s)

P_a = Water vapor partial pressure (Pa)

h_c = Convective heat transfer coefficient($\frac{W}{m^2}$ K)

t_{cl} = Clothing surface temperature(°C)

'This study has the assumptions made following the provided in ISO 7730 and ISO 14505-1. Unknown values were the result of repeated calculations using CFD analysis. Parameter M was used for the operator of the tractor given in ISO 14505-1. Parameter equals to be the sum of 0.5 clo, corresponding to the clothing insulation index in summer and 0.1 clo, corresponding to the index of seat insulation. These values are referred from ISO 7730. Relative humidity was the summer mean relative humidity value described in ISO 7730.'[1]

$$M = 70\ W/m^2 (1.2\ met)$$
$$W = 0\ W/m^2$$
$$I_{cl} = 0.093\ m^2K/W(0.6\ clo)$$

Relative humidity = 60%

- 3.2 Predicted percentage of dissatisfied (PPD)

PPD is an index used to predict the the proportion of people feeling too cold or too warm for thermal equilibrium in terms of quantity. PPD can be obtained from Eq. (7) if the PMV is determined. People with thermal discomfort in a group can also be predicted using PPD.

$$\mathbf{PPD} = 100 - 95e^{(-0.03353PMV^4 - 0.2179PMV^2)} \quad (7)$$

- 3. Material for vent location and glazing

4. Material

For Vent Location: This study uses a model of tractor TYM TX1500.

For Glazing: As the front windshields are made of laminated glass, and the sidelights and backlights of tempered glass. The front laminated glass helps in protecting the driver from shattering of the glass. This is because of the glazing which is thin plastic sheet in between two glasses which absorbs the glass pressure during accidental situations. Due to glazing some visible light enters the glass but most of the IR and UV energy is reflected away and hence is the most effective at maintaining the thermal comfort inside the vehicle cabin. "Even the use of blinds is done to reduce visible lights, glare and increase the privacy within the cabin. While the incidence of the sunlight, blinds capture and radiates solar heat that comes through the glass and expel it upwards in the vehicle.' [2]

4.1 Alternate Glazing systems on the market

"Some alternative glazing systems have been introduced into the open market with varying degrees of success. Bi-laminate and tri-laminate glazing were developed as alternatives to LSG that has traditionally been significantly heavier than TSG for side windows. A Bi-laminate system consists of a singly ply of TSG on the exterior surface and an inner, flexible plastic film of one or more layers. A suitable protective coating (either abrasion resistant or self-healing) is then applied to the inner polymer surface. A tri-laminate system is a slightly different approach where two thin layers of toughened glass are bonded to either side of a thicker polymer in order to provide stiffness, scratch, and chemical resistance to the polymer. There are limited number of polymer glazing systems that have actually made it beyond concept stage and into real-world vehicles. They have nearly all been made from PC." [2]

5. LITERATURE REVIEW

[1] The analysis on STAR CCM+ was referred from the following paper. Boundaries were set as given below;

Monitor seat and steering were adiabatic where in heat flux was set 0. Driver-Head, left foot, left hand, lower left arm, lower left leg, lower right arm, lower right leg, right foot, right hand, torso, upper left hand, upper left leg, upper right arm, upper right leg heat source was set at 40W. There were 4 AC outlets whose temperature were set at 300K, turbulence intensity was 0.01 and turbulence velocity ratio was 10. Bottom panel temperature was 60.5^0 C and heat transfer coefficient was $55Wb/m^2K$.

Ambient temperature and heat transfer coefficient for cabin boundaries are as follows:

Cabin console- ambient temp35^0 C, heat transfer coefficien65 Wb/m^2K

Left window- ambient temp53.5^0 C, heat transfer coefficient

20 Wb/m^2K

Outlet wall- ambient temp 35^0 C heat transfer coefficient

55 Wb/m^2K

Rear window- ambient temp50^0 C, heat transfer coefficient 18 Wb/m^2K

Right window- ambient temp55.5^0 C, heat transfer coefficient

20 Wb/m^2K

Heat flux for roof was 850 Wb/m^2K

For Windscreen ambient temperature was 72.5^0 C and heat transfer coefficient 48 Wb/m^2K

7 derived temperature points was assumed.

Stopping criteria was as follows:

Maximum inner iterations-10,

Maximum physical time-1000 seconds,

Maximum steps-10000

6. CONCLUSIONS

It was observed that the minimum kinetic energy loss was observed when the location of the vent was at the operator's front on the dashboard and PMV calculated was 0.53 and that state was considered to be a pleasant state. This state was the most optimal for use in summer driving conditions because it was observed that the positions around the sides and the operators head were cool. PPD method was used, less than 11% operator's experienced discomfort. As a result of analyzing the temperature and PMV, it was observed and confirmed that the air vent mounted on the dashboard, provides the most comfortable environment inside the cabin. In the present study, extensive CFD simulations were conducted to examine the influence of spectral solar radiation and properties of glass on air flow and temperature distributions in the passenger compartment. This method provides proper measure of transmittance and reflectance with respect to wavelength for different glass types and analyzes the optical characteristics of glass. We came to the following conclusion based on the results. Nearly 99% of Solar energy is distributed in the wavelength range from 280 nm to 2500 nm, in solar irradiation, while more than 80% of solar irradiance is observed in near-infrared range of about 280 nm to 1100 nm. Near-Infrared range is the wavelength where more than 50% of solar radiation is transmitted and absorbed. This proves that transmitted and absorbed radiative energy should be considered in the near-infrared region.

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