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Field Measurement of Air Velocity and Temperature Factors that Influence the Thermal Comfort in Shuttle Bus

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ABSTRACT

Good public transportation that can offer a pleasant peaceful and relaxing environment is necessary for improving people's interest in using it. Thermal comfort is determined in this study by measuring the air velocity and temperature of the air-conditioning from the outlet. Both data are taken using a digital anemometer and thermocouple with three replications for reproducibility. For data collection, a 10-row shuttle bus was held immobile for 30 minutes. According to the data, outlet 5 received the highest air velocity and the lowest temperature, at 9.12 ms^{-1} and 13.6 °C, respectively. It was also discovered that the design of the air-conditioning ducting impacts the reachability of cooled air to the farthest outlets, adversely affecting the target cool temperature and passenger comfortability. It is suggested that in order to promote the attractiveness of public transportation, the inner bus compartment and air-conditioning system in hot countries should prioritise thermal comfort.

1. Introduction

Air-conditioned buses represent a large part of public transit in several countries around the world. The most important factor in providing a comfortable and healthy ambiance for passengers in a bus cabin is thermal comfort. It is discovered that the cooling effect of windy weather in subtropical climates was discovered increases the number of ridership in particularly remote areas [1]. For the thermal comfort of the passengers, a bus passenger compartment and other human-occupied spaces require an air-conditioning system [2] because of its temperature, speed, direction, and volume flow rate, indoor air can be uncomfortable [3]. In these buses, inadequate cabin air circulation is a primary source of passenger discomfort. Inadequate air circulation in a closed space may cause suffocation and discomfort, especially on hot sunny days when symptoms such as headache and vomiting have been reported [4].

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Thermal comfort is a person's satisfaction with the thermal environment around them. Environmental factors, such as air temperature, humidity, air velocity, and radiant temperature, influence it, while individual factors include clothing, activities, and individual situation [5]. The air temperature, radiant temperature, humidity, air velocity, clothing insulation, and metabolic heat are among the six elements that influence the thermal comfort level in general. Fohimi *et al.,* (2020) define the variables that influence the atrium ventilation system can be divided into three categories: external variables such as ambient and outdoor temperature, solar radiation, and wind, internal variables such as internal heat load, expected comfort level, and ventilation technique such as natural ventilation or forced ventilation. Other studies defined thermal comfort factors as the size of the space, the number of passengers, the size of the air vents, and the ventilation system [7]. A study investigated desired thermal comfort values such as temperature distribution, relative humidity ratios, and air velocities inside the bus [8]. These parameters can be analyzed together by altering the secondary parameters of air-conditioning parts in the bus cabin. Hossam *et al.,* [9] investigated the thermal comfort of passengers using various methodologies such as varied outlet design and the effect of outlet angles by modulating the velocities of the air-conditioning system. Aliahmadipour *et al.,* [10] studied the thermal comfort level on a heated mannequin by applying temperature and velocity parameters and discovered that inconsistent air distribution is associated with compartment design. It was also shown that using a hybrid ventilation system can improve the quality of both air distribution and thermal comfort in railway coaches [11]. Chang *et al.,* [12] stated that the number of passengers in the cabin also influences the air velocity speed. Ismail and Jamil (2020) modified the number and arrangement of the exhaust fans in their study to provide proper thermal comfort in the badminton hall. They discovered that the primary goal is to reduce the temperature at the wall. This statement was supported by Widiastuti *et al.,* (2020), who found that in the afternoon, the wall temperature absorbs more heat from solar radiation and requires more energy to cool the indoor space.

The average temperature was measured at the front, center, and back of the bus cabin, with each mean value based on ten readings [15]. Shafie *et al.,* [16] conducted the experiment by positioning the equipment for measuring velocity and temperature at the outlet while the bus traveled for 12 kilometers on campus. This is to ensure that the velocity and temperature remain at $3ms^{-1}$ and 23°C while the CO, CO_2, and CH_2O data are collected. Liu *et al.,* [17] are constructing a model airplane cabin in order to analyze particle concentration distribution. This involves measuring the velocity of the air-conditioning outlet in three directions and the cabin temperature with a thermocouple. The cabin was set idle for 24 hours to allow for constant temperature and velocity. The campus shuttle bus was used as the experiment subject in this study to assess thermal comfort. Thermal comfort was evaluated by varying the bus operating conditions and measuring the air-conditioning outlet velocity and cabin temperature. This preliminary experiment was carried out in order to determine the suitability of data measurement in relation to bus conditions for future study references. As mentioned by Danca *et al.,* [18], in most situations, both in practice and in standards, the most reported and debated of these characteristics is air temperature.

2. Field Measurement Set-up

Field measurements were carried out to measure two parameters which are the velocity and the temperature of the air-conditioning outlet. During the study, only one shuttle bus had been used as an experimental subject. The bus selected was well maintained and is free from any damage or problem related to the air-conditioning system. Danca *et al.,* [18] mentioned that vehicles require sufficient time to reach a uniform temperature environment, therefore, the initial set-up was to let the shuttle bus's inner compartment reach a stable temperature after the engine started. This procedure will take approximately in about 15 minutes before the data are taken. According to Ünal [19] findings, it took approximately 20 minutes after the air-conditioning system is operated from the stalled position to drop the temperature from 50 °C to 25 °C. This is an important step to ensure that the inside compartment establishes a steady-state condition before recording data. A detailed description of the bus is given in Table 1.

Table 1
Detailed description of the bus

Description	
Model	HINO
Engine	JO8C-F EURO 1
Year	2011
Compartment	Length = 11 m
	Width = 2.5 m
	Height = 2.4 m
Passenger seat	Length = 0.7 m
	Width = 0.4 m
Air supply diffuser	Diameter = 59 mm
Air return grille	Length = 37 mm
	Width = 28 mm

A total of 11 pairs of air-conditioning outlets are tested during the study where the temperature and velocity of air-conditioning are being measured using specific devices which is the anemometer and digital thermocouple. Both measurement devices were attached to the outlet for over 30 minutes for each pair and repeated three times for reproducibility. It was noted that the air-conditioning ducting design of the bus has a different angle orientation of the outlet pairs number 1 and 10 which later might affect the reading of velocity and temperature. The sketching of ducting has been depicted in Figure 1.

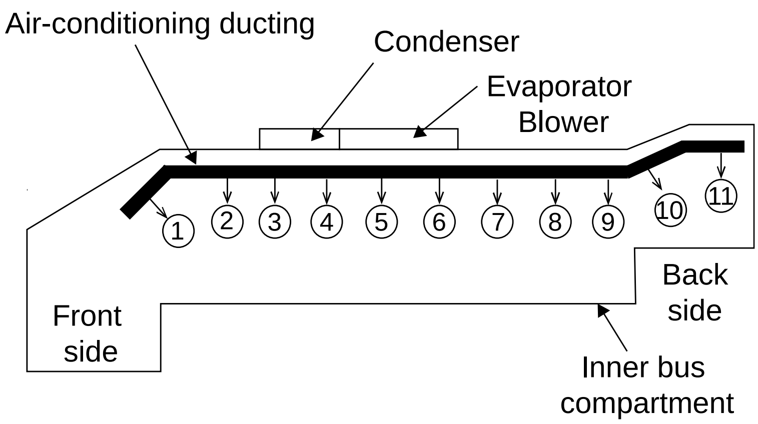


Fig. 1. 3D modeling of the bus inner compartment with the air-conditioning ducting

By assuming that the inside of the bus compartment is symmetrical, the investigation only collected one side of the air-conditioning, which consisted of 11 outlet pairs hereafter referred to as the left outlet and right outlet. Figure 2 depicts the interior bus compartment modeling.

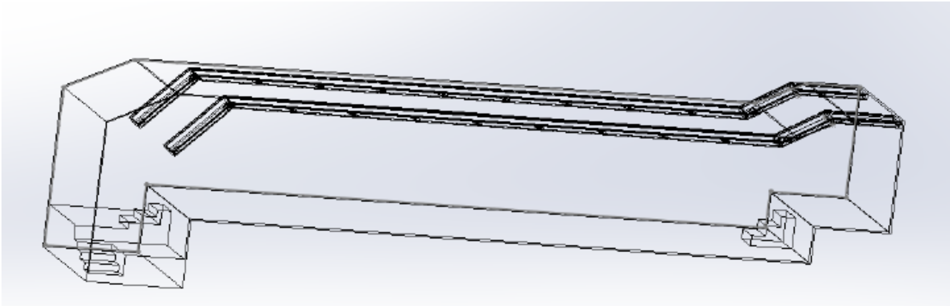
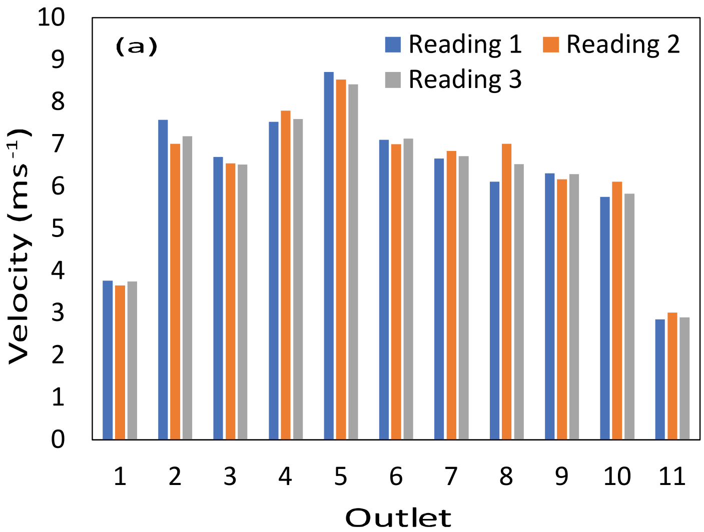


Fig. 2. 3D modeling of the bus inner compartment with the air-conditioning ducting

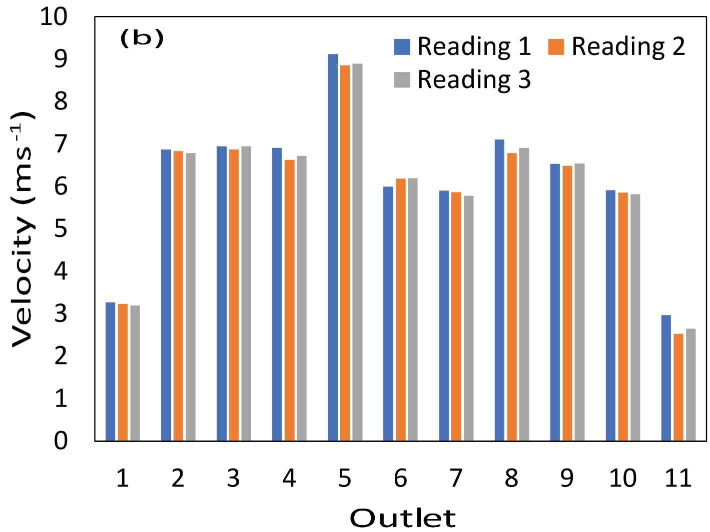
3. Results and Discussions

3.1 Velocity of the Outlets

During the study, we recorded the velocity of the outlets as depicted in Figure 3. The maximum velocity was recorded at 8.71 ms^{-1} and 9.12 ms^{-1} for the right and left outlets respectively. The findings also demonstrate that when other outlets move away from outlet 5, the velocity coming out of the outlet decreases. This condition is caused by the position of the evaporator blower and may differ from various shuttle bus designs. Considering outlet 5 has direct flow from the blower, it obtains the maximum airflow velocity when compared to the others while the lowest velocity for right and left outlets is recorded at 2.85 ms^{-1} and 2.53 ms^{-1} respectively. Figure 1 shows that the air-conditioning ducting has an angular design before reaching outlets 1 and 11. This angular design has interrupted the airflow's capacity to reach the ducting's end evenly, lowering the velocity value. It was also discovered that outlet 10 is located at the ducting angular shape, which releases more airflow and lowers the velocity at outlet 11. There is no significant difference was found between the right and left outlets when compared to the pattern of airflow velocity. Similar results were found where the highest was recorded by outlet 5 and the lowest velocity was recorded by the farther outlets.



(a)

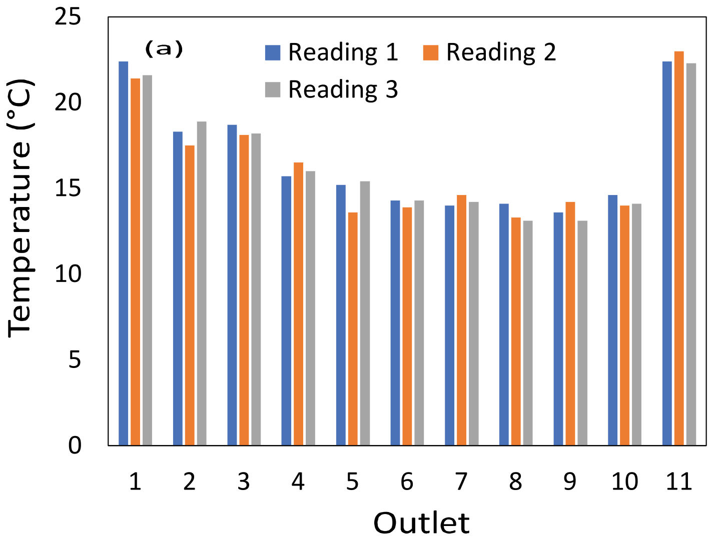


(b)

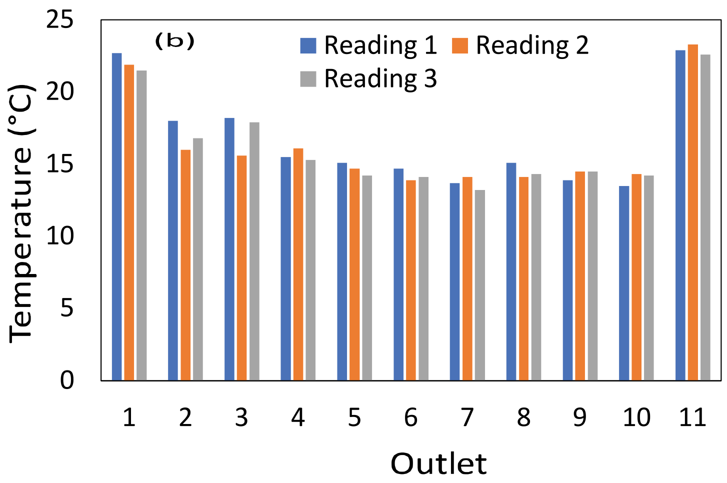
Fig. 3. Individual outlet velocity for (a) right side and (b) left side

3.2 Temperature of the Outlets

The temperature of the outlets was recorded using a digital thermocouple and the data are shown in Figure 4. The highest temperature was recorded at outlet 11 at 22.9 °C followed by outlet 1 at 22.7 °C. Other outlets are recording almost similar readings at a range of 13-18 °C. Since the data was collected while there was no occupancy, the temperature increase was entirely due to the ducting design. As previously stated, the velocity of cooled air from the blower is decreased due to the angular design of the ducting at outlets 1 and 10. This phenomenon is affecting the cooling air supply to reach the farthest outlets 1 and 11 efficiently. The lowest temperature recorded was 13.6 °C and 14.2 °C for right and left outlets respectively for outlet 5. This clarifies that direct access from the blower to the outlet will probably be the coolest seat on the bus. The same result was obtained Unal [19], with the thermocouple near the evaporator blower consistently recording the lowest temperature and the thermocouple near the engine consistently recording the highest.



(a)



(b)

Fig. 4. Individual outlet temperature for (a) right side and (b) left side

According to the temperature data, outlets 1-4 have a higher temperature than outlets 6-10. The positioning of outlets 1-4 in the front of the bus permits radiant heat transmission from the exposure of a large screen. This exposure generates additional heat in the front bus compartment, requiring more energy and time to cool down the participant area. This result is supported by Kilic *et al.,* [20], which utilize a proportion of the cooling system capacity ranging from 18% to 31% to lessen the load caused by the direct input of solar radiation.

3.3 Relation between Velocity and Temperature

In this study, the thermal comfort level was analyzed through velocity and temperature measurements. In general, the level of thermal comfort is at its best position when the velocity is high, and the temperature is lowest. Figure 5 is showing the relationship between velocity and temperature at every outlet's pair during the measurements. From Figure 5, there is a significant trend for outlets 1 and 11 in which the temperature is high due to the air velocity being low. Air velocity is a significant element in transferring cooled air throughout the air-conditioning ducting within the bus. When the air velocity supply to the outlet is poor, the cooled air cannot efficiently reach the outlet, and the infected area does not achieve the desired cooling capacity. The air velocity performance might be improved by using an effective ducting design with minimal pathway obstruction and a smooth surface, as well as having enough power on the evaporator blower.

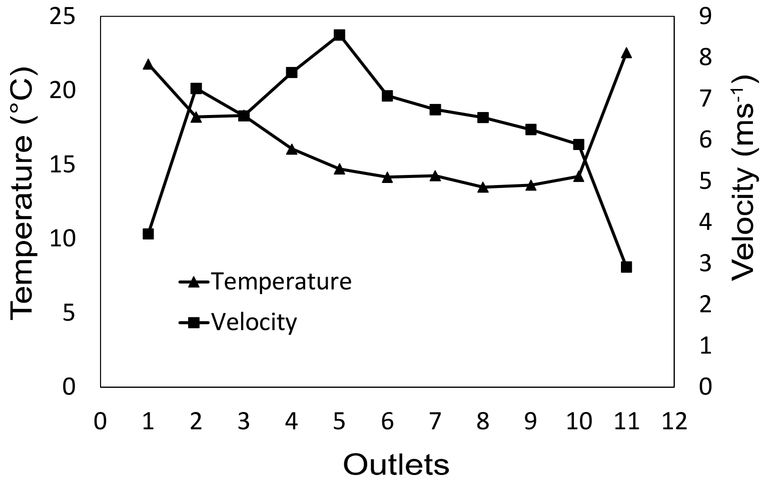


Fig. 5. Relationship between outlets velocity and temperature

Outlet 5 which is located nearest to the blower and received the most air velocity has no problem providing the desired temperature. Even though the air velocity observed at outputs 2 and 10 is low, it manages to produce lower temperatures. This occurs when the angled ducting design obstructs airflow to both exits. The cooled air then accumulated in the area, forcing the majority of it to travel in a direction parallel to outlets 2 and 10. This phenomenon results in a decreased velocity and a lesser quantity of cooled air supply at the remaining outlet.

4. Conclusions

There are several approaches to evaluating the thermal comfort of a shuttle bus. Thermal comfort was determined in this experiment by examining the air velocity and temperature through the air-conditioning outlets. Due to the design of the air-conditioning system, the middle seat section of the bus received the maximum air velocity and the lowest temperature. These advantages are aided by the evaporator blower, which is placed near outlet 5 and neighbouring outlets. Because of the angular ducting design, which obstructs the airflow, outlets 1 and 11 at the end of the air-conditioning ducting received a poor cooled air supply. Further research on the external parameters that impact thermal comforts, such as passenger occupancy, ambient temperature, inner compartment design, varied air-conditioning speeds, and bus speed, can be added to this study in the future.

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References

[1] Tao, Sui, Jonathan Corcoran, Mark Hickman, and Robert Stimson. "The influence of weather on local geographical patterns of bus usage." *Journal of transport geography* 54 (2016): 66-80. https://doi.org/10.1016/j.jtrangeo.2016.05.009

[2] Lee, D. W. "Impact of a three-dimensional air-conditioning system on thermal comfort: An experimental study." *International Journal of Automotive Technology* 16, no. 3 (2015): 411-416. https://doi.org/10.1007/s12239-015-0042-1

[3] Hatif, Ihab Hasan, Azian Hariri, and Ahmad Fu'ad Idris. "CFD analysis on effect of air Inlet and outlet location on air distribution and thermal comfort in small office." *CFD Letters* 12, no. 3 (2020): 66-77. https://doi.org/10.37934/cfdl.12.3.6677

[4] Hassan, Mahmoud Issa. "Numerical Investigation of Air Supply Distribution, Flow Regimes, and Thermal Patterns inside a Private Bus." *SAE International Journal of Engines* 16, no. 03-16-01-0001 (2022). https://doi.org/10.4271/03-16-01-0001

[5] Putra, Nandy, Evi Sofia, and B. Ali Gunawan. "Evaluation of Indirect Evaporative Cooling Performance Integrated with Finned Heat Pipe and Luffa Cylindrica Fiber as Cooling/Wet Media." *Journal of Advanced Research in Experimental Fluid Mechanics and Heat Transfer* 3, no. 1 (2021): 16-25.

[6] Fohimi, Nor Azirah Mohd, Muhammad Hanif Asror, Rosniza Rabilah, Mohd Mahadzir Mohammud, Mohd Fauzi Ismail, and Farid Nasir Ani. "CFD Simulation on Ventilation of an Indoor Atrium Space." *CFD Letters* 12, no. 5 (2020): 52-59. https://doi.org/10.37934/cfdl.12.5.5259

[7] Kee, Tristan Yeo Eng, Chong Kok Hing, Basil Wong Tong Liong, Victor Bong Nee Shin, Lee Man Djun, and Christopher Jantai Anak Boniface. "Alternative Design of Air Ventilation in Passenger Lift for Thermal Comfort." *CFD Letters* 12, no. 1 (2020): 37-47.

[8] Niranjana, S. J., Shivalingappa S. Kubsad, Y. Nagaraj, S. Manjunath, and S. Shivakumar. "Experimental Investigation of Air Circulation Using Duct System in a Non-AC Bus Coach." In *IOP Conference Series: Materials Science and Engineering* 1065, no. 1, (2021): 012006. https://doi.org/10.1088/1757-899X/1065/1/012006

[9] Hossam, Mohamed, Mahmoud Fouad, and Ahmed Abou-Zaid. "Numerical Investigation of Airflow Patterns and Thermal Comfort in a Bus Cabin." *SAE International Journal of Passenger Cars-Mechanical Systems* 13, no. 2 (2020): 145-157. https://doi.org/10.4271/06-13-02-0012

[10] Aliahmadipour, Mohammad, Morteza Abdolzadeh, and Khosro Lari. "Air flow simulation of HVAC system in compartment of a passenger coach." *Applied Thermal Engineering* 123 (2017): 973-990. https://doi.org/10.1016/j.applthermaleng.2017.05.086

[11] Alhassan, Musa I., Aliyu M. Aliyu, Rakesh Mishra, and Naeem S. Mian. "Air Quality Management in Railway Coaches." In *2021 International Conference on Maintenance and Intelligent Asset Management (ICMIAM) IEEE*, (2021): 1-5. https://doi.org/10.1109/ICMIAM54662.2021.9715208

[12] Chang, Zhiyuan, Ke Yi, and Weiwei Liu. "A new ventilation mode of air conditioning in subway vehicles and its air distribution performance." *Energy and Built Environment* 2, no. 1 (2021): 94-104. https://doi.org/10.1016/j.enbenv.2020.06.005

[13] Ismail, Mohd Azmi, and Mohd Sabri Che Jamil. "CFD HVAC Study of Modular Badminton Hall." *CFD Letters* 12, no. 7 (2020): 90-99. https://doi.org/10.37934/cfdl.12.7.9099

[14] Widiastuti, Ratih, Juliana Zaini, Mochamad Agung Wibowo, and Wahyu Caesarendra. "Indoor Thermal Performance Analysis of Vegetated Wall based on CFD Simulation." *CFD Letters* 12, no. 5 (2020): 82-90. https://doi.org/10.37934/cfdl.12.5.8290

[15] Zhu, Xiaoxuan, Li Lei, Jitian Han, Peng Wang, Fushun Liang, and Xingshen Wang. "Passenger comfort and ozone pollution exposure in an air-conditioned bus microenvironment." *Environmental Monitoring and Assessment* 192, no. 8 (2020): 1-17. https://doi.org/10.1007/s10661-020-08471-3

[16] Shafie, N. E. A., H. M. Kamar, and N. Kamsah. "Effects of air supply diffusers and air return grilles layout on contaminants concentration in bus passenger compartment." *International Journal of Automotive Technology* 17, no. 5 (2016): 751-762. https://doi.org/10.1007/s12239-016-0074-1

[17] Liu, Mingxin, Junjie Liu, Qing Cao, Xingyang Li, Sumei Liu, Shengcheng Ji, Chao-Hsin Lin et al. "Evaluation of different air distribution systems in a commercial airliner cabin in terms of comfort and COVID-19 infection risk." *Building and Environment* 208 (2022): 108590. https://doi.org/10.1016/j.buildenv.2021.108590

[18] Danca, Paul, Andreea Vartires, and Angel Dogeanu. "An overview of current methods for thermal comfort assessment in vehicle cabin." *Energy Procedia* 85 (2016): 162-169. https://doi.org/10.1016/j.egypro.2015.12.322

[19] Ünal, Şaban. "An experimental study on a bus air conditioner to determine its conformity to design and comfort conditions." *Journal of Thermal Engineering* 3, no. 1 (2017): 1089-1101. https://doi.org/10.18186/thermal.277288

[20] Kilic, M., and S. M. Akyol. "Experimental investigation of thermal comfort and air quality in an automobile cabin during the cooling period." *Heat and Mass Transfer* 48, no. 8 (2012): 1375-1384. https://doi.org/10.1007/s00231-012-0988-8