



## Evaluating the Effect of Non-Uniform Summer Wearing on Local Thermal Sensation of Passengers in a Bus under Two Common Ventilation Systems

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**ABSTRACT:** Providing thermal comfort conditions for vehicle occupants, especially public transport is a complicated issue due to the density of population and non-uniformity in individual and environmental conditions. So, an important evidence of individual non-uniformity is the variety in passengers' wearing; e.g. in many cases, some passengers have a higher level of clothing and some have less. In this study, we tried to evaluate the impact of non-uniformity in bus passengers' wearing on the local and overall thermal sensation under mixing and displacement ventilation systems. Based on the results, displacement ventilation system has shown a better performance in providing uniform conditions. In the mixing ventilation, the maximum thermal sensation vote is about 1.1, however it is about 0.4 under the displacement ventilation system. As well, the results show that using short sleeves instead of long ones can decrease about 2.5°C in the hands skin temperature and also about 0.1 and 0.4 in overall thermal sensation index, respectively under displacement and mixing ventilation systems. This also shows that the sensitivity level of short sleeves subjects is higher in the mixing ventilation system than in the displacement ventilation system.

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### 1- Introduction

Taking the bus is one of the most popular public transport options. Therefore, providing the comfort of bus passengers, especially in the summer and for the long journeys has great importance. Usually, conventional air conditioning systems of the buses can be mentioned as mixing and displacement systems [1, 2].

It should be noted that the bus passengers generally do not have the same conditions in terms of physical, physiological and clothing conditions [3, 4]. In addition, the clothing thermal resistance at different parts of the body is not uniformly distributed. Moreover, clothing thermal resistance at a part of the body may not only affect the local thermal sensation of that part but also can affect the whole body overall sensation. Also, the air temperature and velocity around different parts of the body are not the same. Therefore, all of these factors lead to make a difference in the local thermal sensation of body parts and also the body overall thermal sensation. Accordingly, in the present study, the body local thermal sensation for two different clothing types has been investigated under displacement and mixing ventilation systems.

### 2- Methodology

The sample space considered in the present study is the Scania 4212 bus; one of the most popular buses in Iran. The dimensions of the length, width and height of its interior space are 12m, 2.45m and 1.95 m, respectively.

In this research, the governing equations are divided into two categories. The first part of the governing equations is

including the conservation equation of mass, momentum and conservation of energy. The second part of the equations is related to the thermal sensation of individuals (65-nodes Tanabe model [5]). In the 65-nodes model, the body is divided into sixteen parts (head, chest, back, pelvis, upper arms, lower arms, hands, thighs, legs, and feet), each with its own four layers (center, muscle, fat And skin). The 65th part of this model is blood that connects between the various components and layers of the body. Heat is exchanged between body and the environment through convection, radiation, evaporation and respiration.

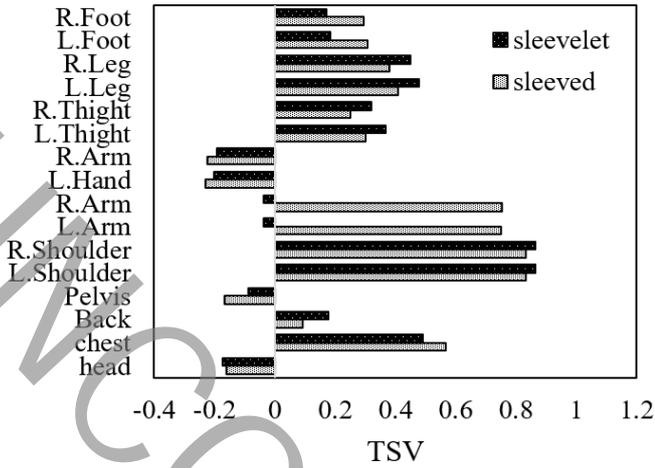
### 3- Results and Discussion

In this research, the effects of sleeved and sleeveless clothing on the thermal sensation of different parts of the body and its effect on the overall body feeling of the body have been studied. In order to study the thermal sensation of different parts of the body, we used the criteria provided by Jane et al. [6] in 2012.

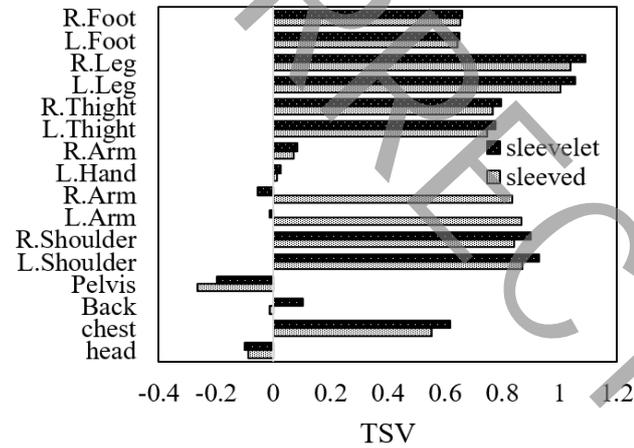
In Fig. 1, the thermal sensation of different parts of the body in both sleeved and sleeveless cloths are shown for people in second row for mixing and displacement ventilation systems. As can be seen, uncovered parts always have thermal sensation less than zero for both systems; therefore, the possibility of dissatisfaction in these areas is very probable. On the other hand, the thermal sensation index of the forearm in covered condition is about 0.6 to 0.8, which is significantly different from that of the uncovered condition. It is observed that the thermal sensation of the lower parts of the body in the displacement ventilation is cooler, due to the different location of the diffusers in the displacement system in comparison with the mixing system. In the case of mixing

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ventilation mode, the maximum thermal sensitivity index is 1.1 which is related to the leg compartment.



(a) Displacement ventilation system



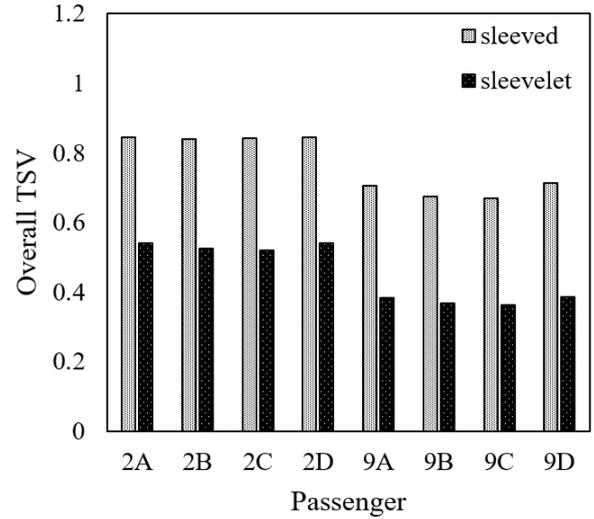
(b) Mixing ventilation system

**Fig. 1. Thermal sensation of different parts of the body in both sleeveless and sleeved clothing conditions (second row, position A)**

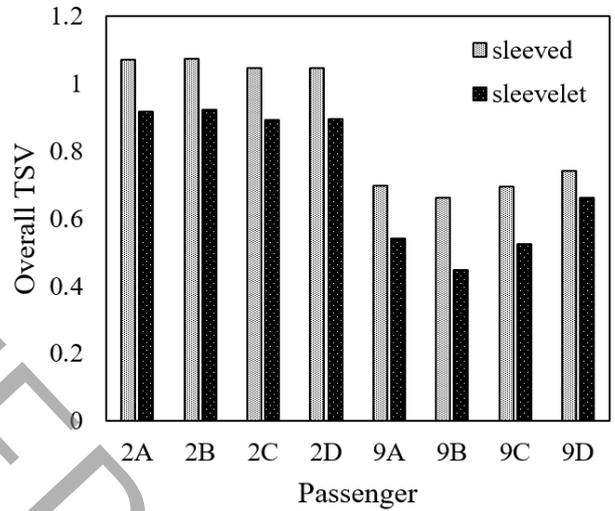
In Fig. 2, the whole body thermal sensation in both sleeved and sleeveless wearing is shown for all individuals in second and ninth rows for two mixing and displacement systems. Fig. 2-a shows that the overall body heat sensation of all individuals for sleeved and sleeveless wearing is about 0.7 and 0.4, and in each row, the overall body heat sensation is not significantly different. By comparing the overall body thermal sensation in two ventilation systems, it can be seen that the displacement ventilation system, with a generally lower overall thermal sensitivity to the overhead mixing system, has been able to provide more proper conditions.

**4- Conclusions**

The main purpose of this study was to investigate the effects of non-uniform wearing on general and local thermal sensation of different parts of the body on a bus with two types of mixing and displacement systems. Therefore, two types of sleeved and sleeveless clothing are considered for



a) Displacement ventilation system)



b) Mixing ventilation system)

**Fig. 2. Overall body thermal sensation in both sleeve and sleeve clothing**

this issue. The results show that uncovered parts always have a cool thermal sensation in both cases and the mentioned parts may have local dissatisfaction. On the other hand, the thermal sensation vote of the forearm in the case of a sleeveless wearing is almost neutral, which is significantly different from that of a sleeveless wearing that has forearm thermal sensation of about 0.7. In addition, the results indicated that the change in the coverage of a body part not only affected the thermal sensation of other parts of the body, but also significantly affected the body overall thermal sensation. As mentioned earlier, the displacement ventilation system has a better performance than an overhead mixing ventilation system. In such a way that the overall thermal sensation of individuals under the displacement system was 0.7 and 0.4 for both cases of individual clothing.

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