

Optimum Seat Cooling Distribution for Targeted Human Thermal Comfort®

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ABSTRACT

Seat cooling and heating strategies have enhanced human thermal comfort in automotive environments. Cooling/heating strategies also need to focus on the distribution of the seat cooling/heating power across the seat and the effect of such distributions on human thermal comfort. This paper studies the effect of active cooling combined with ventilation only strategy on thermal comfort. As part of the study, heat flux between the occupant and seat is mapped and is correlated to a step increase in the occupant's local thermal comfort of body segments in contact with seat. A human physiological model and the Berkeley comfort model were combined to determine power and optimum placement of cooling to effectively cool an occupant using a climate control seat in a warm environment. This leads to a new approach using asymmetric seat cooling to distribute cooling power resulting in improved and balanced subjective comfort than traditional climate seat and ventilation technologies. A computational model was developed and validated through chamber test results. The computational model can deliver temperature distribution and thermal sensation/comfort values for varied boundary conditions such as differing ambient temperatures, mass flow rates and temperatures of cooling air through seat. In this study, the thermal chamber and seat were soaked to 44°C before running the test with the human seated. Active cooling was applied to seat back/lumbar area and ventilation only was applied to the seat cushion area. The occupants recorded their local contact segment sensation and comfort every two minutes. Temperatures for the seat and human as well as heat flux between them were measured every 1 second. The model temperatures correlated to within 1°C of experiment. The computed local thermal sensation and comfort values were also correlated to those measured in the chamber.

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INTRODUCTION

According to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards, thermal comfort is defined as, "That condition of mind which expresses satisfaction with the thermal environment." Traditional approaches to design for automotive thermal comfort are inadequate as the metrics focus on the vehicle, seat, and climate components rather than considering the state of the occupant. Time to temperature, heat homogeneity, and long-term steady state conditions are standard industry methods for assessing the effectiveness of climate seats; however, these metrics do not offer substantive data on the subjective comfort of the occupant. Without considering occupant perception of the thermal environment, thermal conditioning application, or human physiological response to transitional thermal inputs, efforts to provide basic thermal comfort will remain suboptimal (Fig 1). Climate seat designs have also not considered human physiological characteristics, i.e., heat balance across the inner body to optimize the cooling distribution. This study makes a case for climate seat design where both human subjective perception and human physiological characteristics are considered.

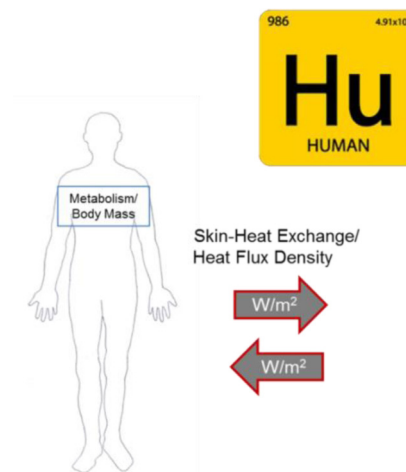


Figure 1. Human-surroundings heat exchange.

EFFECT OF CLIMATE SEAT ON THERMAL COMFORT

Traditional vehicle interior climate systems utilize a central HVAC system for heating and cooling of the cabin to thermally condition passengers. With a renewed interest on occupant based thermal management, automotive OEMs are employing local thermal effectors, such as seat climate systems, steering wheel heating, and interior heating, as a supplement to the primary HVAC system to accelerate comfort. Occupant based thermal management devices improve time to comfort through a personalized and decentralized thermal strategy. As the contact surface of car seats to the occupant is approximately 25% of the total body surface area [1], the seat is positioned to be an anchor in thermal comfort systems. Effective heat exchange utilizing climate seat technology with active conduction, convection, and evaporation is essential to delivering comfort to the occupant in a warm ambient environment.

A well-integrated climate seat will no longer be seen solely as a comfort and convenience feature, but as the cornerstone of the vehicle thermal management strategy independent of vehicle class or segment.

Subjective Rating Method

Thermal comfort modelling is based on the knowledge of human physiology related to metabolic heat production of the body and heat exchange with the thermal environment. Human Thermal Physiology (HTP) is the science about heat exchange with the environment, human heat production, heat management, and heat perception. The understanding of local heat perception, heat regulation, and thermal heat transfer is incorporated in physiology based computer models. The Berkeley Comfort Model, developed by Professor E. Arens and Dr. H. Zhang at the University of California, Berkeley, is the current standard for deriving overall thermal comfort through local sensation and comfort inputs [2].



Figure 2. Sensation and comfort rating index.

The terms thermal sensation (TS) and thermal comfort (TC) are typically quantified separately in experimental investigations, where thermal ratings are conducted by subjects in a controlled thermal environment. The Berkeley-Scale (as shown in Fig 2) allows local and overall TS ratings on a nine point scale between -4 (very cold) to +4 (very hot), including a neutral state, and TC ratings on an eight point scale, -4 (very uncomfortable) to +4 (very comfortable). The experiments from Berkeley [3] showed that under uniform thermal environments, overall ratings are strongly influenced by segmented body ratings. In uniform warm environments, overall comfort ratings follow the head and torso.

MODELING HUMAN THERMAL COMFORT

Computational modeling of human thermal comfort through seat ventilation and cooling allows for a faster design process where several designs of the seat assembly can be tested quickly. Starting the modeling process requires CAD models for the seat and human. Both models shown in Fig. 3, are meshed (Fig. 4) for the purpose of numerical solution of fluid flow and heat transfer equations.

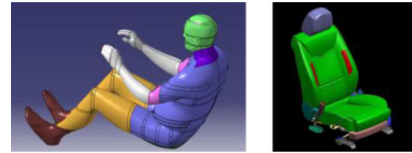


Figure 3. CAD models.

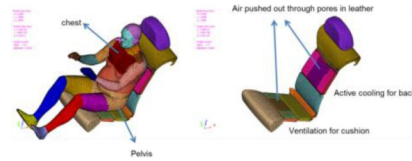


Figure 4. Meshed models.

The CAD models are surface meshed, which means the result of the meshing process are shell meshes representing only the surfaces of the objects.

The meshed human and seat are imported into TAItherm, a heat transfer and human thermal comfort modeling software. Within TAItherm, the human body's physiological properties are defined through the Met rates, height and weight of the body and a multi-layer representation of the skin, tissue, muscle, bone etc. as shown in the Fig. 5. The physiological model is based off Fiala's human modeling work [4].

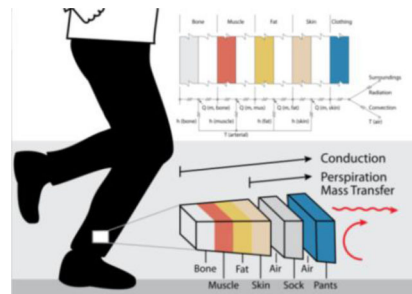


Figure 5. Multi-layer representation.

The seat material properties are defined within TAItherm to reflect the real seat as closely as possible. For instance the shell mesh representing the seat is implicitly defined as a multi-layer part that has leather representing the outer surface material and foam, air layers adjacent to the leather.

After the physiological model and material properties are defined, the next step is to define the thermal conduction and convection links between the human and the environment which includes the seat. To define the boundary conditions, the human model is segmented into a number of different regions corresponding to the body parts, head,

chest legs, arms etc. Similarly the seat is divided into back and cushion zones for creating conduction links between the human back and pelvis. (See Fig. 4)

The air flow being pushed through the porous leather cover is modeled using air-nodes in TAItherm. An air-node represents the mass flow rate and temperature of the air coming out of the Climate Controlled Seat (CCS) system. A consecutive air-node convectively linked to the primary CCS system air-node represents the condition of the air after it passes through the seat materials, thermal masses etc. The cooling air reduces the temperature of the seat surface, thus allowing for conduction heat transfer from human back and pelvis to the seat. Similarly, the cooling air leaking through the pores, allows convection heat transfer from the human back and pelvis to the local air supply.

For validation purposes, the computational model replicated an experiment conducted in a thermal chamber. Initially the chamber with the seat was soaked to 45 °C. While ambient temperatures in a hot soaked car can approach over 50 °C, a higher chamber ambient temperature was not chosen due to regulations in Germany where the testing was performed. The human entered the chamber, waited 5 minutes in the chamber for getting thermally soaked and then seated himself/herself. As soon as the human was seated, the active cooling ventilation system in the seat started and the chamber door opened. The chamber air temperature started dropping due to the draught coming in from the room in which chamber was located.

Taking into consideration, the combined heat transfer effects of radiation, convection and conduction, the human physiological model computes the skin and internal layer temperatures. The Berkeley comfort model [2] in TAItherm computed the local and global sensation and comfort values for the human. The Berkeley comfort model uses Eq. 1 to obtain the local sensation.

$$\text{Local sensation} = f\left(T_{\text{skin},i}, \frac{dT_{\text{skin},i}}{dt}, \overline{T_{\text{skin}}}, \frac{dT_{\text{core}}}{dt}\right) \quad (1)$$

Eq. 1 portrays the dependence of local sensation (feeling of hot or cold) on the local skin temperature, the rate of change of local skin temperature and the mean skin temperature (overall body) and rate of change of body core temperature.

The rate of change of local skin temperature is dependent on the local heat flux of the given body segment. For the seat, a relationship is established between the seat to body conduction heat flux and the local sensation of the body segment in contact with the seat. The global or overall sensation of the body is determined as a weighted summation of the local sensations. The local and global comfort values are computed from the already computed local and global sensation values according to the Berkeley model [2].

The TAItherm temperature results for the given test chamber case are shown below in Fig. 6 for the first 10 minutes of cooldown. These are the clothing temperatures. They correlate to within 1°C of the measured temperatures).

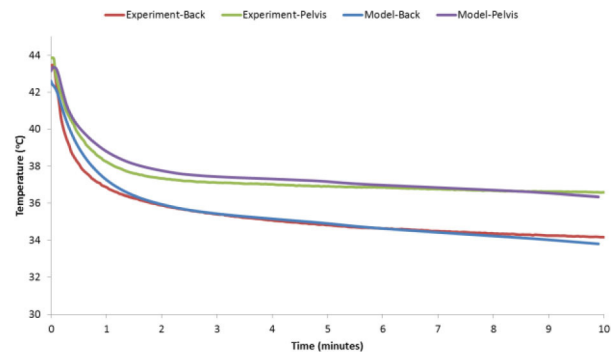


Figure 6. Temperature versus time for seat contact areas

The local sensation and comfort results are shown below in Fig. 7. There is a good correlation between the cross-over point for heat flux to the back and the rapid rise in back comfort at the 2 minute mark. At this point, the heat flux turns negative which means the back is now losing heat (refer to fig. 17). The TAItherm results for Berkeley model's local sensation and comfort are found to be close to the measured responses after 4 minutes. The measurements for thermal sensation and comfort were taken at the start and then every 2 minutes later, while the model results were computed every 1 second. Due to this, the measured response and model results do not show good correlation during the beginning. It is possible that the experimental subject felt immediate comfort when the system started, but he did not record the sensation and comfort until the 2 minute mark. Therefore, any change in thermal sensation and comfort perceived by the subject between 0 and 2 minutes is not known. One other factor that can potentially affect the correlation is the subject's understanding of the Berkeley scale. A total of 10 subjects took part in the measurements and most of them showed the same pattern for sensation and comfort as shown by the subject in Fig. 7.

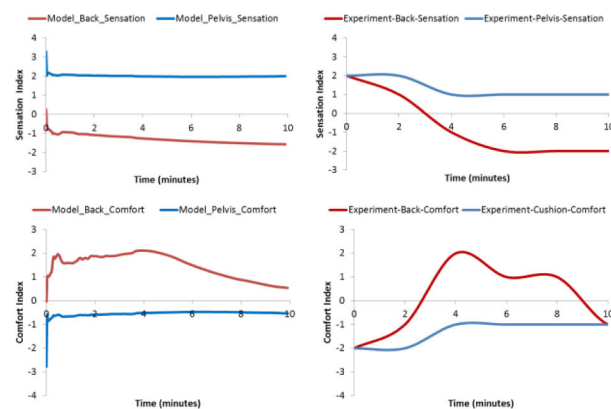


Figure 7. Local sensation and comfort for seat contact areas

COOLING POWER REQUIRED

Using the modeling structure described above, a sweep of negative heat flux, from -20W/m² to -90W/m² was applied to a preconditioned occupant in the primary contact areas of the seat cushion and seat back, via a balanced or symmetrical conditioning approach per typical climate seat practices. Table 1 shows the distribution of applied cooling watts over targeted zones