Thermal Comfort Prediction for Heated Seat

- By ESI GROUP -

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ABSTRACT

While heated and cooled seats used to be integrated only in luxury cars, a wider range of carmakers proposes now such seats for their midrange market too. The design of heated or cooled seats and their optimization, to effectively increase the thermal comfort of the occupant, are very complex. Each of the interactions between the occupant, the seat cover, the cushion foam, and the heating or ventilation systems has to be taken into account. The use of virtual seat prototyping to predict the thermal comfort of a driver seating in a heated seat enables to answer effectively such a challenge.

Key Word: Heated, Cooled, Seat, Thermal Comfort, Cushion compression, Virtual Seat Solution.

1. Introduction

While heated and cooled seats used to be integrated only in luxury cars, a wider range of carmakers proposes now such seats for their midrange market too. The design of heated or cooled seats and their optimization, to effectively increase the thermal comfort of the occupant, are very complex. Each of the interactions between the occupant, the seat cover, the cushion foam, and the heating or ventilation systems has to be taken into account.

This paper presents a numerical study which has been performed in order to predict thermal seat comfort of a driver. A finite element model of a seat equipped with a heating pad is built. To achieve an accurate prediction of the thermal comfort, we first simulate the seating of the driver. This step enables to retrieve the exact position of the occupant, as well as the compression of the seat cushions. The results of this step are then used for the prediction of the seat behavior and the occupant comfort when heating pad is activated. This study shows the importance of an accurate seat thermal model as of the first occupant seating simulation to improve the prediction of the thermal comfort and thus rely on accurate results for the improvement of a heated seat design.

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2. Heated Seat

2.1 Seat Modelling

The seat used for this study is not a real one, but a representative seat of an existing car driver seat, having a similar behavior.

The seat model, which is meshed, contains the following components: frame, suspensions, foam blocks, heating pad, cover and padding with related attachment systems.

Fig.1 ESI's meshed seat model

2.1.1 Seat modelling for mechanical behavior

The frame is considered as rigid since the model will be used only for seating and thermal simulations, which do not induce frame deformation.

All other components are deformable and connected ones to the others through joints and contacts.

The foam and padding properties are extracted from measurement of quasi-static compression and traction stress-strain laws.

The cover properties are extracted from measurements of quasi-static traction laws in different directions.

This modelling method has been extensively validated through comparison between simulations and real tests for H-Point and pressure distribution measurements. [1-2-3-4-5)]

2.1.2 Seat modelling for thermal behavior

1) Thermal material properties

In addition to the mechanical properties defined here before, some thermal material properties have to be added in order to simulate the heat transfer phenomena. Two main parameters have to be fulfilled for the thermal properties of the seat materials, the conductivity and the specific heat capacity, as defined by the Fourier law:

$$\rho C \frac{\partial T}{\partial t} = div\left(\lambda \cdot \overrightarrow{grad}\, T\right)$$

Where $\begin{cases} \rho \text{ is the mass density} \\ C \text{ is the specific heat capacity} \\ \lambda \text{ is the conductivity} \end{cases}$

Those can be measured through the following type of equipment:

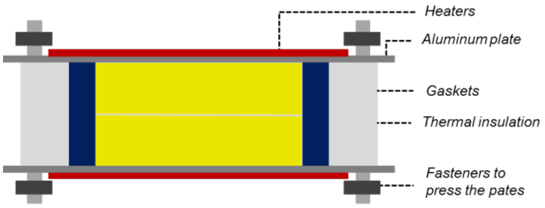

Fig.2 Heating pad positioned on the foam skin

Both can be set as constant or temperature dependent in Virtual Seat Solution. Conductivity can also be made dependent on the level of compression reached by the material after sitting of an occupant. This is what is done especially at the foam level in the seat model.

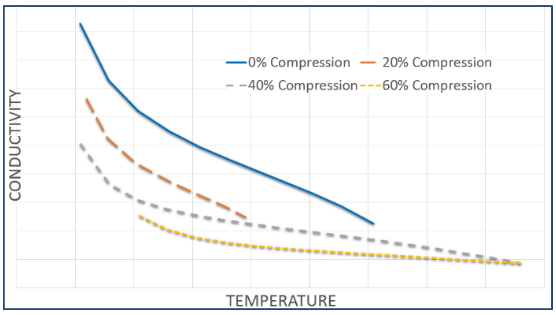

Fig.3 Foam conductivity vs compression strain

2) Heating pas modelling

The heating pads are modelled as beam elements representing the electrical wires, embedded in shell elements representing the unwoven fabric. The whole wire is modeled as a heat source emitting 160 W.

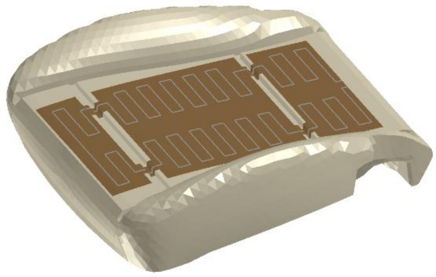

Fig.4 Heating pad positioned on the foam skin

3) Conduction modelling

As indicated previously, contacts are defined between the different sub-components: foam, heating pad and cover. Again, these contacts are defined to manage the mechanical interaction, but also for the thermal interaction defined through a conductance value which is function of the distance between the two interfaces. If those two interfaces are in contact, the heat is transferred without loss, and the more the two interfaces are distant, the less heat is transferred.

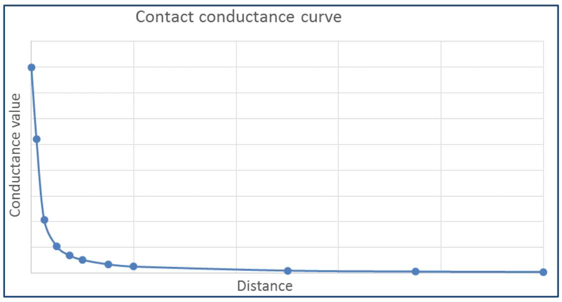

Fig.5 Contact conductance

4) Convection modelling

The loss of heat by convection with air is modelled through a simple constant coefficient applied on all external surfaces of the seat.

2.2 Thermal Behavior of Empty Seat

The effect of air convection is evaluated with two simulations, both performed while the seat is unoccupied and the heating pad is activated. In one simulation, the effect of air convection is taken into account. In the second one, it is not taken into account.

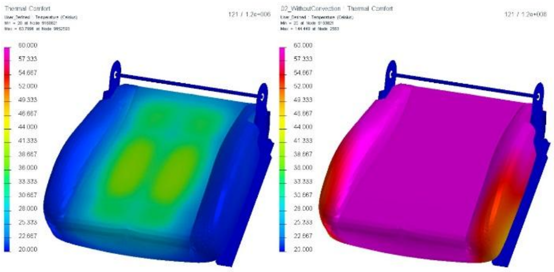

Fig.6 Cover temperature after 20 min
(Left-with / Right-without air convection)

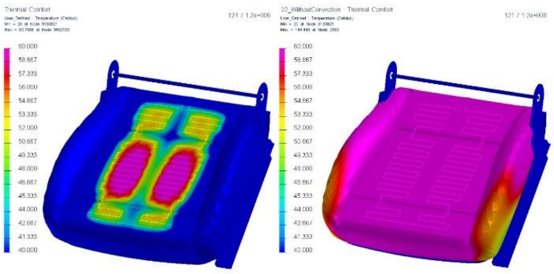

Fig.7 Heating pad temperature after 20 min
(Left-with / Right-without air convection)

Without air convection, the generated heat is kept inside the cushion leading to a non-realistic constant temperature increase. With air convection, the temperature is stabilized after a limited amount of time and is reaching realistic temperatures.

2.3 Heated Seat Occupied with Passive Dummy

A water dummy is composed of two parts, the plastic external part, made of shell elements, and the water inside, meshed with tetra elements. The weight is about 38kg.

In a first step, the dummy is seated, by a simple drop under gravity until equilibrium and stabilized contact between dummy and seat. This enables to predict the right level of seat deformations, and correct dummy position.

Fig.8 Water dummy

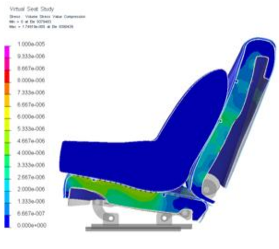

Fig.9 Seated dummy

In a second step, the thermal behavior of the occupied seat is predicted. The dummy is filled with water at a 40°C initial temperature, the ambient temperature is at 5°C and the seat is initially at 20°C. Standard properties are used for convection coefficient and thermal properties of water, i.e. specific heat of 4.185 J.g-1.K-1 and conductivity of 0.6 W.m-1.K-1.

Two simulations are performed: with and without activation of the heating pad at 40 W.

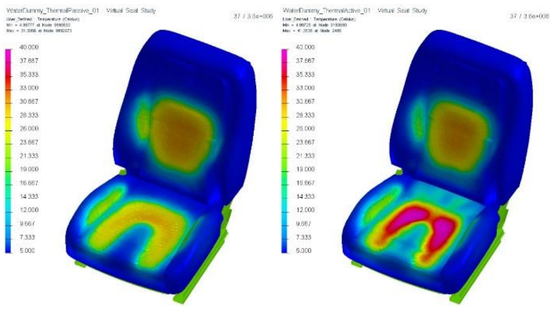

Fig.10 Seat temperature after 1 hour
(Activated heating pad on the right)

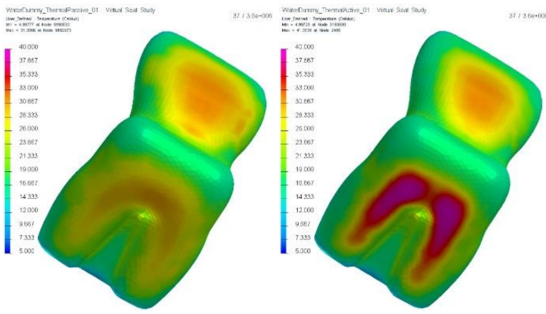

Fig.11 Water dummy temperature after 1 hour
(Activated heating pad on the right)

In the contact zone between the bottom cushion and the water dummy, the cushion is heated initially by the contact with the water dummy leading the temperature from 20°C up to approximately 37°C. Then, the whole system is cooling down due to the convection with air until the heating pad is activated (progressively between 25 and 30 min), enabling the temperature to be maintained. In this simulation, no thermostat is modelled and thus, the heating pad power has been calibrated to maintain the temperature.

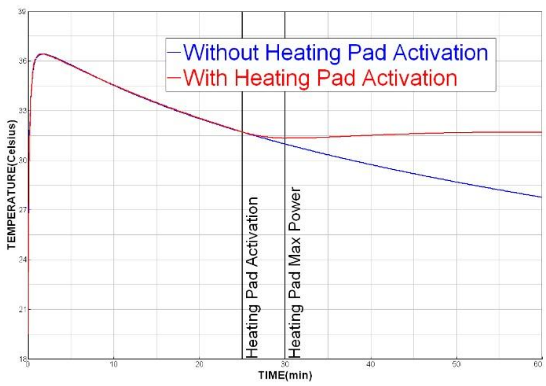

Fig.12 Temperature on bottom cushion

2.4 Heated Seat Occupied with Human Model

2.4.1 Human modelling

Fig.13: ESI's Human model

The human model is set with an initial temperature of 37°C inside the body and an average temperature of 32°C at the level of the skin. The flesh is modelled as a heat source generating 58 W/m2 (metabolic rate of a passive human). The air convection coefficient is computed so that the convection losses are equilibrated by the heat generated by the body, maintaining the initial temperatures as constant in the absence of any other factor influencing the heat exchanges.

2.4.2 Heating pad effect

In a first step, the human model is seated, by a simple drop under gravity until equilibrium. This enables to predict the right level of seat deformations, the correct human model posture, and to establish the right contact interface between the occupant and the seat.

Fig.14: Seating of ESI's Human model

In a second step, the heat exchanges are computed along time between the human, the seat components and the environment. Like previously with the water dummy, the environment is at 5°C while the seat is initially at 20°C. The convection with air is made more severe and the heating pad power is increased to 80 W.

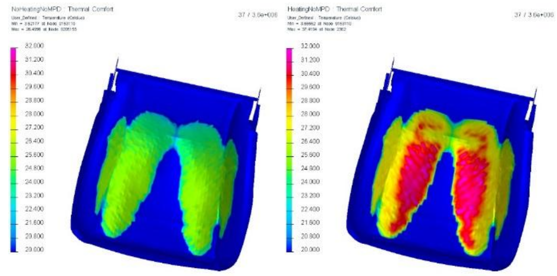

Fig.15: Bottom cushion temperature after 1 hour (Activated heating pad on the right)

Without heating pad activation, the temperature is globally maintained around 27°C. With heating pad activation, the thigh temperature reaches 30°C.

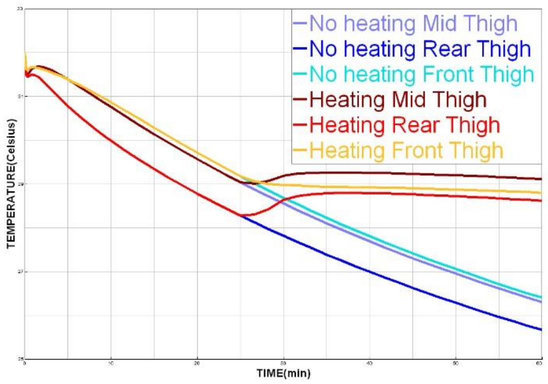

Fig.16: Human Model Temperatures on the thigh (With and without heating activation)

In the contact zone between the bottom cushion and the human model, the temperature is decreasing due to the convection with air until the heating pad is activated (progressively between 25 and 30 min), enabling the temperature to be maintained.

In this simulation, no thermostat is modelled and thus, the heating pad power has been calibrated to maintain the temperature.

2.4.2 Foam compression and thermal conductivity

Foam conductivity has been measured at different compression levels, and differences have been observed. In order to evaluate the importance of the foam compression on the seat thermal behavior, the previous simulation with activated heating pad is performed again by taking into account this conductivity dependency.

At the end of the sitting simulation (1st step), the foam is compressed in a non-uniform manner.

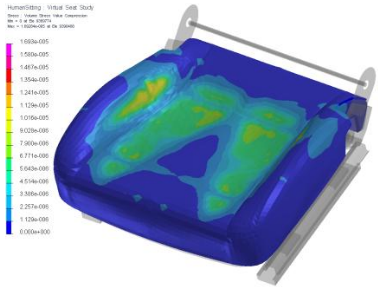

Fig.17: Cushion compression after seating

At the beginning of the thermal simulation, the solver will read for each element the level of compression to assign the exact thermal conductivity. Comparison is performed between uniform conductivity and exact conductivity dependent on compression.

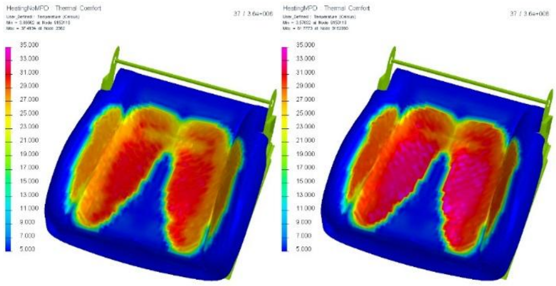

Fig.18: Bottom cushion temperature after 1 hour with activated heating pad
(Thermal conductivity dependency on the right)

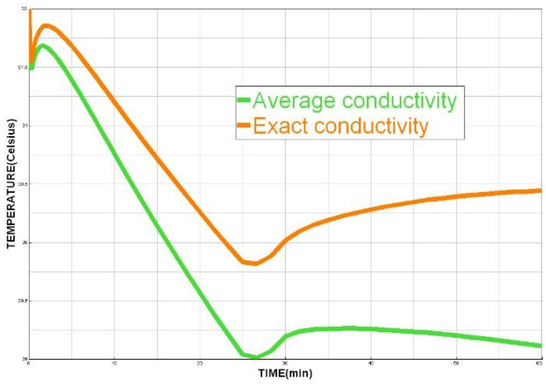

Fig.19: Bottom cushion temperature
(With average and exact conductivity dependent on foam compression)

The effect of the compression on the conductivity doesn't seem huge (approximately 1 degree) in this example, but the difference is increasing along time and can thus not be ignored. Furthermore, this effect would lead to an oversizing of the heating equipment if it is not taken into account.

3. Conclusion

This study highlighted the importance of simulating the chaining of a mechanical seating of the seat occupant followed by the activation of heating system to predict correctly the thermal behavior of a heated seat. This chaining enables to improve the accuracy of the thermal simulation by taking into account the right interactions between occupant and seat, and the accurate materials conductivities which are affected by the foam compression of the seating.

It has been additionally shown, that a seat modeling as close as possible to reality, enables to catch all the thermal phenomena between the different seat components.

Such virtual testing of an occupied heated seat with thermostat is made possible and easy by the use of a single core model of seat for the different simulations steps.

Further work is ongoing to virtually test also occupied cooled and ventilated seats.

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