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SIMULATION OF TRANSIENT THERMAL COMFORT IN TRAINS

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ABSTRACT
The present investigation deals with the challenges in all vehicle industries with respect to air conditioning taking into account transient effects. Transient phenomena occur mainly during door opening and closing, pre-cooling, pre-heating. Numerous vehicles have difficulties to meet the thermal comfort criteria which are imposed by the customer. Typically, requirements are given for the minimum and maximum air velocity, the temperature level, the maximum gradient in different sections and the fresh air rate. More sophisticated requirements includes the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) [1]. Tools which are capable to predict the impact of relevant design options have been used in steady state for several years already. The possibility to use these tools for transient processes in an industrial framework will be discussed.

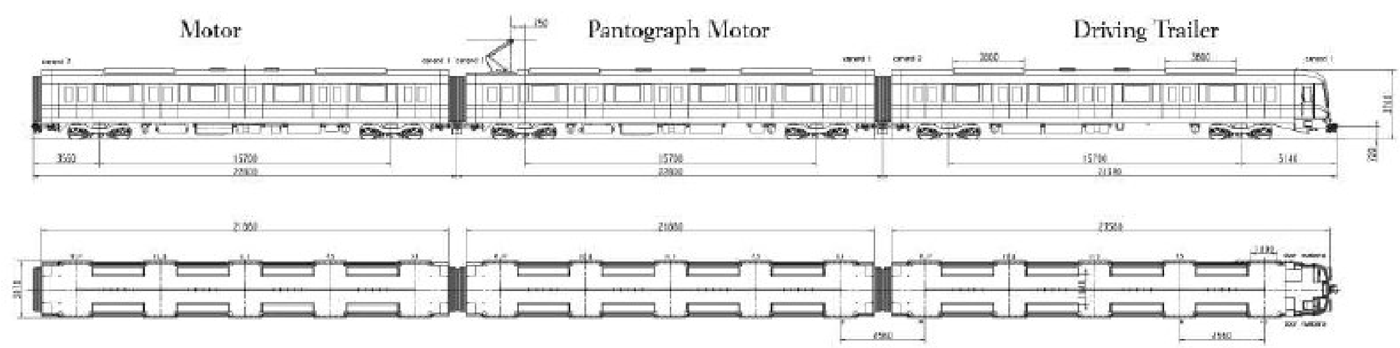

Figure 1: Calculated example - Guangzhou Line 2 vehicles

MOTIVATION
The accurate prediction of thermal comfort values prior to mock-up or prototype construction is a cost efficient means to validate the climate concept. Therefore the computational simulation of thermal comfort is a well established tool in all vehicle branches for steady state processes. [8] Unsteady

simulations are too time-consuming in an industrial framework for whole train coaches.

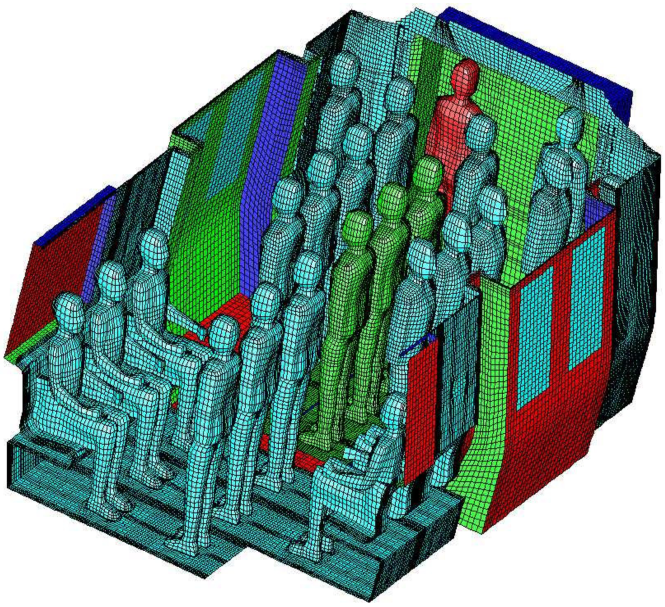

Figure 2: Snapshot into computational domain for steady state simulations

However, time dependent boundary conditions are very important for the thermal comfort in trains as door opening cycles do have an impact on the interior. Therefore there is an urgent need to calculate transient effects in reasonable computing times.

STATE OF THE ART PREDICTION METHOD FOR STEADY STATE

The prediction tool used is a combination of (a) the commercial code STAR CD [6] for the simulation of the air velocity and temperature distribution with eddy-viscosity turbulence modelling,

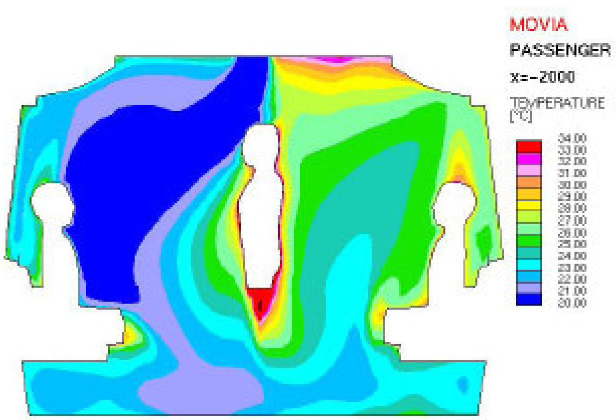

Figure 3: Example for steady state results

(b) SWF [2] for the simulation of the complete heat transfer through the walls as well as solar and thermal radiation and (c) TIM [2] for the simulation of the heat transport mechanisms of the human body (passive system) as well as the thermo-physiological regulation (active system).

This tool (TeCoS [5] – Thermal Comfort Simulation) was developed by DaimlerChrysler for cars and then implemented at Bombardier (ad that time ADtranz, DaimlerChrysler Rail Systems) and adapted to railway needs.

Standard URANS equations with k-ε-turbulence model are employed to solve the basic equations. [6] Buoyancy is taken into account as introduced by RODI [7].

To model solar radiation, a discrete beam approach is taken which is fully explained in the STAR CD methodology [6].

Steady state simulations are used to optimize the arrangement of inlets and outlets inside the passenger area and driver's cab. This is necessary for nearly every new metro because the geometry must follow the tunnel size. Requirements on the thermal comfort in metros are given in the respective European standard which is used in most international projects. [3]

Most of the requirements deal with mean values (average temperatures, temperature gradients, surface temperatures) which are ensured by steady simulations taking into account many details. Figure 3 shows a typical result for a Guangzhou Line 2 (GZ2) coach (figure 1) using a hexahedral domain with 6 million cells partly shown in figure 2.

NEED FOR TRANSIENT SIMULATIONS

In addition to the requirements for steady state there are two basic transient situations to be taken into account, door opening and closing cycles and pre-heating and cooling. Nowadays, it is still too time consuming to calculate this with the same level of details as the steady state because the calculation times are still much too long.

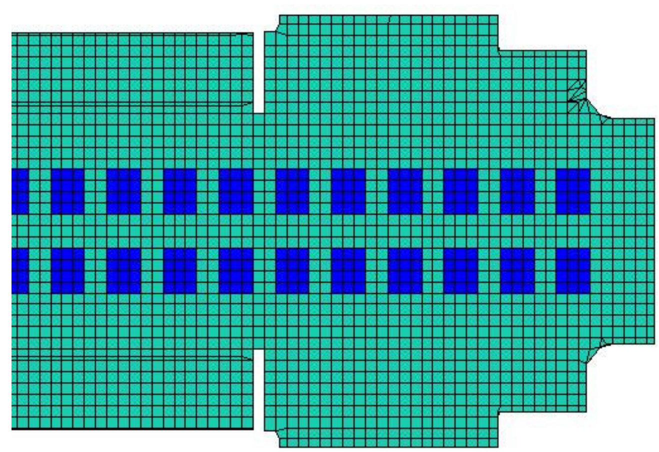

Figure 4: Simplified mesh for transient simulations

The presented work is the transient calculation of the door opening of one GZ2 coach which was performed together with DaimlerChrysler. To obtain these results, simulations running some weeks with high performance computers are necessary. It is today not possible to run some design iterations in industrial projects, which require to take less than 1 year to design the whole vehicle.

RESULTS OF COMPUTATION OF TRANSIENT BEHAVIOUR

Door opening behavior of a GZ2 metro coach is simulated (Figure 1). The example is taken, because of the challenging ambient and interior conditions. The door opening is a dominant factor for the required power by the air-conditioning system.

The initial condition in the interior is the steady state solution for the chosen ambient temperature and humidity. (32.5°C, 65% relative humidity, 700 W/m² solar radiation) Under these conditions the average interior temperature in the interior is 27°C.

To perform the calculation, a simplified model was created which consists of 1 million hexahedral cells. A horizontal section of the grid inside the coach is shown in figure 4. In this case the surrounding of the coach is modeled as well. (1.5 car width at every side and one car height on top.)

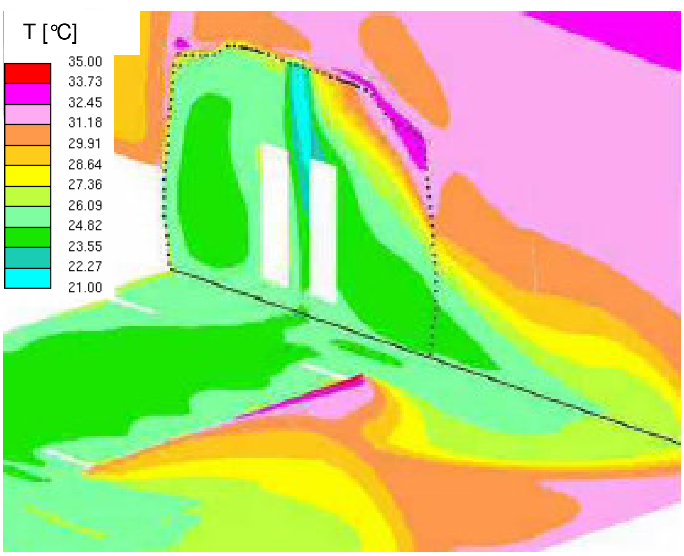

Figure 5: Temperatures 10 s after door opening

Figure 5 shows the temperature results 10 s after the door opening. The horizontal plane is the floor of the coach and the platform. The vertical plane goes through the middle of the middle door of the coach.

10 s after door opening warm ambient air enters the coach and cool conditioned air leaves the coach in the floor region. This is shown in figure 6 which outlines the velocity component orthogonal to the door.

VALIDATION

The results were validated by using results from a climate chamber test performed in Bombardier's climate chamber in Görlitz, Germany.

The chamber is able to control ambient temperature and humidity by means of heating, humidifying and ventilation. The test setup follows the simplified test level outlined in [4]. The temperatures during door opening were measured at 4 heights in the middle door of the coach.

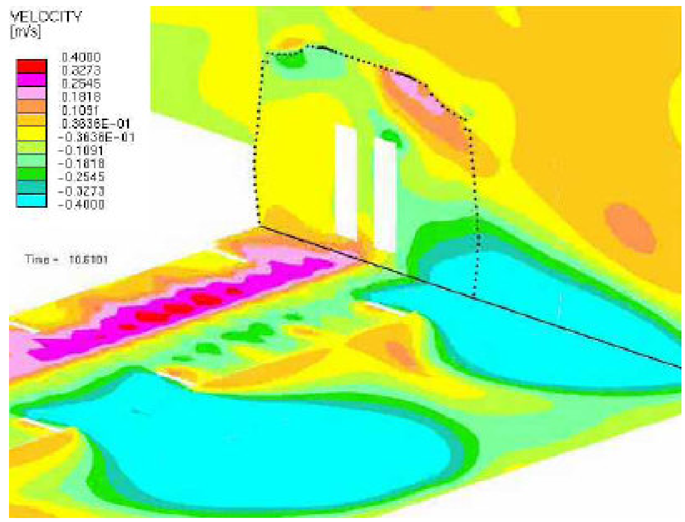

Figure 6: Velocity plot 10s after door opening (velocity component orthogonal through door)

Figure 7 shows the results for the 4 heights for one door opening. t=0s marks the moment of door opening. The measurements show the same qualitative behavior. Cool conditioned air is leaving the coach at floor level and warm air is entering above that.

Figure 7 also compares the results of the measurements and the calculated values. The results show a fair agreement. The general behavior can be reproduced by the simulation. Warm air enters in the upper parts and conditioned air leaves the coach in the floor region.

The deviations are mainly caused by the fact that the simulations were performed with a platform beside the train and the test was without. The accuracy of the used sensors was +- 0.2 K. The accuracy of the used method was validated on real trains in steady state. Deviations between results of measurements and simulations are within 1K. [8]

Other turbulence models like LES and DES need to be validated for transient simulations with TeCoS in the future.

After reaching steady state conditions, the environment is of course not very pleasant, because in the upper part of the coach the temperature is dominated by entering outside air (32.5 °C, 65 % r.H.) which is only a little bit cooled down. Future design work has to concentrate on how to prevent this situation.

The almost steady state situation after the door opening which is predicted well is most important when predicting door opening cycles, because this state is dominating the additional thermodynamic load introduced to the passenger area by the ambient air.

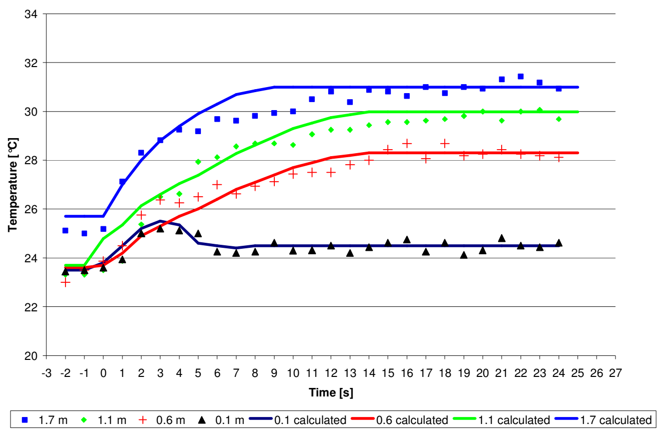

Figure 7: Comparison of measurement results and value taken out of the simulation

However, to comply with the customer requirements, a full driving cycle must not show an increase of the average internal temperature due to door openings. This is not possible to simulate with the presented approach due to the massively needed computer power.

CONCLUSIONS

The method utilised is capable to predict the transient behaviour of door openings in trains. In order to improve the climate comfort design for industrial applications it is needed to improve the methods with respect to speed of unsteady simulation to make it usable on an industrial basis. This would improve the predictive capabilities and could also support more robust design for thermal comfort.

NEXT STEPS

Simplified methods needs to be developed to transient thermal comfort simulation available as a standard tool in the engineering process with moderate computing times. This will be useful to development means to prevent outside air entering the passenger area massively during door opening.

The most promising approach is to freeze the flow field (by switching the field after door opening) and solving only the energy equation transient.

This will be done during one of the next Bombardier Metro projects.

Moreover, more sophisticated turbulence models needs to be tested if they improve the quality of the prediction.

ACKNOWLEDGEMENTS

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