Advanced Method for energy-saving Design of Cabin Air Conditioning

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1. Motivation

2. Creation and Validation of the Model

3. Concepts Investigation

4. Summary and Future Prospects
Motivation

One of the main targets in the automotive development process is the reduction of energy consumption:

- The drivetrain’s efficiency increase is no more the only aspect to be taken into consideration.
- The thermal management of the full vehicle is obtaining more attention.
- The HVAC system has a high improvement potential.
Motivation

Aim of the project: development and validation of an advanced method for a rapid evaluation of new concepts concerning the cabin’s climate control.

New HVAC concepts:
- Improvement of the passengers’ thermal comfort
- Employing at the same time less energy than necessary for a conventional air conditioning system

The Co-Simulation GT-SUITE - TAITherm is used to reproduce the thermodynamics processes in the vehicle cabin.
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Simulation Models

- CAD-Model
- GTSpaceClaim-Model
- TAITherm-Model
- GT COOL3D-Model
- GT-SUITE-Model
Simulation Models – Cabin Volume Discretization

- **50 mm/50 mm/50 mm discretization**: time factor > 30.0
  - Critical simulation time
- **200 mm/200 mm/200 mm discretization**: time factor << 1.0
  - Critical representation of the flow field
- **100 mm/100 mm/100 mm discretization**: time factor ~ 1.0
  - Optimum “simulation time / accuracy” ratio → real-time simulation

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Simulation Speed 100/100/100

![Simulation Speed Graph](image)
Simulation Models

Definition of the material conditions in TAITherm

Car body

Glass

Window

Steel
Polypropylene Foam
Leather

Seats

HTC [W/mK]

1,5mm  50mm  1,5mm

Steel
Polypropylene Foam
Polypropylene

1,5mm  3mm  2mm
Boundary Conditions (Measurements and Simulations)

The model has been validated on the basis of measurements

Test carrier: BMW 116i 2016 year built

<table>
<thead>
<tr>
<th>Cabin Warming-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Outside temperature -10°C</td>
</tr>
<tr>
<td>2 No sun radiations</td>
</tr>
<tr>
<td>3 No wind</td>
</tr>
<tr>
<td>4 No rain</td>
</tr>
<tr>
<td>5 Pre-Conditioning: 12 hours</td>
</tr>
<tr>
<td>6 Vehicle not moving</td>
</tr>
<tr>
<td>7 Engine runs at idle speed</td>
</tr>
<tr>
<td>8 Manual HVAC setting - Step 4</td>
</tr>
</tbody>
</table>
Boundary Conditions (Measurements and Simulations)

15 temperature measuring points and flowmeter
Model Validation: Temperatures in the Cabin and on the Windshield

The temperature course is well simulated if compared to the measurements
- Maximal temperature difference 4°C

![Graphs showing temperature comparison between simulation and measurement for different locations in the vehicle.](image-url)
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Reference Concept

**20°C constant after 20 minutes at driver’s head → reference condition for driver’s comfort**

Additional reference targets for a more comprehensive concepts’ comparison:

- Temperature distribution in the cabin
- Energy efficiency of cabin heat-up
Minimum Air Flow

Minimum air flow rate to reduce the energy supply through conventional heating system

- Trade-Off: CO₂ concentration in the cabin
- Workplaces CO₂ exposure limit defined by law
Optimization Concepts

**Heat Recovery**
- 30 l/s
- Fresh Air Flow
- Cabin Air

**Air Recirculation**
- 22 l/s
- Fresh Air Flow
- Cabin Air

**Surface Heating**
- 8 l/s (CO₂ Limit 5 Passengers)
- 1.6 l/s (CO₂ Limit 1 Passenger)
- Surface Heating System
- Cabin Air

- **Heat Recovery**
  - 30 l/s (30 l/s total, 22 l/s from outlet volume flow recirculation)

- **Air Recirculation**
  - 22 l/s

- **Surface Heating**
  - 8 l/s (CO₂ Limit 5 Passengers)
  - 1.6 l/s (CO₂ Limit 1 Passenger)

- **Heat Flow**
  - 20°C
  - 20°C

- **Temperature vs. Time**
  - Temperature [°C]
  - Time [min]

- **Heat Flow vs. Time**
  - Heat Flow [kW]
  - Time [min]
Simulation Results – Inside Surface Temperatures

The surface heating concept guarantees a more homogeneous temperature distribution on the seats’ surfaces.
Simulation Results – Cabin’s Air Temperature

A higher thermal comfort for the passengers is reached with the surface heating concept

- Lower air temperature gradient
Cabin’s Air Temperature (after 60 Minute)

With the surface heating strategy the temperature progression at driver’s head position is well comparable with the reference model.

The employment of the surface heating system has the additional advantage of a more homogeneous temperature distribution in the cabin volume.
Comparison Energy Balance (after 60 Minutes)

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Reference</th>
<th>Heat Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating Energy</td>
<td>31.7%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Internal Energy</td>
<td>67.4%</td>
<td>80.8%</td>
</tr>
<tr>
<td>Energy Loss at the</td>
<td>1.0%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Outlet Airflow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Loss to the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surround</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Air Recirculation
- Heating Energy: 11.1%
- Internal Energy Increase: 87.6%
- Energy Loss at the Outlet Airflow: 1.3%
- Energy Loss to the Surround: 0.94 kWh

Surface Heating
- Heating Energy: 9.9%
- Internal Energy Increase: 88.2%
- Energy Loss at the Outlet Airflow: 1.9%
- Energy Loss to the Surround: 1.19 kWh

Surface Heating - Driver
- Heating Energy: 1.3%
- Internal Energy Increase: 96.8%
- Energy Loss at the Outlet Airflow: 1.9%
- Energy Loss to the Surround: 0.94 kWh
An energy reduction up to 43% can be achieved by employing a surface heating system and reducing the inlet air flow.
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Summary

- The feasibility of coupling between GT-SUITE and TAITherm has been proved and a cabin warming-up model has been calibrated on the basis of measurements.
- High simulation accuracy has been observed.
- The model has allowed real time calculations and local temperature analysis.
- Three design concepts for the heating system have been investigated:
  - Energy recovery from the outlet flow with a heat exchanger.
  - Air recirculation from the outlet port.
  - Surface heating system.
- Up to 43% energy reduction and higher thermal comfort for the passengers could be stated.
Future Prospects

- Increasing simulation accuracy (e.g. local refinement)
- Inclusion of the “Human Thermal Module”
- Investigation on further heating system concepts
- Integration of the cabin model in the full vehicle model
- Employment of a more complex environment model
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Thank you.
Any Questions?