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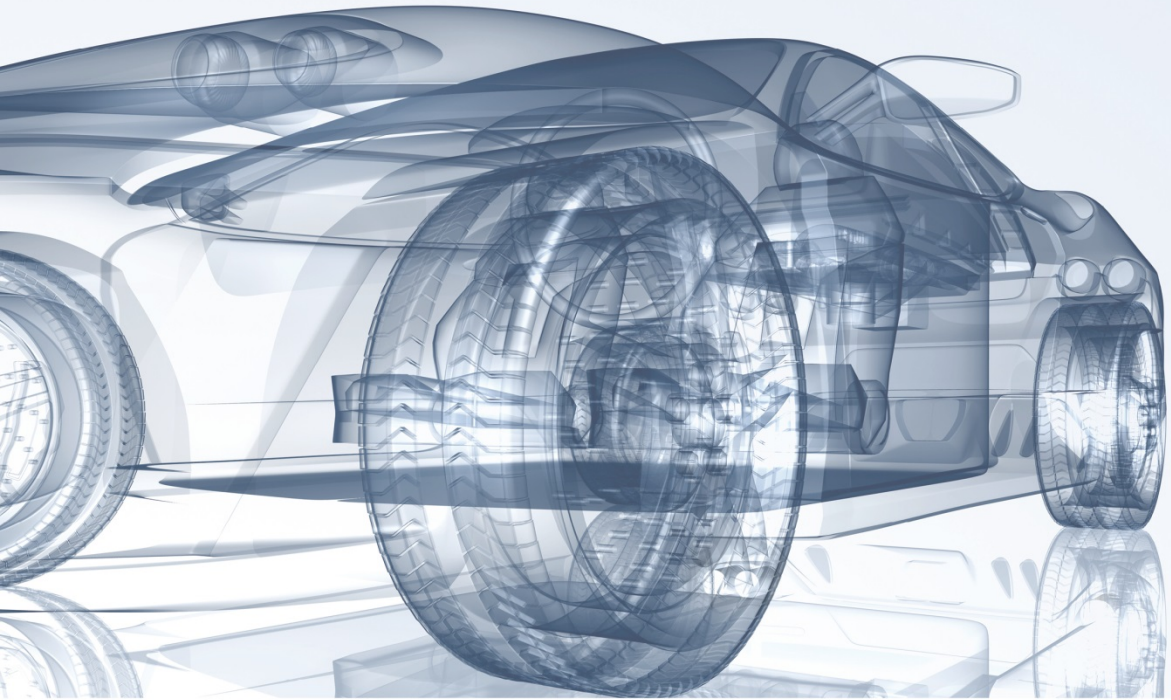

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A Method to Analyze Thermal Comfort and Energy Consumption of Heating Systems for Electric Cars

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Karlsruhe Institute of Technology, Institute of Vehicle System Technology,

Agenda

- **Introduction**
- **Methodology**
  - System Description
  - Experimental Setup
  - Experimental Procedure
- **Results**
- **Conclusion**

- Key challenge for EVs: Range

- High demand of energy for heating the cabin
  → Reduce energy needs of heating system

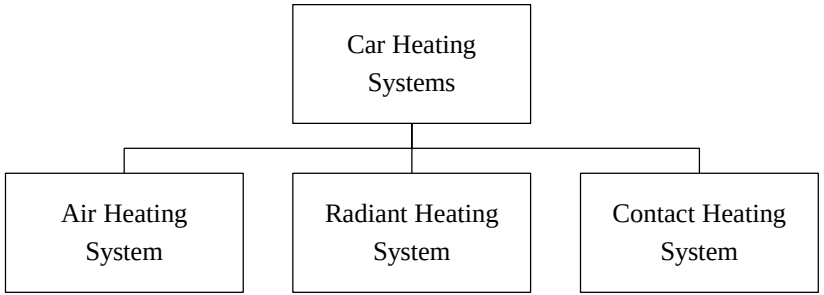
- actual systems base on
  - Combustion engine vehicles
  - Comfort guidelines for buildings

Introduction

- No waste heat
- Unsteady conditions
- Strong impact of surrounding temperature
- Solar radiation
- Clothing of passengers

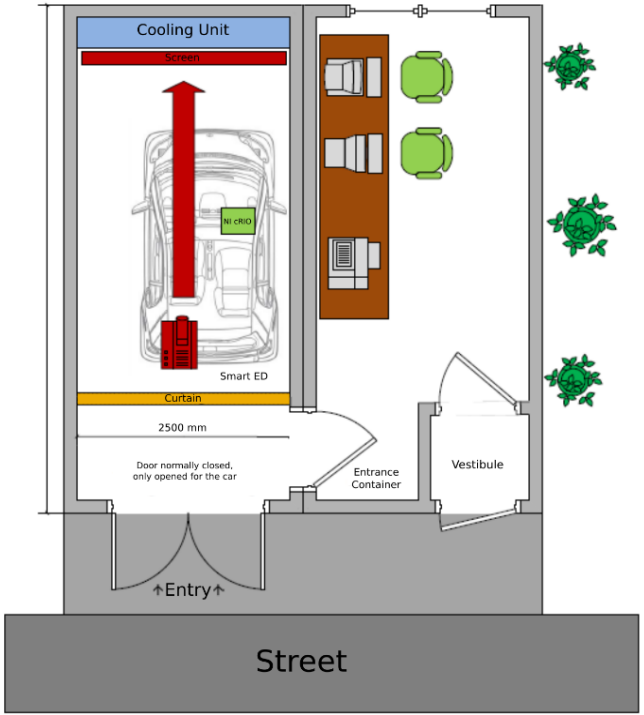
→ Transient conditions at vehicle start
→ Significant influence on thermal comfort and sensation

- Air Heating System: Standard
  - Combustion Engine: waste heat
  - Electric vehicles: PTC-Heater / Heat Pump
- Contact Heating System:
  - Seat heating, driving wheel heating
- Radiant Heating System
  - E.g. floor heating



- Test bench for proband studies

- Two containers
  - Test ground
    - Vehicle
    - Driving simulation
  - Control room
    - monitor test procedure
    - Interim and closing questionnaire
    - briefing

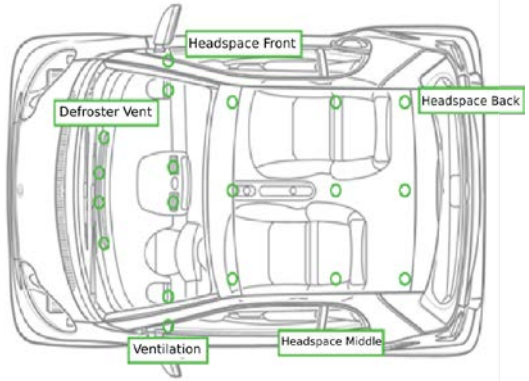


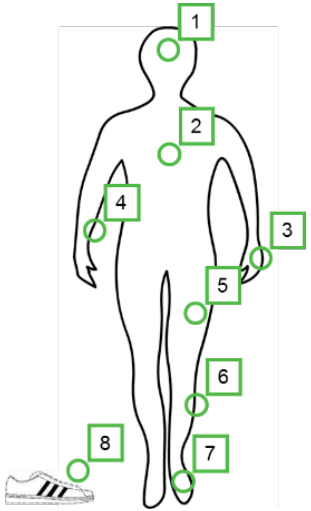
[1]

Technical Data	
Temperature Range	-25°C up to +25°C
Inner Dimensions	5.48m * 2.28m * 2.25m
Max. Vehicle Dimension	3.80m * 2.00m * 1.65m

- Sensors
  - Temperature
  - Air quality
  - Humidity

- Energy consumption of systems is logged





[1], [2]

Proband statistic

Experimental Setup	Number of probands	Age	Sex	Height	Weight
A 1	21	21 – 63 years	19 male 2 female	1.65 m – 1.98 m	62 kg – 120 kg
A 2	21	17 – 32 years	18 male 3 female	1.60 m – 1.92 m	51 kg – 130 kg
A 3-1	18	21 – 61 years	16 male 2 female	1.63 m – 1.95 m	60 kg – 102 kg
A 3-2	18	16 – 46 years	16 male 2 female	1.65 m – 1.93 m	60 kg – 95 kg

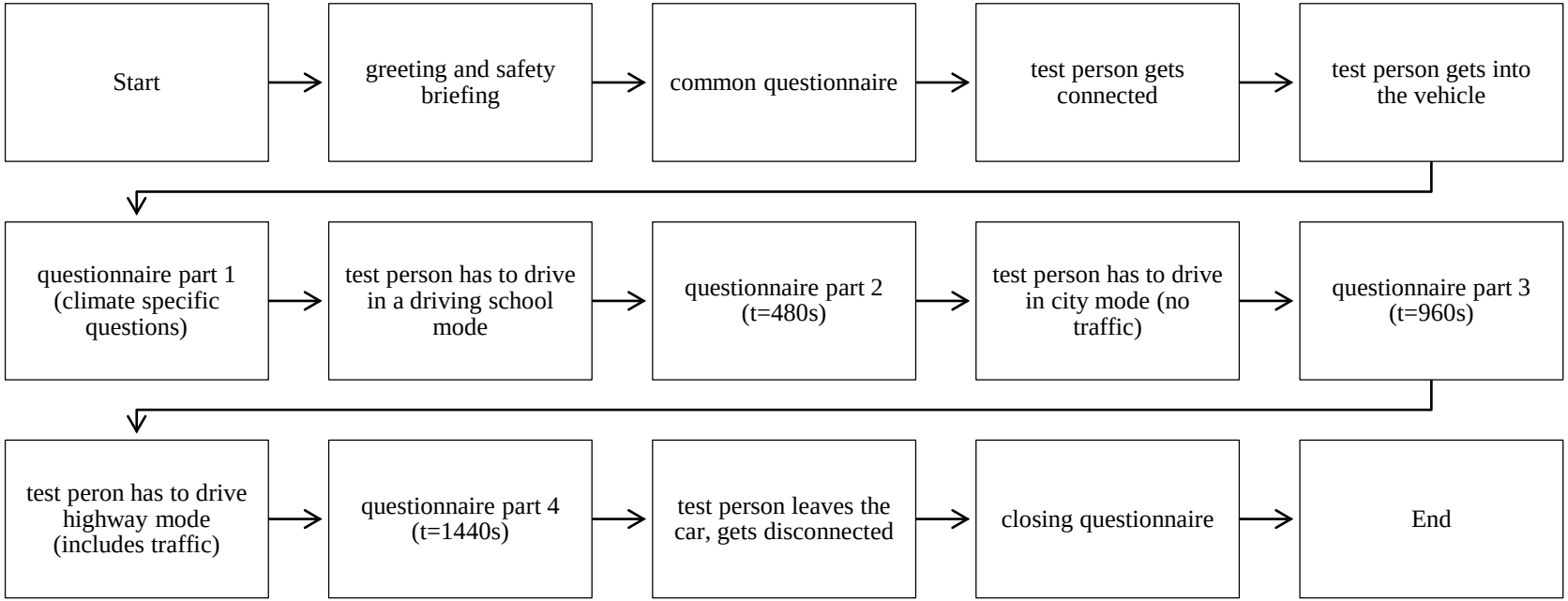
- Thermal sensitivity

Extremely cold	Too cold	Cold	Slightly cold	Neutral	Slightly warm	Warm	Too warm	Extremely warm
-4	-3	-2	-1	0	1	2	3	4

- Thermal comfort

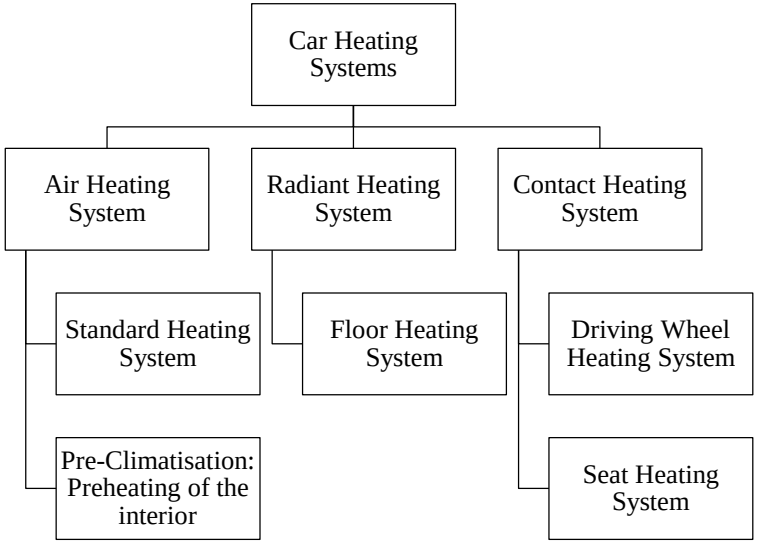
Max. Discomfort	Very Unpleasant	Unpleasant	Slightly Unpleasant	Slightly Pleasant	Pleasant	Very Pleasant	Max. Comfort
-4	-3	-2	-1	1	2	3	4

[2]


Start
greeting and safety briefing
common questionnaire
test person gets connected
test person gets into the vehicle
questionnaire part 1 (climate specific questions)
test person has to drive in a driving school mode
questionnaire part 2 (t=480s)
test person has to drive in city mode (no traffic)
questionnaire part 3 (t=960s)
test peron has to drive highway mode (includes traffic)
questionnaire part 4 (t=1440s)
test person leaves the car, gets disconnected
closing questionnaire
End

Results

- Analyses of different heating systems
- Boundary condition:
  Surrounding temperature -7°C
- Four different setups

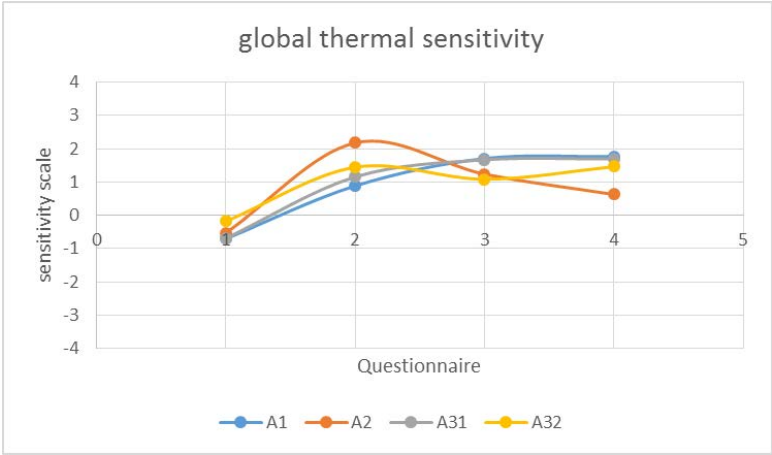


Results

Name	Ambient Air Temp.	Ventilation Adjustment	Seat Heating	Driving Wheel Heating	Floor Heating
A1	22 °C	Front Window	Off	Off	Off
A2	18 °C	Feet	On (permanent)	On (permanent)	Off
A3-1	18 °C	Feet	On (proband is allowed to switch of)	On (proband is allowed to switch of)	On
A3-2	18°C (Preconditioning up to 5°C)	Feet	On (proband is allowed to switch of)	On (proband is allowed to switch of)	On

Results

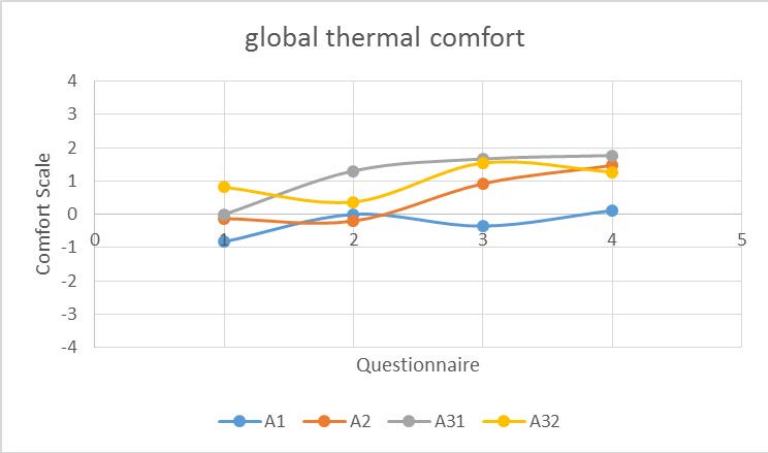
- At the end of the test: warm vehicle
- Best results at the beginning: A3-2 (preconditioned car)
- Best outcome: A2 (18°C, seat and driving wheel heating, no floor heating)



Extremely cold	Too cold	Cold	Slightly cold	Neutral	Slightly warm	Warm	Too warm	Extremely warm
-4	-3	-2	-1	0	1	2	3	4

- Non of the tested systems reaches maximum comfort
- Analysis of the different body parts necessary

→ Further analysis will be published!



Max. Discomfort	Very Unpleasant	Unpleasant	Slightly Unpleasant	Slightly Pleasant	Pleasant	Very Pleasant	Max. Comfort
-4	-3	-2	-1	1	2	3	4

Conclusion

- Method to analyse thermal comfort and energy consumption for heating systems
- Different systems can be studied and compared to each other
- Large potential of improvement in heating systems
- None of the existing methods provides maximum comfort
- Analysis of energy consumption
- Next step: Analysis of other systems and lower ambient temperatures

References

[1] M. Steck, „Messung des thermischen Innenraumkomforts - Einbau bzw. Anpassung der Messtechnik,“ Karlsruhe, 2013.

[2] J. Le Cocq, „Grün im Interieur - Die Konzeption eines Klimapaketes für die Generierung eines energieeffizienten Thermokomforts im smart electric drive,“ Steinbeis-Hochschule, Berlin, Sindelfingen, 2013.

Thank you

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