Cabin Insulation as a Key Factor for HVAC System Performance and Efficiency in Electric Vehicles

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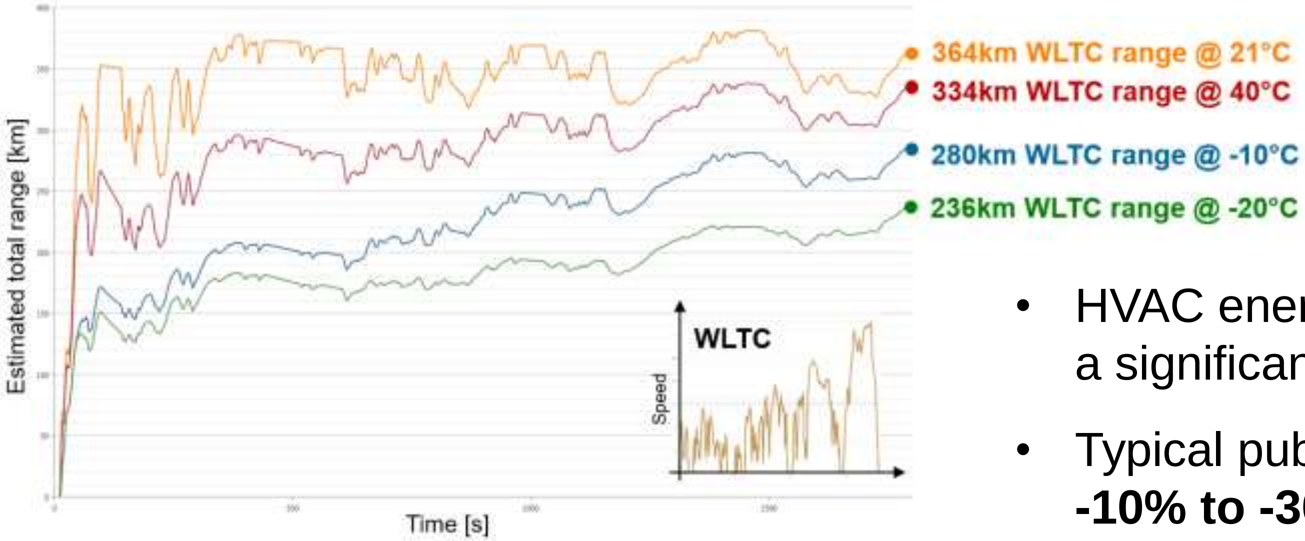
Introduction
EV Range and Ambient Conditions

Range of an Electric Vehicle for the WLTC in different climate conditions:

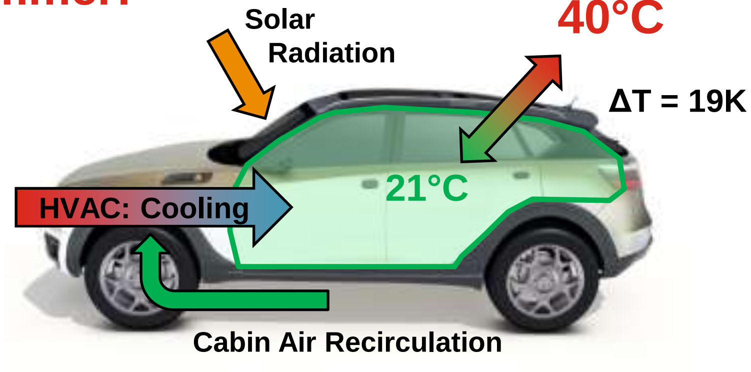


(diagram shows simulation results for Magna E1 demo car based on Tesla S)

- HVAC energy consumption has a significant impact on EV range
- Typical published values **summer** **-10% to -30% range**
- Typical published va **-30% to -50% range**

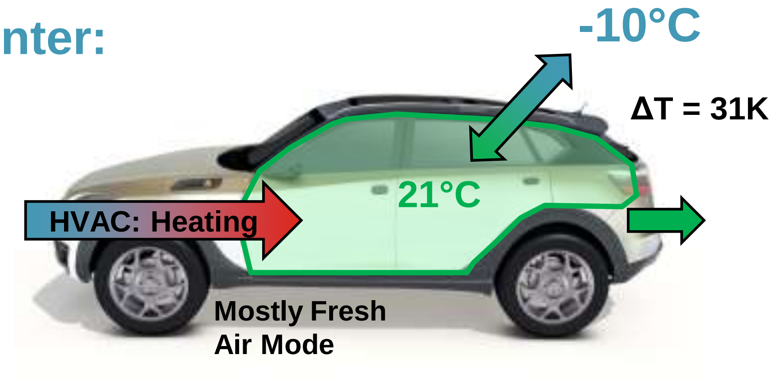
Introduction
Convection and Thermal Cabin Insulation

Summer:



- HVAC system needs cool the cabin
- Heat mainly from solar radiation and convection (→ **insulation!**)
- Usually high air recirculation rates
- Energy consumption from A/C compressor

Winter:



- HVAC system needs heat the cabin
- High losses due to convection (high delta T to ambience → **insulation!**)
- Low air recirculation rates in heating efforts even further
- Energy consumption from P or heat pump compressor

Honeywell Solstice® Blowing Agents

Low Global Warming Products from Honeywell

Pioneers in developing Low-Global-Warming-Potential (LGWP) solutions

Markets

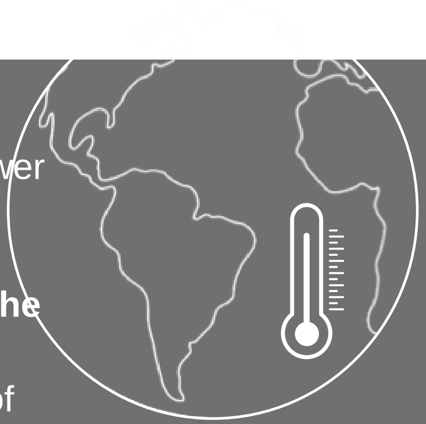
- Air conditioning and refrigeration
- Building and construction
- Appliance and containers insulation
- Aerosols and solvents
- Personal Care

Products / Services

- Solstice® :
  - ✓ Refrigerants
  - ✓ Blowing agents
  - ✓ Aerosols and cleaning solvents

Solstice® Overview

- Solstice offerings have a **Global Warming Potential** of 1 or lower (equal or better than CO_2)
- Solstice yf mobile air conditioning refrigerant can reduce the greenhouse gas equivalent of removing **30 million cars from the road***
- Solstice insulating materials can eliminate the CO_2 equivalent of the energy used by **5 million U.S. homes**



Estimates based on scenario of full global adoption of Solstice LGWP molecules; * equivalent to 3% of the global fleet

Honeywell's Fluorine Products Evolution

Montreal Protocol Ozone Depletion Concerns

Kyoto Protocol Global Warming Concerns

EU MAC Vehicle Refrigerant GWP< 150

	CFCs	HCFCs	HFCs	HFOs
	Chlorofluorocarbons	Hydrochlorofluorocarbons	Hydrofluorocarbons	Hydrofluoroolefins
Ozone Depleting	ODP 1.0	ODP 0.1	NON-ODP	NON-ODP
Global Warming	GWP 8000	GWP 2000	GWP 1000	GWP $\leq$ 1
Honeywell Products	Genetron®	Genetron®	Genetron® Enovate®	Solstice®

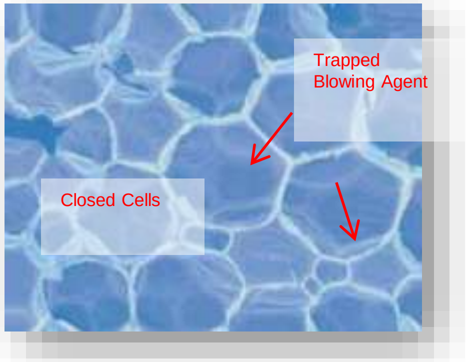
ODP Ozone Depletion Potential is relative amount of ozone degradation compared with R11 ODP = 1.0

GWP Global Warming Potential number equivalent to CO2 impact with GWP =1

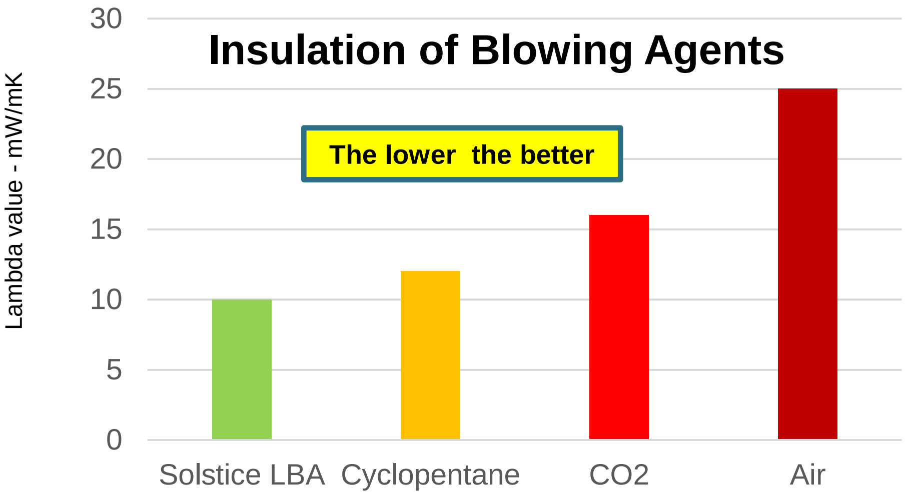
Honeywell innovation to achieve environmental breakthroughs

Honeywell's Solstice® LBA HFO Blowing Agent

- Foam blowing agent contributes to over 60% of the insulation of the foam
- Closed-cell HFO blown PU foam creates the highest level of insulation
- Solstice LBA helps design flexibility (low thickness) for the EV's body components

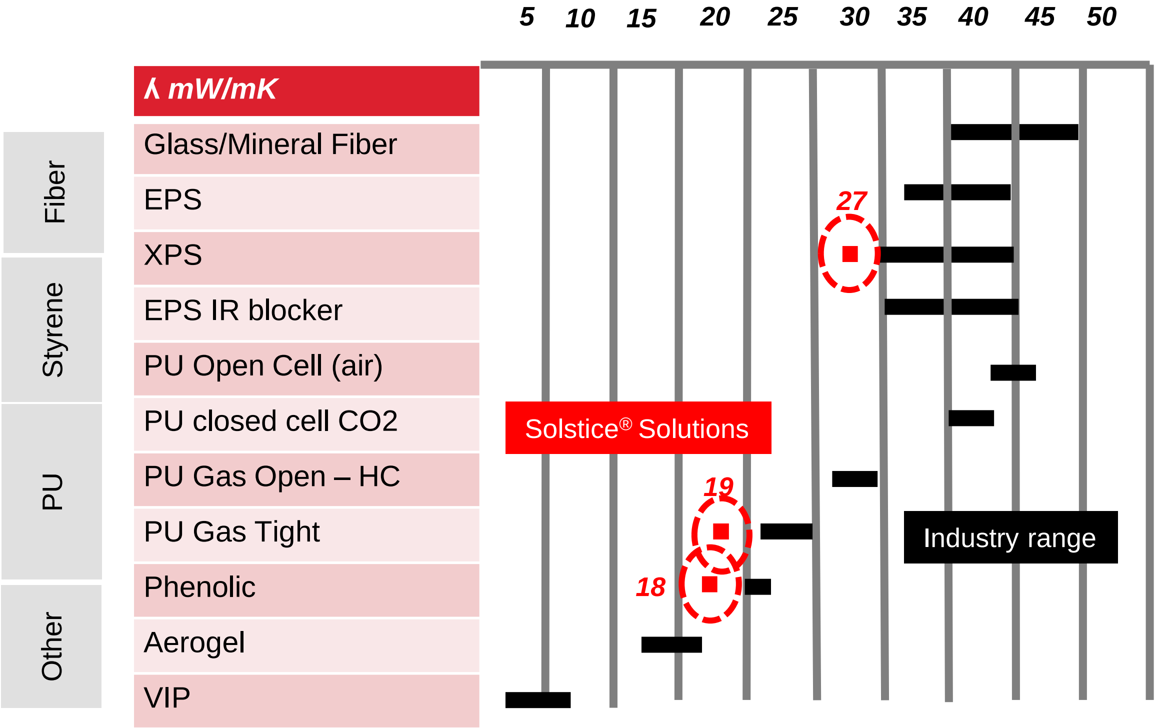


PU foam structure



Good Insulation Gas is Key to a Good Insulated Foam

Lambda Value of Insulation Materials



Values based according to European EN standards for CE marking

Solstice Blowing Agent Provides Best-in-Class Insulation

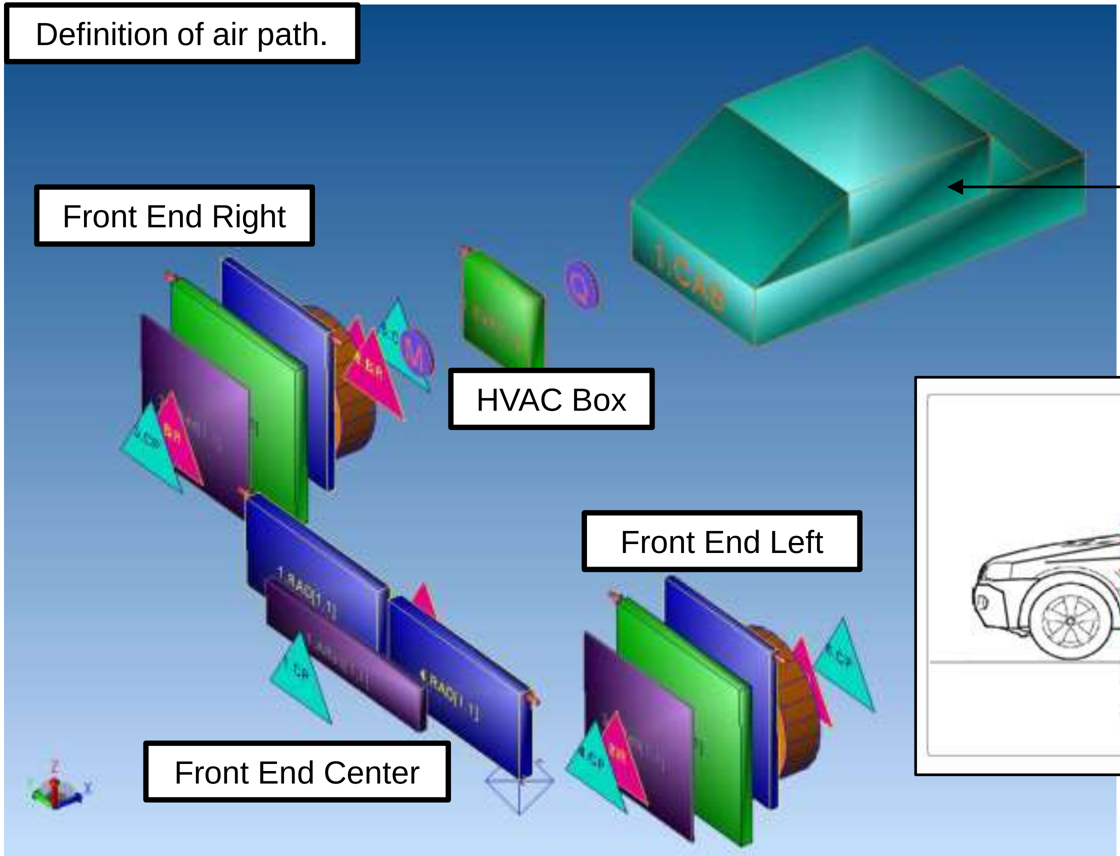
Benefit Study Cabin Insulation

What we did…

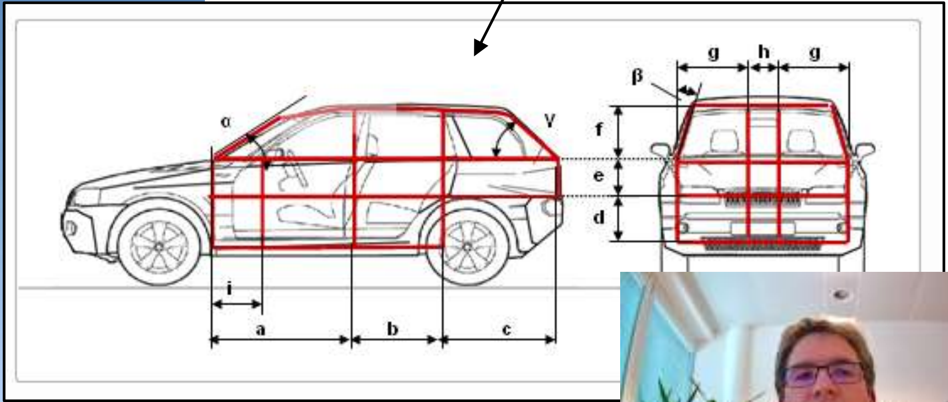
- Take a complete, calibrated baseline VTM simulation model for a car (investigated vehicle Magna E1 Democar)
- Add an insulation layer to the passenger cabin (in the simulation model)
- Compare HVAC energy consumption and vehicle range for different conditions:

	Ambient Temperature [°C]	Cabin Initial Temperature [°C]	Solar Intensity [W/m²]	Drive Cycle	Cabin Recirculation [%]
Hot soaking	30	21	1000	standstill	-
Warm-up	-10	-10	0	WLTC	20
Cool-down	40	60	400	WLTC	80
Warm-continuous	35	21	400	WLTC	80
Cold-continuous	-10	21	0	WLTC	20

Simulation Model Overview
Front-End Cooling Package and Passenger Cabin

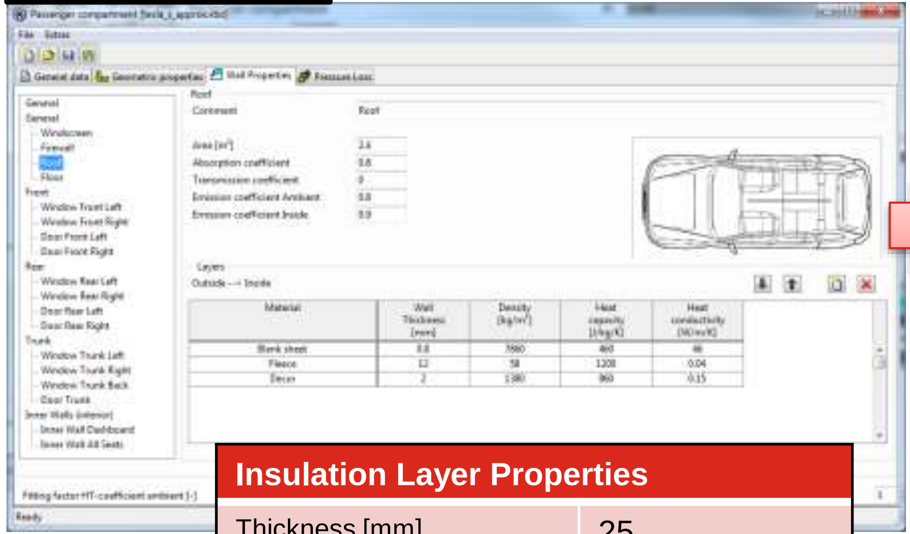


Multi zone cabin model

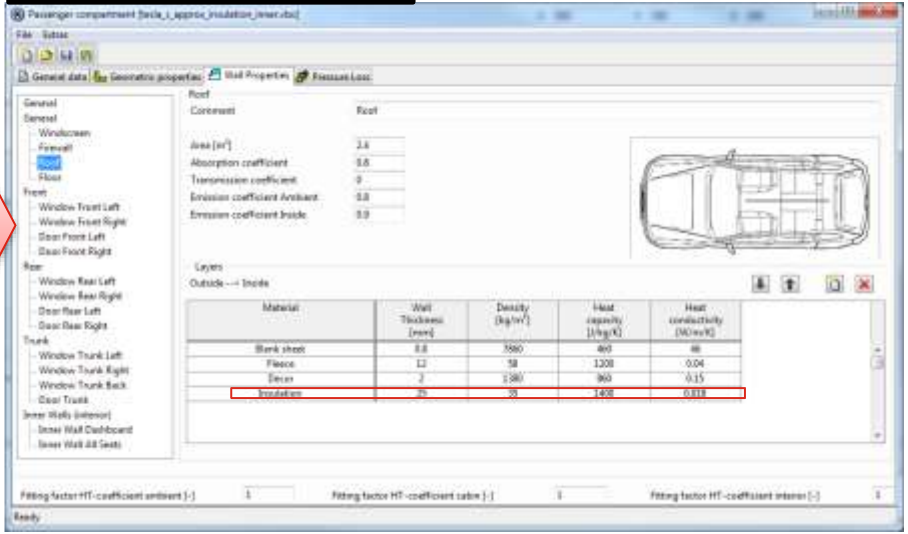


Multi-Zone Cabin Model
Insulation Layer

Base Cabin



Insulated Cabin



Insulation Layer Properties	
Thickness [mm]	25
Density [kg/m³]	35
Heat capacity [J/kg/K]	1400
Heat conductivity [W/m/K]	0.018

Insulation layer on the side of the cabin is add
all walls except the win

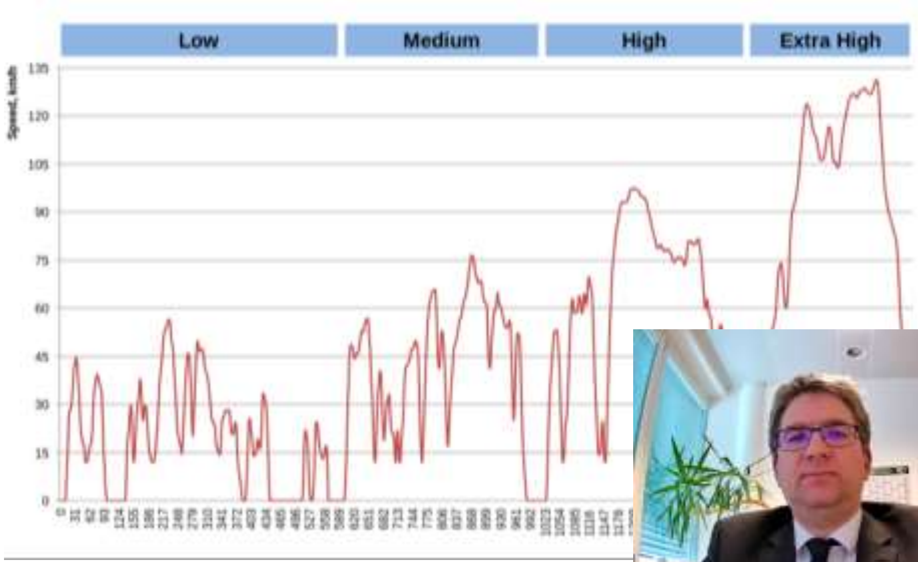
The WLTC Class 3

The WLTC Class 3 velocity profile is intended for vehicles with a power to weight ratio larger than 34kW per ton.

The E1 Demonstrator clearly exceeds this limit (560kW, weight ~2100kg), so we will use this cycle for the following investigations except of hot soaking.

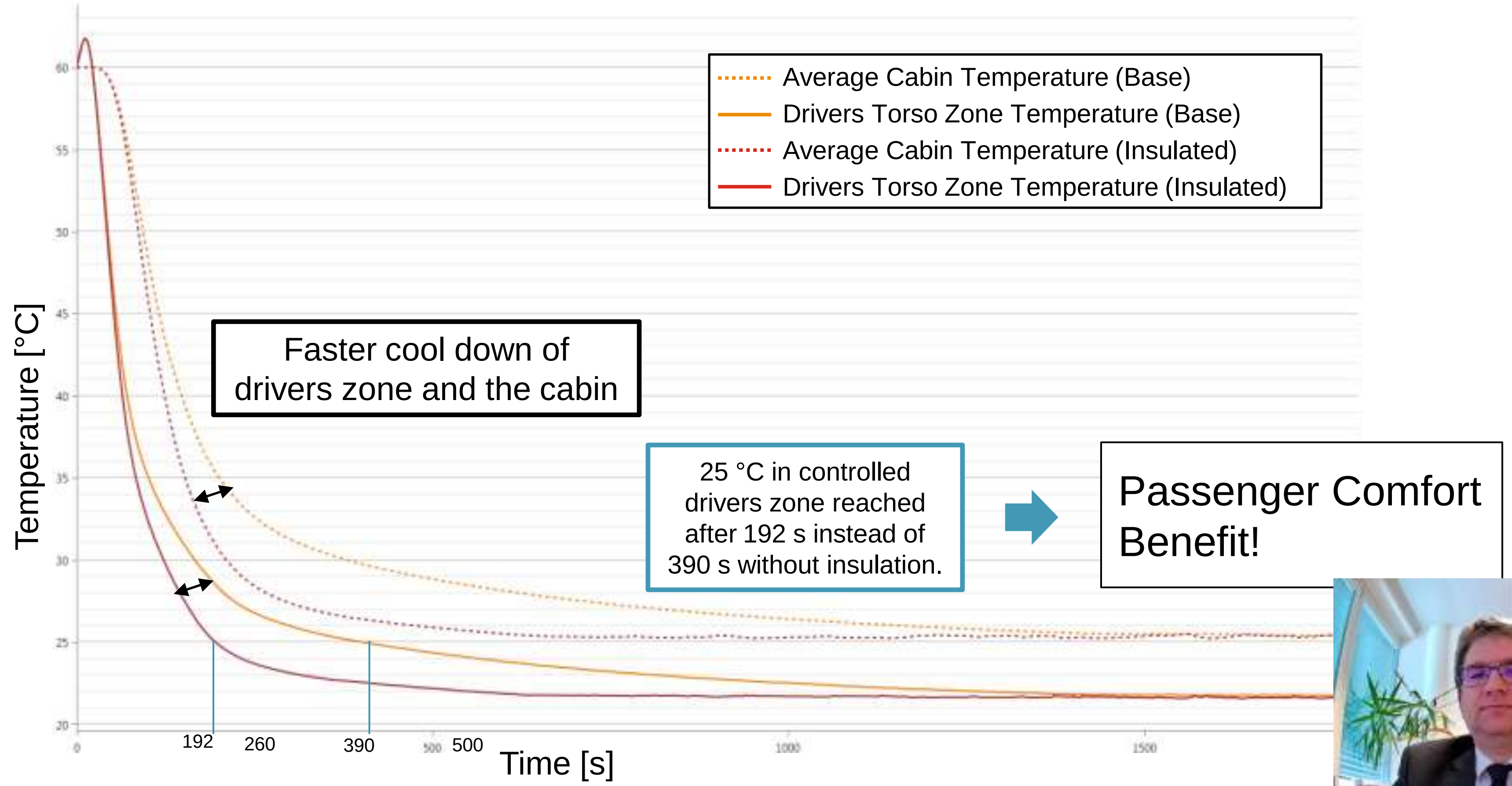
WLTC Class 3 Drive Cycle Definition (Wikipedia)

	Low	Medium	High	Extra High	Total
Duration, s	589	433	455	323	1800
Stop duration, s	150	49	31	8	235
Distance, m	3095	4756	7162	8254	23266
% of stops	26.5%	11.1%	6.8%	2.2%	13.4%
Maximum speed, km/h	56.5	76.6	97.4	131.3	
Average speed without stops, km/h	25.3	44.5	60.7	94.0	53.5
Average speed with stops, km/h	18.9	39.4	56.5	91.7	46.5
Minimum acceleration, m/s^2	-1.5	-1.5	-1.5	-1.44	
Maximum acceleration, m/s^2	1.611	1.611	1.666	1.055	

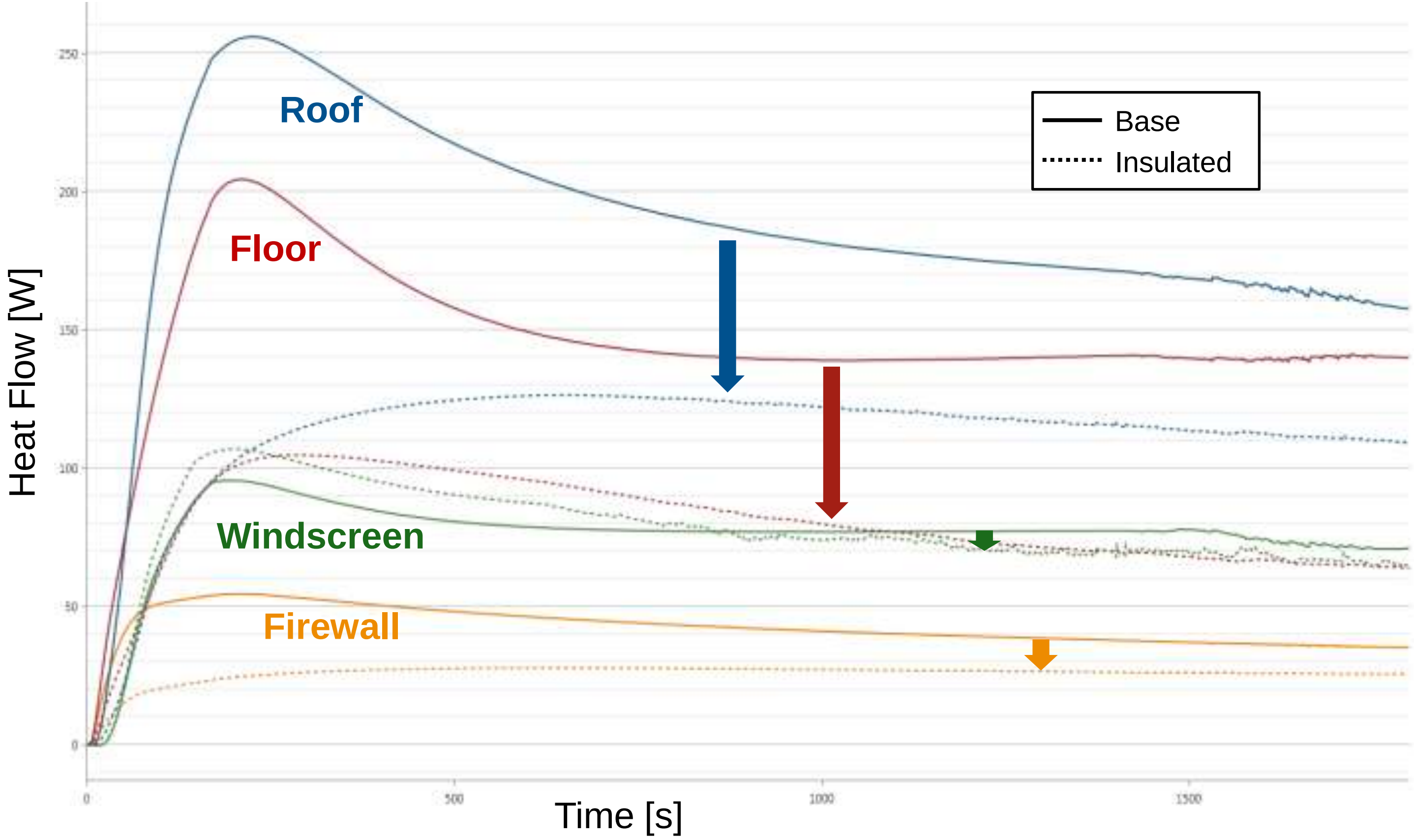


Simulation Results Summer

Simulation Results: Cool-Down Cabin Temperatures



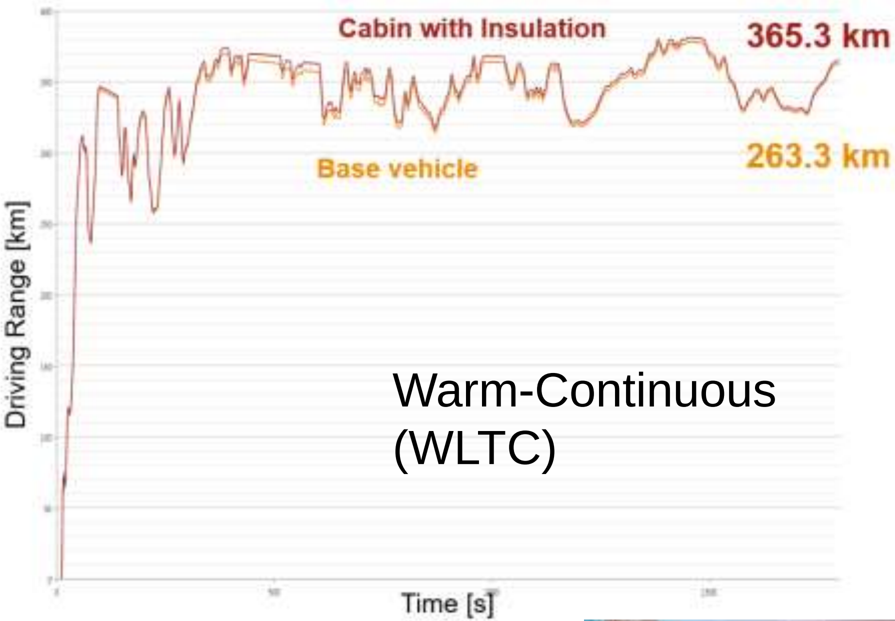
Simulation Results: Cool-Down Heat Flow through Cabin Walls



- The heat flow from the insulated walls to the interior decreases
- Heat flow from the windscreen to the interior slightly increased at the beginning because of lower cabin temperatures.

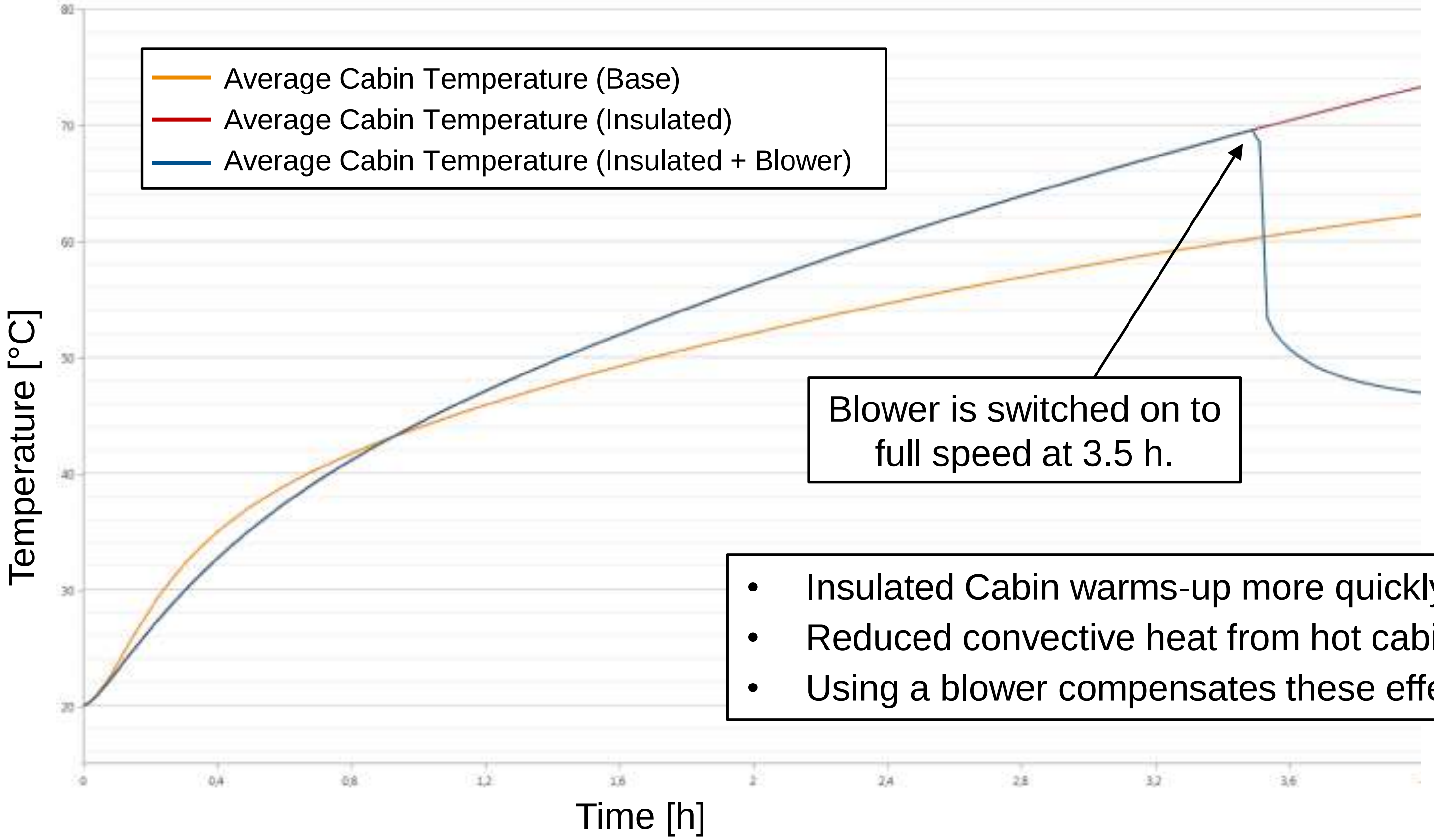
Simulation Results: Warm Ambient Conditions Range Prediction

Reduced power consumption of compressor and blower leads to ~5 km (~1.5%) range increase for WLTC.



Only slightly improved range due t
ambient (2km, ~0.6%)
Main cooling effort during initial co
ambient reduces benefit of insulati

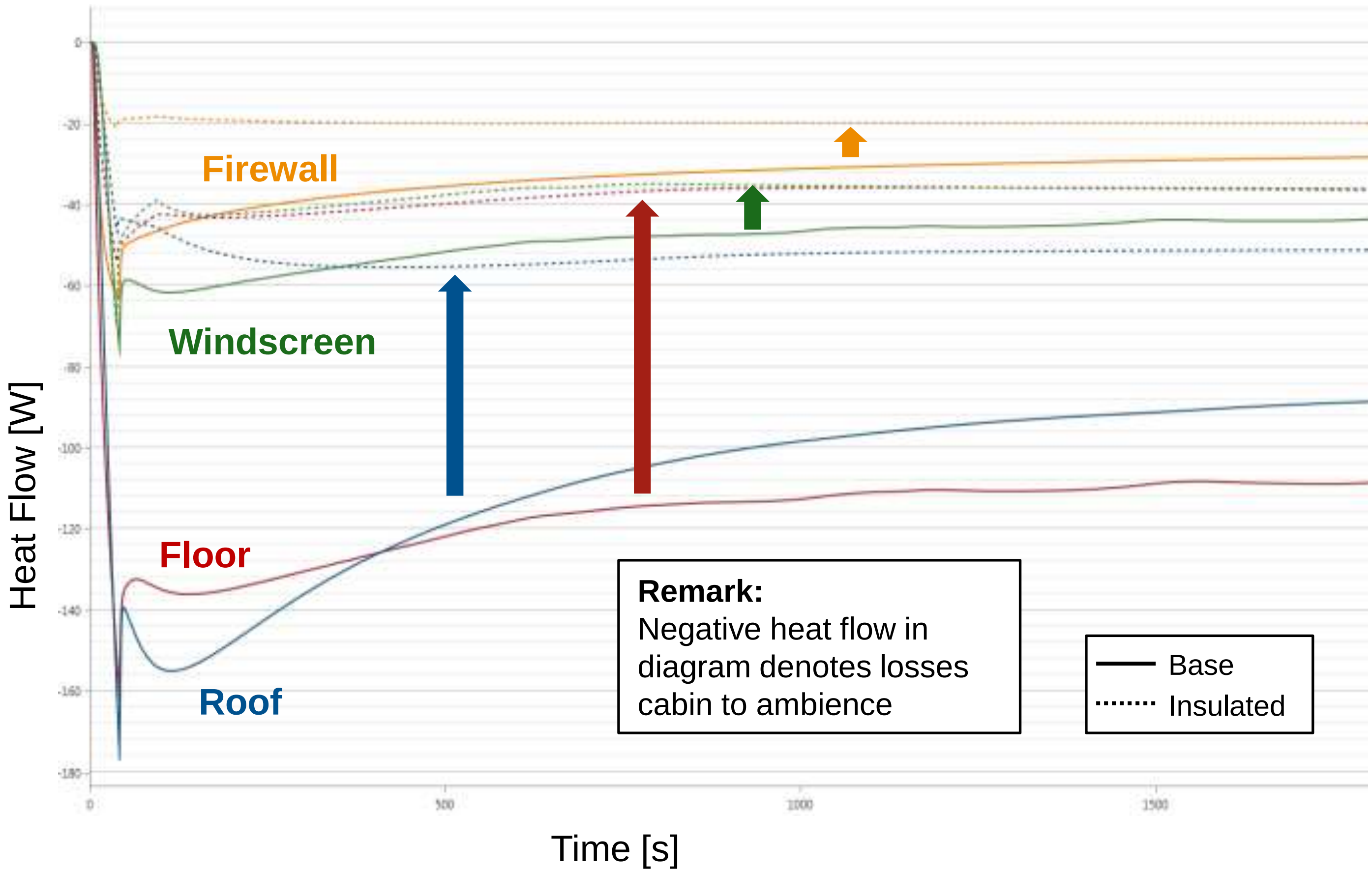
Simulation Results: Hot Soaking Cabin Temperatures



- Insulated Cabin warms-up more quickly due to solar loads
- Reduced convective heat from hot cabin to
- Using a blower compensates these effects

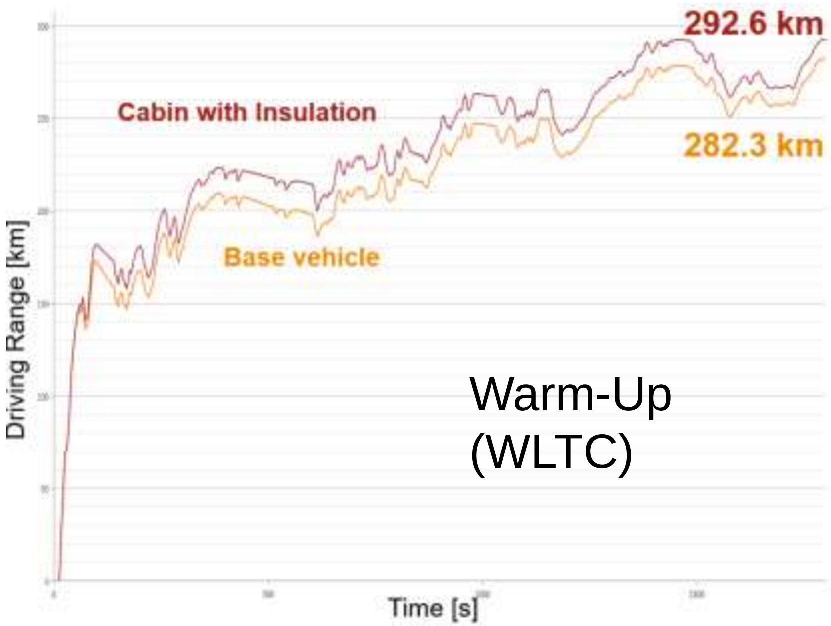
Simulation Results Winter

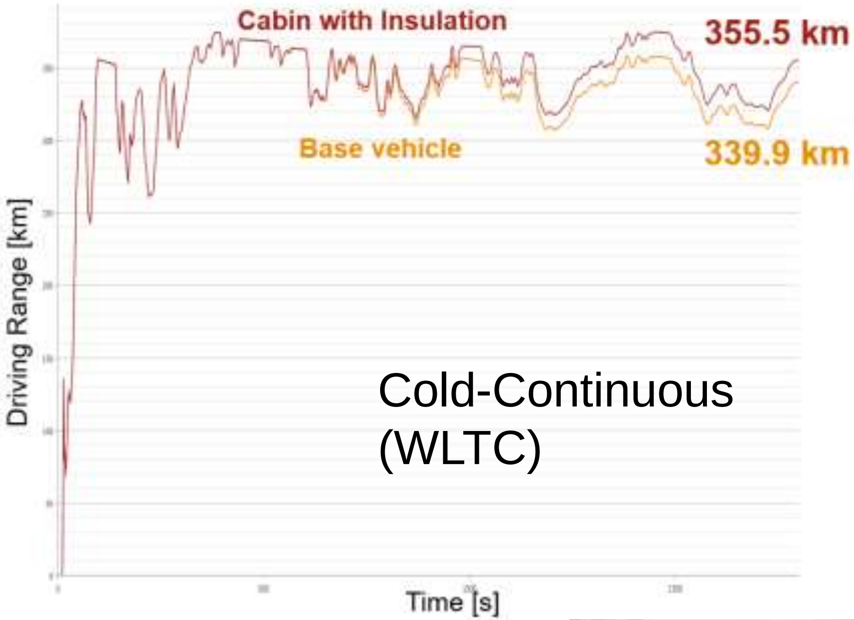
Simulation Results: Warm-Up
Heat Flow through Cabin Walls



- The heat flow from the interior to the insulated walls decreases.
- Significantly reduced thermal losses
- Biggest benefit from cabin roof and floor

Simulation Results: Cold Ambient Conditions
Range Prediction





Reduced heat losses of the cabin lead to ~10 km (~3.5%) range increase for WLTC.

Due to reduced heat losses of the
(4.6%) range increase for WLTC.
Big benefit from insulation due to h
cabin (21°C) and ambient (-10°C)!

Summary

Summary Range Prediction Benefit for WLTC

Operation Mode	Base Cabin Model	Insulated Cabin Model	Range Increase
Warm-up	282.3 km	292.6 km	3.5 %
Cool-down	333.7 km	338.9 km	1.5 %
Warm continuous	362.3 km	365.3 km	0.6 %
Cold continuous	339.9 km	355.5 km	4.6 %
Baseline (no HVAC)	370.9 km	370.9 km	-

- Vehicle range generally benefits from cabin insulation, but effects are strongest in winter conditions
- In summer the biggest impact is on passenger comfort (cool-down
- Cabin ventilation is recommended for hot-soaking conditions
- Actual benefits will, of course, vary for different vehicles

MAGNA

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INSPIRING **INNOVATION.**