

THERMO
ANALYTICS



MAGNA

Forward. For all.

Reducing energy consumption for cabin comfort – a
coupled approach

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May 15th, 2025



Agenda

- 01** Motivation
- 02** Influence of cabin to energy consumption
- 03** A detailed cabin model
- 04** Coupling the tools
- 05** Summary and conclusion



01

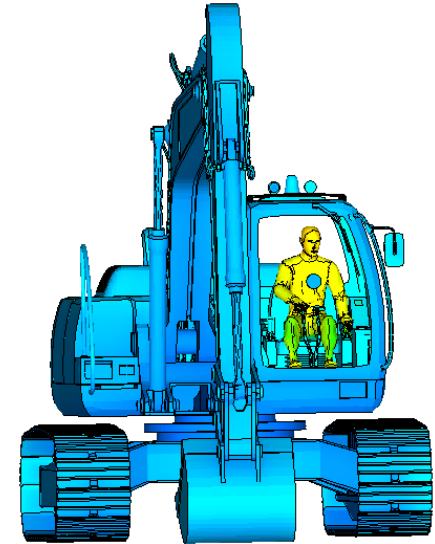
Motivation

Energy efficiency for electric excavators

Motivation

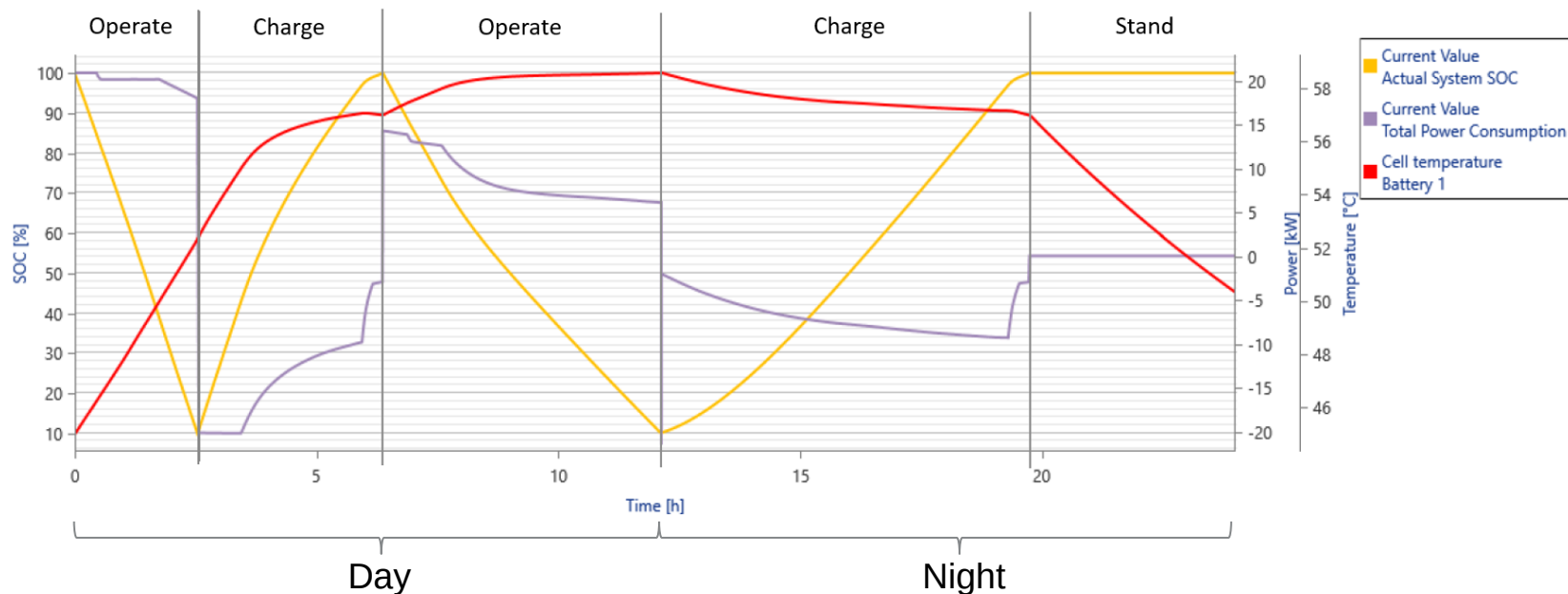
Subtitle Arial 20

- The trend of electrifying vehicles of all types is continuing
- HVAC system has a significant influence on overall energy consumption
 - A/C system in summer to cool down cabin and battery
 - Heaters or heat pump in winter to heat cabin
- For electric passenger cars it is all about range
- For electric long-haul trucks it is even more all about range
- For electric construction machines it is about operation time



A Typical 24 Hour Profile

Excavator



Task: Maximize operation time during day



02

Influence of Cabin

Aspects relevant for energy consumption

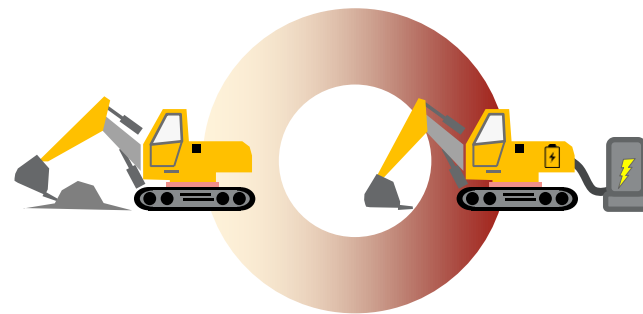
Influence of Cabin

Aspects relevant for energy consumption

- Comfort is becoming increasingly important, even for construction vehicles
- High demand on hvac system due to poor insulation and high proportion of glass
- Total energy consumption vs. „unplugged“ energy consumption
 - Operation of hvac system during charging possible
- Alternative heating/cooling concepts
 - E. g. radiant panels in cabin interior
- Let us have a closer look on some aspects

Total Energy Consumption vs. Unplugged One

- Cooling/heating the cabin during charging could reduce energy consumption during working phase
 - No need to heat up / cool down a pre-conditioned cabin
 - Immediate comfort for driver
- Assumption: There is more charging power available than can be used for charging the battery
 - This is feasible, since often fast charging is only available for low SOC.
 - Towards the end of charging, charging power is reduced such that power is available for operating the hvac system
 - Direct usage of external power must be enabled inside the vehicle

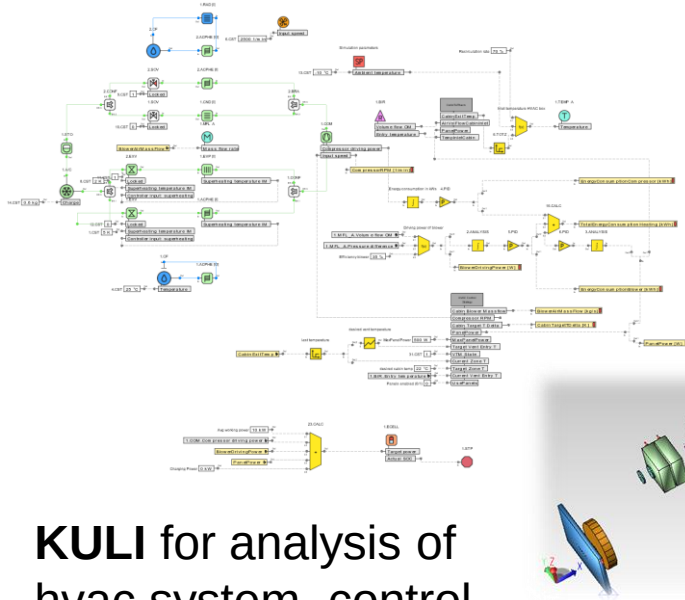


Alternative Heating Concepts

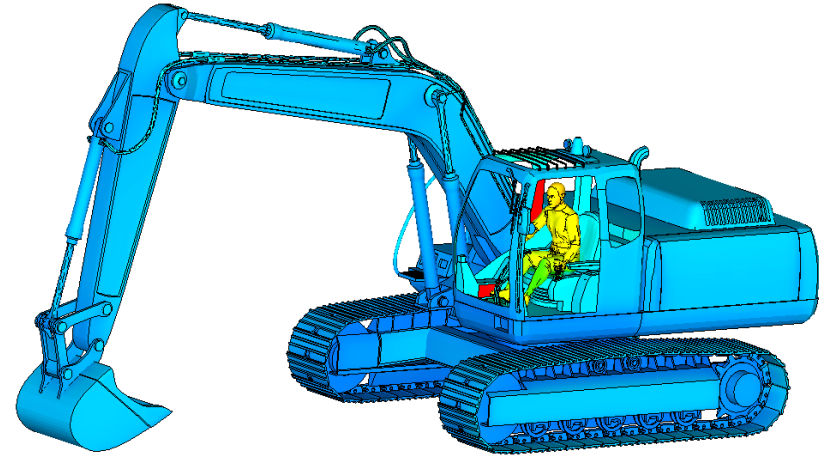
- Heat pumps are very effective for heating the air
- But comfort can also be achieved at lower temperatures by means of radiation, heated seats, etc.
- Radiant heating panels can be placed in cabin at suitable positions
- Good compromise needs to be found between sufficient air heating and usage of radiant panels
 - The target is to ensure sufficient comfort with the least energy consumption
- Comfort models in cabin are suitable for addressing this topic

How to Assess the Energy Consumption

Suitable tools for a detailed investigation



KULI for analysis of hvac system, control logic, overall energy consumption



TAItherm for detailed analysis of cabin

KULI as master





03

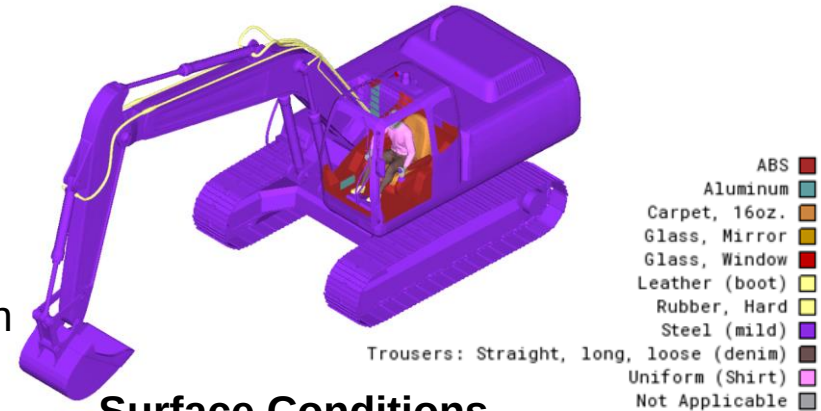
A Detailed Cabin Model

TAITherm cabin model

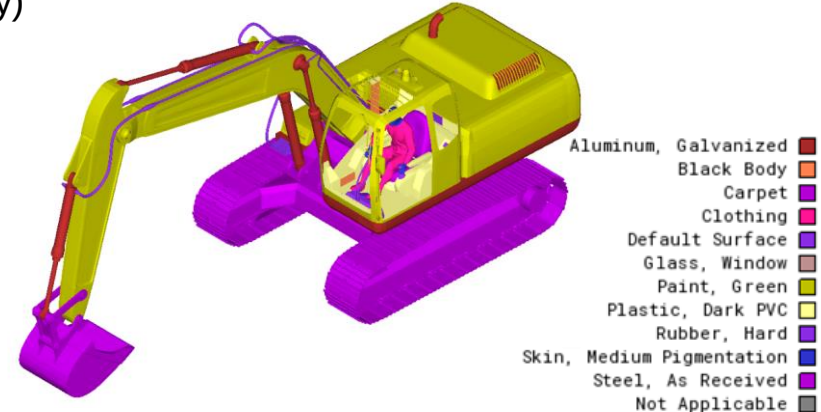
Model Setup

- Geometry:
 - Generic excavator
 - A 50th percentile male human
- Materials and surface conditions setup as shown
- Environment:
 - Cold weather environment (Houghton, MI in February)
 - Lows of -18.3°C , highs of -6.1°C
 - Slightly windy

Materials



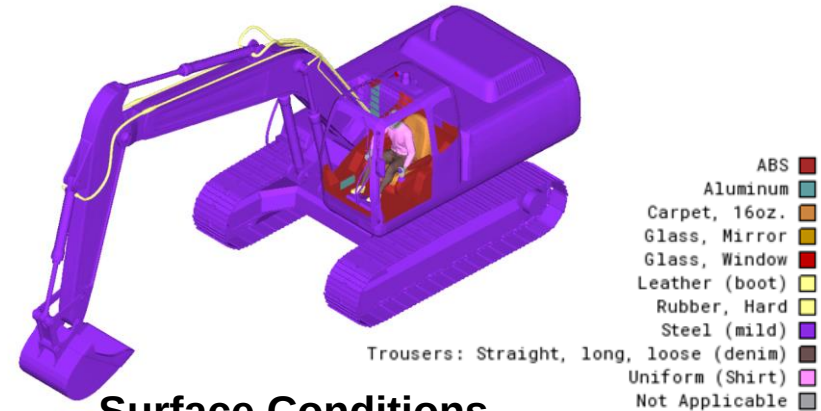
Surface Conditions



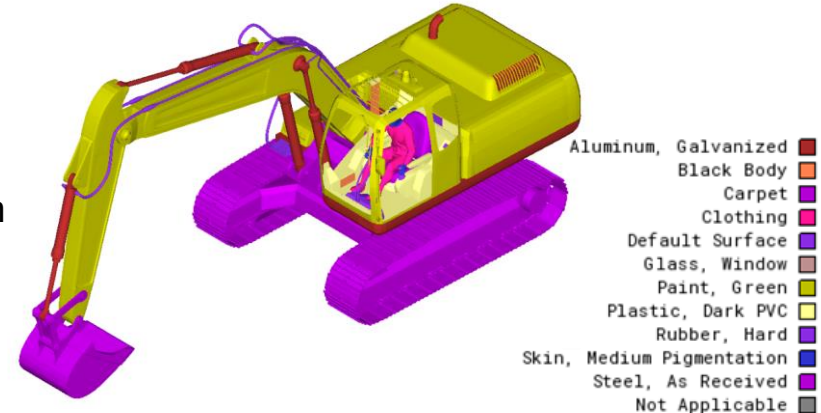
Model Setup

- Convection:
 - Exterior of the excavator receives wind convection from the environment
 - Interior cabin of the excavator receives natural and forced air convection modeled with RapidFlow/Fluid-network
 - Inlets /Outlets
 - Inlets use velocity and temperature curves to simulate a typical HVAC system warm-up scenario
- Additional:
 - Three radiant panels were added to the interior cabin of the excavator
 - Radiant panels are focused on the feet, left arm, and right arm of the human

Materials



Surface Conditions



Human Setup

- Anthropometry & Physiology:

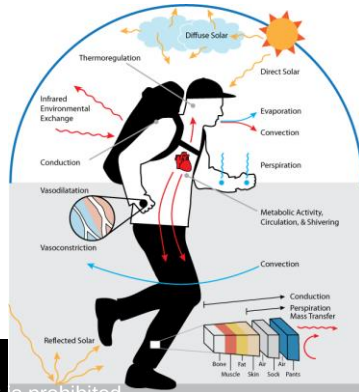
- Gender – Male
- Height – 50th percentile
- Weight – 50th percentile

- Activity:

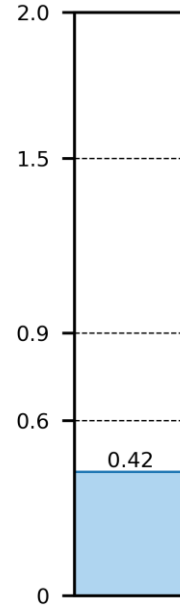
- Type – Sedentary
- Level – 1.0 MET
- Equivalent – Sitting quietly

- Clothing:

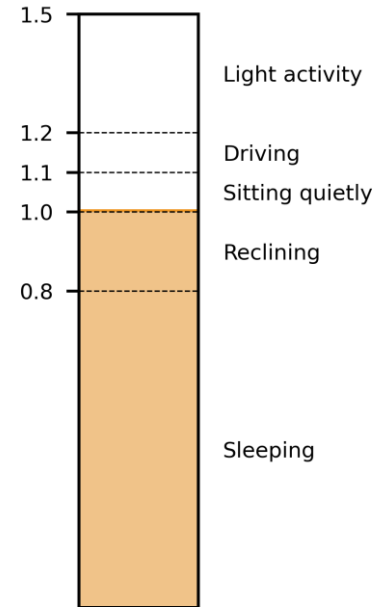
- $I_{cl} = 0.42 \text{ CLO}$
- $i_{cl} = 0.20$
- $f_{cl} = 1.28$



Clothing Thermal
Insulation (CLO)



Activity Level
(MET)



Human comfort technology takes both
environment conditions &
Physiology

FMU Inputs

Thermal model is exported to FMU from TAItherm

- Boundary conditions in the thermal model can be controlled through external sources using input parameters
 - Input parameters are setup in the thermal model before exporting to FMU
 - Input parameters allow for control of temperatures, convection coefficients, flow rates, humidity, and more
 - Excavator FMU is setup with input parameters for:
 - HVAC system volumetric flow rate
 - HVAC system temperature
 - Each radiant panel heat rate

Input Parameters

Name	Parameter Type	Value	Units
Inlet Air Flow Rate	Volume Flow	5000	L/min
Inlet Air Temperature	Temperature	20	°C
RP - Cabin Wall - Left	Heat Rate	96	W
RP - Cabin Wall - Right	Heat Rate	150	W
RP - Footwell	Heat Rate	60	W

Output Parameters

Name	Parameter Type	Entity	Select	ID	Measurement	Node Selection
Berkeley Overall Thermal Comfort	Berkeley Comfort	Human	👉	Human	Not Applicable	Not ...
Berkeley Overall Thermal Sensation	Berkeley Sensation	Human	👉	Human	Not Applicable	Not ...
Cabin Air Temp	Temperature	Part	👉	234	Average	Single Node
Equivalent Temp (EHT)	Equivalent Temperature	Human	👉	Human	Not Applicable	Not ...
Fiala Dynamic Thermal Sensation	Dynamic Thermal Sensation	Human	👉	Human	Not Applicable	Not ...
Interior Cabin Glass - Temperature	Temperature	Part	👉	16	Average	Back
Interior Cabin Walls - Temperature	Temperature	Part	👉	33	Average	Back
Predicted Mean Vote (PMV)	Predicted Mean Vote	Human	👉	Human	Not Applicable	Not ...

Close

FMU Outputs

Results in the thermal model FMU can be read using output parameters

- Output parameters are setup in the thermal model before exporting to FMU
- Output parameters allow for reading various temperature, solar heat, radiation heat, and human comfort results
- Excavator FMU is setup with output parameters for :
 - Cabin average air temperature
 - Interior cabin walls and windows temperatures
 - Human comfort (DTS, EHT, OS, OC, PMV)

Input Parameters

Name	Parameter Type	Value	Units
Inlet Air Flow Rate	Volume Flow	5000	L/min
Inlet Air Temperature	Temperature	20	°C
RP - Cabin Wall - Left	Heat Rate	96	W
RP - Cabin Wall - Right	Heat Rate	150	W
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Cabin Air Temp	Temperature	Part		234	Average	Single Node
Equivalent Temp (EHT)	Equivalent Temperature	Human		Human	Not Applicable	Not ...
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Interior Cabin Glass - Temperature	Temperature	Part		16	Average	Back
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Predicted Mean Vote (PMV)	Predicted Mean Vote	Human		Human	Not Applicable	Not ...

Close



04

Coupling the Tools

FMU as interface between KULI and TAITherm

Integration via FMU

- TAItherm cabin model given as FMU
- Import into KULI via Python controller
 - Online library example „FMU Co-Simulation with KULI as Master“ for streamlined generation of appropriate Python script

 **KULI Online Library**

 All content

 Space settings

 Content

▼ KULI Online Library / FMU Co-Simulation with KULI as Master

FMU Co-Simulation with KULI as Master

  Owned by [Christoph Plakolm](#) ***
Last updated: Jul 30, 2024 • 4 min read



Read input from

☒ FMU file ☐ Generated Python script

FMU location

General

Step size [s] (KULI time step)

Default time interval [s]

Use KULI time step ☒

Include parameters ☐

Connectors

Inputs

Outputs

	Name	Unit	Default value
☒	Inlet Vent - Rear Left - Temperature	K	293.149994
☒	Inlet Vent - Rear Right - Temperature	K	293.149994
☒	Inlet Vent - Front - Temperature	K	293.149994
☒	Inlet Vent - Foot - Temperature	K	293.149994

☒ (de)select all

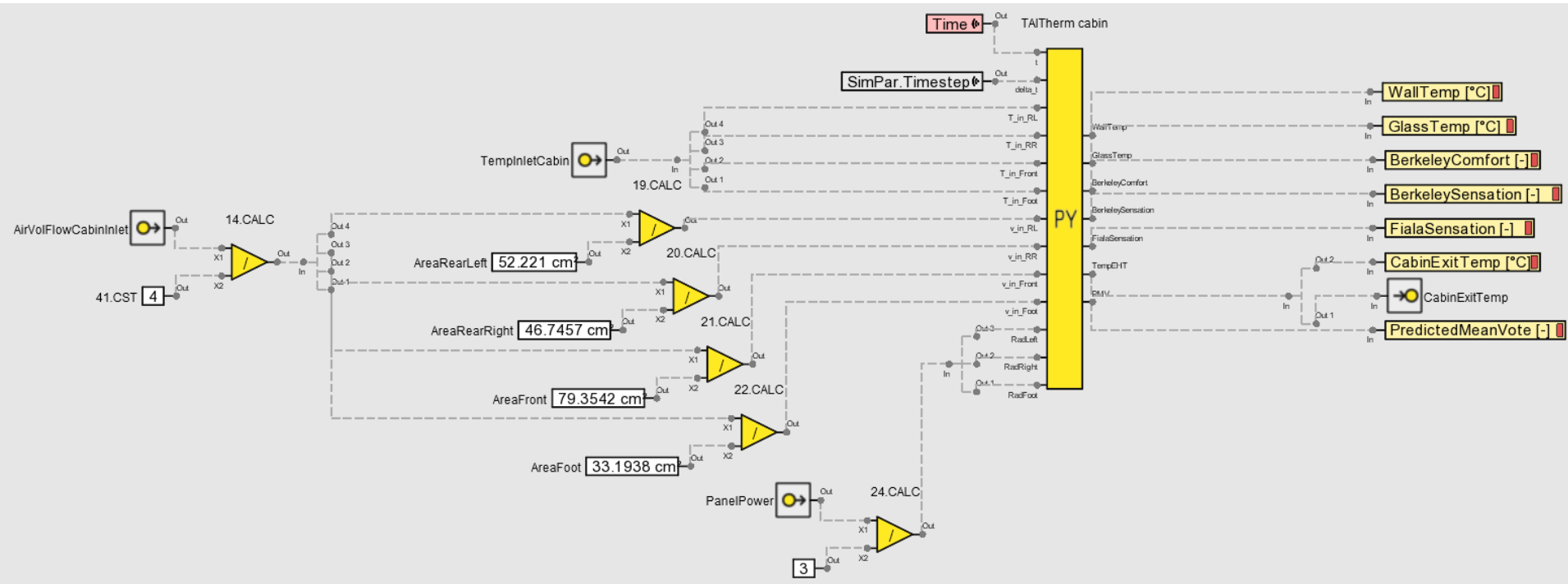
Export Python Script

Export script to...

Interfaces

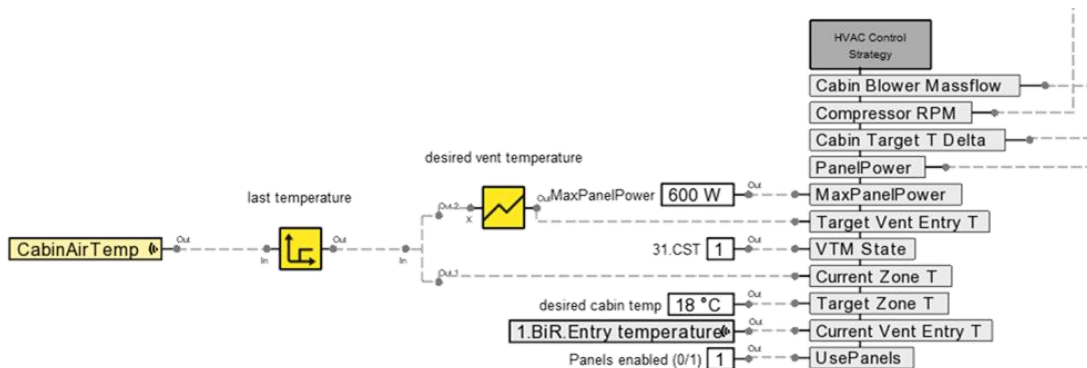
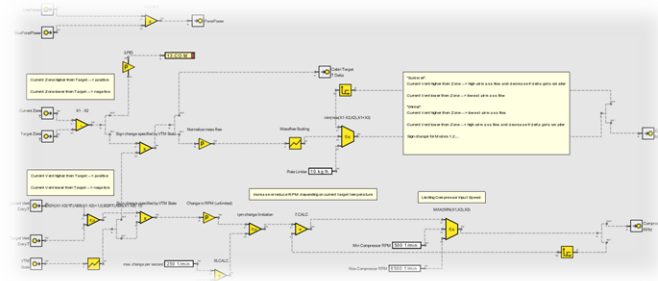
KULI → TAItherm	TAItherm → KULI
Air inlet temperature	Wall temperature
Air flow rates for each vent	Glass temperature
Heating panel power for each panel	Air outlet temperature
Time step	Various comfort and sensation values

Python Interface to TAITherm



Thermal Control Logic

- Sensor values:
 - Vent outlet temperature
 - Direct result within KULI
 - Set point for vent outlet depends on current cabin temperature
 - Cabin temperature
 - Return value from TAITherm cabin
 - Fixed set point
- Control parameters
 - Compressor rpm
 - Affects performance of heat pump
 - Blower flow rate
 - Affects flow rate into cabin



First Results

Warm up case

Comparison of Three Variants

Heating case with ambient temperature -10°C

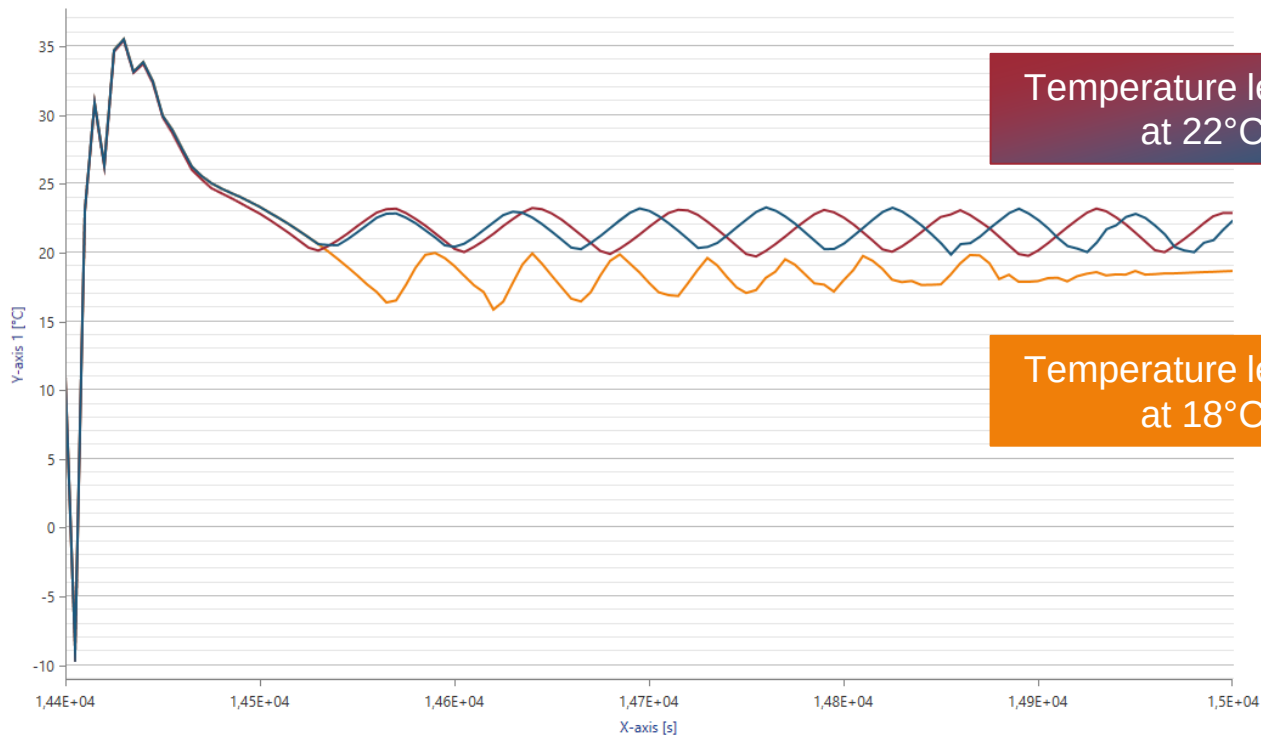
- Variant 1 (red)
 - Heat pump
 - High target cabin temperature (22°C)
 - No radiant panels
- Variant 2 (blue)
 - Heat pump
 - High target cabin temperature (22°C)
 - Radiant panels (600 W)
- Variant 3 (orange)
 - Heat pump
 - Lower target cabin temperature (18°C)
 - Radiant panels (600 W)

Temperature in Cabin

High temp.,
no panels

High temp.,
panels

Low temp.,
panels

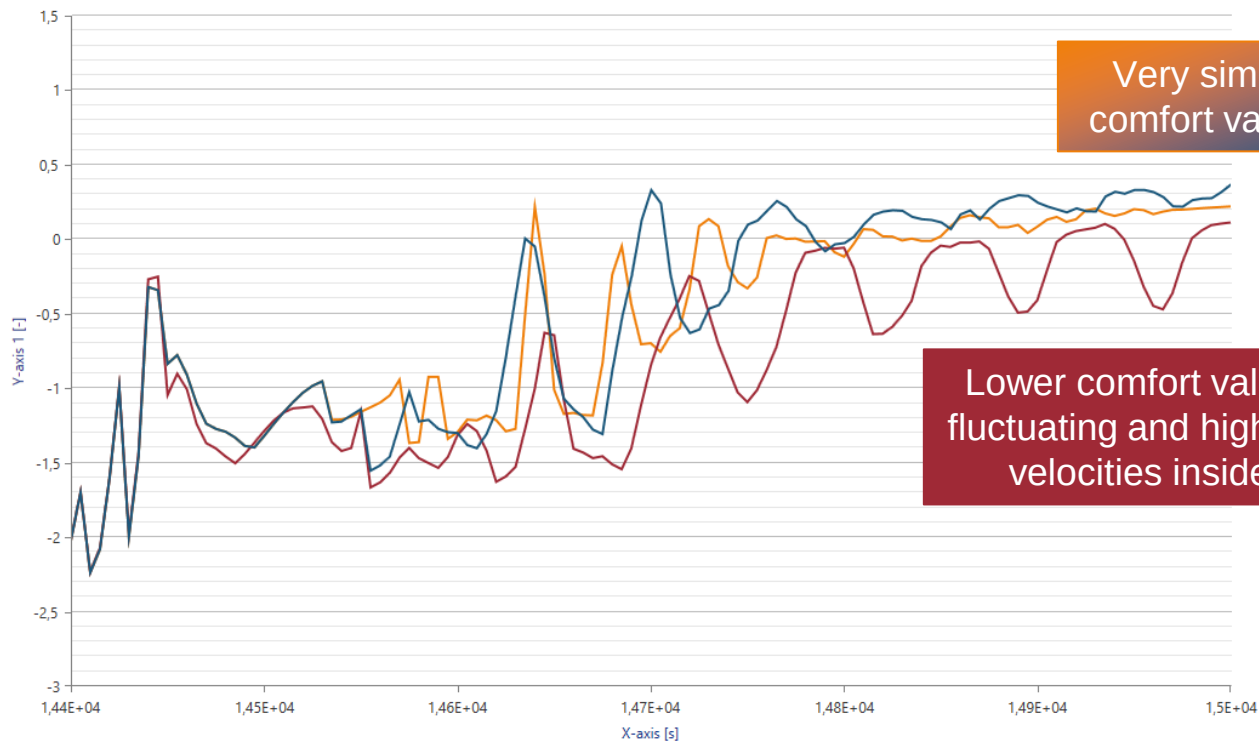


Berkeley Comfort Value

High temp.,
no panels

High temp.,
panels

Low temp.,
panels



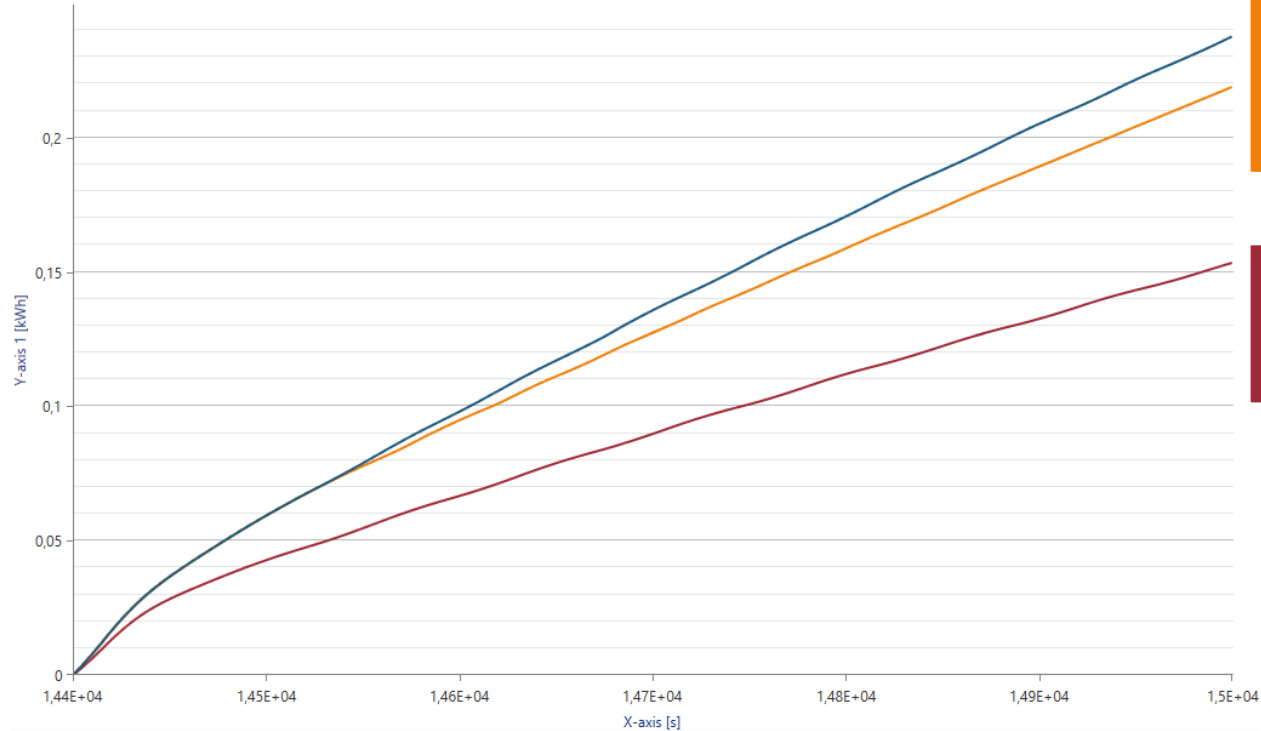
Energy Consumption for Heating

Compressor + panels + blower

High temp.,
no panels

High temp.,
panels

Low temp.,
panels



Lower
consumption for
comparable
comfort

Superior
performance for
heat pump

Energy Consumption for Maintaining Comfort

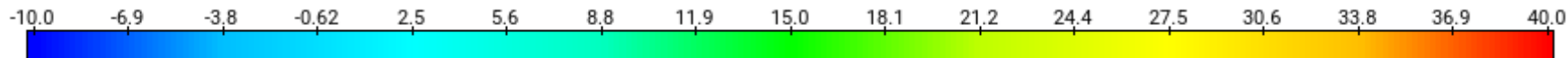
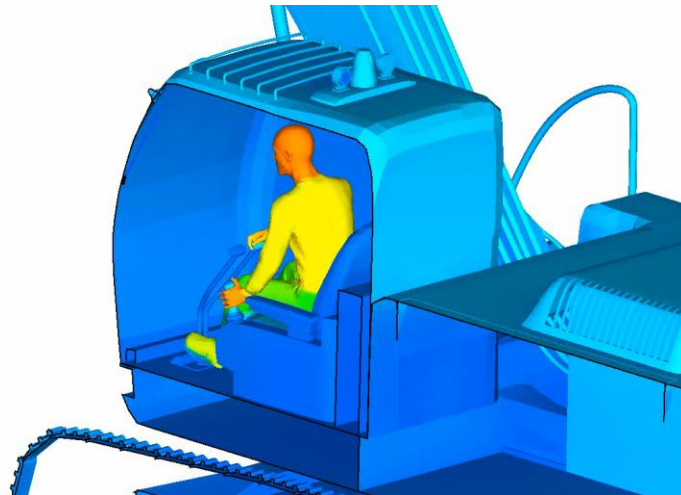
	Heater	Panels	Total
Heat pump, high cabin temp., no panels	720 W		720 W
Heat pump, high cabin temp., panels	580 W	600 W	1180 W
Heat pump, low cabin temp., panels	465 W	600 W	1065 W
Electric heater, high cabin temp., no panels	1950 W		1950 W
Electric heater, low cabin temp., panels	1100 W	600 W	1700 W

Thermal Results

Temperature, (°C) – View 1

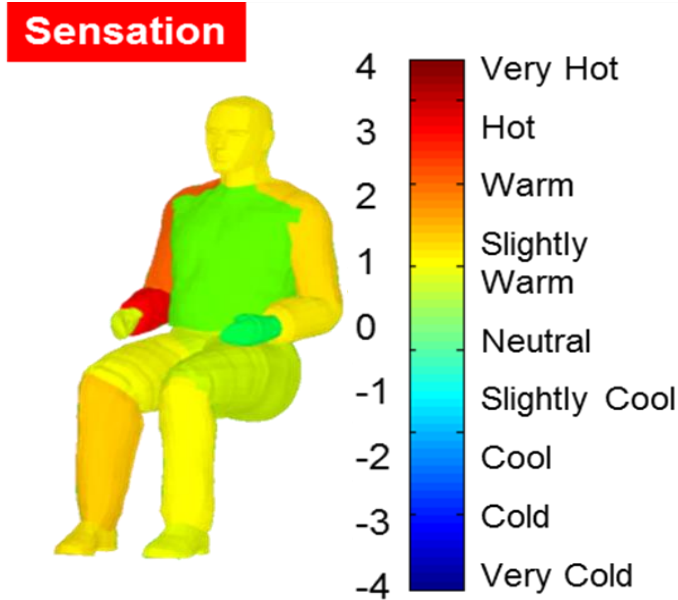


Temperature, (°C) – View 2

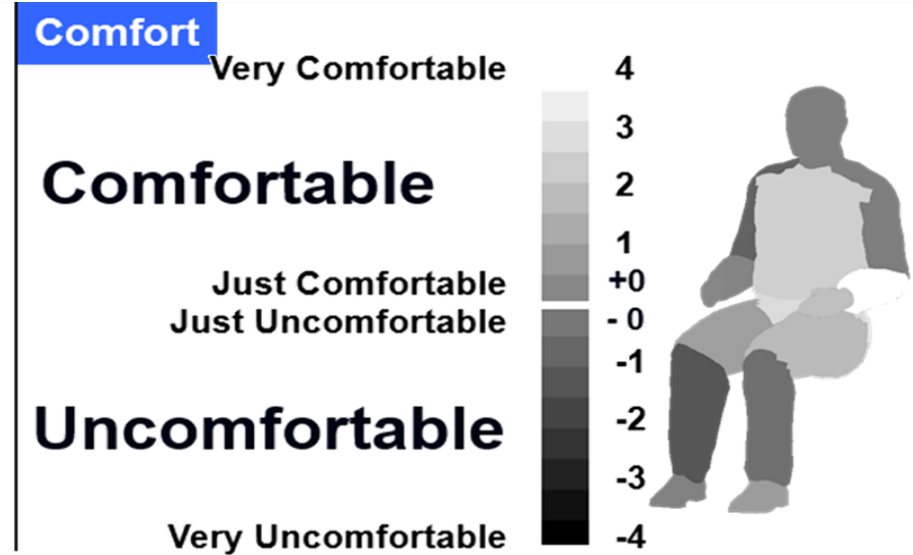


Sensation and Comfort

Two Scales are Needed for Comprehensive Thermal Comfort Assessment



How hot/cold does the body part feel?



Is the sensation good or bad?

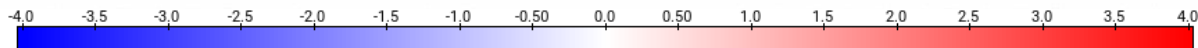
Berkeley Results

Sensation and Comfort

Berkeley Overall Sensation (-)



Berkeley Overall Comfort (-)



Endless Possibilities

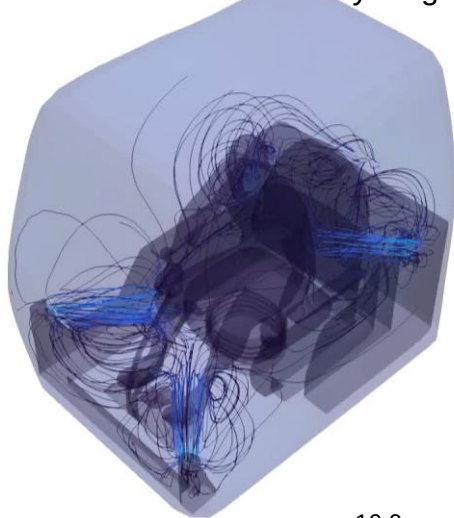
- Investigation of operation time extension due to pre-conditioning the cabin
 - First results show that the benefit is limited
- Control logic based on comfort instead of temperatures
- Controlled usage of radiant panels
- Consideration of heated seats (winter)
- Consideration of ventilated seats (summer)
- Consideration of different types of glass and insulation material
- Coupling with Rapidflow for detailed convection modelling

RapidFlow™ Results

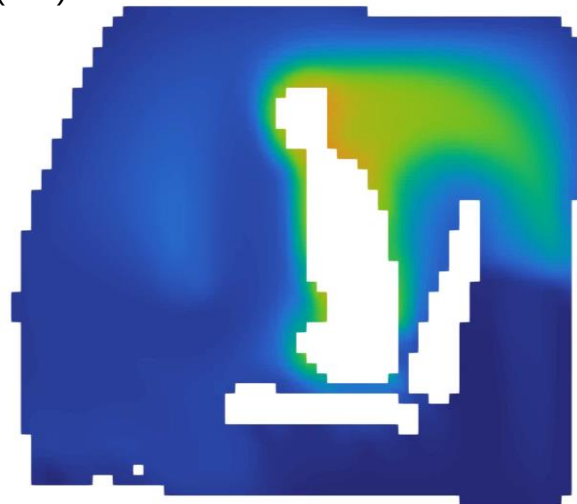
3D flow solver designed for heat transfer problems

- Easy to use (setup & Automated meshing)
- Tightly integrated with TAItherm™

Surface – Fluid Temperature, (°C)
Streamlines – Velocity Magnitude, (m/s)



Fluid Temperature, (°C)



Velocity Magnitude, (m/s)



-10.0

Fluid Temperature,
(°C)

40.0



05

Summary and Conclusion

Benefits and further potential

Summary & Conclusion

- Cabin comfort is becoming more and more important
- Combined investigation of cabin and hvac system required for optimization of energy consumption



- Easy integration of TAItherm cabin into KULI model via FMU and Python Controller
 - Direct access to comfort values in latest version of TAItherm
 - Easy script generation with setup tool available in KULI Online Library
- Postprocessing possibilities for co-simulation with both tools
- Even better comfort value calculation with more detailed flow calculation inside cabin



Forward.
For all.

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