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Total Thermal Solutions

Human Thermal Comfort: Latest Development and Methodologies

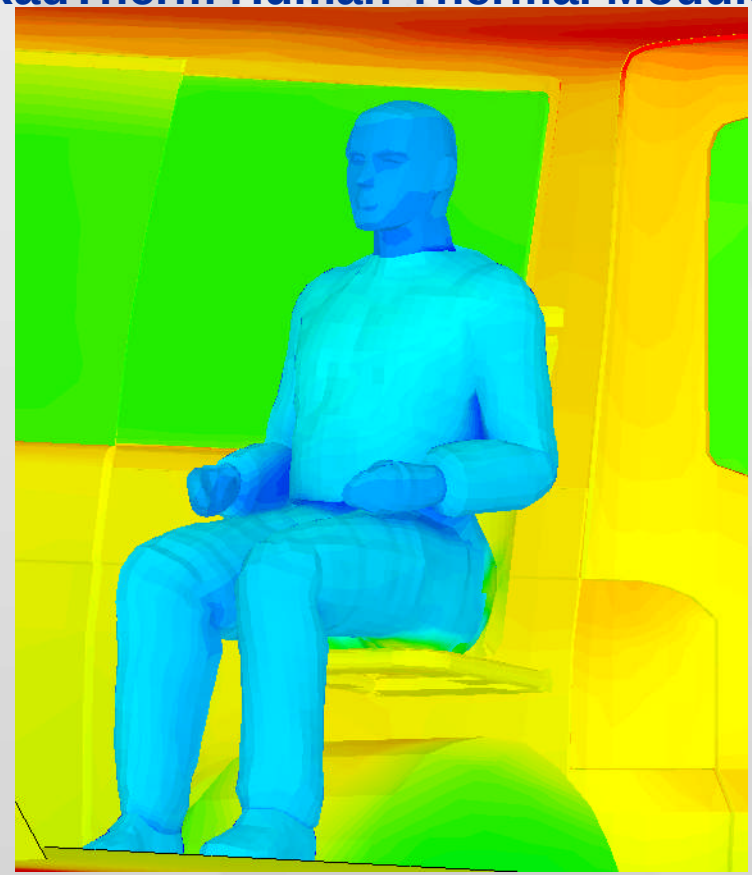
RadTherm UGM 2011

Tony Schwenn

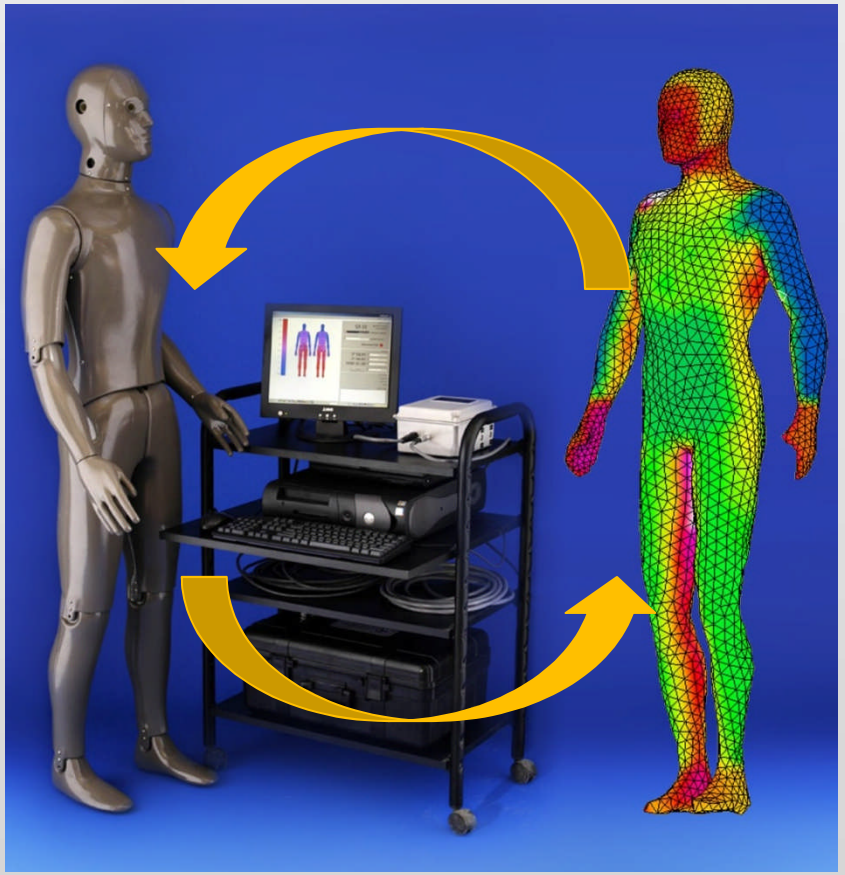
March 2011

TAI Human Thermal Products

RadTherm Human Thermal Module



ManikinPC^2 – MTNW + TAI



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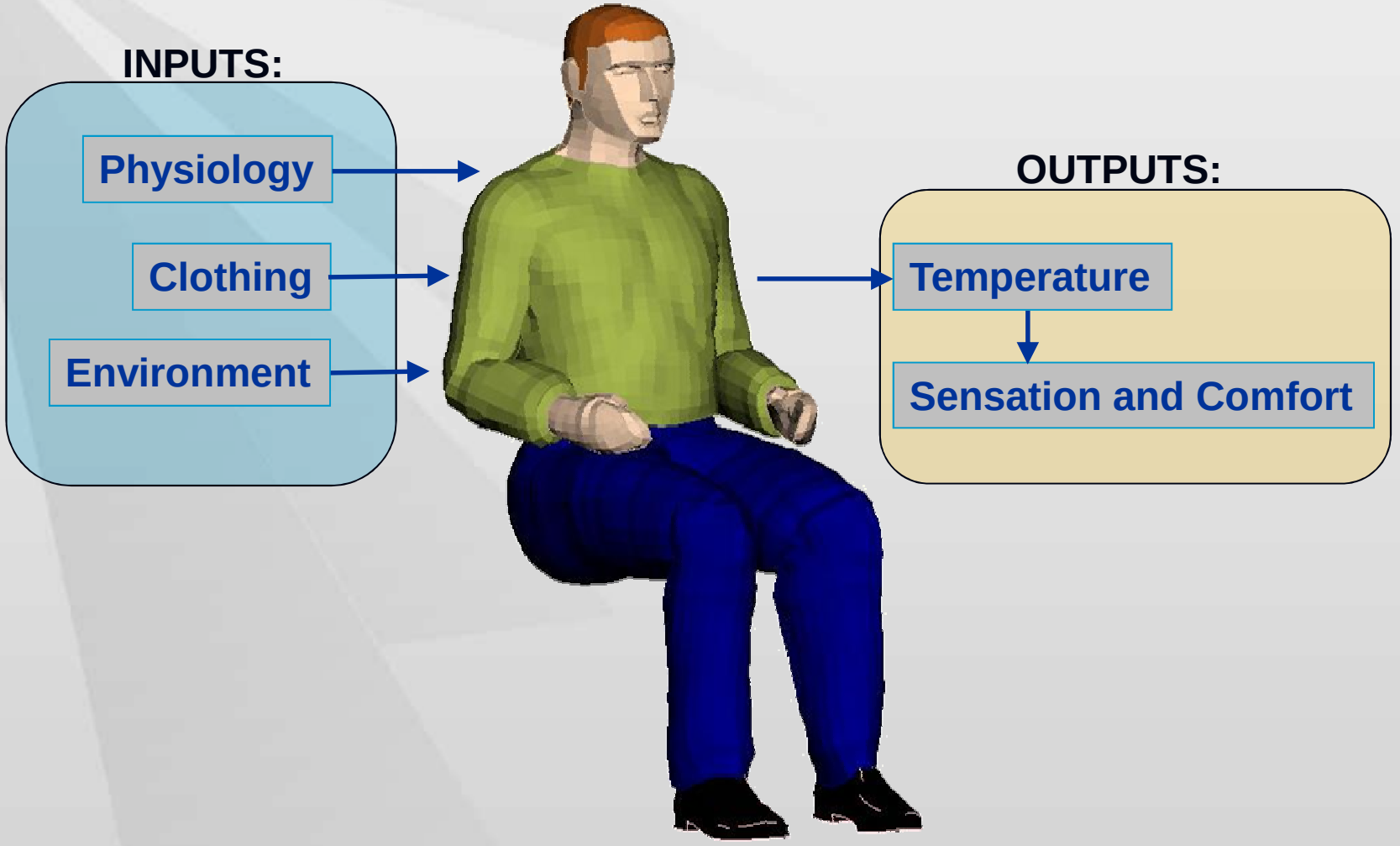
RadTherm Human Thermal Module



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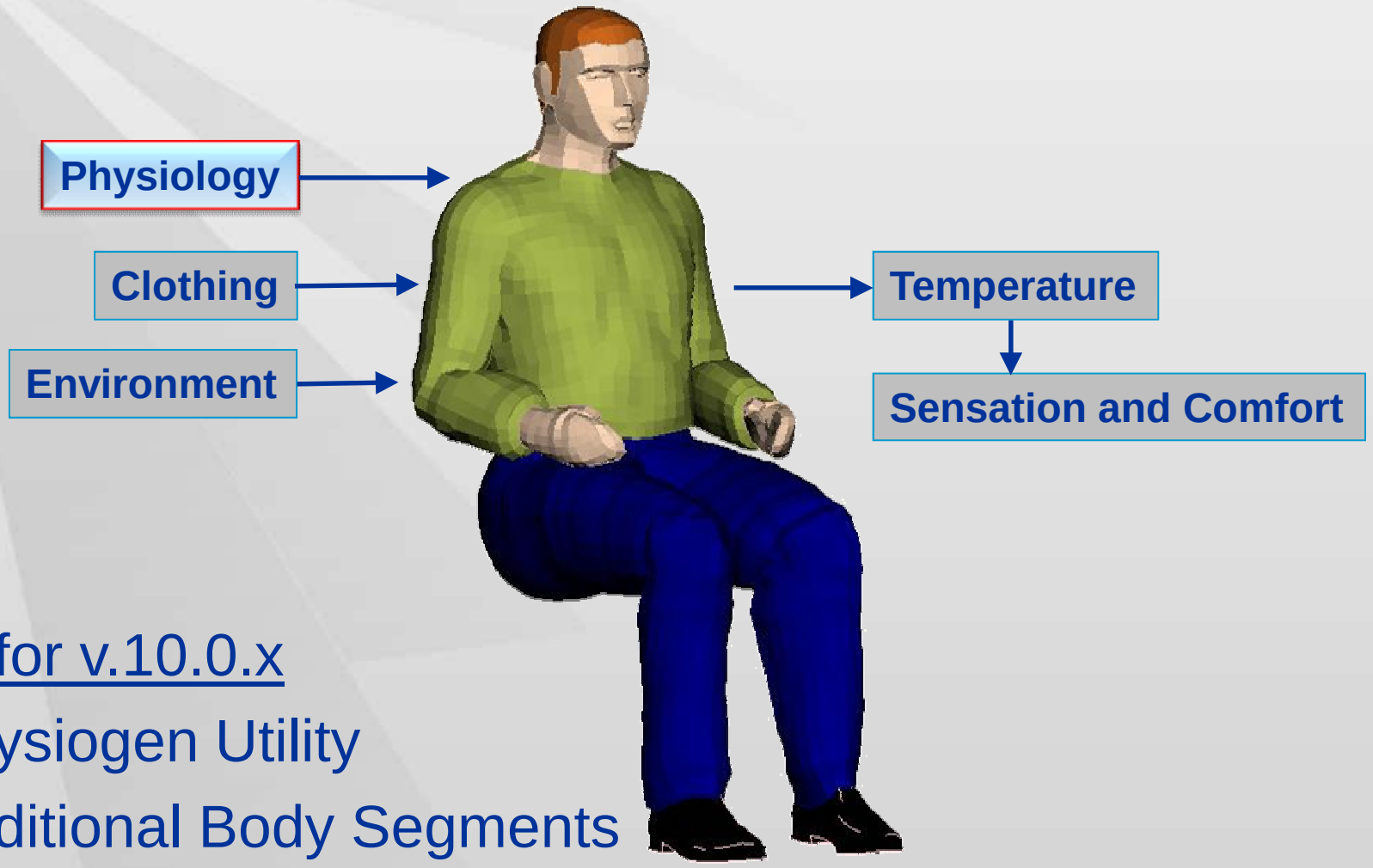
Human Thermal Module - Physiology



New for v.10.0.x

- Physiogen Utility
- Additional Body Segments
- HTM Plugin

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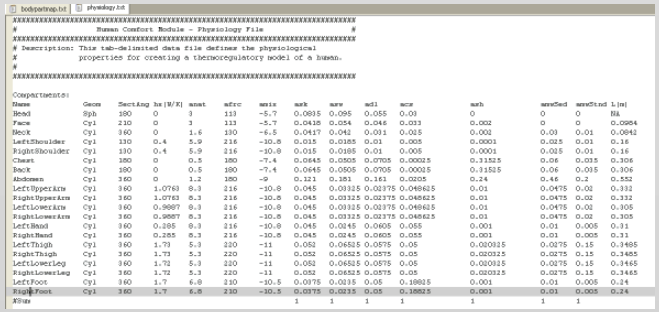
Physiogen Utility

- Account for thermal effects of different body types
  - Input: Simple Parameters
    (height, weight, gender, body fat)
  - Output: Physiological Parameters
    (blood volume, surface area, thermal conductivity, basal metabolic rate, etc.)



- Simple command line utility

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Physiology: Additional Body Segments

- Right and Left extremities have unique arterial blood temperatures
  - Unique local sensation/comfort output
- User may create additional body segments

**Segments are defined in physiology.txt*

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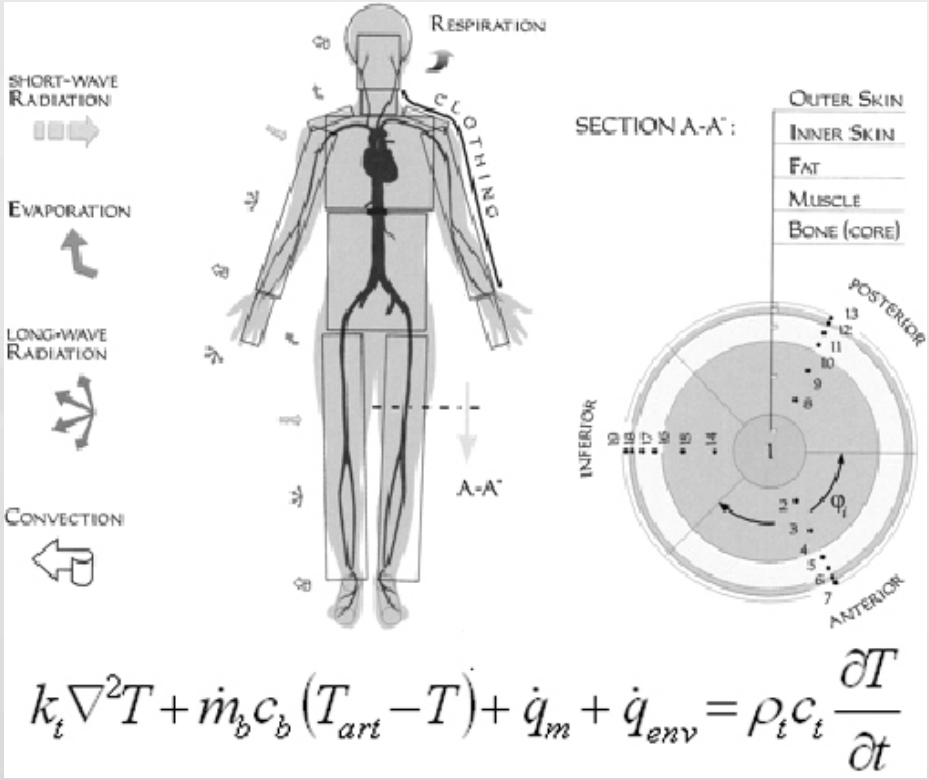
Thermoregulation via Plugin Module

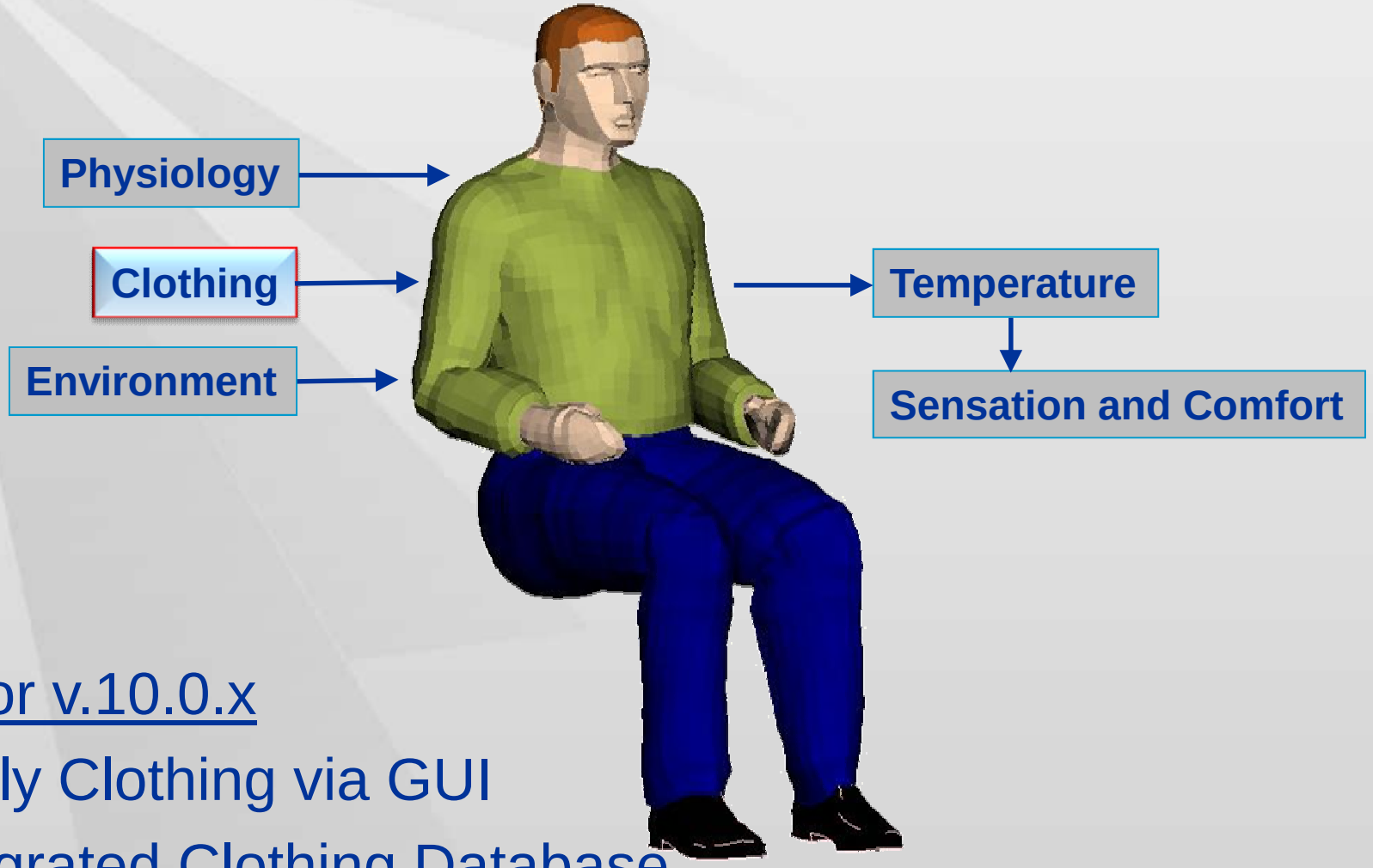
- Based on Established Models
  - 20 body segments, with 4-5 tissue layers
  - Models:
    - Metabolic Heating
    - Shivering & Sweating
    - Respiration
    - Peripheral Vasomotion
  - Solves Bio-Heat Transfer Eqn
  - Predicts tissue, blood and core temperatures under:
    - Varying Environmental Conditions
    - Varying Activity Levels
    - Adjustable Clothing Levels



$$k_t \nabla^2 T + \dot{m}_b c_b \left(T_{art} - T\right) + \dot{q}_m + \dot{q}_{env} = \rho_t c_t \frac{\partial T}{\partial t}$$

- Human Thermal Module is now a Plugin (previously user routine)
- Plugins provide fast integration of future physiology models

Human Thermal Module - Clothing



New for v.10.0.x

- Apply Clothing via GUI
- Integrated Clothing Database

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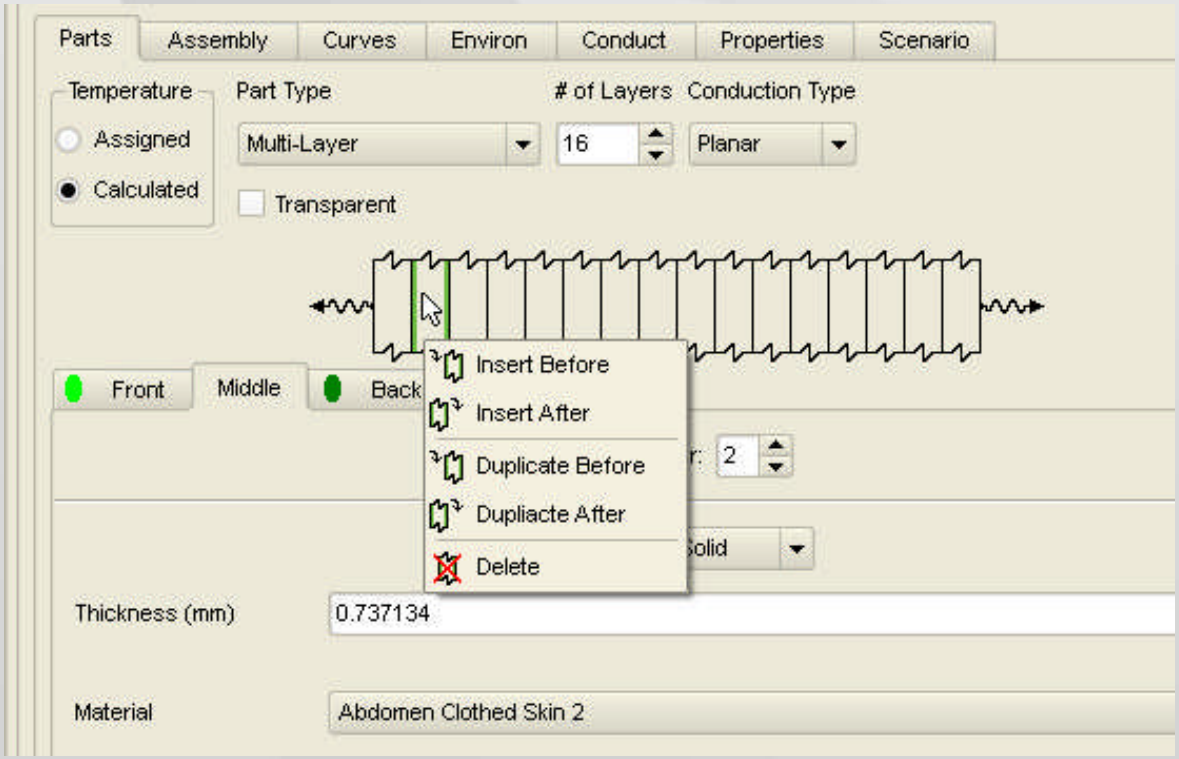
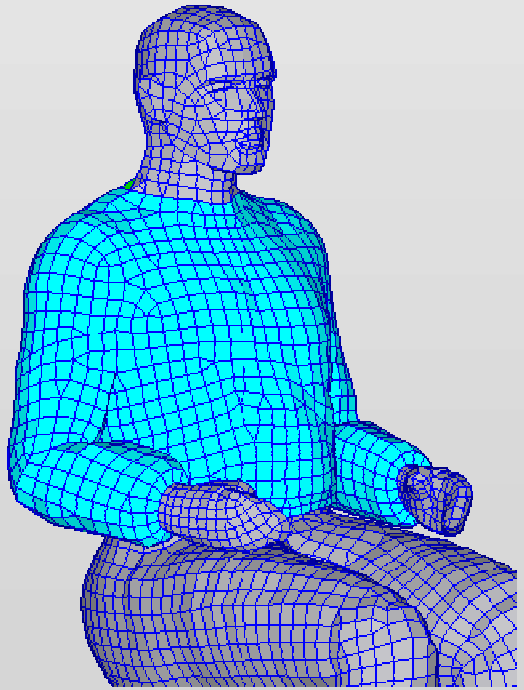
Applying Clothing to Model

- Applied on a part level
  - Boundary conditions applied to outermost layer
- Clothing articles can be modeled as unique layers
  - Add/Remove layers via GUI





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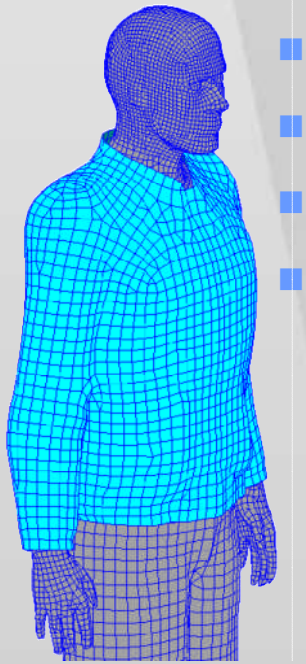
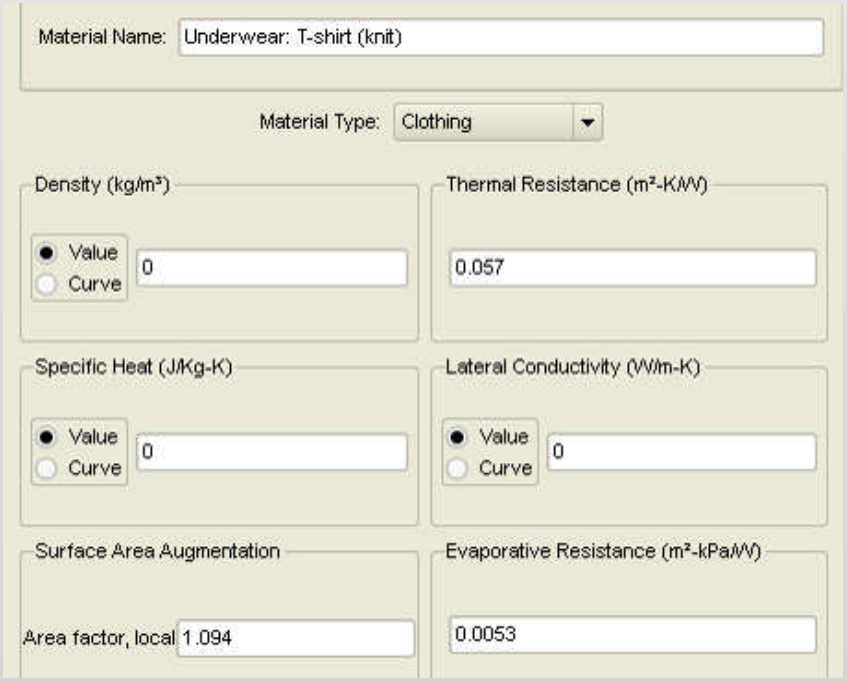
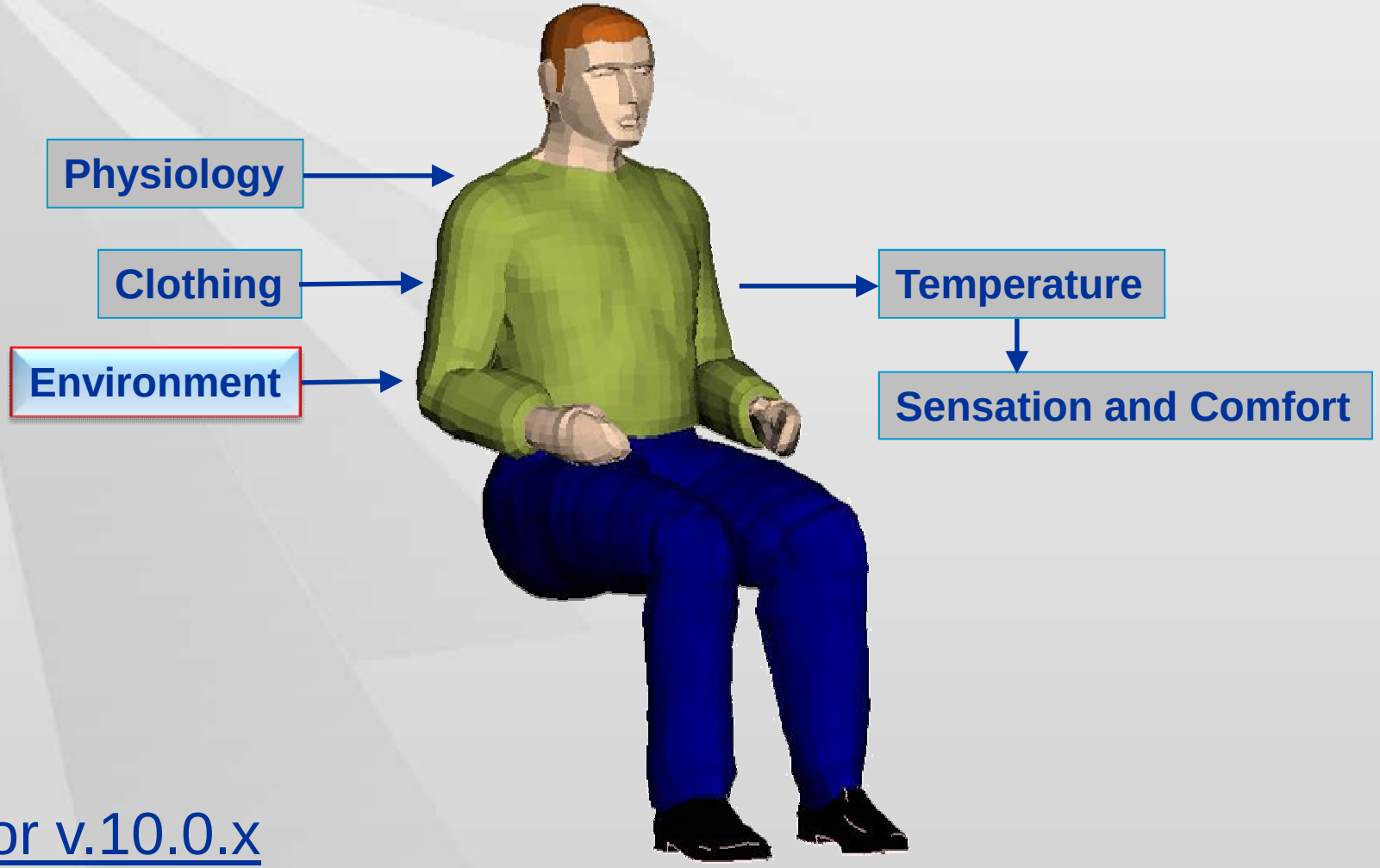
Clothing Properties

- Clothing material database integrated into RadTherm
  - “Clothing” material type
- Integrated clothing database (100+ garments)
- Create & Add new clothing materials
- Clothing parameters
  - Thermal resistance
  - Evaporative resistance
  - Local clothing area factor
  - Heat capacity (optional)
  - Lateral conductivity (optional)





Human Thermal Module - Environment



New for v.10.0.x

- Human Thermal Convection Model

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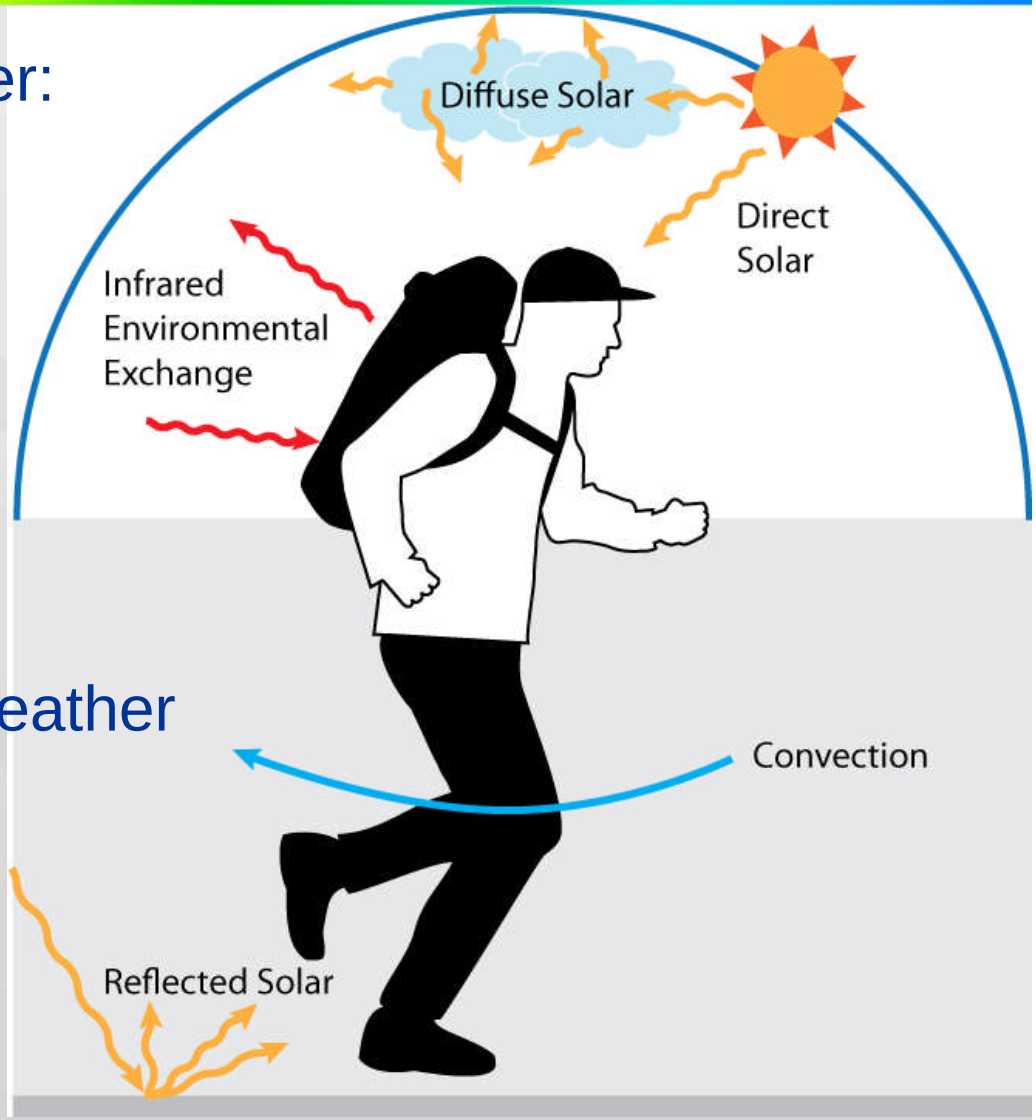
Modeling the Environment

- Environmental Heat Transfer:
  - Radiation
  - Solar Heating
  - Convection
  - Sweating
  - Respiration
  - Conduction
- Bounding Box or Natural Weather
- Surrounding Geometry
- Transient or Steady State



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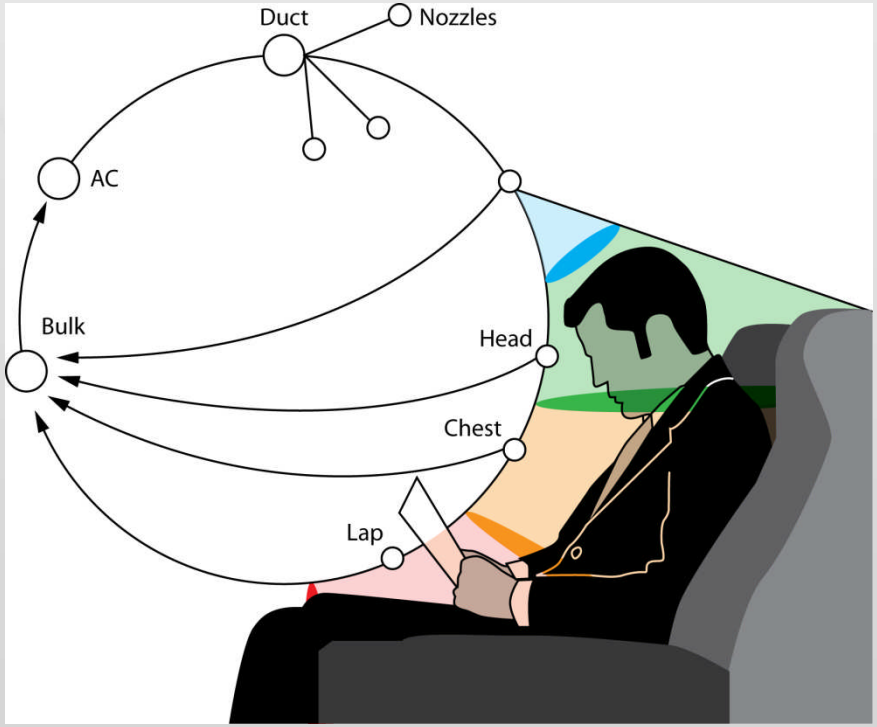
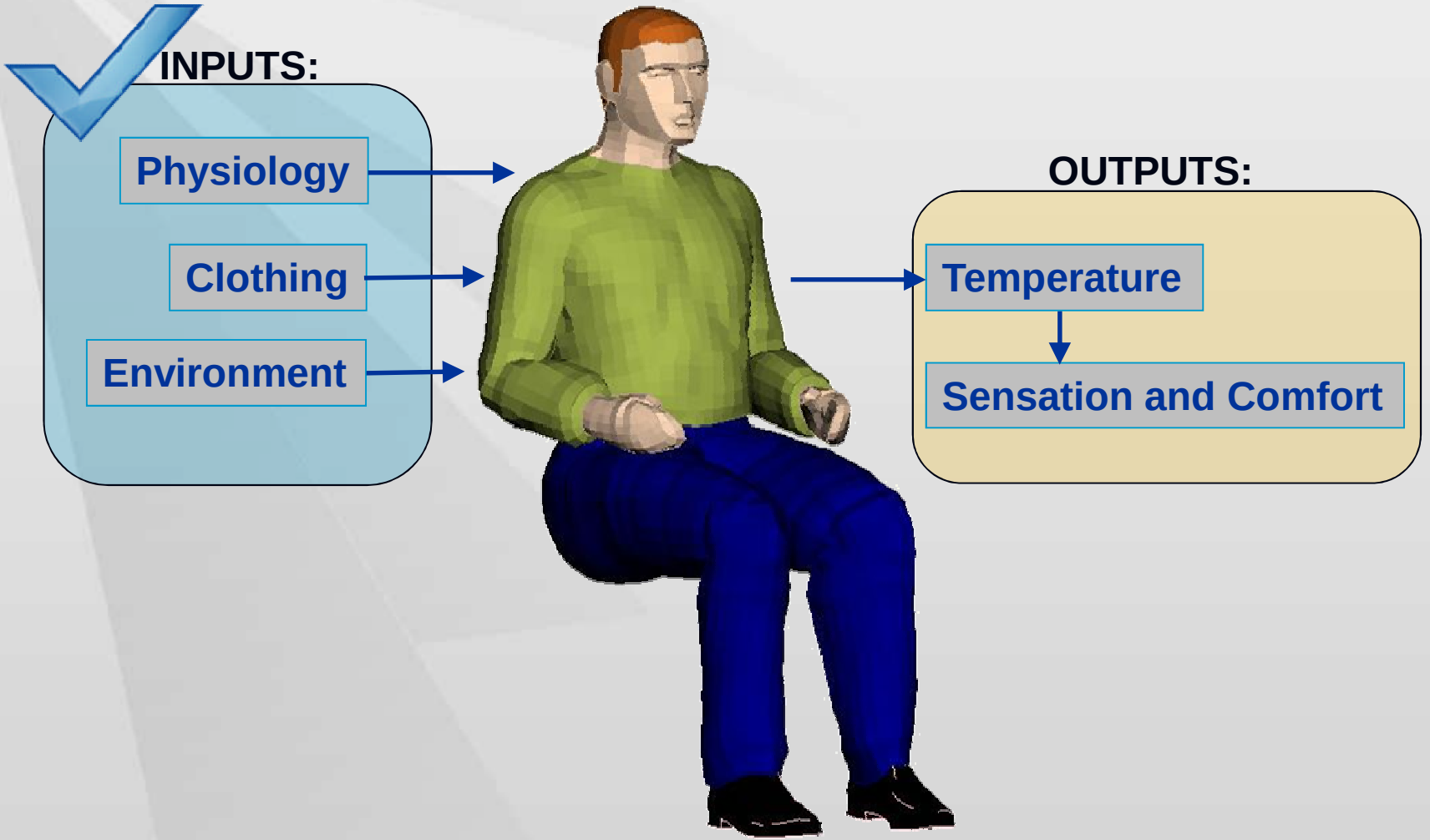
Human Thermal Convection

- Specific human thermal library convection model
- Models natural, forced and mixed convection
  - Air temperature & speed can be provided as a value, curve, routine or node
  - Can be used for all scenarios
    - Vehicle HVAC simulations
    - Natural environment simulations
- Alternative convection methods
  - User defined: h & T_{fluid}
  - Imported CFD



RadTherm Human Thermal Simulation



*Simulation is consistent with existing RadTherm process

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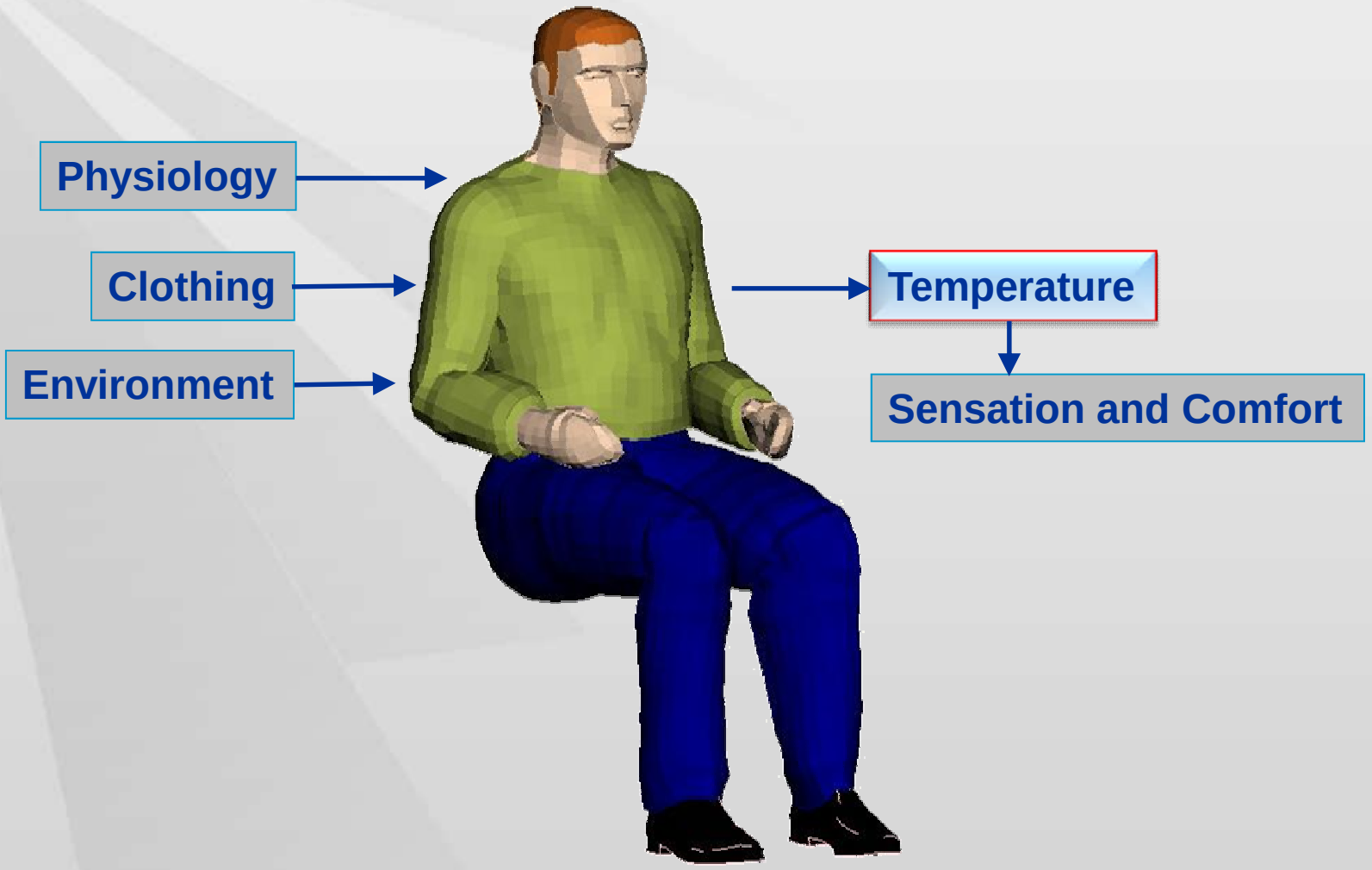
Human Thermal Module - Output



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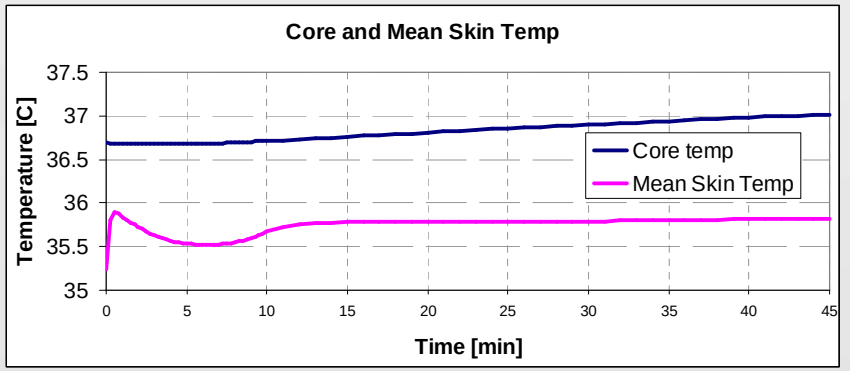
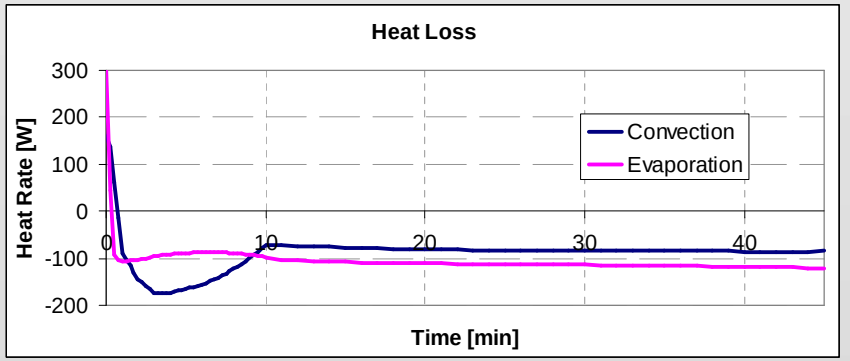
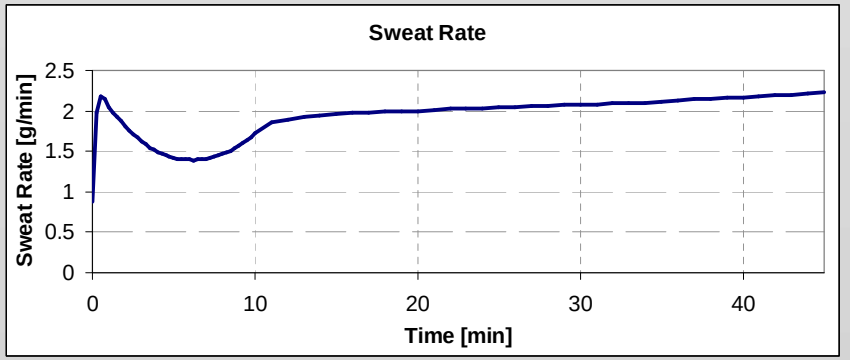
Temperature and Physiological Output

- Temperature Outputs
  - Core temp (hypothalmic, rectal, blood pool)
  - Skin temps (element, segment, mean)
- Heat Rates
  - Evaporation, respiration, convection, solar, thermal radiation, metabolic, shivering
- Physiological Parameter Outputs
  - Dilation, constriction, sweat rate







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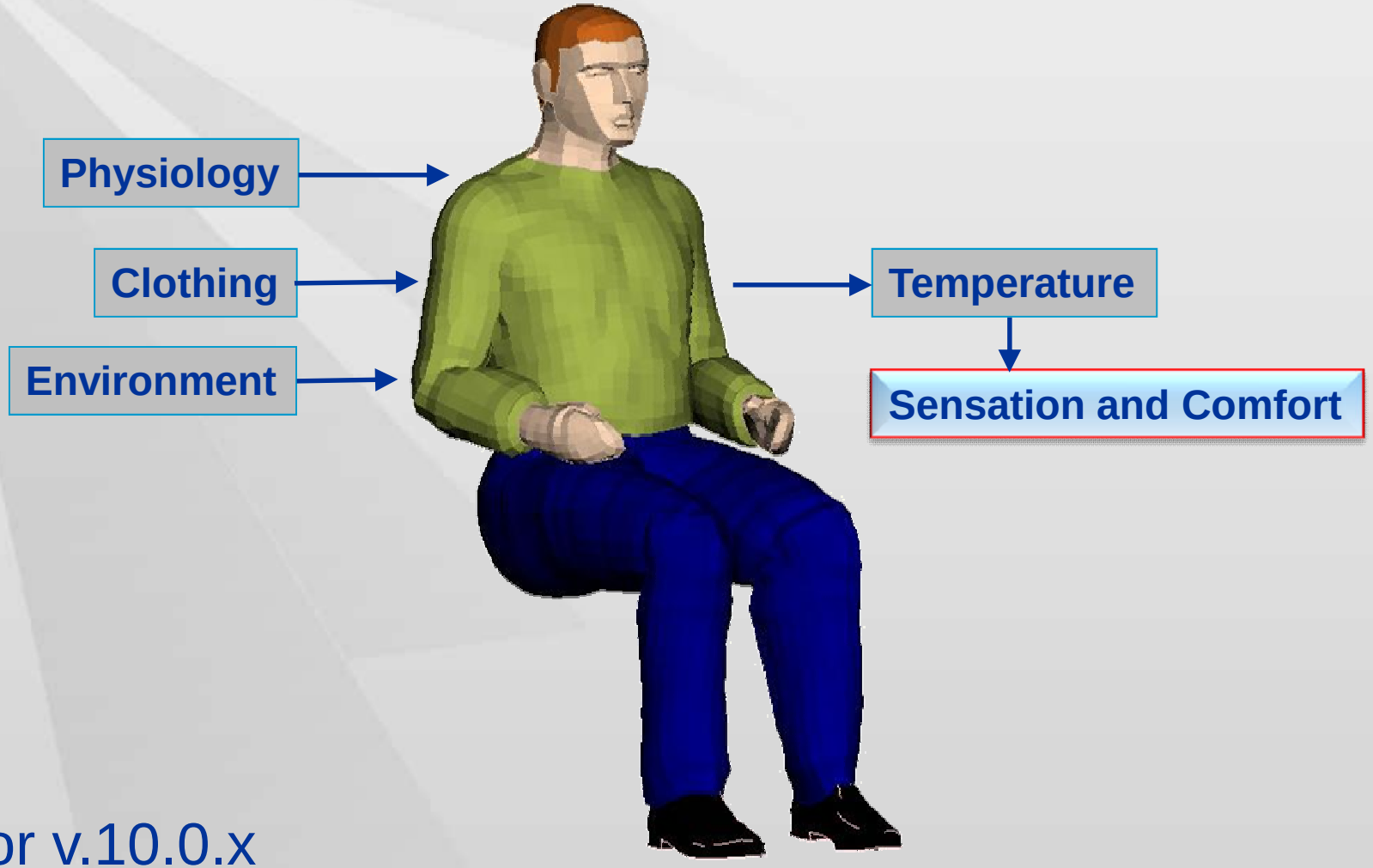
Human Thermal Sensation & Comfort



New for v.10.0.x

- Visualization Utility

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Thermal Sensation & Comfort

- Sensation – How hot or cold a body part is perceived to feel
- Comfort – Whether the sensation makes the person feel good or bad

- New utility “tdfvisualizehuman” to display sensation/comfort on the geometry

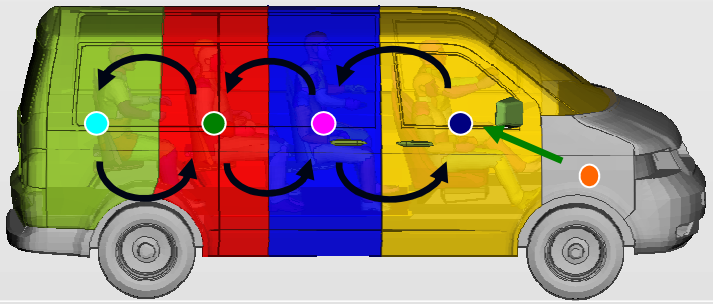
Case Study: Passenger Van

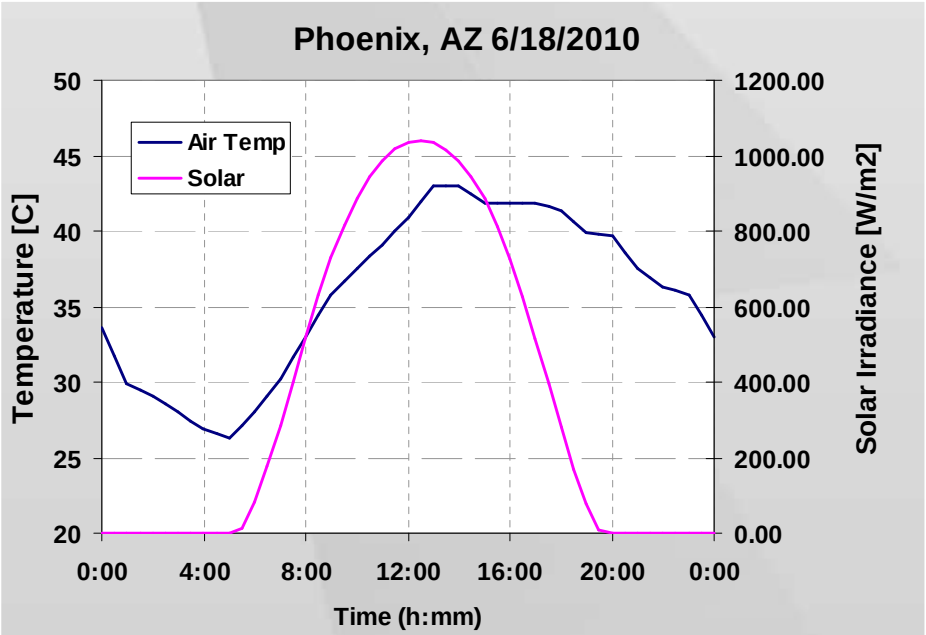
- 7 human thermal models with unique physiologies placed in vehicle
- Each human modeled with unique geometry and pose
- All metabolic rates set to 1.2

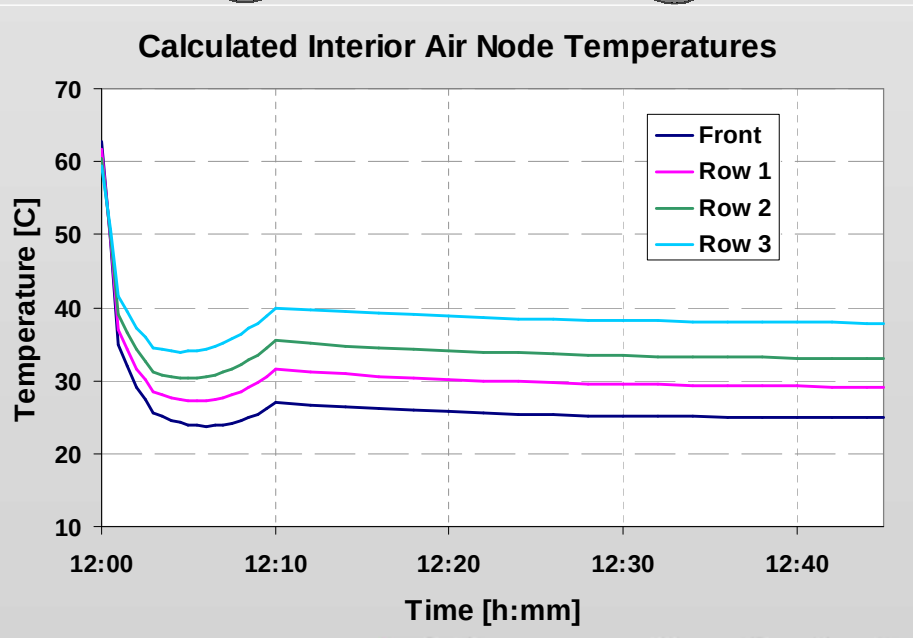
Body Size (percentile)	Height (m)	Weight (kg)
5	1.54	51.7
15	1.62	59.8
25	1.64	64.7
50	1.7	73.5
75	1.76	82.4
85	1.81	87.3
95	1.84	95.3

Passenger Van Conditions

- Passenger van initialized with a heat soak condition
  - 5:00 am to 12:00 pm in hot desert environment
    - Phoenix, AZ 6/18/2010
    - Vehicle Off
- AC pull down
  - 12:00 pm to 12:45 pm







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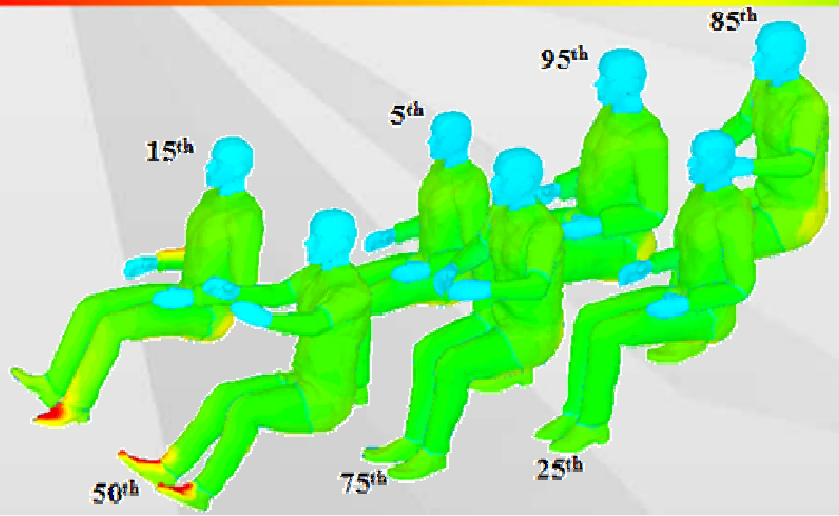
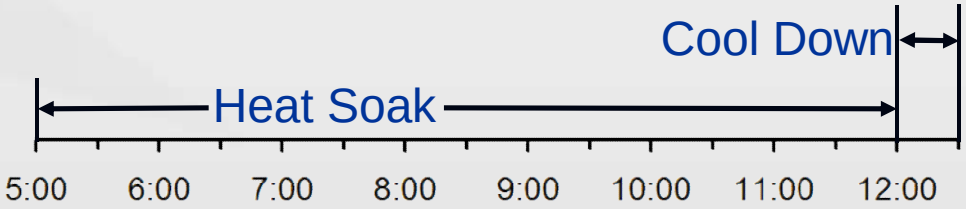
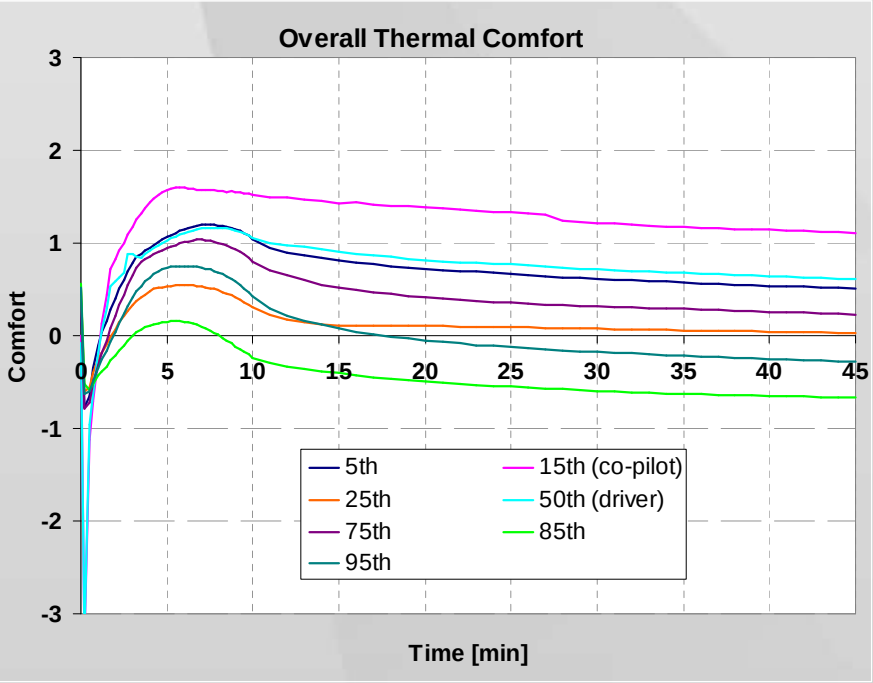
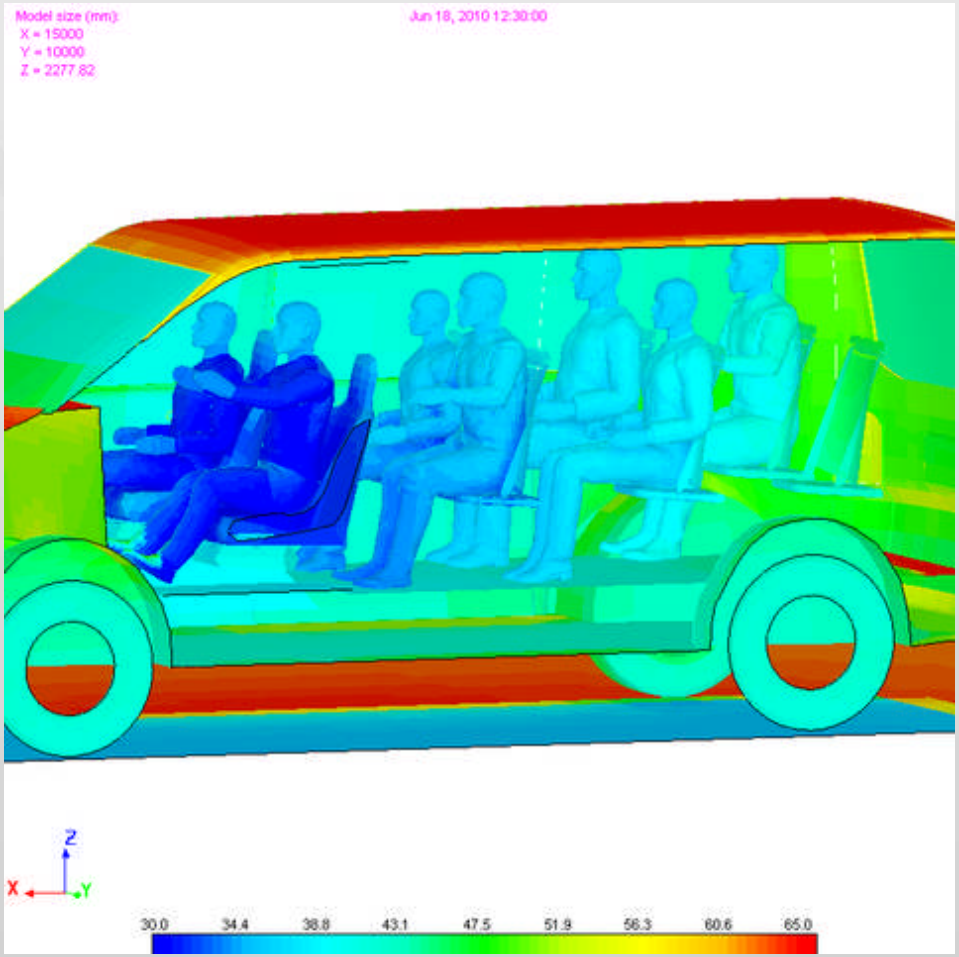
Passenger Van Results

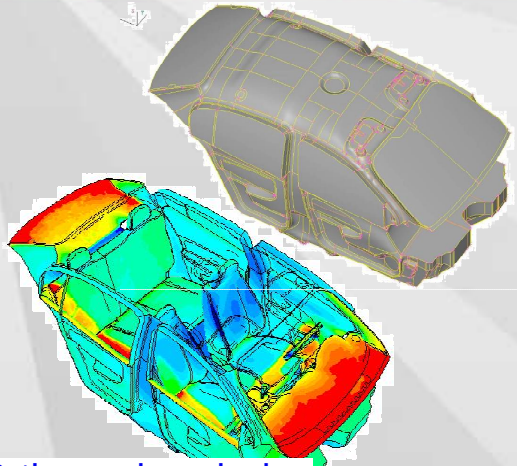








GM Soak and Cool-Down Analysis



Flow & thermal analysis

CAD
Parametric Cabin Geometry

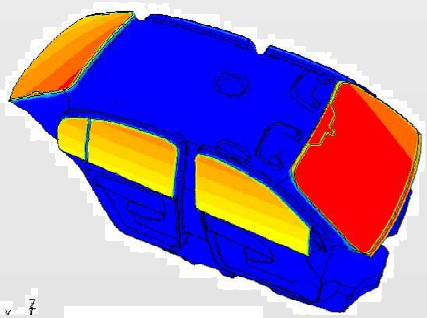
Solar Load
Radiation View Factors

Refrigeration Cycle
Analysis

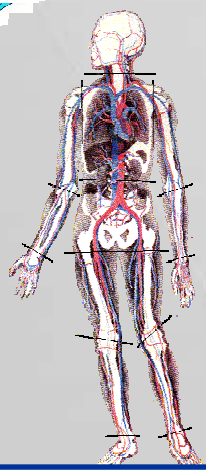
3D Flow and Thermal
Analysis

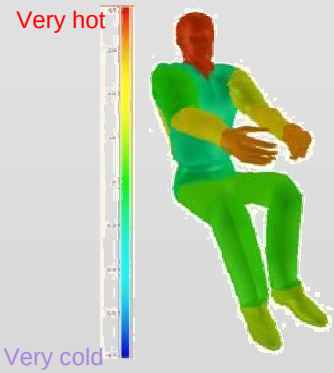
Human Physiology Model

Thermal Comfort



Solar load





"Assessment of Various Environmental Thermal Loads on Passenger Thermal Comfort"
SAE International Journal Paper # 2010-01-1205

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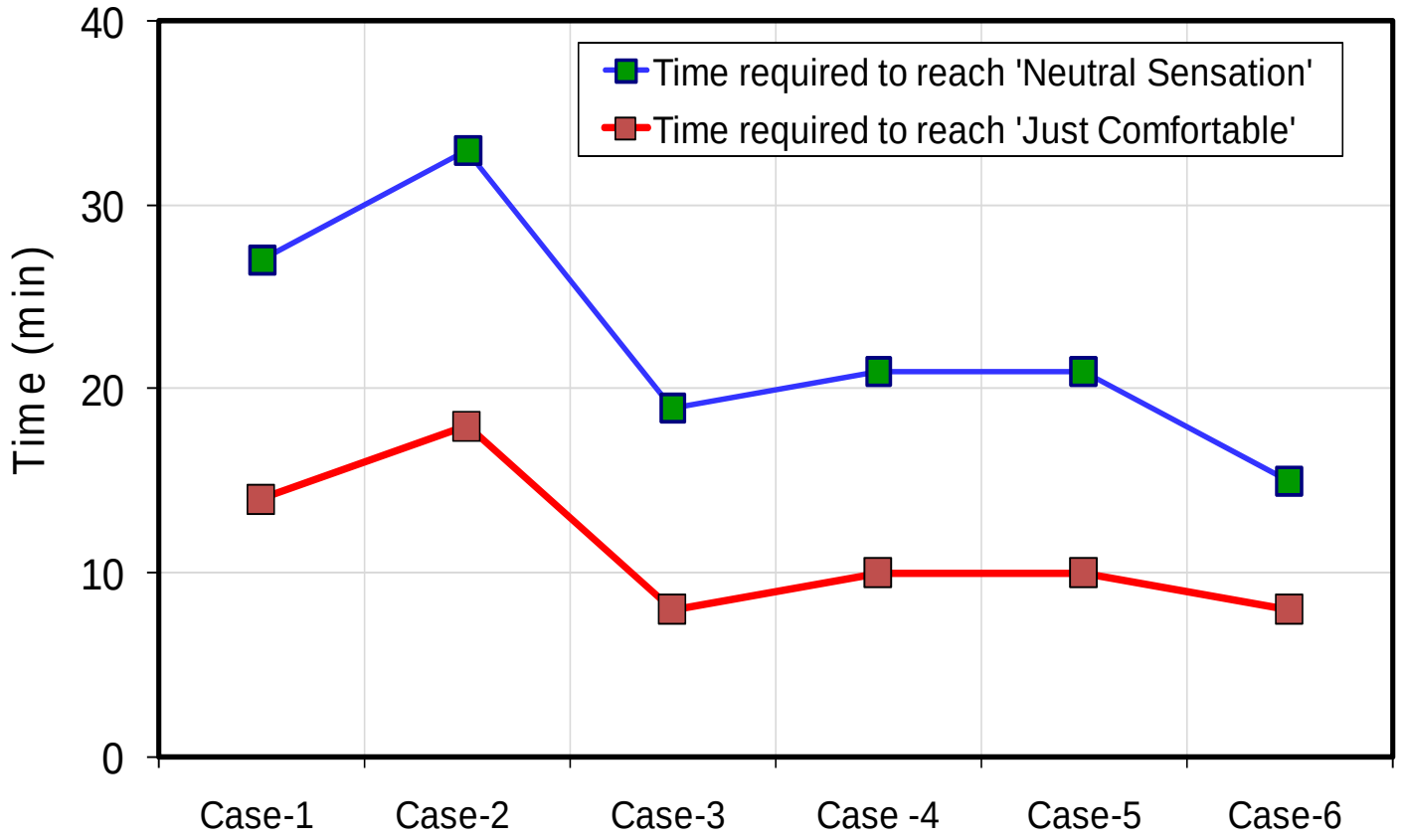
Time to Reach ‘Neutral Sensation’ & ‘Just Comfortable’



Case 1: Baseline case
Case 2: Body Insulation
Case 3: Thermal mass Red.
Case 4: Insul + Mass Red
Case 5: Solar reflection
Case 6: All

- Just comfortable state was achieved about 10 min earlier than the thermally neutral state for all the cases.
- Case 3 and Case 6 produced similar performance in terms of thermal comfort

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Questions?

Human Thermal Focus Group Session

- Thursday, March 17th 2011
- 09:00 – 14:00
- Agenda:
  1. A Detailed Look at Human Thermoregulation Simulation
  2. Demonstration of the RadTherm Human Thermal Model
  3. Coupling RadTherm Model with an Instrumented Thermal Manikin
  4. Hands-on Modeling Activity