Verification and Validation of CFD for the Personal Micro-Environment

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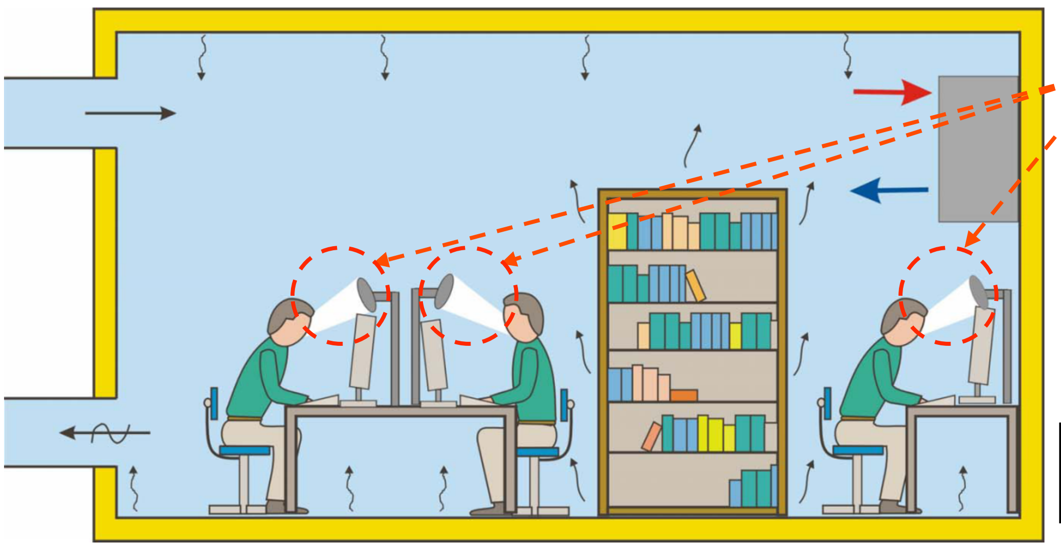
ASHRAE Summer Meeting, Salt Lake City, UT

June 21-25, 2008

Purpose

"Better" Indoor Air Quality

- ❑ For high IAQ need to address:
  - ◆ *Source control*
  - ◆ *Air-cleaning*
  - ◆ *New ventilation approaches (e.g. PV)*
- ❑ Ventilation systems involving localized gradients are difficult to design with traditional IAQ methods
- ❑ Need to look beyond conventional techniques



Fanger:
"99% of Clean Air is Wasted"

Fanger SU Lecture June 2006

Overview

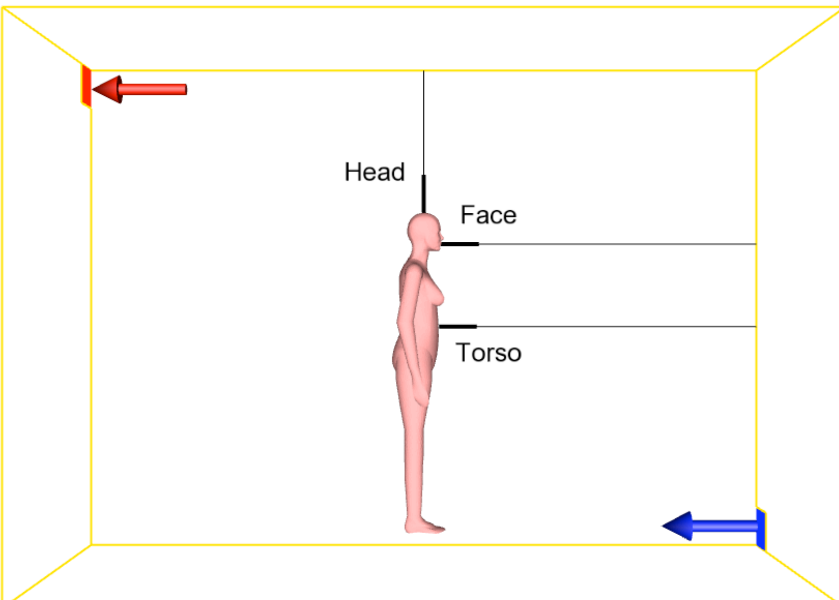
- Extend CFD verification - *solving the equations right*
  - *Grid dependency*
  - *Iterative convergence*
- Extend CFD validation - *solving the right equations*
  - *Turbulence modeling*
  - *Heat transfer models*
- Contributions of convection radiation
- Including effects of radiation
- Future applications

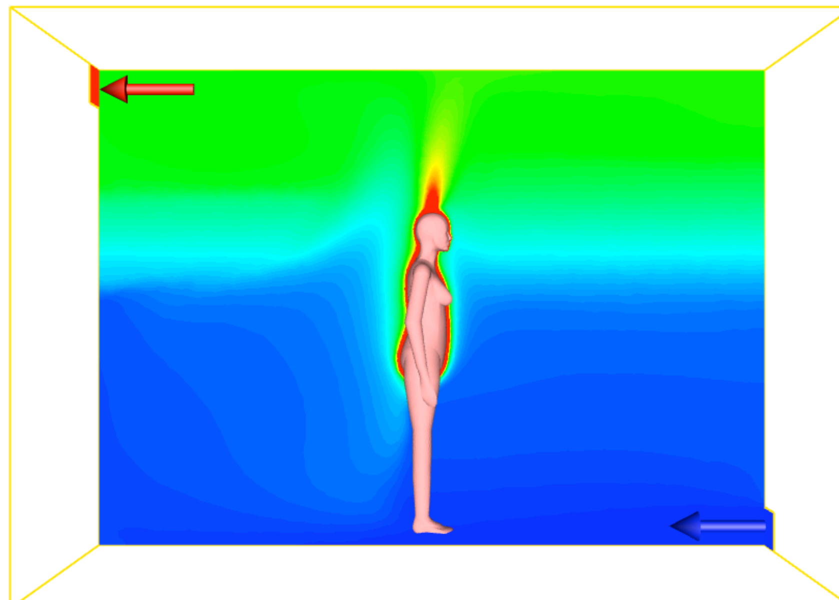
Current State-of-the-Art

- In open literature, grid resolutions are typically on the order of a few hundred thousand (for 3D) → <=10K surface points
- Traditional turbulence models
  - zero-equation (mixing length)
  - *k-ε family*
- Single-point, omni-directional measurements
  - *velocity magnitude and rarely components*
  - *no turbulence information (length scale, intensity)*
  - *minimal (or no) error estimation*
- Rarely detailed measurements of other quantities (contaminant, temperatures)
- Steady-state
  - *Some breathing work, usually steady inhalation/exhalation*
  - *Very little investigations of body motions*
- Very active area of research – regular symposiums

Benchmark Case

- Inlet vent (front, bottom) = 0.2 m/s (33 CFM), 22°C (72°F)
- Heat loss from body = 76 W (4.3 BTU/min) and insulated walls



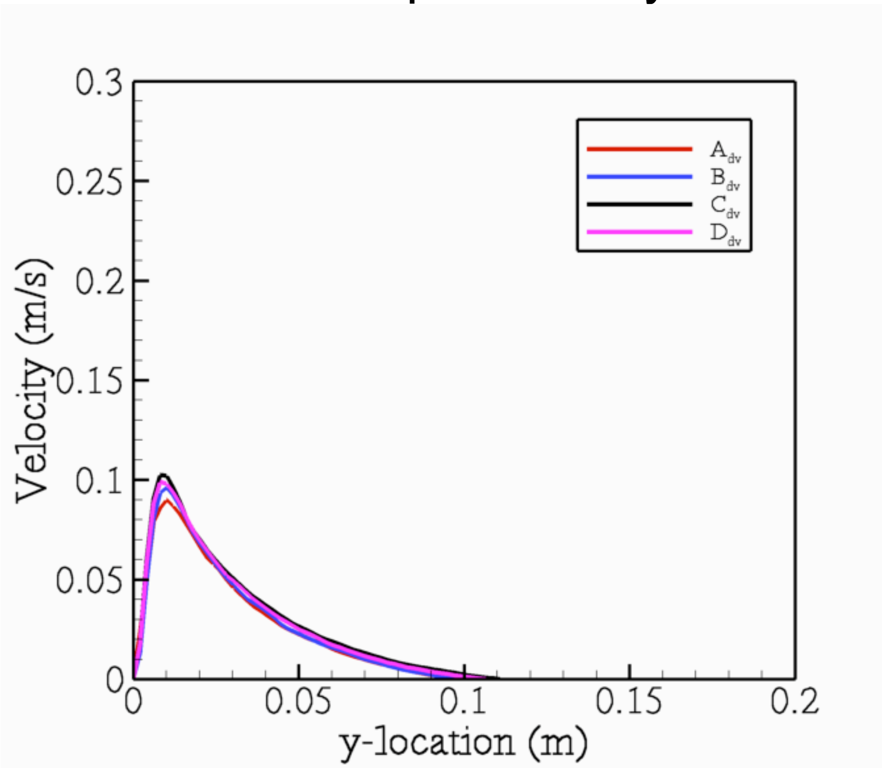


Displacement Ventilation …

… Stratified Flow

Grid Convergence

- Velocity sensitive to BL resolution in near field
- Contaminant sensitive to BL resolution in near field (not shown)
- Grid convergence demonstrated by two finest grids
- ~60K surface pts with layers of BL cells



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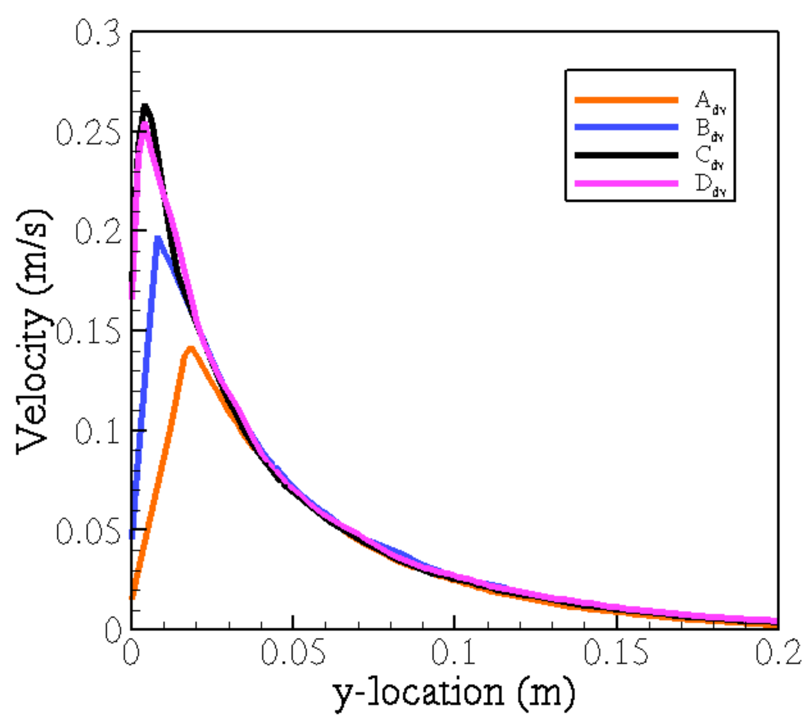
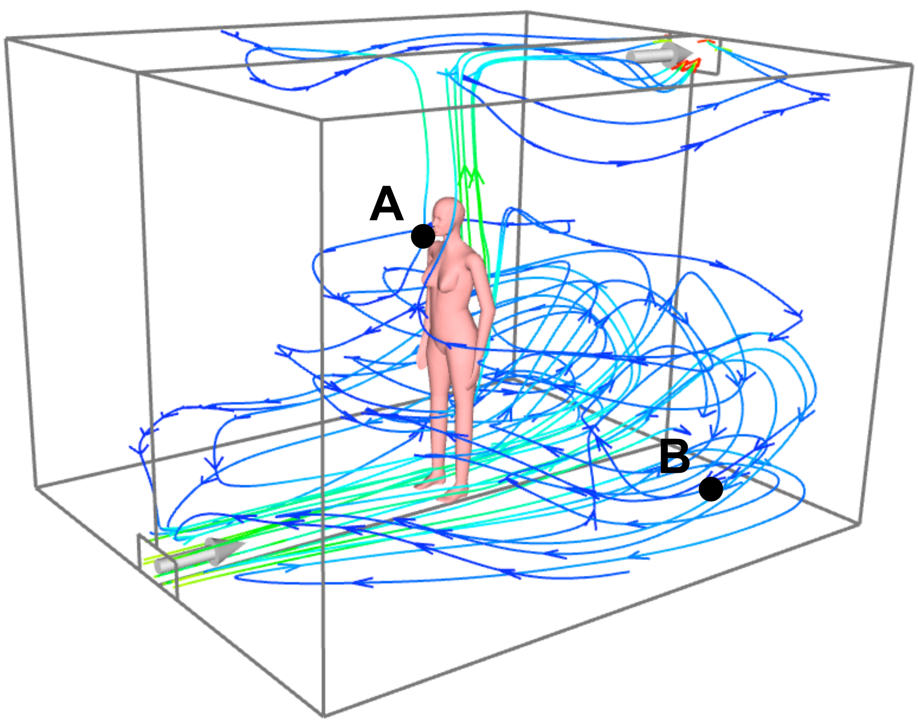


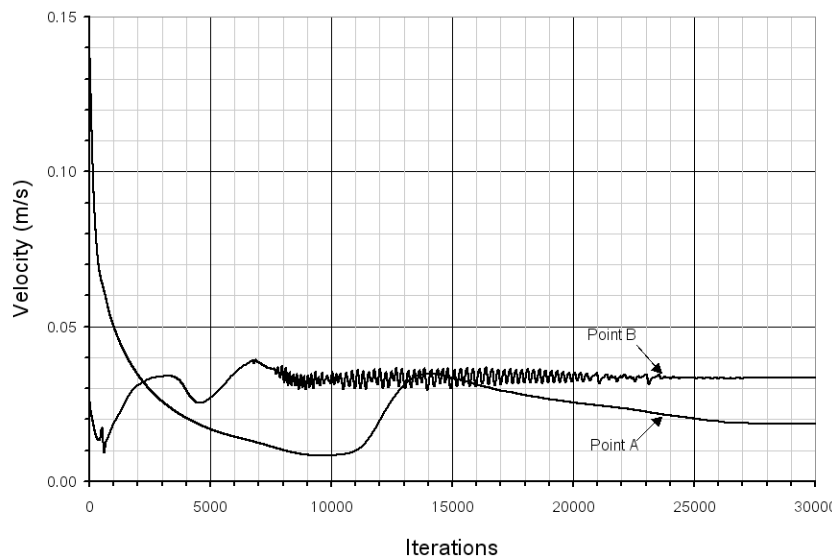
Torso

Iterative Convergence

- Averaged residuals not good convergence indicator
- Two interdependent flow structures – plume and recirculating flow
- Monitor velocity at strategic points



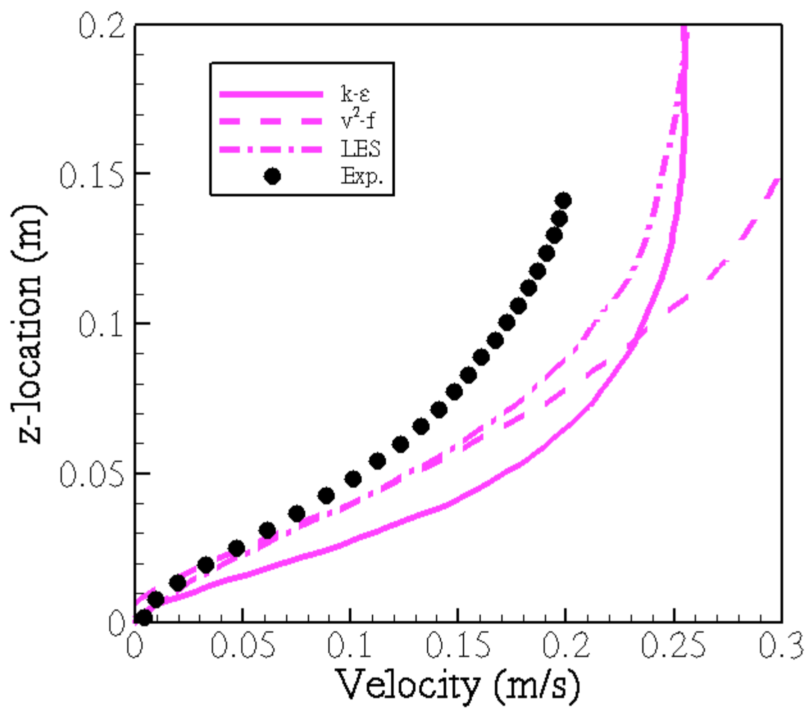
Inlet Streamlines - Recirculating Flow



Convergence of Velocity at pts A and B

Experimental Comparison

- RANS models over-predict the magnitude and mis-predict shape
- LES marginally better
- Missing physics? Assumed ½ total heat transfer due to convection



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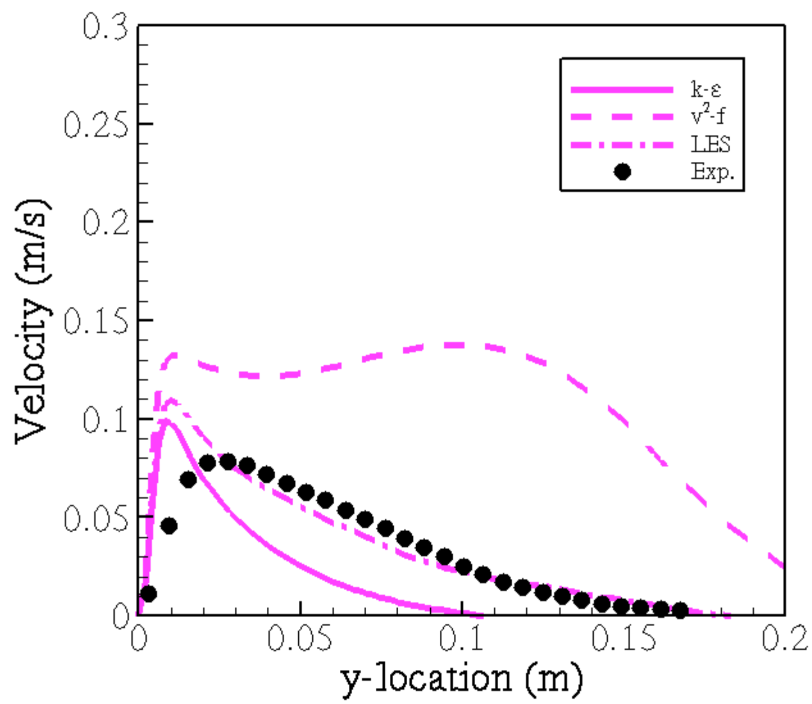

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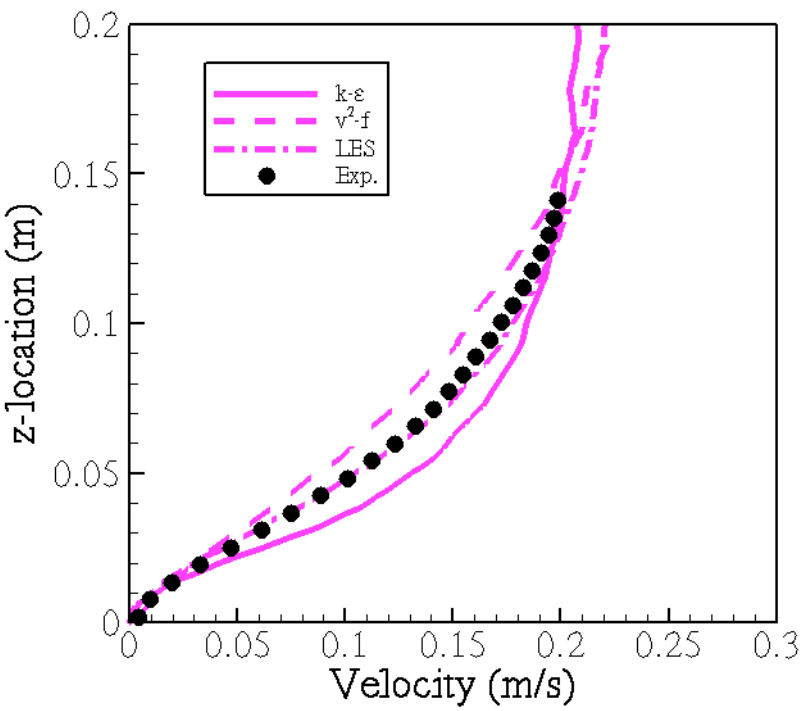
Radiative Heat Transfer

- Marked improvement over convection only results
- RANS provide nearly same results as LES
- Ratio of heat transfer modes: 38% convection / 62% radiation



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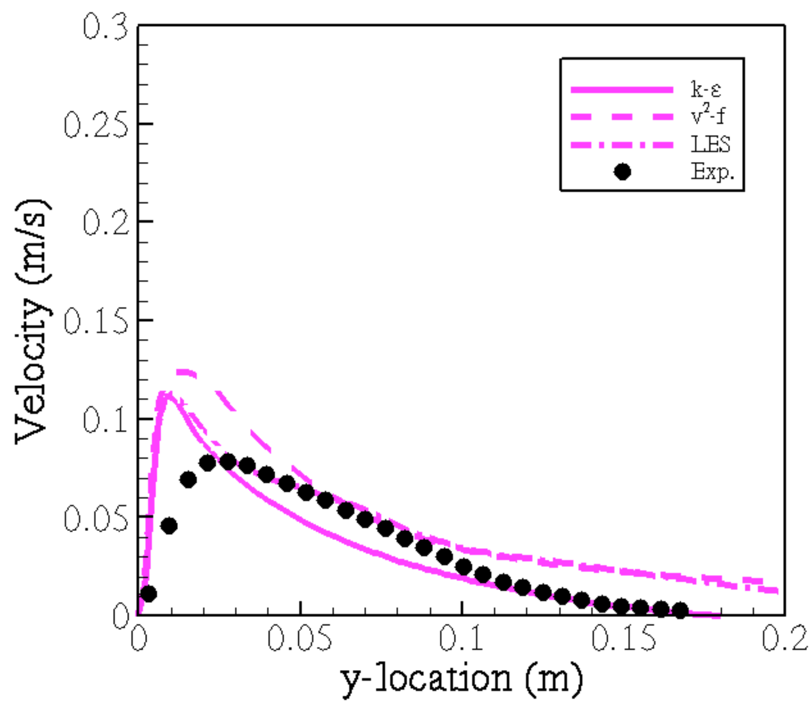

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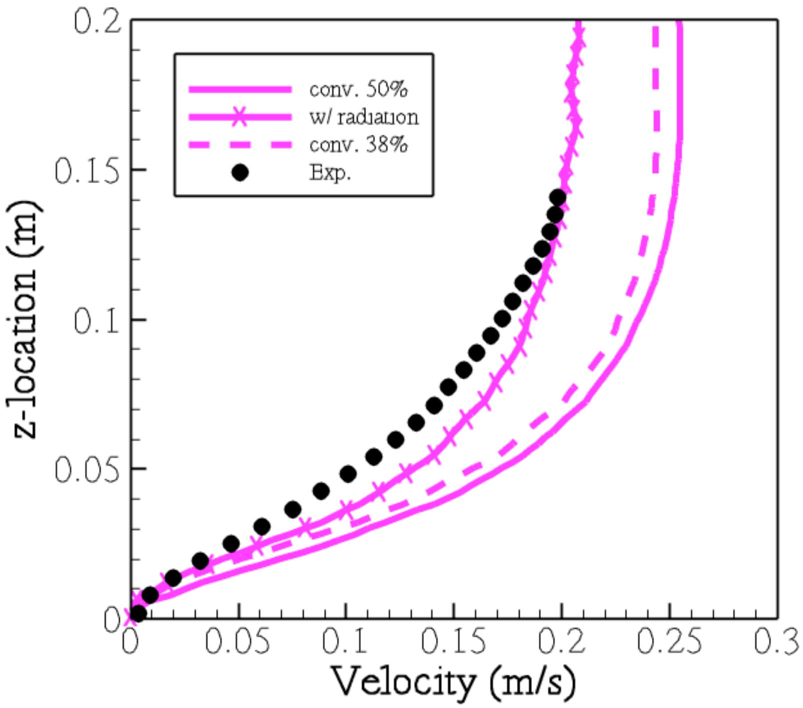
Convection/Radiation Ratio

- ❑ Commonly assumed 50/50
- ❑ Calculation including radiation shows 38/62
- ❑ $T_{manikin}$ ⬆ but also T_{wall} ⬆



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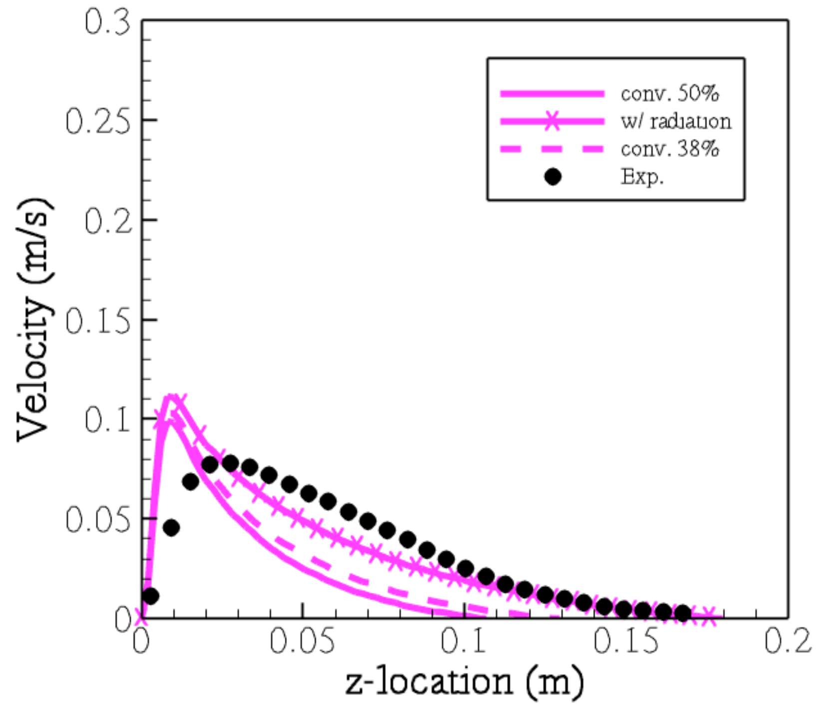

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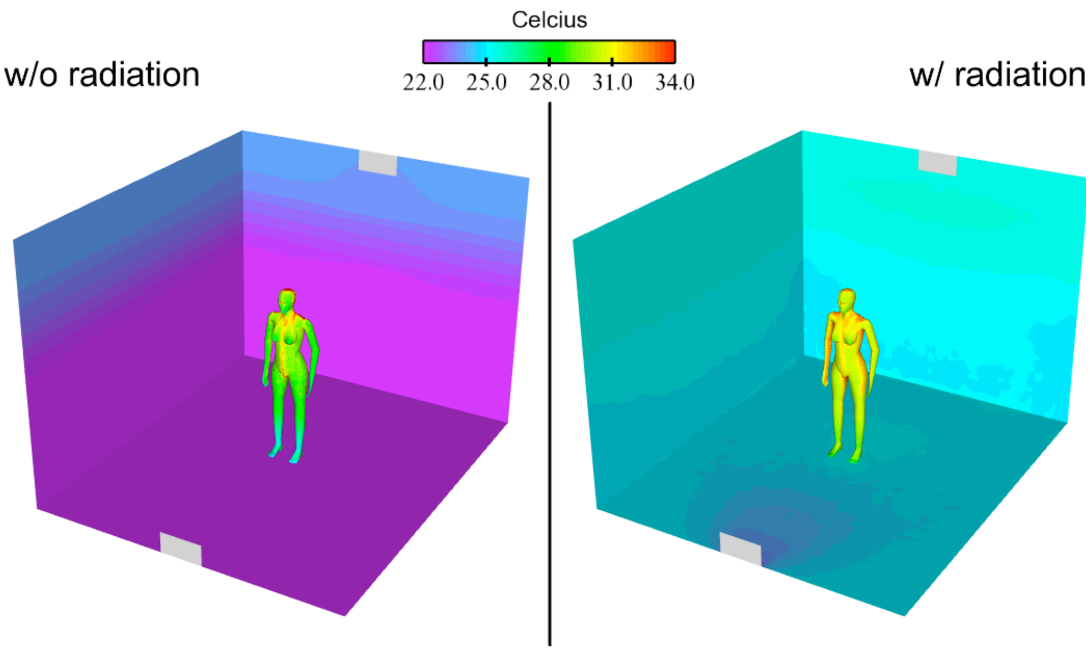
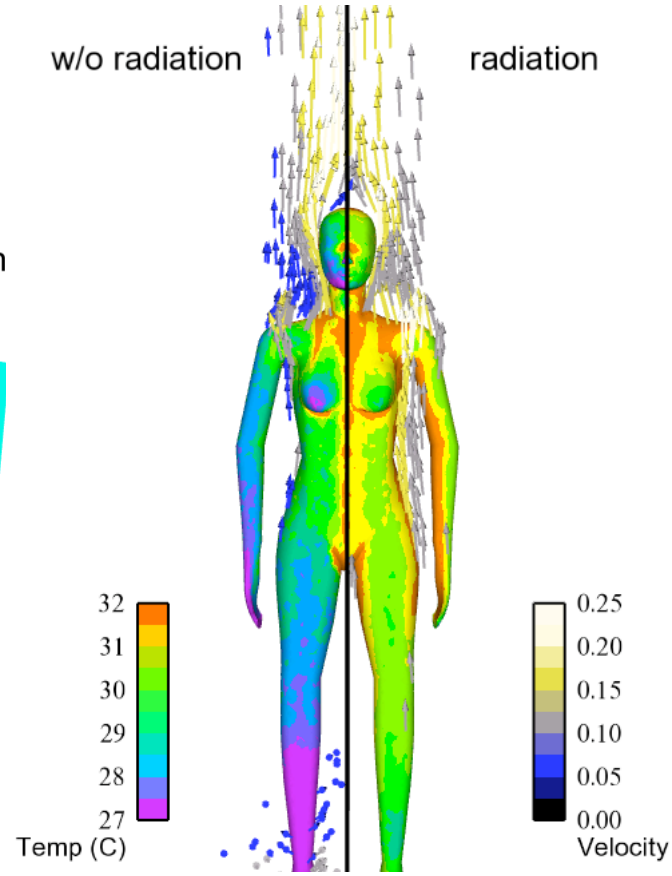
Radiative Heat Transfer

- Major human heat transfer mechanisms: **convection** and **radiation**
- If any heat-flux BC is used ***can not*** neglect radiation



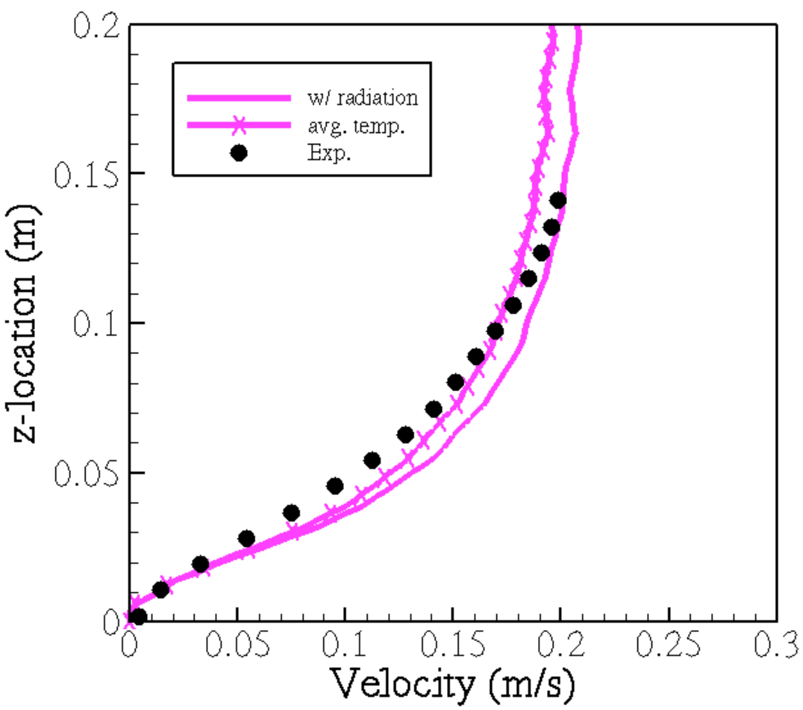
Surface temperature comparison



Plume comparison

Effects of Radiation

- Radiation only involves surfaces → use surface temperature instead
- Detail description of temperature difficult
- Averaged surface temperature → minimal impact on PME flow



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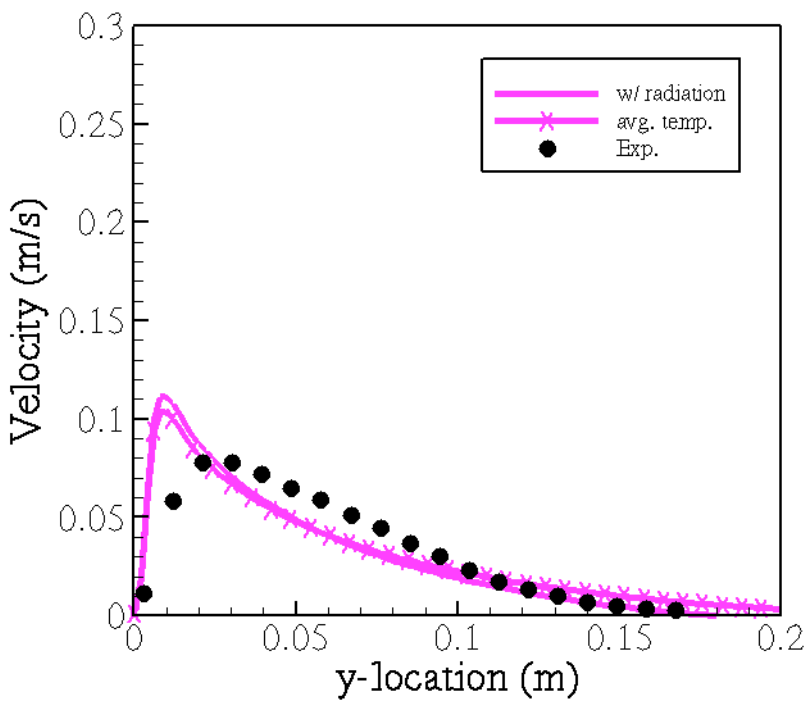

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Summary

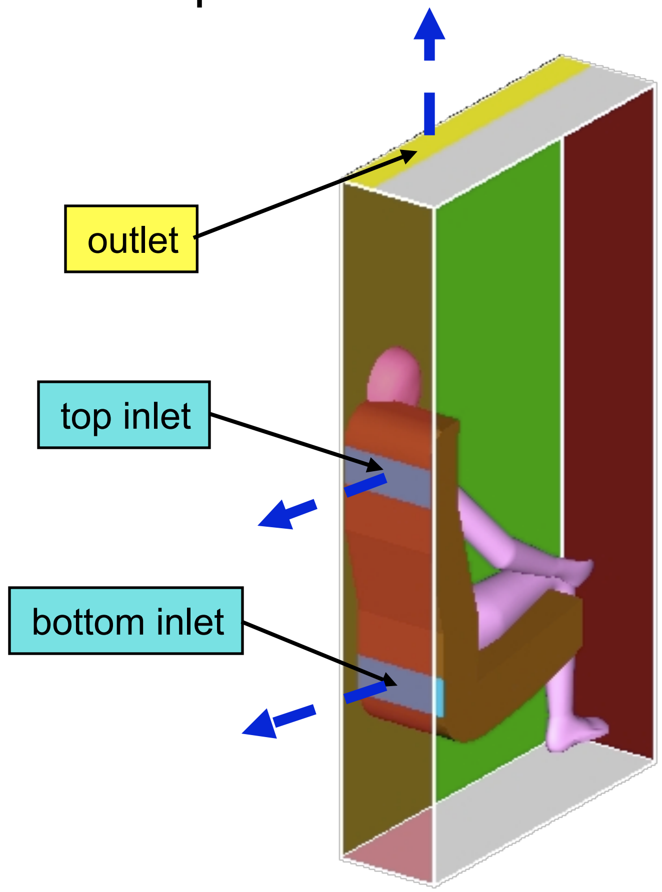
- ~60K surface points + BL resolution = RANS models sufficient
- Radiation (or effect) is key and should not be neglected
- Adjusting convection/radiation ratio not sufficient
- If PME flow - not thermal comfort - of interest, averaged surfaces temperature adequate

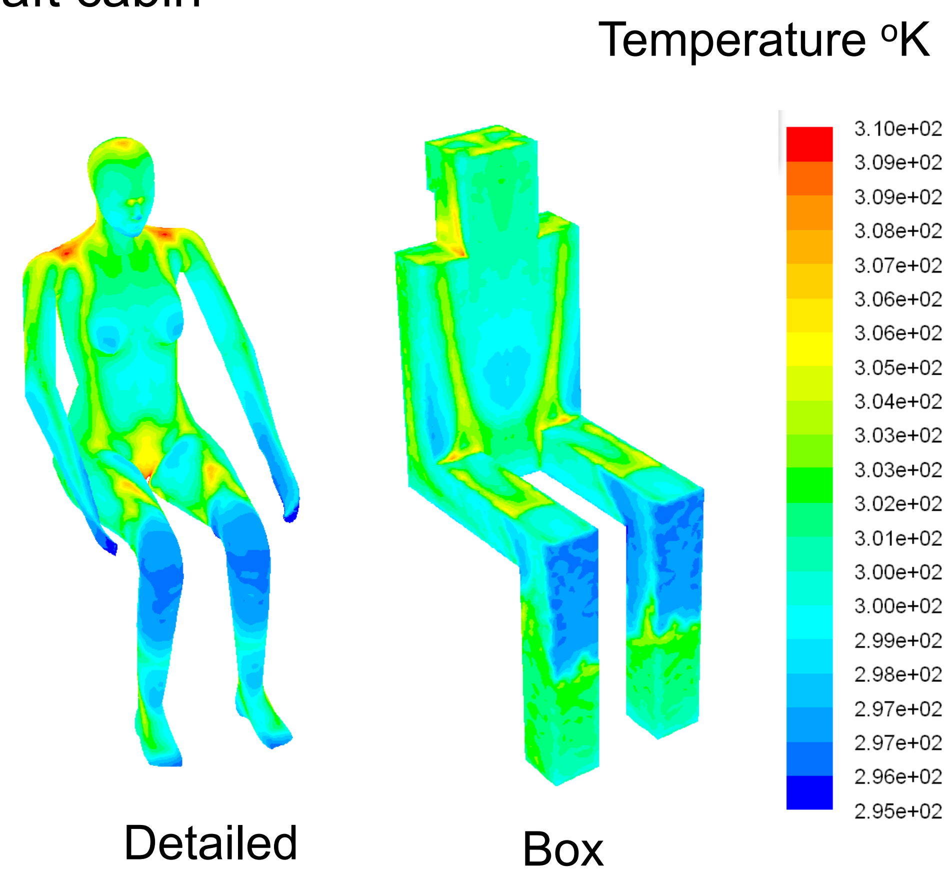
Applications

- CFD evaluation of personal ventilation in aircraft cabins
- Investigate the effects of common realistic details often ignored
  - *Breathing*
  - *Motion*
  - *Motion + breathing*
- Improving conventional air-terminal devices

Personal Ventilation in Aircraft Cabin

- Effects of geometry description, grid resolution and turbulence model on personal ventilation in aircraft cabin



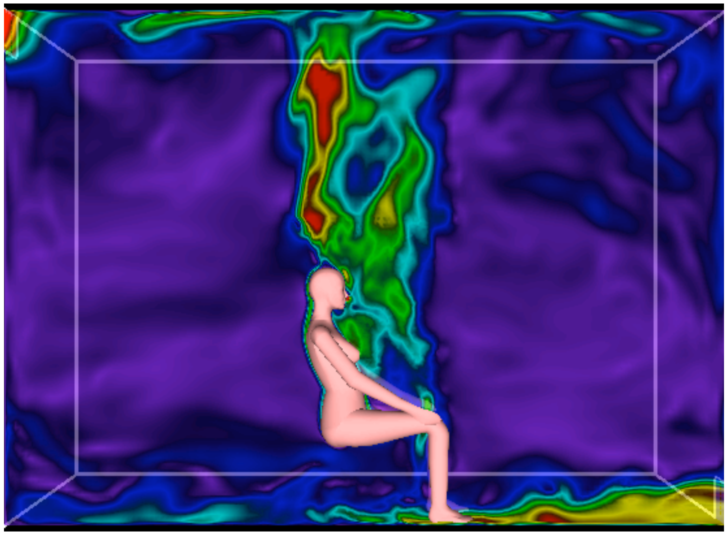


Reference:
Dang 2008 "On the Requirements for Accurate CFD Simulations of the Personal Micro-Environment" ASHRAE SLC 2008 – Seminar 68.

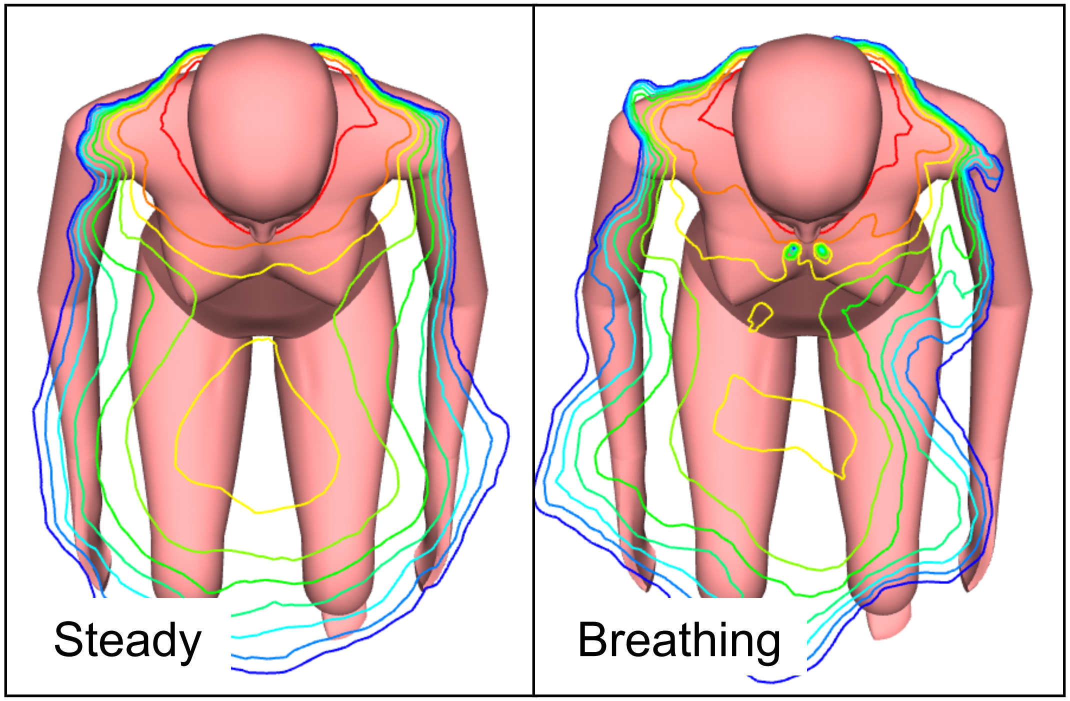
Realistic Details

- Breathing appears to have minimal influence on exposure
- Motion has some affect on exposure
- Small amounts re-inhaled air - in agreement w/ Melikov and Kaczmarcyzk (2007)

Velocity Contours



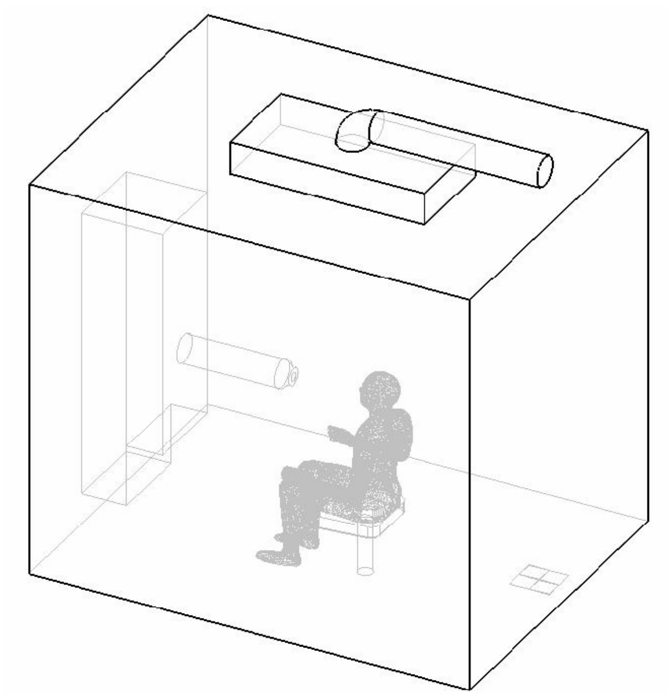
Ventilation Effectiveness



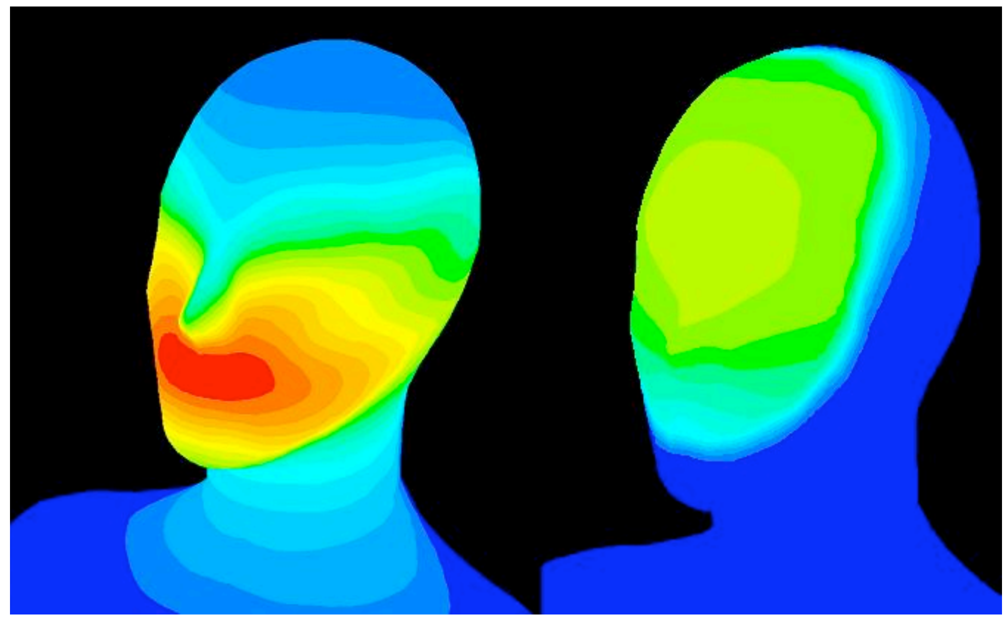
Reference:
Sideroff & Dang 2008 “CFD Study of the Effects of Breathing & Head Motion on the PME” Indoor Air 2008, Denmark

Co-flowing Jet Personal Ventilation

- Investigate improvements to conventional personal ventilation devices – co-flowing jet



Experimental and Computational Configuration



SF_6 Contours:

left - w/ co-flow; right w/o co-flow

Reference:
Russo, Dang and Khalifa 2008 “Computational Analysis of Personal Ventilation Jets” Indoor Air 2008, Denmark