State-of-the-art thermal modeling of complex fenestration systems

Laouadi, A.

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A. Laouadi

Learning Objectives for This Session

- **Define classes of shading devices**;
- Apply control strategies in practice;
- Provide overview of successful application of shading projects in new buildings
- **Explain how can performance of shading devices be modeled**
- Apply computer tools to calculate performance of shading devices
- Define objectives for intelligent shading control.

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Introduction: the Need for New Models

- Current thermal models do not account for heat generation or conversion, and radiation absorption or emission within layers;
- Physical properties of shading devices not accounted for;
- Cavity convection models were developed for specific types of shading devices.

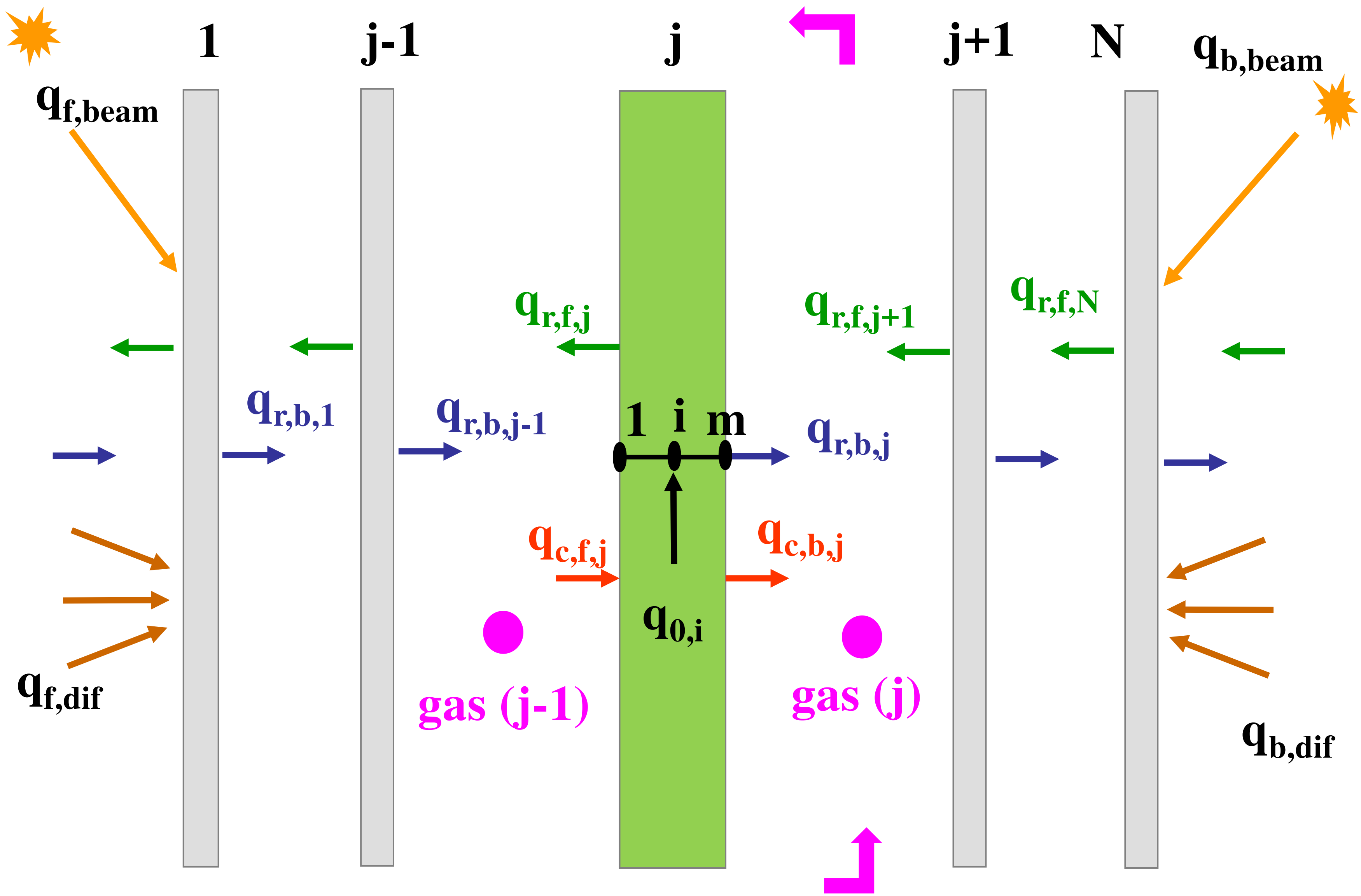
Objectives

- To revisit the current thermal models to include peculiarities of complex fenestration systems;
- To develop models to compute the effective thermal properties of shading devices;
- To develop models to compute the convection film coefficients of gas spaces adjacent to permeable shading layers;
- To validate the new models.

Model Assumptions

- Each fenestration layer is porous with effective radiation and thermal properties;
- Heat transfer through a layer medium is by one-dimensional heat conduction.

Description of a Fenestration System



Conductive Heat Transfer

$$\rho_j c_j \frac{\partial T_j}{\partial t} = \frac{\partial}{\partial x}\left(k_j \frac{\partial T_j}{\partial x}\right) - \frac{\partial q_{r,j}}{\partial x} + q_{sol,j} + q_{0,j}$$

Storage = conduction + radiation + net solar + generation

$$q_{sol,j} = \alpha_j \cdot q_{beam} + \alpha_{d,j} \cdot q_{dif} - SR_{PV} \cdot \eta_{PV,j} \cdot TR_{1:j-1}\left(q_{beam} + q_{dif}\right)$$

$$-\frac{\partial q_{r,j}}{\partial x} = q^{*}_{absorbed,j} - q^{*}_{emitted,j}$$

Radiative Heat Transfer

$$q_{r,f,j} = \tau_{eff,b,j} \cdot q_{r,i,j} + \rho_{eff,f,j} q_{r,fj} + q_{e,f,j}$$

$$q_{r,b,j} = \tau_{eff,f,j} \cdot q_{rfi,j} + \rho_{eff,b,j} q_{r,b,j} + q_{e,b,j}$$

$$q_{ef,j} = \sum_{i=1}^{i=m} \varepsilon_{f,j,i} \cdot \Delta x \cdot E_{j,i}$$

Convective Heat Transfer

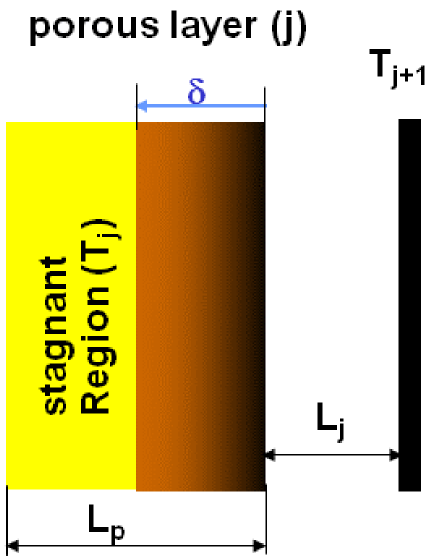
Open cavities (ISO model)

$$h_{c,j} = 2 \cdot h_{cavity,j} + 4 \cdot v_j$$

Thermal penetration length model for free convection

$$h_{cavity,j} = Func\left(L_j + \delta; H; \Delta T\right)$$

$$\delta / H = C / Ra_H^m; \quad (C = 0.56,\ m = 1/4 \ \text{for laminar flows})$$



Wind driven flows

$$v_j = 0.89 \cdot \varphi^{1.25} \cdot v_{j-1}$$

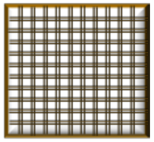
Effective Physical Properties of Layers

Screen shadings

$$P_{shade} = (1-\omega)\cdot P_{fabric} + \omega \cdot P_{air}$$

$$\omega = \textit{Openness Factor}$$

Screen shades



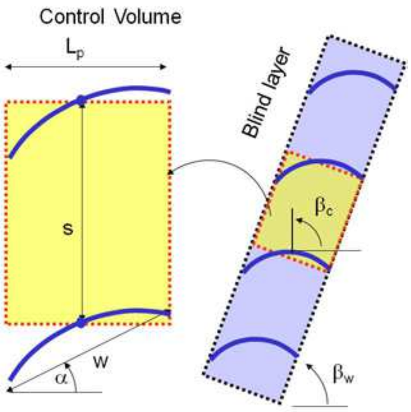
Slat-type blinds & Draperies

$$k_{shade} = (1-\omega)\cdot k_{mat} + \omega \cdot k_{eq}$$

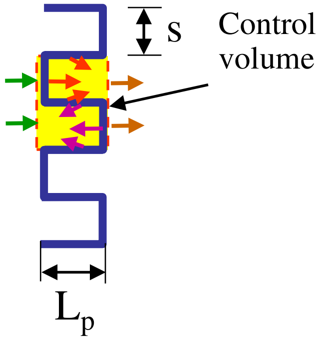
$$k_{eq} = h_c(\Delta T, w, z_c, \beta_c)\cdot w$$

$$\omega = \textit{porosity}$$

Blinds

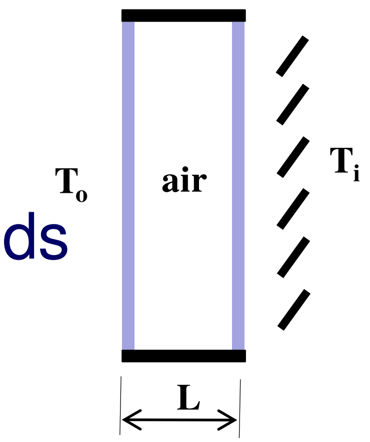


Draperies



Model Validation

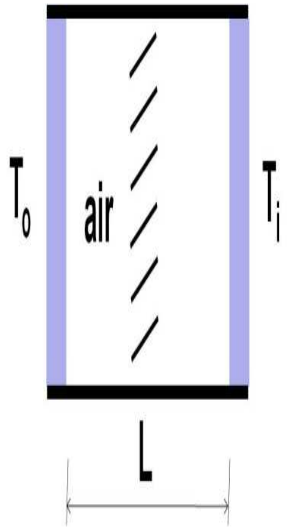
- Third party CFD comparison
  - Double glazed window with internal blinds
  - Double glazed window with between-pane blinds



- Third part measurement comparison
  - Double glazed window with between-pane blinds for:

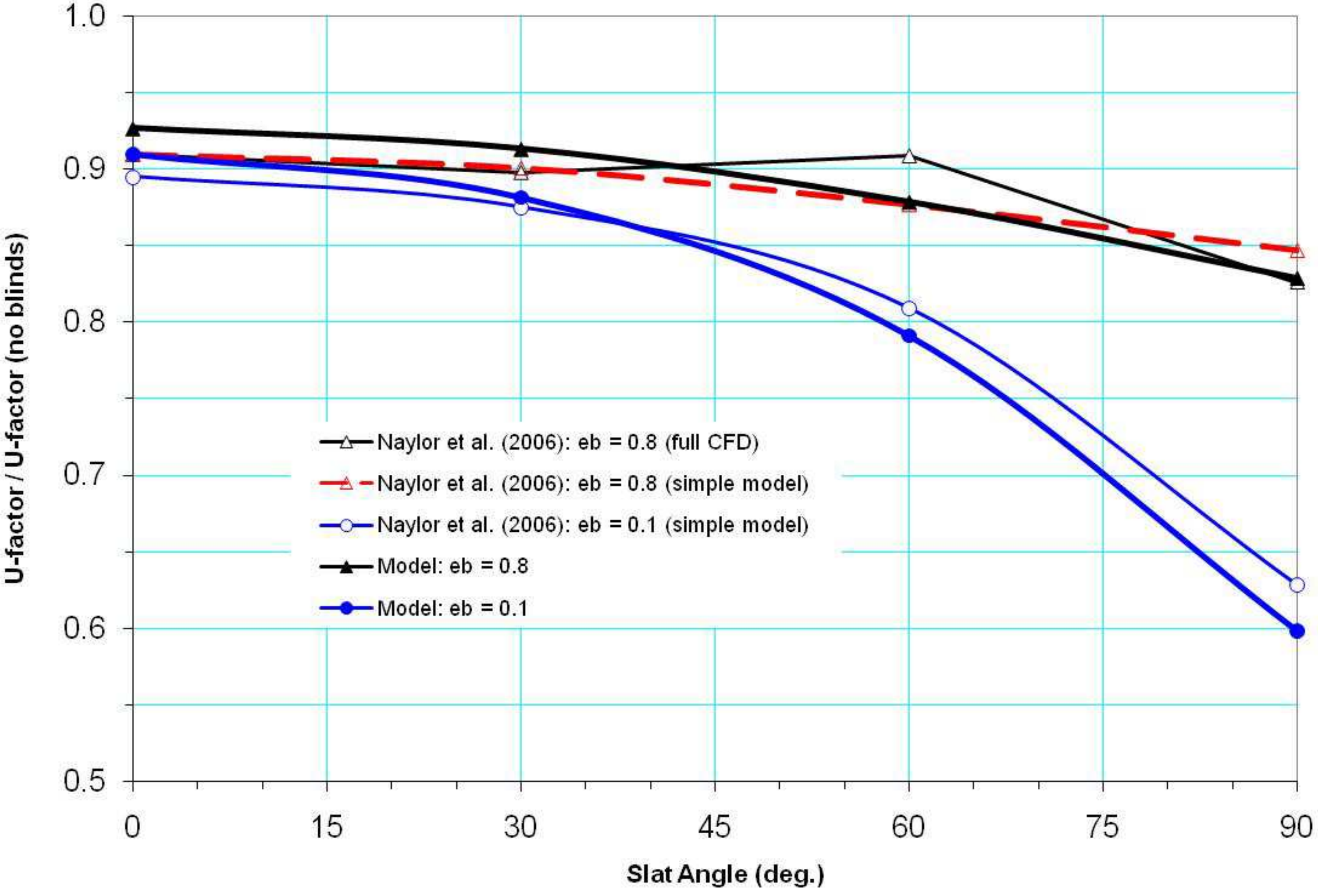
    L = 17.8 mm, 20 mm, 40 mm; and

    ΔT = 10°C and 20°C.



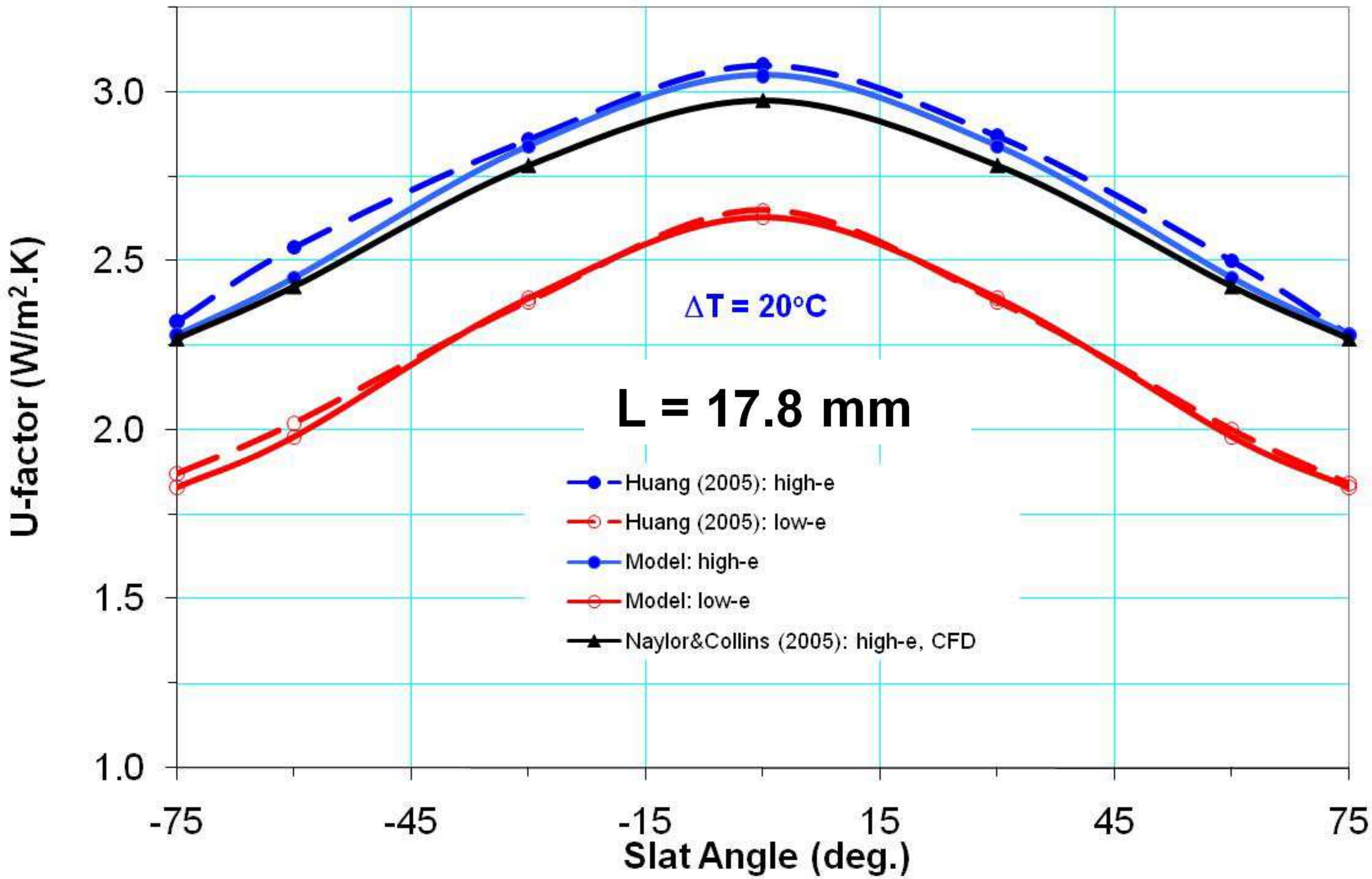
CFD comparison

Double glazed window with internal blinds



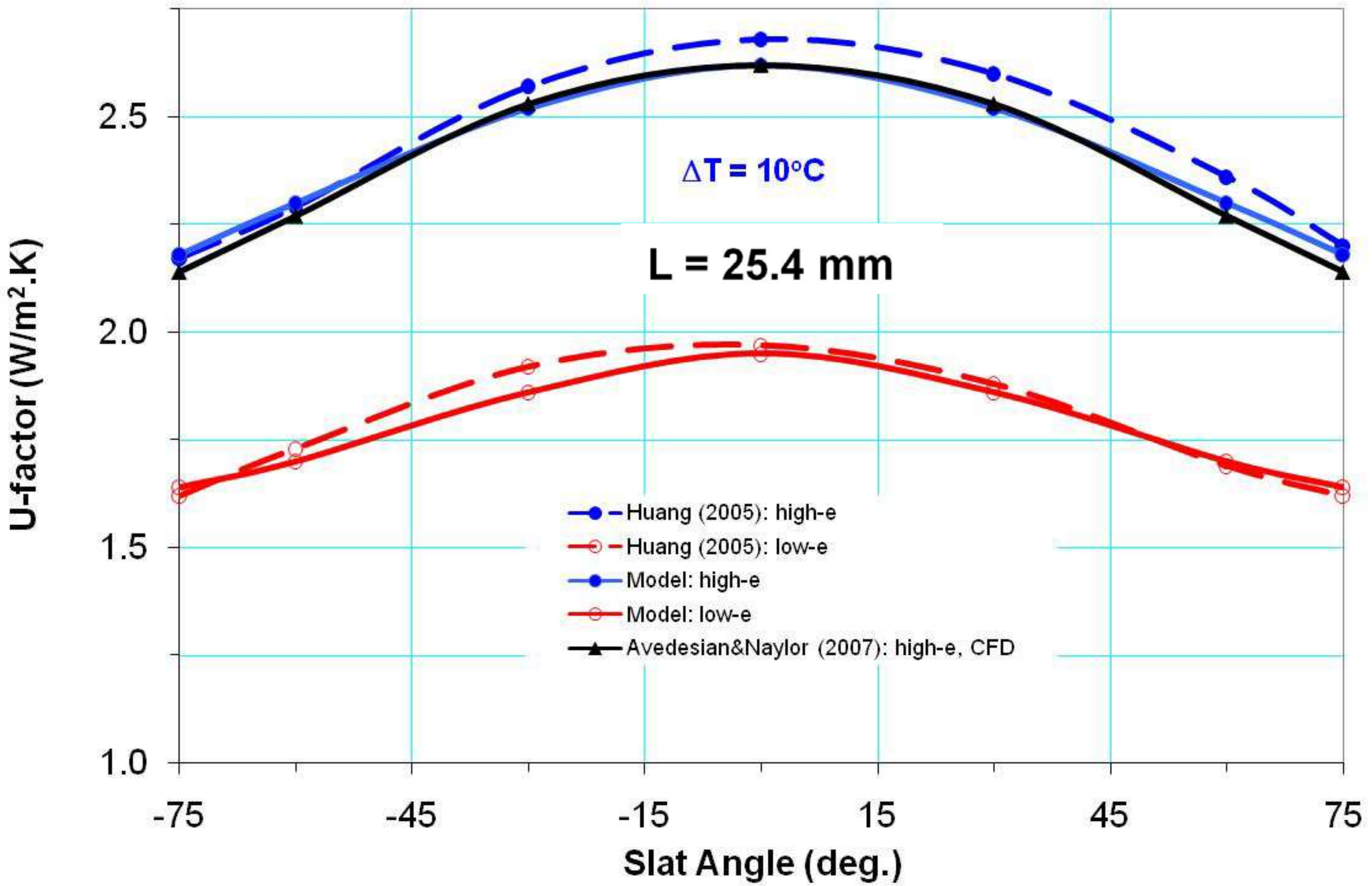
Measurement & CFD comparison

Double glazed window with between-pane blinds



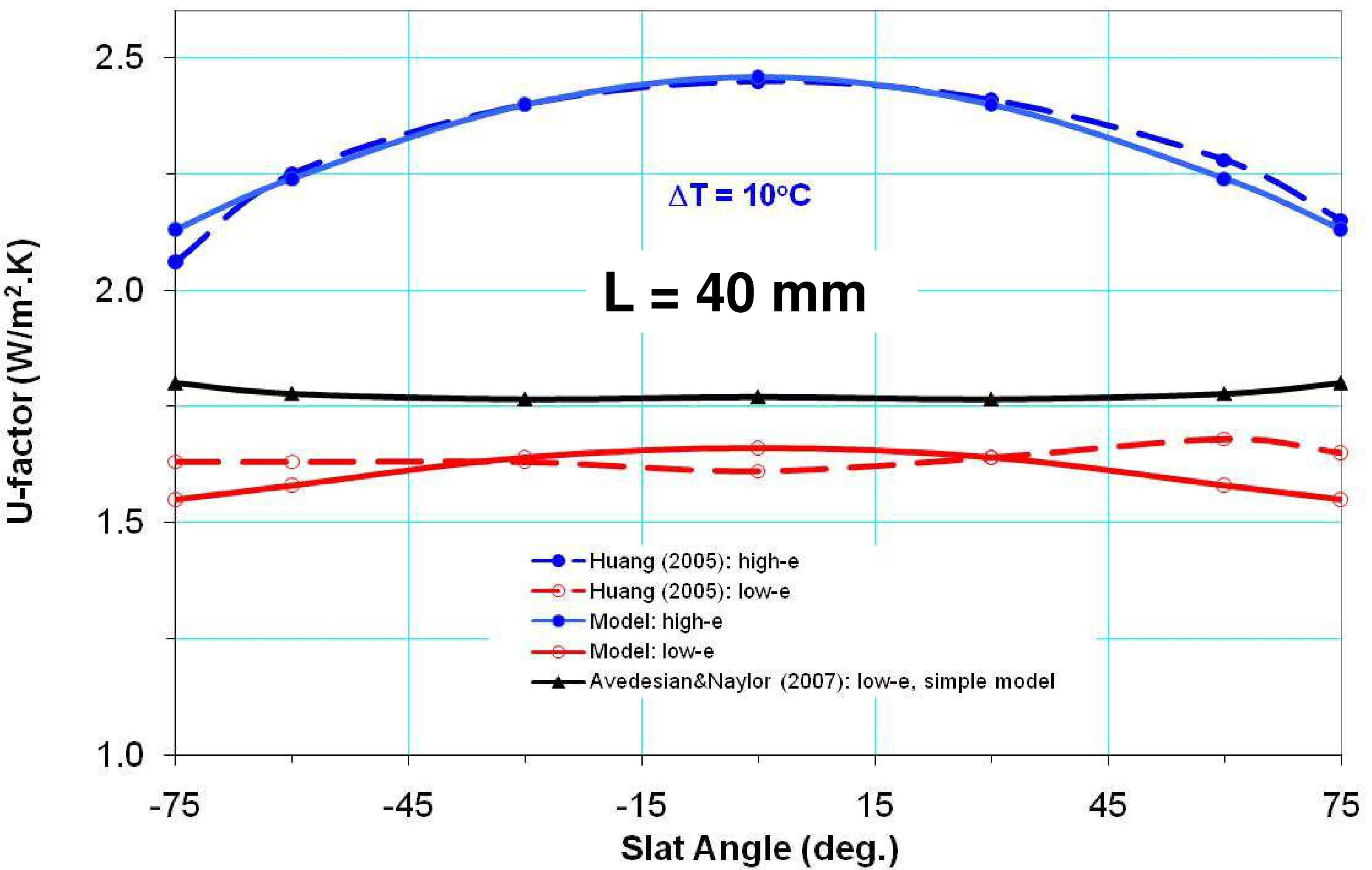
Measurement & CFD comparison

Double glazed window with between-pane blinds



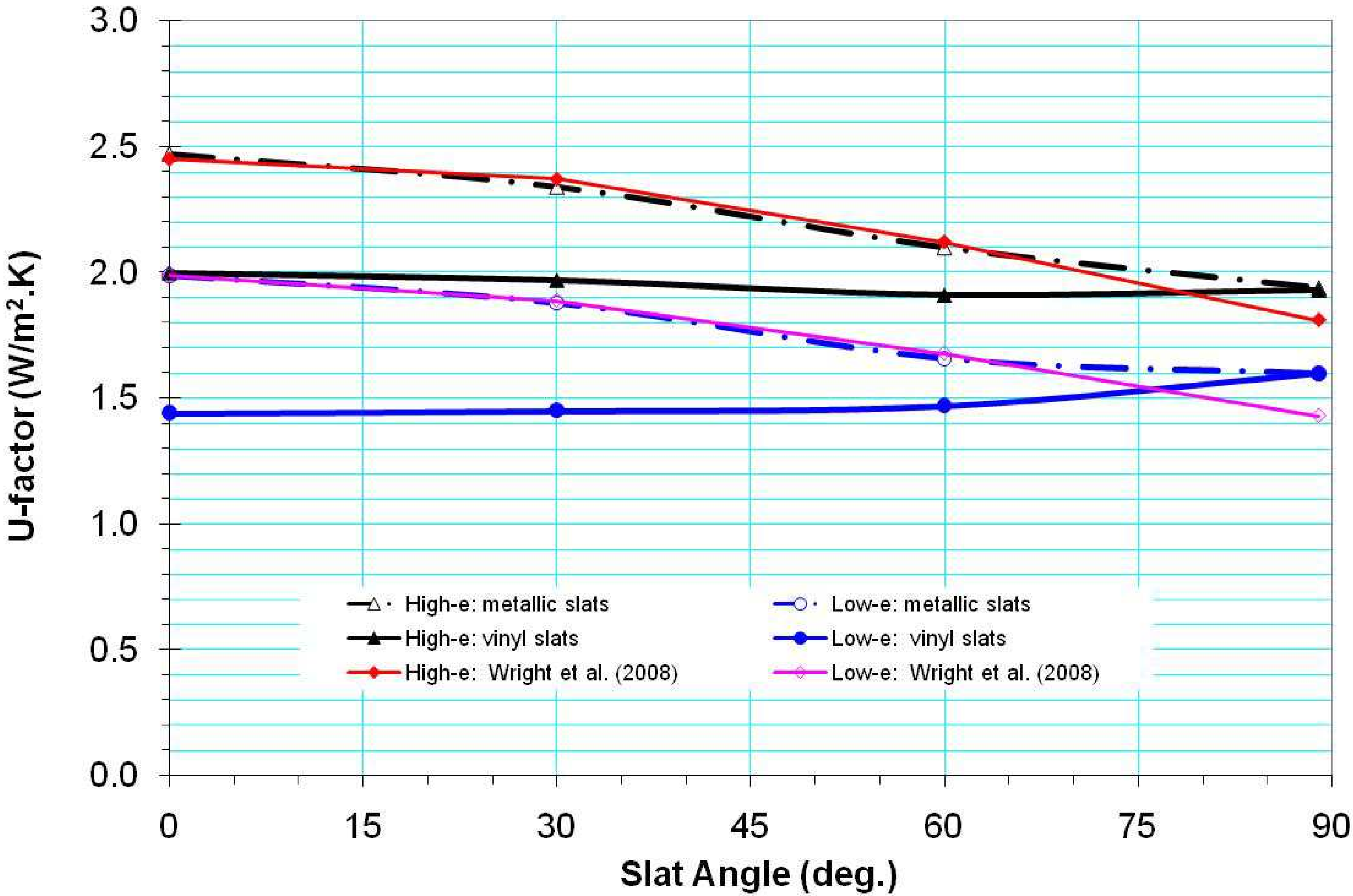
Measurement & CFD comparison

Double glazed window with between-pane blinds



Effect of thermal conductivity of blinds

Double glazed window with between-pane blinds



Conclusion

- A general methodology to compute the thermal performance of fenestration systems with shading devices, and elements imbedded in glazing layers for energy generation and conversion.
- The models assume each system layer as porous with effective physical properties.
- Cavity film coefficient calculated using the thermal penetration length model.
- The model's predictions compared very well with third party measurement and CFD simulations.
- Further validation studies are needed to cover other types of shading devices, tilted windows, cavity turbulent flows, and boundary conditions.

References

- Laouadi A. Thermal Performance Modeling of Complex Fenestration Systems. Journal of Building Performance Simulation, 2:3,189 — 207; 2009.

- Laouadi A. Thermal Modeling of Shading Devices of Windows. ASHRAE Trans., pp. 803-814, 2009.