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

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.

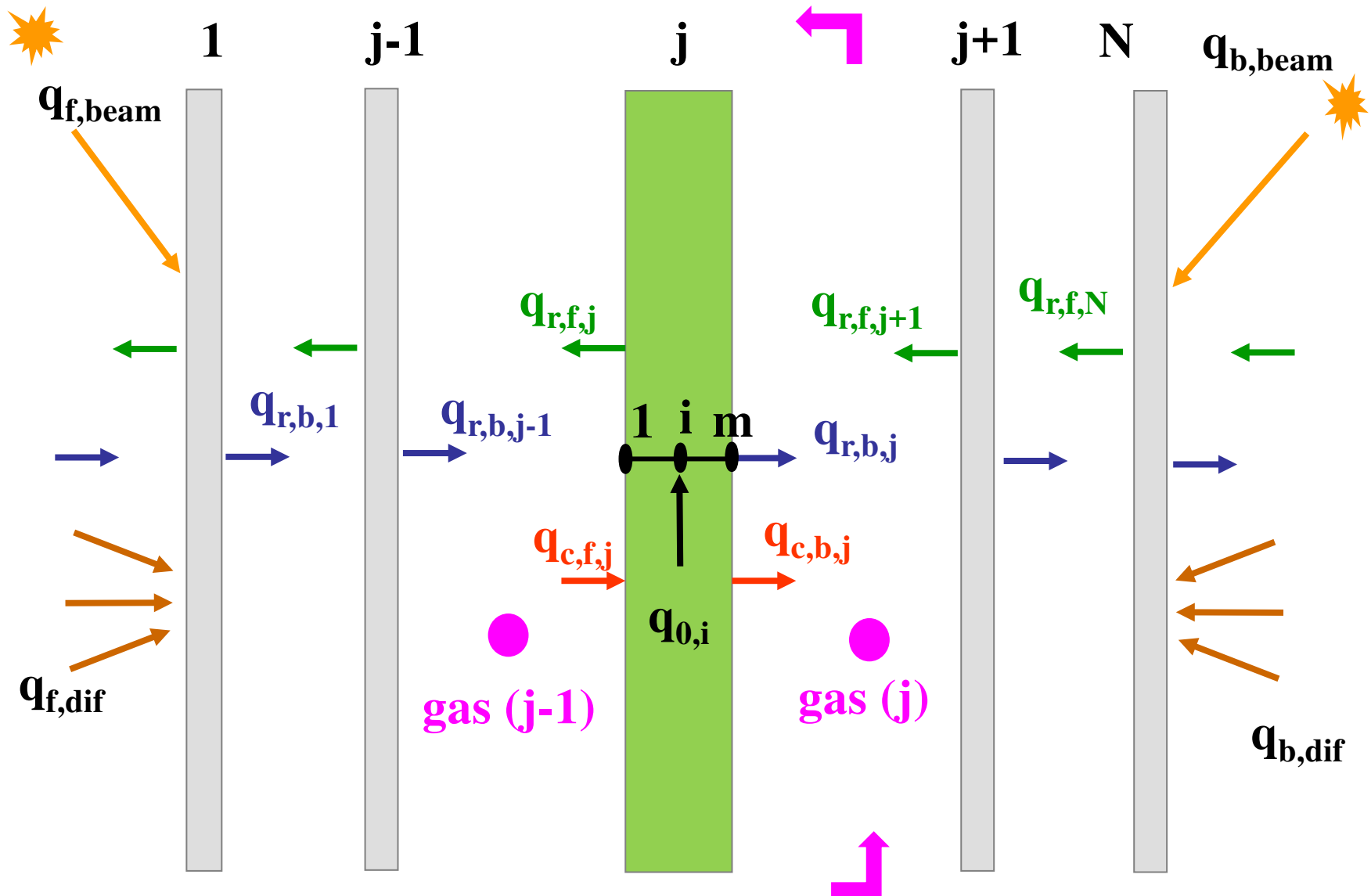
Objectives

- 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

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

Storage = conduction + radiation + net solar + generation

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

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

Radiative Heat Transfer



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

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

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

Convective Heat Transfer

Open cavities (ISO model)

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

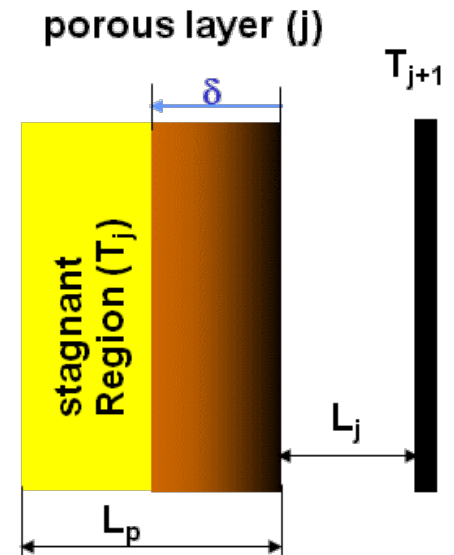
Thermal penetration length model for free convection

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

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

Wind driven flows

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

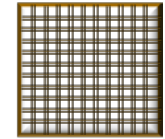


Effective Physical Properties of Layers

Screen shadings

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

Screen shades



ω = *Openness Factor*

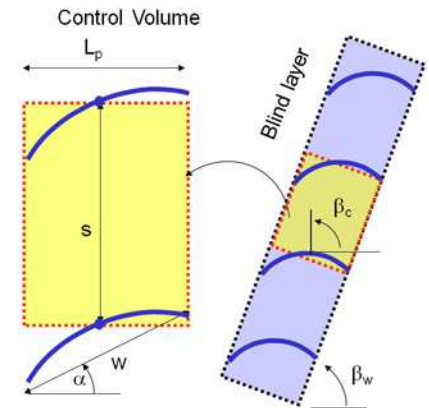
Slat-type blinds & Draperies

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

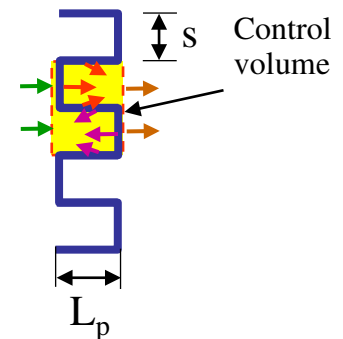
$$k_{\text{eq}} = h_c(\Delta T, w, z_c, \beta_c) \cdot w$$

ω = *porosity*

Blinds

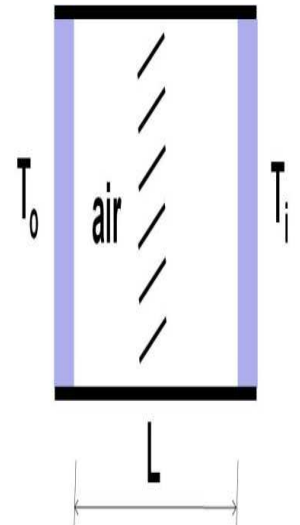
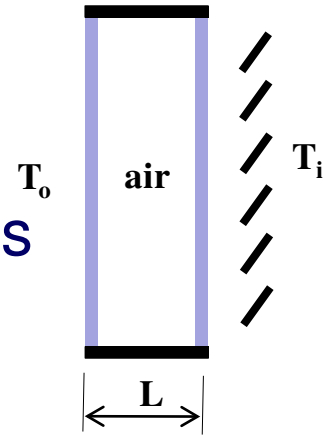


Draperies



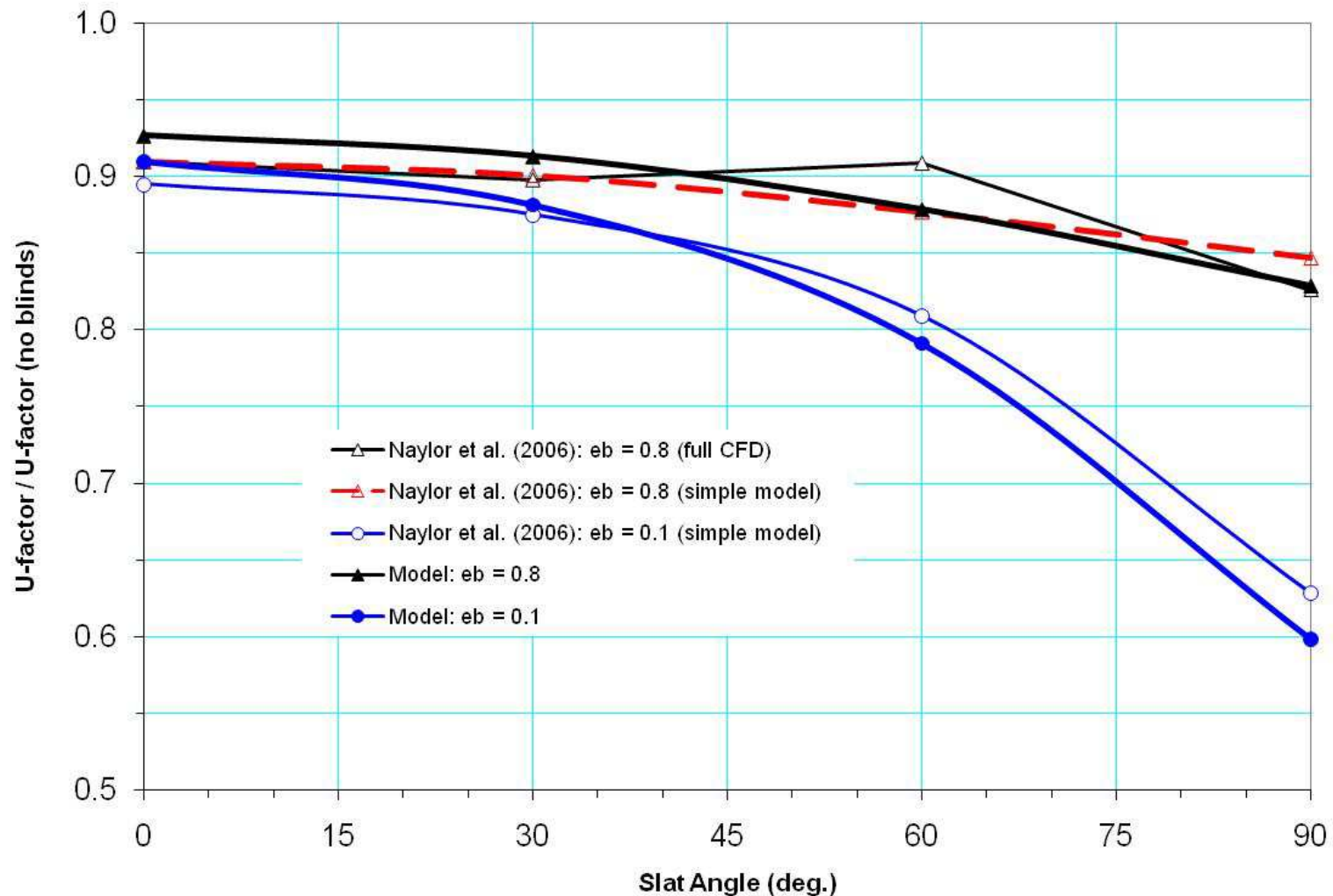
Model Validation

- 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:
 - $L = 17.8 \text{ mm}, 20 \text{ mm}, 40 \text{ mm};$ and
 - $\Delta T = 10^\circ\text{C}$ and $20^\circ\text{C}.$



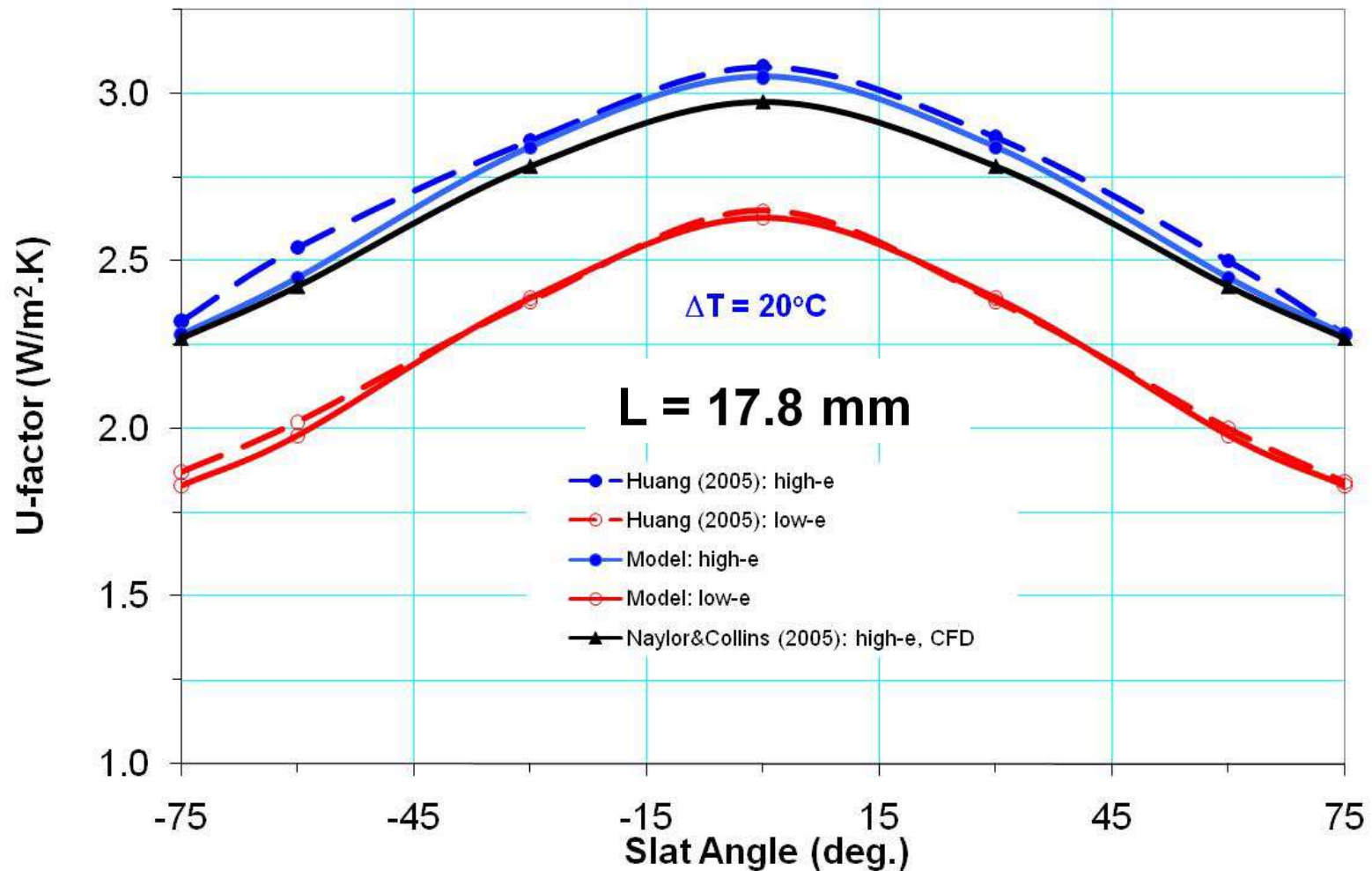
CFD comparison

Double glazed window with internal blinds



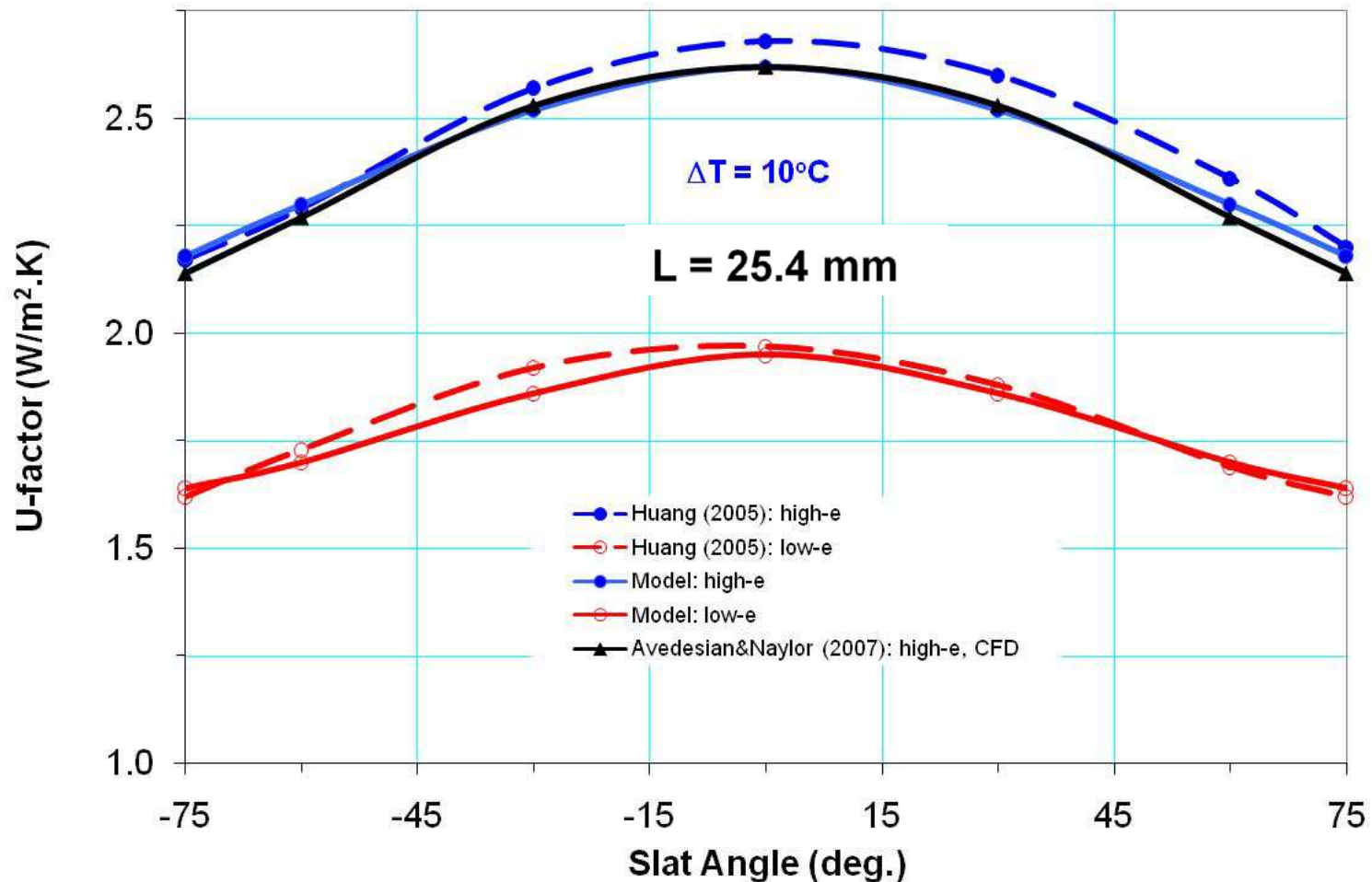
Measurement & CFD comparison

Double glazed window with between-pane blinds



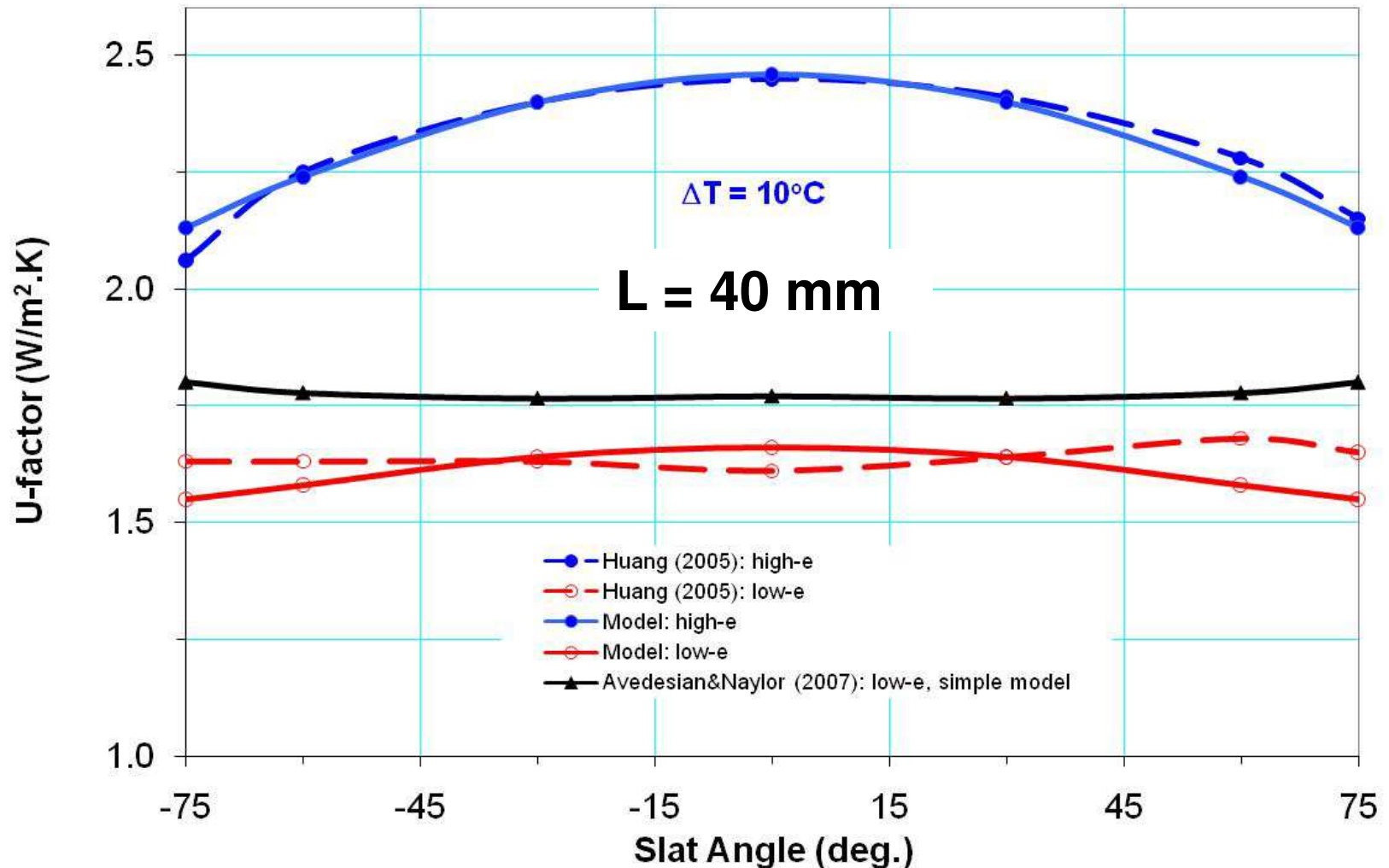
Measurement & CFD comparison

Double glazed window with between-pane blinds



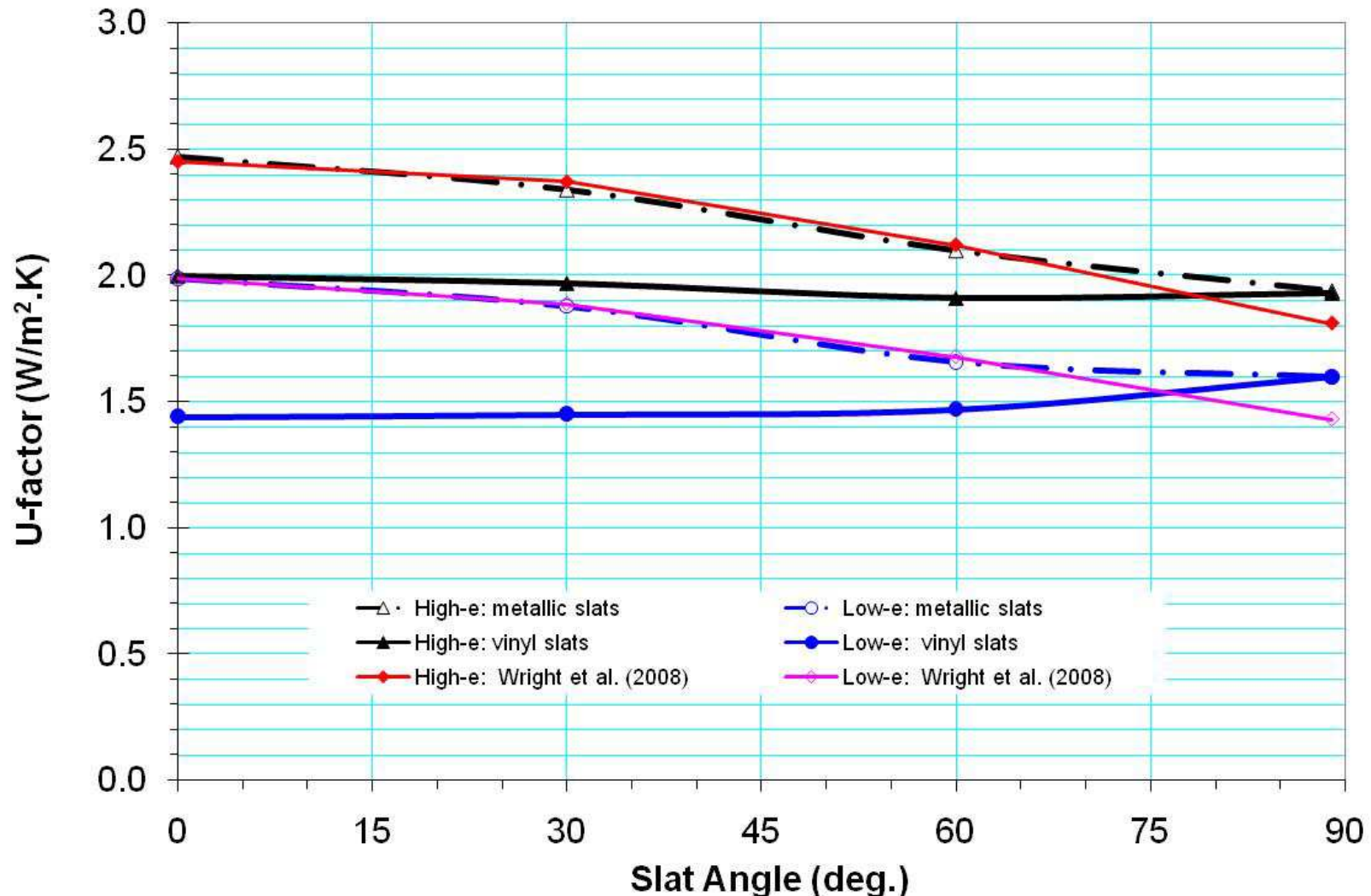
Measurement & CFD comparison

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.