C E E R E

Center for Energy Efficiency and Renewable Energy

Building Energy Efficiency Program

University of Massachusetts

Engineering Laboratory Building

160 Governor's Dr.

Amherst, MA 01003-9265

Progress Report

COMPUTATIONAL MODELING OF HEAT TRANSFER IN TALL RECTANGULAR ENCLOSURE WITH VENETIAN BLINDS

Submitted by: Dr. Aleksandr Fomichev
Dr. Charlie Curcija

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1. EXECUTIVE SUMMARY

Following up on the validation portion of this research project, this report presents computer modeling results and preliminary set of correlations for the in-between glazing venetian blinds. Type "A" venetian blind, as defined in ISO (2003) at slat angles of 0°, 45° and 90° was investigated. Glazing cavity was modeled as a tall rectangular enclosure with fixed vertical side temperatures and adiabatic top and bottom. Actual glazing cavity was replaced by an idealized rectangular enclosure so that appropriate heat transfer correlations could be developed for use with existing algorithms in ISO (2003) and WINDOW program.

The correlations were developed based on the temperature difference and cavity width (*Ra* number), as well as angle of inclination of the slats.

2. DESCRIPTION OF GEOMETRY

The following Venetian blind and glazing cavity configurations are considering for numerical simulations.

Table 1. Venetian Blind Geometry and Properties

Venetian blind ID	***A***
Slat width, mm	16
Slat distance, mm	12
Slat thickness, mm	0.6
Slat material	Aluminum
IR emissivity slat front side	0.9
IR emissivity slat back side	0.9

Table 2. Glazing cavity configuration

Glazing cavity ID	Height H, m	Width L, m	IR emissivity of glazing walls	Minimum gap width between plates and vertical cavity wall *d*, mm
G_20	1	0.02	0.9	2
G_24	1	0.024	0.9	4

3. DESCRIPTION OF THE NUMERICAL MODEL

In Figure 1, the geometry and boundary conditions of the 2-D numerical model of the rectangular cavity with in-between venetian blind are shown. Vertical sides of the rectangular cavity have fixed temperatures, creating uniform temperature differential. This is typical boundary condition used for fenestration glazing cavities and it corresponds to the existing algorithms used in ISO (2003) and WINDOW program (LBNL 2003). The temperature of the warm and cold side of the rectangular cavity were varied from run to run and the following values were used:

T_{in} = 3 ^oC, 5 ^oC, 10 ^oC, 15 ^oC, 20 ^oC and

T_{out} = -3 ^oC, -5 ^oC, -10 ^oC, -15 ^oC, -20 ^oC.

The bottom and the top of glazing cavity are treated as adiabatic in all cases and runs.

Air inside rectangular cavity was modeled and radiation heat transfer between cavity surfaces was also modeled. Natural convection heat transfer resulting from the movement of cavity air was modeled using laminar viscous assumption with Boussinesq approximation. Radiation heat transfer was modeled using Discrete Transfer Radiation Model (DTRM) with angle parameters: theta divisions θ = 6, phi divisions φ = 6 (FLUENT 2003).

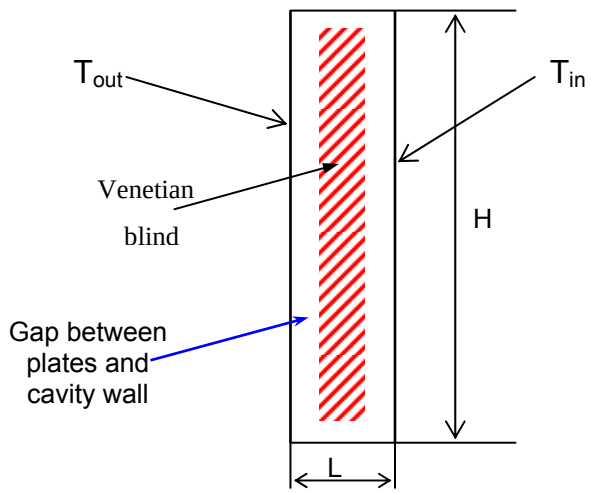

Figure 1. Geometry and Boundary Conditions of the In-Between Glazing Venetian Blind Model.

4. COMPUTER MODELING RESULTS

The glazing cavity *G_20* (see Table 2) with venetian blind *A* (see Table 1) was modeled under the boundary conditions described in Section 3.

Four tilt angles of venetian blind slats were modeled;

- tilt angle 0º (venetian blind slat in the horizontal, or open position),
- tilt angle 45º (front of the venetian blind slat pointing down),
- tilt angle -45º (front of the venetian blind slat pointing up), and
- tilt angle 90º (closed position and no gap between bottom/top of cavity and the blind)

Figures 2 and 3 show temperature and velocity distribution in the glazing cavity for plates at 0º and 45º and 90º tilt angles.

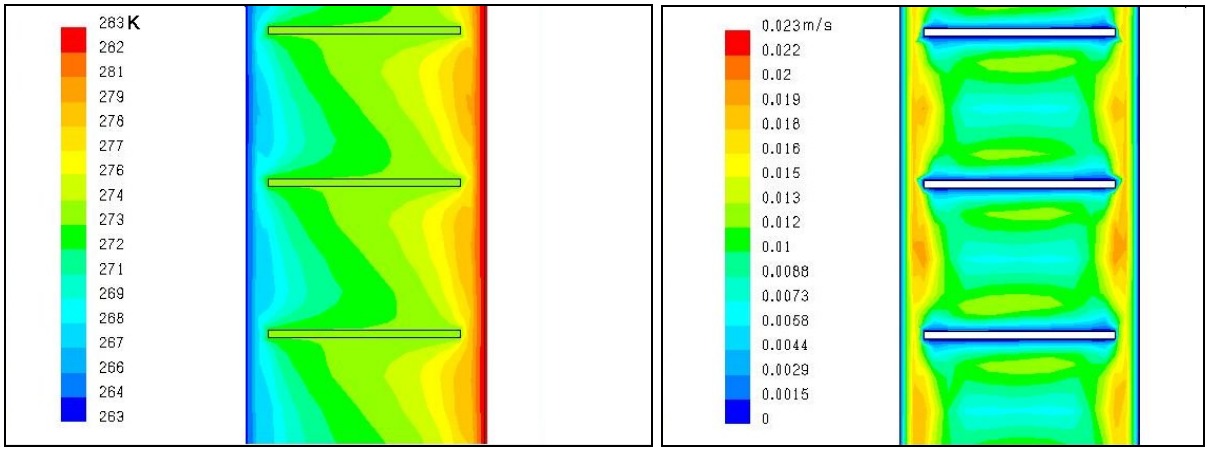

Figure 2. Temperature and velocity distribution in the glazing cavity ***G_20*** with Venetian blind ***A***, Ra = 23260 (plate angle is 0°).

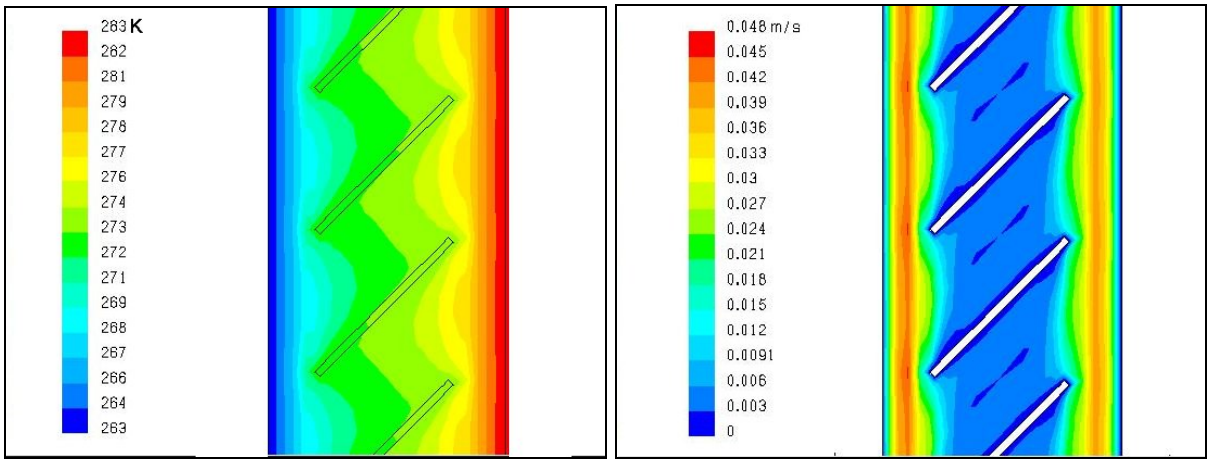

Figure 3. Temperature and velocity distribution in the glazing ***G_20*** with Venetian blind ***A***, Ra = 23260 (plate angle is 45°).

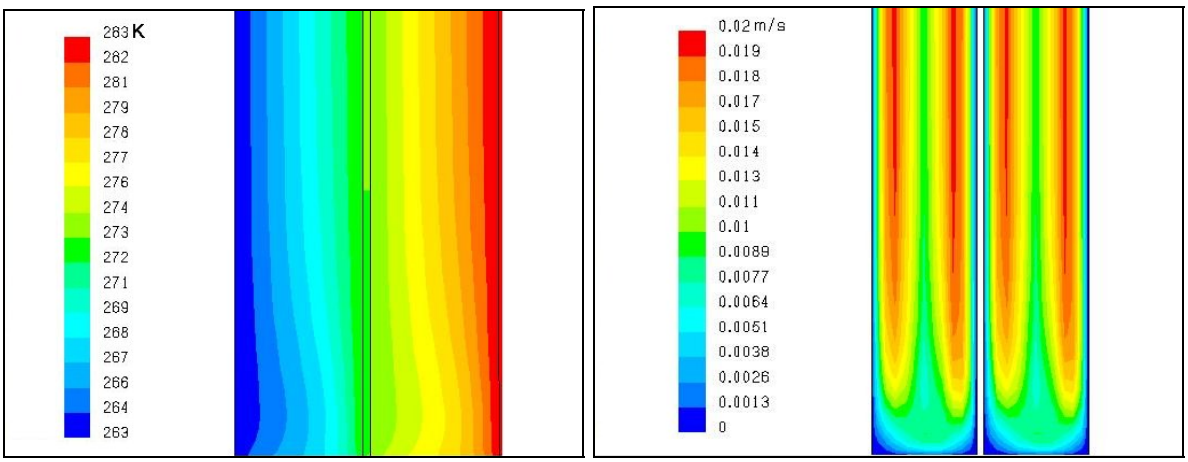

Figure 4. Temperature and velocity distribution in the glazing cavity ***G_20*** with Venetian blind ***A***, bottom part of the cavity, Ra = 23260 (plate angle is 90°).

Convection component of heat transfer through glazing cavity was estimated in terms of Nu number and summarized in the Table 3.

Table 3. Convection heat transfer results for cavity ***G_20*** with Venetian blind ***A***.

ΔT, C°	*Ra*	*Nu*			
		Angle 0°	Angle 45°	Angle 90°	Cavity w/o blind
6	6950	2,200	1,55	1,02	1,106
10	11600	2,520	1,67	1,09	1,180
20	23260	2,690	1,74	1,12	1,366
30	34700	2,736	1,763	1,14	1,527
40	46300	2,768	1,791	1,16	1,664

Nu number dependence on *Ra* number is plotted in Figure 5 for specified blind plate angles.

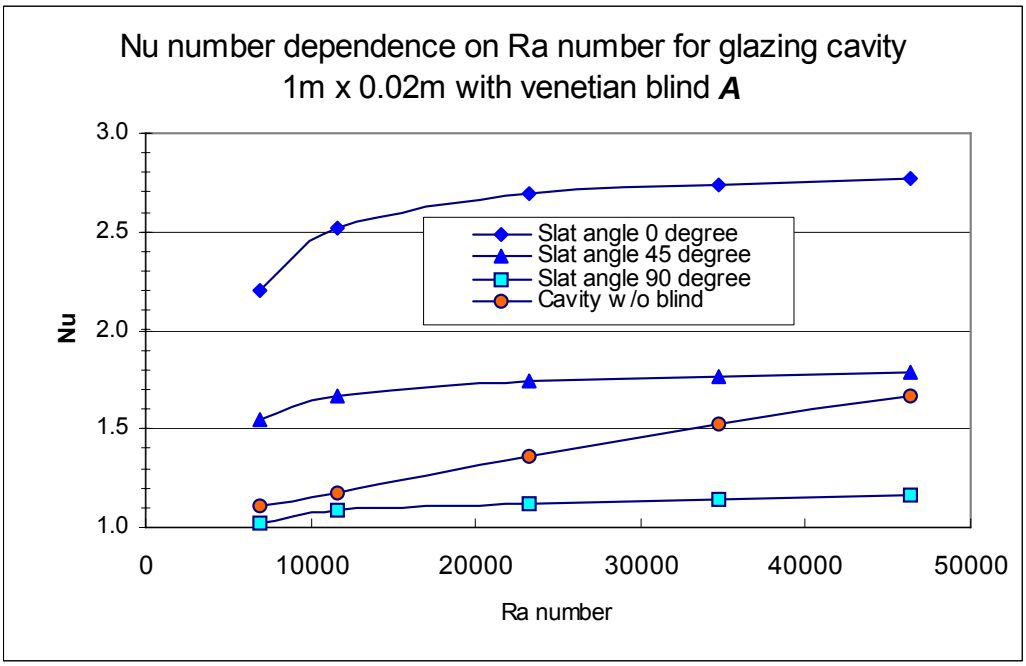

Figure 5. *Nu* Number Dependence on *Ra* Number. Glazing Cavity ***G_20*** with In-Between Glazing Venetian Blind ***A***.

For the purpose of comparison, *Nu* number dependence for the glazing cavity ***G_20*** without blind was also present in Table 3 and Figure 5. As evident from Figure 5, the convection heat transfer for the cavity with venetian blinds, the convection heat transfer is generally higher than for the cavity without venetian blind, except for the case with fully closed slats (90° angle). Fully open blinds have convection heat transfer rates more than twice the rates for the cavity without blinds. The reason for this appears to be due to the blind tips being embedded inside the boundary layer close to glazing surface, which changes the structure of the boundary layer and velocity distribution. This can be observed in Figure 6.

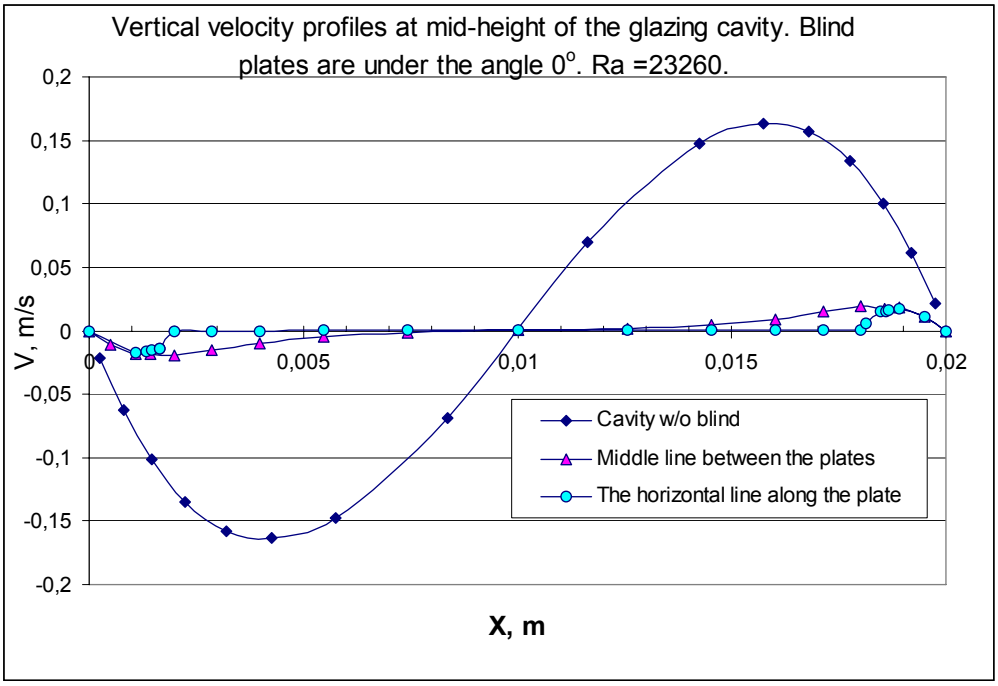

Figure 6. Comparison of the Vertical Velocity Profile in Glazing Cavity with and without Venetian Blinds.

Nu number dependence as a function of blind slat angle is plotted in Figure 7 for the considered range of *Ra* number.

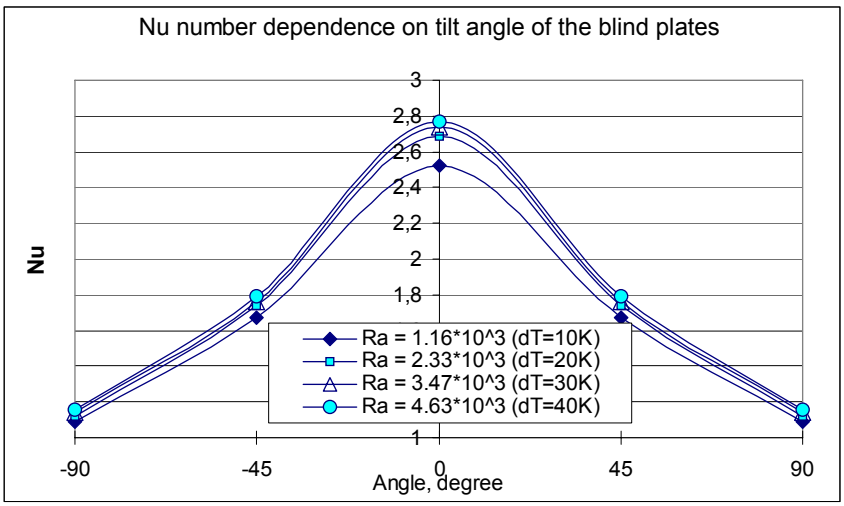

Figure 7. *Nu* Number Dependence on the Blind Slat Angle. Glazing cavity ***G_20*** with Venetian blind ***A***.

5. CONVECTION HEAT TRANSFER CORRELATIONS

The correlations for *Nu* number dependence on *Ra* number were derived with the help of DataFit® software for specified blind slat angles (0°, 45°, 90°). Figure 7 shows the relative agreement between these correlations and modeling results.

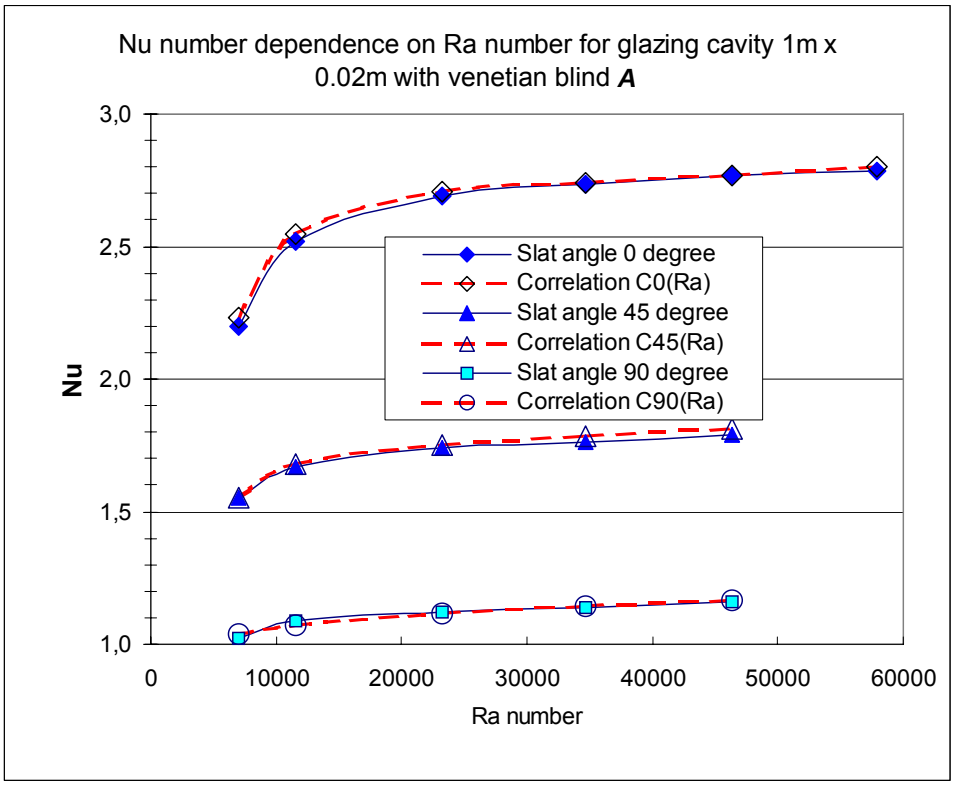

Figure 8. The Comparison of the Heat Transfer Correlations with Modeling Results for the Glazing Cavity ***G_20*** with Venetian blind ***A***.

Correlation A0:

$$Nu = -119.52 + 35.52 \cdot \ln(Ra) - 3.39 \cdot \ln^2(Ra) + 0.109 \cdot \ln^3(Ra) \quad (1)$$

Correlation A45:

$$Nu = -52.43 + 15.87 \cdot \ln(Ra) - 1.556 \cdot \ln^2(Ra) + 0.05108 \cdot \ln^3(Ra) \quad (2)$$

Correlation A90:

$$Nu = 0.4586 + 0.06565 \cdot \ln(Ra) \quad (3)$$

Equations (1) to (3) give heat transfer correlations for natural convection in glazing cavity with in-between glazing venetian blind for a set of fixed angles. Next step is to develop correlations that include blind slat angle as one of variables. In order to determine the top limit of the angle where the correlations would be applicable, it would be necessary to perform extra runs for various slat angles that are outside of the scope of this research. In Figure 9, the example of the derived correlation for the case *Ra* = 11,600 is shown.

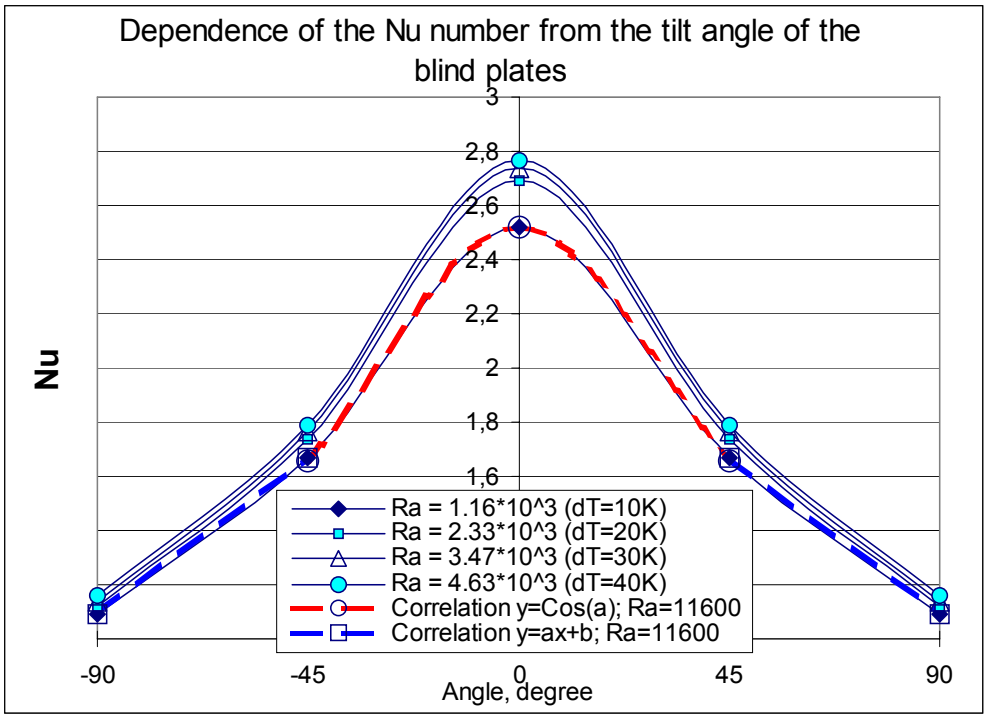

Figure 9. Comparison of the Correlation for Ra = 11600 with Modeling Results. Glazing cavity ***G_20*** with Venetian Blind ***A***.

Correlations for *Nu* number as a function of the slat angle is presented below:

Correlation A(φ):

For angles in the range from 0 to π/4 ($0^o \le \varphi \le 45^o$)

$$Nu = 1 + \left(Nu_{\max} - 1\right) \cdot \cos\left(1.43 \cdot \varphi\right)$$

Where:

φ = blind slat angle in radians,

Nu_{max} = maximum *Nu* number for the specified *Ra* number,

For angles from π/4 to π/2 ($45^o < \varphi < 90^o$), a linear interpolation can be used for *Nu* number between endpoints of the angle range.

Therefore, the combined correlation **A (*Ra*,φ)** that includes dependences on *Ra* number and slat angle, φ can be expressed as:

For slat angles: $0 \le \varphi \le \pi/4$ ($0^o \le \varphi \le 45^o$):

$$Nu = 1 + \left(-119.52 + 35.52 \cdot \ln\left(Ra\right) - 3.39 \cdot \ln^2\left(Ra\right) + 0.109 \cdot \ln^3\left(Ra\right)\right) \cdot \cos\left(1.43 \cdot \varphi\right) \quad (4)$$

For slat angle: φ = π/2 (90°)

$$Nu = 0.4586 + 0.06565 \cdot \ln\left(Ra\right) \quad (5)$$

For intermediate angles in the range from π/4 to π/2 ($45^o < \varphi < 90^o$), the linear interpolation should be used between endpoints of equations (4) and (5).

$$Nu = A(Ra,90°) + (A(Ra,45°) - A(Ra,90°)) \cdot \frac{(90° - \varphi)}{45°} \quad (6)$$

Set of curves are plotted in Figure 10 using correlations (4) to (6) for blind plates angles: 0° , 30°, 45° , 60° and 90° and they are compared with modeling results. It is evident that the agreement is very good.

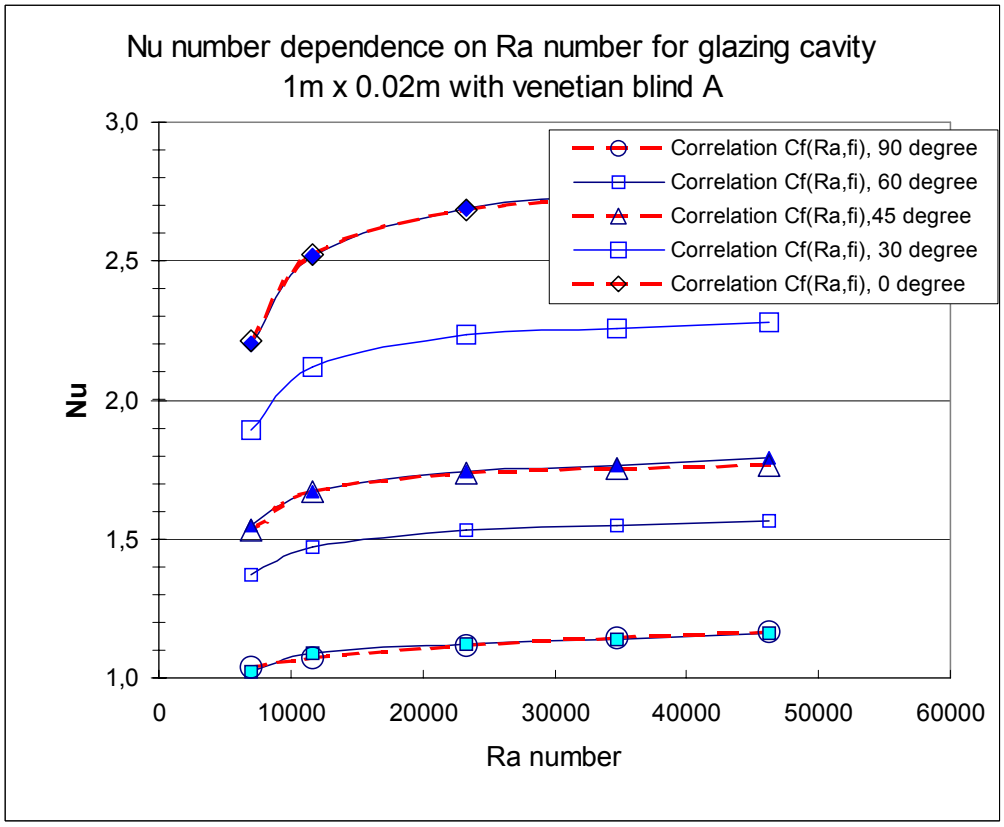

Figure 10. Comparison Between Heat Transfer Correlations and Computer Modeling Results for Blind Slat Angles: 0° , 30°, 45° , 60° and 90°.

6. REFERENCES

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