



National Fenestration Rating Council

REQUEST FOR PROPOSAL

Date: June 25, 2003

Title: Development of a Procedure for U-Factor Rating of Domed Skylights

Due Date: August 29th, 2003.

All bidders shall submit two copies of all bid proposals and shall be received by the NFRC office on or before the due date 5:00 pm (Eastern Time), at the address mentioned below:

National Fenestration Rating Council

8484 Georgia Avenue, Suite 320

Silver Spring, Maryland 22091

BACKGROUND:

Currently NFRC has a procedure to rate “flat” roof fenestration products, also known as skylights, at vertical orientation. “Flat” in this context means, “flat glazing system installed in a skylight frame”. Projections that result from the way the skylights are installed in roofs, which are mostly due to its framing members, require the use of detailed radiation model available in THERM computer program. This has enabled that good number of skylights validate when compared to testing results at vertical orientation. However, classes of fenestration products called domed skylights don’t have flat glazing systems, or parallel glazing lites and their thermal performance cannot be simulated. The new NFRC 100-2001 procedure specifies that all skylights need to be rated at an angle of 20°, and therefore domed skylights will have to be rated at that angle too. NFRC testing procedure NFRC 102-2001 does not have provision for testing at an angle other than vertical and there is no laboratory in United States that can perform commercial testing of products sloped at an angle. For these reasons, domed skylights cannot be tested either and no rating for them can be obtained. While the methodology for simulating “flat” skylights at a slope exists, it is not clear how that methodology can be extended to non-standard products.

OBJECTIVES:

The objectives of this project are to develop methods and procedures to simulate and validate domed skylights for their nighttime thermal performance. It is believed that two areas are especially affected, 1) convective heat transfer inside the irregularly shaped dome cavity or cavities, depending on the number of glazing layers, and 2) indoor surface convective heat transfer, occurring on the

glazing and frame surfaces. Due to implementation of detailed radiation model in THERM, this aspect of heat transfer does not need to be further investigated at this time. Further developments in 3-D heat transfer modeling procedures may necessitate re-opening of this issue, but for now it is assumed that 2-D radiation heat transfer has been fully accounted for.

The simulation methodology will need to include vertical orientation and 20° slopes for both cavity and indoor surfaces convective heat transfer. Correlations shall be developed that account for different environmental conditions, width and height of the domed skylights and ratio of highest to lowest width of the cavity.

SCOPE:

This research project needs to account for all major classes and types of domed skylights, so first task needs to be the identification of typical domed skylights. Framing is not believed to have major impact on convective heat transfer either in glazing cavity or on indoor surfaces, but it is recommended to look at extremes in conductivity for some typical framing projections to determine if there is a need for adjustment for the frame type.

Cavity Convective Heat Transfer: Based on the selection of typical domed skylight systems, representative geometries of glazing cavities will need to be developed, so that an isolated investigation of glazing cavity convective heat transfer can be undertaken. Based on the set of typical boundary conditions, expected range of temperatures on the surfaces of glazing cavities should be developed so that standard investigation of a convective heat transfer in irregularly shaped cavity, subject to temperature boundary conditions on its sides and adiabatic boundary conditions on cavity ends, can be defined (Rohsenow et al 1998, Kakac et al, 1987). This approach allows the development of non-dimensional setup of the problem where non-dimensional convective heat transfer rates, as expressed by Nusselt number, Nu , can be evaluated as a function of non-dimensional natural convection parameter Raleigh number, Ra , average cavity aspect ratio, A , and ratio of largest to smallest width in a single glazing cavity, X .

Natural convection should be investigated using appropriate numerical model for solving 2-D Navier-Stokes momentum equations, continuity equation and energy equation. Applicability of the numerical model shall be demonstrated by validating the model against benchmark solutions to similar geometrical and heat transfer setups. If it is necessary to apply turbulence model, it should be demonstrated that the proposed turbulence model is appropriate for this problem. It will also be necessary to determine the most suitable numerical grid or mesh to ensure quality results. Typically, mesh is successfully refined by doubling the number of nodes, until final results don't appreciably change. Theoretical analysis and/or other studies of similar scope could also be used to recommend the optimal mesh.

Matrix of geometries, Ra , A , and X should be established based on the above considerations and resulting average Nu should be recorded for each numerical run. Mesh densities, velocity vectors, streamline contours, temperature contours, and other important solution indicators should be documented for typical cross sections and included in a report.

It is recommended to first perform analysis for vertical cavity configurations, where the reference plane in the case of the curved glazing cavity should be defined by the line connecting middle points on the sides of cavity ends. It is also advisable to review results for any signs of errors or problems and to first attempt to develop preliminary set of correlations for Nu as a function of Ra , A , and X , before proceeding with modeling sloped configurations. After preliminary results are verified and completed for vertical configurations, run the same set of cavities in sloped orientation.

Convective Heat Transfer on Indoor Surfaces: The natural convection over the indoor surfaces of a domed skylight can be modeled as a natural convection over the curved plate held at constant temperature. Based on the typical geometries, range of surface curvatures and heights should be established as well as range of surface temperatures, expressed in terms of Ra .

It is very likely that the numerical model for glazing cavities, will be appropriate for this part of the problem, because both areas are subject to natural convection heat transfer. However, and especially if it becomes necessary to apply turbulence models, it is recommended to perform validation study to determine the suitability of the proposed numerical model. Best choice is to search for a benchmark model that incorporates similar geometries and boundary conditions and to validate results against that model. Choice of numerical scheme, selection of turbulence model, as appropriate, numerical mesh, etc. should be well documented and explained.

For the matrix of typical geometries and boundary conditions, run the numerical model and record average Nu for each run. As with glazing cavities, document for each typical case, characteristic solution variables, like velocity vectors, streamline contours, temperature contours, etc.

Because the framing geometry may play important role in convective heat transfer on the indoor surface, some typical, but simplified, frame geometries should be included in modeling. It is also advisable to consider studying natural convection heat transfer on indoor surfaces of domed skylight as they would be installed in a hot box, effectively creating long and relatively narrow channel, rather than being subjected to more conventional immersed plate in an infinite fluid medium. This will produce surface heat transfer rates that will better validate against hot box test results.

As with glazing cavities, first run vertical configurations, creating vertical plane in a similar manner as with glazing cavities, except that in this case, just two end points of the indoor surface need to be connected to form a reference plane. After the completion of all vertical configurations, preliminary correlations for Nu , as a function of Ra , height and curvature should be developed and verified. Upon the completion of this phase, the remaining configurations at a slope angle of 20° should be run and average Nu recorded.

After all of numerical simulations are completed, and preliminary correlations are reviewed, the final set of correlations should be developed. These correlations should be applied to selected realistic products and their performance compared to tested results at vertical configurations. After verifying that results agree within the limits of 10%, these same products should be modeled at the slope of 20° and results compared to results from vertical configurations.

REFERENCES:

- Branchaud, T.; Curcija, D.; and Goss W.P. 1998. "Local Heat Transfer in Open Frame Cavities of Fenestration Systems." *Thermal Performance of Building Envelopes VII*, Clearwater, FL. December, 1998.
- Curcija, D.; Zhao, Y.; and Goss, W.P. 1998. "The Effect of Realistic Boundary Conditions in Computer Modeling of Condensation Resistance for Fenestration Systems." *Thermal Performance of Building Envelopes VII*, Clearwater, FL. December, 1998.
- Griffith, B.; Curcija, D.; Turler, D.; and Arasteh, D. 1998. "Improving Computer Simulations of Heat Transfer For Projecting Fenestration Products: Using Radiation View Factor Models." *ASHRAE Transactions*, Vol. 104, Pt. 1. January, 1998.
- Kakac, S.; Shah, R.K.; and Aung, W. 1987. *Handbook of Single-Phase Convective Heat Transfer*. John Wiley & Sons.
- NFRC. 2002a. "NFRC 100: Procedure for Determining Fenestration Products U-factors." National Fenestration Rating Council, Silver Spring, MD. January 2002.
- NFRC. 2002b. "NFRC 102: Test Procedure for Measuring the Steady-State Thermal Transmittance of Fenestration Systems." National Fenestration Rating Council, Silver Spring, MD. January, 2002.
- Power, J.P.; Curcija, D.; and Goss, W.P. 1998. "A Comparison Between Two-Dimensional Laminar and Turbulent Flow Heat Transfer Models with Experimental Results for Transition Regime Condition in Tall Glazing Cavities." *Thermal Performance of Building Envelopes VII*, Clearwater, FL. December, 1998.
- Rohsenow, W.M.; Hartnett, J.P.; and Cho, Y.I. *Handbook of Heat Transfer*. McGraw Hill, New York.
- Zhao, Y.; Curcija, D.; and Goss, W.P. 1997. "A New Set of Correlations for Predicting Convective Heat Transfer in Fenestration Glazing Cavities Based on Computer Simulations Using Finite Element Method." CLIMA 2000 conference in Brussels, Belgium. September 1997.
- Zhao, Y.; Curcija, D.; and Goss, W.P. 1997. "Prediction of the Multicellular Flow Regime of Natural Convection in Fenestration Glazing Cavities." *ASHRAE Transactions*, Vol. 103, Pt. 1. January, 1997.
- Zhao, Y.; Curcija, D.; and Goss, W.P. 1998. "Improved Heat Transfer Correlations For Quantifying Laminar Natural Convection Across Fenestration Glazing Cavities." *Thermal Performance of Building Envelopes VII*, Clearwater, FL. December, 1998.
- Zhao, Y.; Curcija, D.; and Goss, W.P. 1999. "Convective Heat Transfer Correlations for Fenestration Glazing Cavities: A Review." *ASHRAE Transactions*, Vol. 105, Pt. 2. June, 1999.

DELIVERABLES:

Final report including correlations suitable for implementation in NFRC program shall be produced at the end of the project. Periodic progress reports should be given at NFRC task group and annual

membership meetings, until the project is completed. Two technical papers containing results of this research shall be produced at the minimum. One technical paper should be dealing with glazing cavities, while the other should be dealing with the indoor surface heat transfer.

ESTIMATED DURATION:

Final results and report shall be produced 18 months from the start of the project.

SOLE SOURCING:

This project need not be sole sourced.

TERMS:

Any prospective bidder shall submit a proposal that identifies the total cost of performing all the requirements as documented in this RFP, which shall include individual quotations for Task 2 and a combination of Tasks 3 and 4, if bidding all three. Any terms of payment shall also be outlined in the proposal. A schedule which outlines all tasks of the RFP shall be included with the bid submittal, including all associated dates and/or times.

Additional Resources Being Requested from NFRC:

None.

NFRC Staff contact:

The NFRC staff contact for the project is Bipin V. Shah, NFRC, Georgia Avenue, suite 320, Silver Spring, Maryland 20910. Phone: (301) 589-1776, Facsimile: (301) 589-3884.

Resources Being Sought from Sources Other Than NFRC:

None

