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:

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

November 18, 2005

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1 Summary of Activities

Our activities in this project took place in three main areas:

- Literature review of publications with relevance to a heat transfer in domed skylights. The brief review is given in Section 2;

- Development of three-dimensional model of a domed skylight glazing cavity. The description and the basic parameters, including the example of the model are given in Section 3;

- Contacts with the manufacturers for the purpose of a selecting representative domed skylights and acquiring a domed skylight sample that we are planning to use for tests.

2 Literature Review

There are currently very limited numerical or experimental studies on convection heat transfer in curvilinear spaces with varying cavity width between glazing layers.

Laouadi and Atif [1] completed a numerical study on the heat transfer by steady-state laminar natural convection within multi-layer domes with uniform spacing. Theses models assumed heating from the above. They were able to develop correlations for heat transfer as a function of both the dome shape and the gap spacing between the layers. They define the term, δ as the dimensionless gap spacing between dome layers. By performing numerical analysis of both low profile and fully hemispherical domes both with various values of δ, they were able to reach the following conclusions: (1) Convection heat transfer is more that 10% higher for hemispherical domes as compared to low profile domes with small values of δ (<0.1) and (2) convection heat transfer is more than 100% higher for hemispherical domes as compared to low profile domes with large values of δ (>0.3). These results are related to the flow patterns they observed in this analysis. For fully hemispheric domes, the flow patters were consistently single cell for all values of δ. However, for low profile domes, large gap spaces produced two cells. Finally, the research completed also suggests the existence of a critical gap space for each dome analyzed. The convection heat transfer increases to a maximum at this critical value of δ and then decreases upon further increases the gap spacing.
Also relevant are the assumptions, boundary conditions, and modeling techniques employed by Laouadi and Atif [1]. The primary numerical assumptions employed are as follows: the fluid is incompressible, the buoyancy-driven flow within the dome gap is laminar, the physical properties of the fluid are constant except for density, and fluid density is given by the Boussinesq's approximation. The boundary conditions assume no-slip and uniform temperature conditions at the dome walls. Furthermore, symmetry and adiabatic conditions can be employed at the axis of revolution and the edges respectively. Finally, most relevant to the current study the observation made by Lauoadi and Atif [1] with regards to the case when the interior dome wall is hotter than the exterior. This case, which was not the major focus of their research, yielded unsteady, periodic flow, particularly for small values of the gap spacing.

The results of numerical modeling were compared to numerical research of Garg [2] and to correlation developed by Raithby and Hollands [3], in which experimental data of Bishop [4] was used. The results of Laouadi and Atif [1] are in good agreement with numerical results obtained by Garg [2]. However only horizontal located domes models were investigated in considered study [1], i.e. without an inclination to a horizontal surface.

3 Basic Parameters and Geometrical Consideration for Domed Skylights

Figure 1 shows a simplified view of a domed skylight glazing system with uniform spacing between two concentric spheres. The basic geometrical parameters (dimensions and radii) as defined for a glazing cavity are:

- Ri and Ro – inner and outer radii of spheres;
- H – height of glazing cavity;
- *L* – gap spacing between spherical surfaces of glazing cavity;
- Aspect Ratio $A_L = H : L$;
- Aspect Ratio $A_H = H : Ri$.

The parameter $A_H = 1$ for a fully hemispherical domed skylight, $0 < A_H < 1$ for low profile domed skylights and $A_H = 0$ for concentric disks.
Domed skylights often incorporate non-uniform gap widths. These gaps will be accounted for through the use of different radii of each dome. Specific configurations will be derived from the actual domed skylight systems and will be presented in the next progress report.

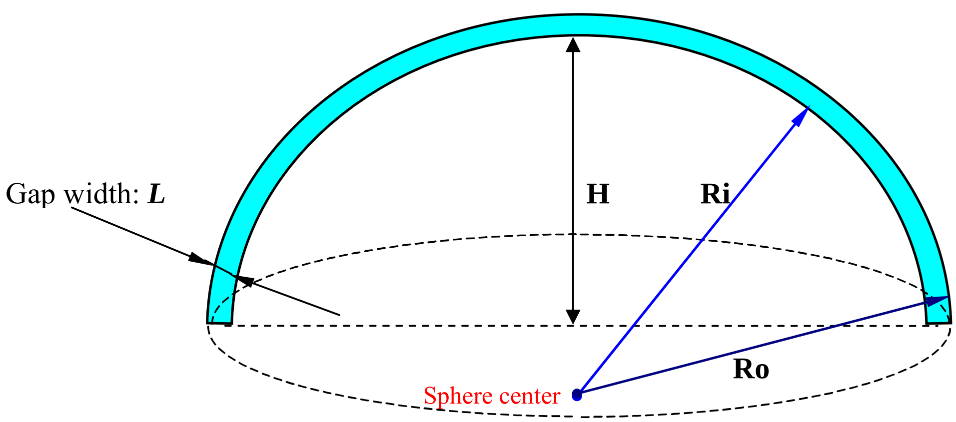

Figure 1. Schematic of domed skylight glazing system.

Table 1 presents the preliminary selected domed skylight parameters for 3-D heat transfer simulation in the range of Raleigh number from Ra = 4000 to Ra = 80000.

Table 1. Matrix of glazing cavity configurations and sizes.

Inner radius Ri = 0.8 m								**Inner radius Ri = 1.2 m**							
$A_H = 1$		$A_H = 1$		$A_H = 0.5$		$A_H = 0.5$		$A_H = 1$		$A_H = 1$		$A_H = 0.5$		$A_H = 0.5$	
L = 16 mm		L = 25 mm		L = 16 mm		L = 25 mm		L = 16 mm		L = 25 mm		L = 16 mm		L = 25mm	
Tilt angle from horizontal direction															
20°	**90°**	**20°**	**90°**	**20°**	**90°**	**20°**	**90°**	**20°**	**90°**	**20°**	**90°**	**20°**	**90°**	**20°**	**90°**

A preliminary 3-D model of the double glazed hemispherical dome has been developed and initial mesh studies have been started. The diameter of the dome is D = 0.6m and gap spacing is L = 0.025m. Figure 2 shows 3-D mesh model of fully hemispherical domed skylight glazing cavity created from T-Grid elements (Fluent software [5]). The details of boundary layer mesh within glazing cavity model are depicted in Figure 3.

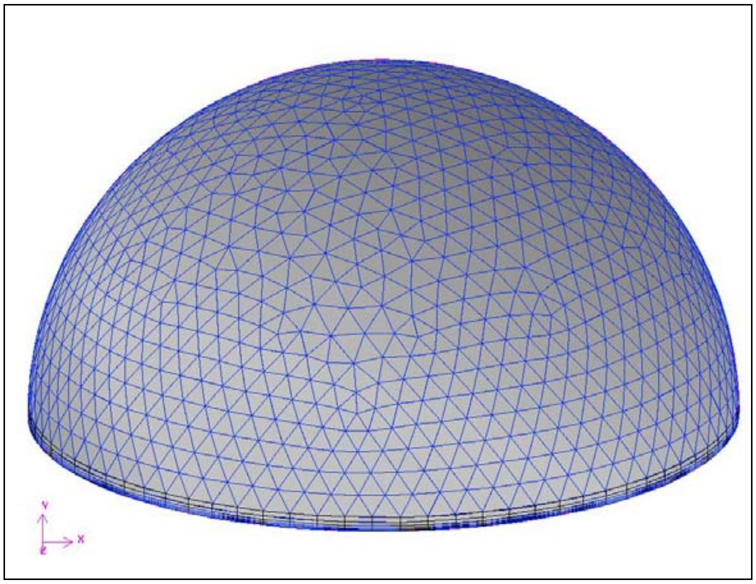

Figure 2. T-Grid mesh model of the hemispherical glazing cavity of a domed skylight. Outer diameter is 0.6 m; glazing gap spacing is 0.025 m.

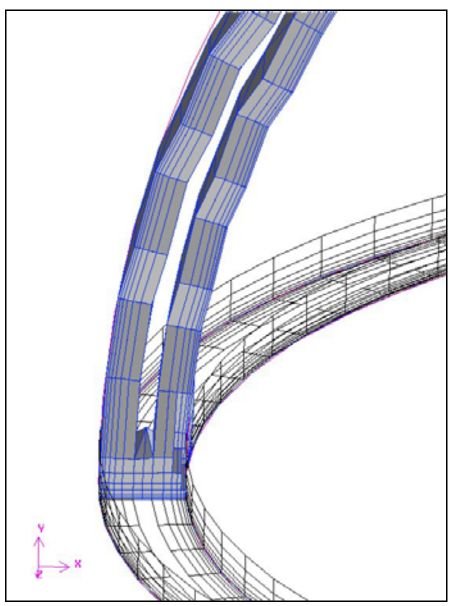

Figure 3. The boundary layer structure of 3-D glazing cavity model.

4 References

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5. FDI 2000. “Gambit 2.0 Users and Reference Manual”. Fluid Dynamics International, Fluid Dynamics Analysis Package Revision 1.3.2, Evanston, IL.

6. FDI 2003. FLUENT 6.5. Users and Reference Manual. Fluid Dynamics International, Fluid Dynamics Analysis Package. Fluent Inc.