5.0 MODEL VALIDATION

5.1 General Validations

Steady-state results were used to verify the performance of the model. In this modeling, the base of the glass dome was maintained at a constant temperature and the glass was exposed to nighttime conditions as described previously. The ALGOR results for a convection coefficient h of 15 W/m^{2}K is shown in Figure 5.1. The dome temperature is characterized as a gradient varying from 0°C at the base to a minimum of –6.6°C at the vertex.

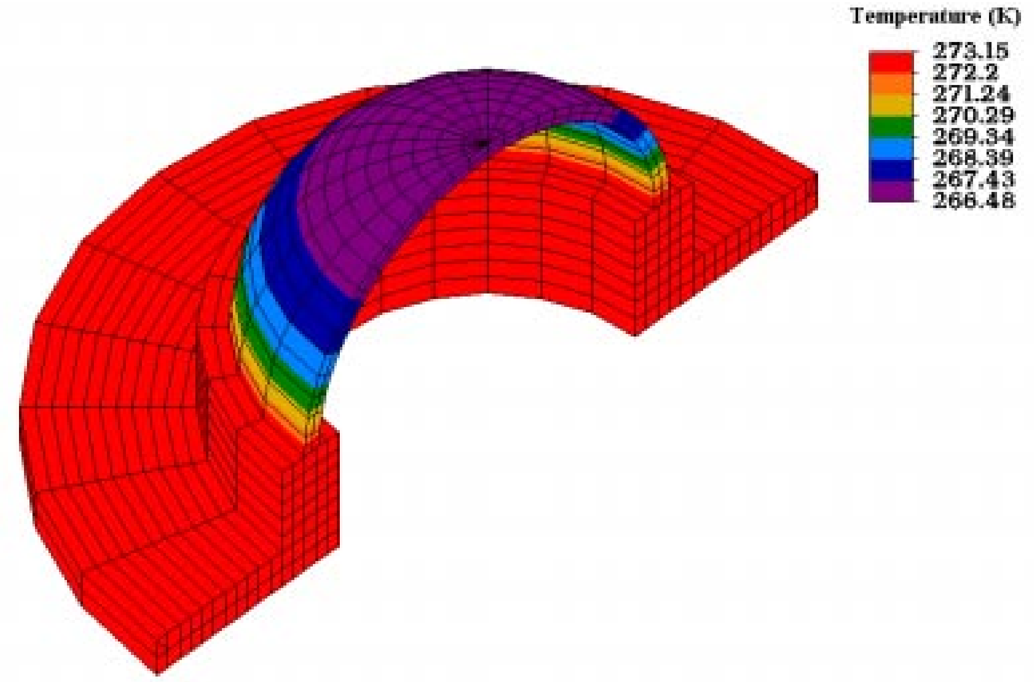

Figure 5.1 ALGOR steady-state temperature results for nighttime conditions

A parametric study verifies the sensitivity of the model to geometric and physical parameters. Two parameters of the steady-state model are individually changed to determine the response of the model results. The thermal conductivity was increased in order to increase the conductive heat transfer from the glass base through the dome. This is similar to the instrument manufacturer’s attempt to increase the conduction of the dome material to reduce the magnitude of the gradient. The glass model, which has a thermal conductivity of 1.4 W/mK, is compared to a quartz model with thermal conductivities of 4.0 W/mK and 8.0 W/mK, and a diamond model with a thermal conductivity of 600 W/mK.

Increasing the thermal conductivity improves the thermal connection between the dome vertex and the fixed temperature glass base, which decreases the magnitude of the gradient. The decrease of the gradient is relative, however. In the absence of winds, a glass (k = 1.4 W/mK) dome will have a 14°C gradient, whereas the first quartz dome (k = 4.0 W/mK) will have only a 7°C gradient, a reduction of 50 percent for a 186 percent increase in conductivity. The second quartz dome (k = 8.0 W/mK) will only have a 4°C gradient, a reduction of 43 percent for a 200 percent increase in conductivity. For very high values of thermal conductivity, such as with diamond (k = 600), the entire dome is in sufficient thermal contact with the base to yield a near-zero gradient. The model results are shown in Figure 5.2.

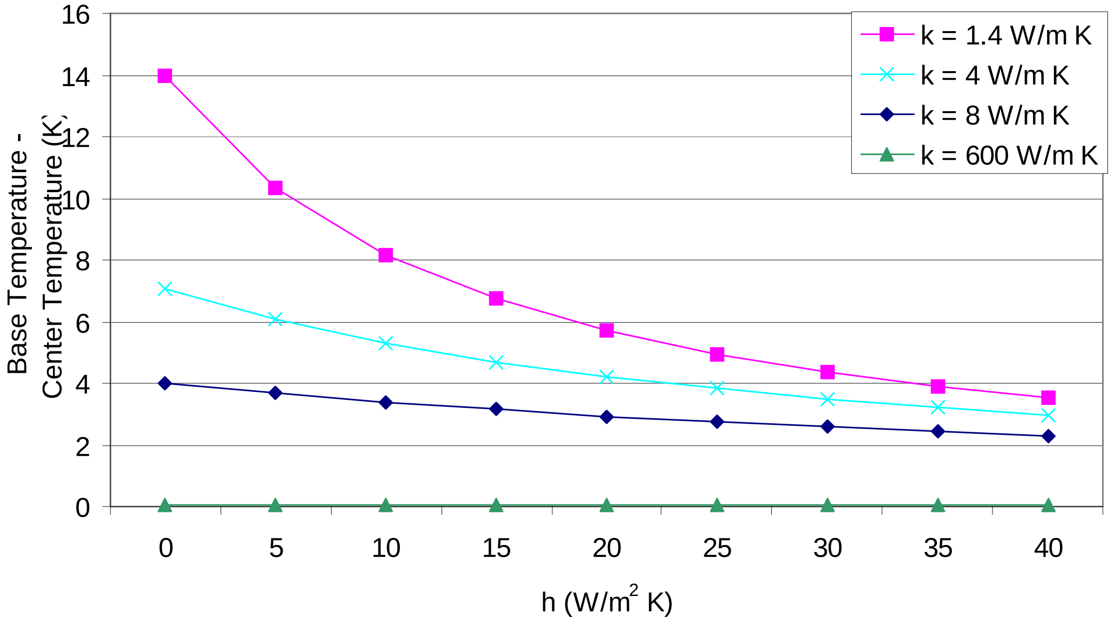

Figure 5.2 Effect of increased convection on the magnitude of the dome temperature spread for a 2-mm thick dome for a range of thermal conductivities

The other parameter variation was performed on the dome thickness. The thickness of the above domes is doubled from 2 mm to 4 mm, which increases conduction through the dome and further reduces the magnitude of the vertex-to-base gradient. This also increases the conductive heat transfer through the dome from the base.

The effect of the increase of dome thickness is also relative. For a given value of thermal conductivity, the increased thickness improves the thermal conduction from the dome vertex to the base. For lower values of conductivity, such as 1.4 or 4.0 W/mK, this is a significant improvement, but for higher values, such as with the diamond dome, the gradient cannot be much improved. The model results are shown in Figure 5.3.

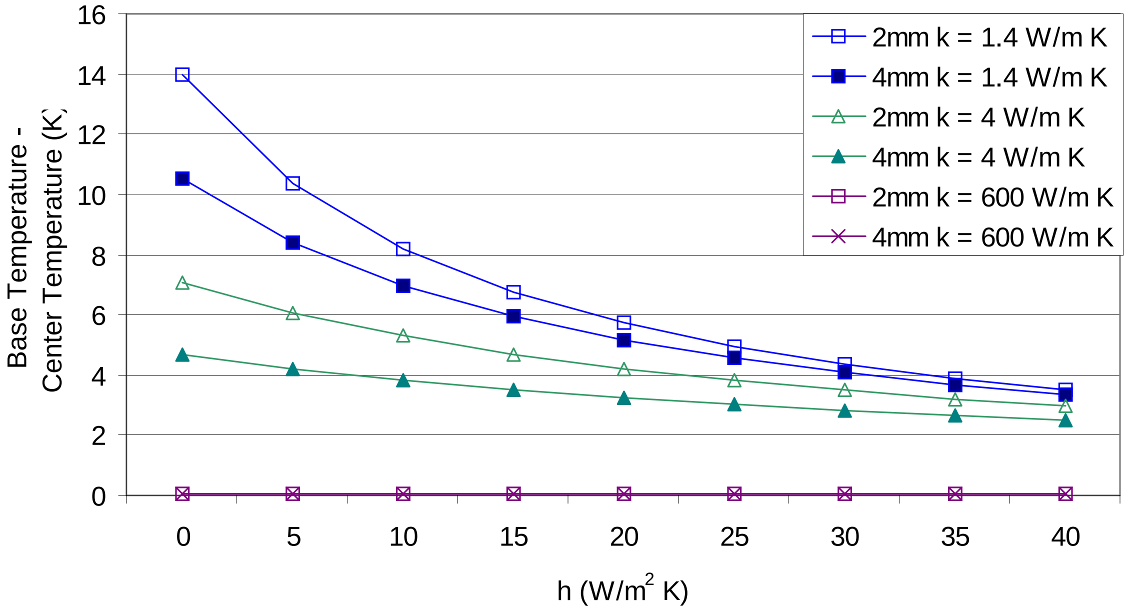

Figure 5.3 Effect of increased dome thickness on the magnitude of the dome temperature spread

5.2 **Comparison of Warming Model with Experiment**

The model for the warming experiment is run several times with different convective heat transfer coefficients in order to determine that which best represents actual conditions. The data from each of the four thermistors are compared to the temperature time history of the respective nodes in the finite element model for each value of h.

The warming experiments were performed on July 2 and July 7. The ambient conditions for each experiment were different so that a model was created to simulate each experiment. The experimental data are then compared with its respective experiment. By visual comparison of the results, the case corresponding to $h = 2\ W/m^2K$ emerges as the most appropriate representation of the actual convective conditions in the room. This value falls within a reasonable range for natural convection.

The transient model results for the July 2 experiment simulation are compared to the data for each of the four thermistors in Figures 5.4 through 5.7. The environmental conditions for the July 2 experiment are:

$T_{init} = 273.15$ K and $T_{ss} = 292.4$ K.

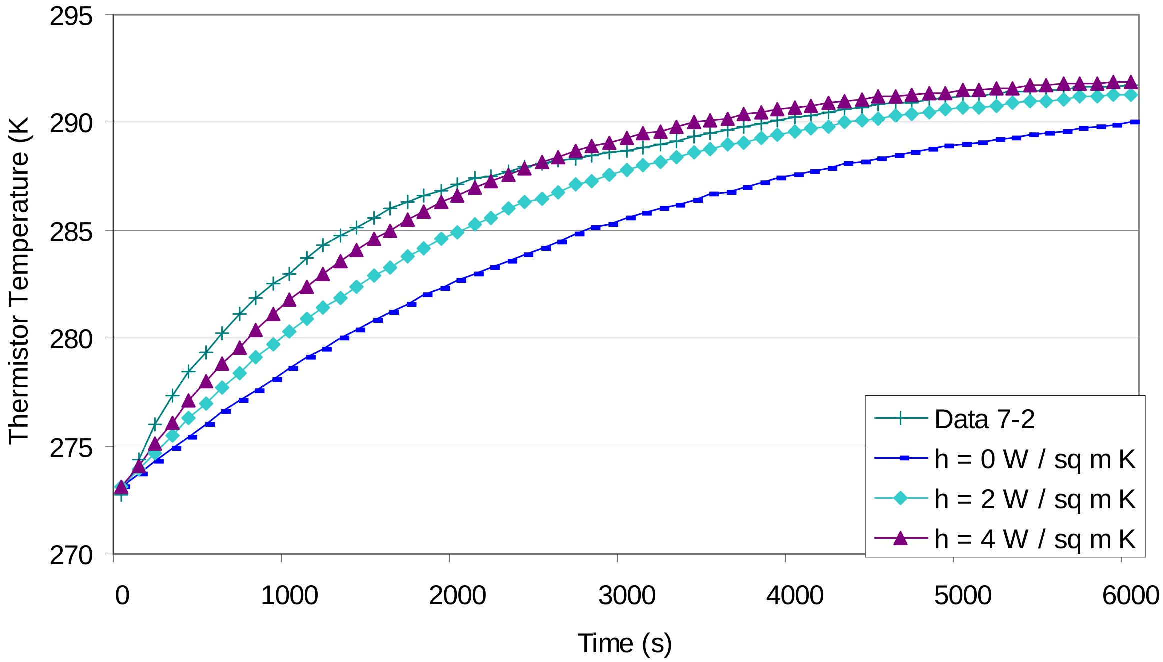

Figure 5.4 Transient time history of steel rim thermistor (T4) subjected to warming conditions (model and 7/2/99 experiment)

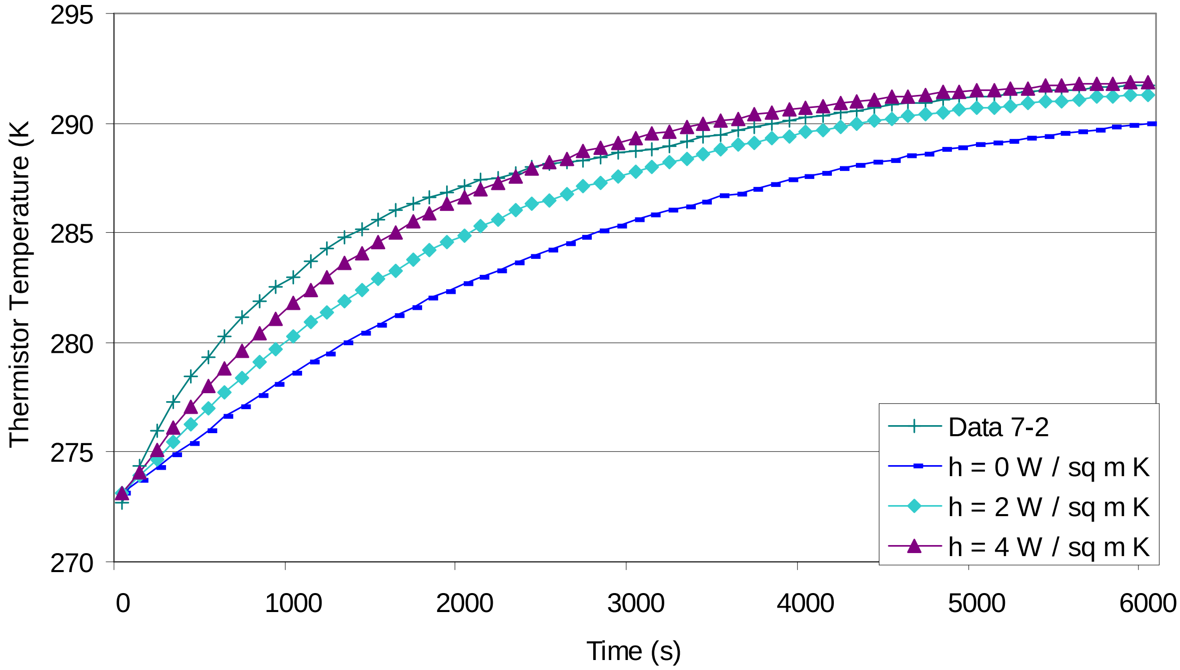

Figure 5.5 Transient time history of dome base thermistor (T3) subjected to warming conditions (model and 7/2/99 experiment)

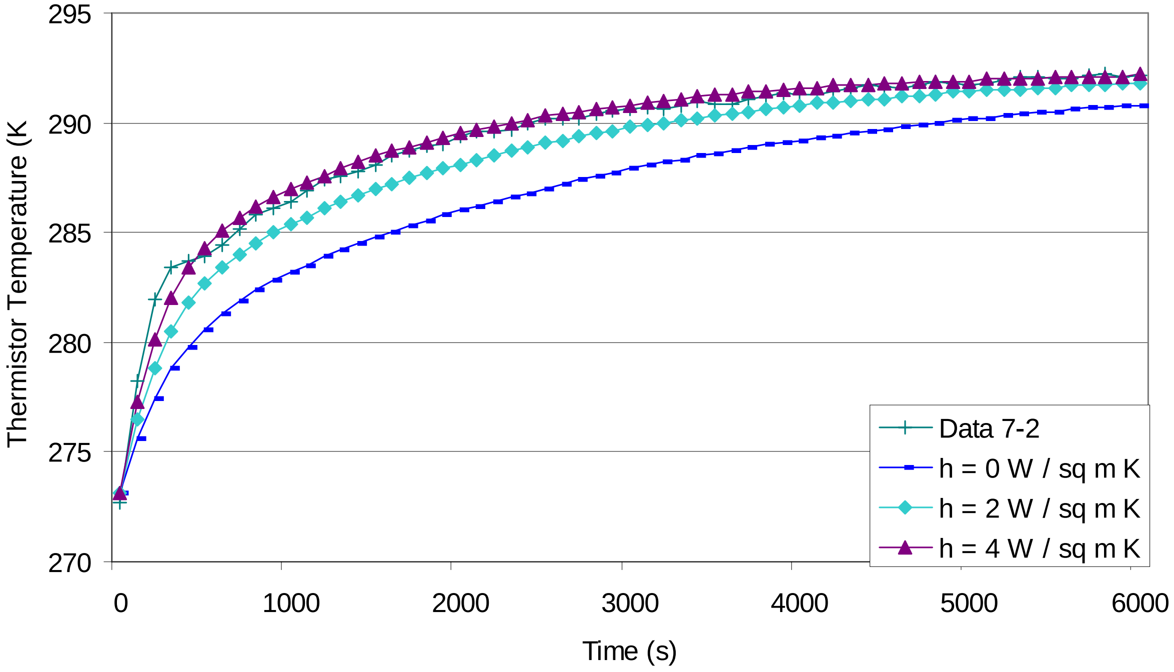

Figure 5.6 Transient time history of dome 45-deg thermistor (T2) subjected to warming conditions (model and 7/2/99 experiment)

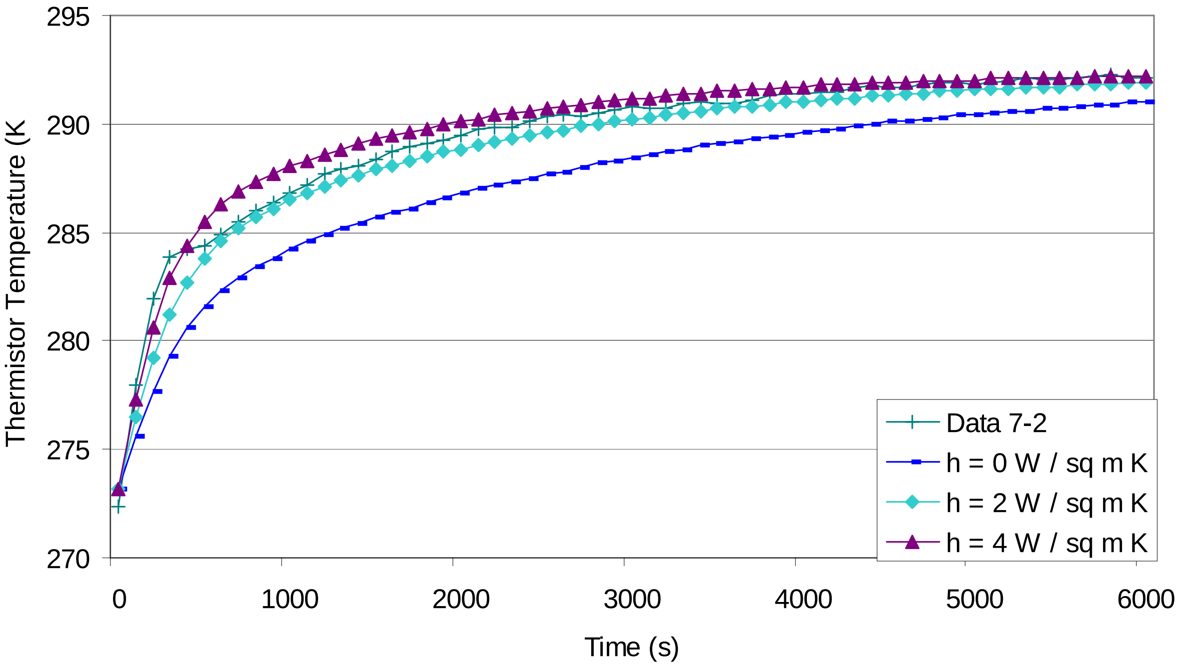

Figure 5.7 Transient time history of dome vertex thermistor (T1) subjected to warming conditions (model and 7/2/99 experiment)

The results for the simulation of the July 7 experiment are compared with data in Figures 5.8 through 5.11. The conditions for this experiment are:

T_{init} = 268.5 K and T_{ss} = 296.0 K.

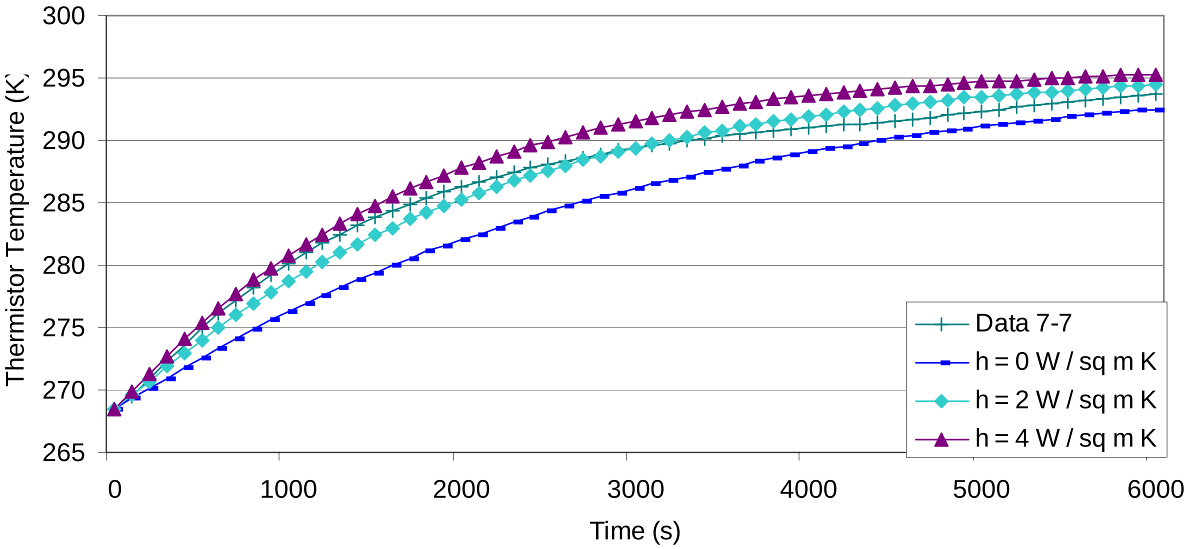

Figure 5.8 Transient time history of steel rim thermistor (T4) subjected to warming conditions (model and 7/7/99 experiment)

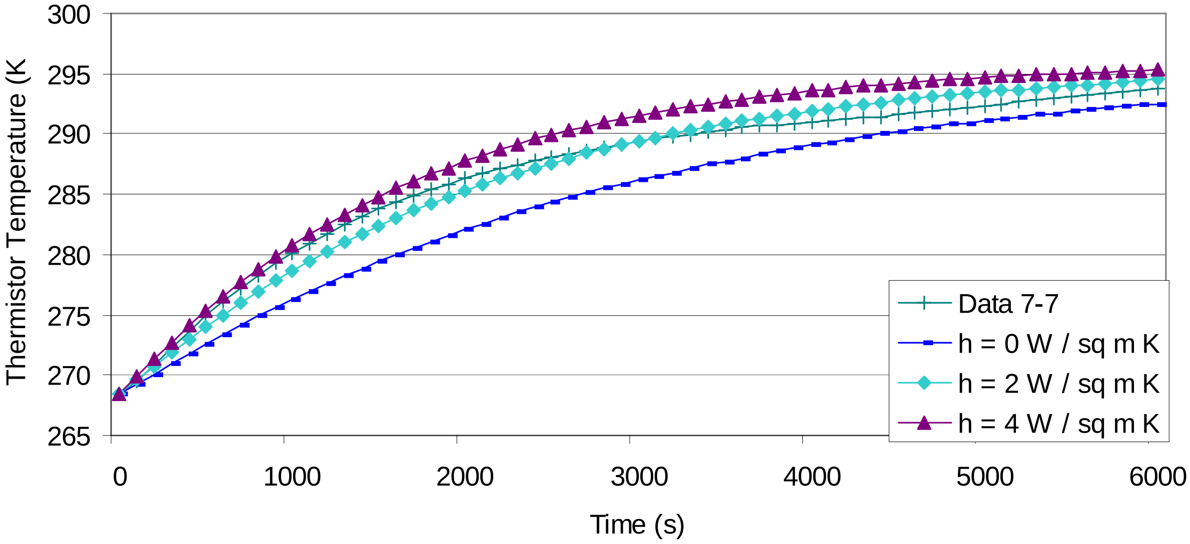

Figure 5.9 Transient time history of dome base thermistor (T3) subjected to warming conditions (model and 7/7/99 experiment)

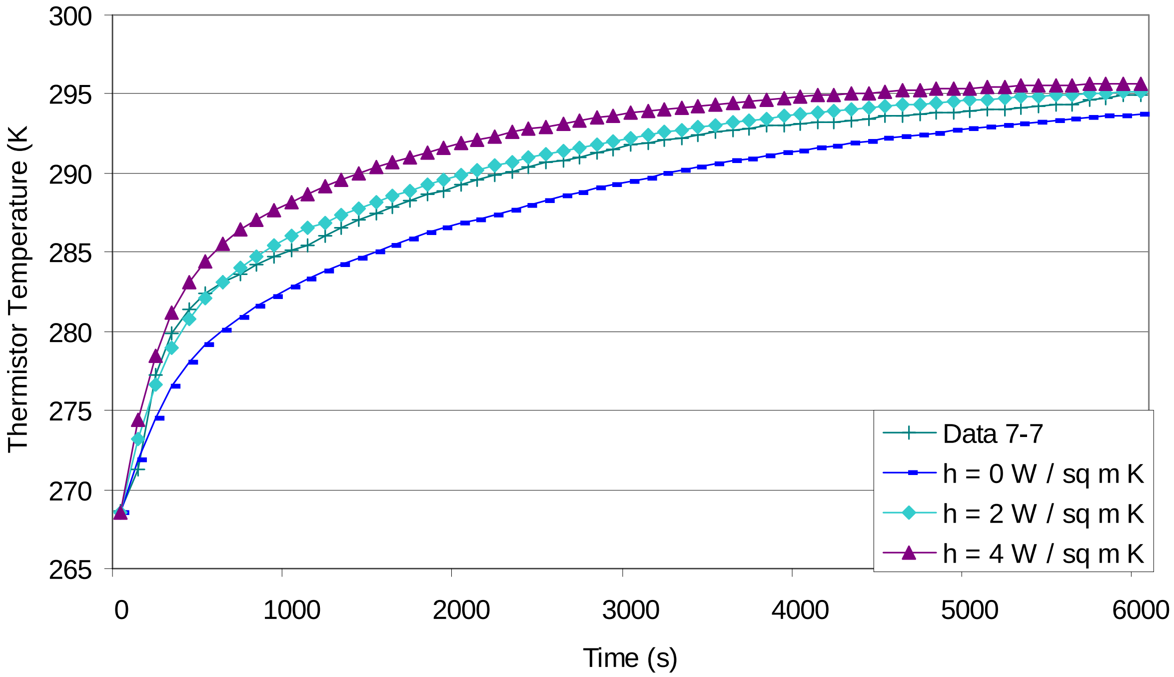

Figure 5.10 Transient time history of dome 45-deg thermistor (T2) subjected to warming conditions (model and 7/7/99 experiment)

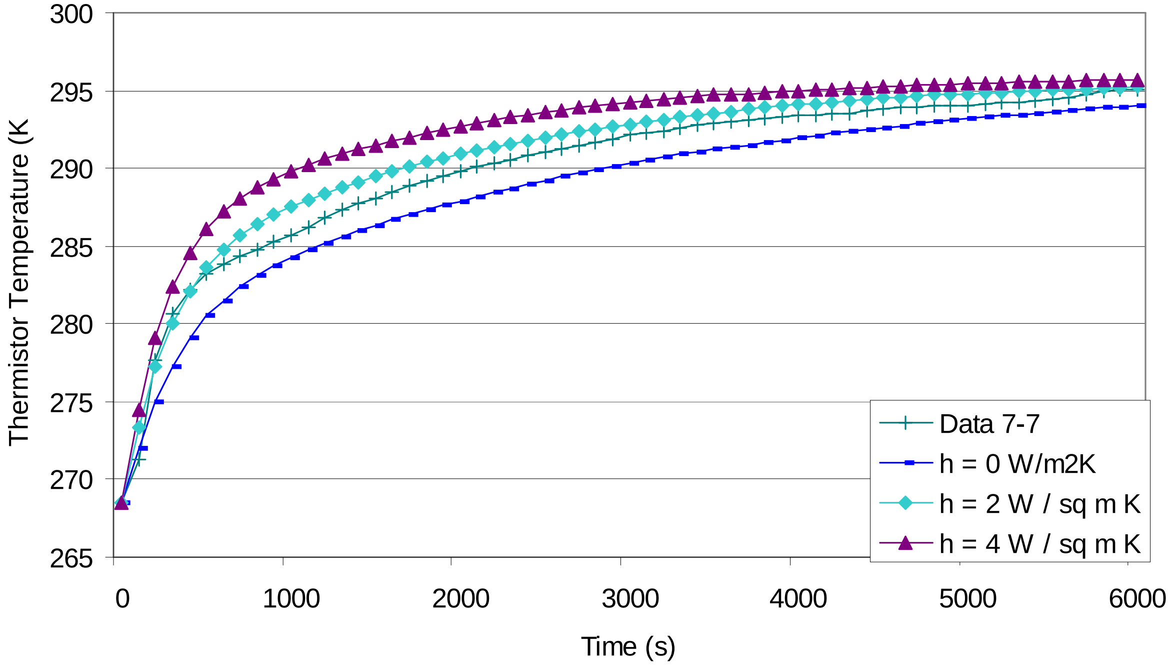

Figure 5.11 Transient time history of dome vertex thermistor (T1) subjected to warming conditions (model and 7/7/99 experiment)

A common characteristic of the warming data is a very rapid warming, followed by a period of slower cooling, and then a return to an asymptotic approach to equilibrium. This is caused by condensation occurring during the experiment. As the dome is removed from the cool, dry refrigerator and exposed to the warm, moist air of the room, condensation immediately forms on the dome, transferring latent energy to the dome and speeding up the warming. Following the condensation, the dome has a greater mass, which slows the warming. As the condensation evaporates, the temperatures resume a normal approach to steady-state conditions.

5.3 Comparison of Cooling Model with Experiment

The model for the cooling experiment is also run several times to determine which heat transfer coefficient best represents actual conditions. During the cooling experiment, the dome is isolated in the refrigerator, so the air circulation is less than that in the room during the warming experiments. The value for h is expected to be less than that selected for the warming experiments.

The cooling experiments were performed on June 30 and July 6. The ambient conditions for these experiments are very close, which allows a single model to simulate both experiments. For the cooling experiment, ambient conditions included the air and wall temperature, which is the steady-state temperature, and the freezer compartment radiative sink temperature, which is assumed to be 5°C below the air temperature.

Comparing model results and experimental data, it appears that a convective heat transfer coefficient of $h = 0.8\ W/m^2K$ is the most appropriate representation of the conditions in the refrigerator. This value falls within a reasonable range for natural convection.

The transient model results for the simulation of the experiment are compared to the data for each of the four thermistors in Figures 5.12 through 5.15. The environmental conditions for these experiments are:

$T_{init} = 292.4$ K, $T_{ss} = 269$ K, and $T_{icebox} = 264$ K.

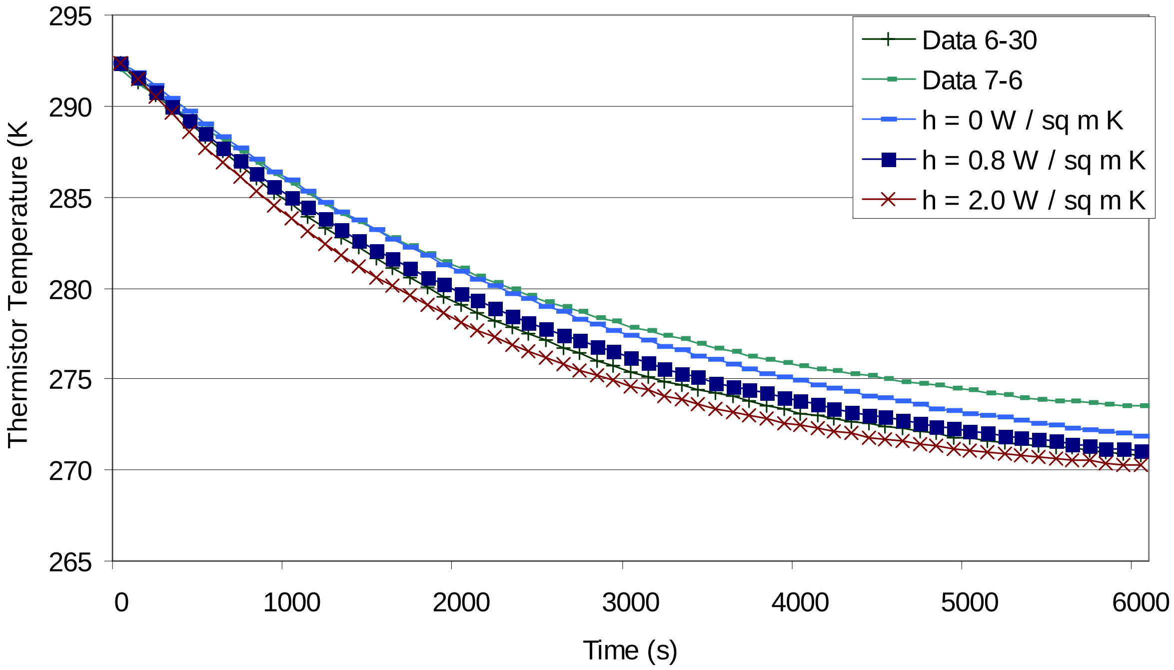

Figure 5.12 Transient time history of steel rim thermistor (T4) subjected to cooling conditions (model and experiment)

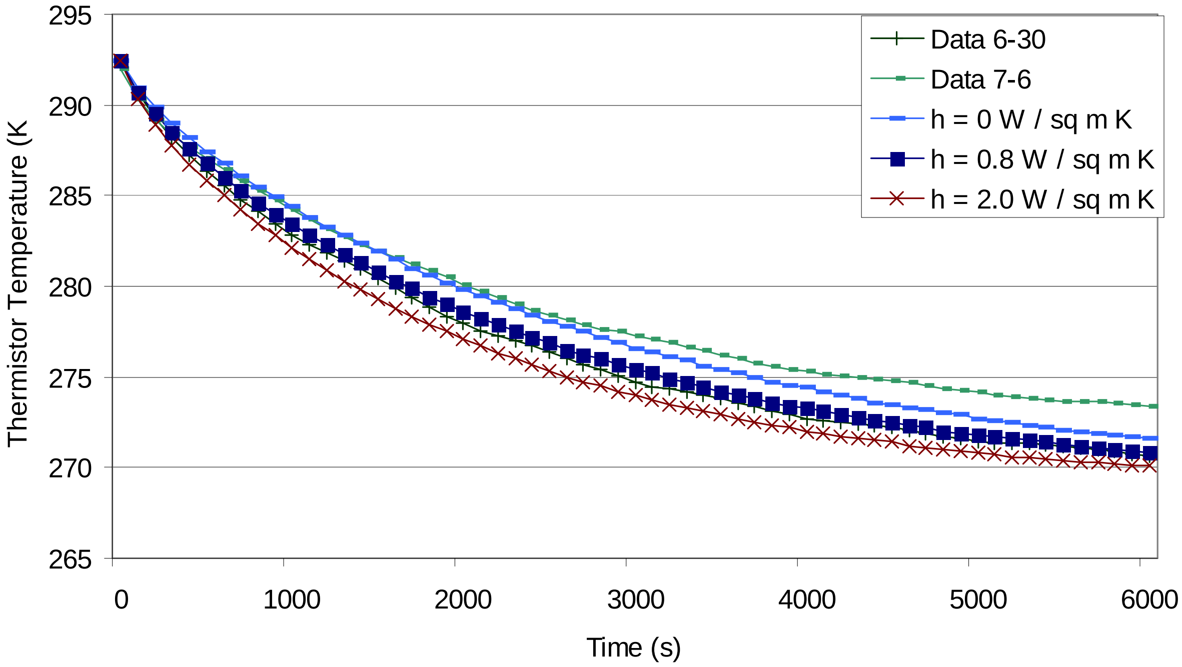

Figure 5.13 Transient time history of dome base thermistor (T3) subjected to cooling conditions (model and experiment)

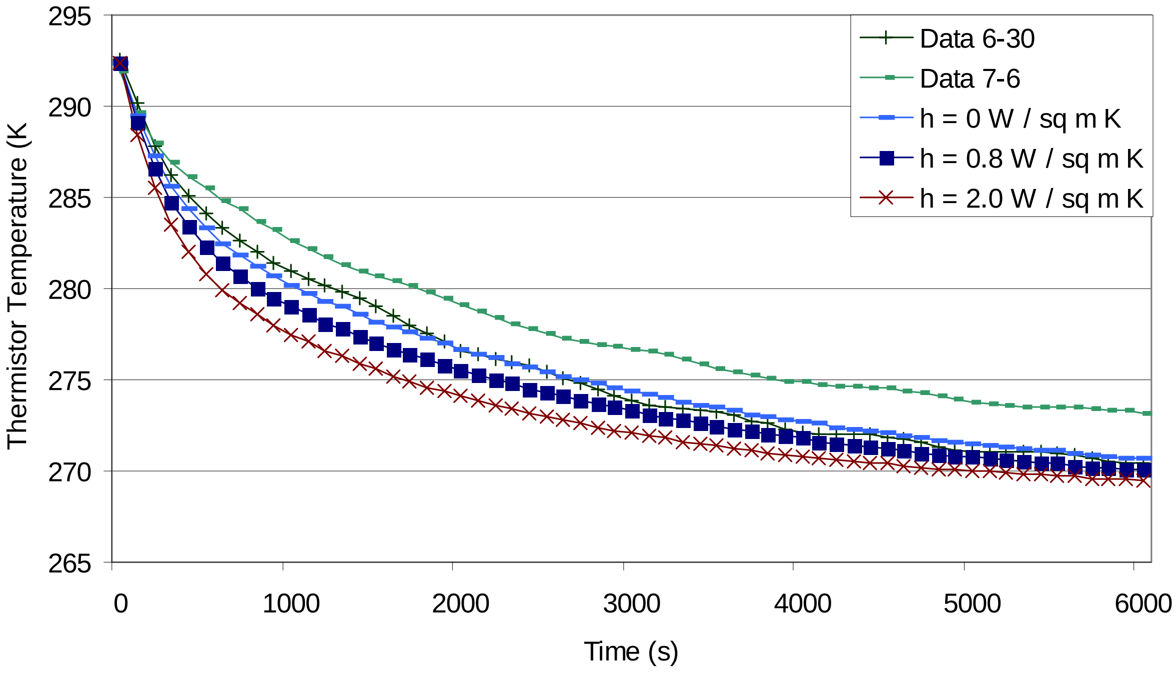

Figure 5.14 Transient time history of dome 45-deg thermistor (T2) subjected to cooling conditions (model and experiment)

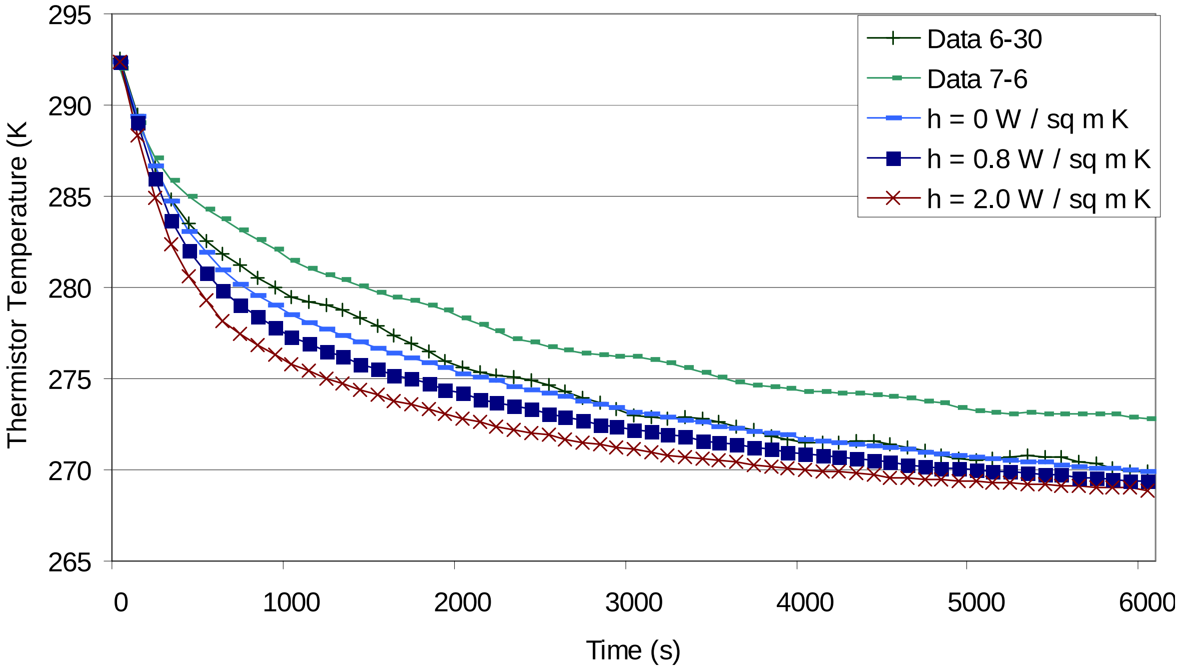

Figure 5.15 Transient time history of dome vertex thermistor (T1) subjected to cooling conditions (model and experiment)

A lower value of h has been selected for modeling the cooling experiment than for the warming experiment. It would seem that the condition of a warm body under cool air would induce greater natural convection than a cool body under warm air. However, natural convection will only occur in either case when the bouyant force of the warmer air is such to overcome the viscous forces resisting convection. It may be that the temperature differences involved do not carry a great enough bouyant force. In addition, the Raleigh number, a dimensionless parameter used to determine the extent of natural convection, is ambient temperature dependent. This would lead to greater heat transfer for warm air than for cool air.

The model developed in Chapter 5 is used in Chapter 6 to determine the thermal conditions of the dome subjected to nighttime conditions. Model results are also used to determine an ideal location for monitoring dome temperature in order to correct pyranometer measurements.