Summer Temperature Testing of Skylights with *Eastman* Specialty Copolyesters

Introduction

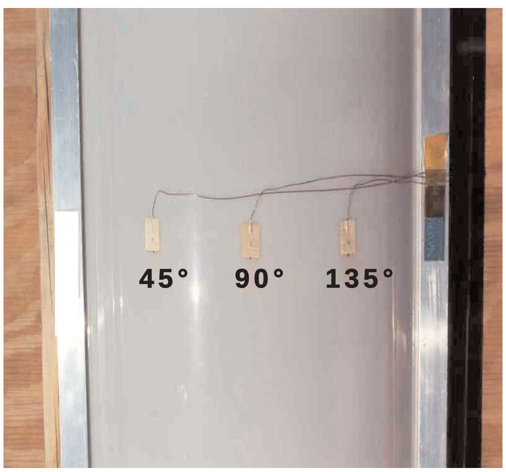
At the request of our customers and as a contribution to the architectural glazing industry, the Architectural Glazing Solutions team at *Eastman* Specialty Plastics conducted an experiment to understand the thermal characteristics of plastic-glazed skylights in high-temperature climates. Different dome tints and configurations were tested in this experiment. The results of the experiment help demonstrate how color or tint of glazing material may affect the service temperatures experienced by skylights in application. This information can be useful in plastic skylight design for calculation of expected thermal expansion and contraction considerations as well as in material selection of plastic glazed skylight units.

This paper also introduces concepts for additional thermal testing of plastic skylights including consideration of the effects of different frame colors, dome shapes and sizes, and glazing material. If you have further questions pertaining to this work, contact your *Eastman* Specialty Plastics Architectural Glazing Solution expert at www.architecturalglazing.com.

The following is a list of the colors, sizes, and designs of the skylights used for the experiment:

1. Clear 19" x 48" single dome skylight
2. White 19" x 48" single dome skylight
3. Bronze 19" x 48" single dome skylight
4. Clear-clear 24" x 48" double dome skylight

Figure 1: Thermocouple Positions



Background

A skylight temperature experiment was conducted over the course of an entire summer at the DSET outdoor testing facility in Phoenix, AZ. The experiment was part of ongoing research for plastic-glazed skylights utilizing *Eastman* specialty copolyesters. The main objective was to understand the heat gain characteristics experienced by the plastic skylight glazing in high-temperature climates.

Four skylight units made from three different colors of plastic glazing—clear, white, and bronze, were tested in this experiment. The skylights were of two different designs: single dome and double dome. All four skylights were produced with 3 mm (0.118") sheet made from *Eastman* specialty copolyesters.

Figure 2: Skylight Test Rig in Arizona

Thermocouples were attached to each dome (inner and outer surfaces) at 45°, 90°, and 135° with respect to ground level (see Figure 1). The positions were varied to account for the curved shape of the domes and the position of the sun at different times of the day. The 45° position thermocouple was placed in an Eastern facing direction, the 135° in a Western direction. The skylights were positioned flatwise on a solid wooden platform (Figure 2).

The manner in which the skylights were mounted created a "worst-case" scenario. The scenario being that heat was trapped below the domes with very limited ventilation. Later testing confirms this statement. In a "normally installed" skylight, it is expected that temperature conditions underneath the skylight would be much less extreme than the temperatures encountered in this experiment. In a typical living or working environment, the air beneath a skylight usually will have free air circulation, which was intentionally eliminated in this experiment.

It should be noted that the information collected in this experiment was obtained from skylights of similar dome shape and size. The comments in this report are based solely on the observation of the above conditions, end appearance of and Eastman's experience of the performance of sheet made from *Eastman* specialty copolyesters.

The Test Data

The highest measured ambient temperature reached in the summer was 44°C (112°F). This temperature was reached on both July 5th and August 22nd. A high ambient temperature did not necessarily result in a high temperature measurement on the plastic glazing. Radiative heat gain can significantly impact the temperature of the glazing material on a glazing product such as a skylight. For example, given two days with the same ambient temperature, a day with substantial cloud cover will greatly reduce skylight temperature readings due to the clouds' absorbtion of a portion of the available solar radiation. In this experiment, though the ambient temperatures on both July 5th and August 22nd were the same, the skylight temperature readings on July 5th were considerably less due to cloud cover. As a result, the discussion of this work will be focused solely on the data recorded from one day, August 22nd, the single day with the highest recorded glazing temperature readings. See Table 1.

Discussion and Recommendations

White and Clear Single Dome Skylights

Temperature curves for both the white and the clear skylights are shown in Figures 3 and 4 respectively. Note that the highest temperature recorded on the white dome was 61°C/141.8°F—averaging 7°F less than the clear dome temperature. The reflective nature of the white color helped to reduce the effects of radiative heating. The temperature difference between the clear and the white glazed domes is attributed to the additional solar radiation that passed through the clear dome and heated the wood surface below the skylight. In both cases, the glazing temperature was in excess of the ambient air as the heat from the wood platform (in the form of thermal radiation) was transferred to the inner portion of the skylight dome and resulted in increased temperature readings on the clear and white copolyester sheets. In both the clear and white tinted skylights, some heat at the outer surface plastic was lost via forced convection (wind) to the atmosphere. See Figure 5 for an illustration of the heat transfer phenomena.

Bronze Single Dome Skylight

The maximum temperature recorded on the bronze glazed dome was 79°C/174.2°F. The temperature curve is shown in Figure 6. It is well known that darker colors will absorb a significant amount of radiative heat. Up to this point of the discussion, the only difference among the three single-glazed skylights studied in this experiment was color. Hence, it is concluded that the temperature differential between the bronze vs. the clear and white single glazed domes was due to the additional solar radiation absorbed by the dark pigment in the plastic. Radiative heat gain increases the chance for thermal failure in plastic applications; however, despite the high temperature measurement, the bronze skylight in this experiment did not show any indications of thermal deformation.

As mentioned previously, the temperatures measured in this experiment were greater than the temperatures expected in an actual installed application. The air temperatures under any of the single domes are unknown, but it is likely that the temperatures were much higher than

Table 1: August 22nd Arizona Skylight Temperature Results

Skylight Prototype Temperatures	Daily Maximum Dome Temperature °C/°F[a]
White single dome	61/141.8
Clear single dome	67/152.6
Bronze single dome	79/174.2
Clear-clear double dome (outer dome)	68/154.4
Clear-clear double dome (inner dome)	81/177.8

[a]*Temperatures reported are five-minute averages.*

would be encountered in any commercial or residential building. Additional testing with dark-tinted skylights installed in buildings with and without climate control systems is therefore recommended.

It would be interesting to determine the effects of high radiative heat gain on plastic skylights of different shapes and different sizes. By increasing the size of the dome there will be higher load on the plastic at the frame, thus increasing the chances for thermal distortion. Varying the dome shape would likely cause different creep behaviors to be observed. The need for further testing is especially important, but not limited to, regions with high radiative indexes where radiative heat gain can be substantial.

Clear-Clear Double Dome Skylight

Double dome skylights come in a variety of configurations. Some different double dome skylight configurations might include:

- Inner and outer domes of different colors or tints.
- Inner and outer domes of varied sheet thicknesses.
- Inner and outer domes made from different materials.
- Inner and outer domes of different shapes or patterns.

For example, a double dome skylight unit could be produced from the same glazing material with both domes being of uniform thickness and color. Conversely, another skylight unit could be made from two different materials with the top dome made a clear color with a thickness of 4.5 mm, while the bottom dome could be made from a different material in a white/opal color with a 3 mm thickness. The skylight used in this test was a clear-clear double dome with the glazing being of uniform thickness, 3 mm (0.118").

Upon inspection of Table 1, one will see that the 67°C/152.6°F clear outer dome temperature matched, almost exactly, the 68°C/154.4°F temperature of the clear single dome. However, a disparity occurred with the temperature of the inner dome. A temperature of 81°C/177.8°F was measured on the inner dome, which was the highest single temperature recorded in any of the units during this experiment. The temperature curve for the double dome skylight is shown in Figure 7.

The temperature differential between the inner and outer dome layers is a result of an insulating effect of the multi-glazed system. In the case of the outer dome, heat can be lost by forced convection to the (cooler) ambient air and by radiation to the atmosphere; hence, a decreased outer dome temperature can be realized. Alternatively, in the case of the inner dome, hot air was trapped above and below the inner dome (free convection) resulting in less effective convective cooling of the glazing material. Thus, the inner dome was unable to lose heat to the outside air because the radiation was blocked by the upper dome and was effectively reflected back to the inner dome. An illustration of the heat transfer phenomena for the double dome skylight is shown in Figure 8.

Additional double dome temperature data is shown in Figure 9. The data in Figure 9 includes additional air temperature measurements from a thermocouple that was positioned between the wood platform and the inner dome. The data from the additional thermocouple clearly indicates there was significant heat gain between the wooden platform and the innermost glazing surface as mentioned earlier. The lack of ventilation between the wood platform and the innermost dome resulted in less effective convective cooling of the inner dome plastic.

It would be expected that the temperatures recorded on the lower dome would be drastically reduced had this skylight been in an actual installation. If the skylight was installed in a building, typical "room temperature" (78°F vs. the 141°F measured in the experiment) would increase the heat loss on the inner dome surface.

Further testing with climate control devices and actual installations is encouraged for double dome skylights. This experiment demonstrates how multiple glazing layers can improve the insulation properties of a glazing unit. Hence, double dome skylight designs are normally used when improved thermal efficiency is required.

In the case of this experiment, in regions where ambient air temperatures are very hot, it is reasonable to assume the air temperature below the installed skylight is climate-controlled. The climate controlled air would serve as free convection and would result in the inner glazing temperatures in application to be lower than those measured in this study.

Comments and Future Work

This work has provided information concerning the heat transfer characteristics in plastic glazed skylight applications. The results also give a basic and fundamental understanding about the thermal conditions that can be encountered in skylight or horizontal glazing applications in high-temperature climates.

Smaller-sized skylight domes have a greater structural strength than larger domes of similar thickness (due to the smaller radius of curvature). The structural strength gained in thermoforming may help to prevent thermal distortion of plastic applications. In addition, smaller skylight domes impart a smaller load upon the skylight structure. To better understand the effects of dome size on thermal stability of skylight applications, further testing is recommended on skylights of varying dome size. A possible experimental approach for this testing would be determination of a relationship between radius of curvature and HDT (heat distortion temperature) of the glazing used in a thermoformed or molded skylight.

Testing could also be conducted in actual installed skylights. This experiment, however, created a "worst-case" heat gain scenario for the skylights tested, i.e., mounted on a solid wooden platform laying on the ground, with no free convection beneath the dome to provide dissipation of heat. Further testing could be performed with dark tinted domes to determine if climate control systems or standard installation practices may reduce the effects of the radiative heat gain measured here.

In this experiment only the plastic glazing temperatures were measured. Additional measurements of skylight frame temperatures and the effects on the plastic glazing could also be conducted. As the frames for all skylight prototypes in this experiment were aluminum extrusions, frame color and frame material of construction could be used as variables in the frame temperature experiment.

Lastly, a study of the effects of temperature on different shaped skylight units is recommended (for all skylight tints/colors). Examples of alternative shapes could be arched, hipped, pyramids, or hemispheres. Varied dome shapes may demonstrate different creep behavior and exhibit different levels of radiative heat gain and therefore different heat transfer phenomena.

Figure 3: White Single Dome Temperature Curve

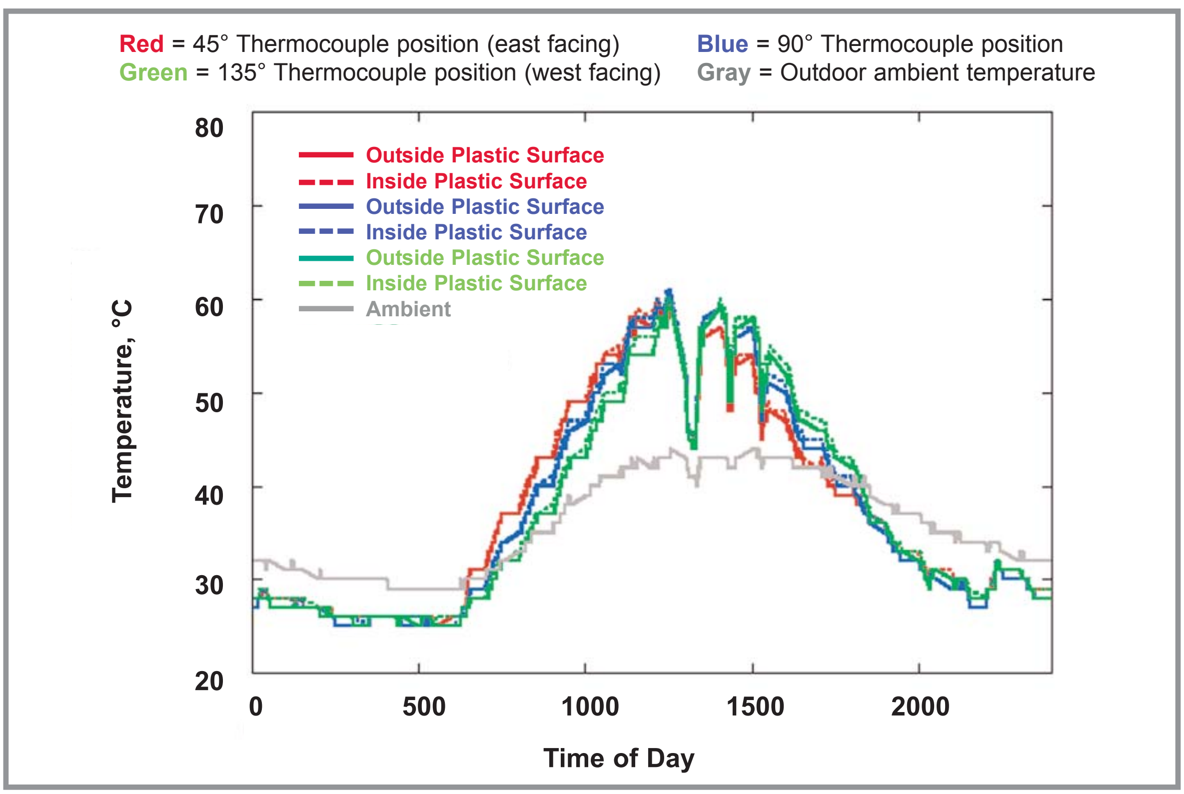


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Figure 4: Clear Single Dome Temperature Curve

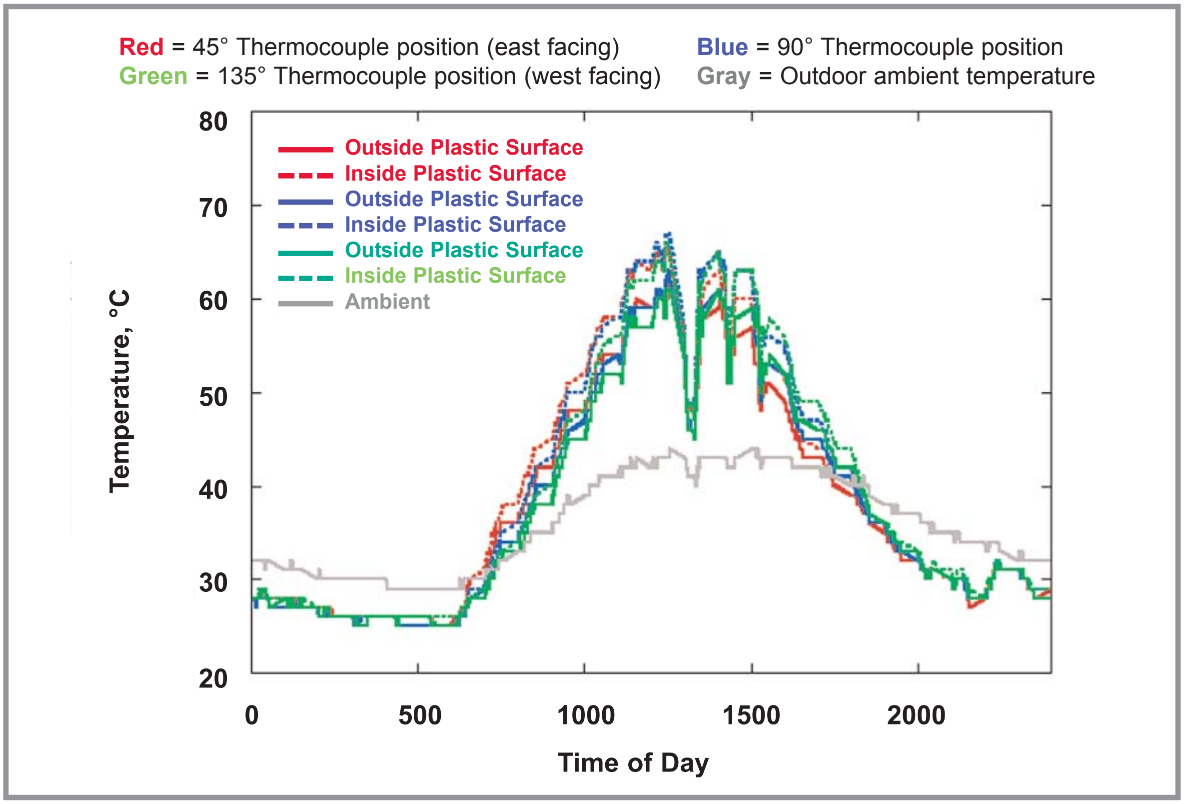

Figure 5: Heat Transfer Model for Single Dome Skylights

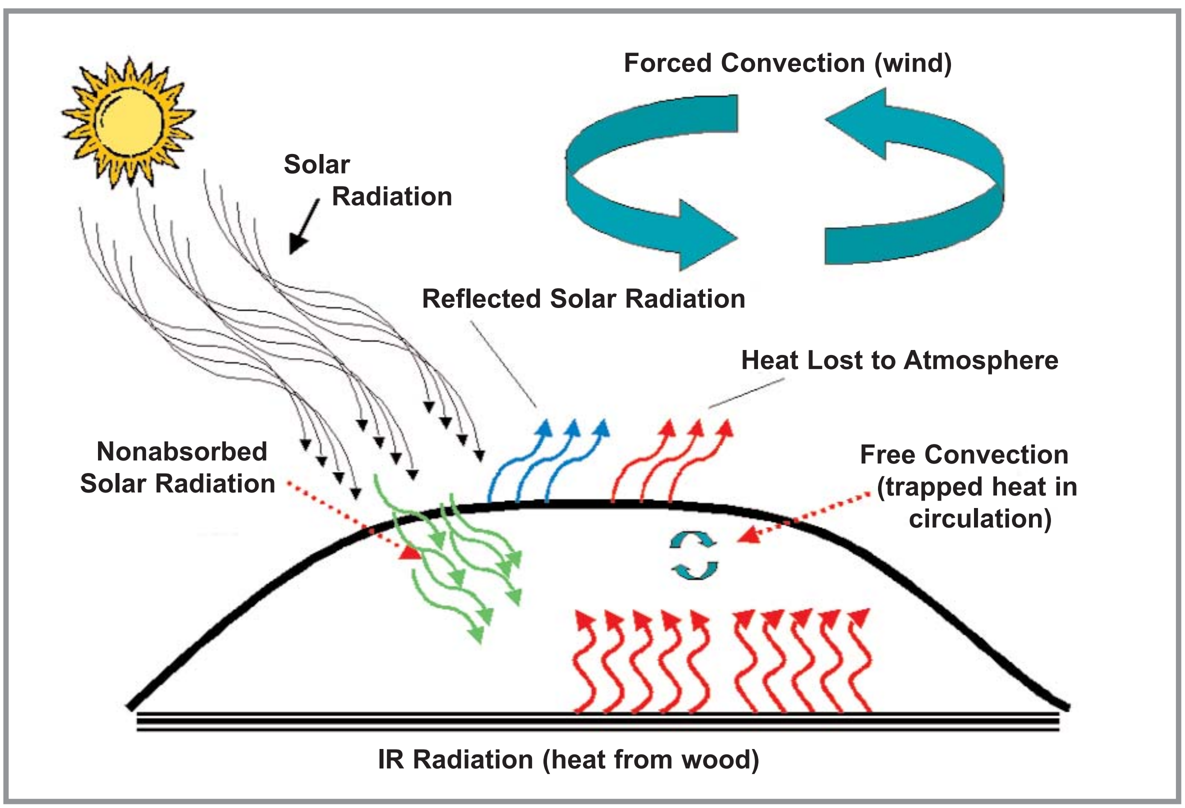

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Figure 6: Bronze (Amber) Single Dome Temperature Curve

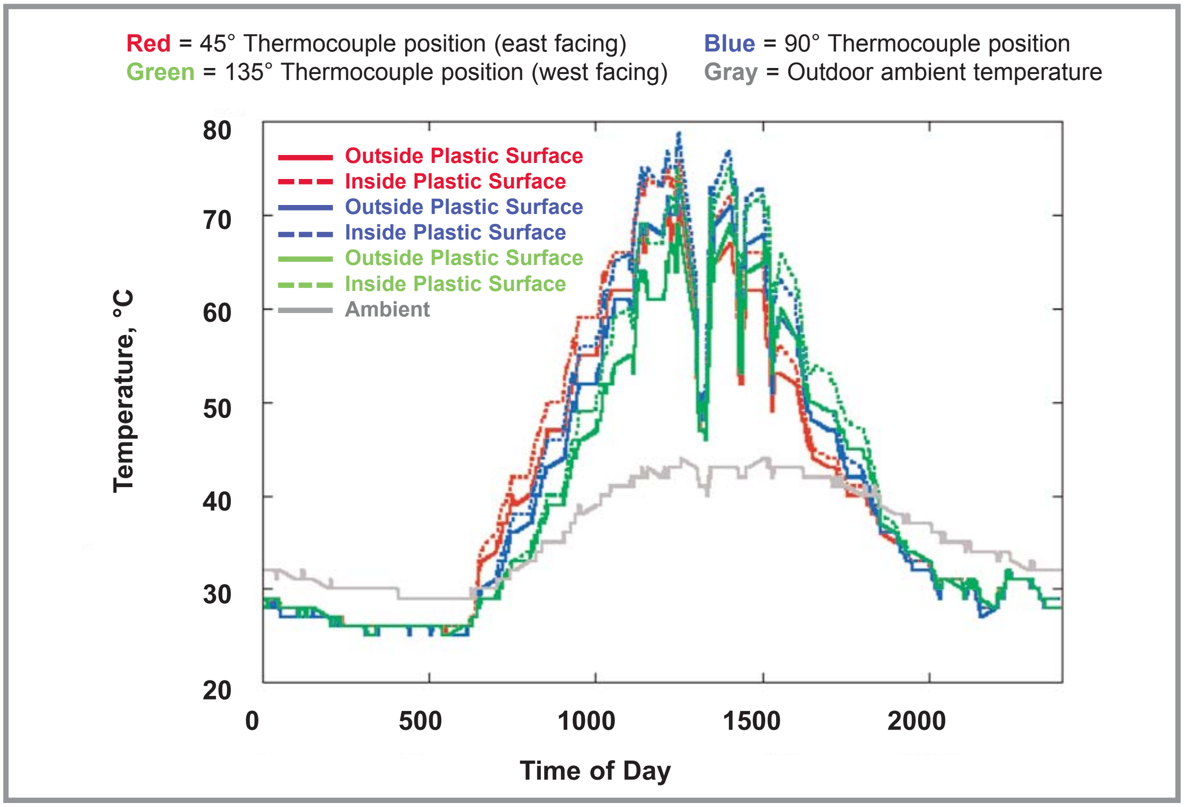


Figure 7: Clear-Clear Double Dome Temperature Curve

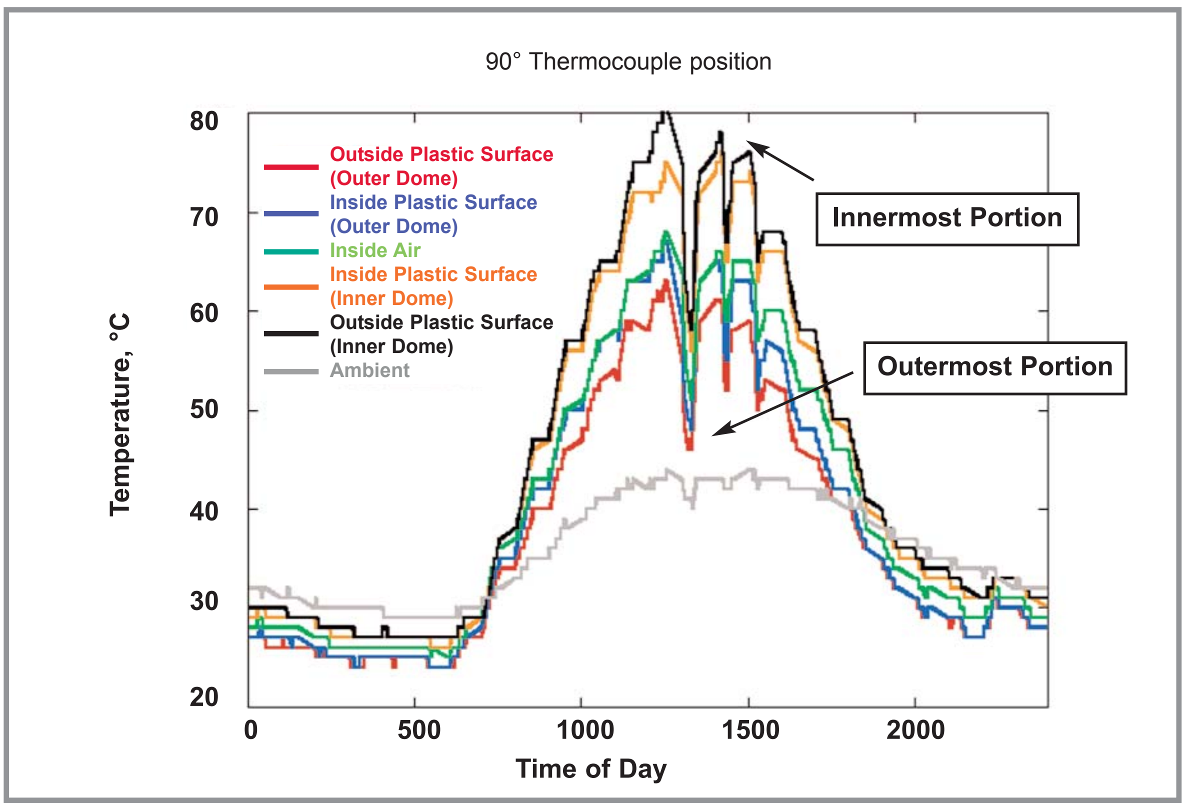


Figure 8: Heat Transfer Model for Double Dome Skylights

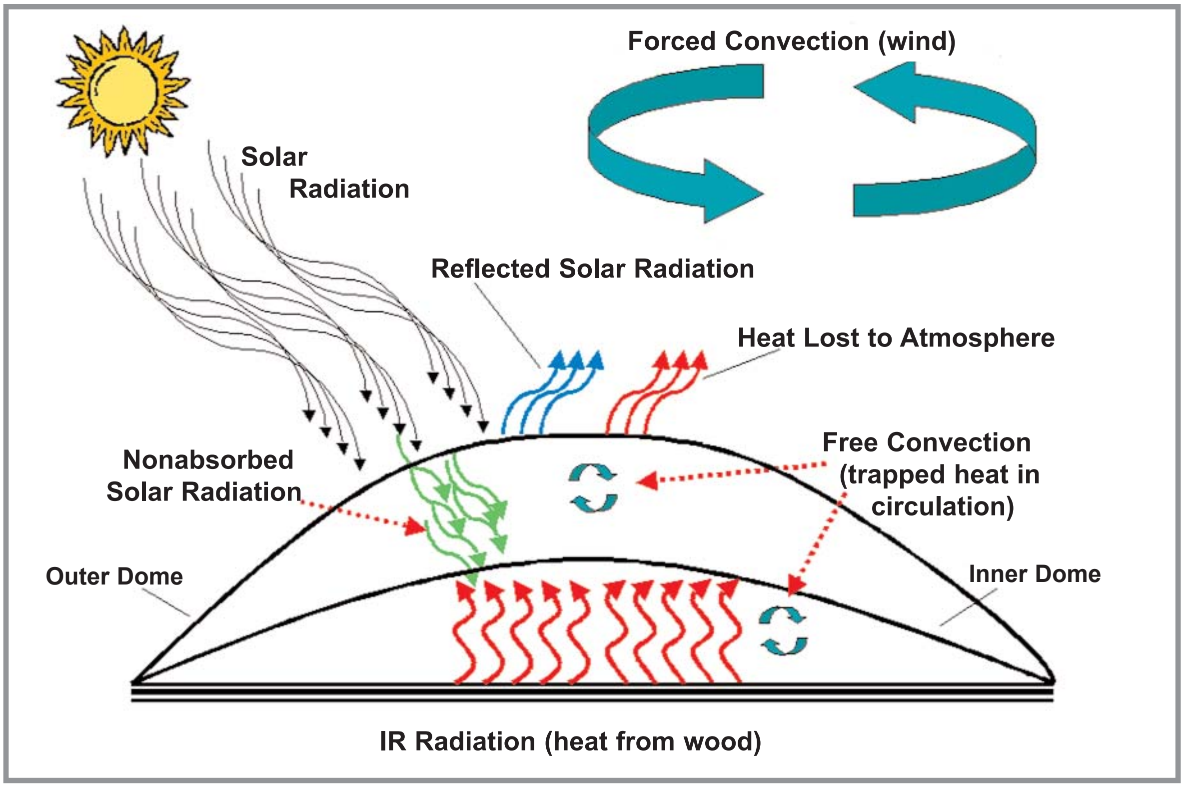
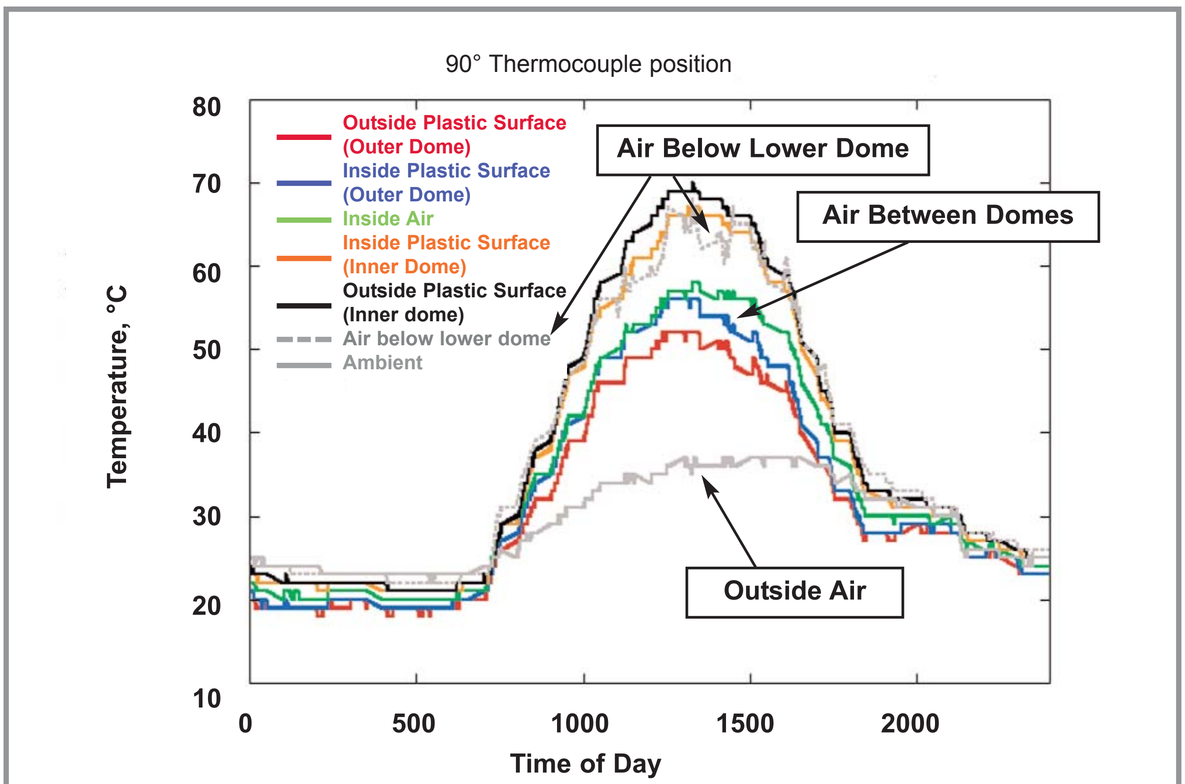


Figure 9: Clear-Clear Double Dome Temperature Curve With Additional Thermocouple Below Lower Dome



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