

Discussion Of Results

January 23: First Test

The “High Back Reflector 7.7 (Closed wings)” as described elsewhere in this report and in this section called simply the ”High Back” unit, was set up and monitored throughout the heat-up portion of the day, that is, the morning through to mid-afternoon. The data are plotted in Figure 7. Relative to the Cookit, the High Back heating rate (or the slope of the temperature curve) was only slightly more until about mid-day, then its slope began to decrease, or level off. There was a significant amount of condensation on the inside of the High Back lid at this time. The Cookit temperature surpassed the High Back at 13:39. The Cookit maintained a constant heating rate until around 14:00 when it began to level off. Improving the High Back geometry at 14:30 by redirecting the rays back down onto the pot showed an improvement in High Back heating rate performance. No cooling rate performance data were obtained for this day.

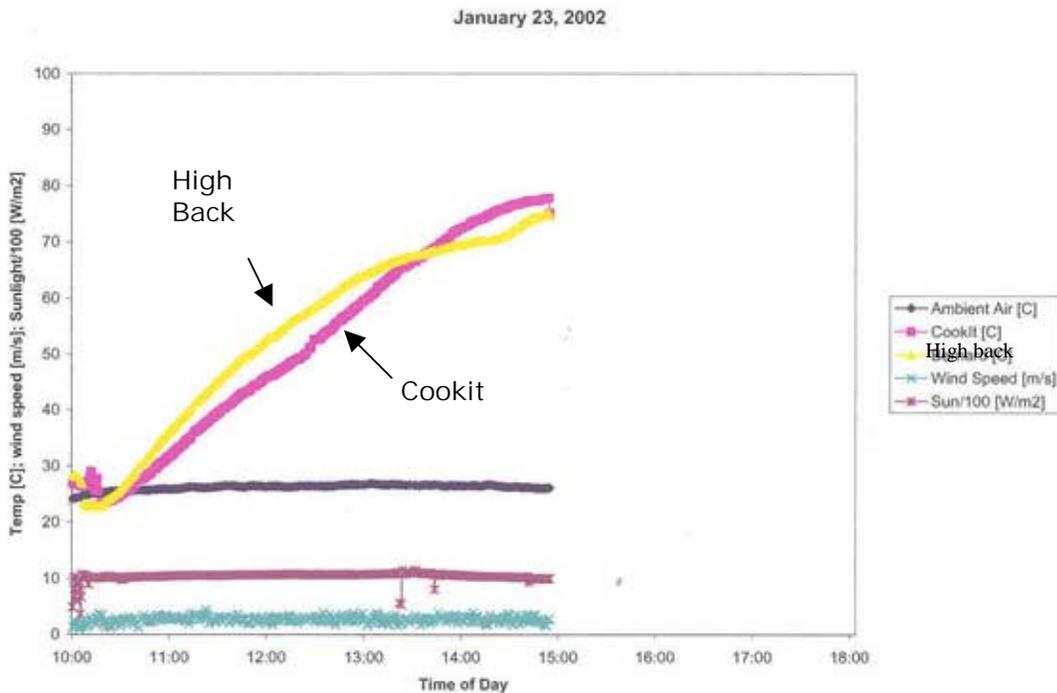


Figure 1

Two reasons were put forward for the relatively poor performance at high temperatures of the High Back. The first was reflector design. The reflector was designed for high sun altitudes found in the tropics. The tests were being conducted in January in Florida, so the mid-day sun altitude was significantly lower than would be found in the tropics.

While the lowest altitude tested by the ray-tracing analysis was 50 degrees, the highest altitude achieved by the sun in Cocoa Florida on January 23 was 41.9 degrees. Therefore, on this day the altitude of all the sun's rays incident on the collector were less than 42 degrees off horizontal. For example, the altitude at 13:39 was 39 degrees. Lower sun altitudes would lead to reflected rays converging at points higher than desired, that is, above the pot. We determined to adjust for this problem by adjusting the sides and back to effectively bring the rays back down onto the pot. When we spread the side "wings" further apart, this had the desired effect. For all subsequent tests, the High Back reflector was set such that the back was tilted in 10 degrees from vertical, or 80 degrees off horizontal. This sets the side triangles tipped in 8 degrees at about 82 degrees off horizontal, and the side quadrangles tipped out 23 degrees at about 67 degrees off horizontal. In fact, the reflector was changed to this setting at 14:30. An improvement, or increase in the heating rate can be seen in the High Back for the remainder of this day's test.

A second possible reason for the poor performance was the condensation of moisture on the lid. In a cooker, the cooking (or heating) effect is obtained when the energy input (sunlight) exceeds the energy output (losses). Heat loss follows three basic paths: conductive, convective, and radiative heat loss. All three are a function of temperature, among other things: the higher the temperature, the greater the loss rate. Condensation could be considered as a combination of conductive and convective loss, and is an indicator of significant heat loss. This is because steam at 100 degrees C contains much more heat than liquid water at 100 degrees C (about 2257 kJ/kg, or 970 Btu/lb more). If the steam gives up all this energy and turns to liquid water (condensation), this is considerably more heat loss than if the steam or water were to give up heat by simple conduction.

To reduce the heat loss due to condensation, a better-insulated lid is needed. We chose to add a black aluminum inner plate to the lid to determine the impact on performance. With this High Back reflector design, many of the sun's rays make it into the pot through the lid, and adding an opaque inner lid would significantly reduce the heat input through the lid. However, we had concerns about the cost of a glass inner lid, and we had concerns about the ability of most plastics to withstand the relatively high stagnation temperatures found at the lid. Hence, we chose an opaque metal inner lid.

January 24: Aluminum Inner Lid

This day's test was run with the black aluminum plate fit tightly to the inside of the glass pot lid. We also added the small front reflector that is shown in the ray trace reflector profile, but was left out of the previous day's test. And, as with all subsequent tests, the reflector was held in its "wide" position.

In spite of a cloudy day and very little sun, both cookers showed a strong temperature rise. Interestingly, the Cookit outperformed the High Back throughout the whole heating portion of the day. The High Back edged slightly closer as both cookers got hotter, and during the cooling portion of this day, the High Back maintained a better, or flatter slope on its heat loss rate. This would indicate that adding the opaque metal plate was

detrimental to High Back heat gain performance, but helped improve its heat loss performance.

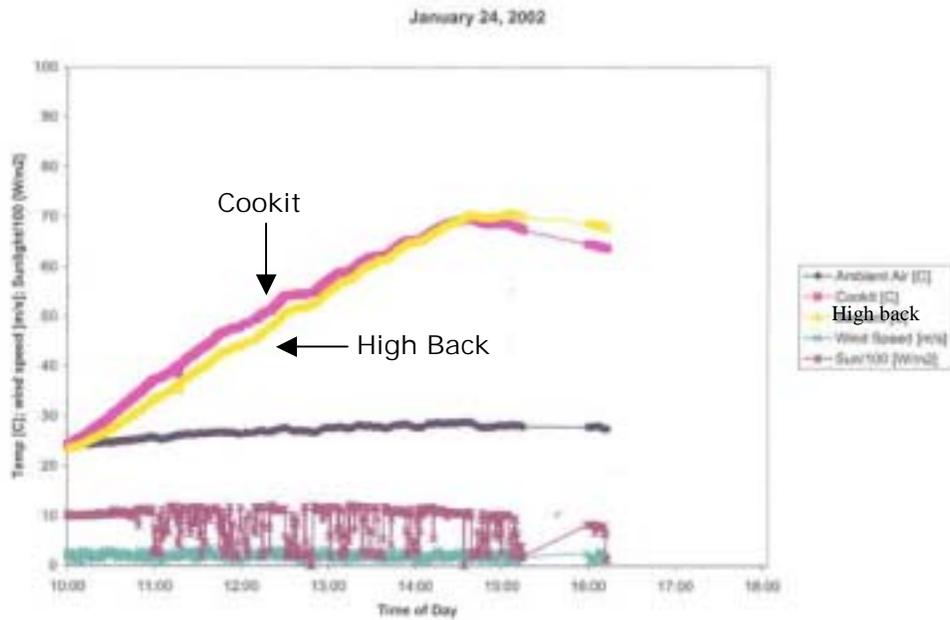


Figure 2

January 25: Wide Position, Front Panel

This day's test was run with the black aluminum plate removed again. As with all subsequent tests, the reflector was in its "wide" position, and the front panel was in place. Thus, this day's test could be compared to January 23 to evaluate the wide position and the front panel. Also, the test was run during the heat loss period to look at the cooling rate. To make the heat loss period more evident, the cookers were turned away from the sun at 16:01, although there was little sun at the time.

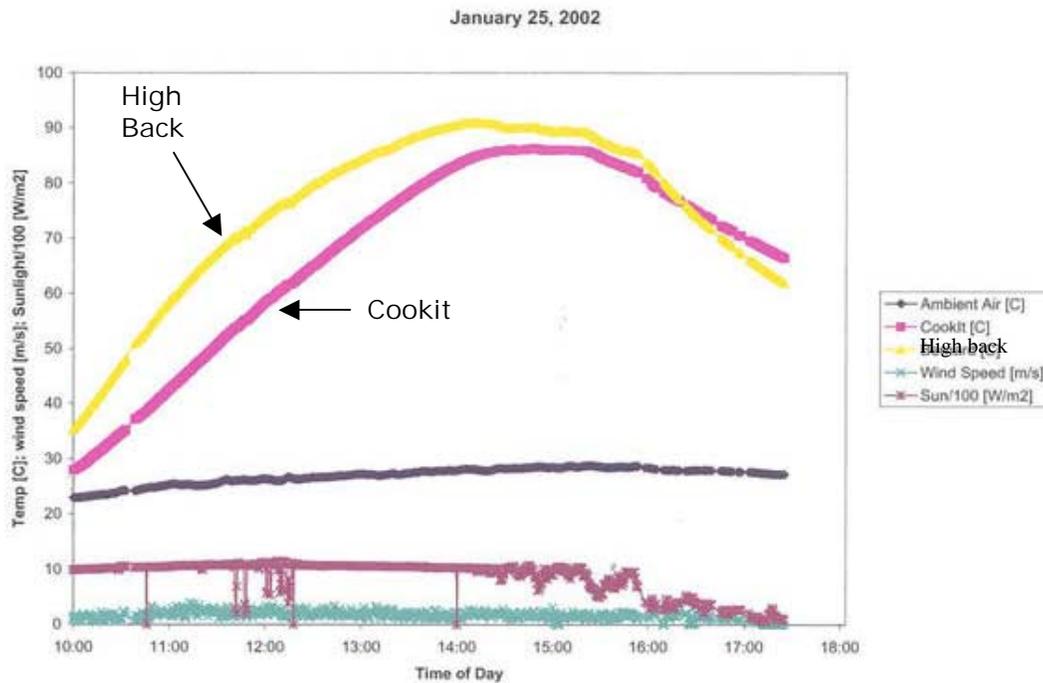


Figure 3

As on January 23, both cookers performed very well during the heating period, with the High Back outperforming the Cookit by a larger margin than on the 23rd. Also, both cookers seemed to perform better than on the 23rd, in spite of similar radiation and ambient temperatures. This may have been due to the earlier start on the 25th, or possibly due to a lower average wind speed during the day. The High Back peaked just after 14:00 at 91 degrees C, and then leveled off at 91.1 degrees C as sunlight began to drop off. The Cookit leveled off a little bit later, with a peak of 86.4 degrees C at 14:49:30. Note that radiation was strong until around 14:30, when it began to get cloudy. Also, at 10:51 the anemometer was moved from being located on the ground next to the cookers, to its position on the ambient cart 2.13 m (7 feet) above the ground. This is the normal position for collector testing. However, winds tend to be slightly higher than right at cooker level, so this measurement location will give readings slightly higher than what the cookers actually see.

During the cooling period, the High Back performed poorer than the Cookit, that is, the slope of the High Back curve was steeper than that of the Cookit. Comparing to the 24th, this would indicate that the inner aluminum disk, while being detrimental to heating rate performance, inhibited heat loss and improved heat loss performance. Touching the outside of the High Back pot during its hottest time supports this observation: the metal rim of the lid could not be touched, the glass part of the lid was too hot to touch for long, and even the glass bowl was very warm. And again, condensation was noted on the inside of the lid. The warmth of the surfaces exposed to the ambient air and wind would indicate high heat transfer to these outside surfaces, or in other words, high heat loss.

The glass lid seems to be a significant heat loss path. The metal rim of the glass lid on the High Back also is a heat loss path, but because of its small area, the actual heat loss is probably not as significant.

That the glass lid is a significant heat loss path actually would seem logical, since there is only a single solid surface between the heated mass and the ambient. In the “greenhouse”, there are two: the pot side and the glass bowl. Furthermore, there is a thin layer of air between the two, which increases the insulation effect. In the Cookit, there also are two: the pot side/lid and the plastic bag. While the entrapped air between these surfaces is a larger volume and more conducive to convective currents than in the High Back greenhouse, there is still an insulating effect contributed by the entrapped air mass. Thus, it would seem beneficial to get an entrapped air pocket in the lid between the heated mass and the ambient, like is done in the Cookit. There would be reduction in the amount of heat gain, since the rays would need to penetrate two glazings rather than one. However, as can be seen in the discussion on transmissivities in Appendix I, a double glazing of glass and polycarbonate reduces the transmissivity by only about 10%, compared to the glass alone. Also, in the current design, a substantial amount of reflected rays enter the pot through the lid. If the design of reflector and/or hotpot were modified so that a greater percentage of the sun’s rays were reflected onto the sides and/or bottom of the pot, then the heat gain penalty for double glazing would be less in terms of actual amount of energy gain. One way to accomplish this would be to raise the hot pot on a small wire tripod to increase the view factor of the pot base. Another way might require adding an additional panel to the back and side reflectors to direct rays from the sun at high altitude to the bottom of the pot.

January 29: Wide Position, Front Panel, Day Two

This day’s test was run in the same configuration as January 25. As would be expected, the results are similar to those of January 25. It was a clear day, and sunlight was strong throughout. During the cooling period, the cookers were turned off-sun at 16:02 to make the heat-loss rate more evident. The pyranometer was covered for a minute to provide a marker in the data of this action. There is also a marked change in slope of the High Back.

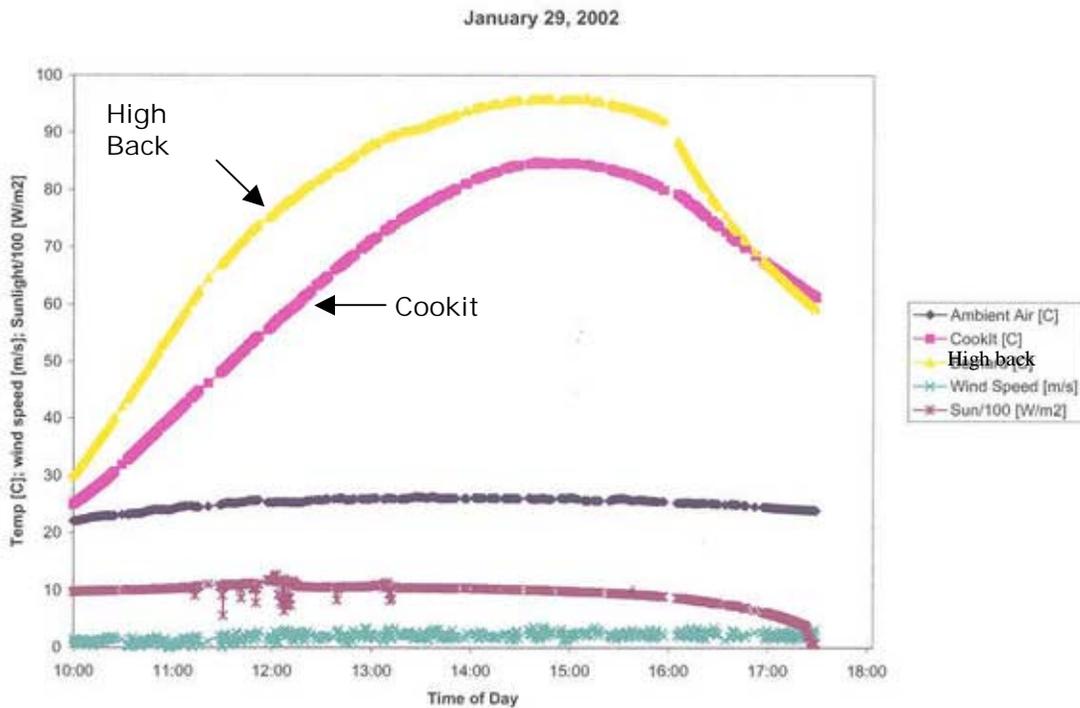


Figure 4

As on the 25th, the High Back had a much higher heat rate than the Cookit during the heating period. The High Back held its lead while it was on-sun, even though it was 10 to 12 degrees C hotter (hence it would tend to have higher losses) than the Cookit. The High Back reached a peak temperature of 96.0 degrees C at 14:46:30, while the Cookit reached a peak temperature of 84.9 degrees C at 14:40:30.

As on the 25th, the High Back demonstrated a higher cooling rate (steeper cooling slope) than the Cookit, especially when it was turned off-sun. This cooling rate more closely matched the Cookit's as their water temperatures converged. This would imply that the High Back might have the same cooling rate as the Cookit under the same temperatures and ambient conditions. It might be useful to check the cooling rate of the final configuration under controlled conditions, possibly checking the impact of wind direction and wind speed on performance.

It is interesting to note that on this day the High Back maintained temperatures above 90 degrees C for over 2.7 hours, until the cookers were turned off-sun. During this time, the radiation averaged 994 W/m2 and the ambient temperatures and wind were as shown in Table 3. Under the same conditions, the Cookit was only able to maintain an average temperature of 81.7 degrees C. As the water temperature approaches boiling (100 degrees C), heat losses due to evaporation from the water mass increase significantly. The heat may be transferred to the lid by evaporation and condensation, then through the thin glass of the lid, then blown away by the wind. Or, it may exit the pot directly by mass transfer when small amounts of steam escape from the pot. However, under the

given combination of ambient conditions, the High Back was able to maintain a high water mass temperature in spite of apparent high heat losses. Note also that sun altitude was fairly high during this time period. This could imply that the High Back reflector might perform better under more summer-like or tropical conditions than those experienced during these tests. Also, in none of the other tests to date was the High Back able to maintain temperatures exceeding 90 degrees C. It might be useful to compare the data for the same time periods (i.e. same sun altitudes) or for the same range of radiation levels or wind speeds.

Table 1 Peak Cooker and Corresponding Ambient Conditions for January 29.

	Solar [W/m ²]	Wind [m/s]	T amb. [Deg C]	FSEC/High Back [deg C]	Cookit [deg C]
Avg.	993.8	2.2	25.9	93.8	81.7
Min.	890.2	1.1	25.4	90.1	74.7
Max.	1043.9	3.6	26.3	96.0	84.9

A comparison of Cooking Power for 29 January is given in Figure 12. The large amount of scatter in the data may be due in part to accepting some points which would normally fall outside the bounds stipulated in Standard X580. At first appearance, the data for the two cookers seem to be almost on top of each other. However, a linear regression shows a High Back curve that is higher but with a steeper slope than the Cookit. This would indicate that the High Back performs better at lower temperatures, but poorer at higher temperatures. In fact, the Cookit performance would exceed High Back performance at Td exceeding 60. However, the Cookit was not even able to achieve Td > 60. So, the High Back did out-perform the Cookit, in that it continued to “cook” at Td > 60. This would be seen if second order curves were fit to the data sets. Therefore, the High Back outperformed the Cookit, although to a limited extent.

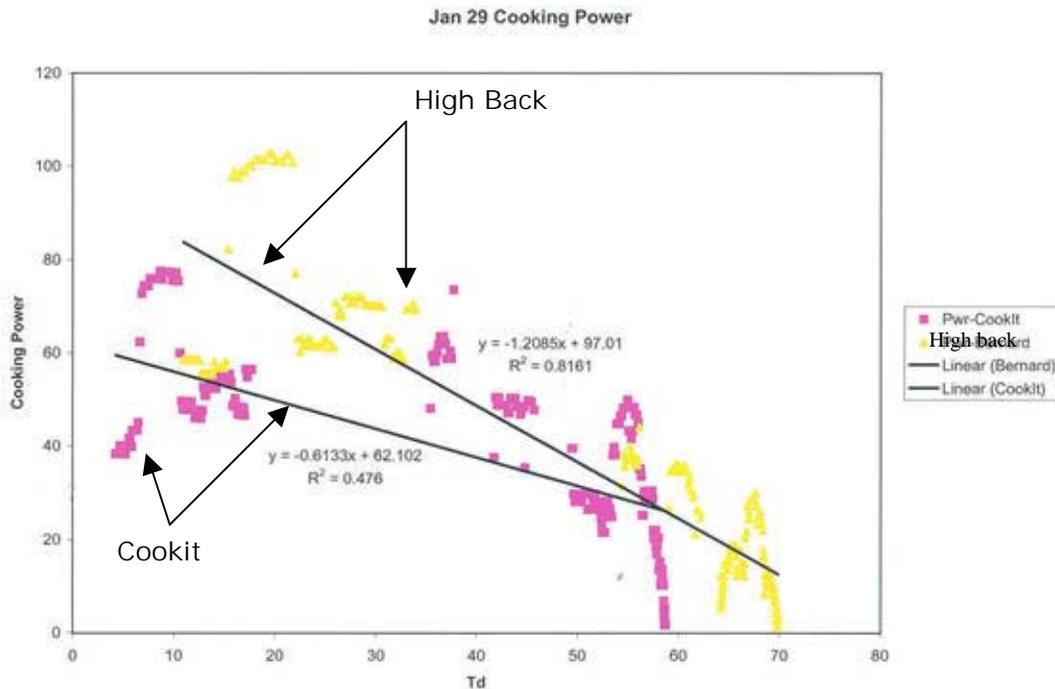


Figure 5

February 04: Acrylic Inner Lid

This day's tests helped look at the impact of adding an inner glazing to the High Back lid. A 2.4 mm (3/32 inch) Plexiglas acrylic disk was sealed in place with silicone to the underside (water side) of the pot lid. This provided two glazings on the lid with a thin layer of air in between them. In the discussion of the Materials Selection Task, acrylic was rejected in favor of glass, because acrylic can not stand up to the high stagnation temperatures anticipated during cooking, or if the pot should be boiled dry in the field. However, it was chosen here because it is easy to cut, and it would allow us to evaluate its performance under carefully monitored conditions. Based on the tests done with the beam splitter, the transmissivity of the glass-acrylic double-glazed lid dropped by 7% for visible light, and by 13.5% for near infrared light. One might expect similar results for a glass-glass double glazed lid.

This day's data show a windier, colder day with a lot of clouds rolling through. Dips in sunlight due to clouds are parroted by subsequent dips in the water temperatures of both cookers. Complete cloud cover after 15:30 gave the same effect as turning the cookers off-sun. At the higher water temperatures, some condensation was noted on the water-side of the acrylic glazing, but not as much as was seen previously with the single-glazed lid. Also, as was the case with the single glazing, when high wind gusts would come, small puffs of relatively cool air could be seen making their way into the pot and evaporating the condensation off the lid. This is because the seal between the pot and lid is not a perfect seal.

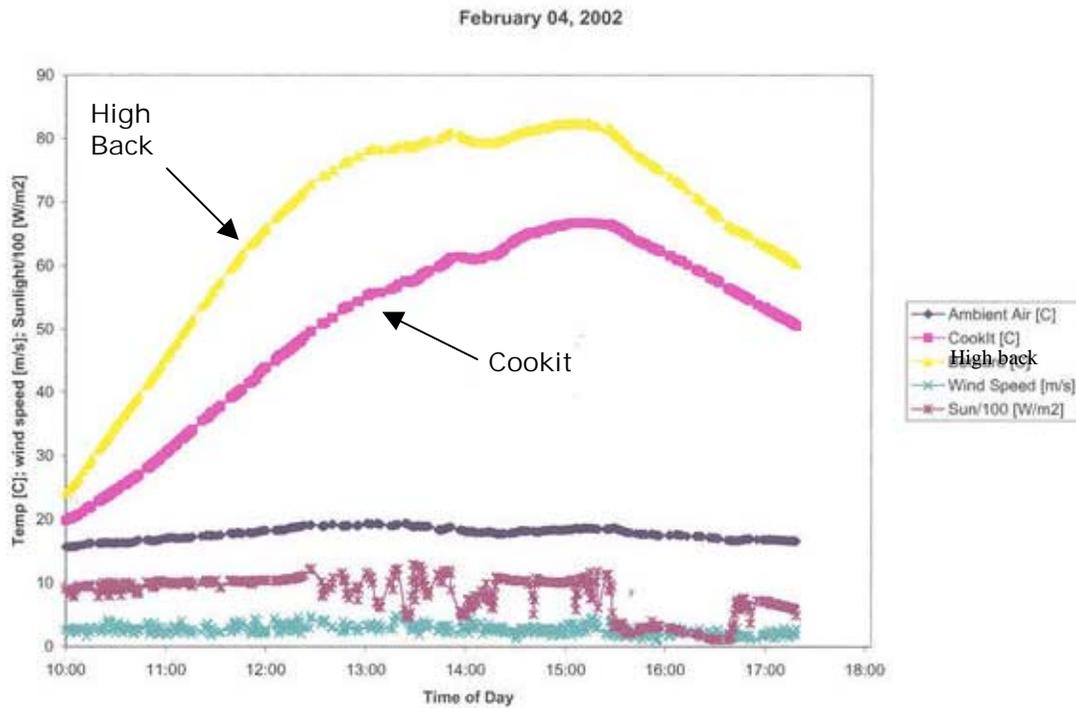


Figure 6

In spite of the added acrylic glazing, the High Back showed significant heat gain over the Cookit, with a higher heat rate and temperatures during the heating period. It also maintained a relatively high temperature, in spite of the cold, windy day. During cool down, the cooling rate slope initially was higher than that of the Cookit. Then, as the sun came back out a little bit (600 to 700 W/m²), the slope matched that of the Cookit, in spite of the High Back being about 10 degrees hotter. This would imply that the added acrylic sheet afforded a small improvement (flatter slope) in cooling rate, and did not seem to penalize the heating rate significantly.

A comparison of Cooking Power for 04 February is given in Figure 14. Again, as on 29 January, the High Back data and curve is higher but with a steeper slope than the Cookit. However, there is a distinct separation between High Back data and Cookit data, and the High Back curve is significantly higher than the Cookit curve. In addition, the High Back data and curve extend to much higher T_d values. Comparing to 29 January, we see that this significant performance improvement is in spite of significantly higher wind speeds. Thus, these results would indicate that the double glazed lid offers a significant improvement over the single glazed lid.

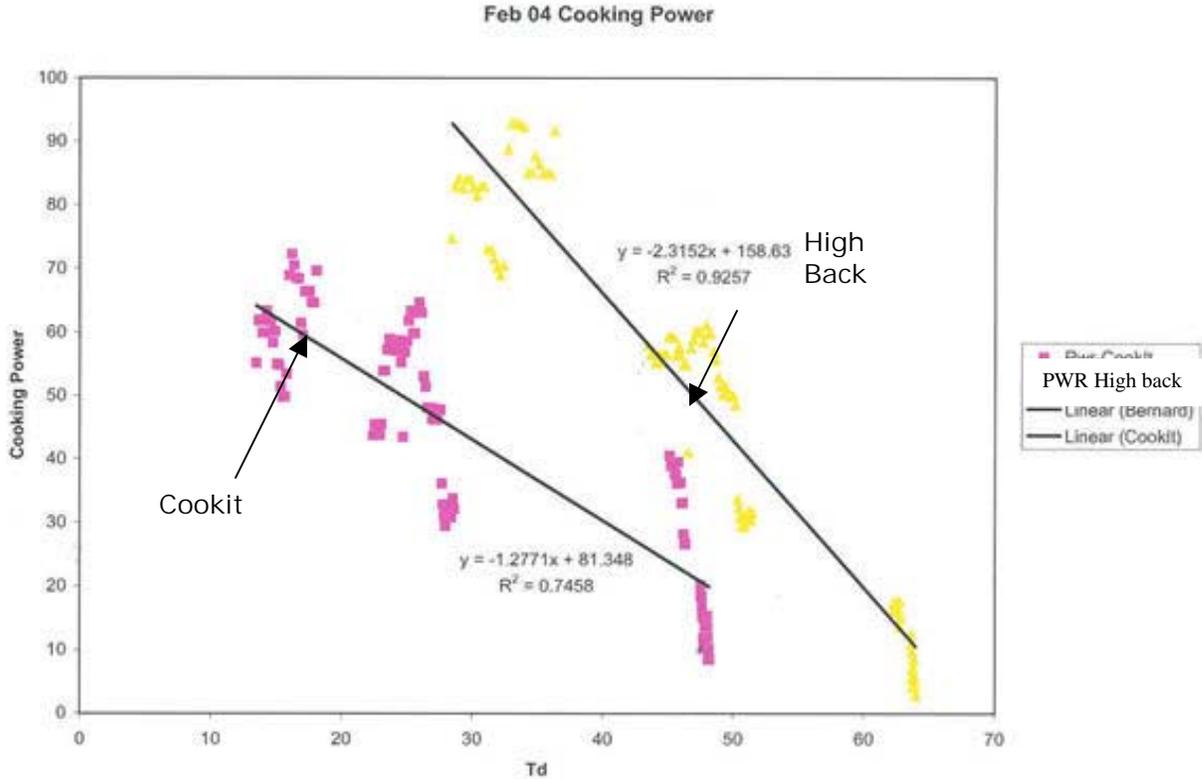


Figure 7

Conclusions

The “High Back 7.7 (Closed wings)” reflector configuration showed performance improvements over a “conventional” Cookit. The “High Back 7.7 (Closed wings)” reflector configuration is with the back plane sloped 10 degrees in and used in combination with the glass bowl and lid around a black steel pot. The “conventional” Cookit is a black steel pot and lid inside a Reynolds cooking bag, in a cardboard fold-up reflector. Significant performance improvement was only seen when the lid was double-glazed.

Based on the data analyzed, it would seem important to specify a double glazed lid. In this greenhouse hot pot design, heat loss through the single-glazed lid seems to be a significant heat loss path. In addition, in this combined hot-pot and High Back 7.7 reflector combination under Florida winter sun, heat gain through the lid also seems to be a significant portion of the overall heat gain, precluding an opaque double glazed lid. Adding a three-legged stand when the sun is low might raise the pot enough to bring it into more of the focal area of the reflector. The stand would need to be well designed to minimize tipping potential. Also, testing a low emissivity coating on the pot might help determine the benefit of adding such a coating.

The reflector geometry of the “High Back 7.7 (Closed wings)” might perform better if tested under sunlight at higher altitudes (e.g., in tropical locations or during the summer in Florida). Much of these data were collected at sun altitudes lower than those anticipated in the ray tracing analysis. The reflector geometry is somewhat sensitive to sun altitude. In addition, it might prove useful to specify designs for specific sun altitudes. For example, a reflector might be designed uniquely for low-altitude sun (e.g. a “1500” model for cooking after 3 p.m.) and a second reflector might be designed for high-altitude sun (e.g. a “1000” model for cooking after 10 a.m.). Or, it might be possible to combine these two reflector configurations into one reflector with two settings.

Further testing of the chosen design over at least three days would be necessary in order to define the Standardized Cooking Power curve and value for $T_d=50C$. In addition, it might be useful to better understand the cooling rates of the chosen design, relative to the Cookit.