CY 2011 Annual Report to CSU Specialty Crop Program –

Grower Research & Education Grant (GREG)

Year Two

Research, Development and Demonstration of

Solar Hops and Herb Drying

For Small Farm Applications

January 10, 2012

(Temperature data logger at exit of a hop drying tray)

Submitted by

Richard D. Andrews, General Partner

J.M. Andrews Family LLLP, 6803 Jay Road, Boulder, CO 80301

CY 2011 Report: Solar Hops & Herb Drying Project

Summary –

The proposal anticipated a two year program of research, development and demonstration of solar hop and herb drying starting with the summer season of 2010. The project required the construction of considerable facilities for the execution of the program, including a new barn and attached greenhouse where the studies would be conducted. Unfortunately, the building of these facilities was greatly delayed by protracted review and approval processes of the Boulder County Land Use Department and permits were not issued until late June 2010 leaving insufficient construction time. Refer to the 2010 year end report for limited accomplishments of the 2010 season.

During 2011, partial completion of the needed greenhouse was accomplished, and solar hot air collection system was built along with substantial revisions to the hop dryer and appurtenances. A series of eight solar hot air hop drying tests were performed during the 2011 hop drying season in late August and early September 2011. The drying systems were instrumented with chart-recording, manually readouts of thermocouples, various remote wired and wireless sensors, pen chart recorders, and data logging temperature and humidity sensors. In addition, measurements of air velocities in the dryer were made with hot wire anemometer instrument and solar radiation intensity recorded. Measurements of moisture content of the hops were made throughout the drying process. Hops were successfully dried using only solar energy with two hot air collection system during these tests, as well as ambient warm air. Due to some overly cloudy days with diminished solar intensity during the latter part of the 2011 hop harvest period, the desirability for solar energy storage systems was apparent to be able to continue hops harvesting in periods of less than optimal solar energy conditions, during night hours, and to ensure that rapid drying during optimal harvest timing for quality can occur.

A workshop seminar presentation was made during July 2011 in Paonia, Colorado on solar drying technology and optimizing hop quality in the drying process, plus methods to determine optimal hop quality and harvest timing. The presentation was well received and reached local Colorado hop growers as well as numerous people from out of State. As part of this outreach program two technical PowerPoint presentations were updated by the project manager and made available to interested parties, technical advisors, and collaborators on this project. The project manager also met with several individuals on site at the Andrews Farm during and around harvest time who expressed interest in hop growing and processing. Tours and explanations of the solar drying system were provided.

Construction of the remainder of the greenhouse continues and will be completed before Spring 2012. The solar hot water and thermal energy storage systems is planned to be installed prior to the 2012 hops and herb harvest seasons to complete this project during the calendar year 2012. Hopefully opportunities for additional outreach can be arranged to present the findings from this solar drying technology to other interested parties. A final report on the project will be completed at the end of 2012.

Materials and Methods –

a. <u>How was project done ?</u>

The basic facility, a barn and attached greenhouse, were not funded by the SCP GREG but were necessary for its execution. The barn is complete and the two eastern most bays (two 12 ft by 10ft bays) of the attached greenhouse were sufficiently completed in time for the 2011 hops harvest and solar drying season.

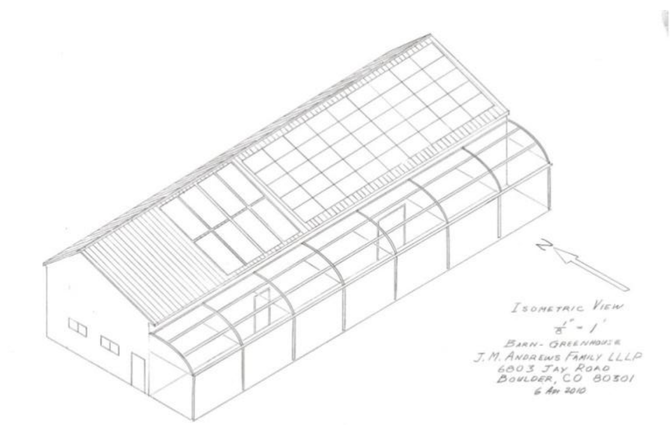


Figure 1 - View of greenhouse hop drying bays (under construction) and hops processing barn

Seven hops drying tests plus a dry run test were conducted during the 2011 hops harvest season with extensive data collection of temperature, humidity, air velocity, and moisture measurements during the tests. Details follow in this interim project report.

b. <u>Detail the methods and materials used to complete the project</u>

A hops and herb dryer was constructed in 2010 inside the barn and accessed through a south facing overhead door connecting the barn and attached greenhouse. Initial tests during 2010 used a 48 inch (122 cm) diameter greenhouse fan driven by a single speed Baldor Farm Duty 1 phase 1.25 horsepower 1725 rpm electric motor was placed at the end of the dryer to force ambient warm dry air in updraft fashion though six 48'' wide x 42" long x 12" deep (122 cm x 107 cm x 30 cm) stacked bins (trays) in which the fresh harvested hops were placed. These bins were arrayed in two vertical stacks of three bins each. The bins were removable with drawer pulls to access, clean, load and unload the hops. The bin/tray sides were plywood with bottoms of ½" mesh galvanized screen covered by plastic mesh window screen. The framing for the dryer structure was made from commercial pallet racking uprights and beams and enclosed on the sides with plywood sheeting. The entire dryer had dimensions of approximately 42" wide x 19' long x 8' high (1.2 m x 5.7 m x 2.4 m). The inlet air flow channel was restricted on the front end of the dryer (following the fan) to achieve suitable air velocities and was modified by trial and error during the drying to avoid fluidization or blow out of the hops in the drying trays. Exhaust air exited the top of the dryer from the top bin in each of the two stacks of bins. Figures 2 and 3 illustrate the construction of this dryer and the drying bins/trays. Hops samples were collected and measured for moisture content in a Thelco (Precision Scientific) lab oven at 150^{0}F (66^{0}C) and masses determined on a Torbal analytical balance (0.1 g precision).

Figure 2 - Hops dryer tray/drawer (one of six in the dryer; two stacks of three trays each)

Figure 3 – Overall view of Hops/Herb Dryer during 2010 tests (garage door open to direct sun insolation onto the black plastic absorber on south side of dryer; greenhouse not yet constructed)

In 2011, two bays of the solar greenhouse were constructed prior to the hops harvest season. It is designed with dual wall polycarbonate top glazing, single wall corrugated polycarbonate side wall glazing, buried perimeter wall blueboard closed cell foam insulation, vent fan, and buried hot air and hot water piping for future soil heating/thermal mass storage.   Solar hot water collector panels will be installed in the coming year (2012) plus a 1500 gallon insulated in-ground hot water storage tank fitted with a heat exchanger loops. In initial drying tests 4 & 5 during 2011 hot air was collected from near the top of the greenhouse (see photos of Figure 4a and 4b).

Figure 4 (a) – Solar Hot Air Hop Dryer (2011) Tests 4 thru 5: Greenhouse Hot Air Collection System (top of greenhouse without roof collector plenum installed)

Figure 4(b) - View of greenhouse bays attached to barn for tests (under construction)

In latter 2011 test numbers 6 and 7 the eastern most 12 foot wide bay has a 6 mil black plastic film interior layer installed on the arched roof and south wall, creating a plenum heat collector for solar heated air. Air intake is low on the south vertical wall from inside the greenhouse. A 10 inch diameter galvanized duct manifold collect hot air at the greenhouse roof peak from the plenum between the top glazing and the black plastic film using a centrifugal induced draft fan. See figures 5a and 5b. The collected hot air is routed through an insulated flexible duct to the bottom of the multiple drying tray racks updraft mode. The induced draft fan is equipped with multi-sheave combinations on motor drive and slave shafts to allow adjustment of fan speed (rpm) and therefore achieve variable air velocities and air volume rates into the dryer. A diversion and damper system also allows regulated cooler dilution air to enter the hot air manifold system on the fan intake side for additional temperature control, as needed. When the hops/herb dryer is not in use during colder months the hot air collection system will be modified to move hot air from the top of the greenhouse and blow air into the buried hot air injection pipes buried in the greenhouse soil mass.

Figure 5 (a) – Solar Hot Air Plenum System for Hop Dryer Tests 6 thru 7 (2011): Hot air concentrating plenum system inside greenhouse roof, black plastic film inside of polycarbonate greenhouse roof glazing; air intake on right vertical wall; induced draft fan intake at top on left

Fig 5 (b) - Solar Hot Air Plenum System for Hop Dryer Tests 6 and 7 (2011): Hot air collection intake manifold ducting system; hot air from plenum on right, dampered dilution air at top left

Fig 5 (c) - Centrifugal fan and multi-sheave drives for variable air volume rate

The same hops/herb dryer trays built in 2010 were used in 2011. The dryer consisted of two vertical stacks of 42x48 inch drying trays, each stack with three trays; depth of each tray 12 inches. Hops or herbs are placed in the tray to varying depths depending upon optimal depths determined from the research. Throughout the tests, various modifications to the air collection and fan systems were made to adjust and improve operating conditions. Various fans, motors, sheave combinations, operating rpm's, and ducting systems and configurations were tested. The dryer rack array was largely rebuilt and relocated from the version used in 2010 with major modifications to the inlet air channeling configuration and dimensions, and the above described new hot air collection system. Air flow was reversed to move from west to east. The dryer was located in the attached barn and immediately inside a garage door connecting the greenhouse and barn. See figures 6 (a) and 6(b). In the coming year (2012) the dryer will likely be entirely rebuilt with improved designs and placed in the east most bay of the greenhouse under the hot air heat collection system, freeing up floor space in the barn for upgraded hop picking and cleaning machinery.

Figure 6 (a) – Dryer fan and tray configuration for 2011 test numbers 0 through 3 (partly disassembled); 48" greenhouse fan housing (foreground) draws low level air from greenhouse

Fig 6(b) – Dryer fan and tray configurations for 2011 test numbers 4 thru 7 (hot air from top of greenhouse in tests 4 & 5 or from greenhouse roof plenum in tests 6 & 7 enters via the insulated ducting on lower left, channeled to bottom of dryer tray stacks to left center in updraft mode)

Major additions to the data collection of temperature, humidity, and air velocities throughout the dryer system were made during 2011. A set of Lascar Electronics data logging temperature and humidity sensors were installed at key locations within the dryer system and for ambient conditions. There were four temperature logging sensors (Lascar Model EL-USB-1), two combination temperature and relative humidity logging sensors (lascar Model EL-USB-2), four digital telemetered sensors with digital readouts with temperature and humidity (Accurite and Shift brands), nine type T thermocouples with digital readout (Fluke Model 19080/2150A and Flike Model 16694/2100A) and a ten channel Automatic Signal Scanner (Omega Dataplex 10), plus a watt meter on solar radiation (associated with the Fronius inverter and 9 kw photovoltaic array on the barn roof), and two 7 day circular strip chart Dickson temperature recorders and one 7 day combination temperature and humidity circular strip chart Honeywell recorder. Some or all of these instruments were utilized for various tests during the 2011 drying season. In addition to the instrument readings, weather observations were recorded at roughly 0.5 to 1 hour intervals during drying tests. Air velocity measurements were made at multiple points across the ducts of the entrance hot air to the dryer and at multiple points at the exit of each tray periodically using a hot wire anemometer (Testo Model 425) with a telescoping wand sensor and digital readout in meters/second and temperature. Figure 7 illustrates some of the instrumentation.

Figure 7 – Monitoring instruments for 2011 drying tests: left to right, top row:

(a) thermocouple scanner and digital readout; (b) temperature and humidity data logger, thermocouple and remote T and rel humidity sensor in dryer tray; middle row: (c) chart recorders; (d) digital air velocity hot wire anemometer ; bottom row: (e) analytical balance for moisture tests; (f) solar watt meter (on PV inverter)

Hop samples of approximately grams (wet mass) were collected at the beginning of drying and at intervals during the tests from each tray. Moisture content was determined by measuring initial and final masses to calculate percent moisture. Samples were dried to bone-dry condition for approximately one hour (to a steady mass) in the previously described laboratory oven set at approximately 100 to 105 ^{0}C. Optimal final moisture was 10% by weight. Typical starting moistures were 60 to 70% at commencement of drying.

Modifications to the dryer to utilize it for the combined purpose of air classification/separation (a winnower) of hop flower from leaf and stem were also tested in 2011 . A multi-compartmented bottom drawer was constructed with provision for installing variable height and horizontally spaced partitions. The inlet air channel was revised to draft across the top of the drawer and to control air stream velocity across the top of the winnowing drawer. A conical bottom stainless steel hopper was installed above the inlet air channel and hops and leaf were dribble fed with a vibratory pan feeder into the air stream. Heavier hops tend to fall into the first drawer compartment and leaf to blow on and collect in later compartments. Plexiglas viewing windows were installed in the side of the dryer and a fluorescent interior light installed to allow viewing of the separation performance under different partition spacings, heights, air velocities, etc.

A second phase (2012) of solar hops drying system using hot water collectors to heat drying air has rough designs at this point. Numerous hot water collector panels were obtained on used local equipment market, as well as differential temperature controllers, pumps and pressure tanks. A manifold hot water distribution valve array is already installed. These used hot water collector panels and components will need to be refurbished including tube cleaning, leak repair, and pressure testing. Materials for closed cell poly insulated and buried hot water storage tanks have been obtained on the used materials market as well as an additional 120 gallon (454 liter) hot water storage tank and heat exchanger.

<u>Dryer Design Modifications for 2012</u> -

The above described dryer was not the originally intended dryer design to be used. The hot air solar dryer design intended for the hops & herb drying research was to have two side by side dryers each independently adjustable/controllable to allow comparative studies of the effects of such operating variables as drying air temperature, velocity, humidity, percent recirculation, hops bed depth, etc. That plan may still be executed for the upcoming 2012 drying season and tests.

Due to apparent and significant air leaks and temperature drops between the hot air collectors and the inlet to the dryer, the systems for 2012 will be rebuilt to seal up leaks and insulate ducting to reduce heat loss. This will improve dryer operation by elevating inlet temperatures and hopefully reducing total drying time to reach final desired moisture of the finished hops.

Partial 2011 Solar Hop Drying Test Results –

a. What information/data was collected?

Overview 2011 Test Review Comments -

Construction of revisions to a hot air solar assisted hops and herb dryer was completed during 2011 (see above descriptions and figures).

Seven fresh hops drying tests were run in late August through early September 2011 using freshly harvested Cascade and Chinook hops. Some hops were from on farm production, some from cooperators from the hops farm located near Niwot, Colorado and operated by Wil Witman and Lisa Dent. Test 0 was a dry run without hops to test initial systems. Test numbers 1 through 5 used moderately solar heated air collected from the enclosed two bays of the greenhouse, drawn at near floor level. Test numbers 6 through 7 used hot air collected from the ceiling hot air plenum collection system described above. Two of these later tests are reported in this progress report as illustrations of the more complete system operation, the type of data collected, and the results obtained. The full review and analysis of all of the dryer tests will be provided in the final project report at the end of 2012, along with more discussion and conclusions about preferred dryer systems and operating conditions.

Optimal beginning dry matter contents of approximately 20 to 22 % is considered optimal using Oregon State University (OSU) dry matter test (dry mass/green mass x 100). This is equivalent to approximately 78 to 80% by weight moisture for the green hops. Field moisture content (dry matter) was measured for different hop varieties at weekly intervals beginning early August, plotting the drying trend to determine optimal harvest time. Picking in the Andrews Farm hopyard began 25 August 2011 with Chinooks which field dried quicker than the Cascades, similar sequencing to 2010. We commenced picking Cascades on 26 August. Total Andrews Farm picking period spanned from 23 August through 10 September 2011, 19 total days, most of which was sold fresh, undried. Hops harvested in the final days were beyond optimal condition when picked. Hop drying tests including hops harvested from the Witman-Dent Farm spanned the period 20 August through 17 September 2011.

The Andrews Farm hops were harvested somewhat drier than optimal according to these OSU guidelines, more in the 35 to 40% dry matter level, but were very good condition and quality by other measures, including customer satisfaction and acceptance. In the end we found that field judgment by olfactory, visual, and touch criteria was more satisfactory than the OSU dry matter guidelines; but selling drier can cut into revenues for fresh hop sales. Furthermore, it is possible that the OSU guidelines are inappropriate for optimizing hop quality in Colorado’s drier climate.

Picking at the Witman-Dent's hop farm was somewhat different than at the Andrews farm. They judged that the Cascades were ready to pick prior to the Chinooks, and harvested in that sequence, with Crystal hops last. Their 2011 harvest & drying period spanned approximately 20 August through 17 September, a total of 23 days. Differences could be due to the relative location of the different variety bines in the hopyard and exposure differences to wind and sun, microclimate and other cultural factors.

During the dryer tests air temperature and relative humidity was measured at the dryer inlet, between drying trays and at the exit from top most tray. Multiple instruments were used at these monitoring points, thermocouples, remote reading sensors, and data logging probes. Temperature measurements were also made at various other points in the solar hot air collection system and ambient air outside the greenhouse. The depth of the fresh hops in the bins/trays were loaded with about 10 to 18 pounds (4.5 to 8.2 kg) of fresh harvest hops per tray, averaging 3 to 6 inches (7.6 to15.2 cm) deep. The cross sectional area of each (42" x 48") bin/tray is 14 ft^2 (1.26 m^2).

The air temperature slowly rose and the relative humidity dropped as the drying progressed, indications of the decline of the evaporative cooling effect as the moisture was removed from the hops. Drying completion was determined by sequential sampling for hops moisture content expressed as weight percent. The optimal dry hop moisture content is generally understood to be between 8 and 10 wt % for good storage characteristics, and to avoid over drying which causes cone shatter and potential loss or degradation of lupulin. Excessively dry hops, since they are sold on a dry weight basis, result in a decline in product revenues. Dried full flower hops were put in a freezer for a minimum of two to three days prior to delivery to herb customers to kill any insects or insect eggs.

Example Results from 2011 Tests:

Test numbers 1 through 3 were run with either ambient outside air or air collected from inside the greenhouse bays, but not from the hot air plenum collection system on the greenhouse roof. Tests 4 and 5 collected hot air from near the roof of the greenhouse. Weather conditions during tests 1 through 4 were generally warmer, drier, and sunnier, averaging from mid 80s to mid 90s ^{0}F during the daytime. Various fan and dryer configurations were tested and adjusted during this initial series of dryer tests. Due to favorable ambient weather conditions, drying was successfully accomplished in 10.5 to 14.8 hours. Table 1 summarizes the basic conditions for all tests 1 through 7.

Tests #6 and #7 were run with the completed plenum hot air collection system via an induced draft fan. Unfortunately, the weather conditions were cooler, some rain, higher humidity and generally heavily overcast during these latter tests, with daytime temperatures generally from mid 60s to mid 70s^{0}F.

Test #6 was a single tray test with 17.4 lb of fresh hops, starting moisture of 61%. Total drying time was 7.25 hours (6.1 hr with fan), all in one day. Typical dryer inlet air temperature was 100 to 120 ^{0}F; hot air plenum temperatures ranged from 120 to 180 ^{0}F, indicating the potential for even faster drying by improved ducting and dryer construction to prevent dilution .

Test #7 was during an adverse weather condition, very cloudy, humid, and cool. Two trays with a total of 31.93 pounds fresh Crystal hops, 3.2 inches deep, initial moisture of 70.6 to 73.2%. Total drying time spanned four days, only running fans during favorable daytime hours, a total of 26.1 hours of on-fan time.

Table 1 - Summary of 2011 Solar Hop Drying Tests

Test Number (Dates of Test)	Number of Drying Trays (Hops wt, lbs)	Solar Heat Air Collection System	Weather Conditions	Dryer Inlet Air Temperature, typical range ^{0}F	Test duration (hours with fan on)
No. 0 (System Trial run) (8/20-21/11)	2 trays, 2 stacks	Ambient (outside) air	Good solar radiation, Warm temp	85 to 100 F	25.0 hrs
No. 1 (8/23-24/11)	2 trays, 1 stack 20 lb hops	Greenhouse air (low level)	Good solar radiation, Warm temp	87 to 99 F	14.8 hrs
No. 2 (8/27-28/11)	2 trays, 1 stack 20 lb hops	Greenhouse Air (low level)	Good solar radiation, Warm temp	85 to 100 F	11.5 hrs
No. 3 (8/29-31/11)	2 trays 1 stack; 37 lb hops	Greenhouse air (low level)	Good solar radiation, Warm temp	75 to 95 F	19.6 hrs
No. 4 (8/31/11-9/1/11)	1 tray 1 stack 18 lb hops	Top of Greenhouse	Good solar radiation, warm temp	90 to 100 F	10.5 hrs
No. 5 (9/4-5/11)	3 trays 1 stack 47 lb hops	Top of greenhouse	Variable solar, cool temp, overcast	80 to 108 F	16 hrs
No. 6 (9/11/11)	1 tray 1 stack 17.4 lb hops	Greenhouse roof plenum system	Poor solar, cool temp, cloudy, rain	100 to 120 F	6.2 hrs
No. 7 (9/13-17/11)	2 trays 1 stack 32 lb hops	Greenhouse roof plenum system	Poor solar, cool temp, cloudy/humid, variable	65 to 80 F (first 2 days); 75 to 90 F 90 to 110 F	26.1 hrs

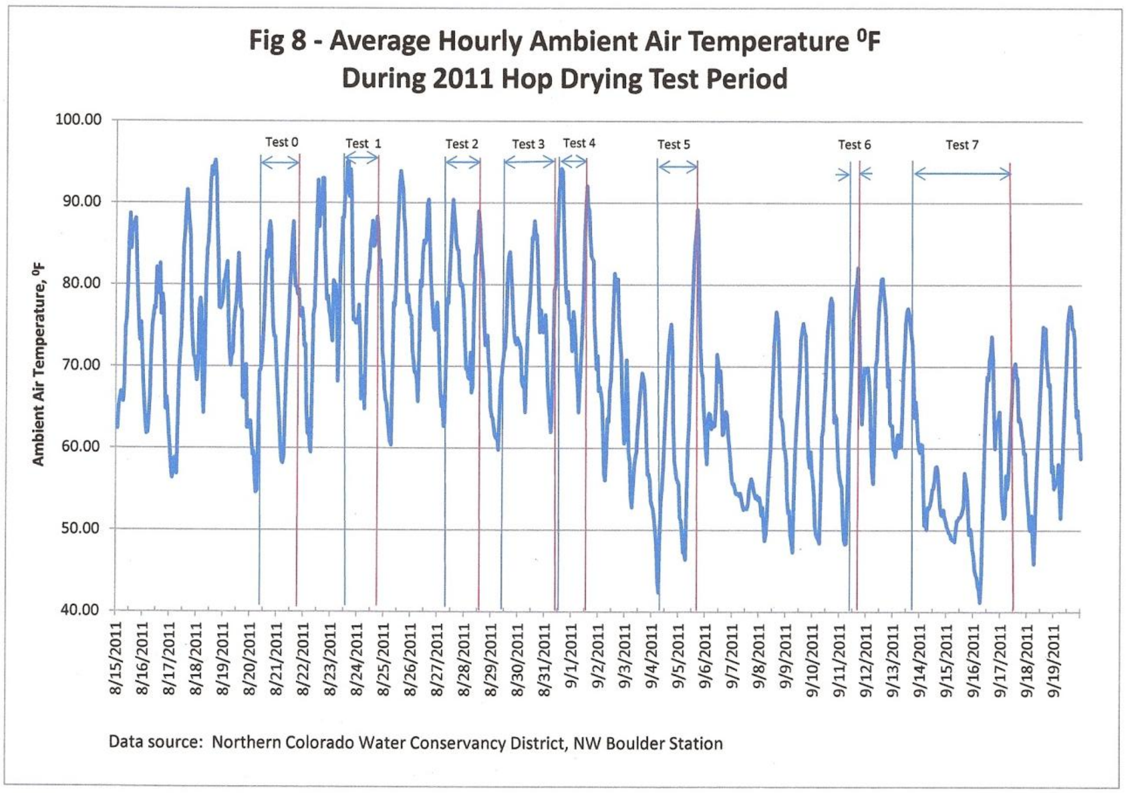
Comparing Tests 4 and 6 is useful in that similar hop quantities were dried but in quite different ambient weather conditions, Test 4 being roughly 10 to 20 ^{0}F warmer than Tests 6. Test 4 was in sunny conditions, Test 6 in cloudy conditions. The other major difference was the dryer hot air collection system, Test 4 using hot air collected from the top of the greenhouse and Test 6 collecting the hot air from the greenhouse roof plenum system. Much higher temperature air was available from the roof plenum system, reaching as high as 180 ^{0}F. Despite the ambient air temperature and cloudy weather disadvantage for Test 6, drying time was reduced to only approximately 6 hours, compared to about 10 hours without the plenum system operational.

A more detailed presentation of data for tests 4, 5, 6 and 7 follows. The results for tests 1 through 3 will be included in the final project report but are not reviewed in this interim report.

In future tests planned for 2012, the potential advantages of solar heated hot water assist in the drying will be researched and assessed, hopefully demonstrating a significantly reduced drying bed area requirement, and faster drying times to allow better more efficient work flow during the frantic harvest period. In these future 2012 tests additional continuous measurement of system temperatures for the hot water system are planned to be added to the measurements used in the hot air system of 2011. These will measure water temperatures in and out of the hot water collectors, storage tank and in heat exchanger loops within the dryer air stream. This will hopefully enable further evaluation of optimal drying operating conditions and design parameters for scale up designs.

Partial tables and graphs and other documentation (preliminary from 2011 data)

Following are graphs of the local temperature (Fig 8), relative humidity (Fig 9), and solar radiation (Fig 10) during the 2011 hop drying test period which spanned from 20 August through 17 September 2011. This data is from the Northern Colorado Water Conservancy District meteorological station, NW Boulder, Station 633. It is located approximately five miles directly west of the Andrews Farm and the site of the hop drying tests. It should be considered typical of the test site but not fully representative. The time frames of the individual tests are indicated on Figure 8. It is notable that tests 0 through 4 occurred during relatively warmer and higher solar intensity than tests 5, 6 and 7. Test #7 was particularly adverse to solar drying due to heavy cloud cover, high humidity/precipitation, and lower temperatures.



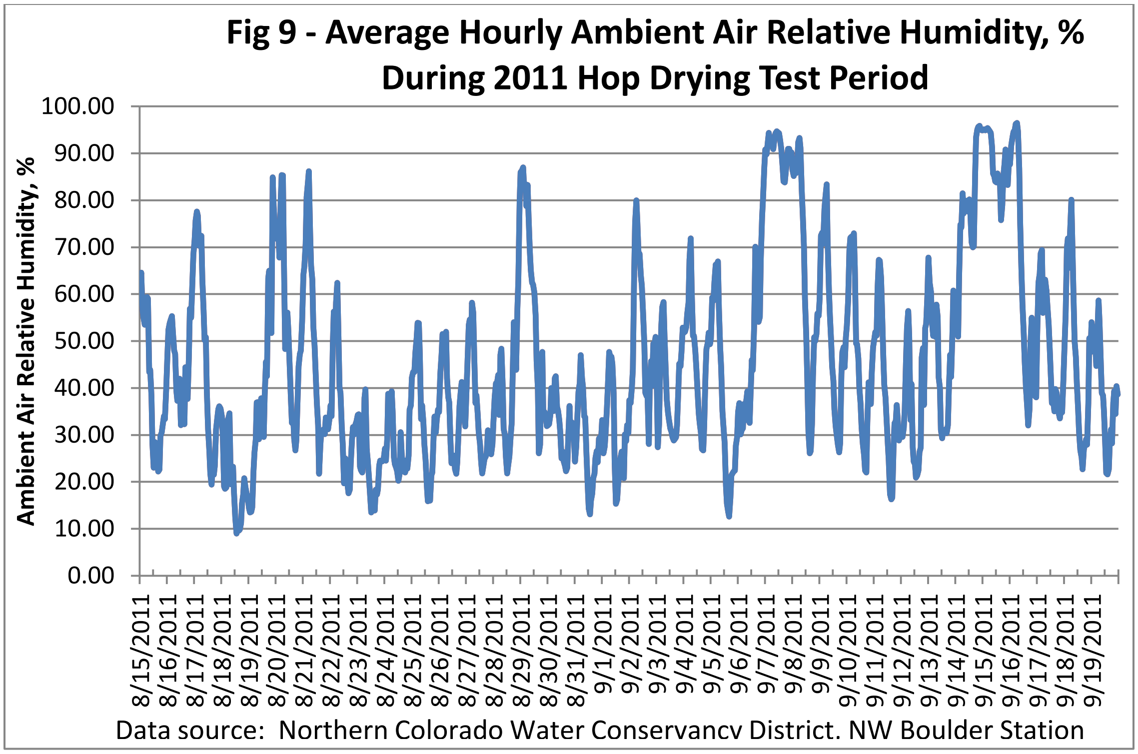


Fig 9 - Average Hourly Ambient Air Relative Humidity, %
During 2011 Hop Drying Test Period
Ambient Air Relative Humidity, %
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
8/15/2011
8/16/2011
8/17/2011
8/18/2011
8/19/2011
8/20/2011
8/21/2011
8/22/2011
8/23/2011
8/24/2011
8/25/2011
8/26/2011
8/27/2011
8/28/2011
8/29/2011
8/30/2011
8/31/2011
9/1/2011
9/2/2011
9/3/2011
9/4/2011
9/5/2011
9/6/2011
9/7/2011
9/8/2011
9/9/2011
9/10/2011
9/11/2011
9/12/2011
9/13/2011
9/14/2011
9/15/2011
9/16/2011
9/17/2011
9/18/2011
9/19/2011
Data source: Northern Colorado Water Conservancy District. NW Boulder Station

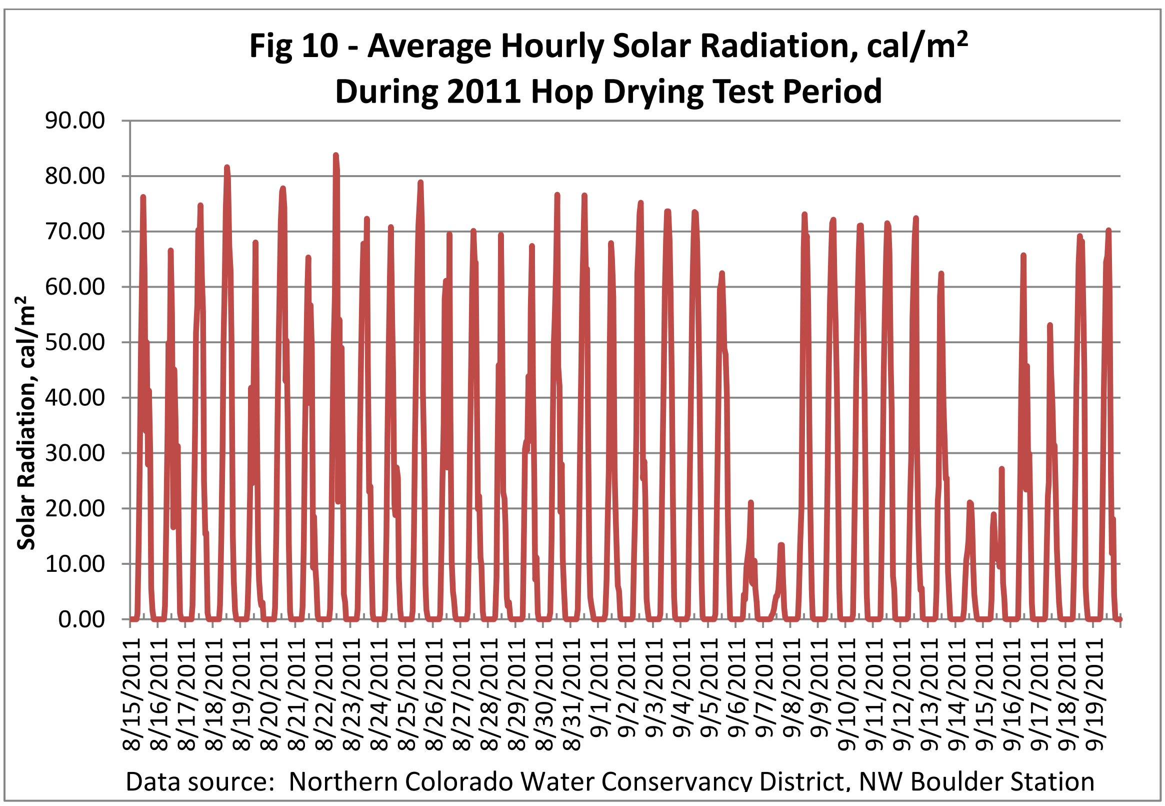
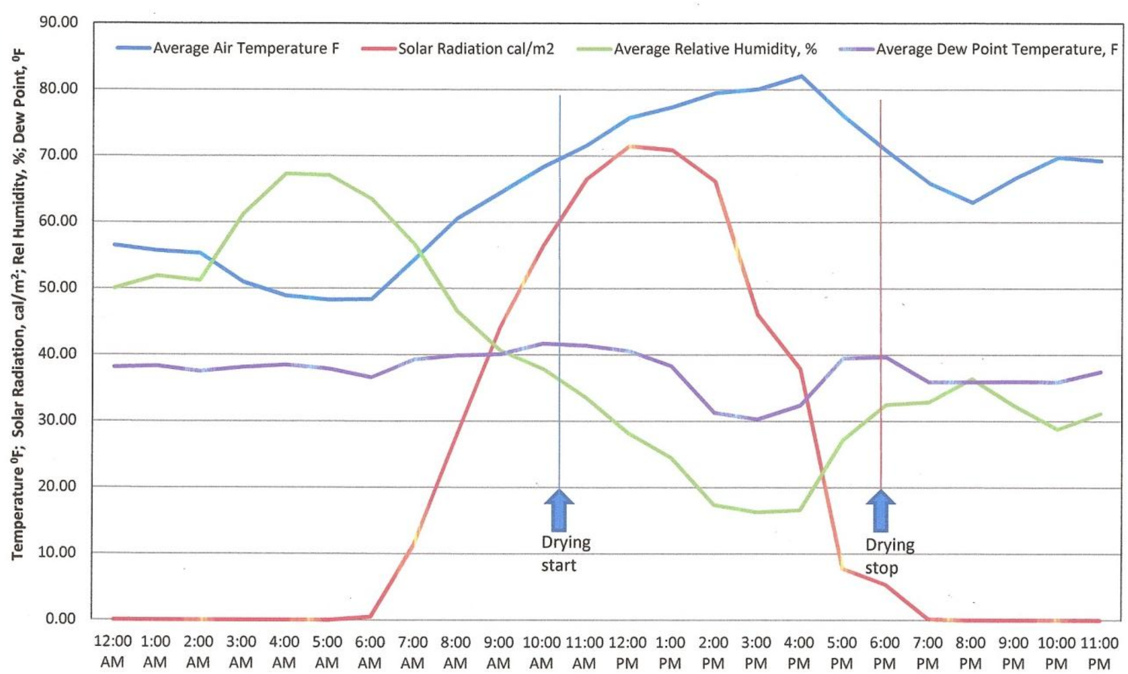


Fig 10 - Average Hourly Solar Radiation, cal/m²
During 2011 Hop Drying Test Period
Solar Radiation, cal/m²
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
8/15/2011
8/16/2011
8/17/2011
8/18/2011
8/19/2011
8/20/2011
8/21/2011
8/22/2011
8/23/2011
8/24/2011
8/25/2011
8/26/2011
8/27/2011
8/28/2011
8/29/2011
8/30/2011
8/31/2011
9/1/2011
9/2/2011
9/3/2011
9/4/2011
9/5/2011
9/6/2011
9/7/2011
9/8/2011
9/9/2011
9/10/2011
9/11/2011
9/12/2011
9/13/2011
9/14/2011
9/15/2011
9/16/2011
9/17/2011
9/18/2011
9/19/2011
Data source: Northern Colorado Water Conservancy District, NW Boulder Station

Tests No. 6 and 7 - Main Solar Hot Air Dryer Configuration with Hot Air Plenum

Following are graphs of the local ambient temperature, relative humidity, solar radiation and dew point for 2011 dryer tests numbers 6 and 7, Figure 11 and 12, respectively.

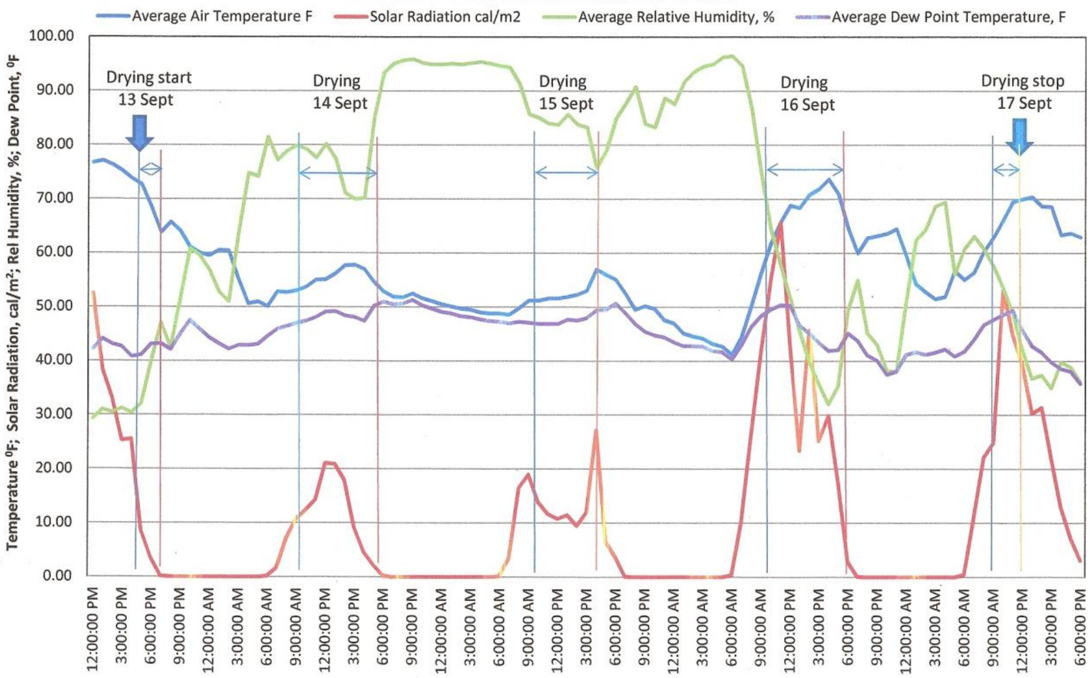
Fig. 11 - Hop Drying Test No. 6 - Sept 11, 2011
NCWCD Ambient Weather Data



Data source: Northern Colorado Water Conservancy District, Boulder NW station, hourly readings

Hop drying weather conditions while not ideal were generally favorable for Test No. 6 with good solar radiation, clear skies, low relative humidity, a low dew point, and ambient air temperatures ranging between 70 to low 80s ^{0}F during the daytime drying period (see begin and end vertical lines). Starting drying somewhat earlier in the day to catch the peak of solar radiation may have further enhanced and shortened the drying time. However, note the ambient air temperature peak somewhat lags by a few hours the peak in solar radiation. Hop drying to final moisture content near 10% by weight was achieved with relatively short period of approximately 7.5 hours elapsed time. Weather conditions were not as good as with Tests 1 through 4 which had higher ambient temperatures, generally clear skies, and low humidity.

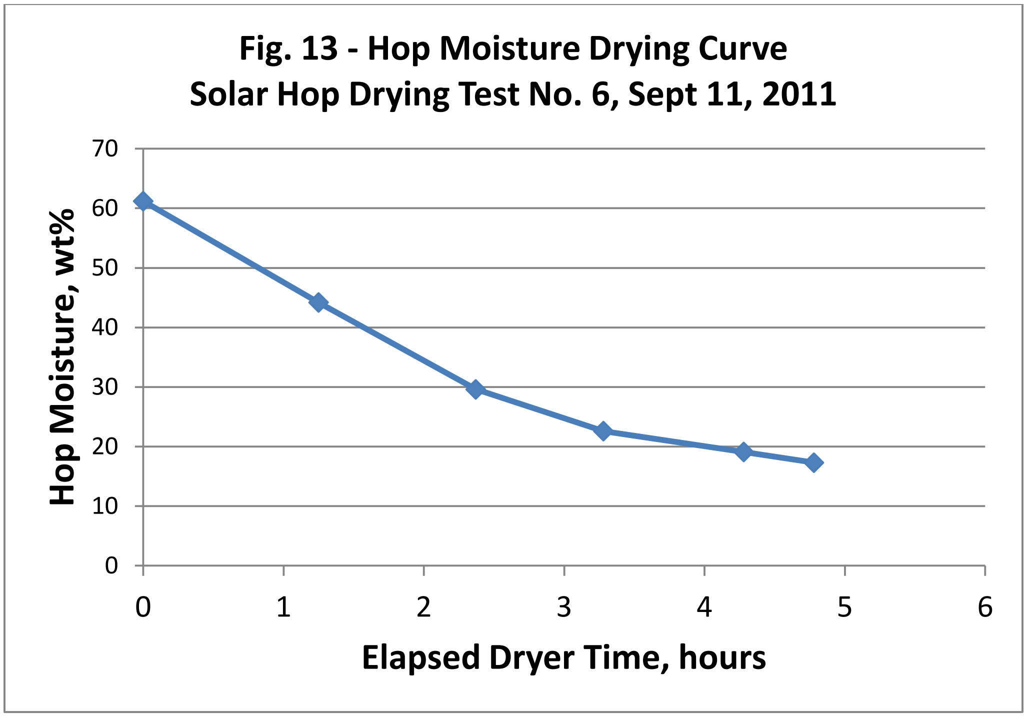
Fig 12 - Drying Test No. 7 - Sept 13-17, 2011
NCWCD Ambient Weather Data

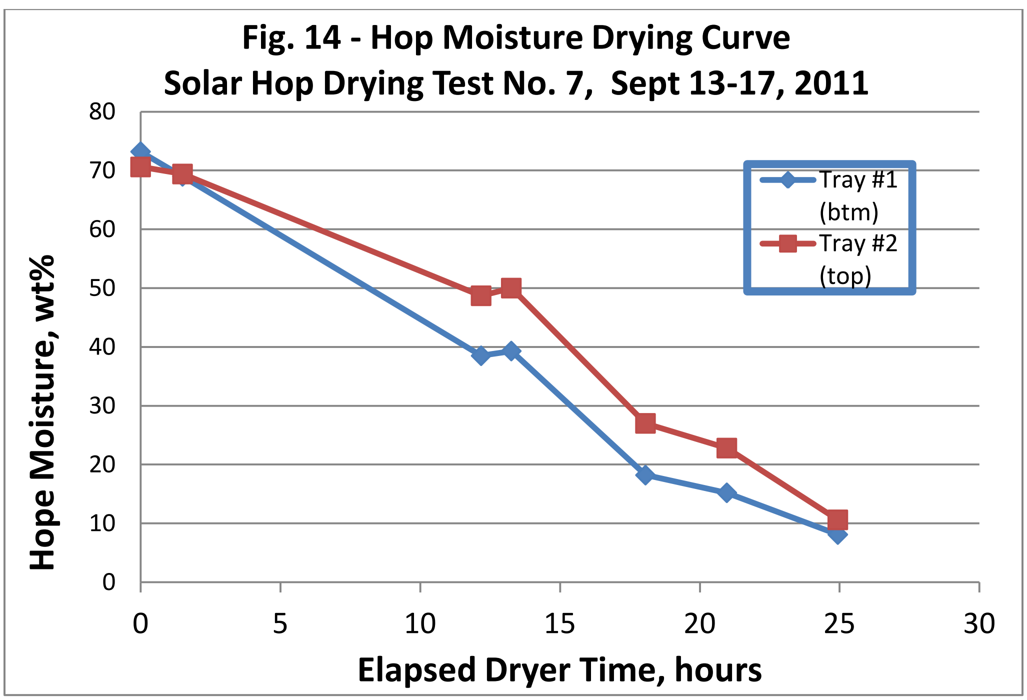


Data source: Northern Colorado Water Conservancy District, Boulder NW station, hourly readings

The ambient weather conditions for Test No. 7 were generally unfavorable for solar hop drying. Solar radiation (red trace) was low, less than 20 cal/m^2 during the days of 14 and 15 September due to rainy and heavily overcast conditions. Somewhat improved solar radiation conditions occurred on 16 and 17 September. Sunny daytime solar radiation is between 50 and 70 cal/m^2 for this time of year. For comparisons see Figure 8 to 10 for the conditions during the more favorable solar radiation period in earlier test numbers 1 through 4 and Test 6. The daytime ambient air temperatures (blue trace) were hovering around the mid 50s ^{0}F on 14-15 Sept , improving somewhat for 16-17 September, but only reaching high 60s to low 70s ^{0}F. Relative humidity levels were also elevated for most of the test, ranging from 40% to over 90%. With these high humidity levels hops could reabsorb moisture overnight after a day of drying, further extending the total drying time required to reach the final desired moisture level of about 10% by weight. The dew point temperature was very close to ambient temperature during portions of test no. 7, a measure of this tendency for possible re-absorption of moisture. The barn was kept closed during nights to try to avoid this problem.

Following are graphs for the hop drying curves during test numbers 6 and 7, illustrating the hops moisture content versus drying time; see Figures 13 and 14, respectively.





As noted previously, the weather conditions during Test No. 7 were adverse for solar drying, low temperatures, poor solar radiation, cloudy with precipitation, and high relative humidity.

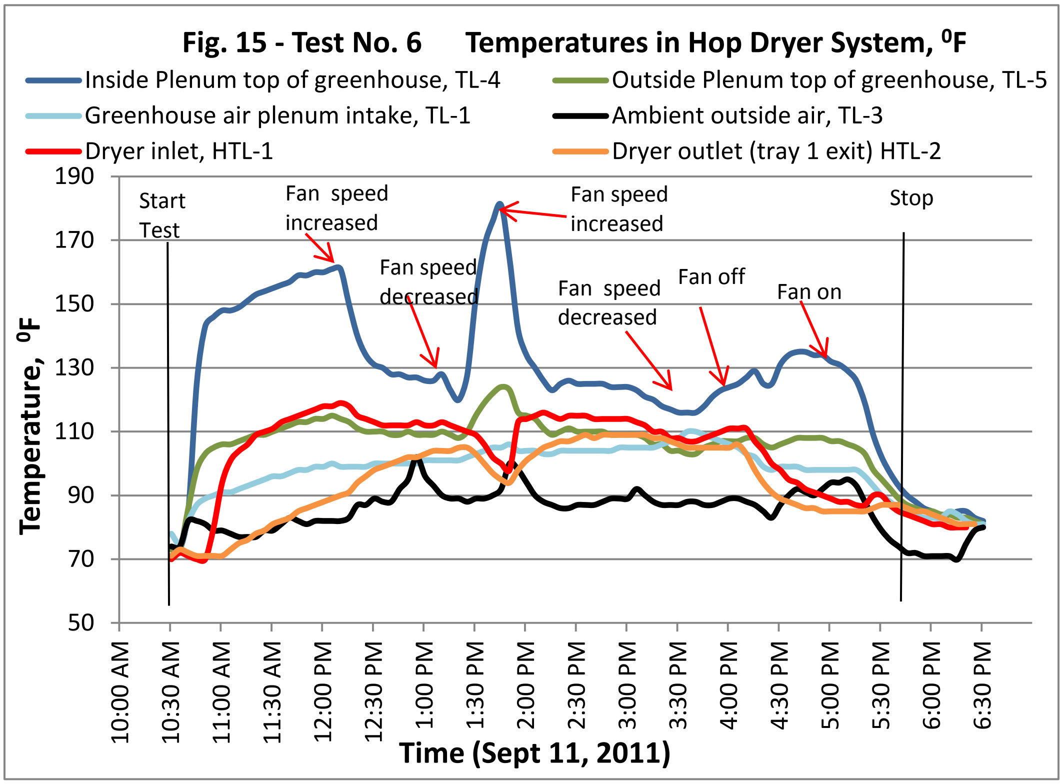


Fig. 15 - Test No. 6 Temperatures in Hop Dryer System, ^{0}F
Inside Plenum top of greenhouse, TL-4
Outside Plenum top of greenhouse, TL-5
Greenhouse air plenum intake, TL-1
Ambient outside air, TL-3
Dryer inlet, HTL-1
Dryer outlet (tray 1 exit) HTL-2
Start Test
Fan speed increased
Fan speed decreased
Fan speed increased
Fan speed decreased
Fan off
Fan on
Stop
Temperature, ^{0}F
190
170
150
130
110
90
70
50
10:00 AM
10:30 AM
11:00 AM
11:30 AM
12:00 PM
12:30 PM
1:00 PM
1:30 PM
2:00 PM
2:30 PM
3:00 PM
3:30 PM
4:00 PM
4:30 PM
5:00 PM
5:30 PM
6:00 PM
6:30 PM
Time (Sept 11, 2011)

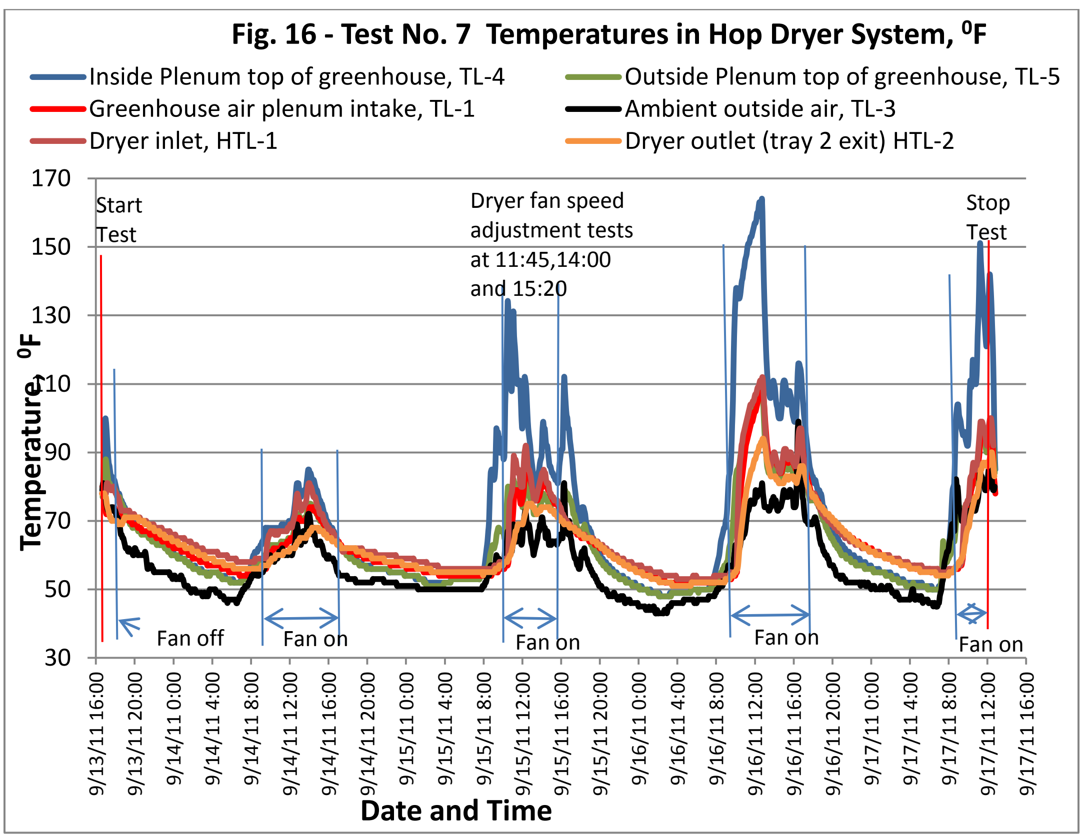


Fig. 16 - Test No. 7 Temperatures in Hop Dryer System, ^{0}F
Inside Plenum top of greenhouse, TL-4
Outside Plenum top of greenhouse, TL-5
Greenhouse air plenum intake, TL-1
Ambient outside air, TL-3
Dryer inlet, HTL-1
Dryer outlet (tray 2 exit) HTL-2
Start Test
Dryer fan speed adjustment tests at 11:45,14:00 and 15:20
Stop Test
Fan off
Fan on
Fan on
Fan on
Fan on
Temperature, ^{0}F
170
150
130
110
90
70
50
30
9/13/11 16:00
9/13/11 20:00
9/14/11 0:00
9/14/11 4:00
9/14/11 8:00
9/14/11 12:00
9/14/11 16:00
9/14/11 20:00
9/15/11 0:00
9/15/11 4:00
9/15/11 8:00
9/15/11 12:00
9/15/11 16:00
9/15/11 20:00
9/16/11 0:00
9/16/11 4:00
9/16/11 8:00
9/16/11 12:00
9/16/11 16:00
9/16/11 20:00
9/17/11 0:00
9/17/11 4:00
9/17/11 8:00
9/17/11 12:00
9/17/11 16:00
Date and Time

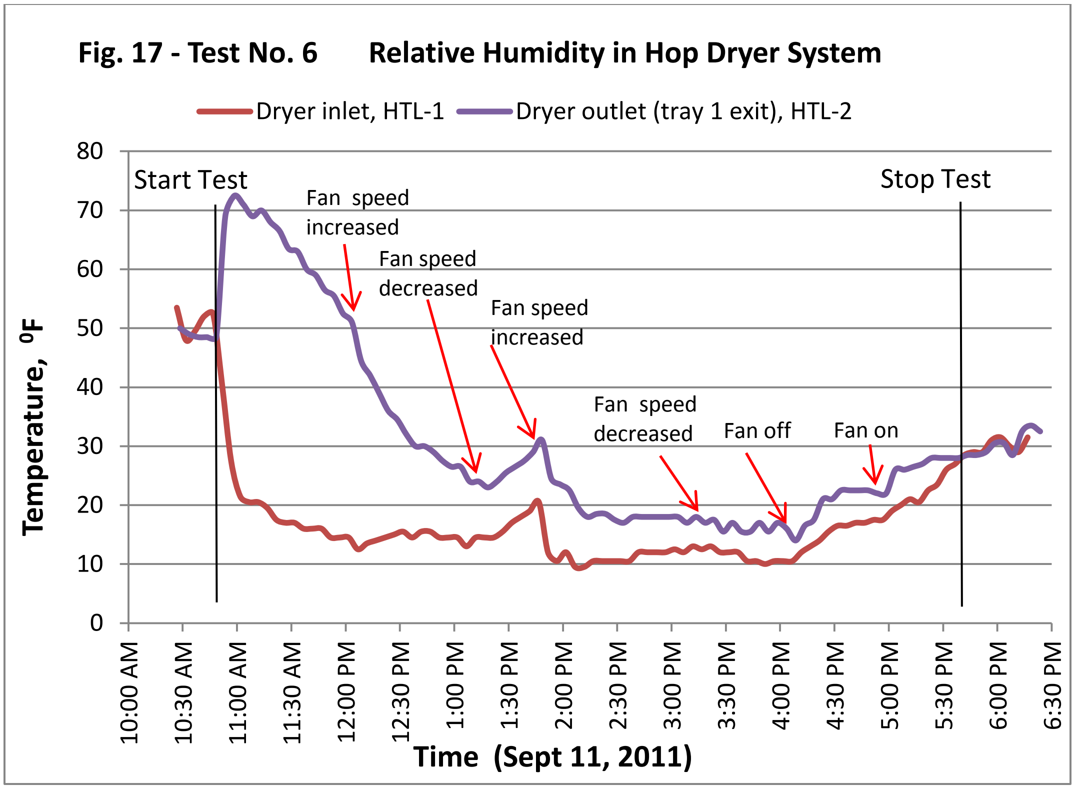


Fig. 17 - Test No. 6 Relative Humidity in Hop Dryer System
Dryer inlet, HTL-1
Dryer outlet (tray 1 exit), HTL-2
Start Test
Stop Test
Fan speed increased
Fan speed decreased
Fan speed increased
Fan speed decreased
Fan off
Fan on
Temperature, ^{0}F
0
10
20
30
40
50
60
70
80
10:00 AM
10:30 AM
11:00 AM
11:30 AM
12:00 PM
12:30 PM
1:00 PM
1:30 PM
2:00 PM
2:30 PM
3:00 PM
3:30 PM
4:00 PM
4:30 PM
5:00 PM
5:30 PM
6:00 PM
6:30 PM
Time (Sept 11, 2011)

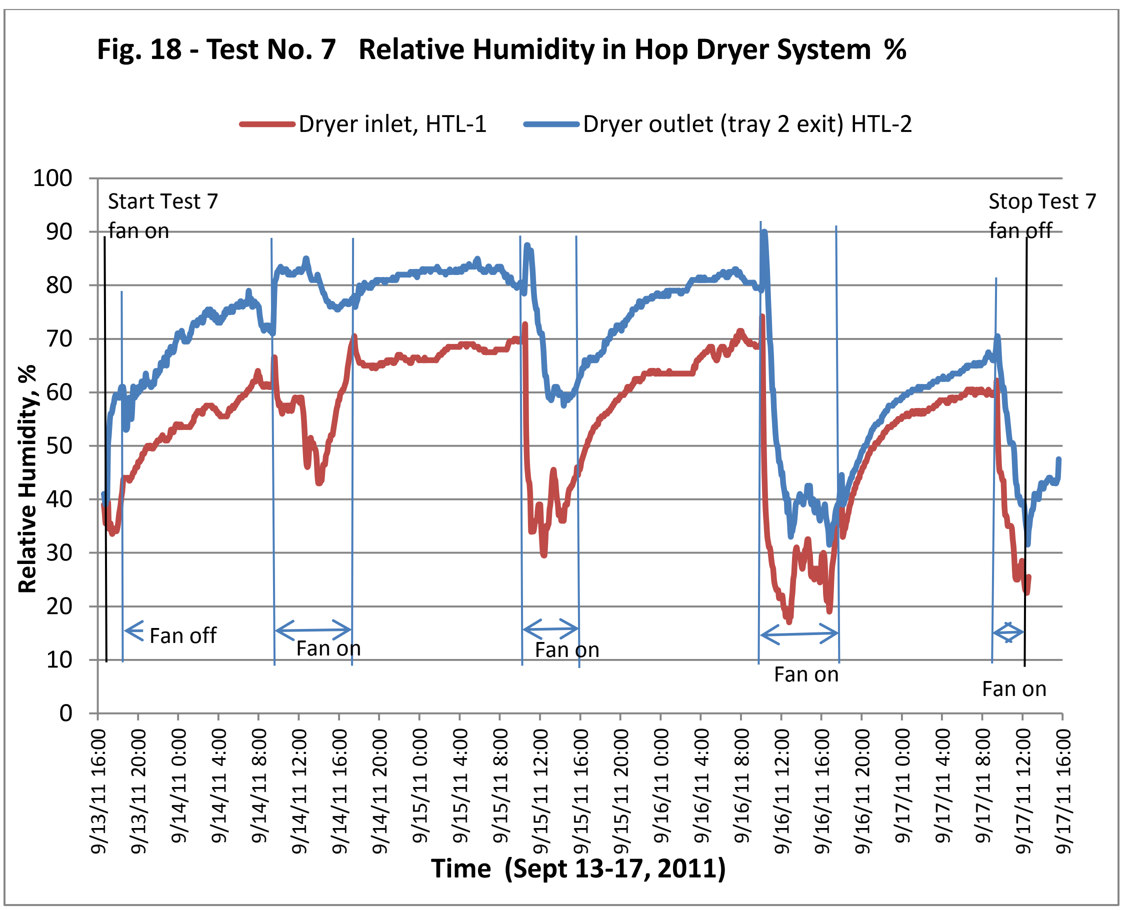


Fig. 18 - Test No. 7 Relative Humidity in Hop Dryer System %
Dryer inlet, HTL-1
Dryer outlet (tray 2 exit) HTL-2
Start Test 7 fan on
Stop Test 7 fan off
Fan off
Fan on
Fan on
Fan on
Fan on
Relative Humidity, %
0
10
20
30
40
50
60
70
80
90
100
9/13/11 16:00
9/13/11 20:00
9/14/11 0:00
9/14/11 4:00
9/14/11 8:00
9/14/11 12:00
9/14/11 16:00
9/14/11 20:00
9/15/11 0:00
9/15/11 4:00
9/15/11 8:00
9/15/11 12:00
9/15/11 16:00
9/15/11 20:00
9/16/11 0:00
9/16/11 4:00
9/16/11 8:00
9/16/11 12:00
9/16/11 16:00
9/16/11 20:00
9/17/11 0:00
9/17/11 4:00
9/17/11 8:00
9/17/11 12:00
9/17/11 16:00
Time (Sept 13-17, 2011)

Observations from tests numbers 6 and 7 reveal several things that will result in improved designs and operation for future solar dryer systems. Major temperature drop is occurring between the relatively high temperatures inside the greenhouse roof air plenum, often in excess of 150 F, and the inlet of the hop dryer, on the order of 100 to 120 F. The available drying heat losses are thought to be due to significant dilution air entering the ducting system and the dryer enclosure. The result being more extended drying times than possible without these losses. Insulation of the ducting may also improve the system to prevent these temperature drops and heat losses between the hot air plenum collector and the inlet to the dryer. From air velocity measurements, hop blow out and lofting velocities were observed for the hop bed depths studied (data not reported in this interim report). This information will be used in subsequent dryer tray designs to avoid these conditions. Tracking the differential between dryer inlet and outlet relative humidity (fig 17 and Fig 18 above) illustrates that this measurement may be able to identify when hop drying has reached desired commercially desired final condition of near 10%. More work is appropriate to refine these evaluations to possibly lead to a control parameter. (See also Figures 22 and 25 for tests 4 and 5).

Another key observation during drying test number 7 was the difficulty with solar drying in periods of inclement weather, lower air temperatures, excessive cloudiness and rainy-humid conditions. Test 7 required parts of four consecutive days to reach final hop dryness conditions. This is unacceptable for commercial operations. It points out that unless improvements noted above can shorten the drying period, solar heat storage for non-daylight hour drying, or supplementing with fossil fuel based energy is necessary. Tests during 2012 will examine these options seeking revised designs to avoid the need for fossil fuel based drying.

<u>Drying Test No. 5 – Alternative Dryer Configuration (without hot air plenum system)</u>

For comparison with a different hot air collection and dryer configuration, the following data is presented for Test No. 5. This test was conducted using hot air collection from both the top of the greenhouse with an induced draft centrifugal fan, and near ground level of the greenhouse with a forced air fan(only for the initial part of the test). The hot air plenum collection system was not yet installed inside the greenhouse roof for this test. Three trays of hops were dried in a single stack configuration, depth of hops from 3.5 to 4.5 inches (8.9 to 11.4 cm). Total drying time spanned parts of two days for Test No. 5, with a total elapsed drying period of approximately 16 hours, not including the overnight period between 18:00 and 09:00 when hot air circulation fans were not operated.

Figure 19 presents the local ambient weather conditions during Test No.5. Figure 20 presents the moisture drying curve; Figure 21 presents the temperature conditions within the dryer system versus time; Figure 22 presents the humidity conditions in the dryer system. The ambient weather conditions for Test No. 5 were more comparable to Test No. 6 than the warmer and sunnier conditions of Tests 1 thru 4, hence make for better comparisons of performance between tests 5 and 6.

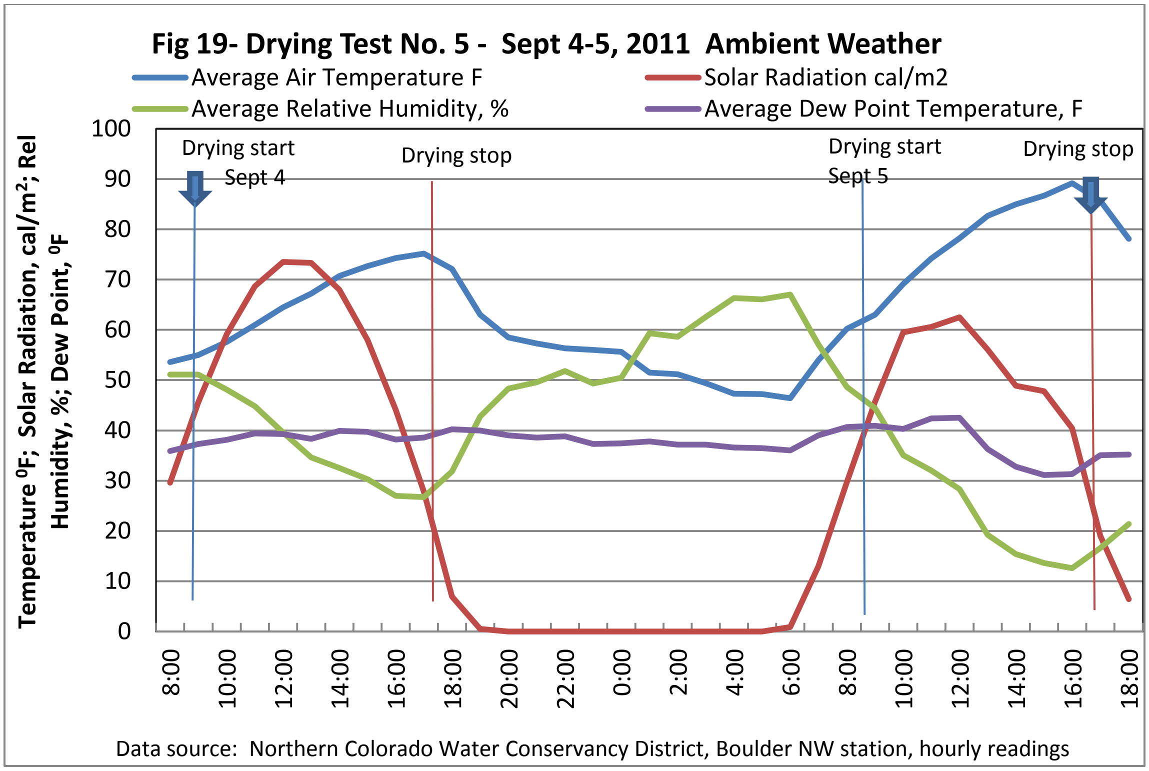


Fig 19- Drying Test No. 5 - Sept 4-5, 2011 Ambient Weather
Average Air Temperature F
Solar Radiation cal/m2
Average Relative Humidity, %
Average Dew Point Temperature, F
Temperature ⁰F; Solar Radiation, cal/m²; Rel Humidity, %; Dew Point, ⁰F
Drying start Sept 4
Drying stop
Drying start Sept 5
Drying stop
100
90
80
70
60
50
40
30
20
10
0
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
Data source: Northern Colorado Water Conservancy District, Boulder NW station, hourly readings

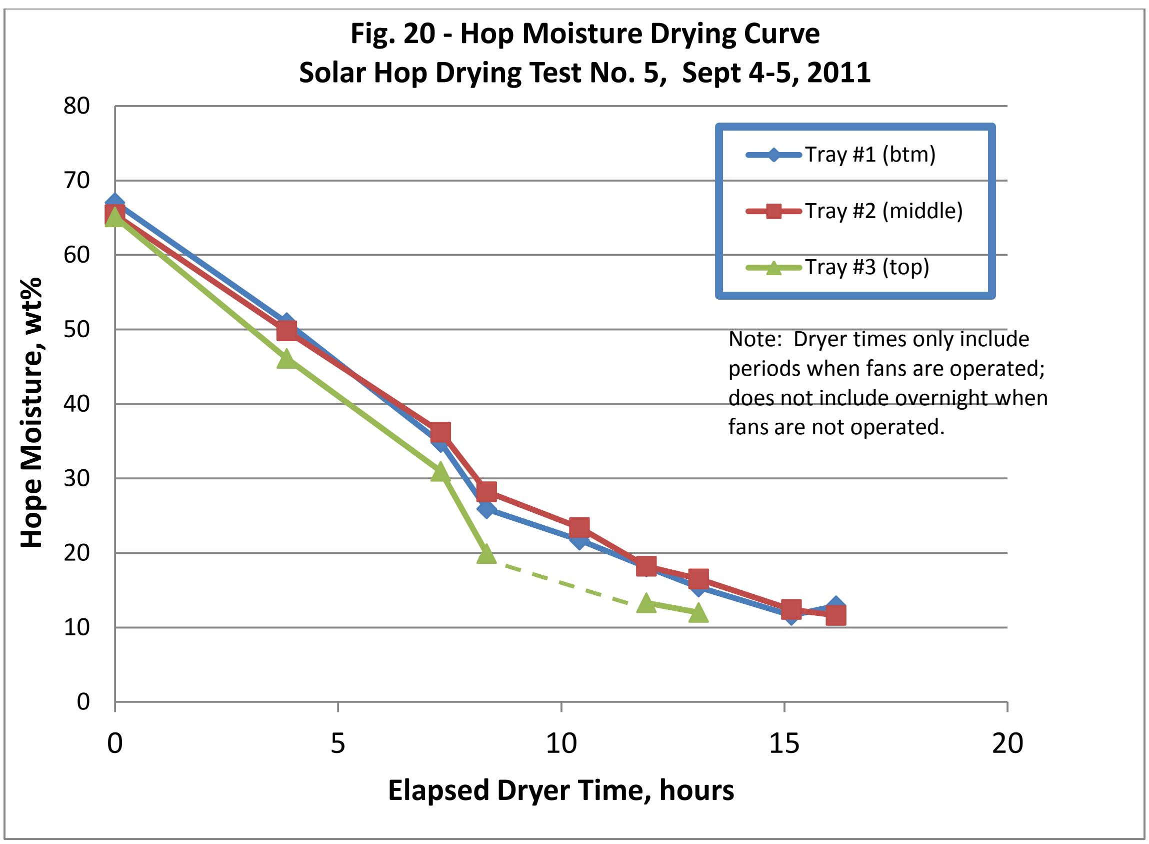


Fig. 20 - Hop Moisture Drying Curve
Solar Hop Drying Test No. 5, Sept 4-5, 2011
Tray #1 (btm)
Tray #2 (middle)
Tray #3 (top)
Note: Dryer times only include periods when fans are operated; does not include overnight when fans are not operated.
Hope Moisture, wt%
80
70
60
50
40
30
20
10
0
0
5
10
15
20
Elapsed Dryer Time, hours

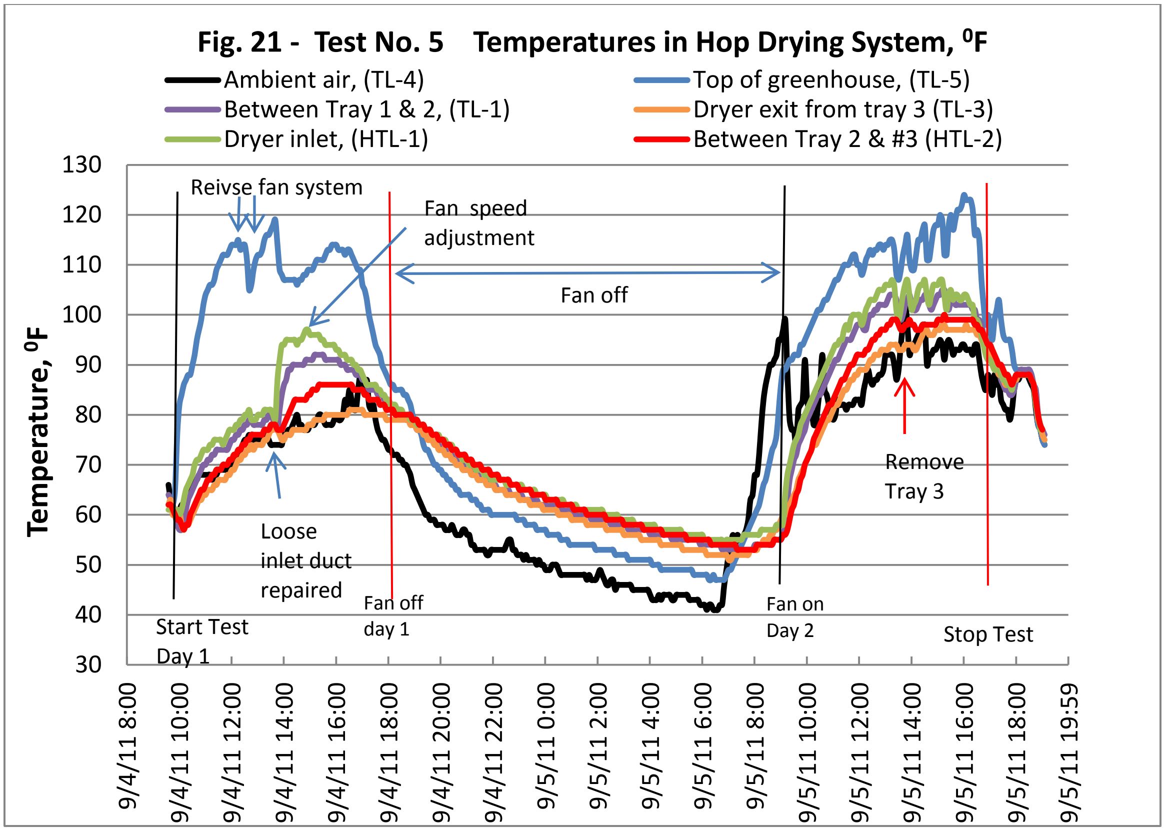


Fig. 21 - Test No. 5 Temperatures in Hop Drying System, ^{0}F
Ambient air, (TL-4)
Top of greenhouse, (TL-5)
Between Tray 1 & 2, (TL-1)
Dryer exit from tray 3 (TL-3)
Dryer inlet, (HTL-1)
Between Tray 2 & #3 (HTL-2)
Temperature, ^{0}F
Reivse fan system
Fan speed
adjustment
Fan off
Loose
inlet duct
repaired
Fan off
day 1
Fan on
Day 2
Remove
Tray 3
Start Test
Day 1
Stop Test
130
120
110
100
90
80
70
60
50
40
30
9/4/11 8:00
9/4/11 10:00
9/4/11 12:00
9/4/11 14:00
9/4/11 16:00
9/4/11 18:00
9/4/11 20:00
9/4/11 22:00
9/5/11 0:00
9/5/11 2:00
9/5/11 4:00
9/5/11 6:00
9/5/11 8:00
9/5/11 10:00
9/5/11 12:00
9/5/11 14:00
9/5/11 16:00
9/5/11 18:00
9/5/11 19:59

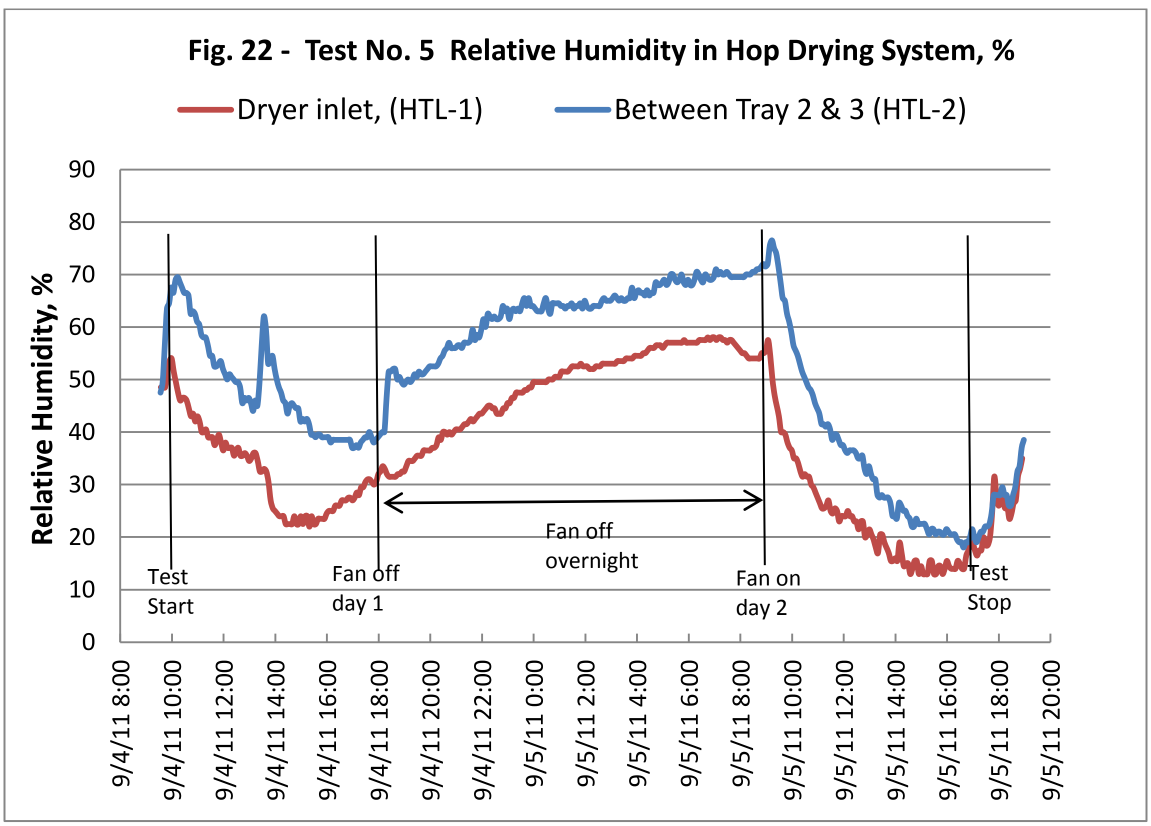


Fig. 22 - Test No. 5 Relative Humidity in Hop Drying System, %
Dryer inlet, (HTL-1)
Between Tray 2 & 3 (HTL-2)
Relative Humidity, %
Test
Start
Fan off
day 1
Fan off
overnight
Fan on
day 2
Test
Stop
90
80
70
60
50
40
30
20
10
0
9/4/11 8:00
9/4/11 10:00
9/4/11 12:00
9/4/11 14:00
9/4/11 16:00
9/4/11 18:00
9/4/11 20:00
9/4/11 22:00
9/5/11 0:00
9/5/11 2:00
9/5/11 4:00
9/5/11 6:00
9/5/11 8:00
9/5/11 10:00
9/5/11 12:00
9/5/11 14:00
9/5/11 16:00
9/5/11 18:00
9/5/11 20:00

Test number 5 results illustrate that drying can be achieved when weather conditions are better than those occurring during Test No. 7. Various air velocities were tested during this test. More detailed analysis of those measurements will be presented in the final project report. Similar observations about the temperature drop (heat loss or available drying energy) from the hot air collected at the top of the greenhouse and the dryer inlet were observed, as with test number 6 and 7. Some of losses occurring in Test 5 were caused by some ducting that had come partly unattached in day 1. Once corrected the dryer inlet temperatures rose by nearly 20 F.

Drying Test No. 4 –
Alternative Dryer Configuration (without hot air plenum/more favorable weather)

Hop drying Test number 4 was conducted without hot air collection from the later installed hot air plenum system (Tests 6 and 7) but under more favorable solar and air temperature conditions. Test 4 used dryer hot air collected from the top of the greenhouse.

Air temperatures during daylight hours were in the 80s and 90s F, compared to temperatures in the 60s and 70s during tests 6 an 7. Solar radiation was considerable higher and humidity was lower. Drying was only begun by mid day on the first day of drying, stopped by 17:30 hours, began again at 0:800 and was complete by 13:30 hours on the second day, a total time with fans operating of hours. Drying may have been possible to complete in a single day if commenced earlier. The late starting schedule was dictated by availability of fresh hops to dry. Figures 23 through 26 present the ambient weather, hop moisture drying curve, dryer system temperature and dryer system relative humidity, respectively for Test number 4.

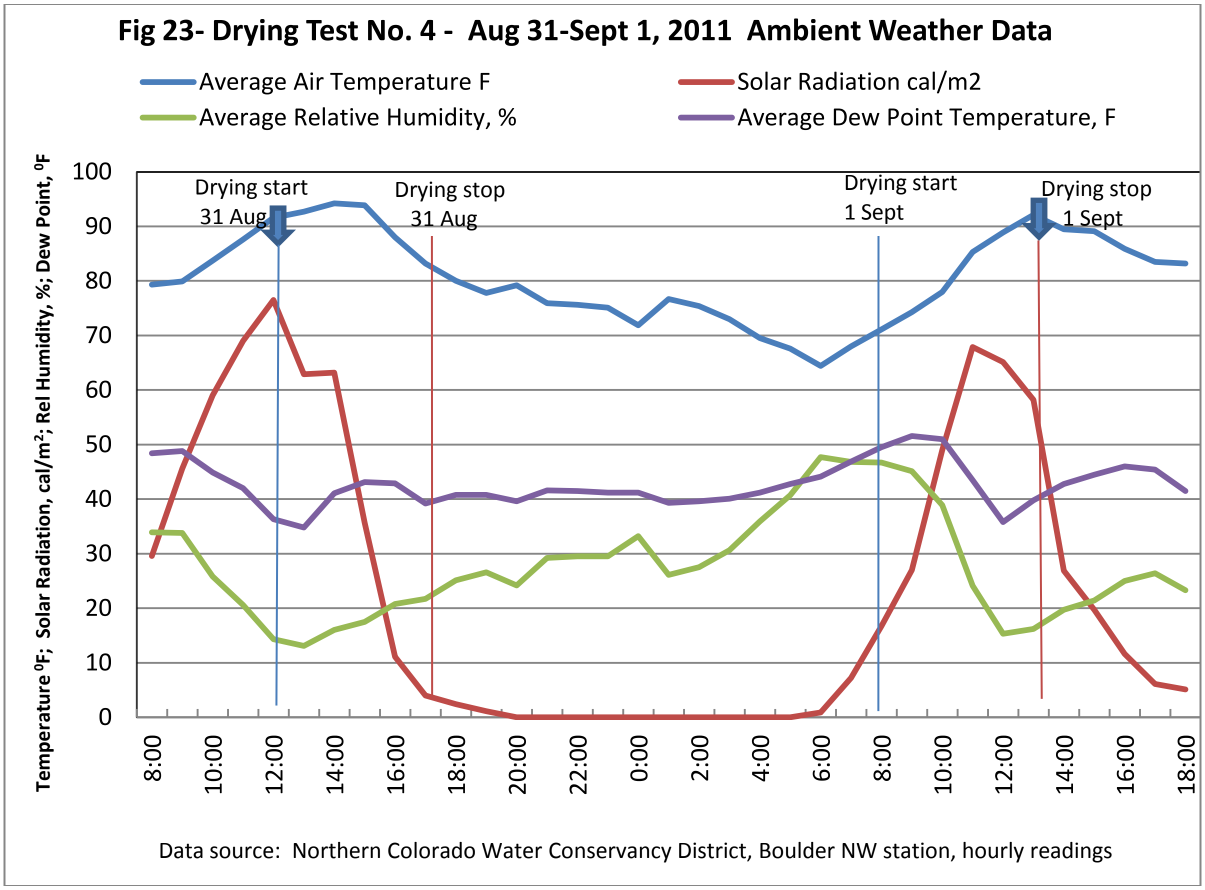


Fig 23- Drying Test No. 4 - Aug 31-Sept 1, 2011 Ambient Weather Data
Average Air Temperature F
Solar Radiation cal/m2
Average Relative Humidity, %
Average Dew Point Temperature, F
Temperature °F; Solar Radiation, cal/m²; Rel Humidity, %; Dew Point, °F
100
90
80
70
60
50
40
30
20
10
0
Drying start 31 Aug
Drying stop 31 Aug
Drying start 1 Sept
Drying stop 1 Sept
8:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
0:00
2:00
4:00
6:00
8:00
10:00
12:00
14:00
16:00
18:00
Data source: Northern Colorado Water Conservancy District, Boulder NW station, hourly readings

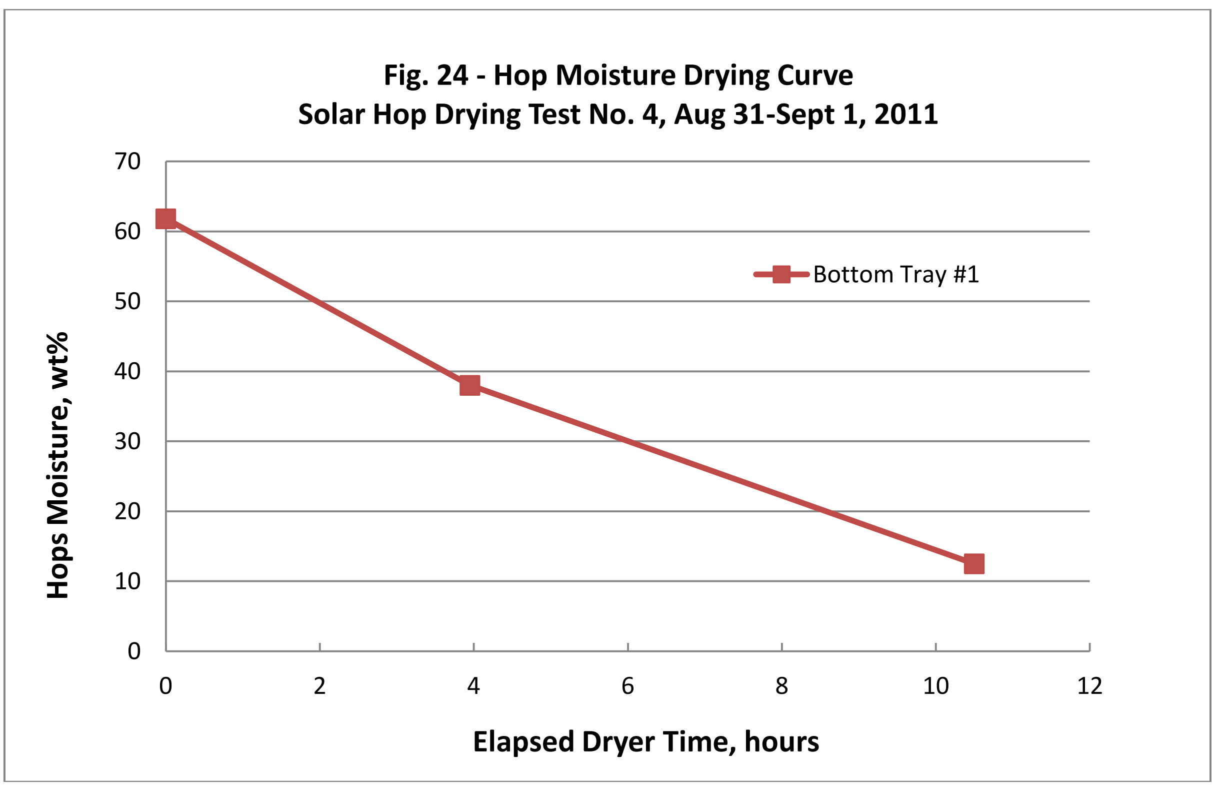


Fig. 24 - Hop Moisture Drying Curve
Solar Hop Drying Test No. 4, Aug 31-Sept 1, 2011
Bottom Tray #1
Hops Moisture, wt%
70
60
50
40
30
20
10
0
0
2
4
6
8
10
12
Elapsed Dryer Time, hours

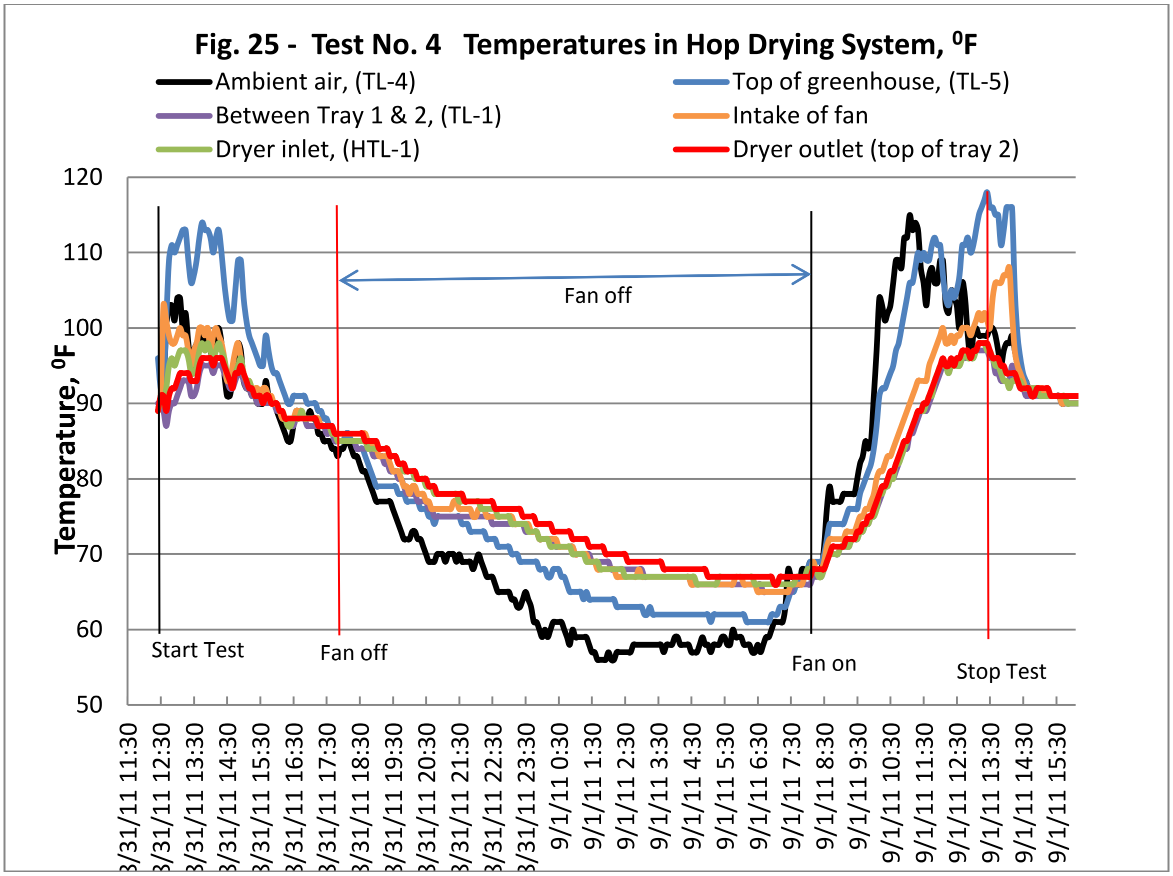


Fig. 25 - Test No. 4 Temperatures in Hop Drying System, ^{0}F
Ambient air, (TL-4)
Top of greenhouse, (TL-5)
Between Tray 1 & 2, (TL-1)
Intake of fan
Dryer inlet, (HTL-1)
Dryer outlet (top of tray 2)
Temperature, ^{0}F
Fan off
Start Test
Fan off
Fan on
Stop Test

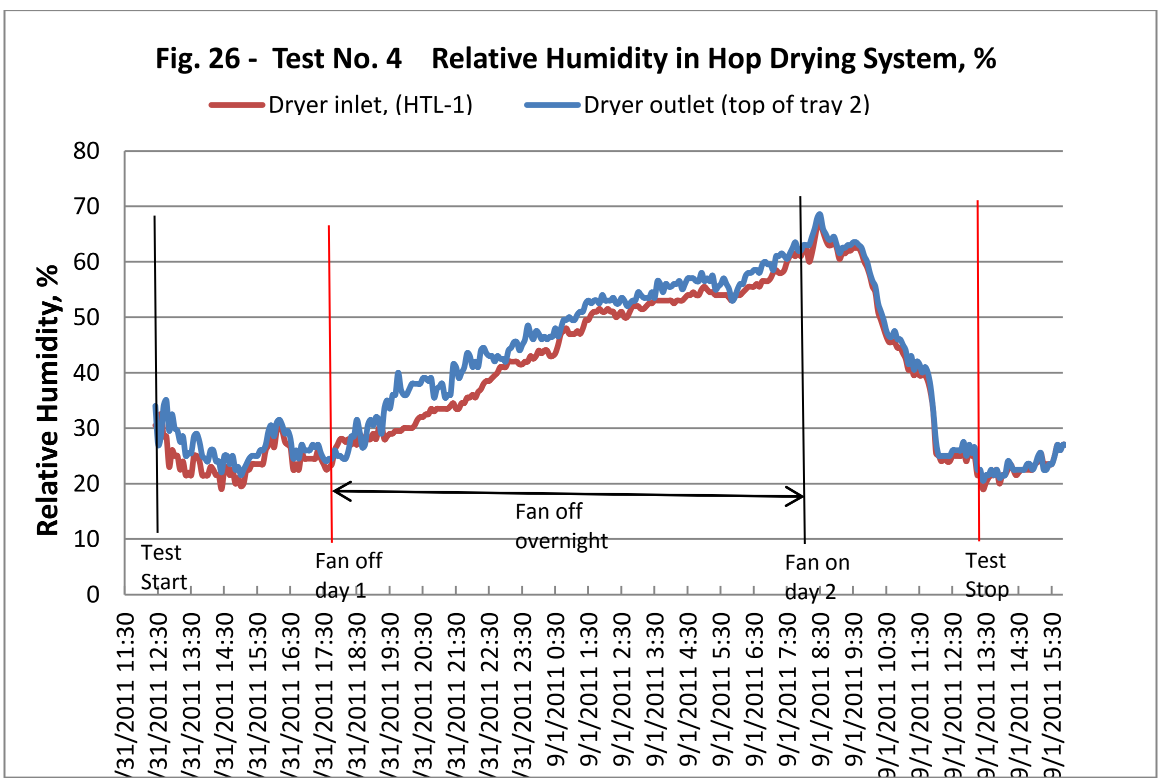


Fig. 26 - Test No. 4 Relative Humidity in Hop Drying System, %
Dryer inlet, (HTL-1)
Dryer outlet (top of tray 2)
Relative Humidity, %
Fan off
overnight
Test
Start
Fan off
day 1
Fan on
day 2
Test
Stop

Tests 0 thru 3 - Other Design and Operating Configurations

All of the test data for tests 0 thru 3 is available in MicroSoft Excel 2007 worksheets and lab notebooks and will ultimately be available on an accompanying compact disk or memory stick. This data has not been completely analyzed at this time. These tests did not involve the plenum hot air collection system and are deemed a less important part of this study. Test 0 was primarily a system dry run check of equipment and monitoring instruments. Similar graphical and tabular presentation of data for all of the drying tests (including Tests 1 through 3) conducted during 2011 will be presented in the final report for the project at the end of 2012, including a more complete evaluation, data interpretations, design parameter recommendations, and conclusions.

Other data:

A great deal of additional monitoring data was collected during the 2011 series of solar hop drying tests. That data includes air velocity measurements with different fan operating set ups and manually recorded data for temperatures and humidity throughout the system with different equipment configurations. This information will be tabulated and interpreted for the final project report, potentially providing additional insights.

Herb Drying Tests –

No herb drying tests (other than hops) were conducted during 2011. No English Comfrey was harvested for commercial sale during 2011, only used for on farm compost, fertility, and mulch purposes in the farm vegetable operations. Some such tests with English Comfrey and perhaps other herbs (calendula and/or various mint crops) are anticipated during the upcoming 2012 year, time, facilities, and resources permitting.

From brief tests with English Comfrey leaf during 2010 ambient air drying was able to effectively dry leaf in a few days. The 2011 improved hot air solar dryer is expected to function quite effectively with herbs, better now that elevated temperatures can be achieved with the greenhouse roof plenum heat gathering system. Drying should be able to occur quicker, within a single sunny day. Figure 27 illustrates the dried Comfrey in the dryer trays (photo taken in 2010). In support of the herb business a hammer mill has been installed in the hops and herb processing barn to process dried herbs such as comfrey into tea size particles following drying and to prepare them for commercial sale, a 240 volt 3 phase hammer mill which operates with on site generated photovoltaic electrical energy.

Figure 27 - Ambient Air Dried English Comfrey (2010 test year)

Supplemental Testing of Hops and Leaf/steam Air Classification –

Although not a part of the GREG research program, additional modifications to the hops dryer were made to further investigate the potential dual use of the facility for separation of hop flower from leaf and stem prior to solar drying. Figures 28 and 29 illustrate a special bottom drawer that was constructed and a feeder arrangement that was installed to dribble the combined hop flower and leaf/stem into the winnower. This system functioned but not well and still needs considerable refinement or total new approaches to obtain acceptable separations and feeding arrangements. The conical feed tank had too narrow discharge point and easily plugged up resulting it its abandonment and substitution of hand feeding into the air stream. The air velocities were not sufficient high to obtain good leaf blow over and considerable recycling was necessary to obtain leaf free hop flower. The winnowing system used in 2010 actually functioned better than the revisions tried during 2011. It may not be reasonable to continue to attempt a combined function use of the dryer to also serve as a winnower. For most of the 2011 harvest hand hop picking was used instead of this winnowing separation. Figure 30 illustrates the separation achieved by the system as used during 2010.

Figure 28 - Hops Air Classifer-Winnower system 2011 (with observation windows and variable height and spacing moveable baffles)

Figure 29 - Conical hop feeder bin and vibratory pan feeder system for winnowing hops

Figure 30 - Air Classifying/Winnowing for separation of fresh hop flowers from Leaf and stem (air flow was from left to right)

Preliminary Conclusions and Discussion –

a. What was learned from the project (in 2011)?

During the August-September 2011 hop drying season we learned that improved solar hot air collection system could significantly speed the drying time, compared to the ambient air drying which was tested during the 2010 season. The relatively simple hot air collection system using a black plastic layer mounted on the underside of the greenhouse roof was very effective and could achieve elevated temperature of 150 ^{0}F or higher. Actual temperatures into the dryer trays was regulated to not exceed 125 to 130 ^{0}F for most cases however.

With good air temperatures and good solar radiation, hop drying can be accomplished in a single day if dryer is loaded early in the day. Even using ambient unheated air (Tests 1 & 2) during favorable weather conditions with inlet dryer temperatures of mid 90s ^{0}F can be achieved. With air drawn from inside a greenhouse (Tests 3 thru 5), not using any special concentrated hot air collection system (such as the roof plenum collectors of Test 6 & 7), drying can be enhanced (see Test 4) and accomplished in a single day. With an improved concentrated hot air collection system such as the hot air plenum, drying can be accomplished in a single day, even with ambient temperatures in the mid 70s ^{0}F. On cloudy and heavily overcast days (Test 7) there was a considerable diminishment in available drying capacity and the drying times became more extended than desirable to keep up with harvest hop picking production. Daytime ambient air temperatures during Test 7 were in the mid 40s to mid 50s ^{0}F with high humidity and nearly complete cloud cover. This situation needs to be overcome by some form of either a backup supplemental heating source or by stored solar thermal energy that can be used during unfavorable solar drying weather conditions. That will be addressed in plans for tests and the second phase using solar hot water collection systems during 2012.

Considerable heat loss and drop in temperature from the high temperatures of the hot air plenum or even from near the top of the greenhouse was observed with the ducting and dryer system. For 2012 a much tighter system with better insulation and less dilution air leakage will be built to improve on the present dryer design. This is anticipated to greatly reduce drying times by allowing dryer inlet temperature to approach 110 to 125 F, instead of the maximums of between 115 and 120 F during the 2011 test series.

Limited evaluation of optimal drying bed hop layer thickness was done during 2011, but more investigation is warranted. The upper beds clearly were slower in drying than the beds receiving the hotter inlet air to the dryer. A method of moving the trays, either automatically or manually should be examined to achieve uniform drying with multiple stacked drying trays. More examination and analysis of the temperature, humidity and moisture data from 2011 is needed to assist in making appropriate design and operational adjustments. Drying bed hop layer thickness at about 3.5 to 6 inches (8.8 to 15.2 cm) was found to be generally appropriate for solar assisted air drying.

Data analysis on 2011 air velocities has not been completed. Generally during the later tests, air velocities across the drying trays was between 0.03 m/s and 0.3 m/s, rates that did not result in bed lofting, fluidization, or blowing out holes, even with the shallow 3.5 to 6 inch (8.9 to 15.2 cm) hop depths studied. Some of the earlier tests did cause bed blow out but the air velocity hot wire anemometer was not yet available at that time to make measurements. As the hops dry down, air velocities become more critical to prevent agitation, fluidization, and bed blow outs. More evaluation and testing of air velocities and inlet temperatures is appropriate and for establishing parameters for future tests. Higher air velocities may cause fluidization of the hops or blow out hole in the trays, an undesirable condition that can cause damage to cones and loss of lupulin from agitation, or uneven drying across the tray due to hot air bypass.

Dryer redesigns for 2012 season may include building two identical dryers to allow simultaneous operation under different operating conditions to allow better comparative analysis. The individual dryer trays will likely be reduced in size to allow this to occur using similar available fresh hops as were available during the 2011 season. This will require additional data loggers and sensors however and budgetary constraints may limit this intended plan.

While the tests schedule has changed from what was originally planned, several insights were gained that will guide the construction and design parameters for the next and final year of solar hop drying tests in 2012.

b. Were the objectives of the project achieved?

The objectives originally planned for year one were accomplished during 2011. The necessary portion of the greenhouse structure was built and the solar hot air collection system became functional in time for the final set of tests during 2011 hops harvest and drying season. A significant set of solar hot air hops drying tests was conducted (details above). Some of the equipment has been procured for the solar hot water collection and dryers and the remainder of the associated greenhouse hot air and hot water systems which will be used during the 2012 testing season. A good outreach effort was achieved by making technical presentations on hops drying at the Paonia 2011 workshop events and by informal contacts and facility tours at other times (more detail on outreach below).

Outreach

a. Describe how the results and/or activities of the project were communicated to other producers and/or interested parties

In March 2010, Richard Andrews, project manager, travelled to Paonia to present a briefing on the literature review and discuss the project plan with the three project hops grower collaborators (Carl Rasmussen of Stillwind Farm, Glen Fuller of Rising Sun Farms, Lance

Williamson of Sabio Creek Farm) as well as Technical Advisor, Ron Godin and Ed Page ,CSU Extension Agent from Montrose . A PowerPoint presentation was prepared that reviews the published and grey literature on the subject of hops drying methods and science.

In July 2010, Richard Andrews presented two technical talks, accompanied with PowerPoint slide shows at the 3rd Annual Hop Growers workshop in Paonia at Rising Sun Farm. An estimated 80 individuals were in attendance, including growers, brewers and others.

In July 2011, Richard Andrews again travelled to Paonia, Colorado to make an updated technical information presentation at the 4th Annual Hop growers workshop sponsored by Rising Sun Farm, Glen Fuller and others. An estimated 50 or so interested parties were in attendance, including existing Colorado hop growers, potential hop growers investigating the opportunities, local residents, and several Colorado craft brewers interested in purchasing locally grown Colorado hops. The presentation included a review of hop drying and processing, focused on solar drying methods. It featured a technical overview of the scientific literature and practices of hops drying, including solar drying studies from Serbia, Spain, Tasmania and the USA. A second presentation was also made covering the measurement of field moisture of fresh hops to forecast optimal harvest date.

A compact disk containing the PowerPoint presentations was made for the two outreach events in 2010 and has previously been provided to all of the project collaborators, to both Technical Advisors (Ron Godin and Adrian Card), and to several persons who expressed interest at the July 2010 and 2011 Paonia workshops. (An updated version presented at the Hops Seminar held at Sunrise Farms in Paonia during July 2011 is now available.)

Project Manager Rich Andrews also attended the first Colorado Hop Growers Association workshop held in July 2011 at the Oscar Blues brewery in Longmont, Colorado, and the hop farm near Hygiene, Colorado. While not making presentations there, he did have the opportunity to speak directly with many individual growers and prospective growers about the current research in solar hop drying and related topics.

Numerous contacts were made with prospective hop grower individuals during 2011, including on site tours at the Andrews Farm, including discussion about the hop establishment, cultivation practices, picking, drying and packaging aspects. Wil Witman and Lisa Dent established a ½ acre hopyard near Niwot, Colorado and became active cooperating participants during the hop drying tests conducted during the 2011 season. The Andrews farm dried virtually all of the Witman-Dent fresh hops that were not sold in fresh un-dried condition to local brewers, and thereby extended the number of drying tests possible for the 2011 season. This was fortuitous since most of the hops sold by the Andrews Farm were sold as fresh condition, un-dried, so it was very important to have the Witman-Dent farm hops to conduct the solar drying tests.

Several brewmasters from local craft breweries came to visit the hopyard and facilities and viewed the growing, drying and handling facilities. Hops from the farm were sold to seven local brewers as fresh hops, and to two local herb products companies as dried full flower hops, all but one located in Boulder County, Colorado.

Professor Frank Stonaker visited the farm and viewed the existing hops facilities. Adrian Card, Project Technical Advisor, visited the farm and drying facilities in mid-summer 2011. A drying workshop day is anticipated to be held after the harvest and after the data analysis is completed, later in 2012 or perhaps in winter of 2013, as opportunities arise. Hopefully the research can be presented at a future Colorado Hop Growers Association gathering. The full project report will be made available to interested parties in electronic form at the conclusion of the project, including drawings and pictures of the equipment designed and built during this project. Publication of the study results in journals may also be considered.

Year Two 2011 Annual Report Signature page for CSU SCP GREG Grant
Research, Development and Demonstration of Solar Hops and Herb Drying for Small Farm Applications
Grant Effective Date 1 Feb 2010

Signed: Richard d. Andrews, Project Manager for GREG Grant
Jessie M. Andrews Family LLLP, General Partner

____ 10 January 2011
(Project Manager Signature)

Hops photo gallery:

Fig 31 - Hot air balloon dropping by for a hops order at Andrews Farm (hops processing barn and attached greenhouse hop drying bays at lower right); vegetable fields in the foreground

Fig 32 - A happy hop grower (Rich) and satisfied craft brewer (Corey, Dam Brewery, Dillon, Colorado) celebrating the finished product (beards are part of the secret)

Fig 33 - Cascade hops in drying tray and a sample for moisture measurement

Fig 34 – Hop farmer all wrapped up in the hops harvest
(solar hop dryer in background)

Fig 35 – Fresh Andrews Farm Cascade and Chinook hops into the wort (Head Brewer Dave Mentus, Pumphouse, Longmont); for a soon to be consumed ….Hot Shot Harvest Ale (in honor of the firefighters of the Four Mile Canyon fire)

Notice that everyone is always smiling that works with hops!! And, yes another beard!!