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Energy Research

CoolBot vs. Commercial Chilling Systems in Walk-in Coolers

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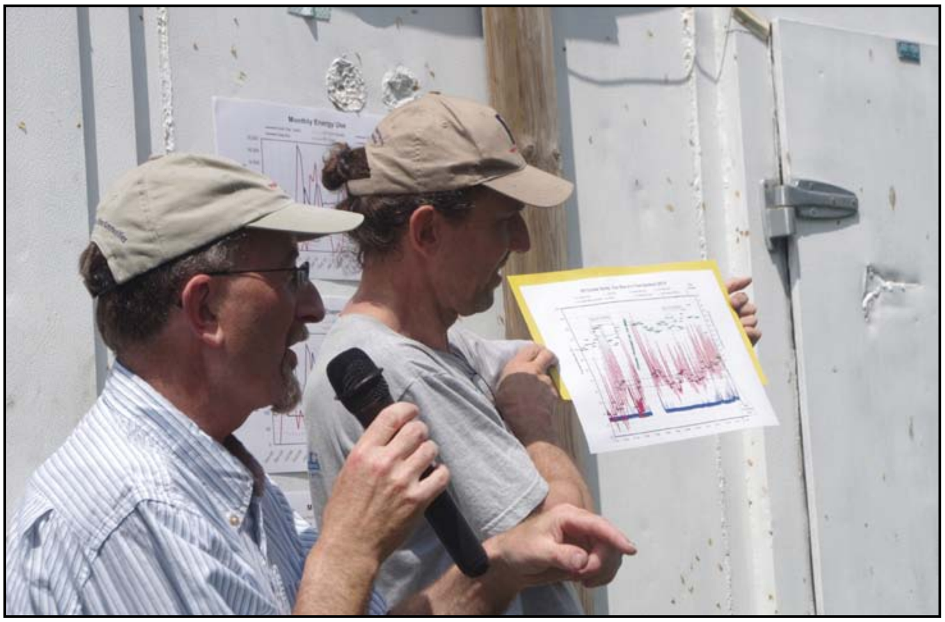
In a Nutshell

- Many fruit and vegetable farmers are building their own walk-in coolers to save money and be able to customize the cooler to fit their needs.
- Window air conditioning units equipped with CoolBot systems have become a popular alternative to commercial chilling systems in coolers, because they are cheaper to install.
- Energy use and temperature control was compared on three farms; two used AC/CoolBot systems, and one used a commercial chilling system.
- Key findings
  - The walls and ceiling of a walk-in cooler should be air-tight, and should have a minimum R-value of 20.
  - Fiberglass insulation with a vapor barrier is not recommended for the primary internal material. Instead of fiberglass insulation with a vapor barrier, closed cell foam is recommended in order to avoid condensation and reduction of fiberglass R-value.
  - In this study, the AC/CoolBot system struggled to maintain temps below 40°F in the heat of the summer.



Tim Landgraf presents data with PFI Energy Consultant Rich Schuler about walk-in cooler efficiency at a field day at One Step at a Time Gardens.

Background

For fruit and vegetable farmers selling directly to consumers, the ability to quickly chill produce after harvest and safely store it until delivery can make or break the value of a crop. For many, a walk-in cooler is one of their first large capital farm expenses. The level of investment varies; a 1,000ft^2 DIY cooler or used walk-in from Craigslist will cost several thousand dollars. A new system of similar size may cost upwards of $6,000.

Additionally, other PFI research has shown that walk-in coolers likely account for large portions of energy expenditures for horticultural growers (Ohde 2015). In recent years, farmers building their own walk-in coolers have installed window air conditioning units equipped with "CoolBots" as an alternative to a commercial chilling system. The devices override the temperature settings on window air conditioners, allowing them to reach a lower temperature set point. CoolBots have been studied for use in developing countries, where capital is a large barrier for producers; similar to small-scale vegetable farms in Iowa (Reid 2011). The devices are a cheap alternative, retailing at about $300 (CoolBot).

The objective of this research project was to compare the energy use and temperature control of walk-in coolers using CoolBot-based and commercial chilling systems. PFI Energy Consultant Rich Schuler collected and analyzed data from walk-in coolers at three farms. This report compares the efficiency and effectiveness of those coolers, and provides recommendations regarding walk-in cooler construction.

Method

This study was implemented at three farms: Pheasant Run Farm near Van Horne, owned and operated by Eric and Ann Franzenburg; One Step at a Time Gardens near Kanawha, owned and operated by Tim Landgraf and Jan Libbey; and Soper Farms near Emmetsburg, owned by Harn Soper.

Two farms' coolers use window air conditioners with CoolBots, and one uses a commercial chiller. The cooler at Pheasant Run Farm (PRF cooler) and the cooler at Soper Farms (SF cooler) use window air conditioners with CoolBots. The cooler at One Step at a Time Gardens (OSTG cooler) uses a commercial chiller. A detailed description of all three coolers can be found in **Table 1.** The coolers were outfitted with electrical and temperature data-logging systems to monitor their energy use and the internal and external temperatures.

Both CoolBot coolers (PRF cooler and SF cooler) were installed inside a larger building and were not exposed to direct sun at any time. As a result, temperature sensors were located at selected regions inside the building and near the exterior walls of the cooler. The OSTG cooler is located outside, and is exposed to direct sun. Consequently, the east, south and west walls of the cooler become extremely warm throughout the day. To determine exterior temperatures, sensors were bonded to the surfaces of the exterior wall.

Data was written to memory in the loggers at specific time intervals, and/or whenever the current drawn by the cooling system changed. Data was collected from August 2012 to May 2013. Because of data limitations and equipment malfunction, general comparisons between the three coolers were limited. Energy use and temperature control ability was therefore divided into three analyses.

First, because consistent data for all coolers was available from September 26 – October 27, 2012, the energy use and temperature control ability for all three coolers was compared during that time period. Secondly, because the SF cooler is much larger than the other two coolers, it was omitted from a longer-term comparison of data in which the PRF cooler and the OSTG cooler were compared for periods of several months. Finally, more detailed observations were made of short time periods for each individual cooler.

Results and Discussion

Results of this study are divided into three sections consistent with the analyses: 1. a comparison of the three coolers over the same one-month period; 2. a comparison between two similarly sized coolers over several months; and 3. an in-depth analysis of short periods of time for each cooler.

Table 1

Cooler Specifications of Three Walk-In Coolers

	One Step at a Time Gardens (OSTG Cooler)	Pheasant Run Farm (PRF Cooler)	Soper Farms (SF Cooler)
Cooling System	Commercial Chiller	Single AC/CoolBot	Four ACs/CoolBots
Volume (ft^3)	287	744	6,750
Insulation/ Construction	Pre-fabricated, foam core sandwich kit construction	Fiberglass insulation	EPS foam core sandwich panel construction
Walls/Ceiling	4.5 in. thick foam and galvanized steel sheet; R-value ~R-20	Framed 2x4 lumber walls & ceiling; R-value ~R-12	6 in total thickness; 5 in foam with 0.5 in. plywood sheets; R-value ~R-30
Door	3.5 in. thick foam and glavanized steel door; R-value ~R-15	R-value ~R-8	4 in thick commer-cial door; R-value ~R-20
Location	Outdoors; stand-alone	Inside storage and packing shed	Inside storage and packing shed
Other information	A roof protects the cool-er ceiling from sun and water; was painted white to reduce insolation	Floor of cooler is the slab for storage/ packing house	Floor of cooler is the slab for storage/ packing house

Table 2

Performance Summary of Three Walk-In Coolers: Sept. 26 - Oct. 28, 2012

	One Step at a Time Gardens (OSTG Cooler)	Pheasant Run Farm (PRF Cooler)	Soper Farms (SF Cooler)
Avg. Daily Energy Use (kWh)	19.2	15.0	39.6
Daily Energy Use/Volume (kWh/ft^3)	0.06700	0.02000	0.00059
Total Power Usage (kW)	1.6	1.6	8.0
Fans Only (kW)	0.50	0.24	1.1
Compressor Only (kW)	1.10	1.36	6.9
Thermostat Maintenance	Maintained setting at 35°F	Did not reach setting of 38°F, minimum temperature achieved was 42.3°F	Was unable to maintain setting of 38°F
Storage Usage	Heavy	Moderate	Light

Section 1: One Month Comparison of Temperature Control Effectiveness and Energy Use of Three Coolers

Three coolers were monitored from Sept 26 - Oct 27, 2012. Ambient temperature, average cooler temperature, and cooler energy use are presented in **Figure 1.**

Exterior Wall Temperatures

The average exterior wall temperatures for the OTSG cooler and the PRF cooler are typically 10-20°F warmer than the SF cooler on sunny days. Under heavily overcast skies throughout the state, the exterior wall temperatures were nearly identical, as is evident on Oct. 10, in **Figure 1**. This shows that the PRF and OSTG coolers experience significant heat gain due to solar radiation.

The OSTG cooler is located outside, and the wall has an exterior layer of galvanized steel, as can be seen in the adjacent photo. The galvanized coating is oxidized, and readily absorbs solar energy. The roof is shaded, and the east wall is separated from the cooled compartment by a second chamber (the cooler is a two chamber design, and the east chamber is used for storage). The south and west walls are exposed to direct sun, and get very warm on sunny days.

The PRF cooler is constructed against the west wall of the building. Convection is suppressed in the space between the west building wall and the cooler wall due to continuous, horizontal, 2x4 girts (horizontal wall supports). As a result, the air between the west wall of the building and the cooler gets very warm in the late afternoon on sunny days.

Interior Wall Temperatures

The PRF cooler was unable to reduce the interior temperature to the thermostat set point of 38°F. The internal cooler temperature varies with the average exterior wall temperature for the cooler. The SF cooler was able to maintain a temperature set point of 42°F, but not 38°F. As is evident in **Table 2**, the OTSG uses more energy per ft^3, but maintains a lower temperature set point and holds temperature more consistently than either CoolBot system.

PFI Energy Consultant Rich Schuler speaks at One Step at a Time Gardens near Kanawha.

Figure 1

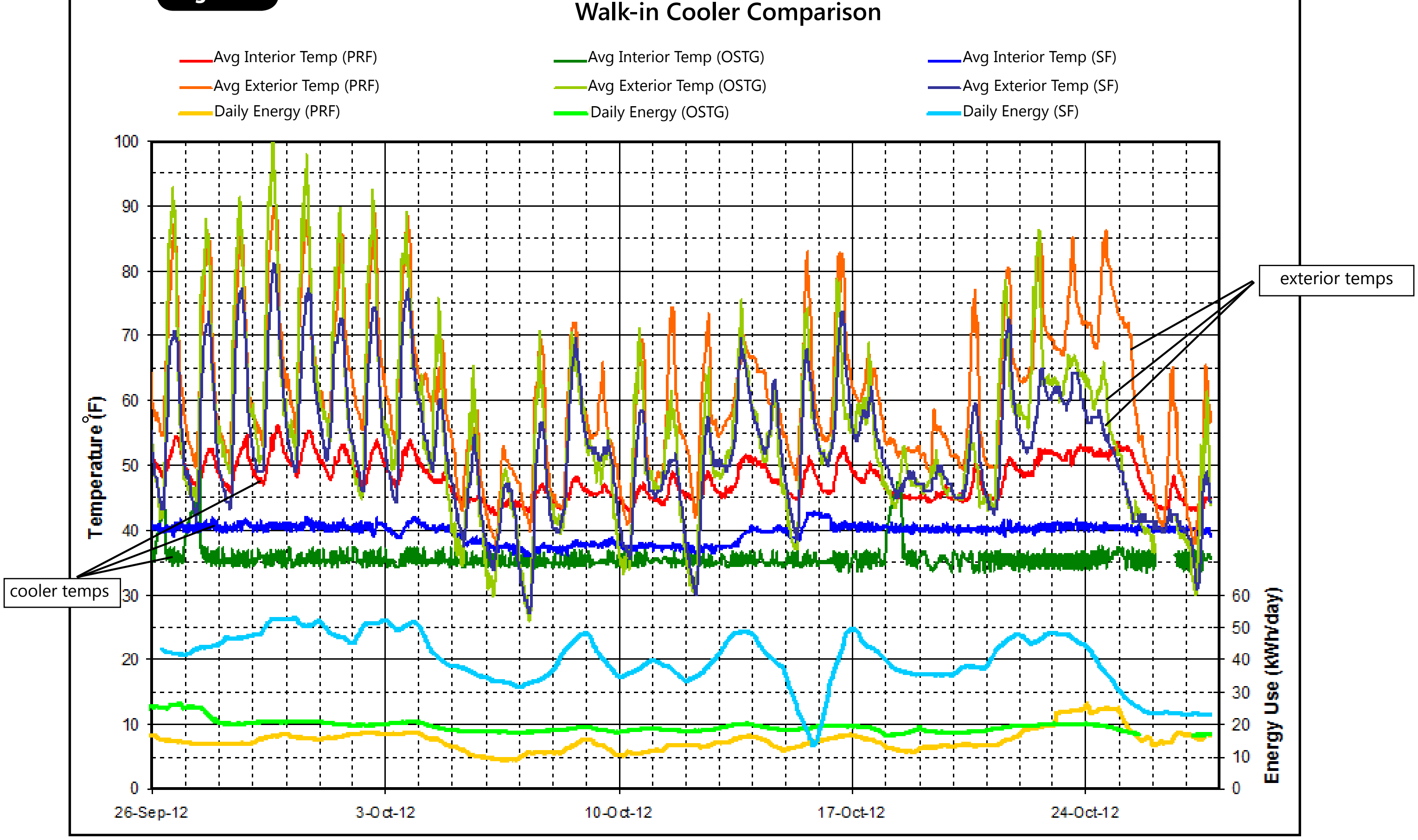


Figure 1. Average daily exterior and interior temperature and daily energy use for walk-in coolers at Pheasant Run Farm (PRF), One Step at a Time Gardens (OTSG), and Soper Farms (SF) from Sept. 26-Oct. 27, 2012. Red/yellow lines correspond to the PRF cooler, green lines correspond to the OTSG cooler, and blue lines correspond to the SF cooler.

Section 2: Comparison of CoolBot vs. Commercial Chilling in CSA-Scale Coolers

The SF cooler was designed to store 100 acres of organic produce. Consequently, it is much larger than the OSTG cooler and the PRF cooler (**Table 1**). Since the SF cooler is so much larger than a cooler utilized on a typical CSA-based horticulture farm, long-term data on its performance is not included. However, the OSTG and PRF coolers are sizes common on many fruit and vegetable CSA farms in Iowa.

OSTG Cooler with Commercial Chilling System

As can be seen in **Figure 2**, the OTSG cooler's internal temperature remains at the thermostat setting of 38°F at all times (with the exception of malfunctions and loss of grid electricity). Daily energy use for the cooler follows the ambient temperature, and drops below 15 kWh/day only when the ambient temperature is below 0°F. The average use for November is 17.8 kWh/day.

This on-going energy draw at cold temperatures is due to the evaporator fans, which draw 0.50 kW, and are on continuously. As a result, the minimum daily energy use for this system would be 12 kWh (powering the 0.50 kWh fans for 24 hours). This would occur if the compressor remained off during the day.

A second effect is the heat given off by the evaporator fans. Only a small portion of the energy used to run a fan is translated into kinetic energy of the air. The remainder is "exhausted" as heat. Since there is a lot of electrical energy input into the evaporator fans in this cooler, there is a considerable electrical heat load.

Walk-in cooler at One Step at a Time Gardens near Kanawha.

Figure 2

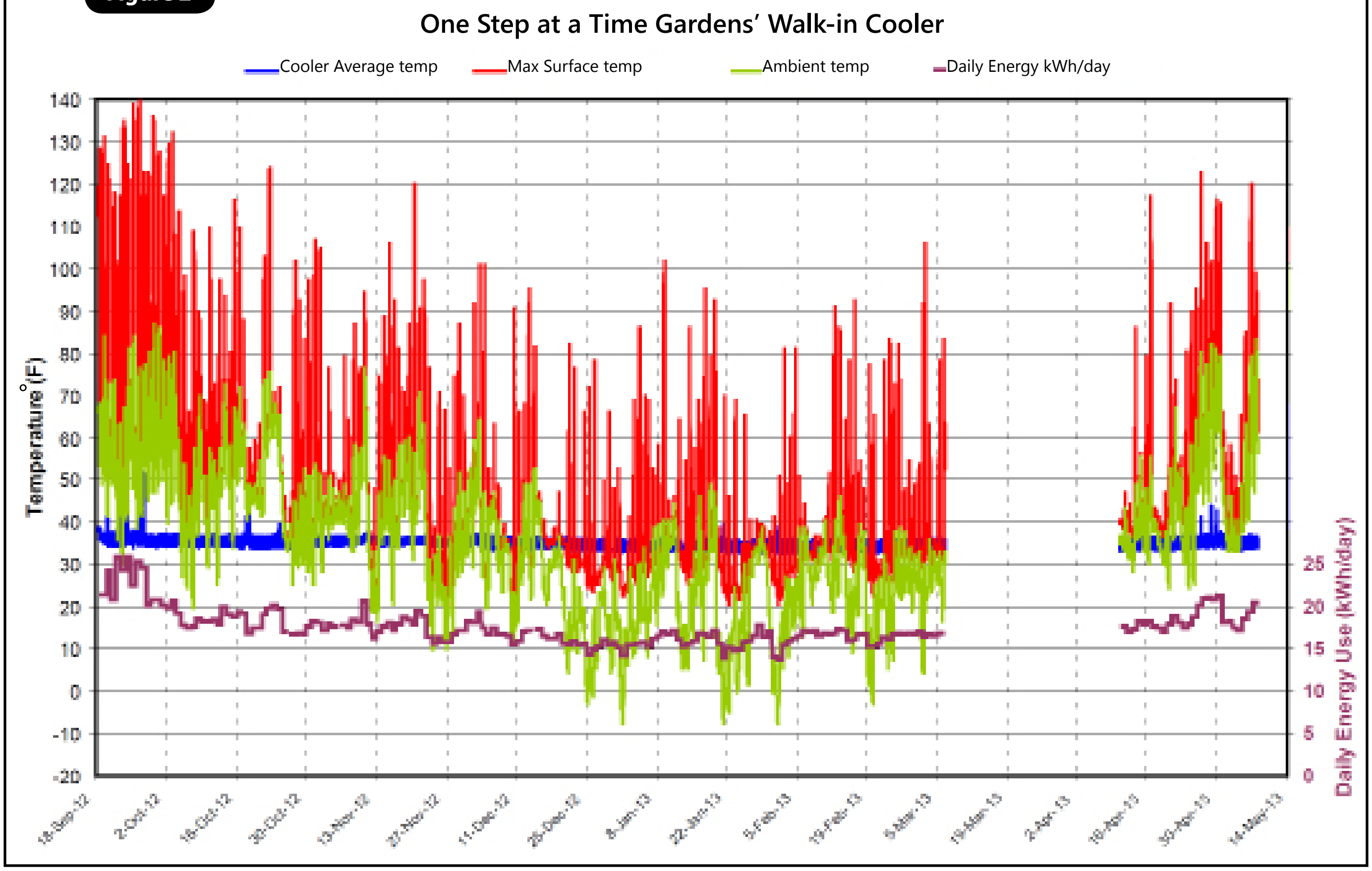


Figure 2. Average daily internal cooler temperature, maximum external cooler surface temperature, ambient air temperature and daily energy use for the walk-in cooler at One Step at a Time Gardens from Sept. 18, 2012 – May 7, 2013. The gap in data corresponds to a data-logging system malfunction.

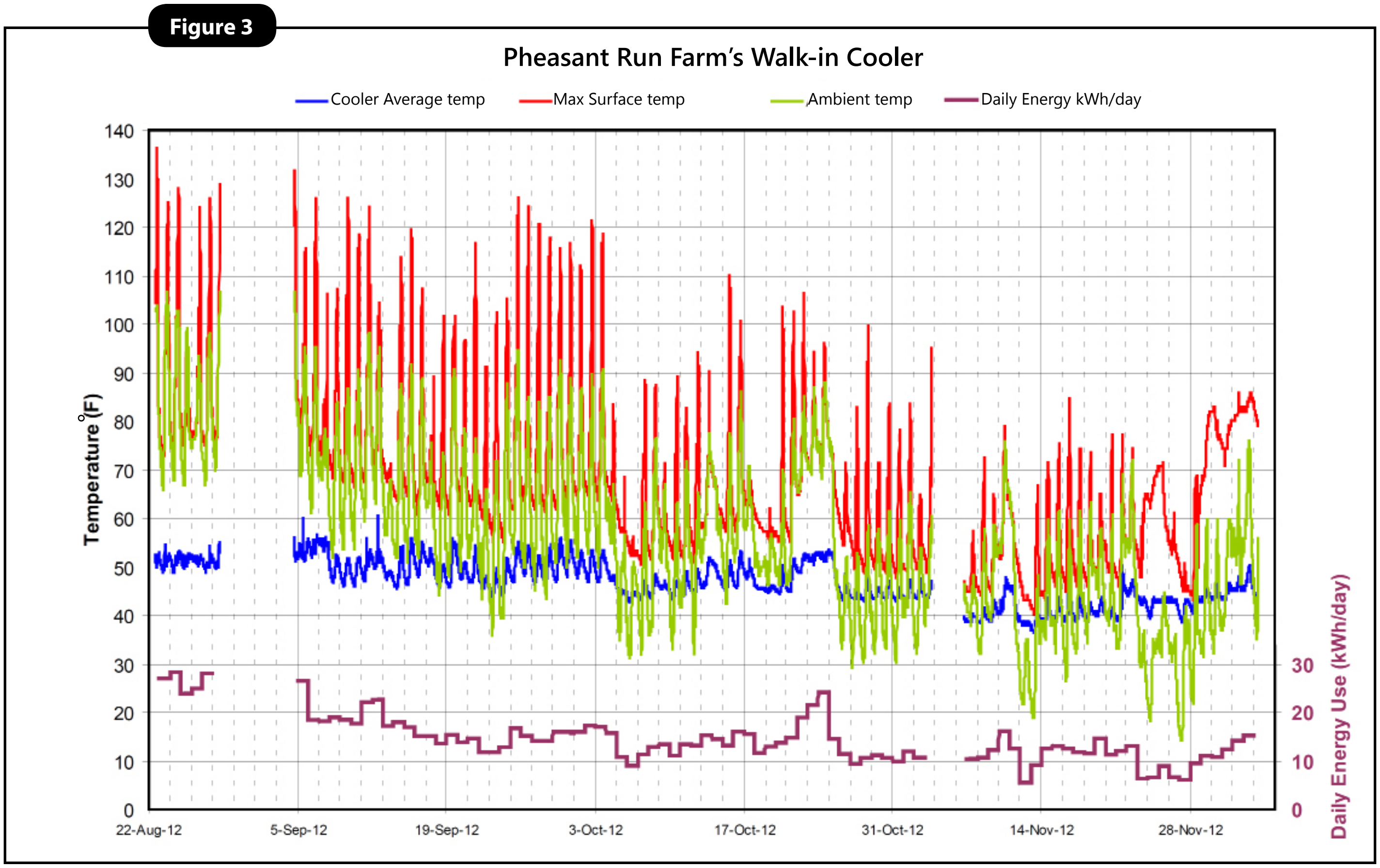


Figure 3. Average daily internal cooler temperature, maximum external cooler surface temperature, ambient air temperature and daily energy use for the walk-in cooler at Pheasant Run Farm from Aug. 22-Nov. 28, 2012. The gaps in data corresponds to a data-logging system malfunction.

PRF Cooler with CoolBot/AC System

For the PRF cooler, internal temperature reaches the thermostat setting only on Nov 11-12, likely because of cold weather–the ambient dropped to below 20°F during this period (**Figure 3**). Daily energy use for the cooler corresponds with the ambient temperature, and averages 10.3 kWh/day (0.014 kWh/day*ft^3) during November (compared to 17.8 kWh/day for the OTSG cooler (0.062 kWh/day*ft^3)).

The extended periods of measured maximum wall temperature on Nov 23 – Dec 4 are due to heating the adjacent room for the farm staff (to the north of the cooler). A situation similar to the evaporator fans in the commercial cooler exists, where heat from an electric heater in the next room migrates into the cooler.

Section 3: Detailed Performance of Coolers on Selected Days

This section provides a detailed look at the most interesting cooler performance days and data highlights of the study. Graphs for each cooler show temperature in more spatial detail to understand how location, construction, and ambient temperature affect cooler performance. A detailed examination of cooler performance on selected days can provide insight to energy efficient design and construction practices for DIY walk-in coolers.

Walk-in cooler at Pheasant Run Farm near Van Horne.

OSTG Cooler with Commercial Chilling System

Heat Gain Due to Direct Sun Exposure

The compressor for the OTSG cooler malfunctioned and operated intermittently from midnight on Sept. 26 through repair completion at 9:45 a.m. on Sept 26. During the repair, a west wall temperature sensor was dislodged, and placed between the north wall and the compressor. As a result, the data in **Figure 4** can be used to show heat gain on Sept 26, and proper compressor function on Sept 27.

Heat Gain Due to Compressor Exhaust

The heat gain progresses as expected from the east wall to the south and west walls. Maximum heat gain is 62°F above ambient (140°F at 4:42 p.m.). At least one wall of the cooler exceeds 110°F from 9:50 a.m. to 4:10 p.m. The compressor is located roughly one foot from the north cooler wall ("wall behind comprsr" in **Figure 4**), and the warm exhaust air blows directly on the cooler wall. The temperature cycling in this area corresponds with the power drawn by the compressor, and results in a 20°F temperature gain on the affected portion of the wall.

Temperature Differential

The temperature differential between the floor and ceiling of cooler (post repair) was an average of 0.4°F (2.1°F max), which suggests minimal heat intrusion through the floor.

Jan Libbey and Tim Landgraf speak at field day on their farm.

Energy Use

Following the repair of the compressor, on Sept. 27, the three evaporator fans inside the cooler used 0.5 kW of power, and when the compressor was operating, the compressor and evaporator fans drew 1.6 kW.

Figure 4

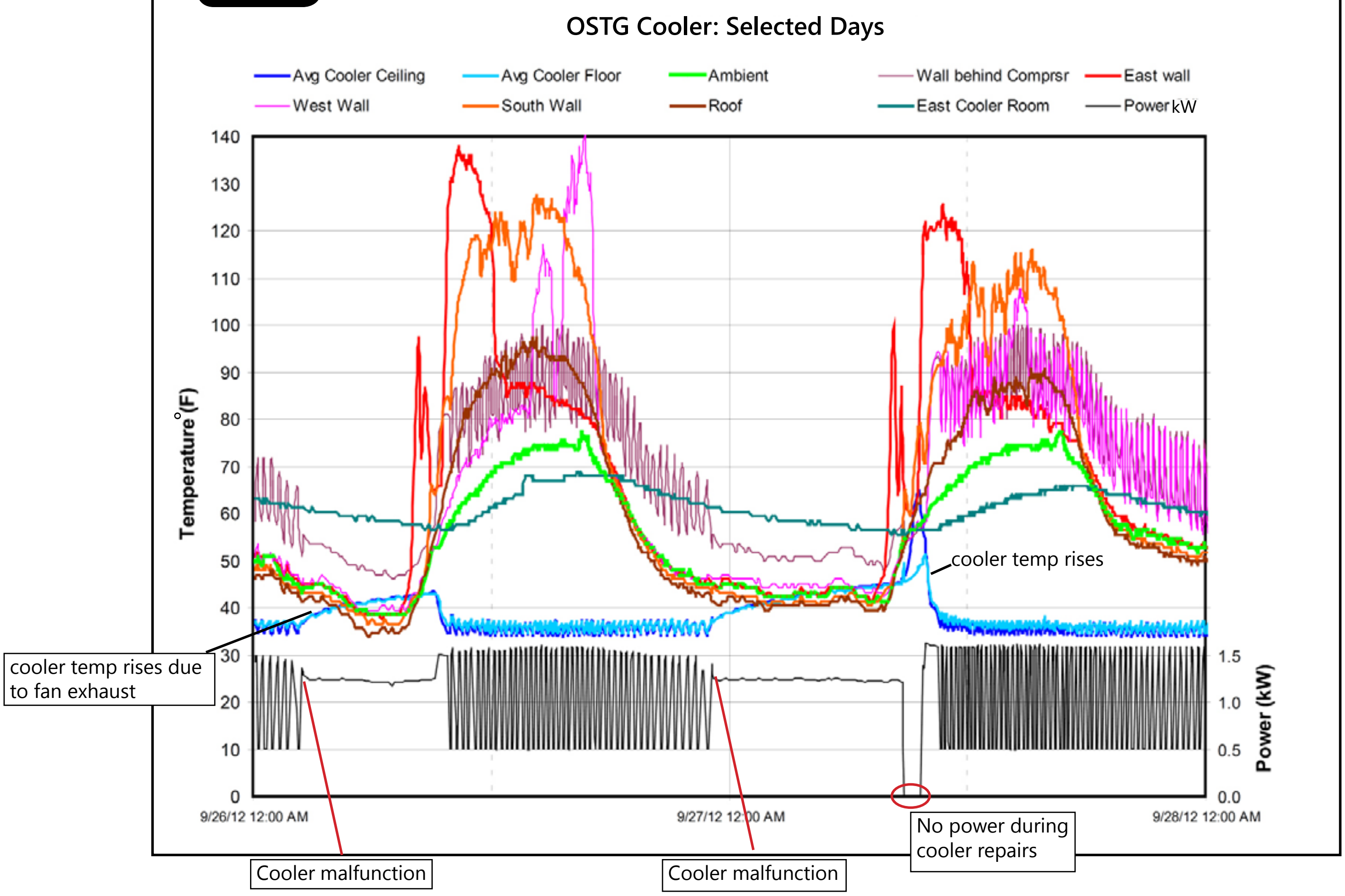


Figure 4. Ceiling, floor, ambient, wall and roof temperatures and power output for the walk-in cooler at One Step at a Time Gardens from Sept. 26-27, 2012.

PRF Cooler with CoolBot/AC System

Internal Cooler Temperature

Figure 5 shows that the internal cooler temperature never reaches the thermostat set point of 38°F. The temperature inside the cooler rises and falls between 45 - 55°F throughout the period, and roughly follows the high and low ambient temperatures.

Heat Gain Due to Indirect Sun Exposure

The west wall of the cooler experiences a maximum heat gain of 40°F above ambient (124°F) at roughly 4:30 p.m. The temperature at the west wall of the cooler, where convection is constricted by girts, remains above 100°F from roughly 2-5 p.m.

Temperature Differential

The temperature differential between the floor and ceiling of cooler was an average of 2.3°F (4.3°F max), which suggests potential heat intrusion through the floor since the slab temperature is higher than the ceiling (slab is warmer than ceiling, and warm air rises).

Energy Use

The LG window AC unit draws 0.24 kW when the compressor is off and 1.6 kW when the compressor is on.

Eric and Ann Franzenburg in their walk-in cooler, cooled by a window air conditioner equipped with a CoolBot.

Figure 5

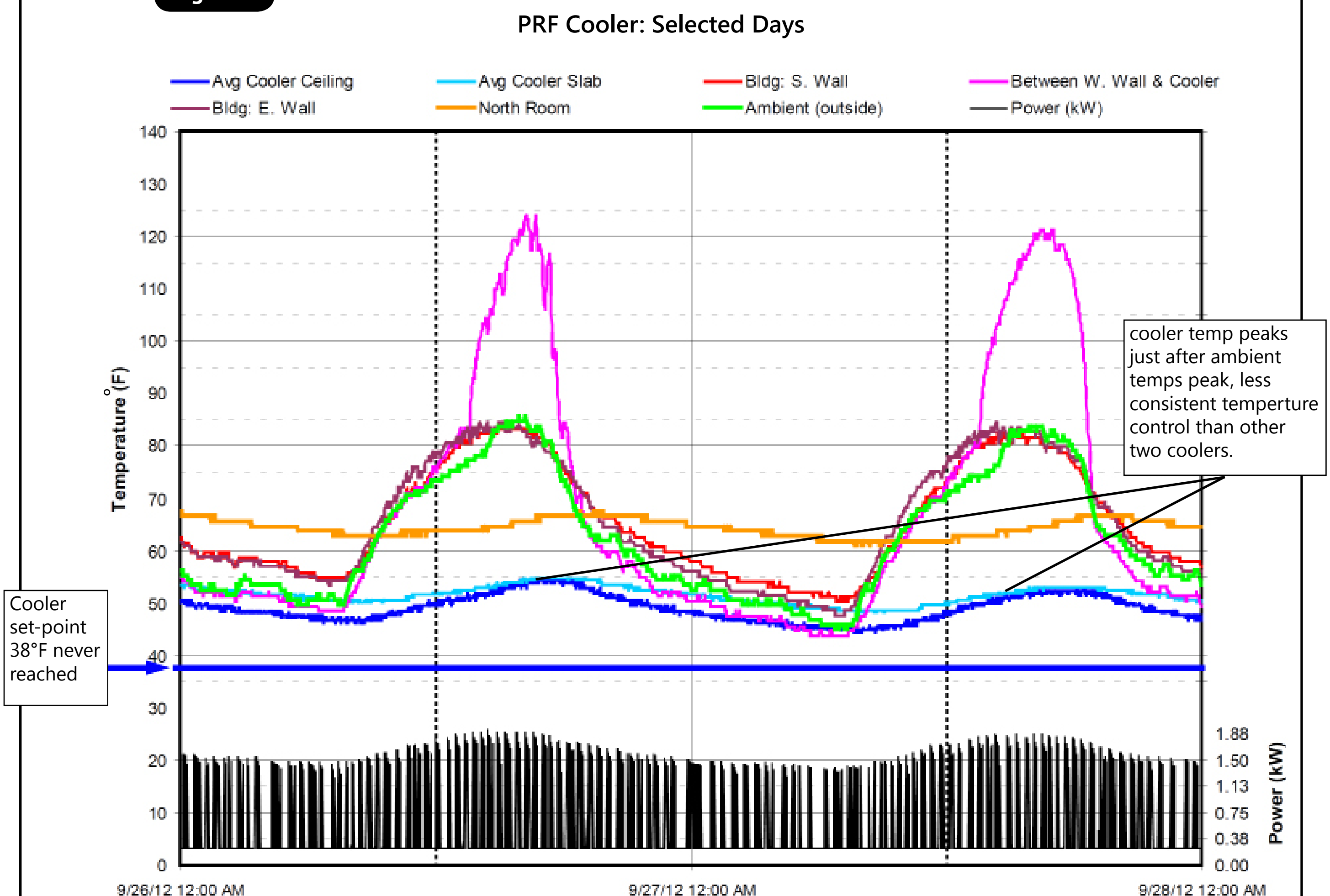


Figure 5. Temperatures for cooler ceiling and slab, building walls, ambient air temperature and power output at Pheasant Run Farm from Sept. 26 – 28, 2012.

Soper Farms' Cooler with Multiple CoolBot/AC System

Heat Gain

There is no heat gain due to sun exposure since cooler is located inside a large building, and has adequate spacing between the east, south and west walls.

Internal Cooler Temperature

The internal cooler temperature reaches the thermostat set point of 42°F with four LG window AC units operating. When the thermostat was reduced to 38°F, it took three days to reach the set point (likely due to a cooling trend in the weather which occurred at the same time). The four units were unable to sustain an internal temperature of 38°F, but roughly 12 days after changing the thermostat setting, three of the four units "iced up." These units were shut off for roughly a day to thaw, and then returned into service at 42°F.

Temperature Differential

Temperature differential between the floor and ceiling of the cooler (post repair) was an average of 0.6°F (1.6°F max; slab temperature higher than ceiling). This suggests minimal heat intrusion through the slab; however, the slab immediately outside the cooler was cool to the touch, so some heat intrusion was occurring.

Energy Use

The four LG window AC units draw 1.1 kW when the compressors are off, and 8.0 kW when the compressors are on.

Harn Soper, owner of Soper Farms near Emmetsburg

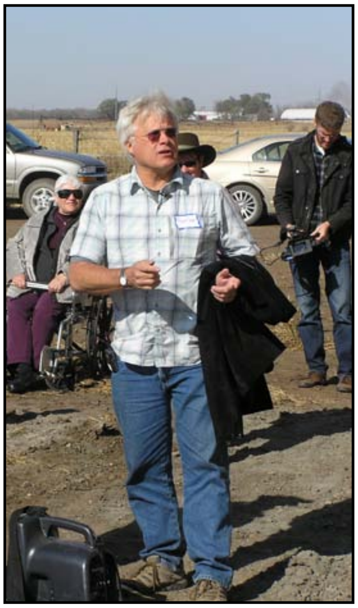


Figure 6

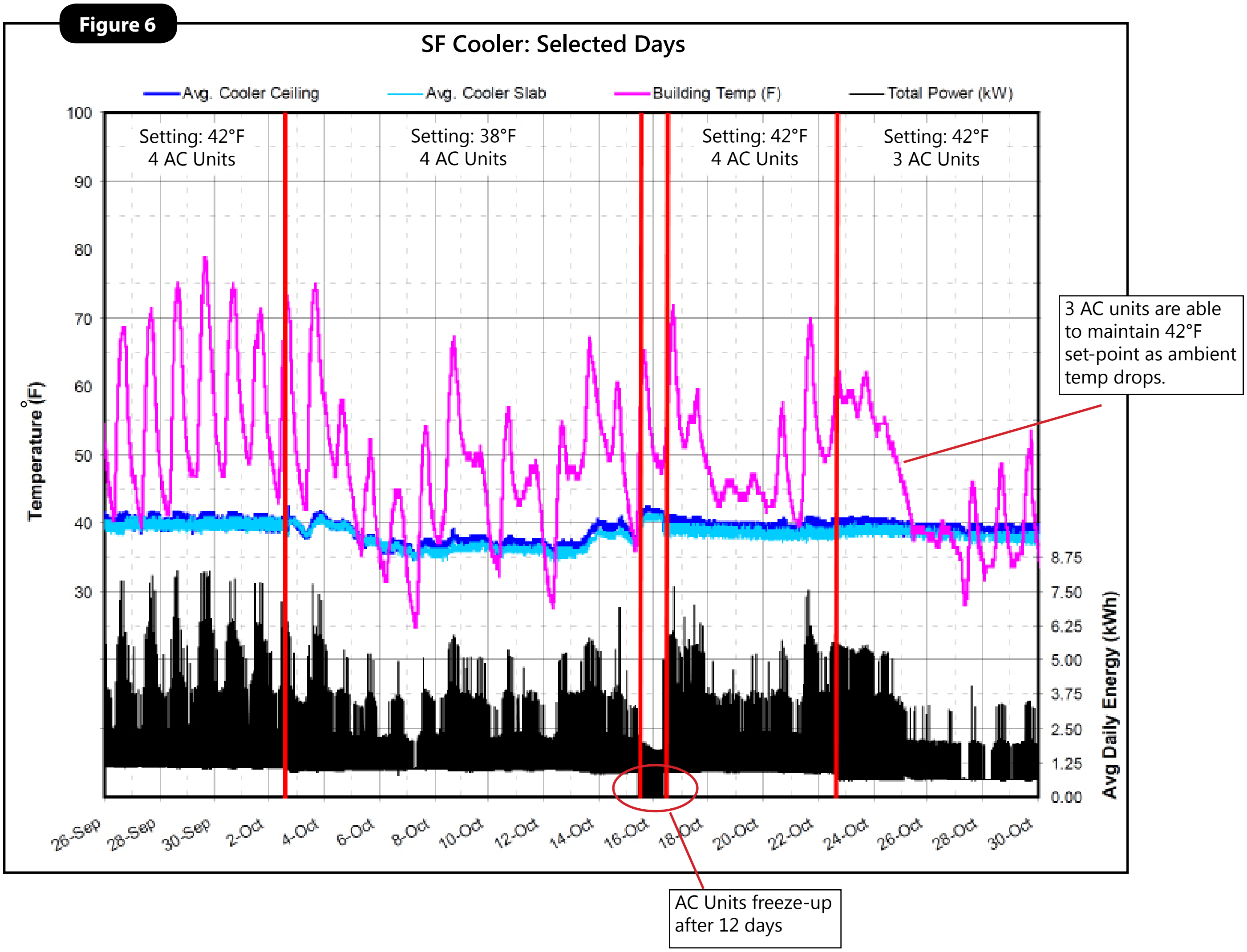


Figure 6. Temperatures for cooler ceiling and slab, building temperature, and power output at Soper Farms from Sept. 26 – 30, 2012.

Recommendations

Walls and Ceiling

The walls and ceiling of a walk-in cooler must be designed and executed with care. The walls and ceiling must be air-tight, and should have a minimum R-value of 20. The OSTG Cooler and the SF Cooler utilize sandwich foam construction (i.e., air-tight joints) with an R-value of 20 and 30 respectively. The PRF cooler utilizes framed 2x4 lumber construction with fiberglass insulation between the studs, a vapor barrier of 6 mil poly sheeting, and a covering of pressboard. The effective R-value for the walls and ceiling is roughly R-12.

Insulation

Fiberglass insulation with a vapor barrier is not recommended for the primary internal material. Prior to installing the logging system in the PRF cooler, the Franzenburgs noted that the AC/CoolBot system was previously able to maintain a temperature of 38°F. They replaced the CoolBot unit as well as the LG window AC unit, but the internal temperature very rarely reached the set point. It is likely that either condensation from the AC unit wetted the wall and entered the fiberglass insulation or, that general condensation because of the reduced temperature at the cooler wall caused wetting of the insulation. Because water is an efficient conductor of heat, it is likely that the wetted fiberglass was conducting heat into, rather than insulating, the cooler. Based on the results of this study, to avoid condensation and reduction of fiberglass R-value, closed cell foam is recommended as insulation material.

Floor

If a cooler is installed on a large slab, and the remainder of the slab is at the ambient temperature, the slab acts as a conductor, transferring heat into the cooler. The chilling system must combat this additional heat intrusion. Heat intrusion through the floor can be significantly reduced, however, by placing polystyrene foam on the slab inside the cooler. The foam can be protected by covering (bonding) ¾ in. plywood. An R-value of at least R-10 is recommended for the floor (2 in. thickness of polystyrene foam).

Joists

When using framed lumber construction, it is recommended that there be no direct thermal path from the inside of the cooler to the outside environment through any piece of the structure. A typical framed wall (or ceiling), with insulation placed between studs (or joists), and covered with plywood sheeting provides a direct thermal path through the wood studs (or joists). A foam sheet can be fastened to the framed wall on the inside of the cooler to eliminate this path.

CoolBot Specific Recommendations

AC/CoolBot systems have become a popular choice for farmers who build their own walk-in cooler. This system is a low cost chilling option. The electronics in the CoolBot apply heat to the AC temperature sensor. As the AC sensor is heated, the compressor turns on. A second CoolBot sensor monitors the evaporator, and turns the compressor off when the evaporator surface temperature nears 32°F.

A window AC unit can thereby achieve temperatures far below the typical factory settings of 60-65°F. The result is a reduction in the efficiency for the AC unit. As an example, the heat extraction capacity of 24,000 BTU for a 240V LG window unit likely drops to 10-20% of this value when used to maintain a temperature of 40°F (2,400-4,800 BTUs).

In order to take advantage of an AC/CoolBot system, the walls, ceiling and floor must be constructed with care as mentioned above. In addition, the volume suggestions of the manufacturer should be strictly adhered to (CoolBot).

Finally, based on this study, it is unlikely that a CoolBot system will be able to maintain an internal temperature below 40F in the heat of summer. This temperature limit should be considered before a CoolBot system is chosen. It is recommended that the window AC unit be installed such that no condensation reaches the wall which supports the unit. Water is an efficient conductor of heat, and will reduce the R-value of the wall – especially if fiberglass insulation is used.

References

CoolBot. http://storeitcold.com/ (accessed April 3, 2015).

Ohde, N. 2015. Farm Metered Energy Analysis. Practical Farmers of Iowa Cooperators' Program. Ames, IA. http://practicalfarmers.org/farmer-knowledge/research-reports/2015/farm-metered-energy-analysis/ (accessed April 10, 2015)

Reid, Michael. 2011. Feasability Analysis of the Coolbot. Coolrooms and Cool Transport for Small-Scale Farmers. University of California-Davis. http://horticulture.ucdavis.edu/main/Deliverables/Reid_report_feasibility_analysis_of_coolbot.pdf (accessed April 3, 2015)

PFI Cooperators Program

PFI's Cooperators' Program gives farmers practical answers to questions they have about on-farm challenges through research, record-keeping, and demonstration projects. The Cooperators' Program began in 1987 with farmers looking to save money through more judicious use of inputs. If you are interested in conducting an on-farm trial contact Stefan Gailans @ 515-232-5661 or stefan@practicalfarmers.org.