

# MEAT DEHYDRATOR

*Construction and Operation Manual*



*Low-cost, Safe Dehydrator for small  
and very small meat processors*



ROBERT M. KERR  
FOOD AND AGRICULTURAL  
PRODUCTS CENTER

Construction and operation manual for:  
Low-cost, safe dehydrator for small and very small meat processors  
by Tim Bowser

INTRODUCTION .....	2
THEORY OF OPERATION.....	3
PRE-CONSTRUCTION .....	5
CONSTRUCTION.....	6
Walls, Ceiling and Interior.....	6
Doors.....	7
Electrical .....	7
Heating.....	7
Ventilation.....	9
Humidification .....	10
MOBILE DRYING RACKS .....	12
INSTRUMENTATION .....	13
STARTUP & OPERATION.....	13
CLEAN UP .....	14
TESTING AND VALIDATION .....	15
SAFETY .....	16
CONCLUSION.....	16
ACKNOWLEDGEMENTS .....	17
DRYER SYSTEM PARTS LIST .....	18
Walls, Ceiling and Interior.....	18
Doors.....	18
Electrical .....	19
Heating.....	19
Ventilation.....	21
Humidification .....	23
Mobile Drying Racks.....	25
Sensors and Data Collection .....	25
LIST OF FIGURES .....	27
REFERENCES .....	29
APPENDIX I .....	44
APPENDIX II.....	30
APPENDIX III.....	35
APPENDIX IV.....	40

## INTRODUCTION

Many small and very small meat processors around the country are entering into the jerky business. Without exception, all processors must purchase, build, or otherwise obtain a meat dehydrator or dryer. Choices for the small-scale processor with a limited budget are very few. Most of the commercially available dryers are either too large or too small for very small processors that could feasibly prepare about 300 to 1,500 lbs. of raw jerky per batch. Depending upon product thickness and shape, the average jerky manufacturer requires about one square foot of drying area per pound of raw product. This translates to a square footage requirement for a dryer of about 300 to 1,500.

In recent times many processors have attempted to build their own small-scale jerky dryer. I believe that there are two reasons for this: one, because of the expense of commercial drying equipment; and two, because they think they can do it. In any case, experience has shown that home-made dryers tend to be unorthodox, difficult to clean and maintain, and are more likely to produce unsafe food products.

The purpose of this document is to provide a complete construction and operation manual for an inexpensive, reliable, and simple dehydrator and drying process that was developed and tested in the Food Engineering Laboratory at Oklahoma State University's Robert M. Kerr Food & Agricultural Products Center (FAPC). Construction and operation of this dehydrator will permit small and very small meat processors to produce safer and higher quality jerky products with a lower capital investment. Processors may build the dehydrator themselves, using off-the-shelf components that are readily available. The dryer is a walk-in style unit with product storage on perforated trays held in mobile carts. All equipment and ductwork is fully visible for inspection and cleaning.

The dryer concept and design was originated by the author. Prototype design and construction was completed at the Biosystems and Agricultural Engineering (BAE) laboratories at the Oklahoma State University, Stillwater, Oklahoma, by Mr. Wayne Kiner, Shop Manager, and his staff. The prototype dryer was built in the BAE shop, disassembled and transferred to the FAPC for testing. The FAPC is a USDA approved and inspected meat processing facility.

The capacity of the dryer ranges up to 300 lbs. (raw material weight) per batch, depending upon product thickness and how it is arranged on the drying trays. All components are available locally and/or from mail-order industrial and restaurant suppliers. Construction of the dryer requires no special skills, except for a familiarity with common house-building techniques and materials and the ability to read drawings and follow written instructions. Photographs of the construction process and completed dehydrator are included. Additional photographs highlighting the operation, maintenance and cleanup of the dryer are also shown. A full scale installed and operating dehydrator is available for viewing and testing at the FAPC.

Expected benefits for jerky processors that build and use the dehydrator:

1. Safer, higher-quality jerky products due to tested and validated dryer and drying process.

2. Increased numbers of processors entering the jerky business due to lower cost of dehydration equipment and reduced product safety risks.
3. Less financial risk for meat processors because of lower equipment costs and increased safety of product.
4. Alternative uses of the dehydrator for non-meat products with little or no modification.

## THEORY OF OPERATION

Mobile bakery racks, or bun-pan racks, are the core functional component of the dehydrator –they are readily available (new and used), inexpensive, and durable. Although bun-pan racks were demonstrated in the prototype dehydrator, any cleanable, sanitary rack will work as long as air is free to flow over and under the product being dried.

A fan coil system was selected to heat the air in the dehydrator because of its relative ease of control, low price, and availability. Many homes and commercial buildings across the United States are heated hydronically (using hot water). Since hydronic heating elements are mass produced, a wide variety of fan coils are available for this purpose. A natural gas continuous hot water heater was used to heat the water. If natural gas or propane is not available at the installation site, other sources of energy (such as electricity) can be substituted.\* An optional temperature controller can be purchased for the continuous hot water heater that allows the remote adjustment of water temperature and flow rate from a keypad.

The microbiological kill step is patterned after Appendix A of the USDA FSIS “Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products” (USDA FSIS, 1999). The following guidelines for cooked beef are taken directly from this document:

1. Cooked beef and roast beef, including sectioned and formed roasts, chunked and formed roasts, and cooked corned beef can be prepared using one of the following time and temperature combinations to meet either a 6.5- $\log_{10}$  or 7- $\log_{10}$  reduction of Salmonella. The stated temperature is the minimum that must be achieved and maintained in all parts of each piece of meat for a least the stated time:

Minimum Internal Temperature		Minimum processing time in minutes or seconds after minimum temperature is reached	
Degrees Fahrenheit	Degrees Centigrade	6.5- $\log_{10}$ Lethality	7- $\log_{10}$ Lethality
130	54.4	112 min.	121 min.

---

\* Note: An electric heater was not tested on the current dehydrator, but may be tested in the future pending available funding and time. Electric heaters should be less expensive to install and simpler to control; however, operating expenses are generally expected to be higher compared to gas-fired heaters.

131	55.0	89 min.	97 min.
132	55.6	71 min.	77 min.
133	56.1	56 min.	62 min.
134	56.7	45 min.	47 min.
135	57.2	36 min.	37 min.
136	57.8	28 min.	32 min.
137	58.4	23 min.	24 min.
138	58.9	18 min.	19 min.
139	59.5	15 min.	15 min.
140	60.0	12 min.	12 min.
141	60.6	9 min.	10 min.
142	61.1	8 min.	8 min.
143	61.7	6 min.	6 min.
144	62.2	5 min.	5 min.
145	62.8	4 min.*	4 min.*
146	63.3	169 sec.	182 sec.
147	63.9	134 sec.	144 sec.
148	64.4	107 sec.	115 sec.
149	65.0	85 sec.	91 sec.
150	65.6	67 sec.	72 sec.
151	66.1	54 sec.	58 sec.
152	66.7	43 sec.	46 sec.
153	67.2	34 sec.	37 sec.
154	67.8	27 sec.	29 sec.
155	68.3	22 sec.	23 sec.

It has been established that high wet-bulb temperatures are an excellent means of reducing pathogens during jerky processing (Buege et al., 2006). The increased humidity reduces evaporative cooling effects. With this in understood, and using Appendix A as a guideline, a wet bulb temperature of 140 degrees F would require a 12 minute hold time to achieve 7-log<sub>10</sub> lethality. Wet bulb temperatures in the range of 130 to 145 degrees F are reasonable to achieve with the dehydrator system when it is built according to plans and the steam injector and water mister (described below) are used to increase the humidity in the dehydrator.

We have found in practice that steam injection is an extremely important factor in the establishment of a hot, humid environment in the dehydrator. When the dehydrator is fully loaded with raw jerky, considerable process time (1 to 2 hours) can be consumed while waiting for the wet bulb temperature to rise to the desired set point. Additional steam capacity (beyond what was installed on our test unit) would reduce the amount of time required to reach the desired wet bulb temperature. When process time is important, an additional or larger steam generator would be useful and could potentially pay for itself quickly.

Appendix I contains the recently published fact sheet “FAPC-165 Consistent lethality treatment for small-scale jerky dehydrators” that discusses the development and maintenance of a lethality program for dehydrators in general. Concepts for FAPC-165 were tested on the dehydrator described in this document.

## PRE-CONSTRUCTION

Before materials are purchased or construction begins, there are four items that require attention (listed in no particular order):

1. Plan review with local USDA inspector
2. Local codes and permit(s) review/application
3. HACCP plan development or modification
4. Location specific criterion

These four points are discussed in this section.

Any building plans for an inspected facility should be discussed with the on-site inspector (USDA, State, or other) prior to the purchase and installation of materials or equipment. This allows the inspector the opportunity to have a role in the project from the beginning, lessening the chances for reactive decisions and surprises. Many inspectors will offer positive criticisms and suggestions to improve the project. A sketch showing the installed equipment, a copy of this construction and operations manual, process flow diagrams, models, and similar materials will be helpful in discussions with inspectors. This document contains a complete set of construction drawings (see figures A through 25) for building the dehydrator.

Local building codes and permit requirements should be considered prior to any construction project. *The building plans in this document have not been designed to meet local code requirements. Meeting local code and permit requirements is the responsibility of the owner.* Owners should also consult with their insurance provider(s) to determine if the construction process or installation and operation of the dehydrator unit will require additional safeguards, such as fire control.

Your HACCP plan may need revising or updating to reflect newly installed equipment and procedures. A draft should be developed in advance of any equipment and procedural changes to determine feasibility. The process will also help identify and correct flaws in plans.

“Location specific criterion” refers to items that must be satisfied at the proposed location for the jerky dehydrator. The items are (in no particular order): space, foundation, utilities, and access. The recommended access space for the dehydrator is shown in figure 26. Overhead clearance of about 11 to 12 feet is necessary for the ventilation ductwork and piping.

The foundation of the jerky dehydrator should be prepared in advance of the installation. In many cases an existing area of floor with a drain can be utilized. The drain must be cleanable and a means of sealing it available. Ideally, the floor slope to the drain should be at least ¼” per foot of horizontal run. NOTE: It is expected that some inspectors will require that the drain be sealed during processing to eliminate potential exposure to bacteria in the drain and associated plumbing. A rubber mat can often be used as a drain seal.

Utilities are an extremely important part of the installation. Sufficient utilities must be available in order to operate the dehydrator:

- Natural gas: ½” line with 0.5” water pressure, minimum
- Softened water for humidification
- Electric:
  - Two, 15 amp, 120V circuits for fans, water heater, and interior lighting
  - One, 30 amp, 240 V circuit for the steam generator
  - Hot water: for washing and cleaning operations

Access for material movement into and out of the dehydrator is critical. Materials movement pathways should be set to eliminate any chances of cross-contamination. Ample space should be available to maneuver and stage bakery racks laden with raw and dried product. In addition, space should be considered for maintenance activities, especially as related to the heating system.

## **CONSTRUCTION**

Included in this manual are a complete parts list, dimensions and shop drawings, as well as digital photos of the finished product. No special skills beyond those needed for home construction are required to build the dehydrator. Tools required are common, except those needed to bend the sheet metal ventilation ducts (see your local heating and ventilation and air conditioning contractor for metal-bending services). The materials needed to construct the dryer are easily accessible. To view the complete parts list, visit the Dryer System Parts List of this manual. A photo of the nearly completed dehydrator is shown in figure 30. The exterior of the dehydrator was left unfinished to reveal construction details. Exterior finishing is optional and may be desired to increase eye appeal for customers and inspectors and to give your dehydrator a “customized” appearance. Please note the following convention for all construction drawings: In this manual the directions “left” and “right” are defined when the viewer is facing the front entrance (product loading entrance) of the dehydrator.

### ***Walls, Ceiling and Interior***

The walls and ceiling of the dehydrator were constructed using standard home-building components and techniques. Figure 31 shows digital photos of one of the dehydrator walls during construction. Foam board was sandwiched between the lumber stud frame and 7/16” oriented strand board (OSB). Nails or screws can be used for construction, based on the owner’s preference. We used a combination of screws and nails. Screws were used when we thought we might like to be able to disassemble the finished product at some time in the future for repairs or modification. For details on the construction of walls and the ceiling, see figures 1 through 22, and 25. These drawings show step-by-step how the walls and ceilings are built and then combined to create the dryer. Figures 18, 19, 20, and 25 show how the center roof of the dryer is built in two parts.

The interior of the dehydrator was lined with PolyMax, a 7.5 oz. (16 mil) fiberglass reinforced polyethylene fabric. Properties of the fabric included resistance to abrasion and heat, waterproof, cleanable, inexpensive, and simple to replace. Rolls of PolyMax

fabric are available in widths from 24 to 144” and are priced by the running foot. Conceptually the interior of the dehydrator is to be lined with the polyethylene fabric with a minimum of seams.

Figure 32 shows a suggested method used to line the interior of the product drying section without including any seams in this area. Plastic cap roofing nails (Figure 33) may be used to secure the polyethylene fabric to the OSB. Supertape polyethylene seaming and repair tape does an excellent job of sealing seams. With careful technique and planning, the number of seams and fasteners can be minimized to reduce potential leaks. Overlap layers of PolyMax fabric just as you would felt paper to prevent leakage on roof surfaces. If the polyethylene fabric tears or abrades, it can be removed quickly and replaced. Figure 34 shows a technician wrapping a dehydrator panel with PolyMax fabric prior to installation. The technique shown in Figure 32 is somewhat similar to gift wrapping.

### ***Doors***

The doors were inexpensive, pre-hung, foam-core metal doors purchased from a local building supply company (see Figure 35). Keyed handles (optional) were installed for product security. Doors and frames were coated with a water-based, brushable epoxy for protection. When painting pre-hung door frames, be careful not to paint over rubber seals, as paint will not stick to the seals and will eventually flake off resulting in a potential product contaminant. Two doors were installed in our research unit –one door for bakery rack entry and removal and an optional door for inspection and cleanup. The optional door is NOT required for production units. For drawings showing the construction of the door frame(s), refer to figures A, B, 1, and 12 through 15.

### ***Electrical***

Figure 36 is a simple plan view wiring diagram for the dehydrator. Parts included are three lights, two electrical outlets, a pump switch, fan speed control (should be hard-wired for high speed), and a fan motor. The fan motor was integrated with the hydronic heating coil. Wire connections were made on the exterior of the dehydrator. A small enclosure (load center) was used to house the main power source connection and system circuit breakers (see Figure 37) and was mounted on the left dehydrator wall. Lighting fixtures with totally enclosed, fluorescent bulbs were used to light the interior of the dehydrator. These lights were needed only when loading, unloading, inspecting, and cleaning the dehydrator. Power cords for the lights were passed through penetrations in the ceiling of the dehydrator. The penetrations were completely sealed with caulking (from the inside) after installation. Positions of lights shown in Figure 36 are approximate.

### ***Heating***

The heating system (schematic shown in Figure 38) is hydronic (hot-water) and was patterned after systems commonly used to heat homes. A gas-fired (natural gas or propane) continuous hot water heater (Figure 29) provided controlled heat for the water. Heat input was rated from 19,500 to 140,000 BTU and was automatically modulated by the heater control board between these values to meet demand. In our installation, the



heater was located on a wall adjacent to the dehydrator. A 4" metal vent pipe must be installed through the roof or an exterior wall to release combustion gases to the atmosphere. Check local codes to determine vent pipe requirements in your area. In general, codes require stainless steel, gasketed ventilation pipes with condensate drains for gas-fired continuous hot water heaters. High-efficiency, condensing, tankless hot water heaters are now available (e.g. Tagaki T-H2-IN) and may be vented with PVC. If more heating capacity is desired, larger heaters (from several manufacturers, including the one that supplied the heater for this application) are available with similar functionality and greater heat input and water circulation capabilities. The hydronic heater capacity should be matched to the water heater.

Hookup of the continuous hot water heater was straightforward as detailed in the owner's manual. The heater manual included a section for hydronic heating systems. The optional remote controller was a handy accessory that allowed monitoring of the water temperature (both heater inlet and outlet temperatures), temperature set point, and water flow rate. Temperature set points for the heater, without the remote controller, were limited to 113, 122, 140, and 182 °F, and were set using dip switches on the heater's main computer board. Using the remote temperature controller, the outlet water temperature could be set to the following temperatures: 99, 100, 102, 104, 106, 108, 110, 111, 113, 115, 117, 122, 131, 140, 158, and 167 °F. In practice, we ran our system with the dipswitch setting at 182 °F and used the remote control to display temperature and flow information. The air temperature in the dehydrator was typically about 10 °F less than the water temperature during steady-state operating conditions.

A circulation pump (Figure 39) kept the water moving throughout the heating system. Our pump was mounted on the roof of the dehydrator to save floor space. Pump capacity should be matched to the flow resistance of the plumbing to provide, as nearly as possible, the maximum flow recommended for the water heater (5.8 gpm for the water heater selected for this system). Configuration of water circulation systems will vary depending on the installation site and conditions (water, electric and gas source locations, obstructions, overhead clearance, etc.). The circulation pump we purchased for our original system performed marginally at about 2 gpm. A more powerful pump (shown on the current dryer system parts list) is preferred.

An expansion tank, air separator, and pressure relief valve were required for the system. The expansion tank allowed for expansion of the fixed amount of water in the circuit as the temperature increased; otherwise the pressure could trip the relief valve. An air separator was needed to remove air that naturally outgassed from the water during the heating process. If air was not removed, the system would be in danger of air lock, a condition that occurs when an air pocket forms across the pump's impeller. An air separator and vent should be installed in the system at the point of lowest pressure (where the greatest amount of air will separate from the water), which is just before the pump for most hydronic systems. On/off valves should also be included in the piping to facilitate maintenance. Valves at the inlet and outlet of both the heater and pump are desirable, plus a valve should be installed at the low point of the system for drainage, and a valve

on the makeup water supply. Plumbing code normally requires a back flow preventer if the system is hard-piped to the potable water supply.

## **Ventilation**

Figures A, B, 16, 23 and 24 give information involving the construction of the ventilation system of the dryer. The core of the ventilation system was the three-speed fan supplied with the air-coil unit which circulated air throughout the dehydrator. The speed of the fan could be adjusted to create the desired drying conditions within the dehydrator. We used the highest speed setting during all tests and recommend hard-wiring the fan to operate at the highest speed. A 6-inch exhaust duct with a manual damper valve (Figure 40) was installed in the back wall of the dehydrator, opposite of the air duct discharge. The damper was opened during the drying cycle to allow moist air to escape. Fresh air entered the dehydrator through a 6-inch inlet duct equipped with a back-flow damper shown in Figure 41. The fresh air inlet was located on the outside wall of the dehydrator adjacent to the ventilation inlet duct as shown in Figure 41.

Results of recent testing suggested that the dehydrator performance could be improved by adding an air exhaust or supply fan. Benefits of a fan include removing moisture-laden air and replacing it with fresh, dry air. Disadvantages of a fan include wasting heat by exhausting hot air too quickly, and use of electricity. A recently published fact sheet “FAPC-175 Dehydrator optimization: reduction of energy use and carbon emissions” (see Appendix II) describes a waste heat recovery system that was added to the dehydrator to reclaim heat from the exhaust air. The system included fans that increased the flow of air through the dehydrator. A side benefit of the heat recovery system was a reduction in product drying time (probably due to the increased air flow).

Variable-speed, in-line fans like the Fantech FG commercial series ([www.fantech.net](http://www.fantech.net)) are simple to install in existing, circular exhaust or supply ducts. Installation in the supply duct permits use of an air filter on the suction side of the fan. A rotary speed control (e.g. Fantech RPE 10) can be purchased to continuously adjust the speed of the fan. The speed control enables the user to adjust fan speed to optimize the air flow rate for drying and energy use. Time of drying cycle or relative humidity in the drying chamber could be used as feedback information for adjusting fan speed. Drying cycle time and chamber relative humidity should be reduced as much as possible, balanced by energy usage to heat incoming, fresh air.

Experimentation with the original dehydrator revealed unacceptable temperature variations within the product drying region. It was discovered that the temperature variations were due to stratified air flow (inadequate mixing) within the unit. A low-speed, high-volume (LSHV) fan, located on the opposite wall of the product loading door, was installed to thoroughly stir the air in the drying chamber of the dehydrator (see Figure 42) to maintain temperature uniformity. The fan system was designed to place the motor outside of the dehydrator to protect it from the high temperatures and humidity inside the dehydrator.

Details of the fan drive assembly are shown in Figure 43. Dimension “A” shown in Figure 43 is half the width of the end wall. Dimension “B” is 37” from the floor to the center of the fan drive shaft. A Power Twist® V-belt drive was selected to allow quick adjustment of the V-belt length during installation. The fan drive motor was mounted on an adjustable base to permit tensioning of the drive belt. Fan rpm should be maintained at greater than or equal to 250 for optimum air mixing in the dehydrator. A fixed-drive is recommended for permanent installations. If a fan drive motor with a speed of 1,750 rpm is selected, a reduction ratio of about 6:1 is needed to achieve 300 rpm fan speed. A drive pulley with a diameter of 2.5” and a driven pulley with a diameter of 13.95” (see items 5.7 and 5.8 in the dryer system parts list table) will provide 313 fan rpm when driven by a 1750 rpm motor.

An adjustable baffle was mounted on the rear wall on the inside of the dryer to direct heated air into the suction side of the LSHV fan (see Figure 44). This simple device played an important role in maintaining uniform drying conditions in the dehydrator. The baffle was made of a 31.75 x 22” piece of galvanized sheet metal. Hinges were fixed to one end of the baffle and attached to the dehydrator’s wall while a small chain was attached to the other end of the baffle. The loose end of the chain was attached to a hook that was anchored on the dehydrator ceiling as shown in Figure 44. The chain was used to adjust the angle of the baffle according to the procedure outlined below.

The optimum baffle angle for our installation was determined by operating the dehydrator at full heat (without product) and measuring the air temperature at six locations in two areas of the dehydrator as shown in Figure 45. Measurements were repeated at both ends of the dehydration tunnel (air entrance and exit) for a total of twelve locations to account for as much variation in air flow as possible. The baffle angle was adjusted (increased or decreased) until all air temperature measurements were within about 5 degrees F of each other. The optimum angle for the baffle was experimentally determined to be approximately 15 degrees below horizontal for our dehydrator. The need for a baffle illustrates the importance of air flow in the dehydrator. The heated air should be introduced to the suction side of the LSHV fan to ensure good air mixing in the dehydration chamber.

### ***Humidification***

Humidity was required to achieve the wet bulb temperatures specified by the pathogen reduction step. Experimentally it was found that high humidity was impossible to reach under dehydrator operating conditions without the introduction of moisture (steam) from sources in addition to the product. Humidity levels in the system were reached using two supplemental sources: (1) water evaporation from the heater coil; and (2) a steam generator (preferred method).

Water evaporated from the heater coil was the simplest method that we used to generate steam in the system. This was the first means of increasing the humidity that was experimented with in the prototype dryer. A small misting nozzle was installed just “upwind” of the heating coil using ¼” flexible plastic tubing (see figure 44). Instant, or push-to-connect, fittings were used to connect the plastic tubing to the water source and

misting nozzle. A manual shut-off valve with push-to-connect fittings was included. A complete listing of items purchased for the humidification system is given in the dryer system parts list under “humidification system”.

A front panel was removed from the air coil enclosure to allow positioning of the mister near the heating coil. The nozzle was positioned to mist water directly onto the coil. Air movement blew water into and through the coil. When the water contacted the coil evaporation occurred; increasing the humid content of the air. Note: Use only softened water to spray on the heater coil. Untreated water may leave mineral deposits on the heater coil which will eventually reduce heat transfer efficiency, affecting the dehydrator’s performance.

Water evaporation from the product and water mist sprayed on the heater coil did not produce enough humidity to reach the levels prescribed by the microbial inactivation step. A supplemental steam source was necessary. A steam generator was purchased and installed to reach the needed humidity levels. Small, packaged steam generators are commercially available for home spas and saunas. These units are relatively inexpensive and simple to install and operate. We purchased a Steamist steam generator for our system (Figure 47) with an optional, factory-installed manual blow down valve. Blow down valves are used to periodically remove accumulated minerals and sludge from the boiler tank. The steam generator was mounted on the exterior of the dehydrator (left wall) with the steam discharge piped into the ventilation duct downstream of the heater coil (Figure 48). The Steamist steam generator is no longer available, and a substitute (and more powerful) model is now shown in the dryer system parts list.

A seal was made for the steam pipe penetration into the ventilation duct (see Figure 46). An aluminum pipe flange was bolted to the duct, sandwiching a 40A durometer silicone rubber gasket between the duct and the pipe flange. The silicone rubber gasket was hand-cut from a sheet of gasket material to match the outside diameter of the flange. Holes were cut in the gasket to accommodate the bolts and the copper tubing.

Two simple options were available for steam generator on/off control. (1) The manufacturer’s standard control system for the generator was an on/off switch that can be timer operated. As long as the timer is on (switch closed), the steam generator runs. Almost any mechanical timer can be used for this application; (2) The second control choice for the generator is the one we used. We permanently wired the on/off switch in the “on” position and manually turned the generator off and on by plugging and unplugging it at the electrical power source.

Used in combination, the water spray and steam generator produced enough humidity to achieve the levels required by the kill step. However, when used separately, neither supplied sufficient steam to achieve specified levels. A larger steam generator could be specified to replace the need for the water spray system. Higher capacity steam generators are readily available from the spa and steam bath industry suppliers. Drawbacks of a larger steam generator include higher equipment cost, an increased requirement for electricity, greater energy usage, and additional wiring. Many meat

processors may already have a steam source available on site that could be used for direct humidification. Check to determine if the steam is suitable for food contact before using it for humidification.

## **MOBILE DRYING RACKS**

Mobile drying racks (Figure 27), used to support and transport product, had three main components:

1. Mobile bun pan rack
2. Stainless wire cloth “shelves”
3. Plastic mesh covers

Mobile bun pan racks hold standard bun pans that are 18 x 26 x 1”. These racks are common in the bakery industry, are mass produced and widely available both new and used. Six racks were purchased for the prototype dehydrator. These racks held 20 pans each for a total of 120 pans. An option to purchase racks with supports for more bun pans was available (e.g. 40 per rack for a total of 240 pans), but not exercised for this project. A rack with a higher pan capacity would increase the holding capacity of the dryer, but not necessarily increase the drying capacity, since airflow might be restricted and the heater is not being increased simultaneously. The ideal bakery rack for the dehydrator has the following features:

- Sturdy, cleanable wheels that can withstand heat
- Smooth, corrosion-resistant surfaces (aluminum is common, and stainless steel is available, but expensive)
- Bun pan supports that do not block the flow of air (rack can be rotated if necessary to place pan supports parallel to air flow)

Several manufacturers of mobile bun pan racks are listed below. The InterMetro units are fabricated of coated wire and as of this writing have a very competitive price. The wire structure also blocks less air flow. Coatings are susceptible to wear, and the coating on the wire is a definite concern for the Metro units that requires further research and experience. A partial list of mobile bun pan rack manufacturers is given below in alphabetical order:

Advance Tabco; [www.advancetabco.com](http://www.advancetabco.com)  
Channel Manufacturing, Inc.; [www.channelmfg.com](http://www.channelmfg.com)  
Eagle Group; [www.eaglegrp.com](http://www.eaglegrp.com)  
GSW; [www.gsw-usa.com](http://www.gsw-usa.com)  
InterMetro Industries Corp.; [www.metro.com](http://www.metro.com)  
Johnson-Rose Corp.; [www.johnsonrose.net](http://www.johnsonrose.net)  
New Age Industrial; [www.newageindustrial.com](http://www.newageindustrial.com)  
Prairie View Industries; [www.pviramps.com](http://www.pviramps.com)  
Storage Products Group; [www.spgusa.com](http://www.spgusa.com)  
Win-Holt Equipment Group; [www.winholt.com](http://www.winholt.com)

Stainless steel trays or “shelves” were purchased to support the product during drying. Many types of stainless steel are available for shelving, including perforated and expanded materials, but welded wire cloth was the least expensive option at the time of this writing. The shelves were custom cut from sheet stock to 20 x 28” and the edges

were “hemmed” 1.0” to form a final product of 18 x 26” that fit into the slots of the mobile drying racks. Figure 49 shows an example of the hemmed edges, which added rigidity to the shelves and concealed the sharp ends of the wires. The shelves were one of the most expensive components of the dehydrator. Non-stainless substitutes (e.g. plastic) were examined to reduce cost, but no acceptable alternative has been identified.

Plastic mesh covers were custom cut (cut by the manufacturer) to 18 x 26” pieces to cover the stainless steel wire cloth shelves. Most dried-meat processors use plastic covers on their drying shelves to prevent product from sticking to the metal surface. When the drying cycle was completed, the plastic covers were quickly flexed, “popping” the jerky off with minimal sticking and product loss. Plastic mesh may be loosely placed on top of the wire cloth shelves, or fastened to the shelves using twist or zip ties. The brand of plastic mesh that we used (see parts list) was very heavy and durable. Other manufacturers of plastic mesh include DelStar Technologies, Inc. ([www.delstarinc.com](http://www.delstarinc.com)), Industrial Netting ([www.industrialnetting.com](http://www.industrialnetting.com)), and Tenax Corporation ([www.tenaxus.com](http://www.tenaxus.com))

## **INSTRUMENTATION**

Instrumentation was selected for simplicity, low-cost, and reliability. Wet-bulb temperature has recently been used as a critical process control point in microbial inactivation for jerky processing (Buege et al., 2006). Based on this information, wet-bulb and dry-bulb thermocouples were used to control operation of the dehydrator. A dual recorder served the purposes of recording and displaying data (data could also be downloaded from the recorder to a PC). Figure 50 shows the instrumentation system mounted on the dehydrator. Both thermocouples were installed in the return air ductwork of the dehydrator to sense temperatures at the most conservative location. Liquid-tight cord grips were used to hold the thermocouples in position and to prevent air and water leaks.

Installation of the temperature sensors is shown in Figures 50, 51, and 52. An automatic water reservoir (typically used for ice machines) provided water for the wet bulb wick. The reservoir was vertically positioned at nearly the same elevation as the wet-bulb thermocouple in order to flood the wick to the maximum extent possible without leaking water into the ductwork (Figure 52). The wick must be thoroughly wetted, or wet-bulb readings will be inaccurate. The wet-bulb thermometer should be inserted about 2 to 3 inches into the air duct (Figure 52). Caution: if the wet-bulb thermocouple is extended too far into the air duct, the evaporation from the exposed surface of the wick may exceed its wicking capacity causing inaccurate wet-bulb temperature readings.

An optional digital psychrometer was purchased and used to check dry and wet bulb temperatures in the dehydrator. A NIST traceable certificate of calibration for the psychrometer was also purchased from the instrument supplier.

## **STARTUP & OPERATION**

Startup and operation of the dehydrator is outlined in this section. Procedures may vary according to unique environmental circumstances, product, and personal preference. The

startup sequence assumes a clean dehydrator with product on shelves, in the drying racks, ready to be processed.

1. Close and cover the air damper and cover the back-draft damper.
2. Turn on the water and gas supplies.
3. Turn on the hydronic system fan (high setting).
4. Turn on the steam heater.
5. Turn on the water spray nozzle.
6. Turn on the hydronic system water recirculation pump.
7. Turn on the water heater and set it to desired temperature. Actual air temperature in the dryer will be less (normally about 10 degrees F) than the hot water temperature set point at the water heater.
8. Turn on the low-speed, high-volume drying chamber fan.
9. Position the drying racks in dryer.
10. Close the dryer door.
11. Turn on temperature data logger.
12. When wet bulb temperature reaches the desired level for the required time period:
  - a. Turn off the steam heater.
  - b. Turn off the water spray nozzle.
  - c. Uncover and open the air damper
  - d. Uncover the back-draft damper.
13. Optional step: rotate drying racks after predetermined time period (e.g. 3 hours) for (possibly) quicker and more uniform drying time.
14. When you believe dehydration is complete, turn off the low-speed, high-volume fan and open the dehydrator and test product for doneness.
15. If product is dry:
  - a. Turn off water heater.
  - b. Turn off water and gas supplies.
  - c. Remove product.
  - d. Download wet and dry bulb temperature history to PC.
  - e. Clean dehydrator and racks according to procedure outlined in “CLEANUP” section
16. If product is not dry: close dehydrator and continue to dry. Turn on low-speed fan and go back to step 14.

Appendix III contains a copy of the fact sheet “FAPC-166 Reduction of Drying Time for Jerky Products”. Application of the concepts in this fact sheet may help to define the operation of the dehydrator while optimizing the production process.

## **CLEAN UP**

Dehydrator cleanup is a fairly simple procedure. The interior surface of the dehydrator is watertight and unaffected by normal cleaning chemicals. Safety precautions should be followed:

- Ventilate the dehydrator to prevent chemical fume buildup.
- Wear proper protection for chemical splashes and drips.
- Do not use a pressure washer.

The sequence of cleaning operations for the interior of the dehydrator follows:

1. Rinse all surfaces with warm or cold water.
2. Foam or brush-on a mild detergent on all surfaces and let stand for the manufacturer's recommended time period.
3. Rinse foam and soil residues from surfaces.
4. Sanitize surfaces with an appropriate product.
5. Allow to air dry.
6. Clean floor and floor drain according to standard practices.

**Mobile rack cleanup:** Mobile racks are manually cleaned using the same procedure as given above for the dehydrator interior. Hand brushing may be required to remove baked-on soils from the rack surface. Air dry racks.

**Wire and plastic tray cleanup:** Stainless steel wire and plastic trays can be soaked in a tub or tray filled with an appropriate cleaner that is capable of removing baked-on protein and product marinade. After soaking, brushing may be necessary, but ordinary soils can be removed by rinsing. Some users have effectively used a COP tank to clean trays. COP tanks are built to clean small food equipment components, pipes and fittings by circulating cleaning fluids over the parts. New and used COP tanks can be purchased from dairy equipment dealers (e.g. [www.schiercompany.com](http://www.schiercompany.com)). Air dry trays after washing.

## **TESTING AND VALIDATION**

A number of air temperature tests were conducted at various fan speeds and baffle settings to test the operation of the dehydrator. The objective of the tests was to determine the optimum fan speed and baffle setting of the dehydration process. The recirculation blower was operated at high speed during all tests. Water heater temperature was set at "maximum" with an output of about 180 °F. As stated in the ventilation section, air temperature measurements were taken in six locations in two areas of the dehydration tunnel for a total of twelve measurements for each data set. The locations are shown in Figure 45. Raw data is given in Appendix IV.

Prior to the air temperature tests outlined above, similar experiments were run to determine the best fan equipment and baffle location. Several iterations of fans were tried before the final version was selected. At first, portable household-type fans were placed in the dehydrator to determine if an improvement in air flow could reduce temperature variations in the dehydrator. After this was proven, six, fourteen-inch diameter fans were installed in the end wall of the dehydrator for air mixing. The fans improved the air temperatures, and could be controlled independently, but the drive mechanism was complex and expensive.

Next a single, 36-inch diameter, four-blade, high-volume, low-speed fan was purchased for the dehydrator to reduce the cost and complexity of the drive system. The fan blade worked well, and was an improvement over the smaller fans, but speed was not consistently related to changes in air temperature distributions. A 48-inch diameter, 5-blade, high-volume, low-speed fan blade was purchased and installed in place of the 36"



fan. The larger fan gave an improved performance when compared to the previous tests with the 36" fan.

Baffle placement and angle turned out to be important variables in controlling air temperature distributions within the dehydrator. The baffle deflected the return air from the duct and directed it into the dehydrator tunnel. Several hinge locations for the baffle were experimented with, including: just below the return air duct discharge; on the end wall, directly across from the discharge duct; and at the very top of the end wall against the interior ceiling of the dehydrator. Best results were realized with the baffle hinged just below the return air duct discharge (Figure 53) when hanging at a negative angle of approximately 15 degrees to the horizontal.

## **SAFETY**

Several features were included in the dehydrator to improve operator safety.

1. A fan guard was added to protect operators from the rotating LSHV fan. The guard was built using PVC tubing reinforced with electrical conduit (conduit was cut, fit, and placed inside the PVC frame members before they were glued together). A plastic fencing material was zip-tied to the PVC framework to prevent workers from contacting the fan blades. An additional safety improvement for the LSHV fan that has been suggested and experimented with on similar dehydrators is a kill switch that was installed on the door frame. The switch was wired to cut power to the LSHV fan when the door to the dehydrator was opened.
2. Ground-fault outlets were used for lights, pump and other items that were plugged in.
3. A removable cover for the fan assembly (figure 43) was fabricated to protect operators from the fan drive components.
4. Circuit breakers were used to protect all of the electrical circuits in the dehydrator.

Product safety is discussed in the section on theory of operation, and in Appendix III.

## **CONCLUSION**

Building and operating your own dehydrator can be a fun and rewarding experience. The parts procurement and construction process will increase the owner's understanding of the dehydrator and should contribute to improved process control and product quality. Niche product manufacturers (organic, Kosher, Halal, exotic meats, etc.) will find it much less expensive to enter the market with product processed in their own facility. Inspectors will be familiar with the design and perhaps more comfortable with the operation of the dehydrator. Ultimately the customer will benefit by receiving more choices of high quality products at competitive prices.

## **ACKNOWLEDGEMENTS**

Many persons participated in the design, construction, testing, and evolution of the dehydrator; however, none of these activities would have been possible without the support of a 2005 Cooperative Agreement Grant from the Food Safety and Inspection Services of the USDA. Dr. Kris Murthy, Senior Staff Officer, New Technology Staff, was responsible for overseeing the project for the USDA.

Mr. Wayne Kiner, Shop Manager, and Mr. Bobby Flores, Instrument Maker, both of the Biosystems and Agricultural Engineering Department at Oklahoma State University, carried out the structural design and construction of the dehydrator. Mr. Kiner turned the concept of the dryer shell into reality and drafted most of the CAD documents. Mr. Flores provided expert craftsmanship and creativity in the construction of the dehydrator.

Many faculty, staff, and student workers at the Food and Agricultural Products Center at Oklahoma State University assisted with the evaluation and testing of the dehydrator. Mr. David Moe, Pilot Plant Manager (recently retired), oversaw the entire installation and operation of the system. Mr. Jake Nelson, Pilot Plant Manager, has ably taken the place of David Moe after his retirement and supports current operation of the dehydrator. Mr. Ben Smith and Mr. Brady Stewart conducted temperature and humidity profiles of the dehydrator. Ms. Stacey Kowalski tested methods to optimize dehydration time of jerky products. Mr. Raghavendra Rao Kakarala installed and tested the ventilation waste heat recovery system. Mr. Kyle Flynn supervised the meat processing and handling for test products. Dr. K.C. Ehlers, DVM, USDA Frontline Supervisor, and Mr. Fred Sizemore, USDA inspector, provided input on the design, installation, and operation of the unit.

**DRYER SYSTEM PARTS LIST**

Identifica tion	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
<b><i>Walls, Ceiling and Interior</i></b>							
1.1	PolyMax All- purpose fabric, 16 mil thickness	CC2981	100	2.21	221.00	Teksupply, Dyersville, IA www.teksupply.com	
1.2	Supertape, 3" x 60' roll	101616	1	23.95	23.95	Teksupply, Dyersville, IA www.teksupply.com	
1.3	Foam board, 48x96x1"		10	13.62	136.20	Local supply	
1.4	Oriented Strand Board (OSB) 48x96x7/16"		10	8.27	82.70	Local supply	
1.5	Studs 2x4x96"		54	3.14	169.56	Local supply	
1.6	Studs 2x4x120"		1	4.50	4.50	Local supply	
1.7	Studs 2x4x144"		1	6.00	6.00	Local supply	
1.8	8 and 16 P nails		As required	15.00	15.00	Local supply	
1.9	2-1/2 and 1" coated screws		As required	20.00	20.00	Local supply	
<b><i>Doors</i></b>							
2.1	2-8 Steel Entry Door	Lowe's stock # 14620	1			Lowe's	NA
2.2	3-0 Steel Entry	Lowe's stock	2	139.00	278.00	Lowe's	NA

Identifica tion	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
	Door	# 14622					
2.3	Water-based stainless steel coating, 1 qt.	Steel-it	1	38.48	38.48	McMaster Carr mcmaster.com	7949T11
2.4	Door knobs		2	28.97	57.94	Local supplier	
2.5	Door shims		2	1.50	3.00	Local supplier	
<b>Electrical</b>							
3.1	Sealed light fixtures		3	81.95	245.85	Teksupply teksupply.com	105447
3.2	Wire, 12-2 NMB W/G			50.00	50.00	Local supplier	
3.3	Octagon boxes, 4"	Raco 146	3	1.76	6.36	Local supplier	
3.4	Switch boxes	Raco 410	2	5.64	11.28	Local supplier	
3.5	Switch boxes	Raco 865	2	1.01	2.02	Local supplier	
3.6	Single pole switches	Hubbell CS1201	2	2.73	5.46	Local supplier	
3.7	Load center	Square D	1	33.29	33.29	Lowe's Lowe's.com	162577
3.8	QO circuit breaker	Square D	3	3.11	9.33	Lowe's	12811
3.9	GFCI receptacle, 3- pack	Cooper, 15A	1	28.40	28.40	Lowe's Lowe's.com	245840
<b>Heating</b>							
4.1	Continuous hot water heater	T-KJr. Flash water heater, Takagi	1	665.00	665.00	www.houseneeds.com	

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
		Industrial Co. USA, Inc. Irvine, CA					
4.2	Remote temperature controller/digital readout for hot water heater (optional)	Model TK-RE30, Takagi Industrial Co. USA, Inc. Irvine, CA	1	114.75	114.75	www.homeneeds.com	
4.3	Heater exhaust vent, length and fittings depends on installation site	Category III approved, single-wall, 4" vent pipe		75.00	75.00	Local supply	
4.4	Fan coil hydronic heater	Precision Metal Products AH-220	1	1,092.00	1,092.00	www.houseneeds.com	
4.5	Hot water circulation pump	Grundfos, UP26-99F	1	289.75	289.75	www.houseneeds.com	
4.6	Temperature, pressure indicator	Winters Tridicator	1	12.75	12.75	www.houseneeds.com	404
4.7	Flange connections with shutoff valve for pump	Webstone, 3/4"	1	32.75	32.75	www.houseneeds.com	40403
4.8	Air vent	Taco, Hy-vent	1	10.65	10.65	www.houseneeds.com	400
4.9	Expansion tank	Flexcon HTX30	1	37.75	37.75	www.houseneeds.com	
4.10	Pressure relief	Watts, 3/4"	1	29.00	29.00	www.houseneeds.com	

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
	valve	PRV 342670					
4.11	Ball valve, ¾", NPT	Cash Acme Sharkbite	7	12.35	86.45	Lowes hardware	72861
4.12	Flexible gas line connector		1	24.94	24.94	Lowes hardware	14038
<b>Ventilation</b>							
5.1	Galvanized sheet metal, 26 GA.		1	75.00	75.00	Local supplier	
5.2	Cape backdraft damper, 6"	Tamarack Technologies, Inc., West Wareham, MA	1	17.75	17.75	RE Williams Contractor, Inc. www.rewci.com	
5.3	Galvanized steel round duct damper, 6"	17355K61	1	49.83	49.83	McMaster Carr www.mcmaster.com	
5.4	Back flow preventer (for water supply)	Watts 9D-M3, ½" FNPT	1	42.95	42.95	www.houseneeds.com	
5.5	Miscellaneous piping and fittings, depending on installation site	May include cPVC, copper, PEX, or other materials suitable for high-temperature	Lot	75.00	75.00	Local supplier	

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
		water service					
5.6	Low speed, high volume (LSHV) fan	Multi-Wing. 48-5-SLP-30-PAG-6WR-P1-1"-BR	1	315.25  (OEM factory price)	315.25	Multi-Wing America, Inc., Burton, Ohio. <a href="http://www.multi-wing.net">www.multi-wing.net</a>	
5.7	Die cast finished bore V-belt pulley, 1" bore	13.95" OD	1	70.74	70.74	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	6204K573
5.8	Die Cast finished bore V-belt pulley, 5/8" bore	2.55" OD	1	9.68	9.68	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	6204K133
5.9	Pillow block bearing for 1" shaft		1	38.65	38.65	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	6244K56
5.10	Flange mount bearing		1	39.43	39.43	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	5967K84
5.11	Partially keyed steel shaft, 1" od x 24" long		1	42.16	42.16	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	6117K26
	Power Twist V-belt, 1/2" x 4'		1	31.95	31.95	Grizzly Industrial, Inc. <a href="http://www.grizzly.com">www.grizzly.com</a>	G3640
	Drive motor for LSHV fan	1725 rpm, 115/208-230 V1 HP, 5/8" shaft, NEMA 56 footprint	1	279.33	279.33	McMaster Carr <a href="http://www.mcmaster.com">www.mcmaster.com</a>	5990K23
	Adjustable motor-mount base	For NEMA 56 frame with 3"	1	17.64	17.64	McMaster.com	62035K21

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
		adjustment					
	On/off switch for motor	Enclosed, pad lockable, 25 amp rating	1	56.70	56.70	McMaster.com	6759K311
	1" PVC tube and fittings		Lot	15.00	15.00	Local home supply store	
	Plastic fence 4' x 50' long roll		1	25.96	25.96	McMaster Carr www.mcmaster.com	60105T44
	Lumber and OSB for outside chain guard and motor mount support		Lot	45.00	45.00	Local home supply store	
	Electrical wire and wire nuts		Lot	40.00	40.00	Local home supply store	
<b><i>Humidification</i></b>							
6.1	Misting nozzle, 2.5 gallons per hour capacity		1	5.30	5.30	McMaster Carr; www.mcmaster.com	3178k44
6.2	1/4" flexible tubing (for potable water)		100	0.25	25	Local supplier	
6.3	Instant fitting 1/4" tube x 1/4" MNPT		10	1.59	15.90	McMaster Carr; www.mcmaster.com	51055K972
6.4	Instant fitting on/off valve 1/4" x 1/4"		4	12.25	51.08	McMaster Carr; www.mcmaster.com	4757K21



Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
6.5	Instant fitting 1/4" tube x 3/8" MNPT; used to connect to water source (may vary according to site conditions)	51055K211	1	2.20	2.20	McMaster Carr; www.mcmaster.com	
6.6	Amerec 5kW steam generator	AK5	1	924.00	924.00	Steam Sauna Bath www.steamsaunabath.com	
6.7	Copper tubing and fittings		Lot	65.00	65.00	Local supplier	
6.8	Aluminum pipe flange (1" pipe size, x 4-1/2" OD, unthreaded, slip-on)		1	15.07	15.07	McMaster Carr www.mcmaster.com	44705K361
6.9	Silicone rubber sheet, 40A durometer, 12 x 12" (used to make gasket)		1	25.29	25.29	McMaster Carr www.mcmaster.com	8632K461
6.10	Power cord for steam generator	Type SJOOW, 300VAC, 10/3 Awg, 0.61" OD	25 ft	2.39	59.75	McMaster Carr www.mcmaster.com	7422K28
6.11	Plug for power cord	Varies according to site conditions	1	15.00	15.00	Local supplier	

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
<b>Mobile Drying Racks</b>							
7.1	Side-loading mobile bun pan rack	Model RS1, InterMetro Ind. Corp. Wilkes-Barre, PA	6	200.00	1,200.00	EPSTexas.com	RS1
7.2	Custom cut, 20 x 28", 304 stainless steel wire cloth with ½ x ½" spacing of 0.063 welded wire		120	9.90	1,188.00	Wire Cloth Manufacturers, Tulsa OK, www.wireclothman.com	
7.3	Custom cut, 18 x 26" plastic mesh	XN-5010	120	\$5.13	\$615.60 + \$75.00 cutting fee	InterNet, Inc., Minneapolis, MN, www.internetplastic.com)	
<b>Sensors and Data Collection</b>							
8.1	Wick tube for wet-bulb thermocouple, 500 yard spool for 1/8" temperature probe	S4WBLW SKU: 4430	1	80.19	80.19	Pepperell Braiding Company, Pepperell, MA www.wickstore.com	
8.2	Mini-plug thermocouple, type K		2	32.74	65.48	McMaster Carr; McMaster.com	39095K54
8.3	Thermocouple Recorder/display		1	249.58	249.58	McMaster Carr; McMaster.com	9281T44

Identification	Description	Mfg. & Part No.	Quantity	Price* Each, \$	Price* Total, \$	Source	Source Part No.
8.4	Masterclear PVC tubing, ½" ID		25	0.29	7.25	McMaster Carr; Mcmaster.com	5233K66
8.5	Reservoir with float valve		1	34.48	34.48	McMaster Carr; Mcmaster.com	7973k55
8.6	Liquid-tight cord grip (holds dry bulb thermocouple in air duct) ¼" NPT x 0.08 to 0.20" cord		1	2.37	2.37	McMaster Carr; mcmaster.com	69915K46
8.7	Liquid-tight cord grip (holds dry bulb thermocouple in air duct) ¾" NPT x 0.35 to 0.63" cord		1	4.34	4.31	McMaster Carr; mcmaster.com	69915K56
8.8	Digital psychrometer ( <i>optional</i> ) used to measure wet and dry bulb temperatures	Check-it Electronics Corp., Elizabeth, NJ, model 0622	1	199.00	199.00	Davis Inotek Instruments, Cincinnati, OH, www.davisinotek.com	
8.9	Digital psychrometer ( <i>optional</i> ) calibration certificate		1	99.00	99.00	Davis Inotek Instruments, Cincinnati, OH, www.davisinotek.com	
				TOTAL	\$7,974.11	(does not include optional items)	

\*Prices shown do not include tax, handling, and freight.

## LIST OF FIGURES

- Figure A. Jerky Assy: a view of the complete dryer (left side)
- Figure 1. Jerky Dryer wall: right side wall view
- Figure 2. Exploded Wood View: a view of individual wooden ribs of left side
- Figure 3. Jerky Wall with Foam: right side view of dryer showing foam pieces
- Figure 4. Jerky Dryer Wall: view of the left side of the dryer
- Figure 5. Exploded wood view: a view of the individual wooden ribs of the right side wall
- Figure 6. Wall and Dimensions: width dimensions of the right side wall
- Figure 7. Left side wall with foam and OSB width dimensions
- Figure 8. Left side wall: width dimensions
- Figure 9. End Wall No Door: view of the back wall of the dryer
- Figure 10. Exploded End Wall: a view of the individual components of the back wall
- Figure 11. End Wall: width dimensions of the end wall
- Figure 12. End Wall with Exploded Foam/OSB: a view of the end wall with the individual foam and OSB pieces
- Figure 13. Front Wall with Door: dimensions of the front wall including the door
- Figure 14. Exploded Front Wall View: individual pieces of front wall construction
- Figure 15. Front Wall Foam and OSB Detail: view that shows structure of the front wall including individual foam and OSB pieces
- Figure 16. Exhaust: exhaust panel (facing front side)
- Figure 17. Dryer Top Exhaust End: roof of exhaust end
- Figure 18. Center Assy : construction drawing of the center roof of the dryer
- Figure 19. Center Assy 1: a close-up view with dimensions of half of the center roof of the dryer (closer to exhaust end)
- Figure 20. Center Assy 2: a close-up view with dimensions of half of the center roof of the dryer (closer to front end)
- Figure 21. Door End Top: the roof of the front side of the dryer
- Figure 22. Door End Top Assy: dimensions of the roof of the front side
- Figure 23. Exhaust Duct: exhaust duct with dimensions
- Figure 24. Inlet Duct: inlet duct with dimensions
- Figure 25. Center Assy 2, exploded: an exploded view of the entire center roof
- Figure 26. Recommended Access Space for Dehydrator: drawing showing suggested dimensions of the dryer
- Figure 27. Mobile bakery rack used to hold product during processing
- Figure 28. Fan coil heating system
- Figure 29. Continuous hot water heater
- Figure 30. Photo of the nearly completed dehydrator
- Figure 31. Photos of one of the dehydrator walls during construction
- Figure 32. Conceptual drawing of application of the PolyMax fabric lining in the dehydrator's product holding area.
- Figure 33. Plastic cap roofing nails used to secure the PolyMax lining to the interior of the dehydrator.
- Figure 34. Photo of a technician wrapping a dehydrator ceiling panel with PolyMax fabric prior to installation.

- Figure 35. Photo of pre-hung, foam-core metal door used in dehydrator
- Figure 36. Electrical Wiring Plan View: a view from above the dehydrator depicting wiring
- Figure 37. Electrical enclosure mounted on the left-hand side of the dehydrator
- Figure 38. Heating System schematic
- Figure 39. Continuous hot-water recirculation pump
- Figure 40. Air damper valve installed on back wall of dehydrator, opposite of air duct discharge
- Figure 41. Fresh air inlet duct with back-flow damper
- Figure 42. Low-speed, high-volume fan installed to mix air within the dehydrator
- Figure 43. Fan drive assembly drawing of the circulation fan located on end wall of dehydrator.
- Figure 44. Adjustable baffle for directing air flow within the dehydrator
- Figure 45. Temperature measurement locations used to determine baffle angle setting
- Figure 46. Misting nozzle installation
- Figure 47. Steamist steam generator (DSCN0152) installation
- Figure 48. Steamist steam generator discharge piping
- Figure 49. Detail of dehydrator shelf or tray showing “hemmed” edge, which added rigidity to the shelf and concealed the cut edge of the wire cloth.
- Figure 50. Dehydrator instrumentation system
- Figure 51. Temperature sensor installation diagram
- Figure 52. Wet and dry bulb thermometer sensors viewed from the inside of the air ductwork.
- Figure 53. Optimum baffle angle: -15 degrees from the horizontal
- Figure 54. Guard protecting product from fan blades

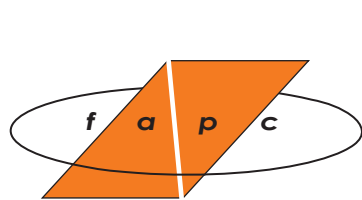
## REFERENCES

Buege, D.R., G. Searls, S.C. Ingham. 2006. Lethality of commercial whole-muscle beef jerky manufacturing process against *Salmonella* serovars and *Escherichia coli* O157:H7. *Journal of Food Protection*, Vol 69, Number 9, pp. 2091-2099.

USDA FSIS. 1999. Appendix A of the “Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products”. Accessed on June 15, 2006 at <http://www.fsis.usda.gov/oa/fr/95033F-a.htm>; updated June, 1999.

## **APPENDIX I**

FAPC-165 Consistent lethality treatment for small-scale jerky dehydrators.



## FOOD TECHNOLOGY FACT SHEET

Adding Value to Oklahoma

405-744-6071 • [www.fapc.biz](http://www.fapc.biz)

# Consistent Lethality Treatment for Small-Scale Jerky Dehydrators

**Timothy J. Bowser**  
FAPC Food Process Engineer

**Jacob Nelson**  
FAPC Value-Added Meat Processing Specialist

### Introduction

Dehydration of meat products is an important process that can be extremely profitable for meat processors of any size. Large-volume jerky processors use specialized equipment that has been developed over many years under rigorous scrutiny in an inspected environment. Smaller processors may not require large capacity industrial equipment or be able to afford custom-made dehydrators. In this case, processors may turn to commercially available products or homemade equipment. When this is true, performance of the dehydrator may be substandard to the industrial version, especially when considering the lethality step. The purpose of this fact sheet is to provide guidelines for ensuring a robust lethality process.

### Lethality Treatment for Jerky

For food safety requirements, all jerky products must include a lethality treatment prior to sale to the public under USDA inspection (USDA FSIS, 2007). Two methods of achieving lethality are feasible for the small-scale processor. They include moist heat per Appendix A “Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products” and a customized, validated process (other options like irradiation and high-pressure processing are too expensive to consider). The two lethality treatments are described below.

#### Moist Heat

Moist heat lethality treatment requires heating product in a high-humidity environment, which is more effective at killing microbes at lower temperatures compared to the dry heat method. Table 1 shows required times to achieve lethality at different wet-bulb temperatures, with data taken from USDA FSIS (1999). Water vapor must be introduced to

the environment around the product to achieve the required wet-bulb temperatures.

#### Customized Validation Process

Heat, marinade and other factors may be combined as microbial interventions (USDA FSIS, 2007). Since no combination of product, marinade recipes, equipment and drying conditions are alike, a custom validation of this process is required. The USDA has suggested that a jerky making process has sufficient lethality if it results in 5-log reduction of Salmonella (Buege et al., 2005). Validation should be conducted by a qualified laboratory (e.g. the Robert M. Kerr Food & Agricultural Products Center, [www.fapc.biz](http://www.fapc.biz)). The parameters used in the customized validation shall model the

**Table 1. Required time and temperatures for beef jerky lethality compliance at high humidity (>90%) conditions.**

Minimum internal temperature, F	Minimum processing time after minimum temperature has been reached for 7- $\log_{10}$ lethality
130	121 min
135	37 min
140	12 min
145	4 min
150	72 sec
155	23 sec
156	19 sec
157	15 sec
158	0 sec



**“Improve dehydrator efficiency by increasing air-flow to reduce temperature variations; reduce exhaust airflow when humidity levels in the dehydrator are low to conserve energy; and, add insulation to curb heat losses.”**

– Tim Bowser  
FAPC Food Process Engineer

exact conditions of the actual process; dry bulb, wet bulb, humidity, time, marinade pH, recipe, etc.

## Temperature

Regardless of the lethality treatment selected, temperature consistency in the dehydrator is important. All of the product in the dehydrator should experience the required temperature (or greater) for the prescribed time period to achieve pathogen reduction. This section describes how to measure temperature in the dehydrator, how to minimize temperature variations and how to select the temperature setting of the dehydrator.

### Measuring Temperature

Dry-bulb and wet-bulb are the terms most frequently used for temperature measurement in dehydration systems. Dry-bulb temperature is the temperature of the air (in the dehydrator) as measured by a sensor that is shielded from moisture (ordinary sensor open to the air). Wet-bulb temperature is the temperature of the air (in the dehydrator) as measured by a sensor that is wrapped with a cloth that is kept continuously wet with water by wicking action. Because of the evaporative cooling on the wet-bulb sensor, it is impossible for the wet-bulb temperature to exceed the dry-bulb temperature.

Generally speaking, thin meat products initially undergoing heat treatment have an internal temperature that tracks closely with the wet-bulb temperature of the environment (Buege et al., 2005). This is because the moist meat loses moisture at a rate similar to that being lost by the wet cloth covering the wet-bulb temperature sensor. As the meat product loses (evaporates) most of its natural moisture, evaporative cooling decreases and the product temperature begins to approximate the ambient dry-bulb temperature.

Types of sensors used to measure temperature vary, but include thermocouples, RTDs, thermistors and thermometers. The first three are the easiest to interface with data loggers and are explained in more detail.

## Thermocouples

Thermocouples are two wires made of different materials that are connected in a closed loop. Each connection, or junction, is a “thermocouple” that converts thermal energy to electrical energy. If one junction is kept at a constant temperature, the other junction can be used to sense an unknown temperature. Thermocouples are inexpensive but

can be relatively difficult to interface with electronics. They also have the widest temperature range.

## RTDs

“RTD” is an abbreviation for “resistance thermal device” that makes use of the physical property of some material (usually platinum) to change resistance with temperature. RTDs are expensive temperature sensors, but they are very stable, perform well during a wide range of temperatures, are easy to interface, and are more reliable in an electrically noisy environment.

## Thermistors

A thermistor is a temperature sensitive resistor made from a specially processed oxide material. Resistance of a thermistor varies with temperature. Thermistors have high sensitivity, are fairly inexpensive and are easy to interface with data loggers. Disadvantages include a limited temperature range, fragile nature and non-linearity.

## Dataloggers

Data loggers are used to automatically record temperatures during a given period of time. When purchasing a data logger, search for a unit that is compatible with the temperature sensors selected. A data logger with a “universal” input can accept most sensor types. Another important feature is the capability of the data logger to interface with a personal computer. This feature will assist with logger setup functions and the transfer of collected data from the logger to the computer. The format of transferred data should be compatible with spreadsheet or graphing software. Figures 1 and 2 show examples of multi-channel data loggers that are capable of recording data from more than one sensor simultaneously.

## Wet-bulb Temperature Measurement

Wet-bulb temperature can be measured by placing a wet cotton sock or tube (available, for example, from Pepperell Braiding Co., Pepperell, Mass.) over the active portion (e.g.



Figure 1. 8-channel data logger for universal inputs (includes thermocouples). [www.iseincstore.com](http://www.iseincstore.com)



Figure 2. 4-channel data logger for thermistors, RTDs, voltage and current sources.

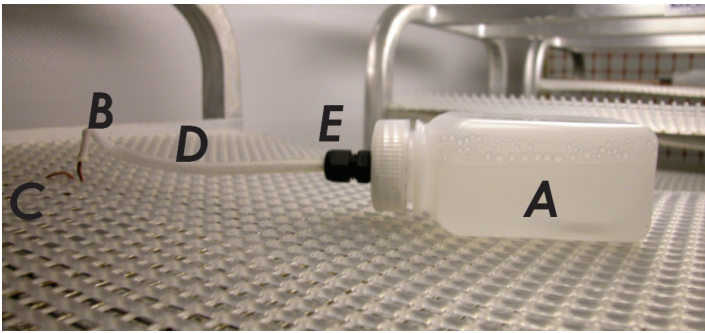


Figure 3. Setup for wet-bulb temperature sensing with a water reservoir “A” (plastic container) and 36-inch long by ¼-inch diameter cotton sock “B” placed over the tip of the thermocouple “C.” A clear 10 cm long Tygon® tube “D” covers the cotton wick from the reservoir to within about 2 cm of the terminus of the wick to maintain cleanliness. When the exposed portion of the cotton wick becomes soiled, fresh material is exposed by pulling the wick out of the reservoir and cutting off the soiled portion. A Nylon liquid-tight cord grip “E” (69915K47, McMaster Carr, Atlanta, GA) was threaded into the lid of the container and used to hold the Tygon® tubing in place.

bulb or tip) of the temperature sensor (see figure 3). The sock must be kept continuously moist and clean for accurate readings. Placement of sensors should be adjacent to the product at locations in the dehydrator where temperature variation is the greatest (e.g. corners or edges or areas where air flow and heat treatment may be blocked or limited).

### Fans, Fan Placement and Air Flow

Good air circulation will reduce temperature variation in the dehydrator (Bowser and Weckler, 2008). Airflow should be uniformly directed over the heating source, across the product and returned back to the fan for recirculation. Some air should be exhausted during the drying process to remove moisture. Return air to the fan is always directed to the suction (or low pressure) side of the blades. Fan speed, or air flow volume, can be set to provide enough air velocity to maintain the desired temperature in the dehydration chamber and consume a minimum of energy; see Bowser and Weckler (2008) for details.

### Temperature Setting

Dehydrator temperature setting is an important factor for effective pathogen reduction. To determine the temperature set point, two pieces of information are needed: a numerical value that represents the natural variation of temperature in the dehydrator (called the standard deviation) and the total temperature variation that can be tolerated in the jerky dehydrator.

### Standard Deviation

Standard deviation is a measurement of variation of a data set (temperature data) collected at different locations in the dehydration chamber. To determine the standard deviation of a data set for the dehydrator, collect at least 12 temperature data points at different locations in the dehydrator and perform the following calculation:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Where  $x$  is an individual temperature data point,  $\bar{x}$  is the average value of all of the data points, and  $n$  is the total number of data points collected. More data (temperatures at different points in your dehydrator) will result in a more accurate number for the standard deviation. The value “ $s$ ” is the standard deviation of the data set and can be used as an estimate of the standard deviation “ $\sigma$ ” of the population of all possible data, and  $\bar{x}$  can be used to estimate  $\mu$ , the average of the population of all data.

### Acceptable Variation

What is an acceptable variation for the application? The distribution of temperatures measured in most dehydrator systems will approximate a bell curve (known as a “normal” distribution) shown in figure 4. The distance from the mean,  $\mu$ , to the point of inflection of the curve is one standard deviation ( $\sigma$ , or sigma).

If the lethality process temperature set point (wet-bulb temperature in the dehydrator) is equal to  $\mu$ , then there is a chance that half of the product will not meet the lethality requirement (the amount of product under the bell curve to the left of  $\mu$ ). To reduce chances that product does not meet lethality requirements,  $\mu$  can be increased by a given amount or the processing time (for lethality) can be increased according to Table 1. Increasing  $\mu$  and/or the processing time may cause issues related to product quality, consistency and economy.

The lethality process set point temperature,  $\mu$ , or the processing time should be increased enough to reduce the risk of producing under processed product to an acceptable level. Modern statistical control schemes often determine equipment settings by adding a multiple of sigma to  $\mu$ . Table 2 (Joglekar, 2003) shows several levels of sigma and their

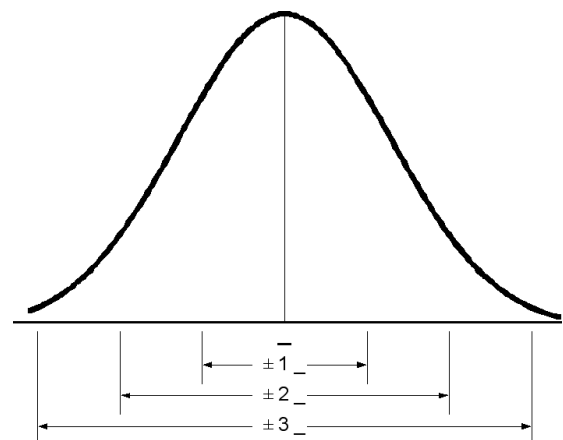


Figure 4. Normal distribution curve showing levels of standard deviations ( $\sigma$ ) from the mean value,  $\mu$ .

effect on the process. For example if the lethality process temperature is set at  $\mu + 3\sigma$ , the result would be 33,400 possible defects (under-processed product) per million pieces of product. If the temperature setting is  $\mu + 6\sigma$ , the number of defects per million pieces is statistically less than 2. Many companies are working to reach a six-sigma goal for their processes.

**Example 1:**

If the average wet-bulb temperature in a dehydrator is  $\mu = 140.0$  F with  $\sigma = 0.83$  F, and the processor wishes to achieve a six-sigma level of product lethality, then the temperature set point of the dehydrator should be adjusted to  $\mu + 6\sigma$  or  $140.0$  F +  $6 \times (0.83) = 145.0$  F with the process time remaining at 12 minutes (for a 140.0 F process).

**Example 2:**

The average wet-bulb temperature in a dehydrator is  $\mu = 140.0$  F with  $\sigma = 0.83$  F, and the processor wishes to achieve a six-sigma level of product lethality by increasing the processing time. The processing time should be set according to the lowest lethality temperature ( $\mu - 6\sigma$ ) reached in the dehydrator. The lowest temperature is calculated as  $140.0$  F -  $6 \times (0.83) = 135.0$  F. The process time should be set to 37 minutes according to Table 1.

**Food Safety**

Jerky is considered a safe food, but studies have shown that pathogens can survive the moderate drying conditions of some jerky processes (Allen et al., 2007). A process that meets six-sigma requirements (as described in table 2) for lethality is statistically capable of producing fewer than two defects

**Table 2. Wet-bulb temperature setting for a dehydrator ( $\mu + \text{sigma level}$ ) and the expected number of products not reaching target temperatures (assumes a normal distribution with a 1.5 s shift in the mean).**

Sigma level	% Lethality	Number of units not reaching lethality temperature per 1,000,000 units processed
3 s	96.66	33,400.0
4 s	99.699	3,105.0
5 s	99.9884	116.5
5.5 s	99.9969	31.5
6 s	99.99983	1.7

Download the plans to build a small-scale (up to 300 lb raw batch size) jerky dehydrator that features a robust lethality process from OSU at [www.fapc.biz/files/DehydratorManualV1.pdf](http://www.fapc.biz/files/DehydratorManualV1.pdf).

(under-processed products) per million units (Joglekar, 2003). Jerky processors can improve food quality and safety by understanding and minimizing temperature variation in their dehydrator and establishing a lethality process that minimizes the likelihood of under-processed products.

**Conclusion**

Dehydrated meat products are a popular snack item in today’s food market. The proper understanding, measurement, and control of heat and moisture are crucial to manufacturing a product that meets regulatory requirements, satisfies consumer demands and, most importantly, is profitable.

**References**

Allen, K.D., D. Cornforth, D. Whittier, M. Vasavada, and B. Nummer. 2007. Evaluation of high humidity and wet marinade methods for pasteurization of jerky. *Journal of Food Science*; (72)7: 351-355.

Joglekar, A.M. 2003. *Statistical methods for six sigma in R&D and manufacturing*. John Wiley and Sons. New Jersey.

Bowser, T.J. and P.R. Weckler. 2008. *Validation guidelines for a jerky pasteurization process in a low-cost dehydrator*. Bentham Science Publications, [www.bentham.org/open/index.htm](http://www.bentham.org/open/index.htm), *The Open Food Science Journal* (2) 43-48.

Bowser, T.J. 2007. *Construction and operation manual for: Low-cost, safe dehydrator for small and very small meat processors*. Oklahoma State University, Robert M. Kerr Food & Agricultural Products Center. Internet: <http://fapc.biz/files/DehydratorManualV1.pdf> (accessed May 23, 2008).

Buege, DR, Searls, G, Ingham, SC. 2005. Lethality of commercial whole-muscle beef jerky manufacturing process against Salmonella serovars and Escherichia coli O157:H7. *J Food Protection*; 69(9): 2091-99.

USDA FSIS. 2007. *Compliance guideline for meat and poultry jerky produced by small and very small plants*. Internet: [http://www.fsis.usda.gov/PDF/Compliance\\_Guideline\\_Jerky.pdf](http://www.fsis.usda.gov/PDF/Compliance_Guideline_Jerky.pdf). (accessed May 23, 2008).

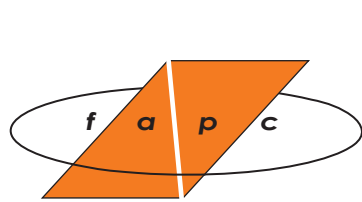
USDA FSIS. 1999. *Appendix A of the “Compliance Guidelines for Meeting Lethality Performance Standards for Certain Meat and Poultry Products”*. Internet: <http://www.fsis.usda.gov/oa/fr/95033F-a.htm>; updated June, (accessed May 23, 2008).

Oklahoma State University, in compliance with Title VI and VII of the Civil Rights Act of 1964, Executive Order 11246 as amended, Title IX of the Education Amendments of 1972, Americans with Disabilities Act of 1990, and other federal laws and regulations, does not discriminate on the basis of race, color, national origin, gender, age, religion, disability, or status as a veteran in any of its policies, practices or procedures. This includes but is not limited to admissions, employment, financial aid, and educational services.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Robert E. Whitson, Director of Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. This publication is printed and issued by Oklahoma State University as authorized by the Vice President, Dean, and Director of the Division of Agricultural Sciences and Natural Resources and has been prepared and distributed at a cost of 74 cents per copy. 1208

## **APPENDIX II**

FAPC-175 Dehydrator optimization: reduction of energy use and carbon emissions.



## FOOD TECHNOLOGY FACT SHEET

Adding Value to Oklahoma

405-744-6071 • [www.fapc.biz](http://www.fapc.biz)

# Dehydrator Optimization: Reduction of Energy Use and Carbon Emissions

**Tim Bowser**

FAPC Food Process Engineer

Food dehydration is an age-old process that is extremely popular today. While production of canned foods is on the decline (Steel Works, 2011), production of dehydrated foods is experiencing a resurgence (Cosgrove, 2010). Jerky (especially beef) continues to be a favorite in Oklahoma, while dehydration of fruits, vegetables and spices are increasing.

Dried foods are inherently stable and safe, but these properties come at a cost. Large quantities of energy are needed to remove the water, and energy use has an obvious environmental impact. Options must be explored to reduce the energy needs and environmental impact of dehydration. This fact sheet describes one method that can be used to reduce energy consumption and carbon emissions associated with food dehydration.

### Waste Heat Recovery

A simple schematic of a conventional dehydration chamber is shown in figure 1. Air in the dehydrator is heated by circulation through a heating coil. Fresh air is brought in through a duct in the side of the chamber and exhausted through a similar duct in the other side of the dehydrator. The exhaust air contains waste heat that can be recovered using a heat exchanger (Krokida and Bisharat, 2004). Heat exchangers are devices used to transfer heat from a source to a sink. Heat exchangers can be observed in everyday equipment like the radiator of an automobile, or the coils of an air conditioner.

A special type of heat exchanger has been developed for modern air-conditioned homes that are built with virtually air-tight exterior envelopes. This heat exchanger,

**R. Scott Frazier**

Biosystems & Ag Engineering, Energy Systems Engineer

known as a Ventilation Heat Recovery (VHR) unit, is designed to capture waste heat in the home ventilation system exhaust stream and use it to preheat incoming fresh air. VHRs are mass produced by several companies (see side bar on page 4) and used in new home construction to provide energy savings and improve indoor air quality. Figure 2 shows an example of a VHR designed for home use that is rugged, durable, cleanable and inexpensive.

Flexible, insulated ventilation ducts can be used to connect a VHR unit to a dehydrator. Figure 3 shows a schematic of how a VHR may be connected to a dehydrator. Fans in the VHR move the air through the unit. Some VHRs have variable speed fans, which can be adjusted to optimize the ventilation rate. The next section describes the results of a study to test the performance of a dehydrator with a VHR installed.

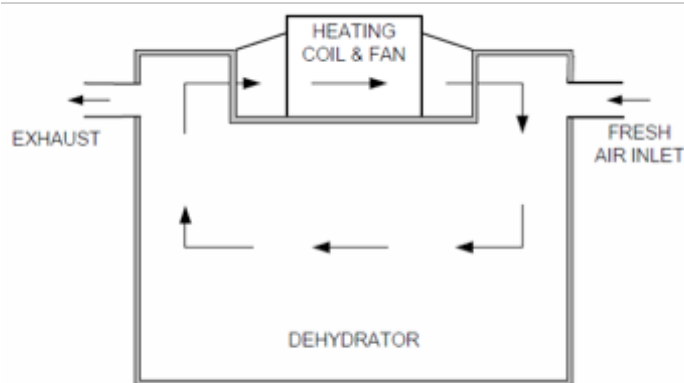


Figure 1. Conceptual side view of conventional dehydrator.



Figure 2. Typical VHR unit used to recover waste heat.

### Example of Dehydrator Waste Heat Recovery

A low-cost home-built dehydrator (Bowser, 2011) was outfitted with a VHR unit (Fantech model SHR 2004, Lenexa, Kansas) and tested on cilantro (*Coriandrum sativum*). Cilantro was fresh-cut by hand, water-washed and dripped-dry prior to dehydration on perforated trays. The drying temperature was set at 165 degrees Fahrenheit. A complete description of the test is given in Bowser et al. (2011).

Table 1 shows results of dehydration tests with and without the VHR unit installed. The relative performance number (see column 2 in table 1) gives an indication of how efficiently energy was used in the system (referenced to system performance without a VHR). A higher value of relative performance indicates a better use of energy.

The relative energy efficiency of the dehydrator improved 38 percent when the VHR was installed. Also, the time to dry the product to 10 percent moisture content was decreased by 28 percent.

Table 2 shows calculated greenhouse emissions for the dehydrator based on an annual operation of 1 batch (225 pounds initial product weight) of cilantro per day for 220 days. The temperature set-point of the dehydrator was 165 degrees Fahrenheit. Carbon emissions equivalent (CO<sub>2</sub><sup>e</sup>) of the system was reduced by an estimated 34 percent by installing the VHR unit.

### Economic Analysis

A financial analysis of a dehydrator with an installed VHR unit was determined using the assumed system costs and calculated savings shown in Table 3. Calculated

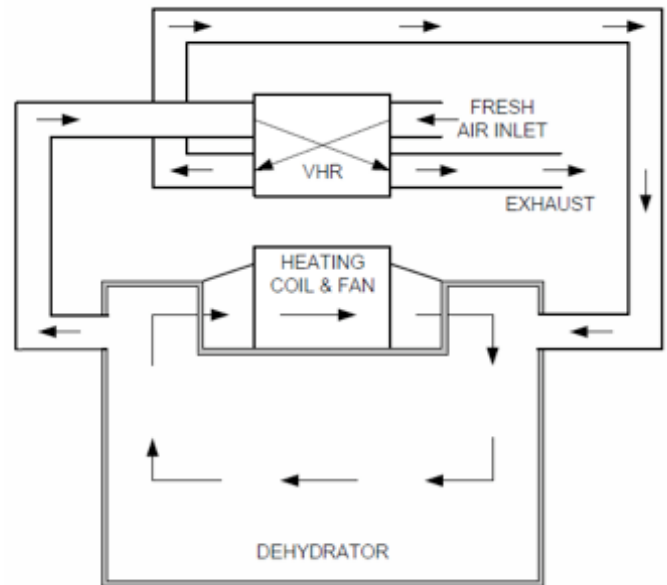


Figure 3. Conceptual side view of dehydrator with VHR unit installed.

lated savings are based on the difference between the costs of operation of the dehydrator with and without the VHR. Simple payback for the investment requires about 125 hours of dehydrator operation (22 batches of cilantro at 225 pounds/batch). Net present value for the VHR installation based on 1 batch of product per day and 220 days per year is \$51,806 (assuming no residual value for the VHR unit and no maintenance costs). For some products and dehydrators, the processing time may not significantly change after installing a VHR. For this case, simple payback due to energy and carbon emissions savings alone would be 1.5 years with a net present value of \$4,112.

### Conclusion

As energy, labor and equipment prices continue to rapidly increase, the efficiency of a food dehydration system is becoming more important. Environmental stewardship is also a factor that should be weighed when considering operations of dehydration equipment. Ventilation heat recovery units are now available off-the-shelf and may be quickly installed on most dehydrators. For the example described above, the VHR paid for itself after processing 22 batches.

Depending on the particular dehydration equipment installed, the value of production time, energy costs, and value of carbon credits, a ventilation waste heat recovery unit may be a profitable investment. Call or e-mail the Robert M. Kerr Food & Agricultural Products Center (405-744-6071, fapc@okstate.edu) to request assistance with your decisions involving the purchase, installation and operation of VHR equipment for food processes.

Table 1. Dehydrator performance with and without a VHR unit.

Condition	Relative performance	Time to dry cilantro to 10% m.c., hr
No VHR	1.0	7.86
VHR installed	1.38	5.69

Table 2. Estimated greenhouse gas emissions (annual) for dehydration of cilantro with and without a VHR unit.

Emissions source	Emissions at given operating conditions, tons CO <sub>2</sub> e	
	No VHR	VHR installed
Purchased electricity	4.6	3.4
Natural gas	15.4	9.7
Combined emissions (total)	20.0	13.1

Table 3. Estimated value of inputs used in an economic analysis assuming a discount rate of 7% and a period of 5 years.

Input item	Value	Annual value w/o VHR	Annual value with VHR	Annual Savings, \$
Natural gas	0.030 \$/kW·hr	\$2,539.63	\$1,606.20	933.43
Electricity	0.104 \$/kW·hr	\$141.48	\$102.48	39.00
Plant operation	25.00 \$/hr*	1,729 hr	1,252 hr	11,925.00
Carbon emissions	10.00 \$/ton CO <sub>2</sub> e **	20 ton CO <sub>2</sub> e	13.1 ton CO <sub>2</sub> e	69.00
Installed cost of VHR system	\$1,500	-	-	-

\*estimate of hourly operation expenses for a small dehydration facility.

\*\*August 2011 value of carbon credits per metric ton (Carbonfund.org).

*"Dehydration is an age old process, but we're constantly learning new methods to improve it." -Tim Bowser*

## **Manufacturers of Ventilation Heat Recovery (VHR) units:**

### **American Aldes Ventilation Corporation**

4521 19th Street Court E., Suite 104  
Bradenton, FL 34203  
Phone: 800-255-7749; 941-351-3441  
Fax: 941-351-3442  
www.americanaldes.com

### **Aprilaire, Research Products Corp.**

P.O. Box 1467  
Madison, WI 53701  
Phone: 800-334-6011  
Fax: 608-257-4357  
www.aprilaire.com

### **Broan-NuTone, LLC.**

P.O. Box 140  
Hartford, WI 53027  
Phone: 800-558-1711  
www.broan.com

### **Fantech**

10048 Industrial Blvd  
Lenexa, KS 66215  
Customer Service:  
Phone: 800-747-1762; 913-752-6000  
Fax: 800-487-9915; 913-752-6466  
www.fantech.net

### **RenewAire, LLC**

4510 Helgesen Drive  
Madison, WI 53718  
Phone: 800-627-4499  
Fax: 608-221-2824  
www.renewaire.com

### **Suncourt Inc.**

500 West Second Avenue  
P.O. Box 40  
Durant, IA 52747  
Phone: 800-999-3267  
www.suncourt.com

## **More Information**

If you would like guidance calculating the carbon footprint of your food manufacturing facility or products, please call the Robert M. Kerr Food & Agricultural Products Center 405-744-6071 or e-mail [fapc@okstate.edu](mailto:fapc@okstate.edu) to request assistance.

## **References**

- Bowser, T.J. 2011. Meat dehydrator construction and operation manual. Available at: <http://fapc.okstate.edu/files/DehydratorManualV1.pdf>. Accessed on 15JUN11.
- Bowser, T.J., R.S. Frazier, Kakarala, R.R. 2011. Improvement of efficiency and environmental impact of a low-cost food dehydrator. submitted to The Open Food Science Journal, Bentham Science Publications, [www.bentham.org/open/index.htm](http://www.bentham.org/open/index.htm).
- Cosgrove, J. 2010. The future of dehydrating and freeze drying. Available at: <http://www.nutraceuticalsworld.com/contents/view/30175>. Accessed on 9JUN11.
- Krokida, M.K., G. I. Bisharat, G.I., 2004, Heat Recovery from Dryer Exhaust Air. *Drying Technology*. 22(7):1661-1674.
- Steel Works, 2011. Canned food alliance (CFA) program overview. Available at: [http://legacy.steel.org/Content/NavigationMenu/SteelMarkets/CansContainers/CannedFood/Canned\\_Food.htm](http://legacy.steel.org/Content/NavigationMenu/SteelMarkets/CansContainers/CannedFood/Canned_Food.htm). Accessed on 9JUN11.

---

## **Ideas to help reduce costs**

Reducing the cost of food dehydration will decrease overhead cost for the food processor. Reduced overhead increases profit. Examples of areas in the dehydration process that can be examined to reduce cost include: Out-of-specification product (rework or waste), air leaks from the dehydrator, inefficient gas burners, inefficient electric motors, heat loss (inadequate insulation), over-dehydration, excessive equipment downtime, and inefficient startup and shutdown procedures.

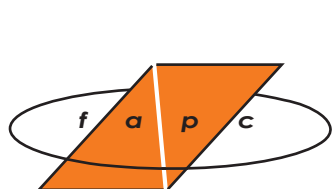
---



## **APPENDIX III**

FAPC-166 Reduction of drying time for jerky.

# Robert M. Kerr Food & Agricultural Products Center



## FOOD TECHNOLOGY FACT SHEET

Adding Value to Oklahoma

405-744-6071 • [www.fapc.biz](http://www.fapc.biz)

### Reduction of Drying Time for Jerky Products

**Timothy J. Bowser**  
FAPC Food Process Engineer

**Jacob Nelson**  
FAPC Value-Added Meat Processing Specialist

**Stacey J. Kowalski**  
FAPC Research Assistant

Jerky manufacturing is a time-consuming process because meat must be dried slowly at a relatively low temperature. Dehydration time varies from processor to processor and depends on many variables such as dehydrator temperature setting, humidity control, jerky slice thickness and equipment configuration. Some dehydration cycles that include a lethality step take more than 12 hours. Processors may be able to reduce production costs and increase product throughput by reducing dehydration times. The objective of this fact sheet is to report on three factors that have been identified and proven to reduce dehydration time without drastically affecting the final product (Bowser, et al. 2009).

#### Three Factors That Can Reduce Jerky Drying Time

The three factors that can reduce drying time are (in order of importance):

1. Chemical tenderization
2. pH
3. Product orientation

Tenderization helps to break down the fibers of the meat product creating more avenues for moisture to escape during the dehydration process. Many tenderizers will probably work, but Bowser et al. (2009) used a liquid papain product (Liquipanol T-100, Enzyme Development Corp., New York) that was applied at the rate of 1 mg of tenderizer per pound of meat. The tenderizer was added to the marinade and the jerky was allowed to sit for 1 hour at 40°F. All of the marinade was soaked up by the jerky.

Adjustment of raw product pH may help dehydrate the meat more rapidly because of a unique physical property called the isoelectric point. The isoelectric point is the pH value (5.2) at which meat products hold the least amount of moisture. A small amount of vinegar was added to the marinade to adjust the pH to the isoelectric point.

Orientation of product may have a significant effect on dehydration time. Research results indicate that vertical orientation is the best. Products with a vertical orientation may dry faster because free water runs off the surface, rather than accumulating on a horizontal surface. This is especially important during high-humidity pasteurization processes that many jerky manufacturers are now using. Most jerkys can be hung vertically by hooks, draped across supports or pierced by and hung on a support.

Reducing the cost of the jerky dehydration process decreases the overhead cost for a food plant facility. This adds more profit directly to the bottom line.

Examples of areas in the dehydration process that can be examined to reduce cost include:

- out-of-specification product (rework or waste)
- air leaks or excessive air flow
- inefficient fuel use
- inefficient electric motors
- heat loss
- heat waste
- over-dehydration
- underutilization
- downtime
- inefficient startup and shutdown procedures

Restructured jerky products do not permit handling prior to dehydration and must be oriented horizontally and fully supported by trays.

Virtually any processor will be able to test one or more of the factors to speed up their manufacturing process. The three factors are fairly simple to implement – but some might be inappropriate for a specific product and production process used by a given manufacturer. For instance, orientation does not make sense if the product cannot be physically manipulated into a vertical position (e.g. extruded jerky) or if vertical placement results in unacceptable cosmetic changes in the final product. Tenderizer might not be an acceptable ingredient in an organic, natural, premium product.

### **Five Steps to Reduce Jerky Drying Time**

Reducing drying time can add dollars directly to the profit of your operation by reducing the cost of energy and increasing product throughput. Five steps to take to reduce jerky drying time are:

1. Analyze the drying process and equipment. Develop an understanding of the following:
  - a. Requirements for processing and materials handling.
  - b. Product attributes.
  - c. Type of equipment.
  - d. Product/process safety.
2. Identify the factors (tenderizer, pH and orientation) that can be successfully applied to the product without upsetting the production system or negatively affecting the final product.
3. Implement the factors identified in step 2.
4. Track results.
5. Adjust factors and production system to make continuous improvements.

The five steps are described further below.

#### **1. Analyze the Drying Process and Equipment**

A solid understanding of the drying process and equipment is needed.

- How is the meat treated prior to dehydration? Can any of the factors (e.g. tenderizer and pH adjustment) be added during the marinade or mixing process without extra work?
- Will the final product be negatively affected

by the addition of tenderizer or an acid? Can the product be dried in a vertical orientation without negatively affecting the final appearance and feel of the product?

- Will the equipment accommodate processes changes to add liquids to adjust pH or a tenderizer? Can the product be supported in a vertical orientation without sacrificing capacity and increasing preparation time?

#### **2. Identify the Factors that Successfully Can Be Applied to Your Product**

Based on an analysis of the drying process and equipment, which factor(s) can be applied to the dehydration process? Tenderization can change product texture, which may affect physical properties like tear strength and mouth-feel. Changes can be viewed positively or negatively. Tenderizer may permit the use of a less expensive grade of meat that was previously rejected because of toughness. Adjustment of pH may result in some flavor change; but other ingredients could be added to offset acid tartness and improve final flavor. Bromelain (a tenderizer) is a potential example of an ingredient that may be classified as a nutraceutical that promotes joint health; therefore, increasing the appeal of the final product for a target audience (any label statement would require supporting evidence). Also, the ingredient statement must be considered when identifying factors, since the tenderizer, acidifier and any additional ingredients must be included on the label.

#### **3. Implement the Factors Selected**

Put the new ideas to work by trying them out in a limited production run or in a portion of a production run. Experimentation does not need to be expensive and risky. Try new factors on a single tray or rack of product; using the natural divisions within your process equipment (e.g shelves) to subdivide the treatment.

#### **4. Track Results**

Keep careful records of everything done to modify the product and compare results to the standard. If the dehydration time of the standard product is not well documented, this activity must

be undertaken as well. Overall drying times should decrease significantly and permanently because of the treatment(s).

## 5. Make Continuous Improvements

The activity of recording the results of the dehydration processes will help to identify areas of improvement or to determine if something has changed. When changes have occurred, the five-step process can be reiterated to solve new problems. The process of making incremental changes for the best is called “continuous improvement.” Data collected should include (but is not limited to): date, drying time, product identification, operator, yield, outdoor conditions (temperature and relative humidity) and any unusual observations (e.g. non uniform drying, special weather conditions like hail or sleet, power failures and personnel changes). Use continuous improvement activities to look for patterns that might show cause and effect, like propped open doors in the processing room that allow more fresh air to enter into the dehydrator, reducing drying time.

### Food safety

Dehydrators often are used to achieve a critical control point (CCP) for food safety. A reduction in dehydration time should not affect food safety of jerky products as

**“Jerky drying is an age old process, but we’re constantly learning new things that can be applied to improve it.”**

– Tim Bowser  
FAPC Food Process Engineer

long as an approved lethality step is included in the dehydration process. See fact sheet FAPC-165 Consistent Lethality Treatment for Small-Scale Jerky Dehydrators for additional information on this topic.

### Conclusion

As energy, labor and equipment prices continue to rapidly increase; the efficiency of a jerky dehydration system is becoming more important. Reducing jerky drying time can result in increased cash flow and improved product quality. Modifications in the process and final product may be needed, but when properly implemented, changes will be classified as improvements.

### References

Bowser, T.J., R.S. Frazier, P.R. Weckler, S.J. Kowalski. 2009. Optimizing jerky drying time with minimal product impact. submitted to The Open Food Science Journal, Bentham Science Publications, [www.bentham.org/open/index.htm](http://www.bentham.org/open/index.htm).



Figure 1. Beef jerky hanging in a dehydrator from two wire hooks (thermocouple wire is visible in top center of photo).

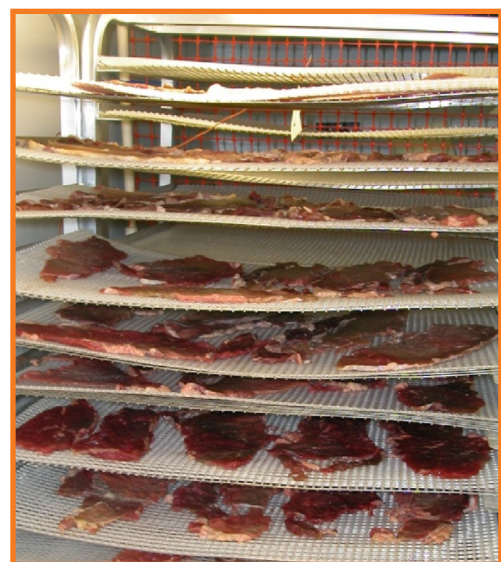
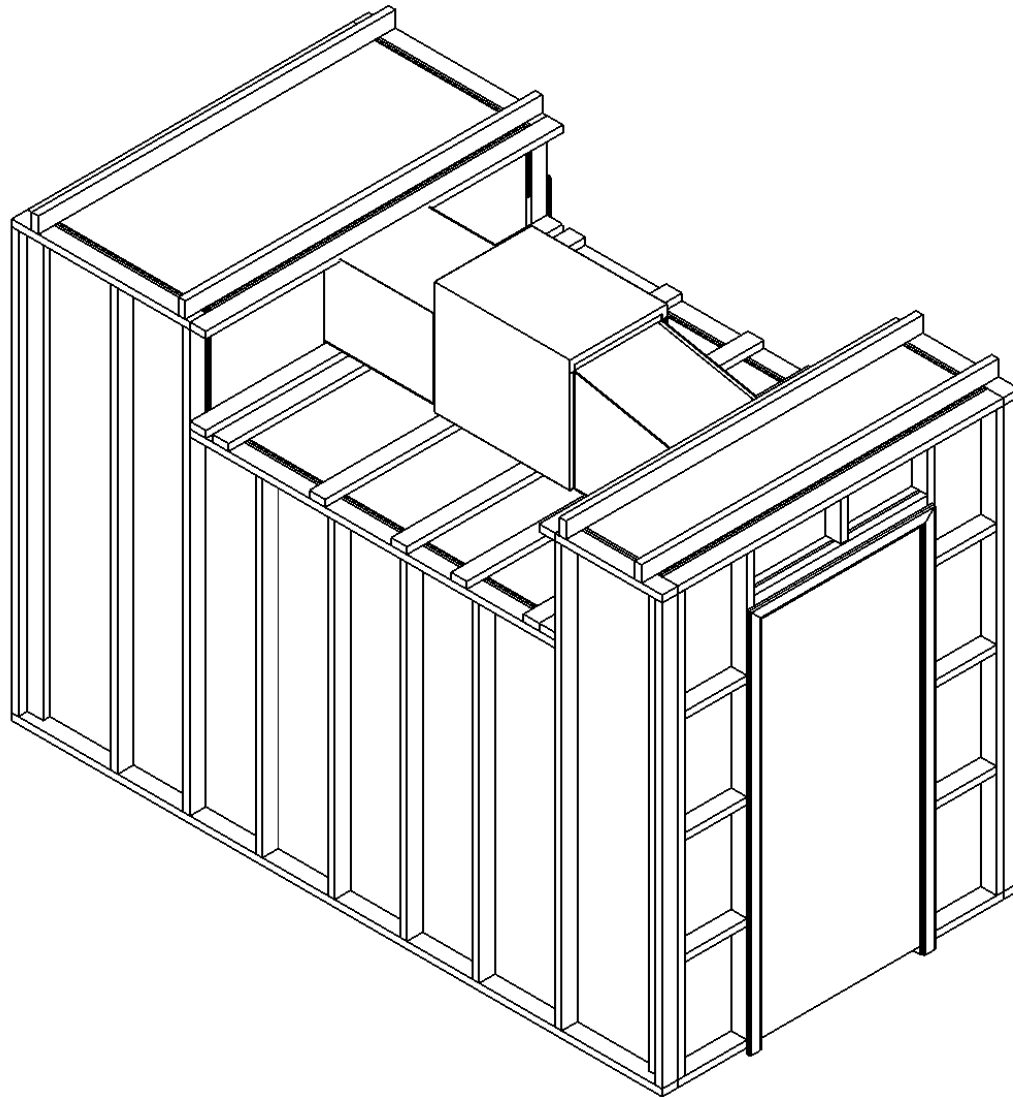


Figure 2. Beef jerky slices on horizontal racks in a dehydrator.

## APPENDIX IV

BAFFLE ANGLE*	TEMP LOC.	FRONT	BACK		BAFFLE ANGLE*	TEMP LOC.	FRONT	BACK	
-30	1	163.7	160.3		45	1	163.3	163.6	
	2	164.5	160.9			2	160	161.4	
	3	162.5	160.1			3	163.5	164.4	
	4	163.5	157.5			4	158.4	160.3	
	5	162.5	158.1			5	163.9	164.3	
	6	162.9	157.1			6	162.6	157.2	
	Range	2	3.8			Range	5.5	7.2	
Std Dev	0.784007	1.623576		Std Dev	2.229574	2.821111			
-15	1	162.5	161.7		60	1	165.3	161.3	
	2	162.9	161.7			2	164.1	158.8	
	3	161.4	161.5			3	165.5	162.2	
	4	161.9	157.7			4	161.7	156.7	
	5	161.5	159.7			5	165.9	161.9	
	6	161.7	159.1			6	165	154.8	
	Range	1.5	4			Range	4.2	7.4	
Std Dev	0.594699	1.666933		Std Dev	1.536772	3.047239			
0	1	165.7	159.1		90	1	165.9	162.6	
	2	164.5	158.1			2	163.4	160.2	
	3	165.7	158.9			3	166.5	163.5	
	4	163	154.4			4	162.6	159.1	
	5	165.4	157.6			5	166.7	162.8	
	6	164.5	152.3			6	166.1	158.4	
	Range	2.7	6.8			Range	4.1	5.1	
Std Dev	1.03923	2.757293		Std Dev	1.745852	2.144761			
15	1	163	163.8						
	2	159.7	161.5						
	3	163.5	164.5						
	4	158.2	159.9						
	5	163.3	164						
	6	162.9	158.6						
	Range	5.3	5.9						
Std Dev	2.242915	2.437006							
30	1	167.6	160.8						
	2	165.7	158.3						
	3	167.9	161.6						
	4	163.1	156.3						
	5	167.9	160.9						
	6	167.1	158.2						
	Range	4.8	5.3						
Std Dev	1.88016	2.063734							
* baffle angle with respect to horizontal (0 degrees at horizontal)									



BIOEN LAB

TITLE:

JERKY ASSY

SIZE

**A**

DWG. NO.

**A**

REV

NAME

DATE

DRAWN

WK

SCALE: 1 : 30

SHEET 1 OF 1

5

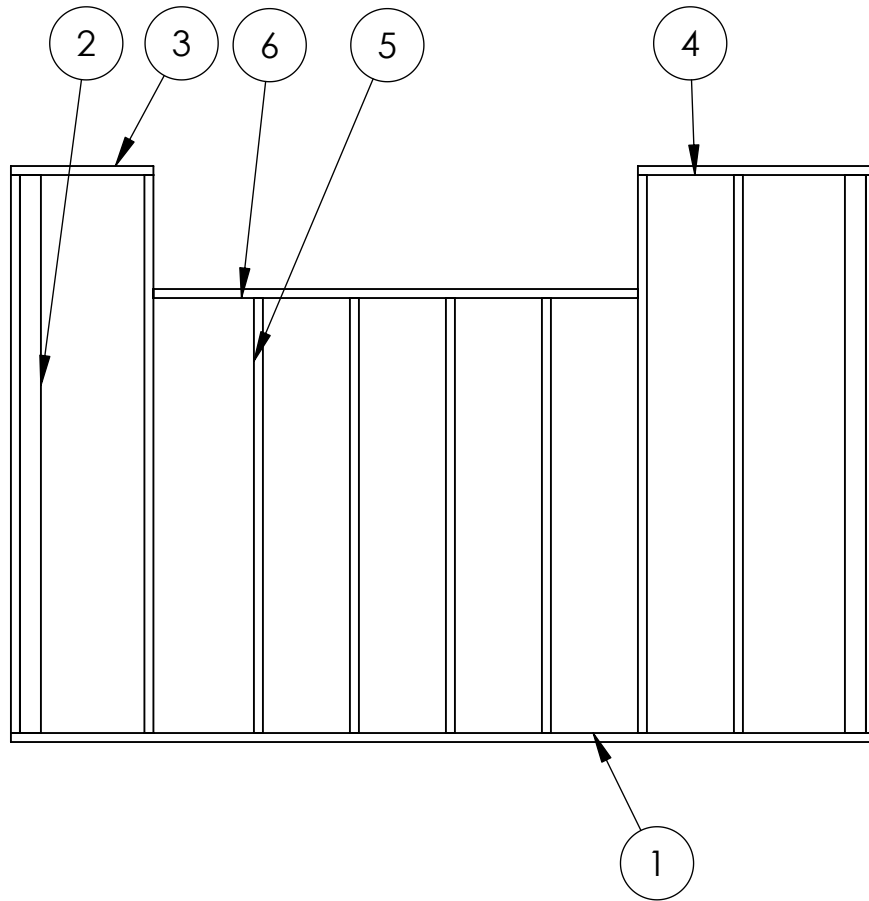
4

3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1005	2X4X144	1
2	1004	2X4X93	7
3	1011	2X4X23.75	1
4	1012	2X4X39.5	1
5	1001	2X4X72.5	4
6	1013	2X4X80.75	1



<b>BIOEN LAB</b>		
TITLE: JERKY DRYER WALLWO DOOR		
SIZE <b>A</b>	DWG. NO. 1	REV
DRAWN	NAME WK	DATE
SCALE: 1:32		SHEET 1 OF 1

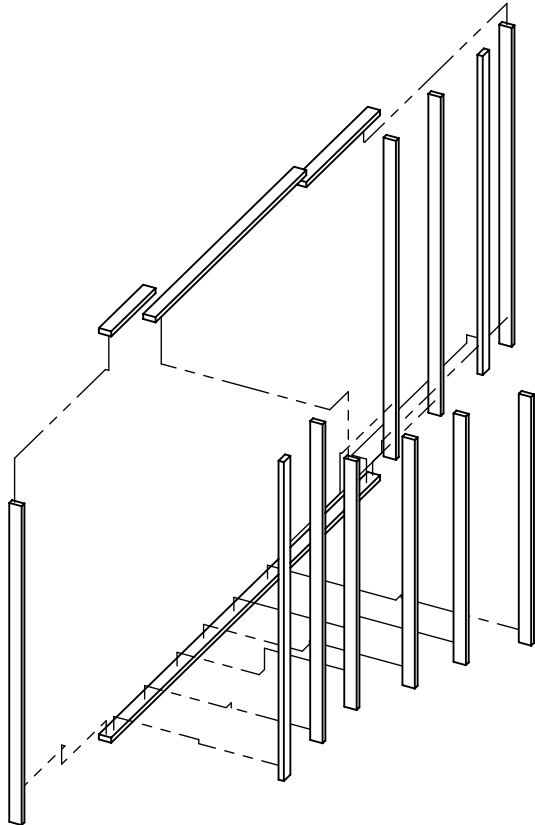
5

4

3

2

1



# BIOEN LAB

TITLE:

## LEFT SIDE WALL

SIZE	DWG. NO.	REV
<b>A</b>	<b>2</b>	

DRAWN	NAME	DATE
	WK	

SCALE: 1:48 SHEET 1 OF 1

5

4

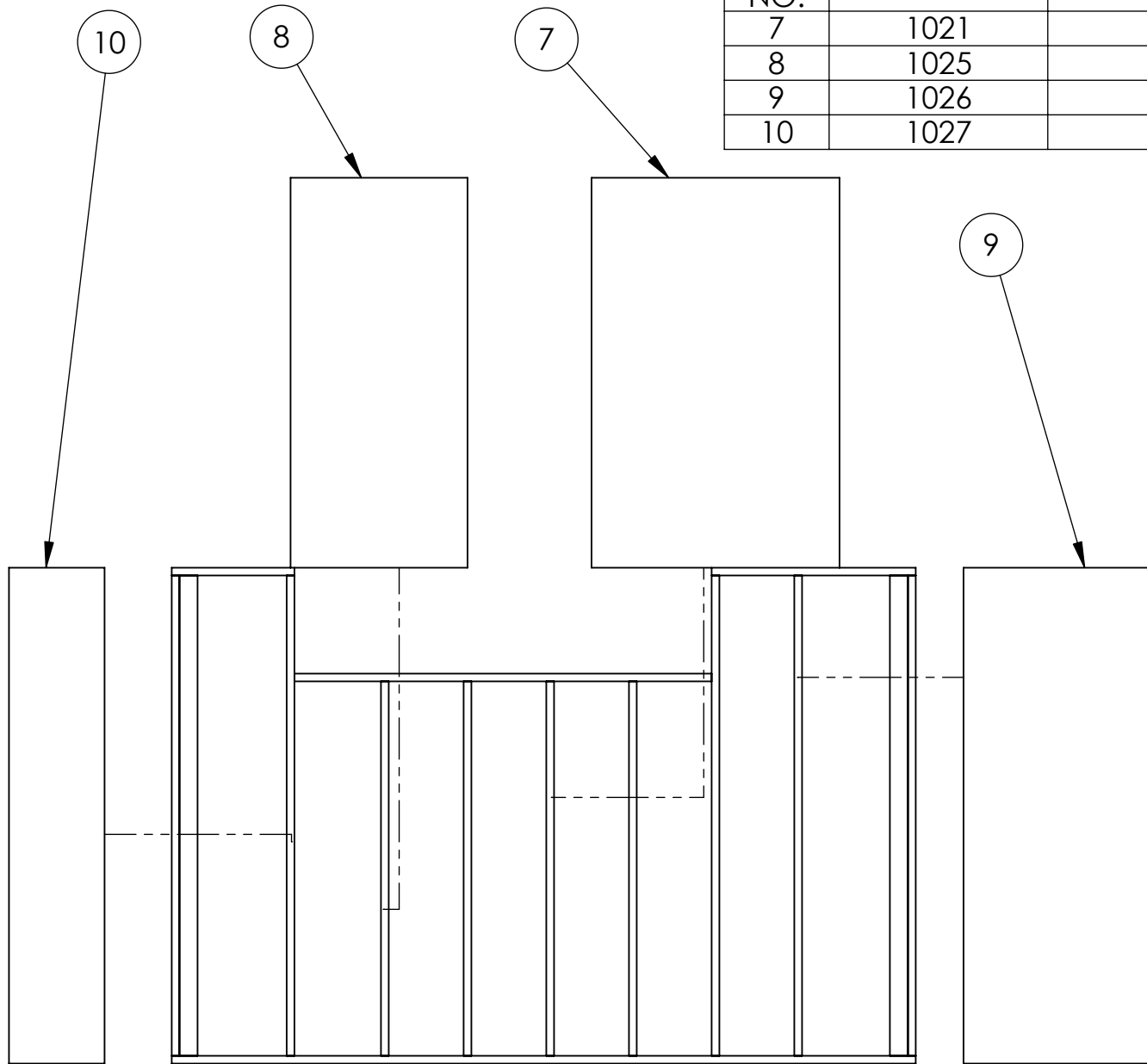
3

2

1



ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
7	1021	1	48X75.5
8	1025	1	34.25X75.5
9	1026	1	35.75X96
10	1027	1	18.5X96



## BIOEN LAB

TITLE: WALL WITHOUT DOOR  
FOAM AND OSB SIZES

SIZE	DWG. NO.	REV
<b>A</b>	<b>3</b>	

SCALE: 1:32	SHEET 1 OF 1
-------------	--------------

DRAWN	NAME	DATE
	WK	

5

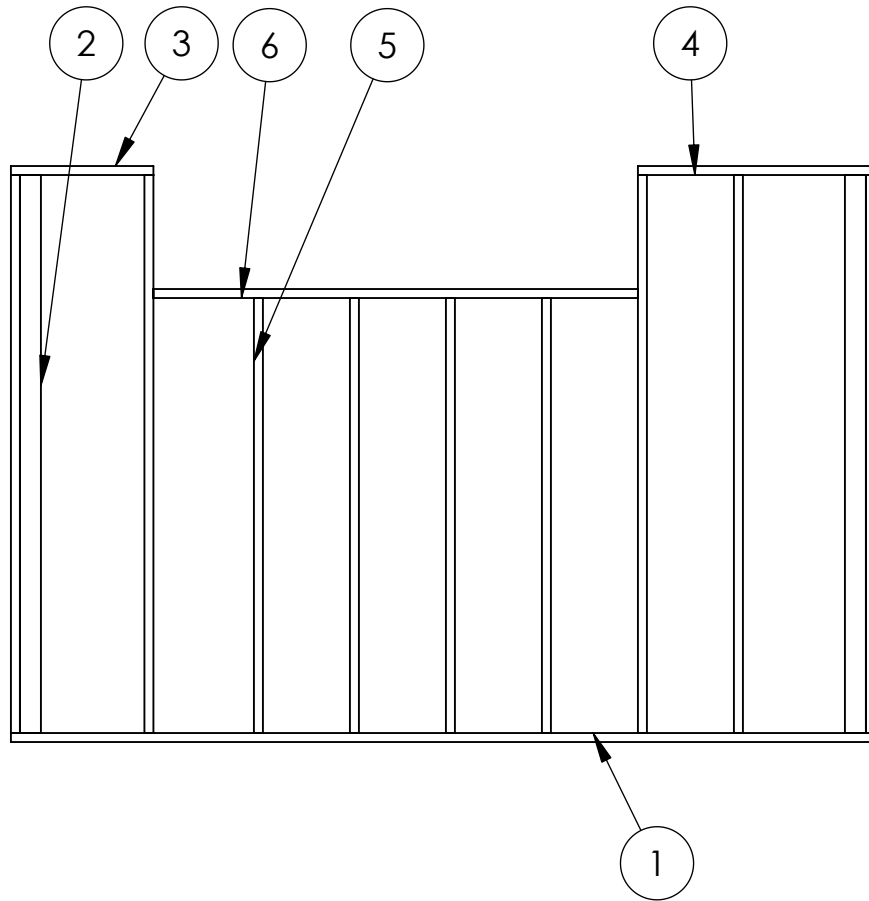
4

3

2

1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1005	2X4X144	1
2	1004	2X4X93	7
3	1011	2X4X23.75	1
4	1012	2X4X39.5	1
5	1001	2X4X72.5	4
6	1013	2X4X80.75	1



## BIOEN LAB

TITLE:

JERKY DRYER WALLWO DOOR

SIZE	DWG. NO.	REV
<b>A</b>	4	

DRAWN	NAME	DATE	SCALE: 1:32	SHEET 1 OF 1
	WK			

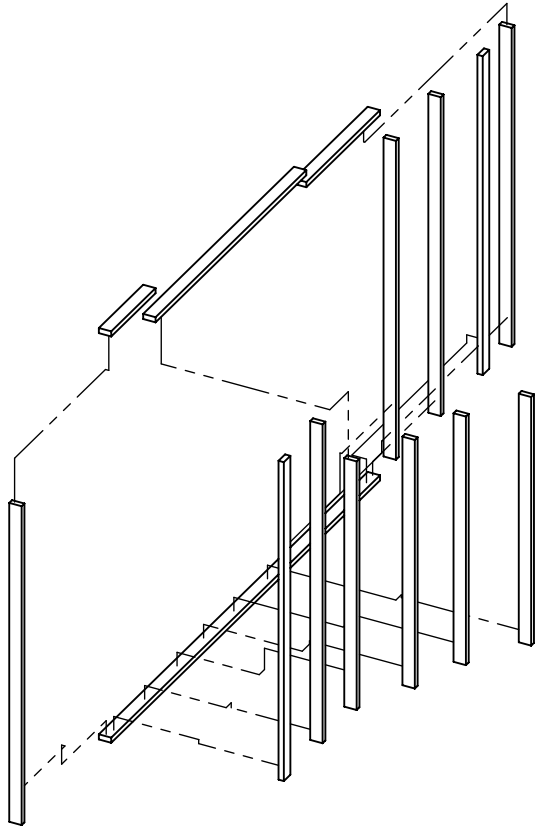
5

4

3

2

1



# BIOEN LAB

TITLE:  
WALL WITH OUT DOOR

SIZE	DWG. NO.	REV
<b>A</b>	<b>5</b>	

DRAWN	NAME	DATE
	WK	

SCALE: 1:48	SHEET 1 OF 1
-------------	--------------

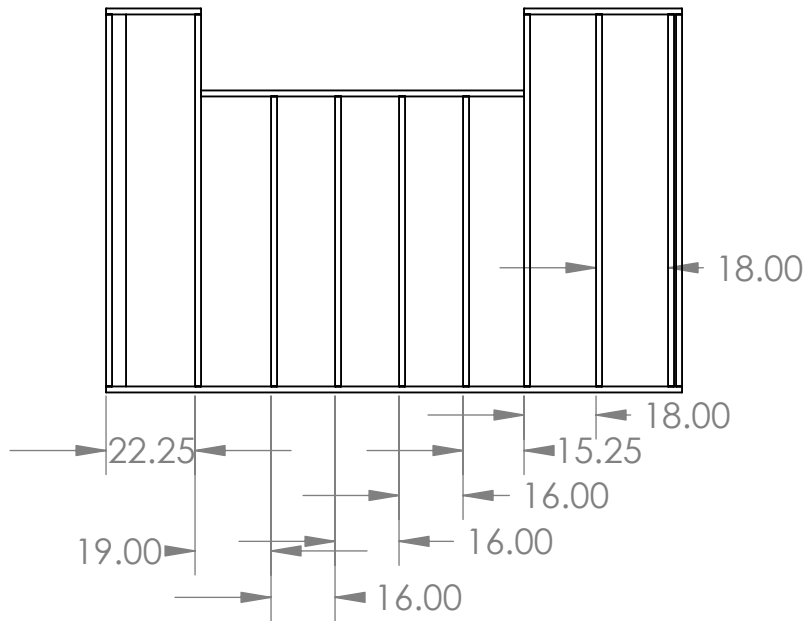
5

4

3

2

1



# BIOEN LAB

TITLE: RIGHT SIDE WALL DIM

SIZE	DWG. NO.	REV
<b>A</b>	<b>6</b>	

DRAWN	NAME	DATE
	WK	

SCALE: 1:48	SHEET 1 OF 1
-------------	--------------

5

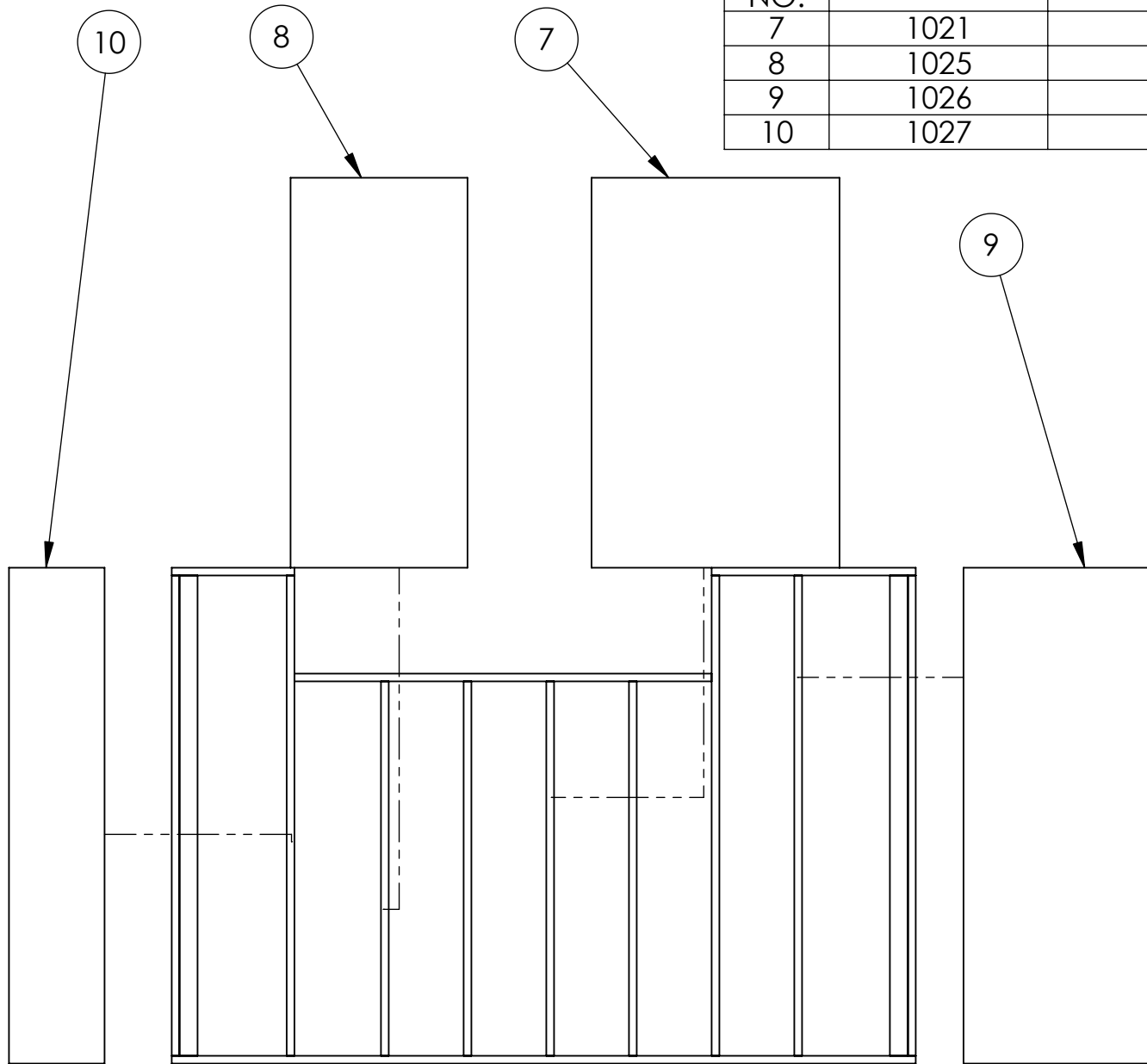
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
7	1021	1	48X75.5
8	1025	1	34.25X75.5
9	1026	1	35.75X96
10	1027	1	18.5X96



5

4

3

2

1

## BIOEN LAB

TITLE: WALL WITHOUT DOOR  
FOAM AND OSB SIZES

SIZE	DWG. NO.	REV
<b>A</b>	<b>7</b>	

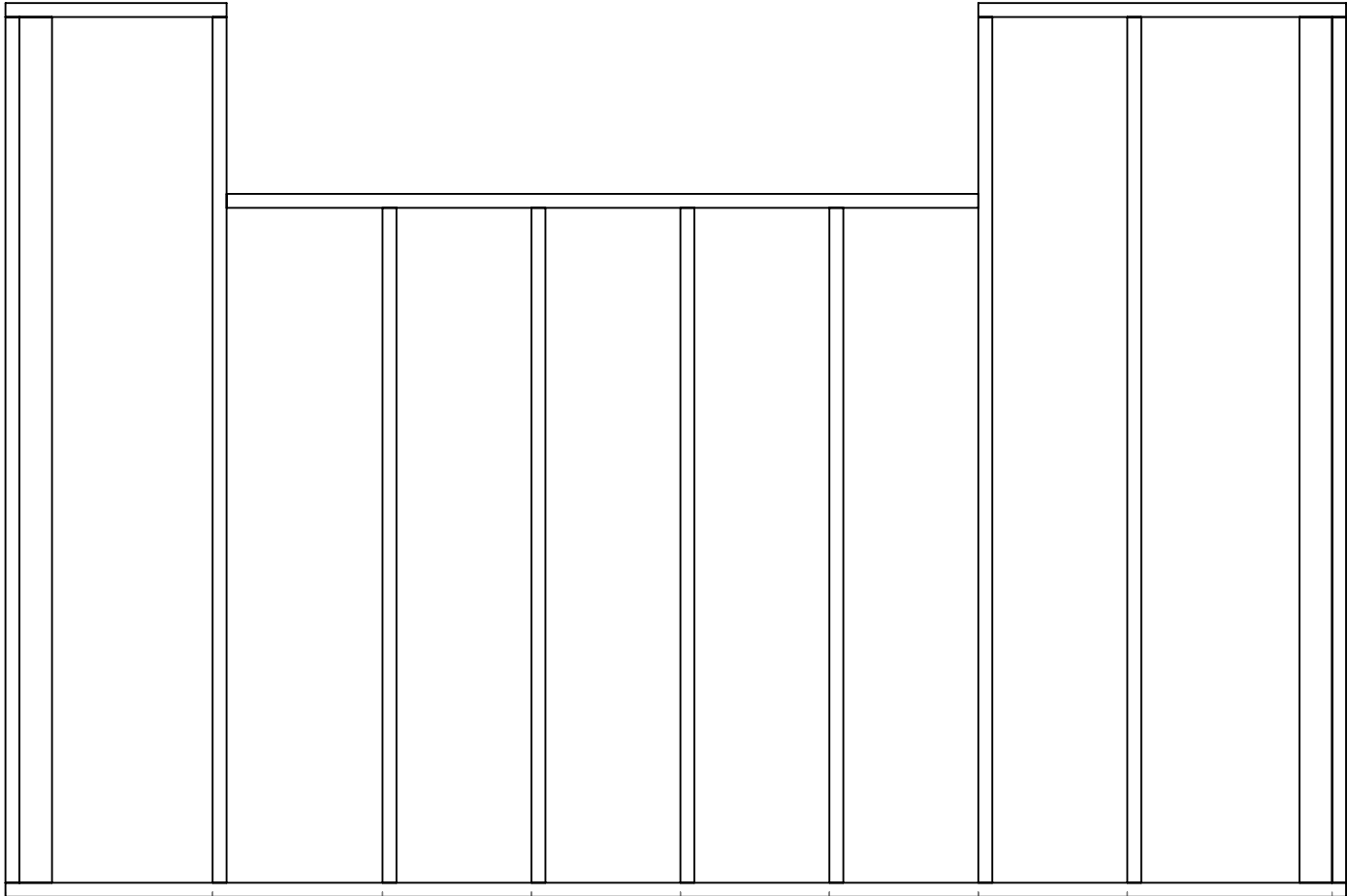
SCALE: 1:32	SHEET 1 OF 1
-------------	--------------

DRAWN

NAME

DATE

WK



22.25 18.25 16.00 16.00 16.00 16.00 22.00

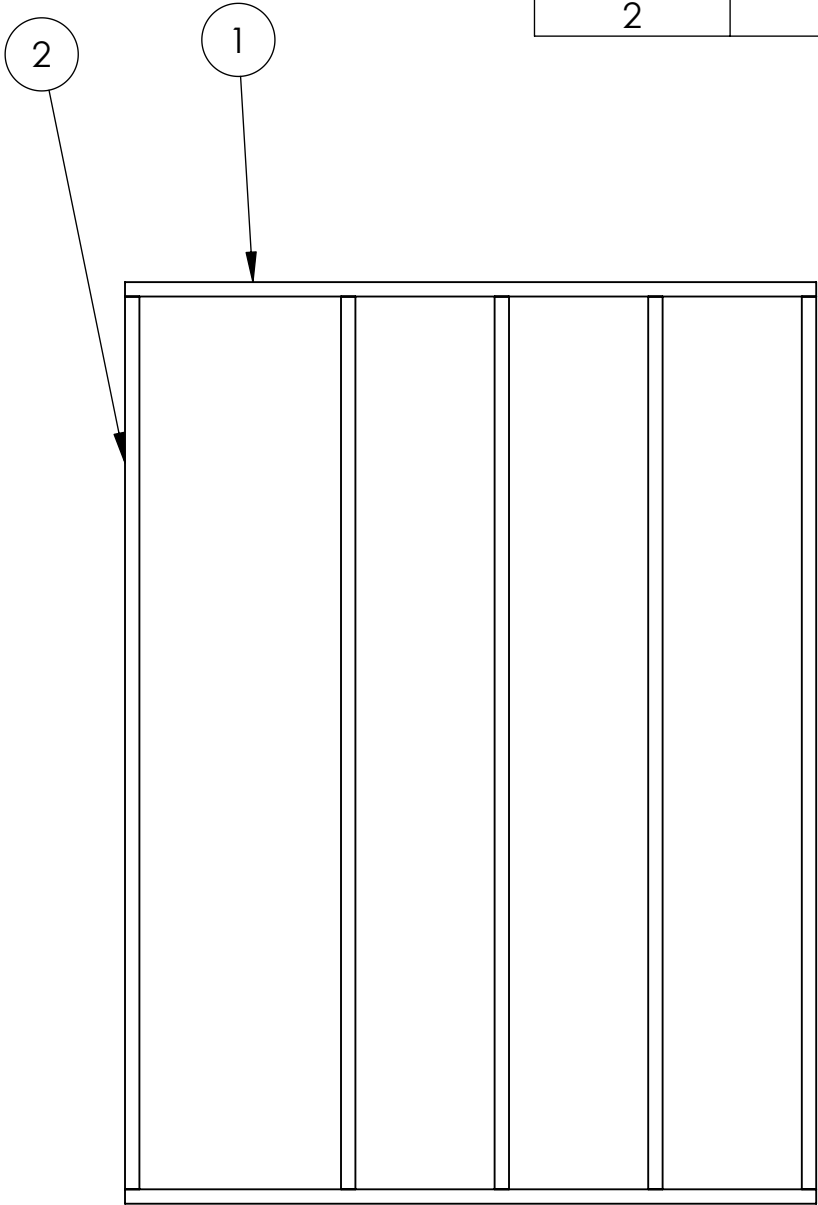
**BIOEN LAB**

TITLE: **WALL NO DOOR WITH DIMENSIONS**

SIZE	DWG. NO.	REV
<b>A</b>	<b>8</b>	

DRAWN	NAME	DATE	SCALE: 1:64	SHEET 1 OF 1
	WK			

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1028	2	2X4X72
2	1004	5	2X4X93



<b>BIOEN LAB</b>		
TITLE: <b>END WALL NO DOOR</b>		
SIZE <b>A</b>	DWG. NO. <b>9</b>	REV
DRAWN	NAME WK	DATE
SCALE: 1:32		SHEET 1 OF 1

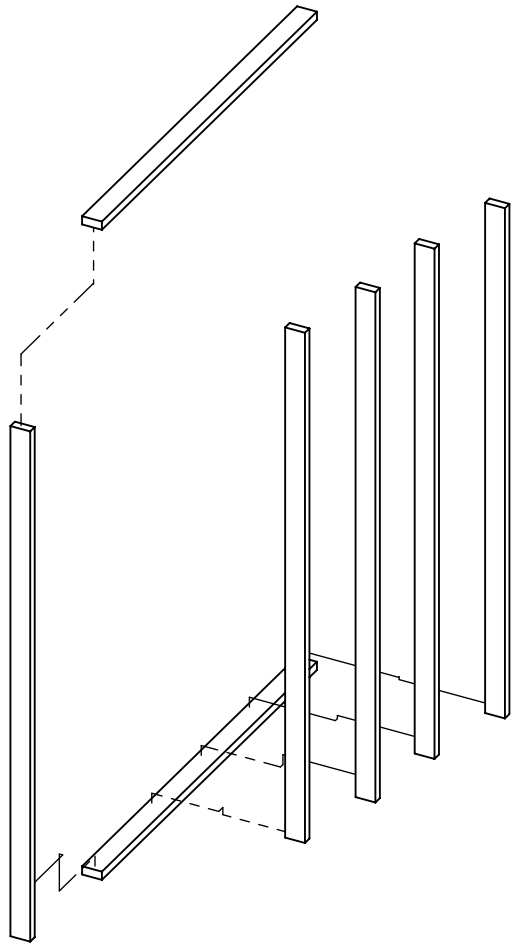
5

4

3

2

1



# BIOEN LAB

TITLE: EXPLODED END WALL  
NO DOOR

SIZE	DWG. NO.	REV
<b>A</b>	<b>10</b>	

DRAWN	NAME	DATE	SCALE: 1 : 30	SHEET 1 OF 1
	WK			

5

4

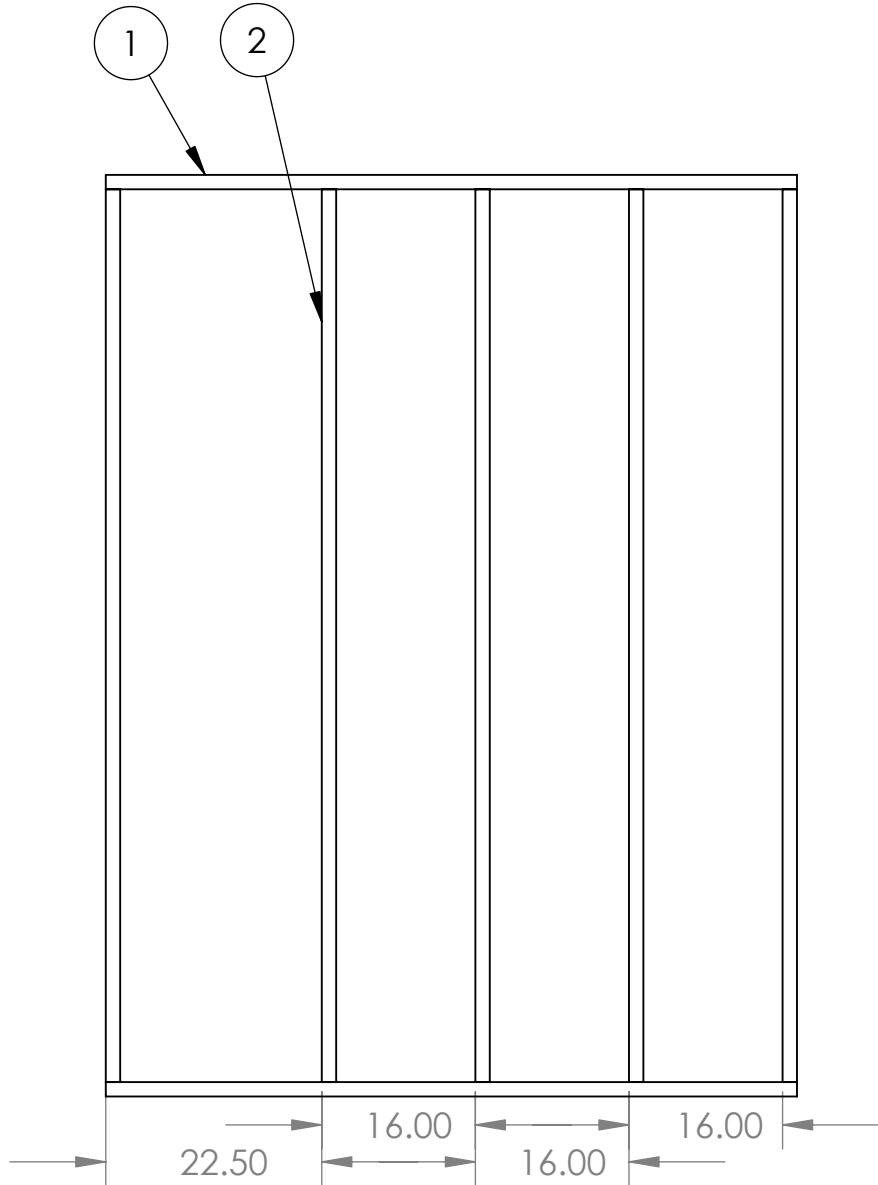
3

2

1



ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1028	2	2X4X72
2	1004	5	2X4X93



## BIOEN LAB

TITLE:  
END WALL NO DOOR 11

SIZE	DWG. NO.	REV
<b>A</b>	<b>11</b>	

DRAWN	NAME	DATE	SCALE: 1: 20	SHEET 1 OF 1
	WK			

5

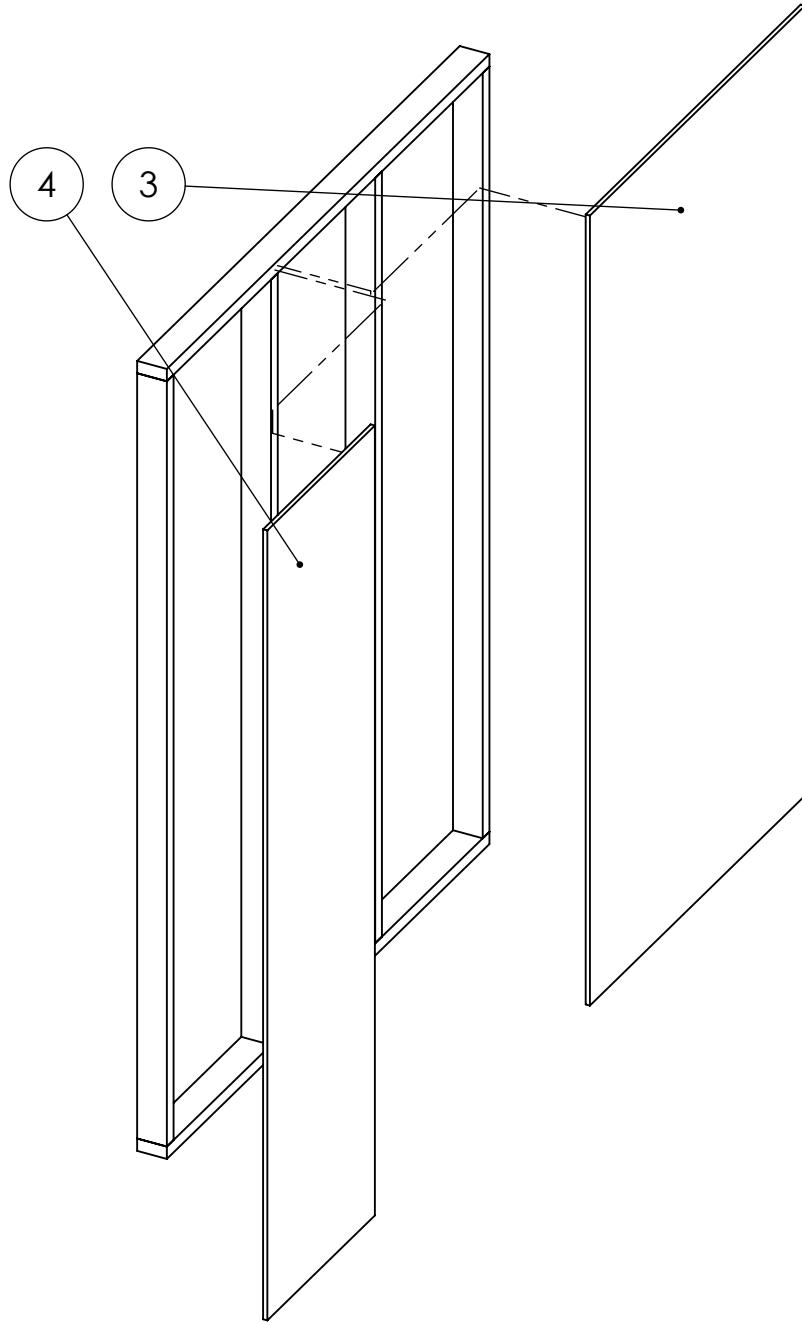
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
3	1007	1	48X96 FOAM/OSB
4	1034	1	24X96 FOAM/OSB



## BIOEN LAB

TITLE: END WALL WITH  
EXPLODED FOAM/OSB

SIZE	DWG. NO.	REV
<b>A</b>	<b>12</b>	

DRAWN	NAME	DATE	SCALE: 1 : 20	SHEET 1 OF 1
	WK			

5

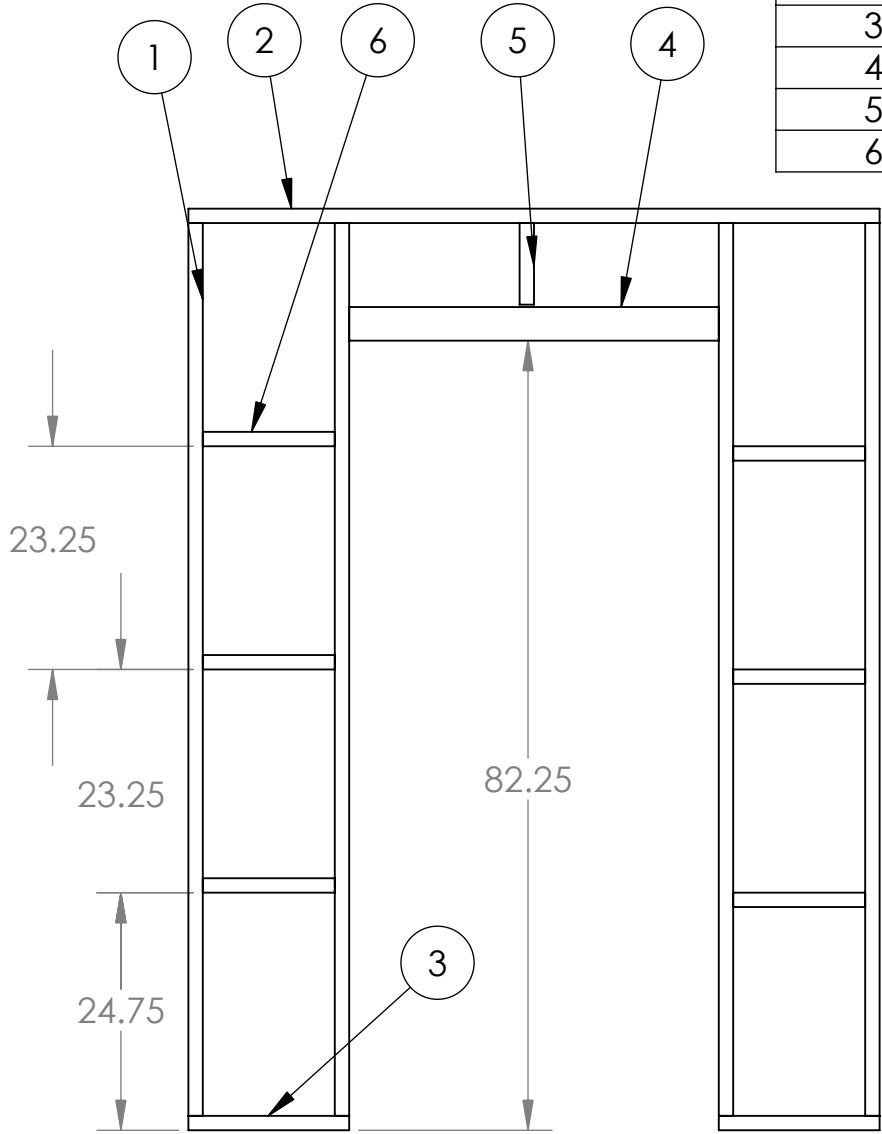
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1004	4	2X4X93
2	1028	1	2X4X72
3	1030	2	2X4X16.75
4	1029	2	2X4X38.5
5	1020	1	2X4X8.5
6	1031	6	2X4X13.75



**BIOEN LAB**

TITLE:  
**END WALL WITH DOOR**

SIZE <b>A</b>	DWG. NO. <b>13</b>	REV
DRAWN	NAME WK	DATE
SCALE: 1: 20		SHEET 1 OF 1

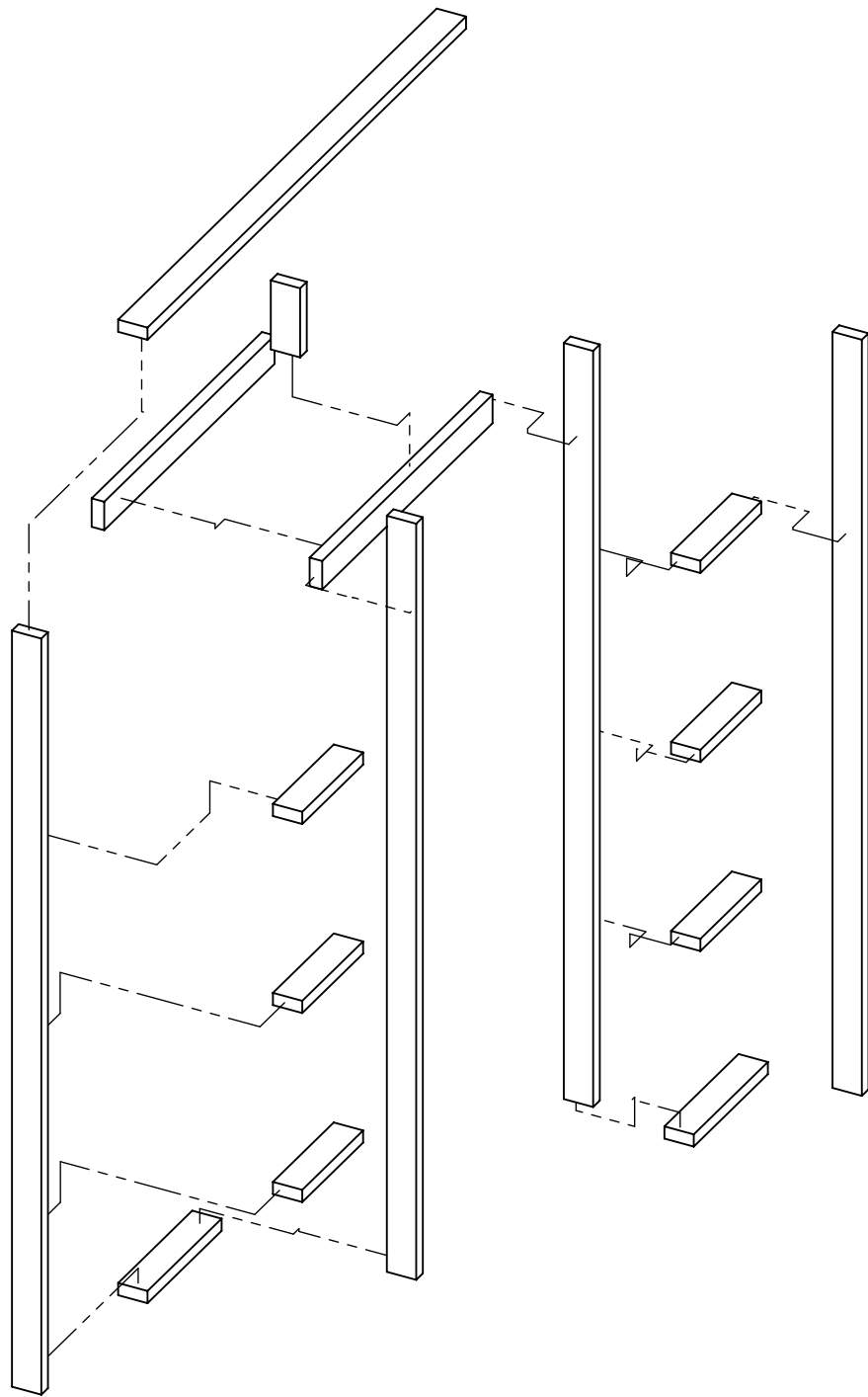
5

4

3

2

1



# BIOEN LAB

TITLE:  
EXPLODED END WALL  
VIEW

SIZE	DWG. NO.	REV
<b>A</b>	<b>14</b>	

DRAWN	NAME	DATE	SCALE: 1 : 20	SHEET 1 OF 1
	WK			

5

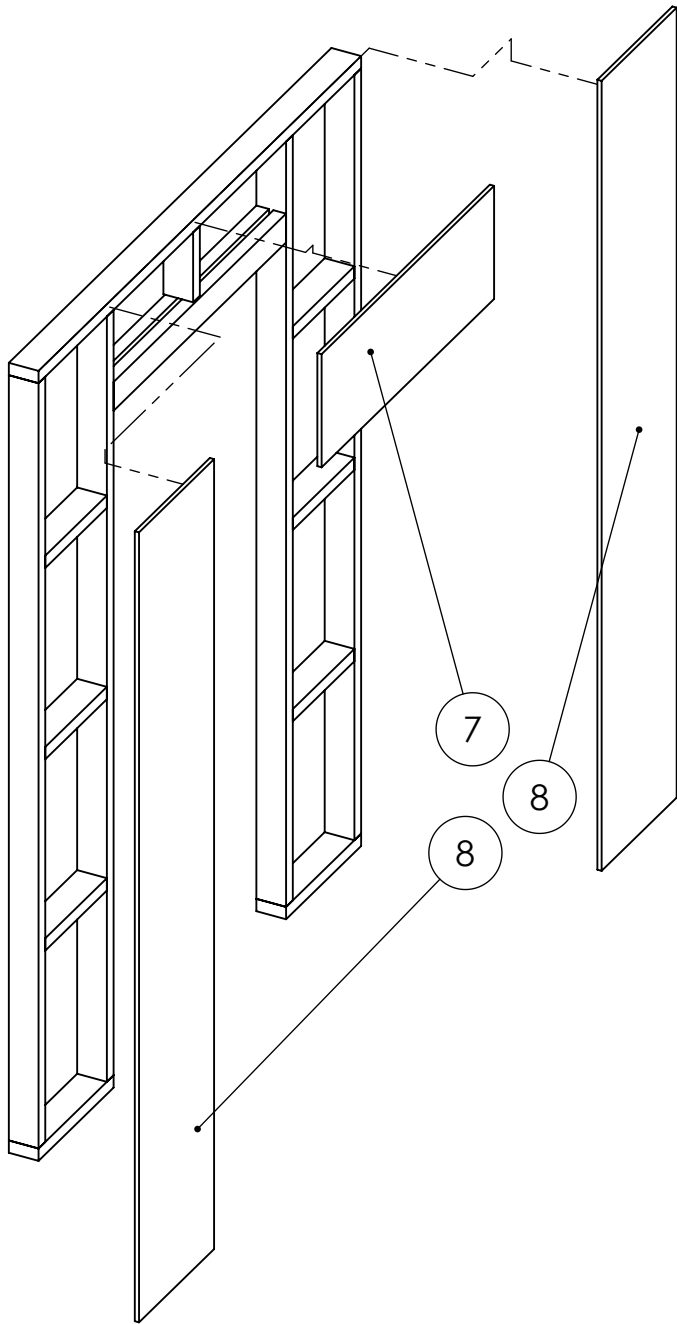
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
7	1033	1	13.75X38.5 OSB/FOAM
8	1032	2	96X16.75 OSB/FOAM



## BIOEN LAB

TITLE: ENDWALL FOAM  
AND OSB DETAIL

SIZE	DWG. NO.	REV
<b>A</b>	<b>15</b>	

DRAWN	NAME	DATE	SCALE: 1: 20	SHEET 1 OF 1
	WK			

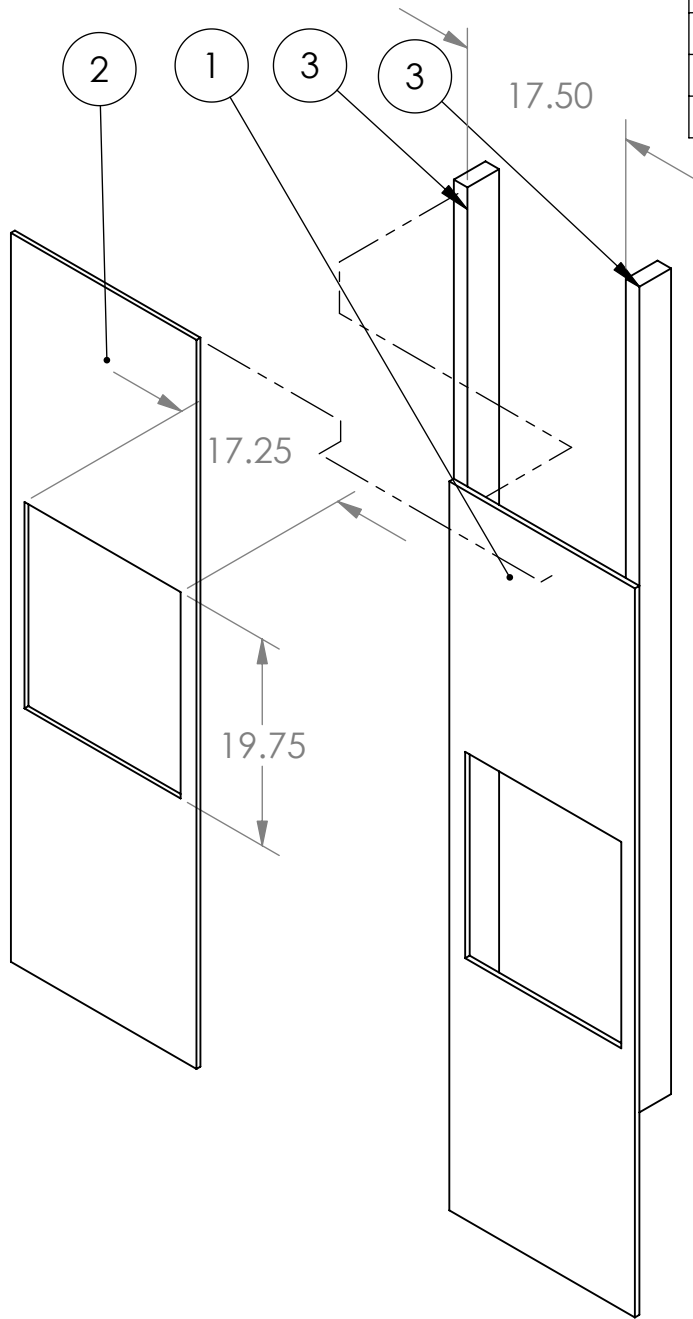
5

4

3

2

1



ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1048	1	20.5X69.75 FOAM
2	1049	1	20.5X69.75 OSB
3	1043	2	2X4X79

# BIOEN LAB

TITLE:

EXHAUST

SIZE

**A**

DWG. NO.

**16**

REV

NAME

WK

DATE

DRAWN

SCALE: 1:15

SHEET 1 OF 1

5

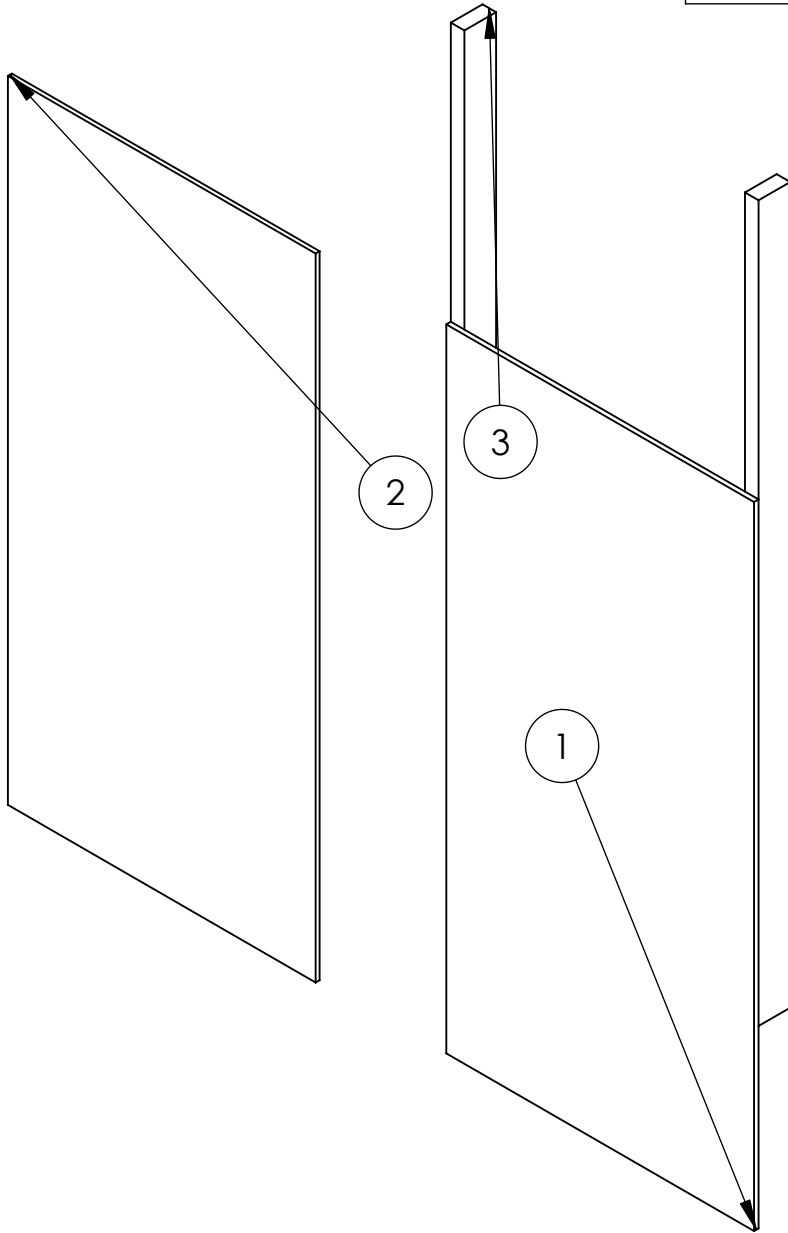
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1051	1	34X69.75 FOAM
2	1052	1	34X69.75 OSB
3	1043	2	2X4X79



## BIOEN LAB

TITLE:  
DRYER TOP EXHAUST END

SIZE	DWG. NO.	REV
<b>A</b>	<b>17</b>	

DRAWN	NAME	DATE	SCALE: 1:15	SHEET 1 OF 1
	WK			

5

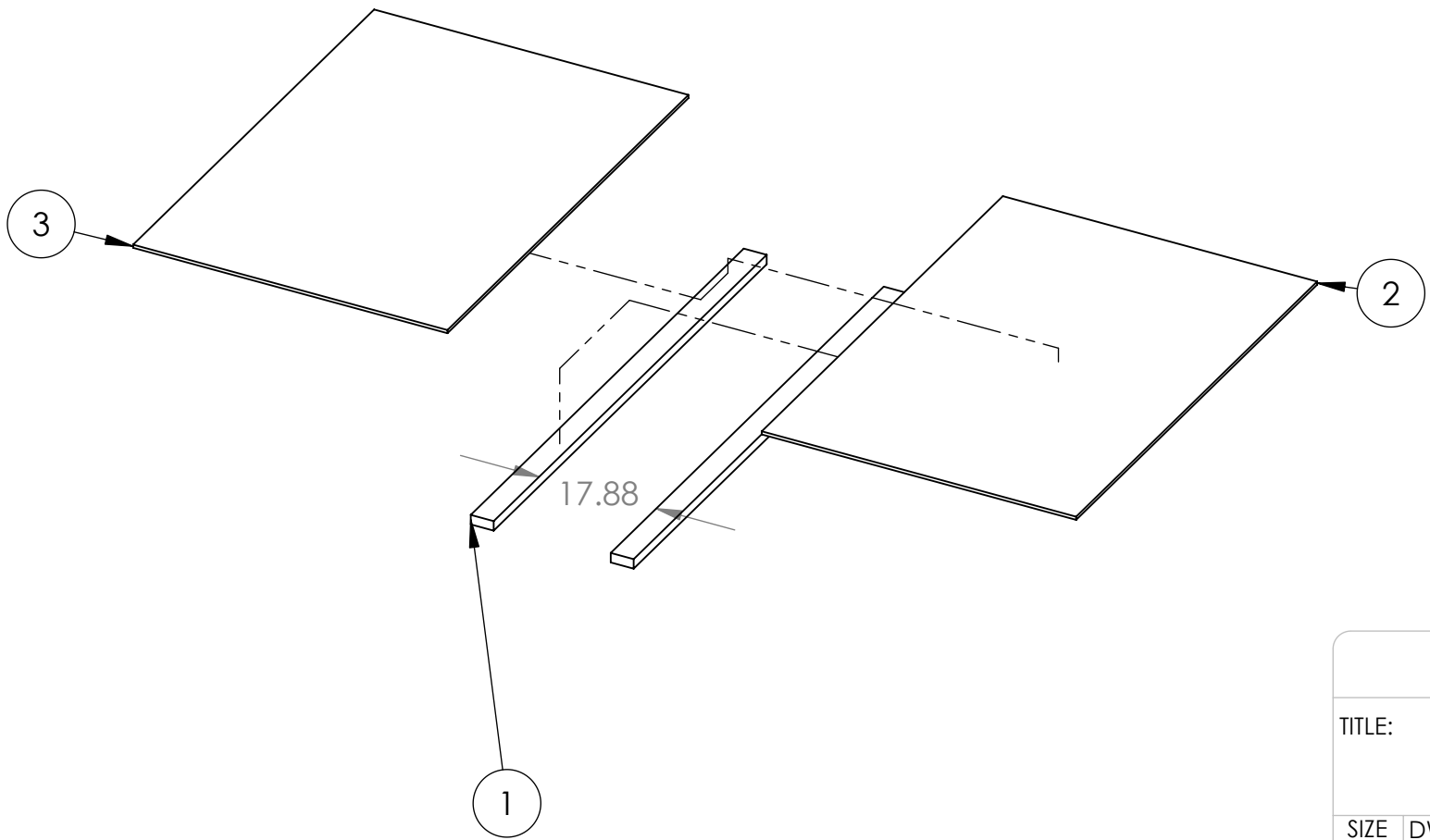
4

3

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1043	2	2X4X79
2	1044	1	48X69.75 FOAM
3	1045	1	48X69.75 OSB



<b>BIOEN LAB</b>		
TITLE:		
CENTER ASSY 1		
SIZE	DWG. NO.	REV
<b>A</b>	<b>18</b>	
DRAWN	NAME	DATE
	WK	
SCALE: 1:24		SHEET 1 OF 1

5

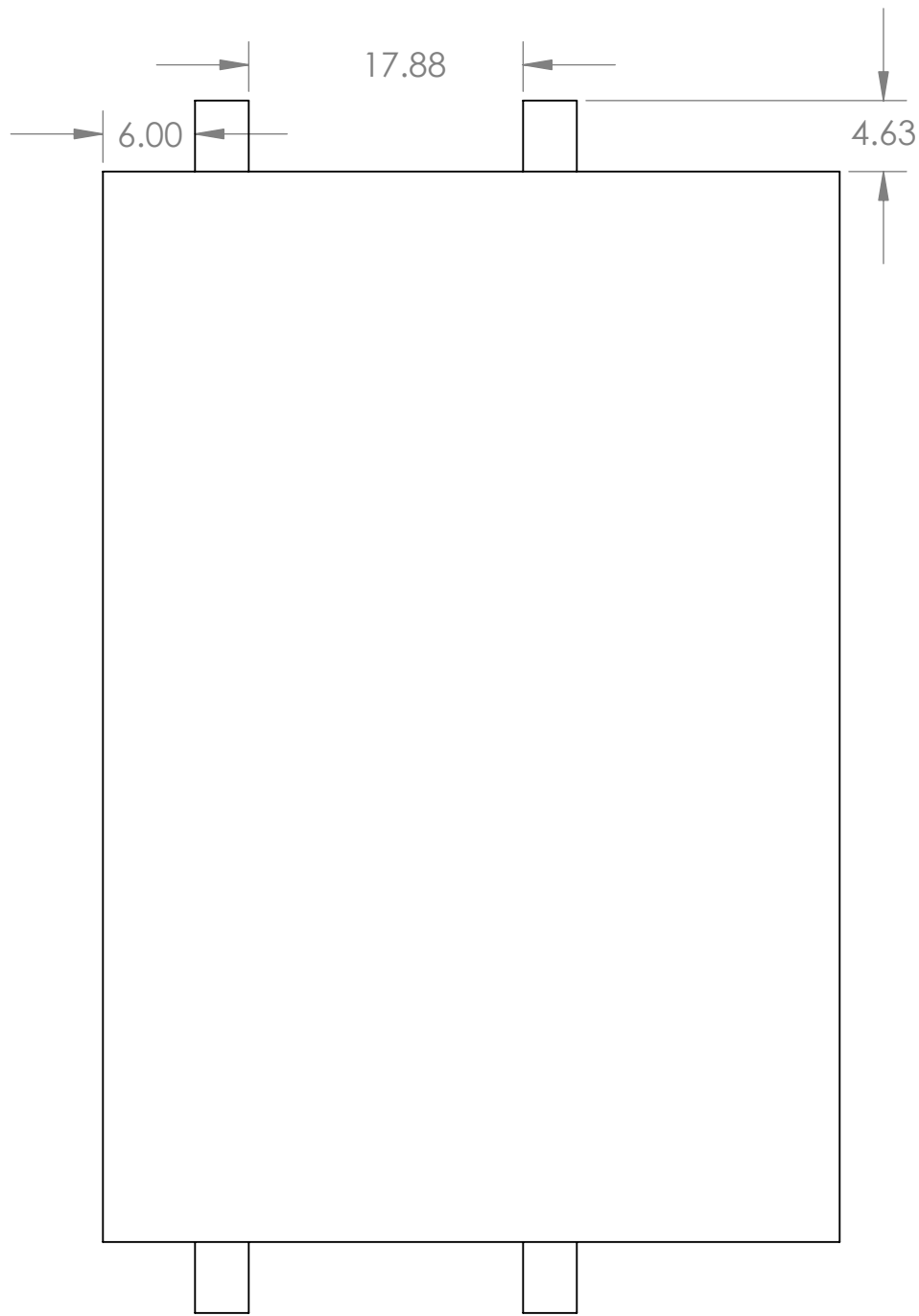
4

3

2

1





# BIOEN LAB

TITLE:  
CENTER ASSY 1

SIZE	DWG. NO.	REV
<b>A</b>	<b>19</b>	

DRAWN	NAME	DATE	SCALE: 1:12	SHEET 1 OF 1
	WK			

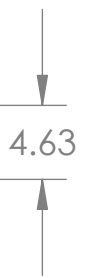
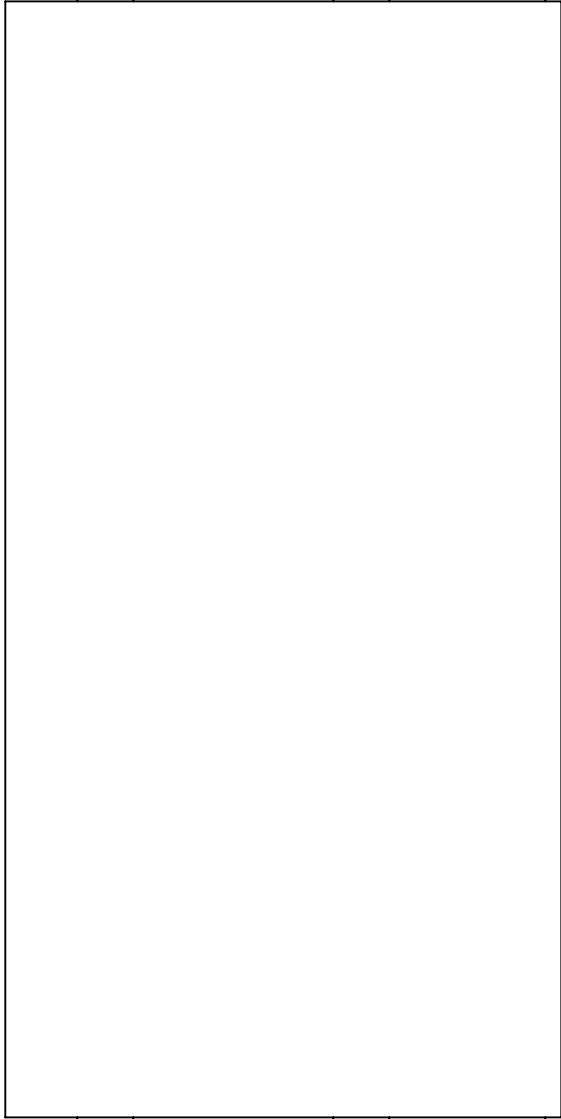
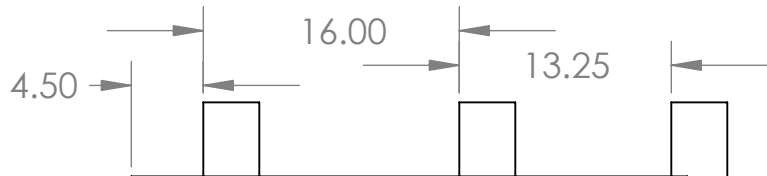
5

4

3

2

1



5

4

3

**BIOEN LAB**

TITLE: **CENTER ASSY 2**

SIZE	DWG. NO.	REV
<b>A</b>	<b>20</b>	

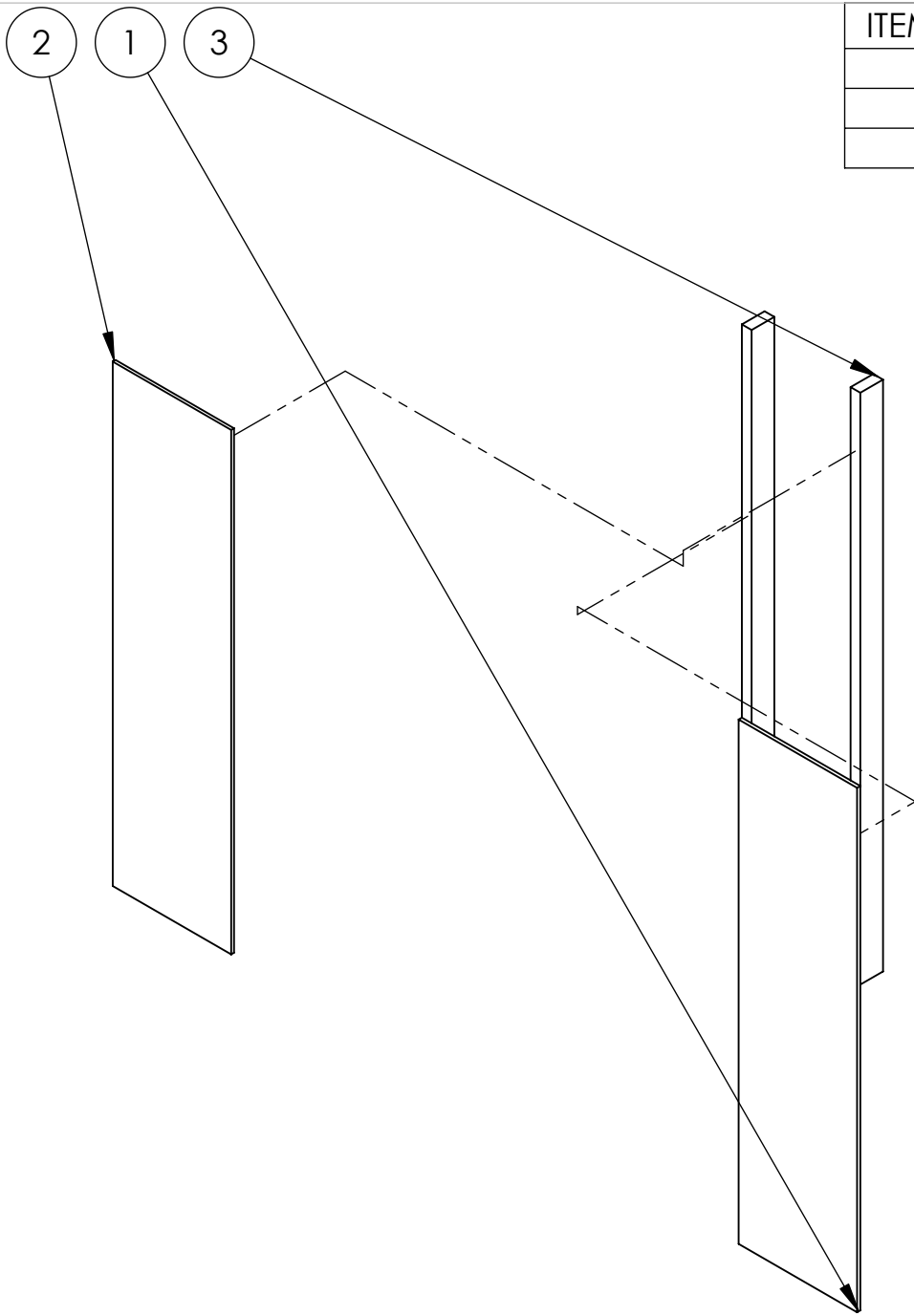
DRAWN	NAME	DATE
	WK	

SCALE: 1:12	SHEET 1 OF 1
-------------	--------------

2

1

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1054	1	18.25X70 FOAM
2	1055	1	18.25X70 OSB
3	1043	2	2X4X79



<b>BIOEN LAB</b>		
TITLE: <b>DOOR END TOP</b>		
SIZE <b>A</b>	DWG. NO. <b>21</b>	REV
DRAWN	NAME WK	DATE
SCALE: 1:24		SHEET 1 OF 1

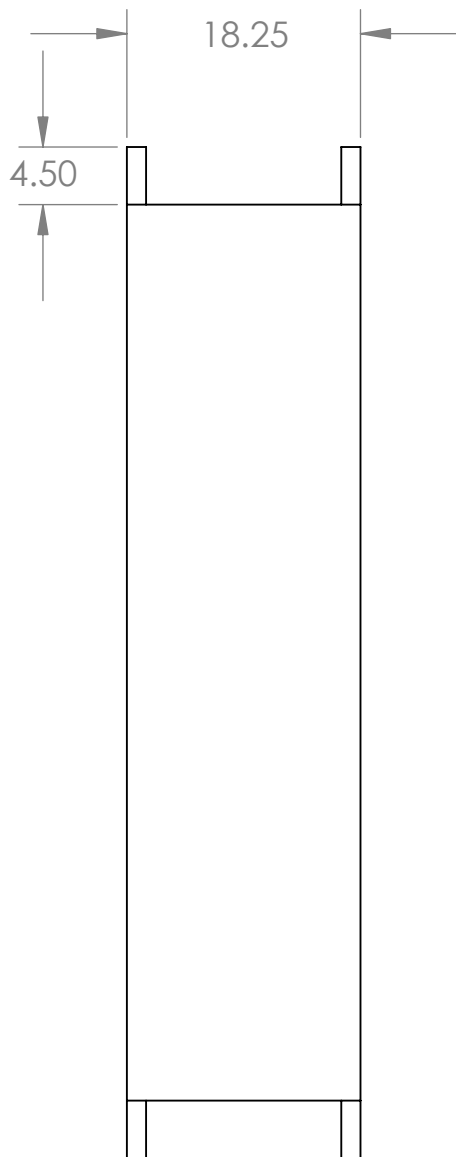
5

4

3

2

1



# BIOEN LAB

TITLE:  
DOOR END TOP ASSY

SIZE	DWG. NO.	REV
<b>A</b>	<b>22</b>	

DRAWN	NAME	DATE	SCALE: 1:24	SHEET 1 OF 1
	WK			

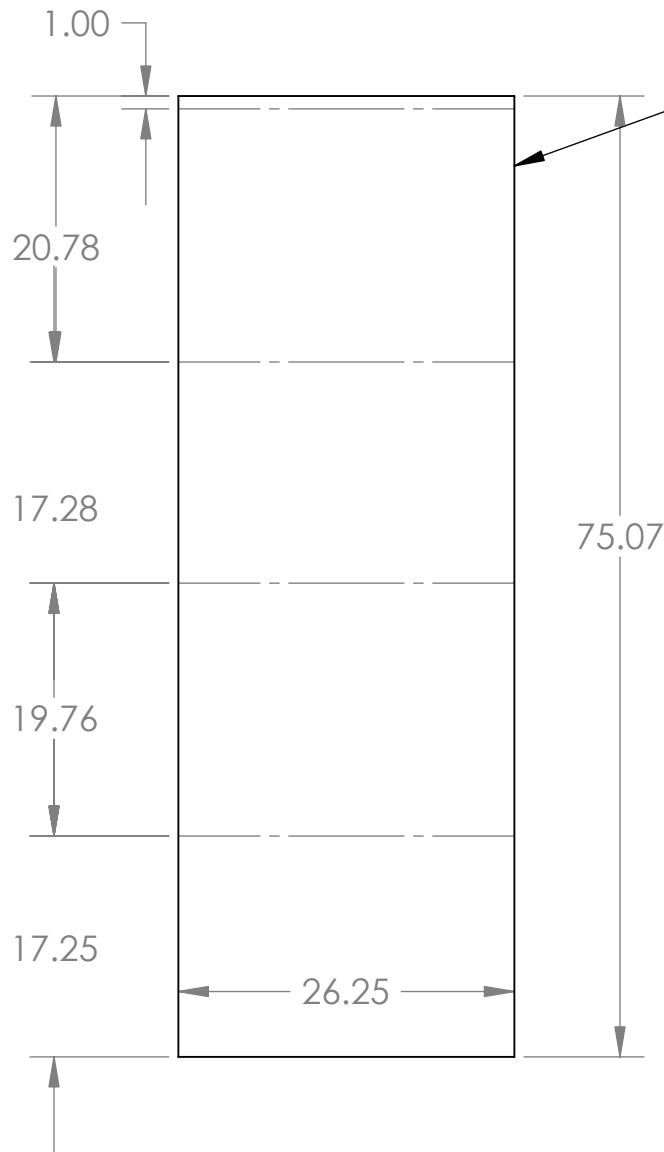
5

4

3

2

1



26 GUAGE GALVANIZED SHEET

ALL BENDS 90 DEGREES

Dimensions provided are for the version 1 (original) fan coil hydronic heater supplied by Triangle Tube (Blackwood, NJ, model AHS2-125). Dimensions for the current version fan coil hydronic heater (Precision Metal Products, model AH-220) are given in the air handler installation manual available at: <http://www.houseneeds.com/shop/manualsindexpage.asp#pmp>

BIOEN LAB

TITLE:

EXHAUST DUCT

SIZE  
**A**

DWG. NO.

**23**

REV

NAME

DATE

DRAWN

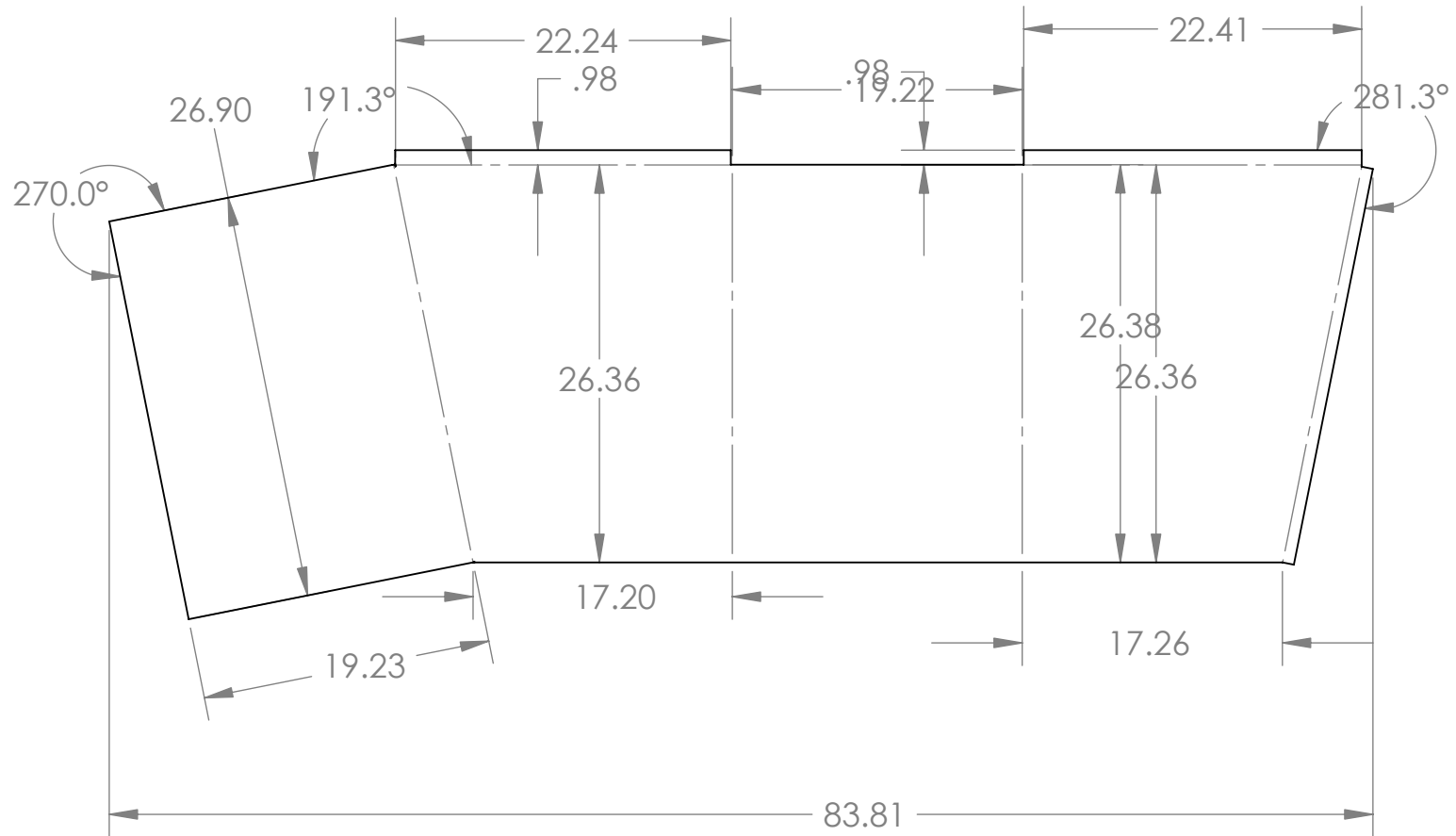
WK

SCALE: 1:15

SHEET 1 OF 1

ALL BENDS 90 DEGREES

MAKE FROM 26 GAUGE GALVANIZED SHEET



Dimensions provided are for the version 1 (original) fan coil hydronic heater supplied by Triangle Tube (Blackwood, NJ, model AHS2-125). Dimensions for the current version fan coil hydronic heater (Precision Metal Products, model AH-220) are given in the air handler installation manual available at: <http://www.houseneeds.com/shop/manualsindexpage.asp#pmp>

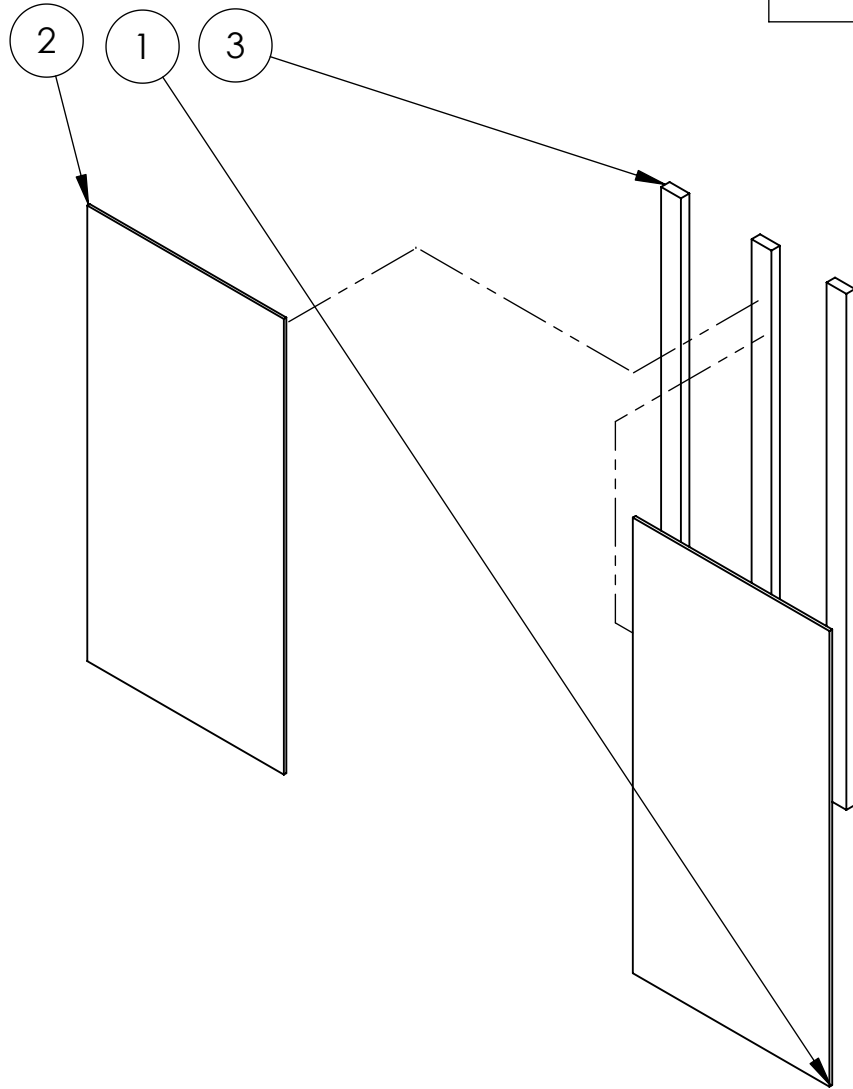
BIOEN LAB

TITLE: INLET DUCT

SIZE	DWG. NO.	REV
<b>A</b>	<b>24</b>	

DRAWN	NAME	DATE	SCALE: 1:12	SHEET 1 OF 1
	WK			

ITEM NO.	PART NUMBER	QTY.	DESCRIPTION
1	1046	1	34.75X69.75 FOAM
2	1047	1	34.75X69.75 OSB
3	1043	3	2X4X79



## BIOEN LAB

TITLE:

CENTER ASSY 2 EXP

SIZE

**A**

DWG. NO.

**25**

REV

NAME

WK

DATE

DRAWN

SCALE: 1:24

SHEET 1 OF 1

5

4

3

2

1

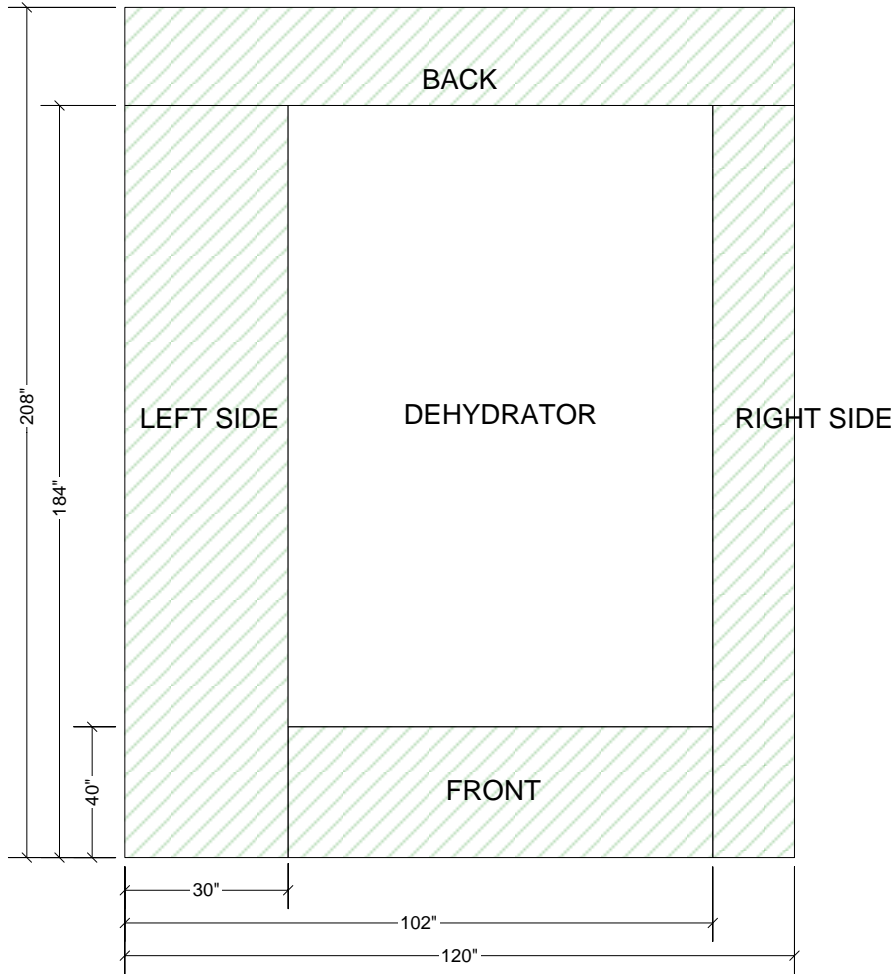


Figure 26. Recommended Access Space for Dehydrator: drawing showing suggested dimensions of the dryer



Figure 27. Mobile bakery rack used to hold product during processing



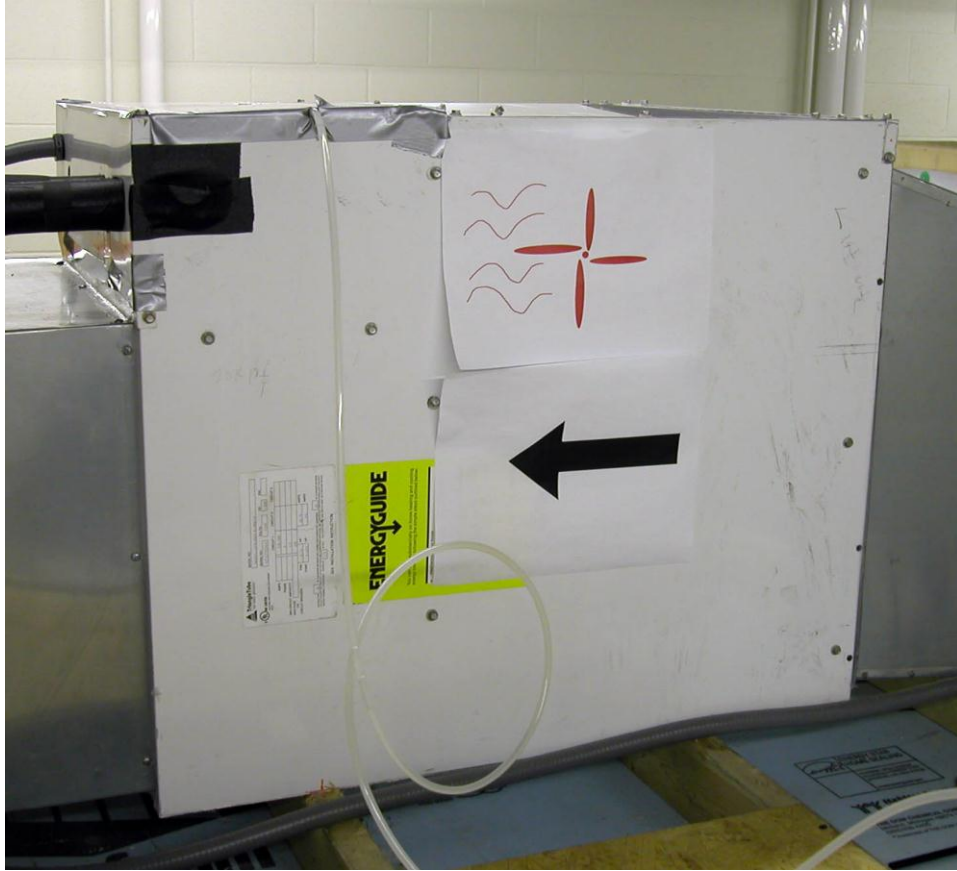


Figure 28. Fan coil heating system mounted on top of dehydrator. Arrow shows direction of air flow.



Figure 29. Continuous hot water heater and temperature controller mounted on wall adjacent to dehydrator.



Figure 30. Photo of the nearly completed dehydrator



Figure 31. Photo of one of the dehydrator walls during construction.

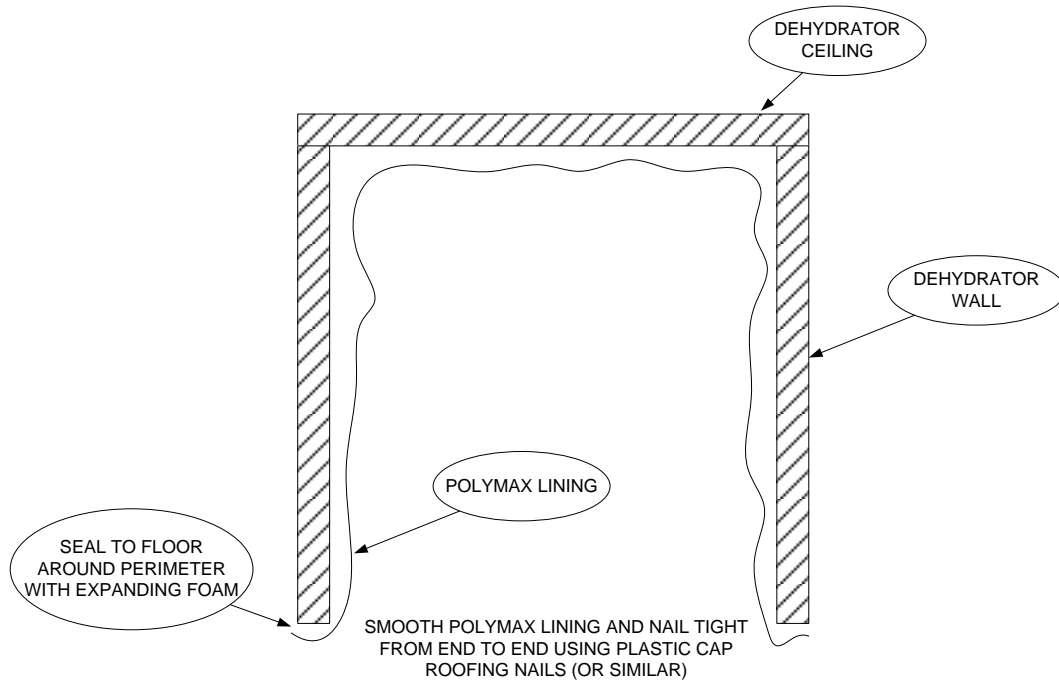


Figure 32. Conceptual drawing of application of the PolyMax fabric lining in the dehydrator's product holding area.



Figure 33. Plastic cap roofing nails used to secure the PolyMax lining to the interior of the dehydrator.



Figure 34. Photos of a technician wrapping a dehydrator ceiling panel with PolyMax fabric prior to installation.



Figure 35. Photo of pre-hung, foam-core metal door used in dehydrator

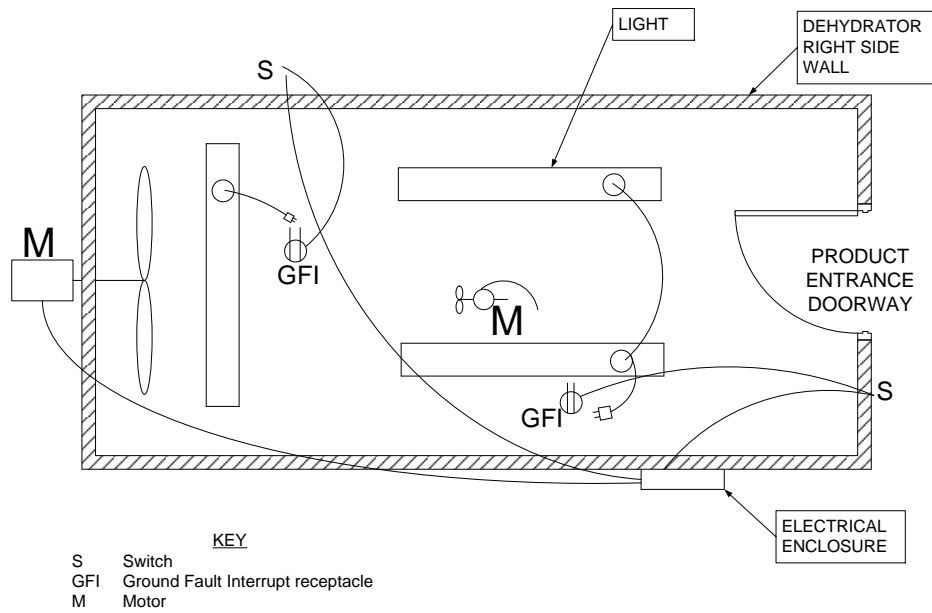


Figure 36. Electrical Wiring Plan View: a view from above the dehydrator depicting wiring and approximate component layout.



Figure 37. Electrical enclosure mounted on the left-hand side of the dehydrator

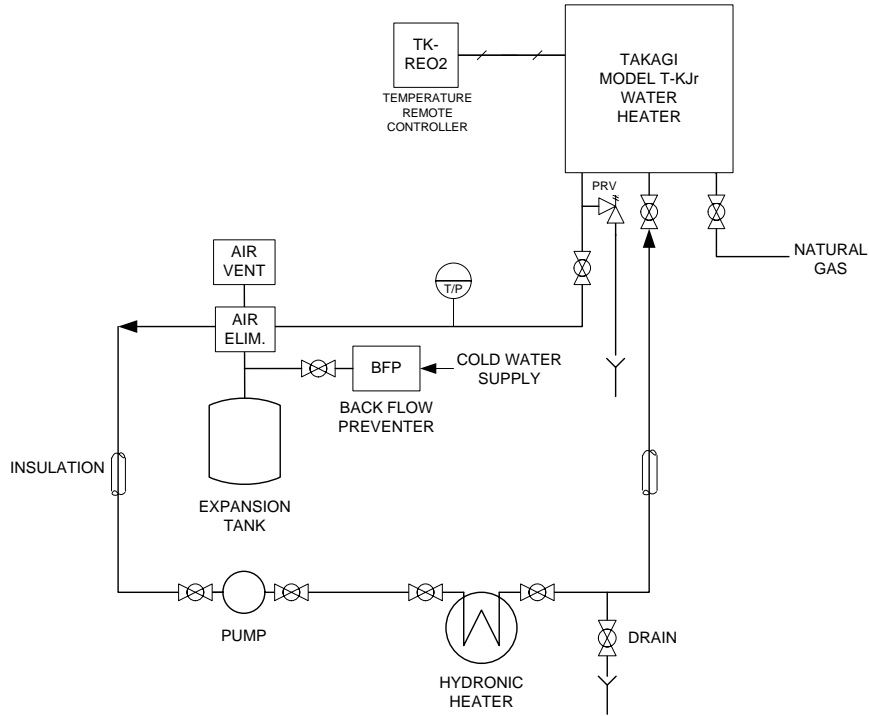


Figure 38. Heating System schematic



Figure 39. Continuous hot-water recirculation pump; also shows expansion tank.



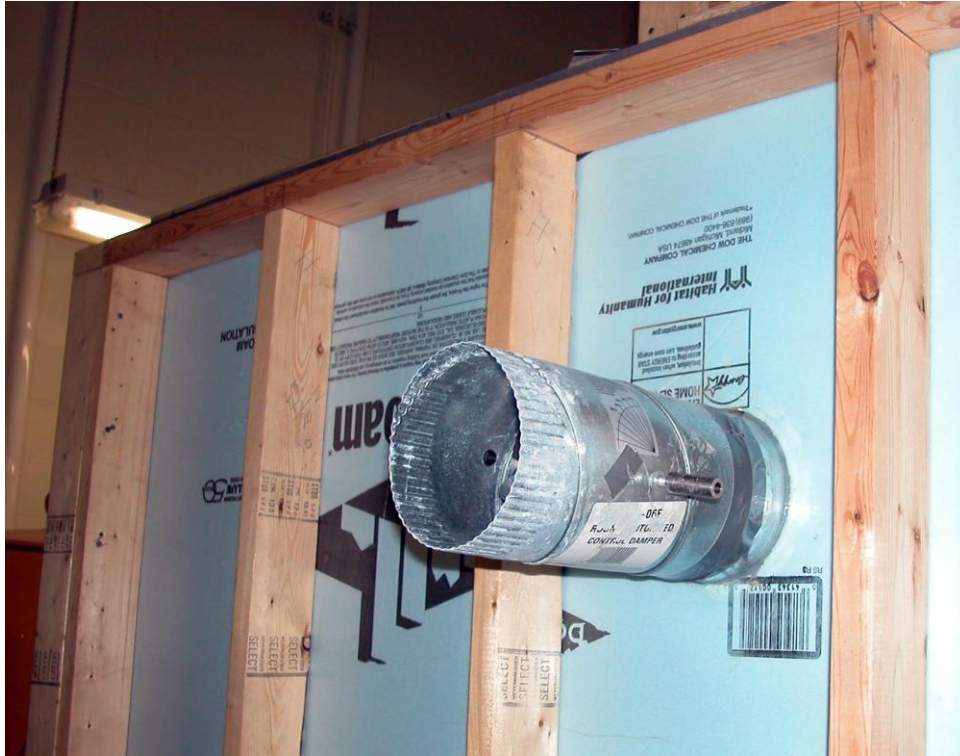


Figure 40. Exhaust duct with air damper valve installed on back wall of dehydrator to remove moisture-laden air.

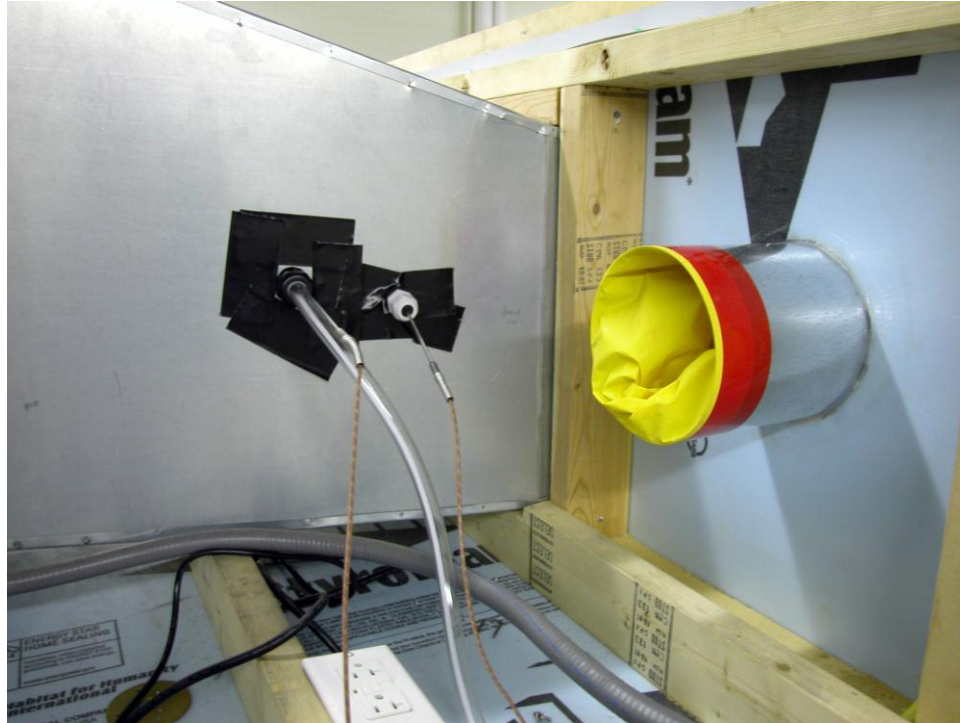


Figure 41. Fresh air inlet duct with back-flow damper; installed through dehydrator wall near the ventilation duct.



Figure 42. Low-speed, high volume fan installed to mix air within the dehydrator.

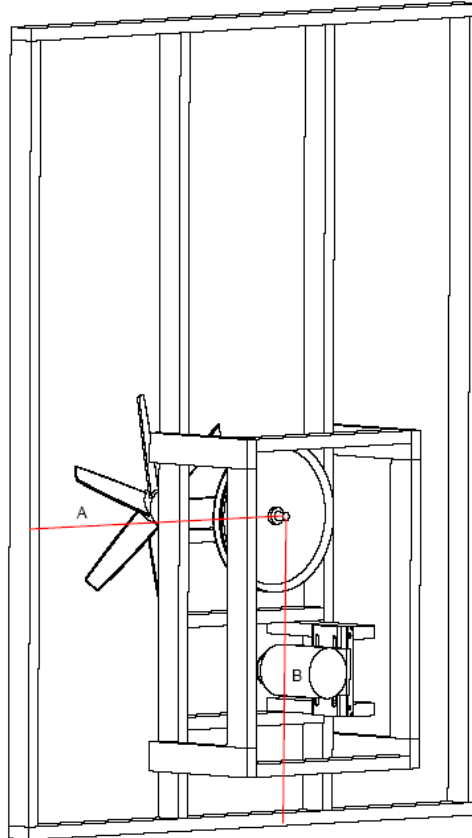


Figure 43. Fan assembly



Figure 44. Air deflection baffle mounted parallel to and adjacent to the bottom side of the heated air discharge duct. The angle shown is 15 degrees below horizontal. The baffle serves to direct the heated air to the low pressure side of the LSHV fan.

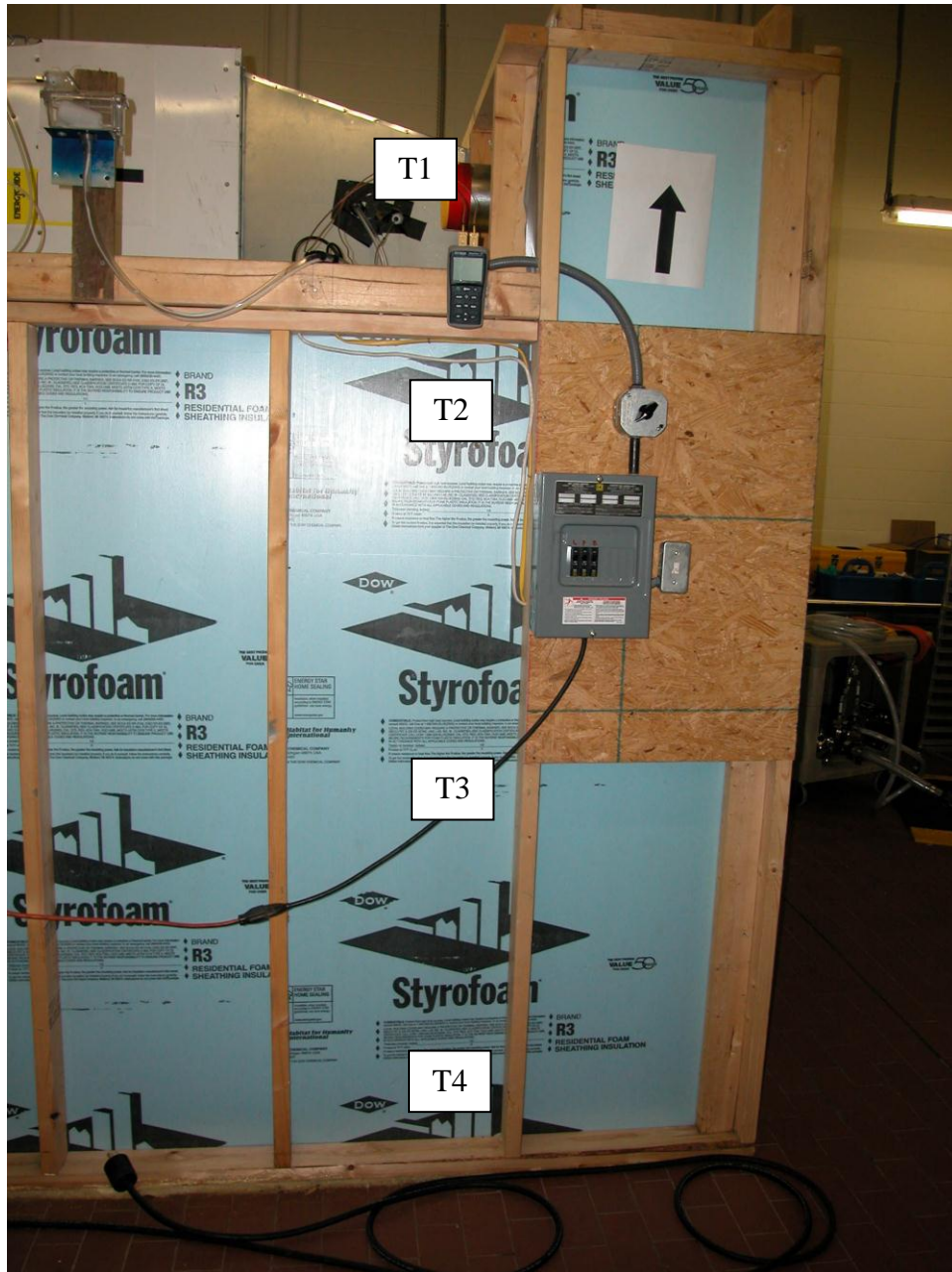


Figure 45. Four temperature measurement locations used to determine baffle angle setting. T1 is the dry bulb thermocouple in the ventilation duct. T2, T3, and T4 are accessed by drilling

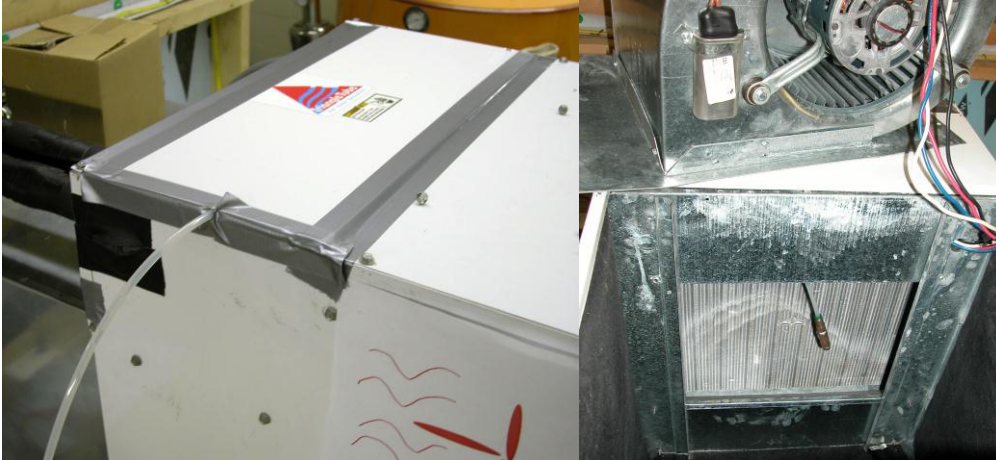


Figure 46. Misting nozzle installation. Left photo shows water tube entering through removable panel on ventilation unit. Right photo reveals the misting nozzle hanging in front of the heating coil (panel cover and fan motor removed).

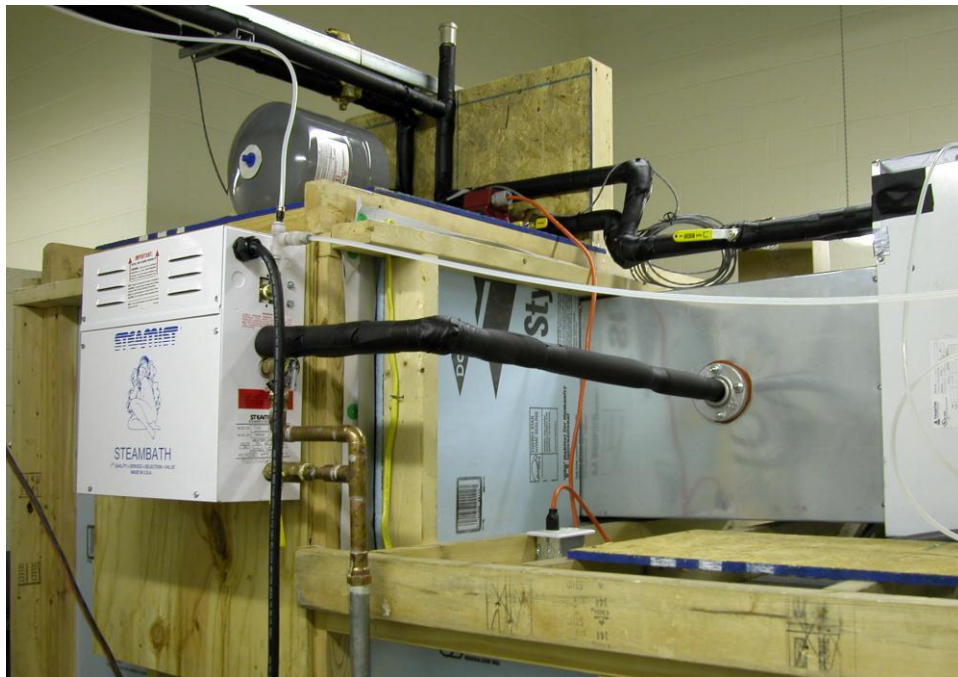


Figure 47. Steamist steam generator installation.



Figure 48. Steamist steam generator discharge piping. Left photo shows pipe discharge inside of duct, right photo shows piping from generator to duct



Figure 49. Detail of dehydrator shelf or tray showing “hemmed” edge, which added rigidity to the shelf and concealed the cut edge of the wire cloth.

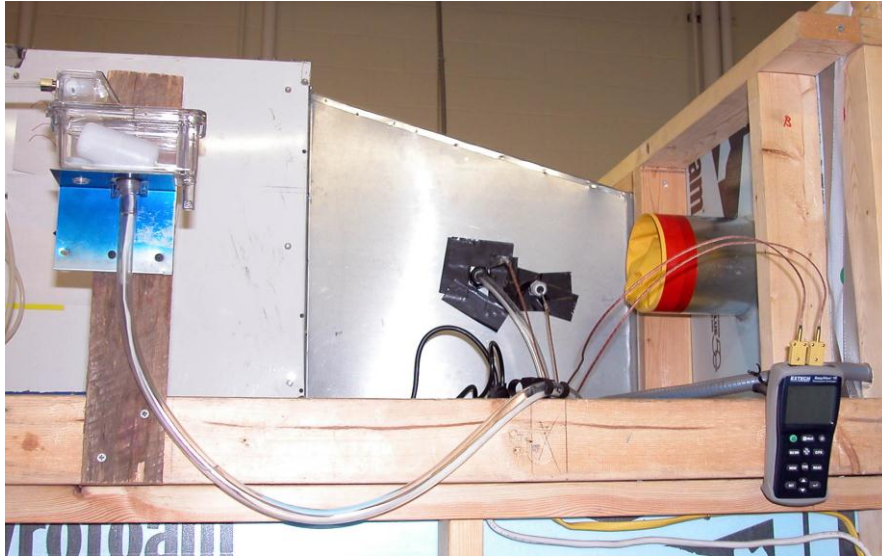


Figure 50. Dehydrator instrumentation system showing (left to right) wet bulb water reservoir, thermocouples and data logger.

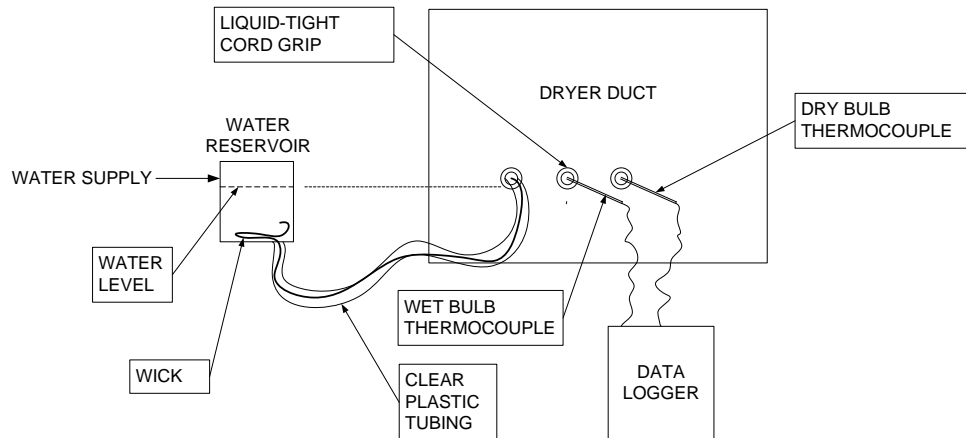


Figure 51. Temperature sensor installation diagram. The clear plastic tubing protects the wet wick. The water level in the reservoir should be just slightly below the level of the penetration (for the plastic tubing) in the air duct to prevent water leaks into the duct.



Figure 52. Dry (foreground), and wet bulb thermocouples, and water wick viewed inside the air ductwork. The fan shroud for the hydronic heater is visible in the background.



Figure 53. Optimum baffle angle at -15 degrees from the horizontal.





Figure 54. Guard protecting product from fan blades. Guard is constructed of PVC tubing reinforced with conduit.