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Building of a Prototype Grain Dryer

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Problem Statement
Loebach Brothers LLC is a company consisting of Dave and Joe Loebach. They hold design patents for the "Dorothy" projects. There are no stakeholders for this company. The group created a system that rapidly removes moisture from grain without using a heating element. The group redeveloped a previous prototype that is scaled to a full-size grain bin. The previous prototype was built without drawings and how it was manufactured was mostly through speculation and the client's industry experience. However, the group does have a picture of how it was built. The client wanted this built for proof of concept on a large scale. The group was tasked to focus on building just the dehumidification unit, as the project scope constantly changed.

Disciplines
Bioresource and Agricultural Engineering | Industrial Technology

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Department of Agricultural and Biosystems Engineering (ABE)

TSM 416 Technology Capstone Project

Building of a Prototype Grain Dryer

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*course instructors and corresponding authors.

Client: *Loebach Brothers contact: Dave Loebach: 208-697-7777*

1 PROBLEM STATEMENT

A. Problem Statement

- *Loebach Brothers LLC is a company consisting of Dave and Joe Loebach. They hold design patents for the "Dorothy" projects. There are no stakeholders for this company.*
- *The group created a system that rapidly removes moisture from grain without using a heating element. The group redeveloped a previous prototype that is scaled to a full-size grain bin.*
- *The previous prototype was built without drawings and how it was manufactured was mostly through speculation and the client's industry experience. However, the group does have a picture of how it was built. The client wanted this built for proof of concept on a large scale.*
- *The group was tasked to focus on building just the dehumidification unit, as the project scope constantly changed.*

B. Business Case Statement -

- **What**- *The previous prototype needed to be re-engineered to upscale a larger bushel operation than before. The need for this to be built was proof of concept and future licensing.*
- **How-** *The problem was very extensive and required much building time. Lots of parts were needed to build this, and Loebach LLC put much money into this.*
- **When** and **where-** *problems occurred, they were very small. The group placed a lot of time and effort into taking the time to properly design the system so that it went together smoothly and operated properly.*

- **Why**- *This project makes strategic sense because it can be used on other farms and could be a superior product for specialty grain and seed drying.*
- **Who** *cares about the problem? Our client, but also people that are looking for an alternative solution to dry grain.* **Why** *anyone should care is because this can save people money on drying when natural gas prices are high, and it is a great alternative for drying specialty crop without burning it.*

2 GOAL STATEMENT

By capstone day our goal was to build the second generation prototype of a grain dryer and design the rest of the system needed to dry grain on a full-size operation. The team based the prototype off of the original prototype "Dorothy I" and the patent our client has. However, the team must make our prototype compatible with a full-size grain bin. To compare data or measurements with the previous prototype and with other grain dryers is out of the project scope, so the team did not do a full test on the prototype. The entire design is based on the client and his patent. The client purchased the parts, and the group designed the layout and constructed the dehumidification unit. The process will carry on to testing in the future and will hopefully be implemented to dry specialty grain crop (rice).

- **Main Objective(s) and Specific Objectives**
    - **The main objective is to** *design and construct a full-scale grain dryer based on the first prototype design and principles.*
    - **Specific objectives include**:
        - *Design grain drying system on AutoCAD*
        - *Fabricate the platform of system*
        - *Build prototype with dehumidification system*
        - *Run dryer to make sure all parts work properly*
        - *Keep in budget of $16,000*
        - *Grain Dryer must be portable*
    - **Rationale**
        - *Our client will be able to prove his patent works and proof of concept*
        - *The dryer will pull in warm air and reduce moisture in its air system*
        - *Less crop will be damaged because of no heating element*

3 PROJECT PLAN/OUTLINE

A. Methods/Approach

- **Reference Material(s)**
    - *The largest reference the team used was the refrigeration knowledge of the client which has significant experience working in commercial refrigeration and was the main contributor when it came to building the refrigeration system.*
    - *The next primary source to all references was the text materials from TSM 322, including Grain Handling After Harvest, and MWPS 13: Grain Drying, Handling and Storage Handbook.*
    - *The research findings and data from Kurt Rosentrater's tests on the first generation unit "Dorothy I" were used as a base design for this project.*
    - *Other online sources from industry standards were used as needed for bin sizing, fan sizing, and air ducting.*
- **Data collection**:
    - *The team definition of data when entering the project was how the machine performs and what is the numerical output.*

  - *The primary plan was to take data on the whole system when it was hooked up and running. Issues during the project did not allow the team to complete the system to take the needed data. Therefore data needs to be taken when the system is completed.*
- **Skills**:
  - *Grain drying and handling knowledge along with mechanical knowledge were the two largest skills that were utilized and developed by group members.*
  - *Working with clients from a distance was a skill surprisingly further developed. The main skills developed while working within the group was learning to communicate over conference calls and emails and working with multiple personalities with different working and thinking styles.*
- **Solutions:**
  - *The solution is simple and complete; design a custom grain dryer using existing grain handling equipment with a custom drying unit.*
- **Organization:**
  - *Group meetings were held once a week to deal with design and acquisition of parts. Assigned work was done outside of meetings and was divided up to teammates based on their expertise, the complexity, the timeline, and the amount of work currently assigned to them.*
  - *Phone calls were held at least once a week and emails as necessary with the client. The client was present most days while the system was being built.*
  - *During the build process, most nights were spent at the shop working on the unit.*
  - *The major milestones completed included Platform build, coil and fan assembly, plenum design and assembly, refrigeration assembly, Electrical, CAD drawings and finally full system design.*
  - *Budget constraints caused cutbacks back to just building the dryer and designing the rest of the system.*

B. Results/ Deliverables

- *The main deliverables were to build a drying system, design a system to move the grain, and determine components to test and automate the entire system.*
- *The current state of the entire project is unfinished. The electrical components need to be brought to electrical code, and the refrigeration system needs fully charged.*
- *Next steps for this project are to acquire and install the automation system, configure drying unit to a bin, test and collect data, and continuous improvement.*

C. Timeline

Steps	What Was Done	Time Period
1	Platform Design	Oct 30, 2016 - Jan 10, 2017
2	Build of Platform	Jan 12, 2017 – Feb 20, 2017
3	Theoretical Analysis of System	Feb 25, 2017 – April 20, 2017
4	Development of Presentation	March 25, 2017 – April 18, 2017
5	Creating and Finalizing Client Deliverables	April 1, 2017 – April 27, 2017

4 Broader Opportunity Statement

A. *The opportunity statement delves into a broader nature of the problem. The broader opportunity is a description and analysis of your potential market and broader impact of your project.*

B. *To an average person, the concept might be difficult to grasp. This would appeal to people that have some agricultural experience and knowledge of basic grain drying methods.*

C. *Keeping high-quality grain and seed has been a big challenge with typical grain dryers. Usually, higher heat and shorter drying times are at the expense of quality. Using dry air from evaporative coils, grain and seed can be dried quickly enough to alleviate spoilage and cool enough to help maintain high-quality products.*

D. *This system is mainly designed for seed companies and crop farmers who produce specialty crops that are fragile to high heat. With some careful considerations, this system can be used for anything that requires moisture removal. For example, most crops and ventilated buildings.*

E. *Industries that could use this system are grain handling and seed production industries.*

F. *Trends for high grain quality and lower energy use affect the broader opportunities for this system.*

G. *Grain handling companies are currently working on different ways to manage grain quality, but most are still using some sort of added heat in their systems. The dehydrating system stands apart from current companies.*

H. *Companies should be willing to spend as much for this system as they would for similar drying systems. From reviewing "Dorothy I", costs seem to be less than similar heat-added systems. Income from the improved grain quality would be higher, both in the short-term and long-term aspects.*

5 Project Scope

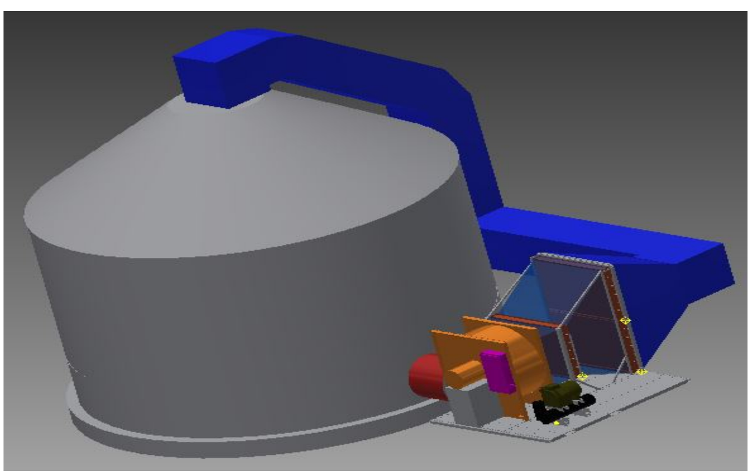
A. *The scope of this project was to design and build a second-generation moisture removal system. This system needs to be designed and fitted around a refrigeration system and components determined by the client. Budget constraints changed the project scope drastically. The scope began as a design, build, and test of the system and was redefined into a design and partial build of the system.*

B. *Throughout the course of this project, the group relied on the experience of the client had in refrigeration systems. The entire circuit was built from his knowledge of the system. The team had access to any parts that the client had on hand that helped to keep the budget down.*

C. *The team didn't use any bins or grain during this project. Due to the change in scope, they were unable to test the drying system.*

D. *The option to use any other form of drying system was not considered due to the nature of this project and request by the client. The system was designed around "Dorothy I".*

6 Graphical Abstract



Further description of this picture will be in the appendixes

7 APPENDIXES

Given in following pages.

Budgets for built system and recommendations

Dorothy II	qty	price per 1	net
Evaporator coils	2	$ 3,400.00	$ 6,800.00
condensor coil	1	$ 4,600.00	$ 4,600.00
compressor	1	$ 3,772.72	$ 3,772.72
reveiver	1	$ 680.00	$ 680.00
fan	1	$ 1,000.00	$ 1,000.00
fabrication steel	1	$ 1,017.00	$ 1,017.00
expansion valves	2	$ 191.00	$ 382.00
liquid line solenoids	2	$ 246.00	$ 492.00
high pressure solenoid valves	2	$ 129.00	$ 258.00
reversing valve	1	$ 249.00	$ 249.00
solenoid valve	1	$ 39.00	$ 39.00
solenoid coil	4	$ 44.00	$ 176.00
dual pressure control	1	$ 159.00	$ 159.00
alls liquid line stabilizer	2	$ 60.00	$ 120.00
sight glass	3	$ 18.65	$ 55.95
oil saftey control	1	$ 192.14	$ 192.14
refrigerant dryers	1	$ 117.50	$ 117.50
120# refrigerant r404a	1	$ 693.25	$ 693.25
refrigerant oil	1	$ 127.00	$ 127.00
75A contactor	1	$ 124.55	$ 124.55
60A contactor	1	$ 97.19	$ 97.19
timer and relay	1	$ 27.62	$ 27.62
unistrut and clamps	1	$ 70.32	$ 70.32
copper fittings and tubing	1	$ 418.73	$ 418.73
electrical supplies	1	$ 194.96	$ 194.96
misc. supplies	1	$ 332.00	$ 332.00
	total	$ 22,195.93	
	tax	$ 1,553.72	
	grand total	$ 23,749.65	

Shivvers System	qty	price per 1	net
Dri-Flo 8" 500 bu	1	$ 10,078.00	$ 10,078.00
18 ft Sm Grain Floor	1	$ 2,050.00	$ 2,050.00
18 ft floor legs	1	$ 1,630.00	$ 1,630.00
Jumpster 8 inch 5 ft	1	$ 2,954.00	$ 2,954.00
floor door	1	$ 242.00	$ 242.00
3 hp 1 phase motor	1	$ 875.00	$ 875.00
10 hp 1 ph motor	1	$ 1,625.00	$ 1,625.00
3-3/4" 3grv 1-3/8 bore pulley	1	$ 114.00	$ 114.00
v-belt 3ab groove 4" pulley	1	$ 125.50	$ 125.50
8"grain sample valve	1	$ 368.00	$ 368.00
plenum clean out door	1	$ 210.00	$ 210.00
1 hp grain hog spdw/sml pan	1	$ 1,290.00	$ 1,290.00
8-12 ga comb bin stiffeners-s	1	$ 787.00	$ 787.00
100 bin bolts nut+washer	1	$ 82.00	$ 82.00
dial thermometer	1	$ 114.00	$ 114.00
static pressure gauge	1	$ 137.00	$ 137.00
furnas overload heater	2	$ 26.00	$ 52.00
premier 1ph 8"	1	$ 14,950.00	$ 14,950.00
tripod roof brace 8"x66"	1	$ 382.00	$ 382.00
total			$ 38,065.50

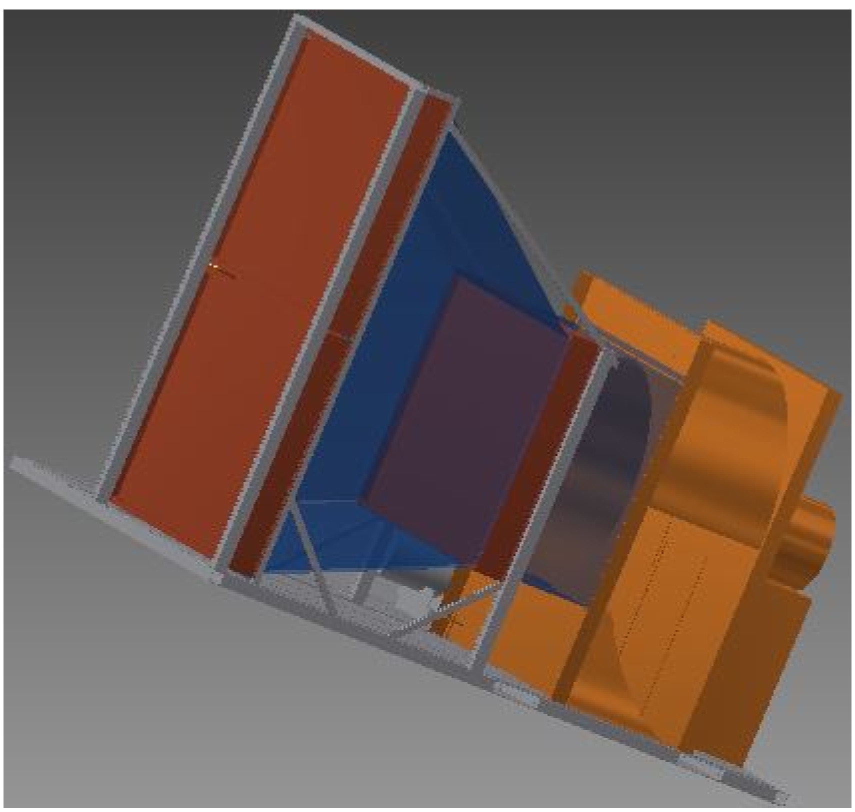
Sukup Bin	qty	price per 1	net
18-4 ring bin 44" door	1	xxx	
hawk cut floor and supports	1	xxx	
ladder inside and out	1	$ 5,590.00	$ 5,590.00
fasstir double auger	1	$ 2,995.00	$ 2,995.00
set of airways	1	$ 645.00	$ 645.00
spreader for 8"auger	1	$ 850.00	$ 850.00
concrete 18' bin 18" aboe ground	1	$ 2,200.00	$ 2,200.00
bin labor	1	$ 1,400.00	$ 1,400.00
fasstir labor	1	$ 775.00	$ 775.00
airways labor	1	$ 150.00	$ 150.00
spreader labor	1	$ 150.00	$ 150.00
bin freight	1	$ 200.00	$ 200.00
total parts		$ 12,280.00	
total labor		$ 2,675.00	
grand total bin		$ 14,955.00	

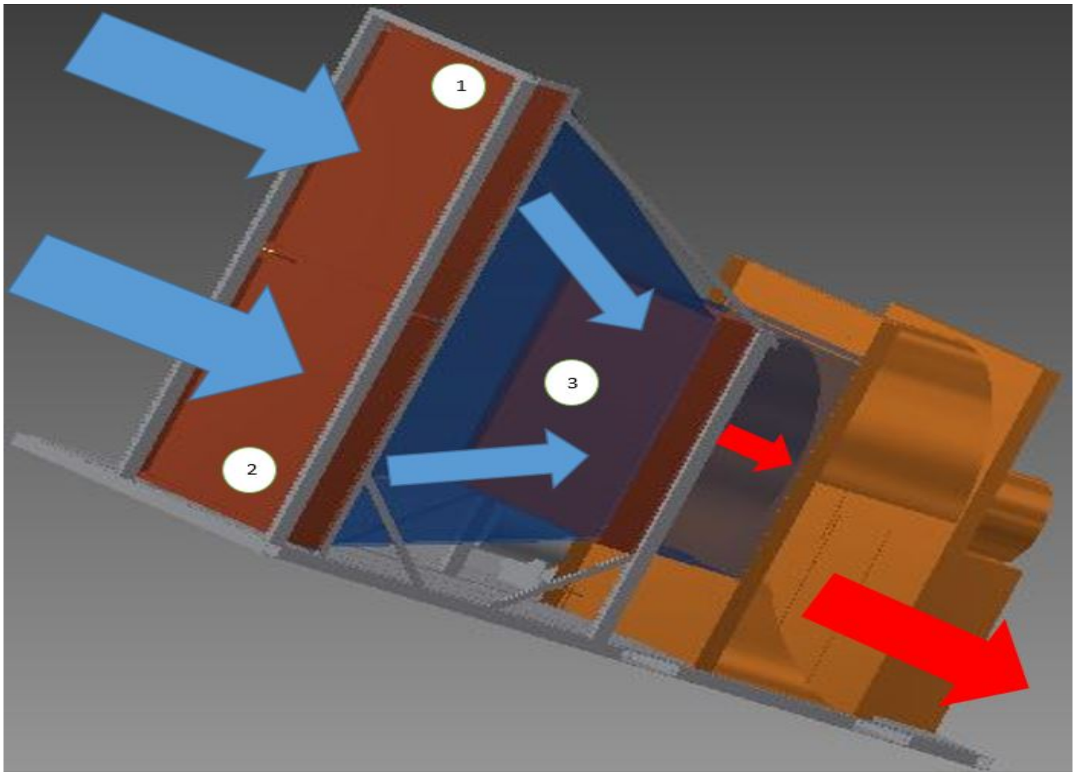
automation costs

(Automation will replace shivvers premier system)

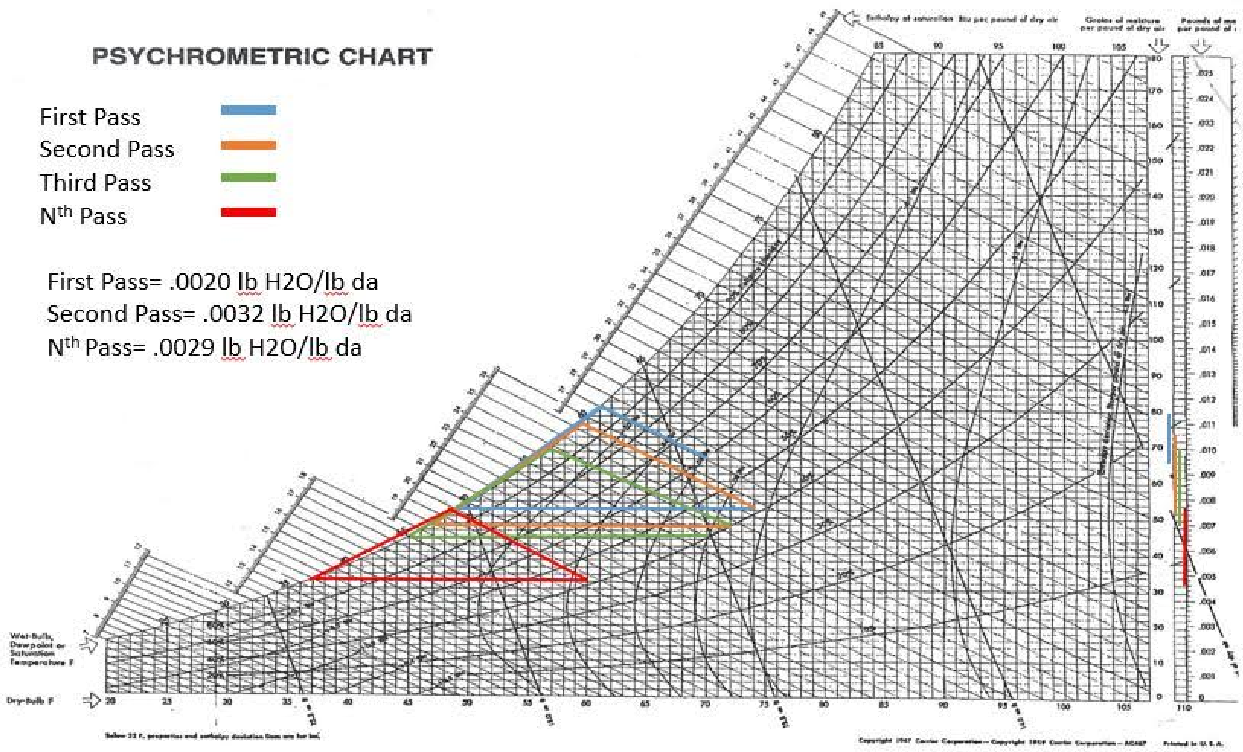
item	qty	price per 1	net
3ph 20hp AC drive (Teco Westinghouse) 230V	1	$ 848.00	$ 848.00
PLC with HMI Idec - KIT-FC6A-24-RC-HG1G	1	$ 679.00	$ 679.00
Additional HMI display for monitoring Delta DOP-W127B	1	$ 1,662.70	$ 1,662.70
real time moisture sensors Drier Master	6	$ 249.50	$ 1,497.00
Digital Thermometer Drier Master	8	$ 55.00	$ 440.00
Static Pressure Sensor Drier Master	3	$ 550.00	$ 1,650.00
Allotment for extra switches and wiring	1	$ 500.00	$ 500.00
	total		$ 7,276.70

Extended Graphical Abstracts




1
2
3

Psychrometric Chart for The System



Fan curves

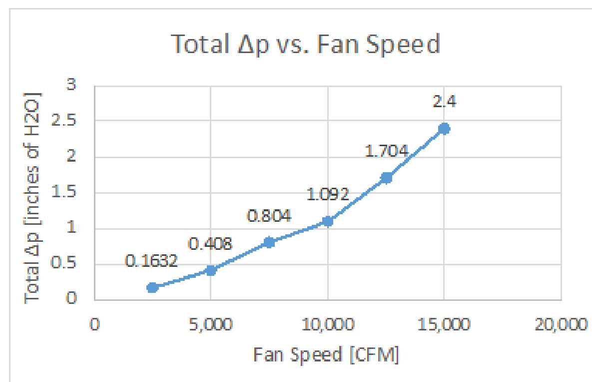
Dorothy II

Procedure:	Notes:
• Pick Q (cfm) value from Fan Curve.	1.245 [sq ft per bu]
• Calculate Q/A values. (Q = cfm, A = area of floor)	• 0.00 Values are found from Shedd's Curve
• Look up values from Shedd's Curve. (Δp/l, inches of water per ft)	• Pack Factor found from Table 8-1 in MGAH
• Correct Δp/l for Pack Factor.	Input Cells
• Multiply corrected Δp/l by heigth to get total Δp.	
• Plot Δp vs. Q on Fan Curve.	

Bin Radius	9.00	[ft]
Bin Heigth	3.00	[ft]
Area of floor	254.34	[sq ft]
Volume	763.02	[cu ft]
Volume	612.87	[bu]
Pack Factor	0.80	[multiplier]

Pack Factors: (found from Table 8-1 in MGAH)			
Moisture Content	Placement Method	Not auger stirred	Auger stirred
Dry	Gravity	0.86	0.76
Dry	Thrower type spreader	1.24	0.76
Wet	Gravity	0.80	0.60
Wet	Thrower type spreader	1.68	0.83

Q (cfm)	Q/A (cfm / sq ft)	Δp/l (in. H2O / ft)	Corrected Δp/l (in. H2O / ft)	Total Δp (in. H2O)
2,500	9.829	0.068	0.0544	0.1632
5,000	19.659	0.17	0.136	0.408
7,500	29.488	0.335	0.268	0.804
10,000	39.317	0.455	0.364	1.092
12,500	49.147	0.71	0.568	1.704
15,000	58.976	1	0.8	2.4
17,500	68.806		0	0



Airflow	20,000	[cfm]
Airflow	32.63	[cfm/bu]

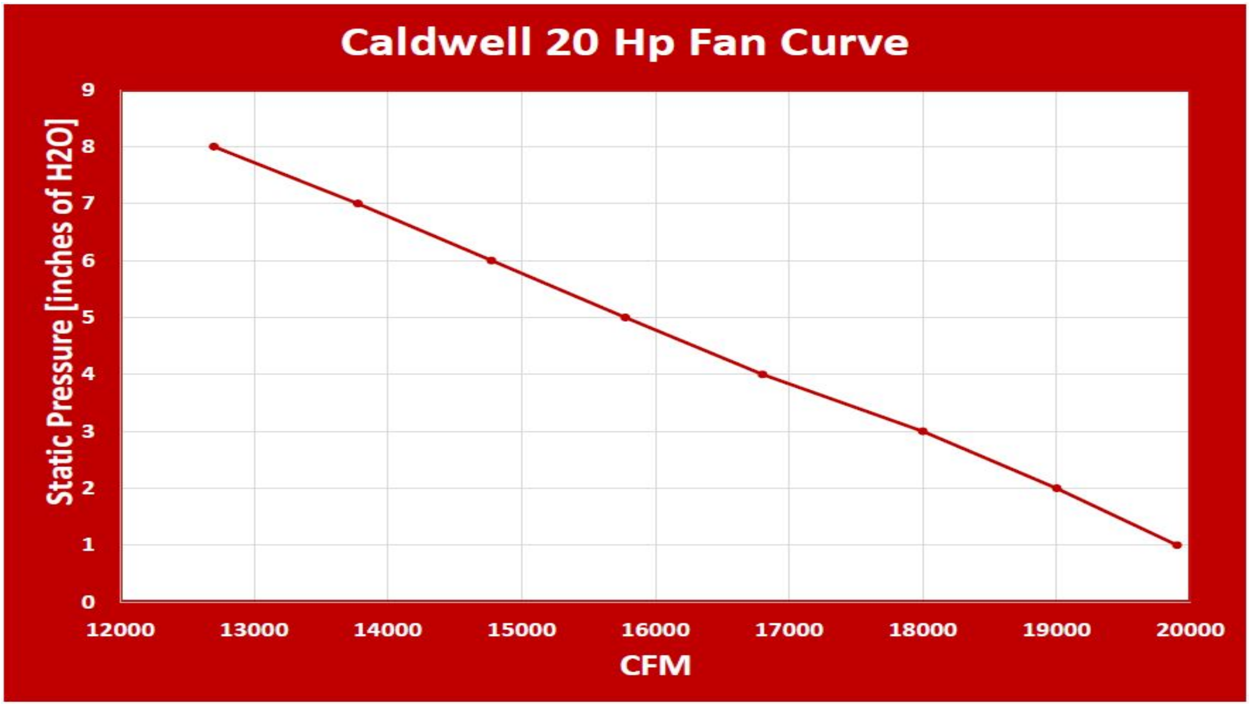
Data for Fan curve

fan guidelines

	rpm	cfm	static pressure		
	1750	19900	1		linear
	1750	19000	2		y=-1038.392857*x+21013.39286
	1750	18000	3		quadratic reg
	1750	16800	4		y=(-1.339285714*x^2)+(-1026.339286*x)+20993.30357
	1750	15775	5		
	1750	14775	6		
	1750	13775	7		
	1750	12700	8		
	1750	11667.8571	9		
	1750	10629.4643	10		
0	1750	9591.07143	11		
0	1750	8552.67857	12		
	1750	7514.28571	13		
	1750	6475.89286	14		
	1750	5437.5	15		
	1750	4399.10714	16		
	1750	3360.71429	17		
	1750	2322.32143	18		
	1750	1283.92857	19		
	1750	245.535714	20		

slopes	needed cfm		output rpm	FACTOR	CFM NEED
19900	5500	1	483.668342	27.64%	5500
9500	5500	2	506.578947	28.95%	
6000	5500	3	534.722222	30.56%	
4200	5500	4	572.916667	32.74%	
3155	5500	5	610.142631	34.87%	
2462.5	5500	6	651.43824	37.23%	
1967.85714	5500	7	698.729583	39.93%	
1587.5	5500	8	757.874016	43.31%	
1296.42857	5500	9	824.915825	47.14%	
1062.94643	5500	10	905.50189	51.74%	
871.915584	5500	11	1003.53752	57.35%	
712.723214	5500	12	1125.37843	64.31%	
578.021978	5500	13	1280.89354	73.19%	
462.563776	5500	14	1486.28154	84.93%	
362.5	5500	15	1770.11494	101.15%	
274.944196	5500	16	2187.94398	125.03%	
197.689076	5500	17	2863.9745	163.66%	
129.017857	5500	18	4144.55978	236.83%	
67.575188	5500	19	7496.52295	428.37%	
12.2767857	5500	20	39200	2240.00%	

Fan Curve


Caldwell 20 Hp Fan Curve
Static Pressure [inches of H2O]
9
8
7
6
5
4
3
2
1
0
12000
13000
14000
15000
16000
17000
18000
19000
20000
CFM

Power Consumption

starting torque
% rated
150%

starting current
%rated
450-800
650.00% low load
50 operational amps

FAN ONLY

SP	FACTOR	starting torque	operational amps	starting amps	voltage	starting wattage kW	operating wattage kW	WPD operating 24	hard load WPD 24	operating month 30	hard load month 30	energy cost $ 0.11	kWh operating 720	kWh hard load 720
1	27.64%	41.46%	13.81909548	89.82412060	230	20.65954774	3.178391960	76.28140704	495.8291457	2288.442211	14874.87437	$ 247.61	3.17839196	20.65954774
2	28.95%	43.42%	14.47368421	94.07894737	230	21.63815789	3.328947368	79.89473684	519.3157895	2396.842105	15579.47368	$ 259.34	3.328947368	21.63815789
3	30.56%	45.83%	15.27777778	99.30555556	230	22.84027778	3.513888889	84.33333333	548.1666667	2530	16445	$ 273.75	3.513888889	22.84027778
4	32.74%	49.11%	16.36904762	106.3988095	230	24.47172619	3.764880952	90.35714286	587.3214286	2710.714286	17619.64286	$ 293.30	3.764880952	24.47172619
5	34.87%	52.30%	17.43264659	113.3122029	230	26.06180666	4.009508716	96.22820919	625.4833597	2886.846276	18764.50079	$ 312.36	4.009508716	26.06180666
6	37.23%	55.84%	18.61252115	120.9813875	230	27.82571912	4.280879865	102.7411168	667.8172589	3082.233503	20034.51777	$ 333.50	4.280879865	27.82571912
7	39.93%	59.89%	19.96370236	129.7640653	230	29.84573503	4.591651543	110.199637	716.2976407	3305.989111	21488.92922	$ 357.71	4.591651543	29.84573503
8	43.33%	64.99%	21.65354331	140.7480315	230	32.37204724	4.980314961	119.5275591	776.9291339	3585.826772	23307.87402	$ 387.99	4.980314961	32.37204724
9	47.14%	70.71%	23.56902357	153.1986532	230	35.23569024	5.420875421	130.1010101	845.6565657	3903.030303	25369.69697	$ 422.31	5.420875421	35.23569024
10	51.74%	77.61%	25.87148257	168.1646367	230	38.67786644	5.950440991	142.8105838	928.2687946	4284.317514	27848.06384	$ 463.56	5.950440991	38.67786644
11	57.35%	86.02%	28.67250047	186.371253	230	42.8653882	6.594675107	158.2722026	1028.769317	4748.166077	30863.0795	$ 513.75	6.594675107	42.8653882
12	64.31%	96.46%	32.15366949	208.9988517	230	48.06973588	7.395343982	177.4882556	1153.673661	5324.647667	34610.20983	$ 576.13	7.395343982	48.06973588
13	73.19%	109.79%	36.59695817	237.8802281	230	54.71245247	8.41730038	202.0152091	1313.098859	6060.456274	39392.96578	$ 655.74	8.41730038	54.71245247
14	84.93%	127.40%	42.46518682	276.0237143	230	63.48545429	9.766992968	234.4078312	1523.650903	7032.234937	45709.52709	$ 760.89	9.766992968	63.48545429
15	101.15%	151.72%	50.57471264	328.7356322	230	75.6091954	11.63218391	279.1724138	1814.62069	8375.172414	54438.62069	$ 906.19	11.63218391	75.6091954
16	125.03%	187.54%	62.5126852	406.3324538	230	93.4564638	14.3779176	345.0700223	2242.955145	10352.10067	67288.65435	$ 1,120.10	14.3779176	93.4564638
17	163.66%	245.48%	81.82784272	531.8809777	230	122.3326249	18.82040383	451.6896918	2935.982997	13550.69075	88079.4899	$ 1,466.18	18.82040383	122.3326249
18	236.83%	355.25%	118.4159938	769.70396	230	177.0319108	27.23567859	653.656286	4248.765859	19609.68858	127462.9758	$ 2,121.77	27.23567859	177.0319108
19	428.37%	642.56%	214.18637	1392.211405	230	320.2086231	49.26286509	1182.308762	7685.006954	35469.26287	230550.2086	$ 3,837.77	49.26286509	320.2086231
20	2240.00%	3360.00%	1120	7280	230	1674.4	257.6	6182.4	40185.6	185472	1205568	$ 20,068.07	257.6	1674.4
		0.00%	0											
compressor use		0.00%	0											
75	100%	150.00%	75	487.5	230	112.125	17.25	414	2691	12420	80730	$ 1,343.84	17.25	112.125

Power usage

STATIC PRESSURE	FAN KWH	COMP KWH	TOTAL KWH	600 C
1	3.17839196	17.25	20.428392	800F
2	3.328947368	17.25	20.5789474	
3	3.513888889	17.25	20.7638889	
4	3.764880952	17.25	21.014881	
5	4.009508716	17.25	21.2595087	
6	4.280879865	17.25	21.5308799	
7	4.591651543	17.25	21.8416515	
8	4.980314961	17.25	22.230315	
9	5.420875421	17.25	22.6708754	
10	5.950440991	17.25	23.200441	
11	6.594675107	17.25	23.8446751	
12	7.395343982	17.25	24.645344	
13	8.41730038	17.25	25.6673004	

OLD FAN CFM	NEW SYSTEM CFM	RATIO		
574	6000	10.4529617	EFFICENCY TO OLD SYSTEM	7.82% MORE EFFICENT THAN OLD
			0.92184725	
OLD SYSTEM KWH	NEW SYSTEM KWH			
2.12	20.42839196	9.63603394		

Airflow through system