Natural Draft Cooling Tower Test Model & Performance Improvement Design

by

JASON LAINE

Submitted to the
MECHANICAL ENGINEERING TECHNOLOGY DEPARTMENT
In Partial Fulfillment of the
Requirements for the
Degree of

Bachelor of Science
In
MECHANICAL ENGINEERING TECHNOLOGY

at the

College of Applied Science
University of Cincinnati
May 2007

Signature of Author ______________________
Mechanical Engineering Technology

Certified by ______________________
Thomas Boronkay, PhD,
Thesis Advisor

Accepted by ______________________
Dr. Muthar Al-Ubaidi, Department Head
Mechanical Engineering Technology

Natural Draft Cooling Tower Test Model
Heat Load Improvement Design

Jason Laine

ABSTRACT

Power generation plants using a natural draft cooling tower are subject to a decrease in power production, and a loss of profits during hot summer months. In order to prevent this type of profit loss a test apparatus should be constructed to test alternatives to natural draft cooling. A specific idea that should be tested would utilize a system of fans to pull the exiting air out of the tower at a faster rate. These fans could run on solar power to reduce energy usage.

In light of this idea a survey was conducted to determine what the key factors in such an apparatus should include. Results from this survey were interpreted through the application of a Quality Functional Diagram. This diagram proved that the accuracy in the performance of the test apparatus was the most important factor, while the aesthetic appeal was the least important.

Once the key factors were determined, schedules and budgets were formed to allocate time and finances to complete the task of designing and constructing a test apparatus to simulate conditions in a functioning natural draft cooling tower. The overall cost of such a task was determined to be around $670.00. The time allocated to complete the project was a slightly over 4 months.

TABLE OF CONTENTS

PRELIMINARY ENGINEERING

Problem Statement & Background Research

During the summer months with high heat and humidity, the efficiency of a cooling tower significantly decreases. This forces power production stations to decrease output load, which reduces overall profit and could also possibly contribute to a blackout. There are two basic designs for cooling towers; natural draft and mechanical draft. Although, each design can be manipulated for different plants, the fundamental design is the same

A natural draft cooling tower is based on the concept that by the process of heating, the density of air decreases, which causes it to rise. The temperature difference that occurs within this process causes more air to flow into the tower at the air inlet. This ultimately produces a perpetual cycle that continues without the use of any mechanical application. The downfall to this system is that when the power production plant needs maximum output from the cooling tower, it is only capable of operating at minimum efficiency. When atmospheric temperatures are high, the temperature difference between the exiting air and incoming water is not significant enough to bring more air into the tower at the rate necessary for cooling. Another disadvantage to natural draft towers is that they are very large in size.

Mechanical draft towers use fans (one or more) to move large quantities of air through the tower. There are basically two different classes; forced draft and induced draft. In a typical forced draft cooling tower, the mechanical fan is located at the base of the tower. During operation, the fan forces air at a low velocity horizontally through the packing and then vertically against the downward flow of the water that occurs on either side of the fan.

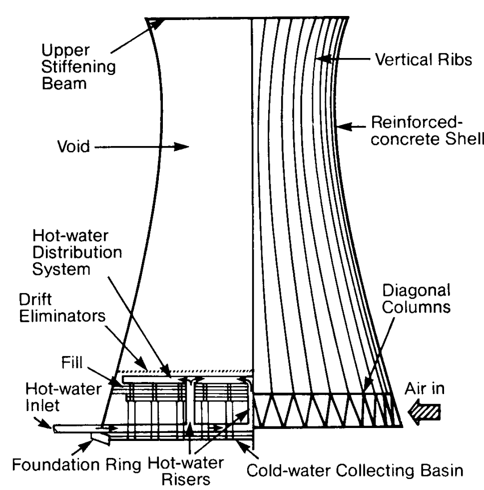


Figure 1.1: Breakdown of a Natural Draft Tower

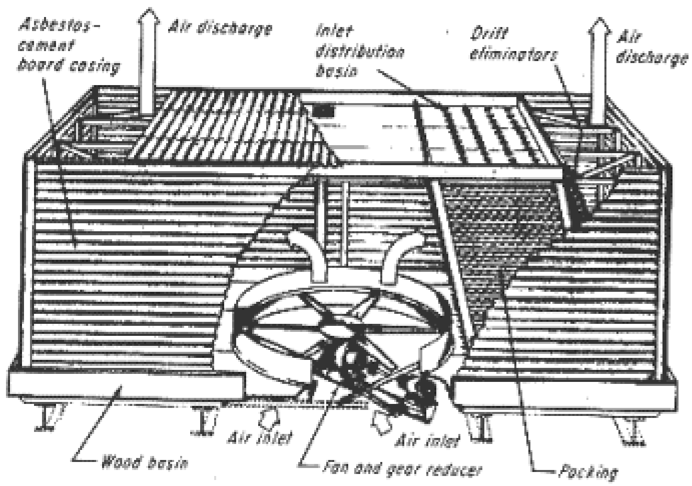


Fig. 1.2 Forced Draft Fan and Assembly

In a typical induced draft tower, the fan or fans are located at the top of the tower, where they draw air upwards against the downward flow of water.

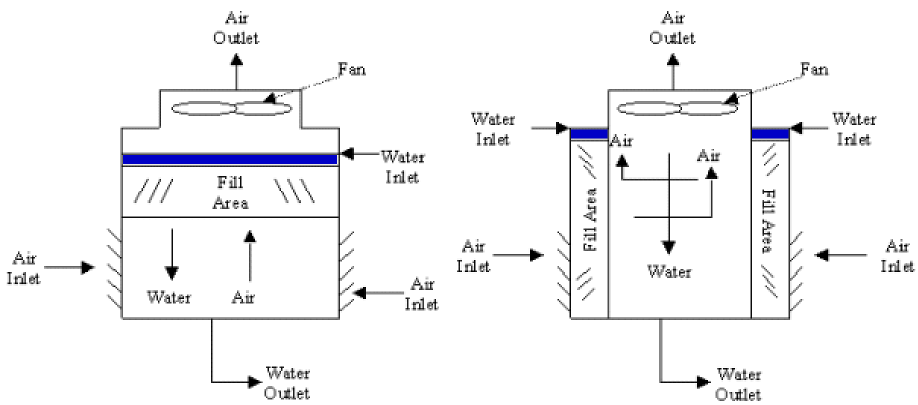


Fig 1.3 Induced Draft Fans

Since the airflow is counter to the water flow, the coolest water at the bottom is in contact with the driest air while the warmest water at the top is in contact with the moist air, resulting in increased heat transfer efficiency. Mechanical draft towers are typically smaller in size than natural draft towers, however the addition of the mechanical fans makes them less energy efficient, because it takes energy to run the fans. Mechanical draft towers are also incapable of handling high water flow rates.

The air flow in either mechanical draft system may be cross-flow or counter-flow with respect to the falling water. Cross-flow indicates that the airflow passes horizontally in the filled portion of the tower, while counter-flow means the air flow is in the opposite direction of the falling water. The counter-flow tower occupies less floor space than a cross-flow tower, but is typically taller for a given capacity. The principle advantages of the cross-flow tower are the low pressure drop in relation to its capacity and lower fan power requirement, ultimately leading to lower energy costs. All mechanical towers must be located so that the discharge air diffuses freely without recirculation through the tower, and so that air intakes are not restricted.

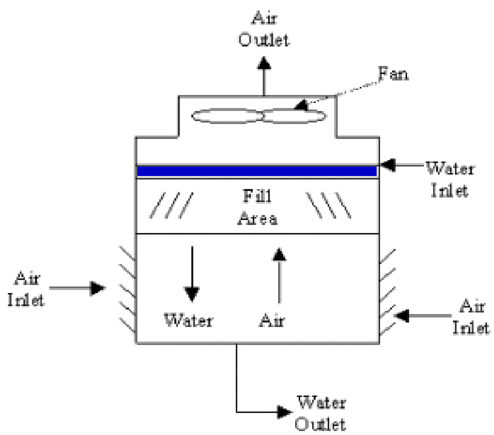


Figure 1.4: Mechanical Draft Counter-flow Tower

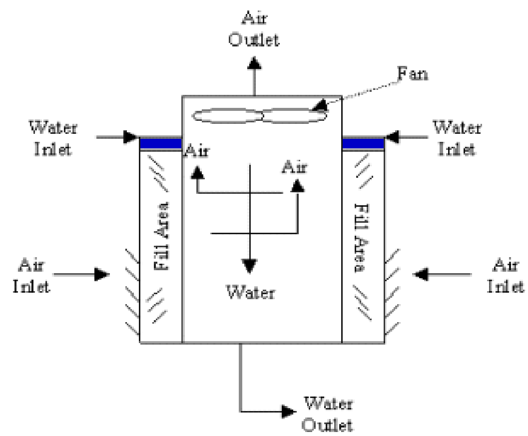


Figure 1.5: Mechanical Draft Cross-flow Tower

When considering the construction of a cooling tower, the primary objective is to maximize the cooling load. There are several advantages of using a typical natural draft or mechanical draft tower based on the plant requirements. However, as we discovered, there are also several significant drawbacks.

Voice of the Customer

In order to determine if engineers in the industry would be interested in this product, and if they are what the features are they find to be the most important. In order to do this a survey was distributed to many different engineers and other people that work with the towers at Duke Energy. An example of the survey with the results can be found in Appendix B. The first question was to gauge the level of interest to ensure that this is a test device that would interest them. The average answer for the first question was a three which was expected because the cooling tower usually is not a worry for anybody until it is not operating correctly. The customer was then asked to rank five features on a scale of one to five where one is not important and five is very important. The first feature the customer ranked was the importance of the aesthetic accuracy of the model compared to the full scale version. We needed to know if the customer wanted the model to look exactly like the existing tower or if it was not a factor that concerned them. We found that the physical similarity between the model and full scale version was not something that most customers were concerned about. The next question asked them to rank the importance of the accuracy of the model to meet the same performance goals as the full scale tower. This was the number one most important factor that the engineers were concerned with. The third feature the customer ranked was the level of automation. We wanted to know if customers want this device to operate safely with no human supervision, or would they rather a human be responsible for the controls. The fourth factor was one of the concerns for this project and that is the mobility of the device. It was expected that the tower would be too large and bulky to easily maneuver around, so we were happy when we discovered that the mobility was not an important factor for our potential customers. The final feature ranked was the accuracy of the instrumentation which received an average rating of four. We know for sure that this is the second most important factor of this system, so it will be vitally important to include reliable data collection hardware and software, as well as accurate thermocouples. Next we wanted to know how often their plant must reduce load due to high circulating water temperatures. We found the average answer to be between two and three meaning that it doesn’t occur often but it is not a rare event either. Typically this happens when air is very hot and humid and power is needed the most to operate all the air conditioners. For the last question we wanted to know what kind of heat load increase would peak their attention and make them seriously think about the upgrade, and the average answer was 5% - 15%. We also left room at the bottom of the survey where the customer could make suggestions about other features they may want to see incorporated in to the design. The next goal was to generate product or engineering features that will meet the specifications developed from the customer survey.

Engineering Features

In developing an idea to increase the cooling capacity of a cooling tower, several objectives had to be considered. These objectives were discovered through surveying engineers and technicians at Duke Energy. This information was collected and then put into a weighted decision matrix to help determine appropriate concepts. The primary feature to consider was a low KV downstream. This is a representation of the amount of resistance to air flow that a fan would experience. Using induction fans in the place of force draft fans will allow a very low KV, because there is little air resistance above the tower fill. Another important consideration was the distribution of weight for a heat load improvement design. A cooling tower is made of concrete which has very little tensile strength. In order to add any application to the tower, weight has to be evenly distributed around the tower. This reduces any risk of a collapse of the tower itself. Also, as stated earlier, the added application must be capable of increasing cooling load by approximately 10% to be worthy of consideration. This means that the application had to increase air flow to a value of 47.78 CFM. Energy conservation is also a concern. In order to counter a significant loss in energy, solar energy will be utilized to assist in the powering of the heat load improvement design.

Project Objectives

The objective for the project is develop, build, and test a heat load improvement design that can be used to increase the cooling capacity of existing cooling towers. This improvement is capable of increasing the cooling capacity of a tower by 10%, without utilizing generated electricity as a primary energy source. Also the data collecting equipment proved very accurate, incorporating a data collection system that allows the user to manipulate the test data using well known software. Another objective was to make the system as automated as possible. Using an array of sensors the tower is constantly monitored and controlled by a computer so that water levels will always be safe. Data is collected automatically, and the necessary calculations are performed automatically. The system is also equipped with the capability of both a manual stop button, and computer controlled trip to avoid a situation that could damage the test device or cause a safety hazard.

PRODUCT DESIGN

Selected design & alternatives

The selected design involves incorporating a system of mechanical induction fans inside of a cooling tower that utilize solar energy for propulsion. These fans have been placed at a 55 degree angle in order to force air up and around the tower to the next fan in series. This was implemented to force more air out of the tower at a faster rate, which increases the cooling capacity of the tower itself. It also induces air into the middle of the tower where air is not typically available. Using induction fans instead of forced draft fans decreases the value of KV downstream. The fan orientation creates a vortex that pulls the air out of the tower instead of pushing it, which is much more efficient. The fan placement also evenly distributes the weight on the tower shell itself. This idea was tested using a model to prevent infringement on CTI Codes and also prevent unnecessary spending.

The primary focus of this experimentation was to utilize solar energy as the primary fuel source for the fans. The fans will only operate during hot days where the temperature difference between the inside and outside of the tower is minimal. This should work very well considering that during a hot day the solar panels will be capable of absorbing a large amount of solar energy. So although the hot temperatures are creating a problem for the natural draft tower, the sun is powering the fans that are used to compensate for this problem.

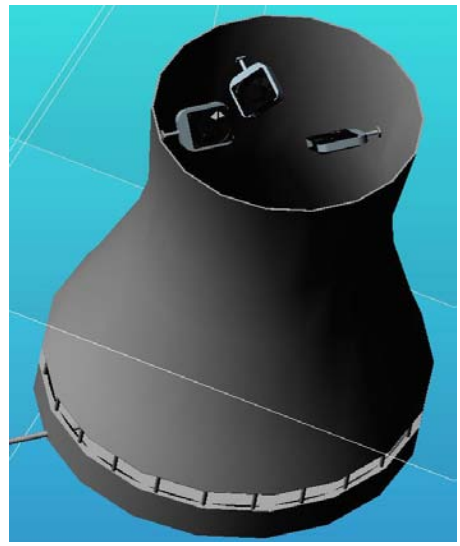
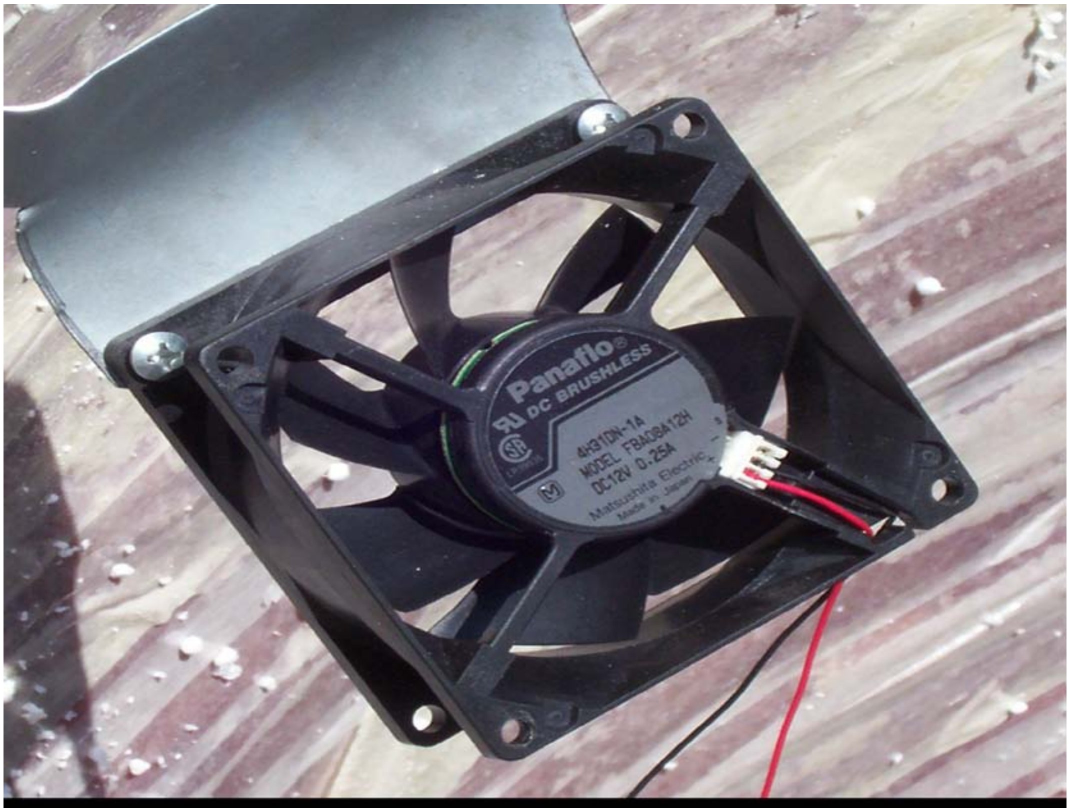


Figure 2: Cooling Tower Shell

The ideas that have been presented were intended to be used on existing natural draft cooling towers. However, if new towers were built utilizing these proposals, they could be built smaller. This could help decrease constructing costs and overall construction time. As stated earlier, all of these proposals were tested using a model to prevent unnecessary expenditures, and also make it easier to acquire data from testing. This particular model was designed by Brent Grimm and followed dimensions of the Zimmer Plant cooling tower.

Component Selection

Figure 3.1: Induction Fans 1

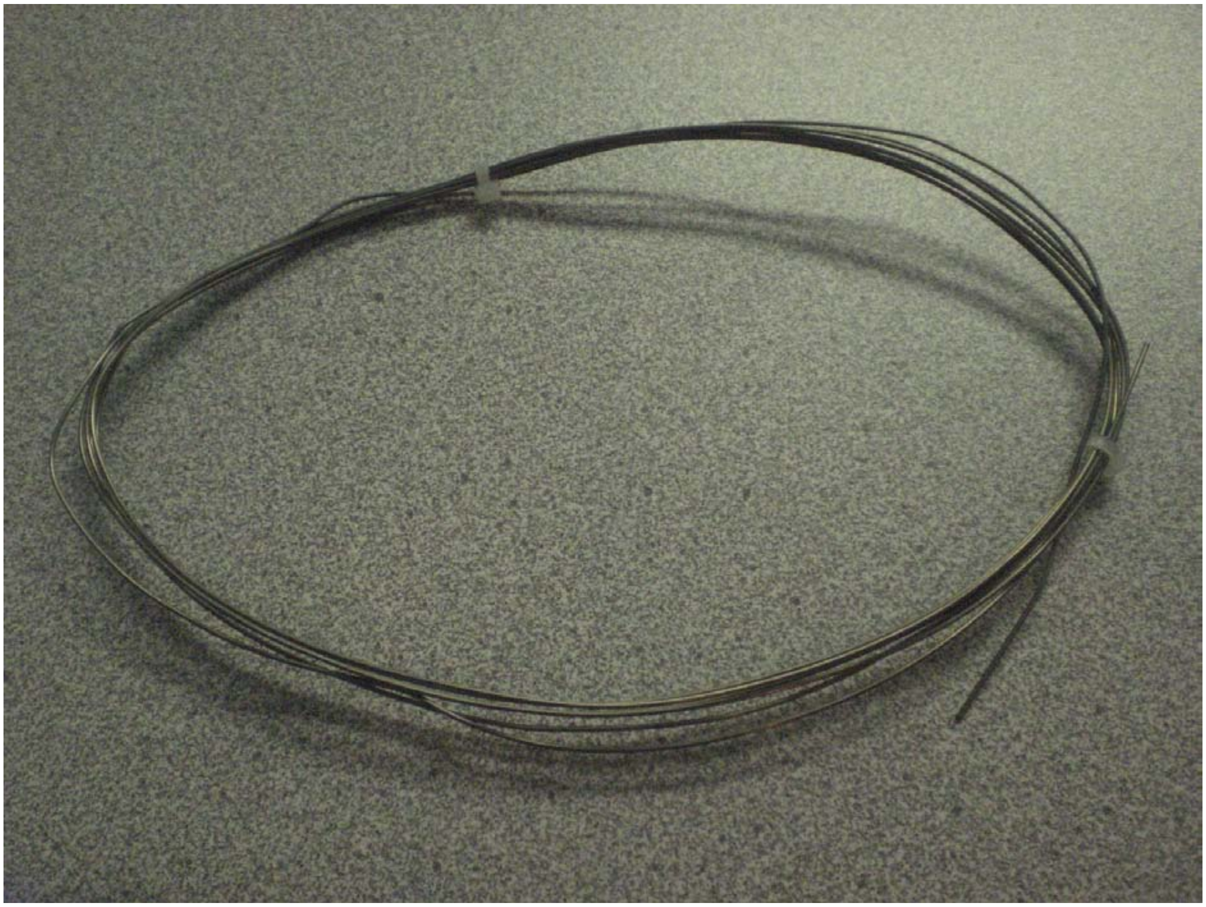


Induction Fans - The fans chosen to for the induction fan system were selected based upon their capacity to increase air flow. It was necessary for each fan to have the capability of producing 11.95 CFM as found in the design analysis. Each of the selected fans was capable of producing 15 CFM @.08 Amps. These fans were also very light weight and only 3" in diameter, which decreased the risk of threatening the structural integrity of the fiberglass tower.

Figure 3.2 USB I/O Module 1

USB I/O Module - The USB I/O module is used interpret the data from the thermocouples and forward the data to the computer. This module was chosen because it contains 8 differential thermocouple inputs, is capable of a sample rate of one sample per second on all eight channels, and includes software for calibration and data logging in Microsoft Excel.

Figure 3.3: Thermocouples



Thermocouples - The thermocouples that were used were donated by Duke Laine, and were all submersible type K instruments. They have an accuracy of ±.1% which met the specifications determined earlier using the customer survey.

Design Analysis

Calculations considering a 10% increase:

G = m_a = 185.9*10% = 18.59 lb/hr

$L = m_w$ = 231 lb/hr

L/G = $\frac{231 lb/hr}{18.59 lb/hr}$ = 12.43

$q_{air} = \frac{m_w}{L/G} = \frac{231 lb/hr}{12.43} * (\frac{1}{60*0.7096})$ = 4.37 btu/min*60min= 262.1 btu/hr

$q_{original_{air}} = 6238.8 + 262.1 = 6500.9 btu/hr$

$\Delta T_w = \frac{6500.9 btu/hr * 1 lb/btu}{231 lb/hr} = 28.14^o F$

$m_a = m_{original} + m_{fan} = 185.9 * 1.1 = 204.49$

$\Delta h_a = \frac{6500.9 btu/hr}{204.49 lb/hr} = 31.79 btu/hr$

$h_{a_{exit}} = h_{a_{inlet}} + \Delta h_a = 10.03 + 31.79 = 41.82 btu/lb$

$T = 78.25$ @ 100% *relative humidity*

$v = 14.02\, ft^3/lb$ @ 100% *relative humidity*

$14.02 * m_a = 14.02 * 204.49 = 2866.95\, ft^3/hr$

$\frac{2866.95}{60} = 47.78\ CFM$

$\frac{47.78}{4\ fans} = 11.95\ CFM/Fan$

Design Analysis

In order to achieve the projected 10% increase in cooling capacity, it was necessary to increase air flow by 47.78 CFM. Distributed between four fans the value for air flow increase is found to be 11.95 CFM per fan. The values in the calculations for the design analysis were derived from scaled values of an existing cooling tower.

PROOF OF DESIGN AGREEMENT

Mechanical Addition to a Natural Draft Cooling Tower Model

Through this agreement the objectives of the project and the methods in which those objectives have been addressed will be expressed. The objectives presented for this projected are intended to directly coincide with those of the completion of the natural draft cooling tower model proposed by Brent Grimm. The majority of this projects focus is to design and build a mechanical addition to increase the cooling capacity of a natural draft cooling tower. This addition will be installed inside of the natural draft cooling tower model, and it will consist of a series of fans oriented appropriately. Results utilizing this mechanical addition will be tested, and these results will be compared to those of the model without a mechanical addition.

Safety

1. Each fan will be mounted inside of a plastic casing that will prevent any objects or extremities from coming in contact with the fan blades.
2. The system will be monitored by a computer that will shut down the system if a malfunction or emergency occurs.
3. An emergency stop button will be located on the control panel that will cut power to all components.

Level of automation

1. Temperature sensors will be utilized in order to allow the temperatures to be monitored constantly, once a certain temperature is reached the mechanical addition will automatically activate until desired cooling load requirements are met.
2. Data collecting devices will be connected to a laptop computer where all the data will be loaded in to Microsoft Excel.

Accuracy of the calculations

1. The performance test will be conducted as outlined in an industry standard code.
2. Data will constantly be recorded so that all temperature fluctuations can be monitored, and reduce the risk of operator error.
3. Devices used for collecting data will have an accuracy of at least .1%.
4. Calculations will be performed as the data is collected by the computer further reducing the possibility for operator error.

FABRICATION AND ASSEMBLY

Tower Shell Construction & Fan Installation

In order to create an accurate test model, a natural draft cooling tower shell had to be built to scale. This was done by first selecting an actual cooling tower and scaling it down to 1/100th of its actual size. This produced an overall height of 5ft and an overall diameter of 4ft for the test model. Once the size of the model was determined, it was necessary to obtain a Styrofoam mold fabricated to the predetermined dimensions. It was possible to obtain a mold of this magnitude through Knauff Insulation, however the contour of the tower would have to be shaped by hand. This was a very important step, because without an appropriate shape, the tower would not function properly when considering the Venturi effect created at the throat of the tower. It was then necessary to fiberglass over the Styrofoam mold and remove the mold from inside of the fiberglass structure. This had to be done by removing small sections of the Styrofoam from within the tower using a reciprocating saw. After the Styrofoam was removed it was necessary to create brackets for the fans and install them into the tower. The brackets were formed from 1/8" aluminum, and were fastened to the fans by two stainless steel screws for each fan. Each fan assembly was then installed on the tower using one stainless steel screw for each assembly. The final step was to wire all of the fans to a common power source which was plugged into the basin. It was possible to wire the fans together because the total amperage used by the four fans collectively was approximately .32 A. The total time that it took to complete the fabrication of the tower shell including installation of the fans was about 5 weeks.

Figure 4.1: Styrofoam

Figure 2.2: Removal of Styrofoam from tower shell

Figure 4.3: Finished Tower Shell

CONCLUSION

The results from our test model proved very positive. The initial test using the test model was performed to determine a base performance curve for the system. This information was compared to that of an actual tower to determine if the model was functioning properly. This information is presented in Figure 5.1, and shows that there is only a deviation of about 5% between the test model and an actual tower. This falls in the allowable range that was determined to be about 10%. Once these series of values were determined the test model was ran again utilizing the induction fans. As shown in the graph in Figure 5.2, utilizing the induction fans produced an average of a 1.5 ^{o}F temperature drop, which is a very significant improvement to scale. This proves that in increasing air flow with the utilization of induction fans it is possible to increase the overall cooling capacity of a cooling tower.

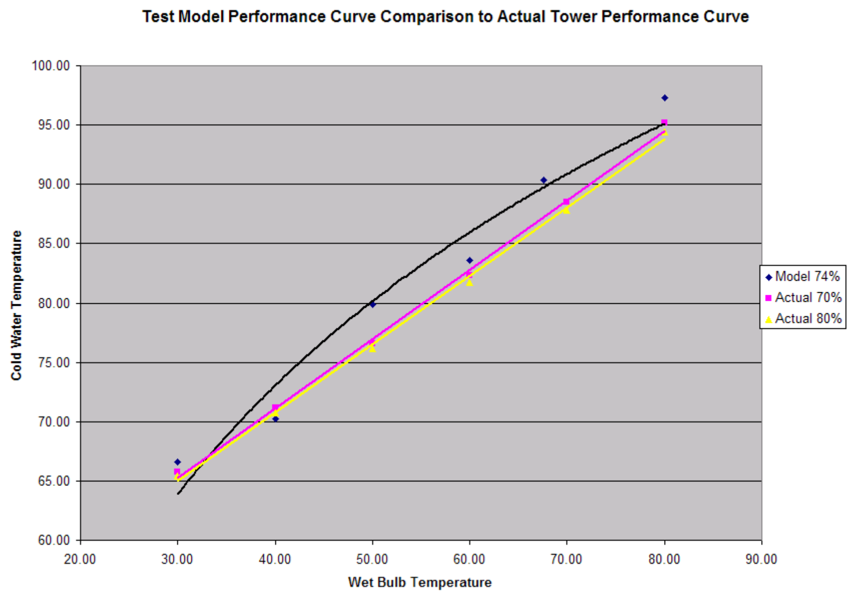


Figure 5.1: Base Performance Curve

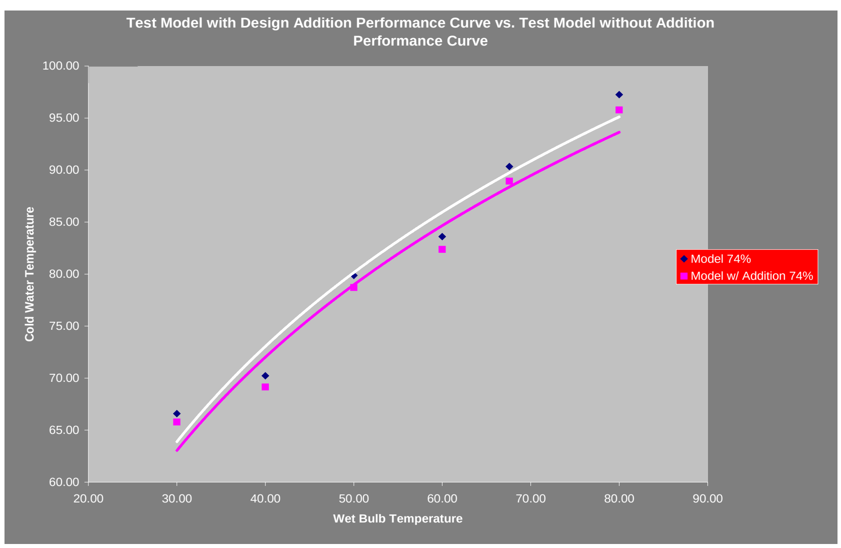


Figure 5.2: Heat Load Improvement

REFERENCES

Johnson, B M. Cooling Tower Performance Prediction and Improvement. 1st ed. Vol. 1. Richland, Washington: Batelle-Pacific Northwest Laboratories, 1998. 1-102.

Johnson, B M. Cooling Tower Performance Prediction and Improvement. 1st ed. Vol. 2. Richland, Washington: Batelle-Pacific Northwest Laboratories, 1998. 1-102.

ENGINEERING DRAWINGS

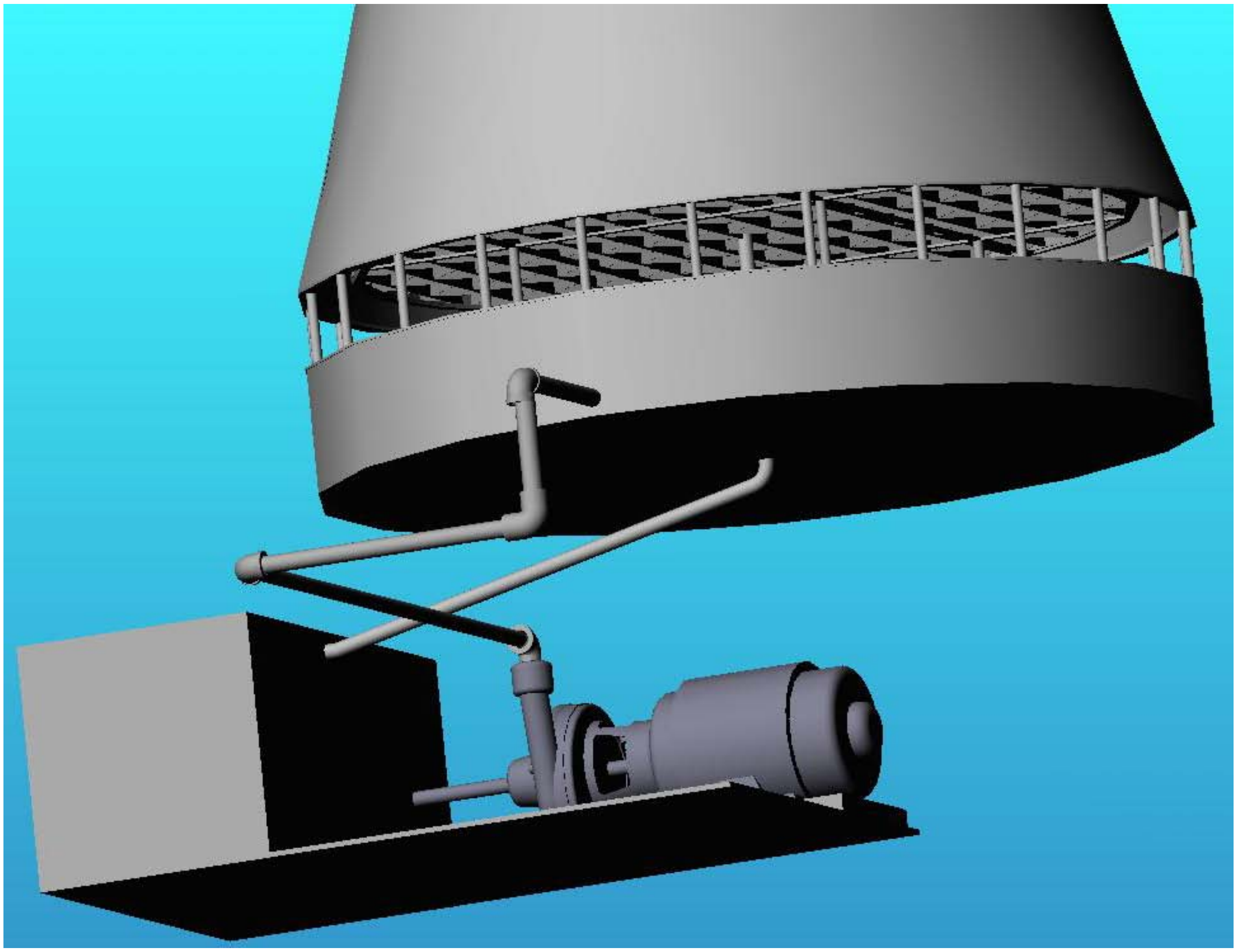


Figure 6.1: Tower including Pump & Basin

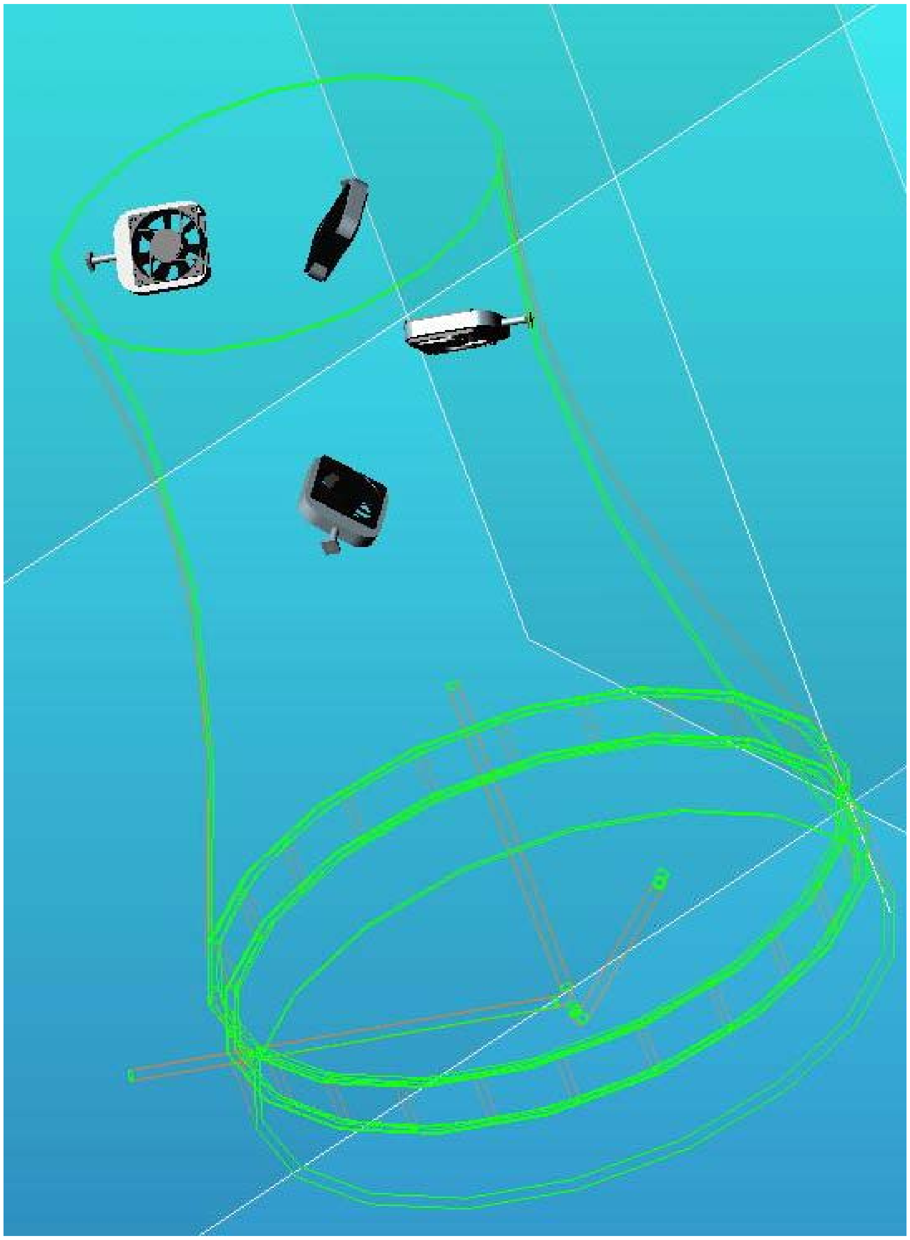


Figure 6.2: Inside View of Tower w/ Fans

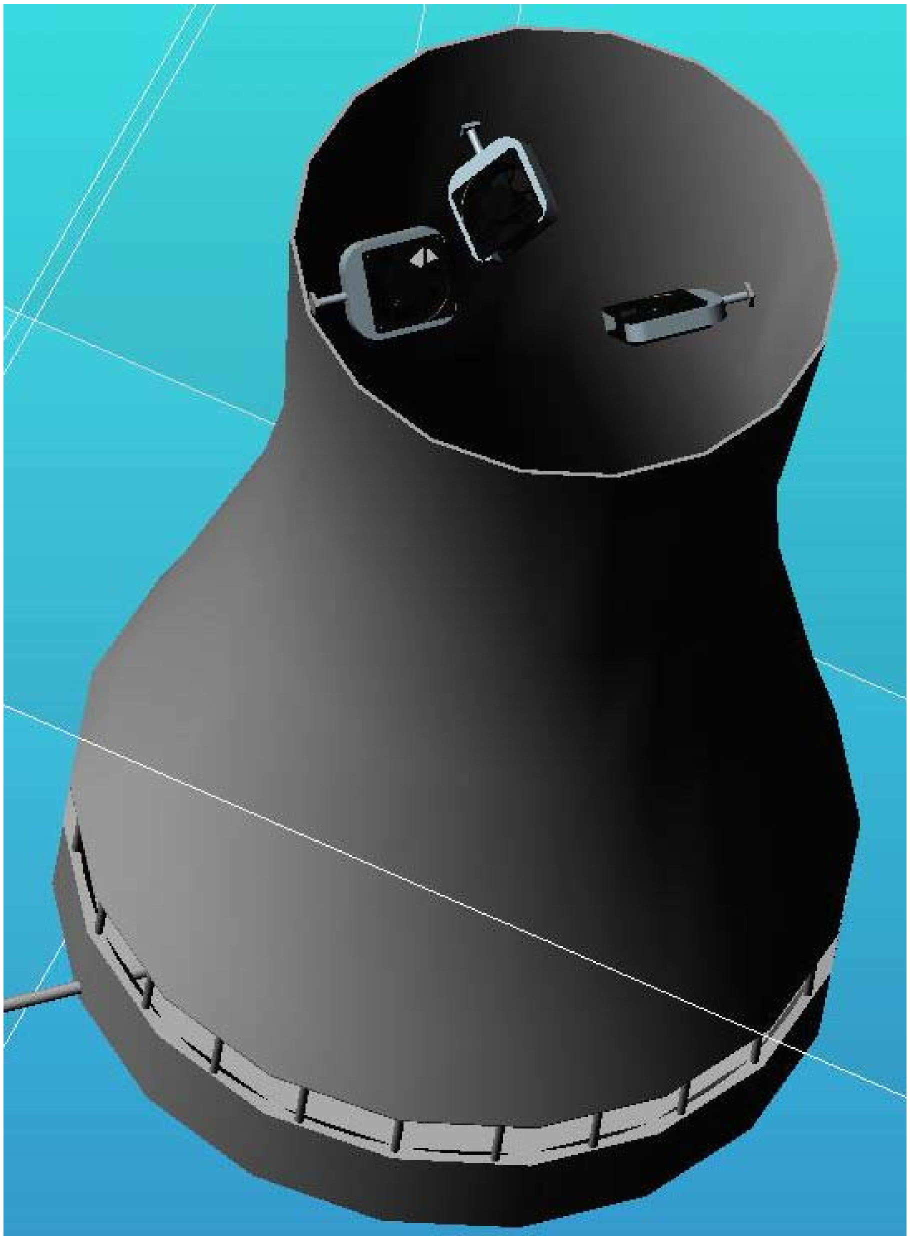
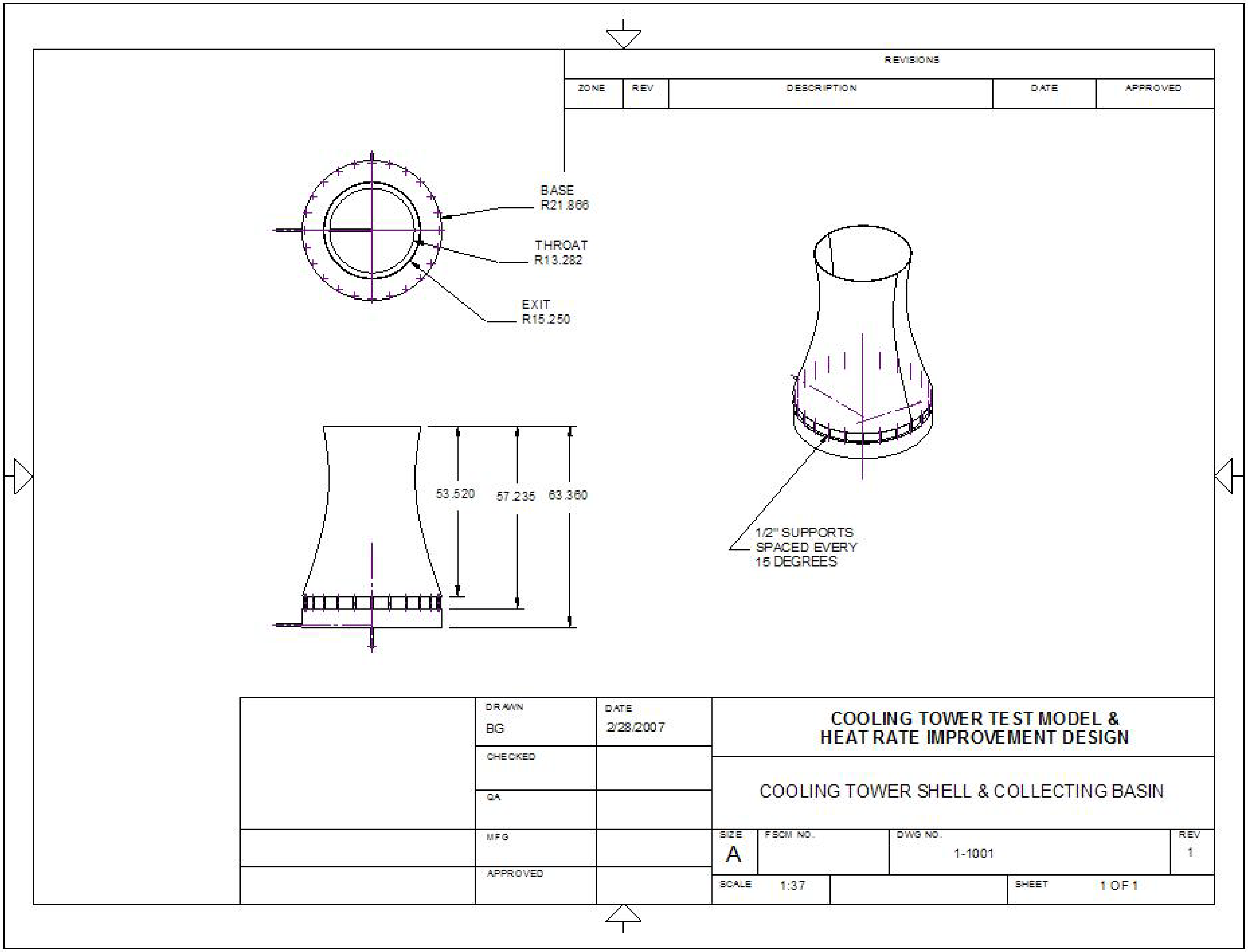
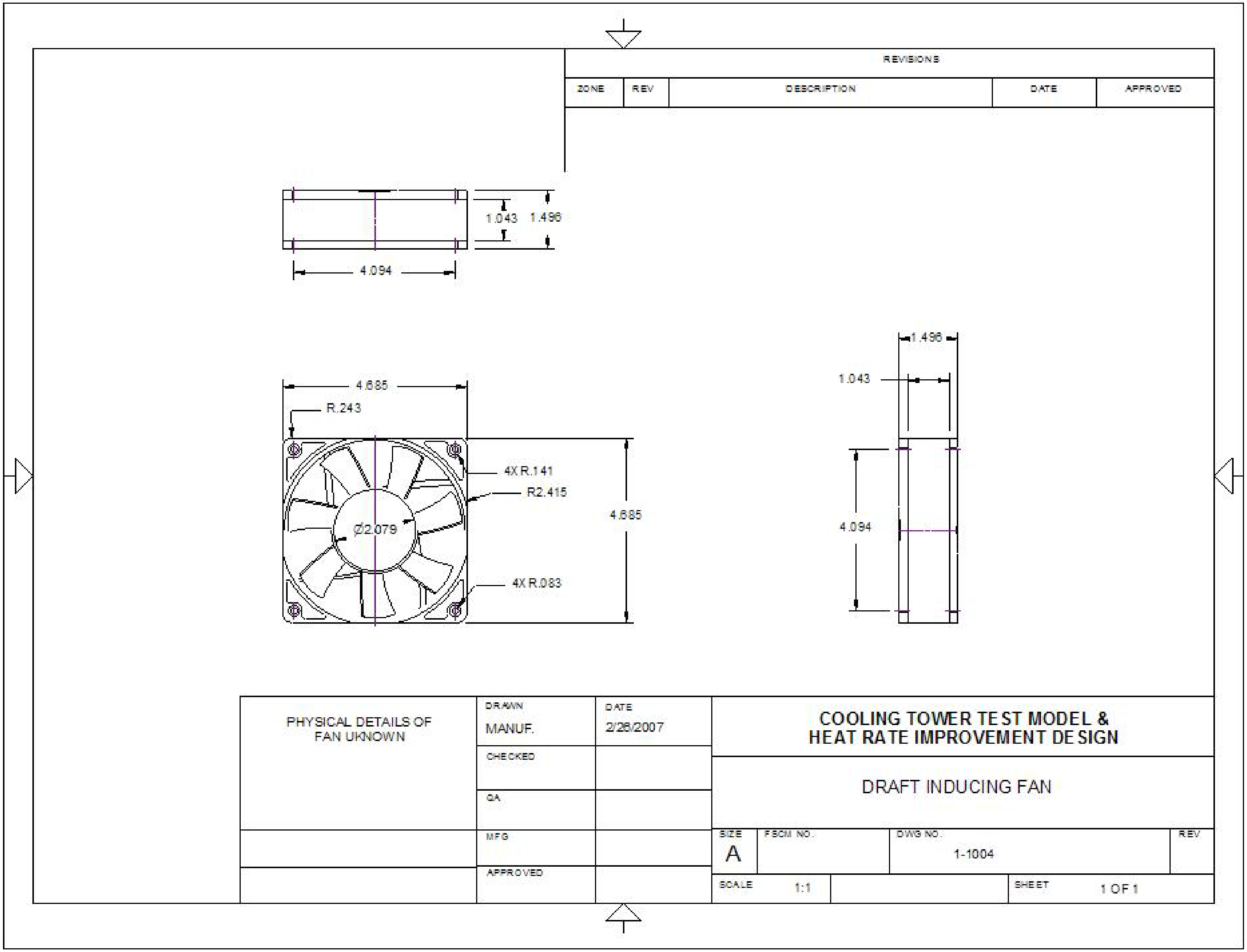


Figure 6.3: Complete Assembly


REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
BASE
R21.866
THROAT
R13.282
EXIT
R15.250
53.520
57.235
63.360
1/2" SUPPORTS
SPACED EVERY
15 DEGREES
DRAWN
BG
DATE
2/28/2007
CHECKED
QA
MFG
APPROVED
COOLING TOWER TEST MODEL &
HEAT RATE IMPROVEMENT DESIGN
COOLING TOWER SHELL & COLLECTING BASIN
SIZE
A
FSCM NO.
DWG NO.
1-1001
REV
1
SCALE
1:37
SHEET
1 OF 1

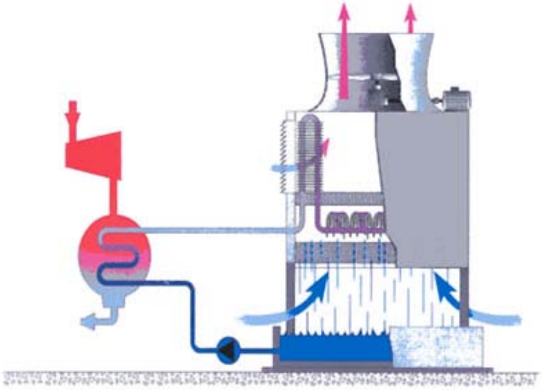

REVISIONS
ZONE
REV
DESCRIPTION
DATE
APPROVED
1.043
1.496
4.094
4.685
R.243
4X R.141
R2.415
Ø2.079
4X R.083
4.685
1.496
1.043
4.094
PHYSICAL DETAILS OF FAN UKNOWN
DRAWN
MANUF.
DATE
2/26/2007
CHECKED
QA
MFG
APPROVED
COOLING TOWER TEST MODEL &
HEAT RATE IMPROVEMENT DESIGN
DRAFT INDUCING FAN
SIZE
A
FSCM NO.
DWG NO.
1-1004
REV
SCALE
1:1
SHEET
1 OF 1

APPENDIX A - RESEARCH

Circular Fan Assisted Natural Draft Cooling Tower. This tower uses the similar idea of combining the natural draft with fans used to assist the movement of the air. The fans are on the air inlet and are built in to the cooling tower upon construction. This type of system could not be fitted on to an existing tower, it must be the original plan or the existing tower must be demolished and replaced. The tower must have the fans on at all time during operation, which means power must be supplied at all times in order to run the fans. The tower is much smaller than a typical natural draft tower because it utilizes the fans, instead of relying on the natural draft to move the air over the water. By placing the fans on the air inlet of the cooling tower the fans are trying to force air through the tower rather than pulling the air through the fill.

BDT Engineering, "Circular Tower Fan Assisted Natural Draft", [Online Document] Copyright 2006, [Cited 10/2/2006], Available HTTP:
http://www.poweronline.com/content/productshowcase/product.asp?docid=baaf74c2-afa2-11d4-8c75-009027de0829

Plume Abated Towers is a cooling tower designed to eliminate the plume typically associated with a natural draft cooling tower. The tower does not eliminate the amount of water lost to evaporation; it just hides it by mixing hot dry air near the discharge so that the air absorbs the excess moisture that creates the plume. This mainly addresses laws in certain areas that may prohibit a natural draft tower that creates a plume. This type of tower does utilize a large fan near the tower discharge that draws air through the fill similar to an induced draft mechanical draft tower. This type of system cannot be retrofitted to an existing tower, so unfortunately in order to utilize the design an existing tower would have to be demolished. The design requires a source of heat in order to create the hot dry air that will absorb the plume. If some source of waste heat could be utilized to heat the air then it would be efficient; however if extraction steam or some other type of non-waste heat were utilized this would make the tower even less efficient than either a mechanical draft, or natural draft tower.



GEA Power Cooling, "Wet Cooling - Plume Abated Towers", [Online Document], Copyright 2005, [Cited 10/2/2006], Available HTTP
http://www.geapcs.com/plume.php

APPENDIX B - CUSTOMER SURVEY

Cooling Tower Test Apparatus

Customer Survey

For a senior design project at the University of Cincinnati we are developing a working model of a natural draft cooling tower that will serve as a test apparatus. First baseline performance curves will be developed then we will install our designed upgrades to determine if the upgrades increased the cooling load. If you could please take a couple minutes to fill out our survey it would be greatly appreciated.

Would you be interested in a test apparatus that simulated the conditions in a natural draft cooling tower?
Circle One: 1 = Not Interested 5 = Very Interested

1	2	3	4	5

What features would be important to include in this type of test apparatus?
Circle One: 1 = Not Important 5 = Very Important

1 Aestetic Accuracy	1	2	3	4	5
2 Performance Accuracy	1	2	3	4	5
3 Level of Automation	1	2	3	4	5
4 Mobility of Test Apparatus	1	2	3	4	5
5 Accuracy of Instrumentation	1	2	3	4	5

How often does your plant experience periods of reduced output due to high cooling water temperatures?
Circle One: 1=Not Often 5 = Very Often

1	2	3	4	5

What level of cooling load increase would be necessary in order for your plant to consider purchasing and installing a cooling tower upgrade?
Circle One:

2.5 - 5%	5 - 15%	15 - 25%	25 - 50%	50 +%

If there are any other qualities you would like to see in such a product, please list them below.

Five professionals that work specifically with natural draft cooling towers were surveyed to determine the following results. Results show that the accuracy of the performance is the factor that is the most important, while aesthetic accuracy was found to be the least important.

APPENDIX B1 – CUSTOMER SURVEY RESULTS

Cooling Tower Test Apparatus

Customer Survey

For a senior design project at the University of Cincinnati we are developing a working model of a natural draft cooling tower that will serve as a test apparatus. First baseline performance curves will be developed then we will install our designed upgrades to determine if the upgrades increased the cooling load. If you could please take a couple minutes to fill out our survey it would be greatly appreciated.

Would you be interested in a test apparatus that simulated the conditions in a natural draft cooling tower?
Circle One: 1 = Not Interested 5 = Very Interested

Average Answer = 3

What features would be important to include in this type of test apparatus?
Circle One: 1 = Not Important 5 = Very Important

1 Aesthetic Accuracy → **Average Answer = 2**

2 Performance Accuracy → **Average Answer = 5**

3 Level of Automation → **Average Answer = 3**

4 Mobility of Test Apparatus → **Average Answer = 2**

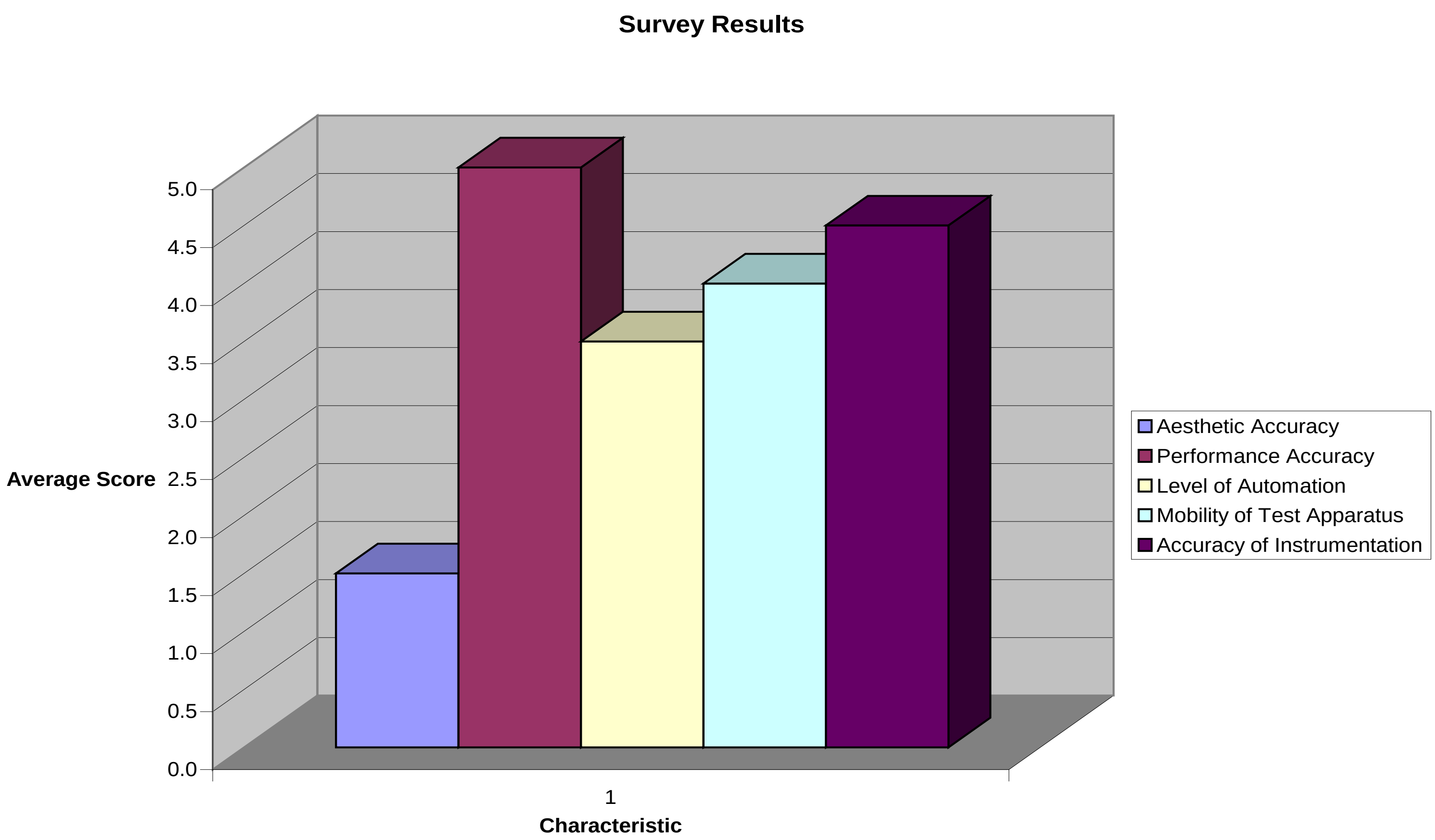
5 Accuracy of Instrumentation → **Average Answer = 4**

How often does your plant experience periods of reduced output due to high cooling water temperatures?
Circle One: 1=Not Often 5 = Very Often

Average Answer = 3

What level of cooling load increase would be necessary in order for your plant to consider purchasing and installing a cooling tower upgrade?
Circle One:

Average Answer = 5% – 15%


Survey Results
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Average Score
1
Characteristic
Aesthetic Accuracy
Performance Accuracy
Level of Automation
Mobility of Test Apparatus
Accuracy of Instrumentation

APPENDIX C – QFD & RESULTS

	Accuracy of Sensors	Water Flow Rate	Tower Dimensions	Temperature Drop	Number of Nozzles	Size of Piping	Fill Height	No. of air inlet temp. sensors	Discharge Pressure of Pump	Weight of System	Hours of Data Storage	No. of Solenoid Valves	Importance to Customers	Sales Point	Modified Importance	Weighted Importance
Aesthetic Accuracy			9			6	5						2	1.0	2	0.097
Performance Accuracy	9	7		9	5	6	7	8	6		4		5	1.5	7.5	0.362
Level of Automation	3							2			9	7	3	1.2	3.6	0.174
Mobility of Test Apparatus			3							9			2	1.0	2	0.097
Accuracy of Instrumentation	9							7			8		4	1.4	5.6	0.271
Absolute Importance	0.67	0.11	0.70	0.15	0.08	0.40	0.36	0.52	0.10	0.75	0.83	0.33				
Relative Importance	0.13	0.02	0.14	0.03	0.02	0.08	0.07	0.10	0.02	0.15	0.17	0.07				

APPENDIX D – WEIGHTED DECISION MATRIX & RESULTS

Weighted Decision Matrix	Wgt. Factor	Units	Tower Exit Induction Fans		Tower Base Force Draft Fans		Induction Fans in Series	
Design Criteria			Score	Rating	Score	Rating	Score	Rating
Heat Load Improvement								
Even Weight Distribution	0.25	compare	1	0.25	3	0.75	4	1
Low KV Downstream	0.3	compare	3	0.9	1	0.3	4	1.2
Low Cost of Installation	0.2	compare	1	0.2	4	0.8	3	0.6
Low Cost of Manufacture	0.1	compare	2	0.2	4	0.4	4	0.4
Low Cost of Service and Repair	0.15	compare	2	0.3	4	0.6	3	0.45
	1			1.85		2.85		3.65

APPENDIX E – SCHEDULE

Name: Laine

Cooling Tower Test Apparatus

Tasks	12/11-12/12	12/14-12/16	12/21-12-25	1/7-1/13	1/13-1/18	1/18-1/19	1/22-1/26	1/29-2/2	2/5-2/9	2/12-2/16	2/19-2/23	3/12-3/16	3/26-3/30	4/9-4/13	4/16-4/21	4/22-4/30	5/1-5/13	5/14-5/16	5/17-6/4
Weighted Objective Method																			
Verify Donation of Base Material																			
Design of Shell and Basin																			
Verify Donation of Basin Material																			
Design of Mechanical Addition																			
Verify Donation of Fan Components																			
Pick-up Fan Components																			
Design of Instrumentation																			
Verify Donation of Shell Mold																			
Verify Donation of Instrumentation																			
Design Freeze						19-Jan													
Present Oral Design Presentation (7 min)							24-Jan												
Design Touch up																			
Pick-up Shell Mold From Kanauf																			
Proof of Design Agreement																			
Pick-up MDF Board (Base Material)																			
Purchase Casters																			
Design Report Due												13-Mar							
Build Base with Casters																			
Build Shell and Basin																			
Install Instrumentation																			
Initial Testing																			
Base Performance Curve																			
Testing with Addition																			

Alterations to Addition																				
Final Testing																				
Tech Expo																			16-May	
Design Presentation																				24-May
Design Report Due																				4-Jun

*Base

*Shell

*Instrumentation

*Mechanical Addition

*Other

These schedules were set up to allocate enough time for months of product testing. This particular project involves extensive testing and manipulation to determine that the test apparatus will produce results that can be accurately compared to an actual cooling tower. Once accurate results are achieved, it will then be possible to apply proposed ideas to increase the maximum cooling load of the system. These ideas must then be tested to determine if they will in fact assist in maximizing the cooling load efficiency.

APPENDIX F - BUDGET

Budget
Cooling Tower Test Apparatus

Parts and Materials		Projected Cost ($)
1. Fiberglass Mat and Resin		20.00
2. Fans		Donation
3. Styrofoam Mold		Donation
4. Pumps		25.00
5. Pump Motors		75.00
6. Sensors		Donation
7. Switches		Donation
8. PVC Pipe		25.00
9. PVC Pipe Connectors		50.00
10. Copper Tubing		Donation
11. Copper Tube Fittings		Donation
12. Nozzles		25.00
13. MDF Board		Donation
14. Casters		20.00
15. Misc. Wiring		10.00
16. Misc. Hardware		20.00
17. USB I/O Module		400.00
17 Total Parts	**Total Cost**	**670.00**

Brent’s Budget for Cooling Tower Test Apparatus

Parts and Materials		Projected Cost ($)
1. Pumps		25.00
2. Pump Motors		75.00
3. Sensors		Donation
4. Switches		Donation
5. PVC Pipe		25.00
6. PVC Pipe Connectors		50.00
7. Copper Tubing		Donation
8. Copper Tube Fittings		Donation
9. Nozzles		25.00
10. USB I/O Module		400.00
10 Total Parts	**Total Cost**	**600.00**

Jason's Budget
Cooling Tower Test Apparatus

Parts and Materials		Projected Cost ($)
1. Fiberglass Mat and Resin		100.00
2. Fans		Donation
3. Styrofoam Mold		Donation
4. MDF Board		Donation
5. Casters		20.00
6. Misc. Wiring		10.00
7. Misc. Hardware		20.00
7 Total Parts	**Total Cost**	**150.00**

The budget was separated to allocate funds for each element of the product assembly. Brent's responsibilities required more expensive materials and supplies, however much of which was donated. Jason's responsibilities focused primarily on the fan assemblies. There were also several donations utilized in Jason's portion of the project. If funding is not received as planned it is understood that the group will have full responsibility over financing the project.

APPENDIX G – BILL OF MATERIALS

Bill of Materials

Item #	Description	Part Number	Quantity
1	Fiberglass Shell	1-1001	1
2	MDF Board w/ Plastic Lining	1-1002	1
3	3/4" PVC Pipe	1-1005	10'
4	3/4" PVC Elbows	1-1005	5
5	3/4" PVC Tee Fitting	1-1005	1
6	1/2" PVC Pipe	1-1005	2'
7	1/2" PVC Elbows	1-1005	4
8	1/2" PVC Tee Fittings	1-1005	2
9	2" Casters	1-1006	4
10	Corded Drill	1-1007	1
11	Drill Pump	1-1008	1
12	Misting Nozzles	1-1009	4
13	Heater Element	1-1010	1
14	Thermocouples	1-1011	8
15	USB I/O Module	1-1012	1
16	In-line Flow Meter	1-1013	1
17	Power Switch	1-1014	1
18	Fan Assembly	1-1015	4
19	Mounting Brackets	1-1016	4
20	Rheostat	1-1017	1
21	Misc. Wiring/Electrical	1-1018	
22	Misc. Connectors	1-1019	