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Senior Design Project Report

Design & Construction of a Pilot-Scale Cooling Tower

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team Members:

1- Ali Abdullah Ben Obaid 201100293
2- Salem H Al Salem 201100294
3- Hussain A Al Mubarak 200901660
4- Mohammed A Al Nemer 201100192

Supervised by: Dr. Esam Jassim

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Abstract

Cooling tower is a heat exchanger in which air and water are brought into direct or indirect contact in order to reduce the water's temperature. In this project a design of a pilot system that incorporates both a heat exchanger component and a cooling tower is constructed. A mathematical model for a counter-flow wet cooling tower is derived, which is based on one-dimensional heat and mass balance equations using the measured heat transfer coefficient. The balanced equations are solved to predict the temperature change of air and water, as well as the humidity. Experimental measurements on the pilot-scale cooling tower will be carried out in order to analyze the performance and study the comparison with the analytical model.

The experiment was conducted based on three cases. Case (1); conduct the experiment with both forced and induced fan in service. The results revealed a 4 to 5 degrees water temperature difference. Case (2), uses one fan only for forced draft fan. 3.5 to 4 degrees water temperature difference is achieved. In third case, Using only induced fan to move the air across the tower. 1.9 degrees difference is achieved. Incorporating both forced and induced draft fans have positive impact on cooling tower performance. They contributed in increasing the efficiency of the cooling tower by enabling more volume of air to pass through the tower and hence more heat will be dissipated. The zigzag water flow pattern has made the water movement to slow down and longer time of water exposure to air is achieved. Stainless steel fills have higher conductivity and this helped us in achieving as excellent results. Further discussion of the results is in section 4.3 of this paper.

Table of Contents

List of tables

List of figures

Chapter 1

Introduction

1.1 Project Definition

The project is mainly about designing of a pilot-scale cooling tower that uses different fill material and arrangement than the traditional ones. It is a proof of heat exchanger device where air and water are brought together in direct contact. The increase of surface area of the falling water will encounter the air coming in cross or counter-flow causing it to evaporate. As a result, the vapor will lower the temperature of the water. It is an effective method with relatively reasonable costs. The air entering the tower is either by a mechanical or natural draft. Different types of cooling towers are widely used in industries. The mass volume of water and the "free" ambient temperature make the amount of heat transfer to be high and hence satisfy the desire. The scarcity of water is the challenge when utilizing this type of heat exchanger in areas where water is scarce like the Eastern Province of Saudi Arabia.

1.2 Project Objectives

The objectives of this project are to:

1. Study the heat transfer effectiveness in cooling towers.
2. Increase the rate of heat transfer by changing the exchanger fills material and arrangements.
3. Minimize the water usage by having an insulated cooling tower frame.
4. Take advantage of combining both induced and forced draft fans in a cooling tower.
5. Show how a cooling tower can be realistically modeled.
6. Compare experimental and analytical data of the energy performance.

1.3 Project Specifications

These are the project's specifications:

a) Environmental friendly and cost effective.
b) Easy to implement with no complications.
c) A pilot-scale with light weight frame materials.
d) A 220V power source for the fans and the water pump.
e) Distilled water is used as the substance to be cooled and air as the cooling medium.
f) Galvanized with carbon steel frame structure.

1.4 Product Architecture and Components

Basic components that constitute a cooling tower are: the frame, drift eliminator, casing, exchange fill, cold water basin (sink), air inlet, fans and nozzles (spray distribution). (Krishna S. Vishwakarma, 2015)

Exchanger fill: this can be in both splash or film layer. Its function is to slow the motion of falling water and increase the contact area between water and air by spreading the water. It is made of stainless steel for better conductivity and corrosion resistance.

Cold water basin: It is the bottom sink of the cooling tower where it receives the cooled water. The accumulation of falling water is kept in the bottom basin then it is pumped to its application.

Drift eliminator: this eliminates the water droplets from going out the tower through the induced upper fan.

Air inlet: the air enters the tower from the air inlet fan (forced draft fan). This will allow the air to contact the water in counter-flow pattern.

Nozzles: nozzles are used in the cooling tower to spray the water and to wet the exchange fills.

Fans: These are used to forcedly draft the inlet air and to induce the exit air, too.

A typical counter flow cooling tower with its schematic diagram is shown in figures 1.1. The basic components of a cooling tower are indicated clearly in the figure. The diagram also explains the direction of the inlet and outlet air. The water comes in direct contact with the air in counter flow direction which then leads to the evaporation of small amount of water and hence cooling occurs.

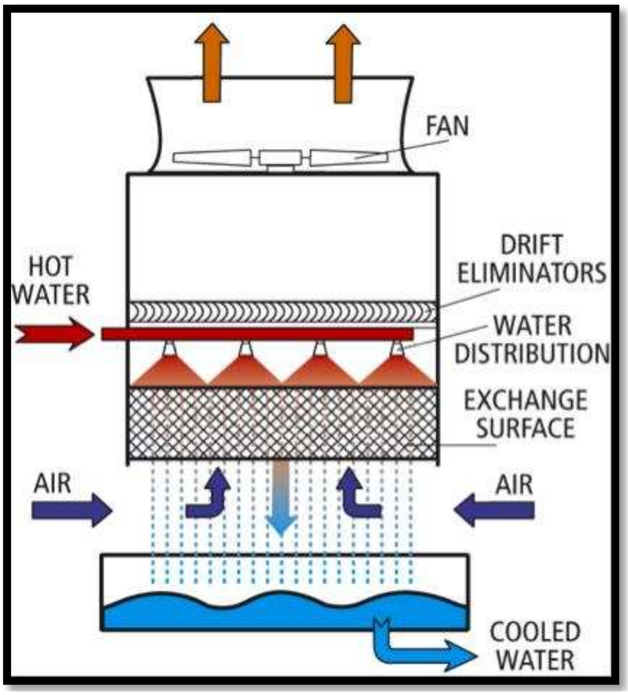


Figure 1.1 Counter-flow cooling tower

1.5 Applications

Cooling towers are used in many applications in both industrial and non-industrial facilities. The common application of cooling towers is in HVAC systems. They are also used for providing cooled water to power generation plants, manufacturing and the air conditioning systems (What is a cooling tower, 2012-2015).

According to Harrison Cooling Tower Pvt. Ltd. many different applications for cooling towers exist in Kuwait, UAE and Jordan. They use cooling towers in centrally A/C plants, pharmaceutical and laboratories, industrial refrigeration, process cooling, plastic industries, solvent extraction plants, chemical industries, metal & alloy industries, and textiles. See figures 1.2 &1.3. Moreover, they are also used in food and dairy industries. (Cooling Tower and its Industrial Applications, 2012)

Figure 1.2 A/C cooling tower


Figure 1.3 Electric power plant cooling tower

Chapter 2

Literature Review

2.1 Project Background

2.2 Previous Work

2.3 Comparative Study

2.1 Project background

Cooling towers are heat rejection devices where air and water are brought together in direct contact. This results in evaporation of small portion of water which will cause the water temperature to drop. The warm air is discharged from the tower to the atmosphere. The principle of evaporative cooling is inferred from that in human body's perspiration (sweat). As the body produces sweat it absorbs the heat to cool off your body (What is evaporative cooling, 2010).

Cooling towers have been employed since a long period of time in both industrial and non-industrial facilities. Starting in 1800, they were used in developing countries and then their usage was widely spread to be worldwide, (The Secret History of Cooling Towers, 2016).

Cooling towers are characterized by the pattern of air flow and movement. Some uses a fan to force the air in or induce the air out of the tower. These are called "mechanical draft towers". The other types get advantage of the natural draft of air in and out of the tower. Two common types of flow are counter and cross flow towers. In counter flow cooling towers air travels vertically from bottom to top, opposite to the falling water. Whereas in a cross flow tower, air moves horizontally crossing the water that comes from the fills (What is a cooling tower, 2012-2015)

With the limited resources, users of cooling towers are experiencing vulnerable challenges. Scale deposits in the fills (Figure 2.1) and the air flow that enters the cooling tower are some of the challenges that most industrial and non-industrial facilities encounter (G.Srinivasan, 2016). These challenges have been studied in the last decade. Different types of fill materials have been used to overcome the scale deposits phenomenon which significantly impacts the efficiency of heat transfer in cooling towers, (Buecker, 2015). Scale deposit can not only be a defect source in cooling towers, but it can also cause harm to the environment through the need of using excessive amount of make- up and blow down water.

Figure.2.1 Scale deposits in the fill (Buecker, 2015)

According to Shivaraman, most of fill materials in cooling towers are made of plastics and wooden films. This is because they provide greater heat transfer efficiency due to the lack of debris that may be built on the fill surfaces which can block the water passageway (Shivaraman, 2004).

2.2 Previous Work

Many studies have been conducted for a cooling tower to find the best ways to improve its efficiency. One of these studies is mainly about studying the cooling tower chemistry to improve its performance (Hasan, 2011). Report begins with content, showing that it studied the cooling tower in details. However, the target of this report is to show how we can improve the performance of cooling tower. The editor indicated that if lower approach (figure 2.2) is employed, cooling tower performance becomes better (Hasan, 2011).

$$CT\ Approach\ (^{\circ}C) = CW\ outlet\ temp\ (^{\circ}C) - Wet\ bulb\ temp\ (^{\circ}C)$$

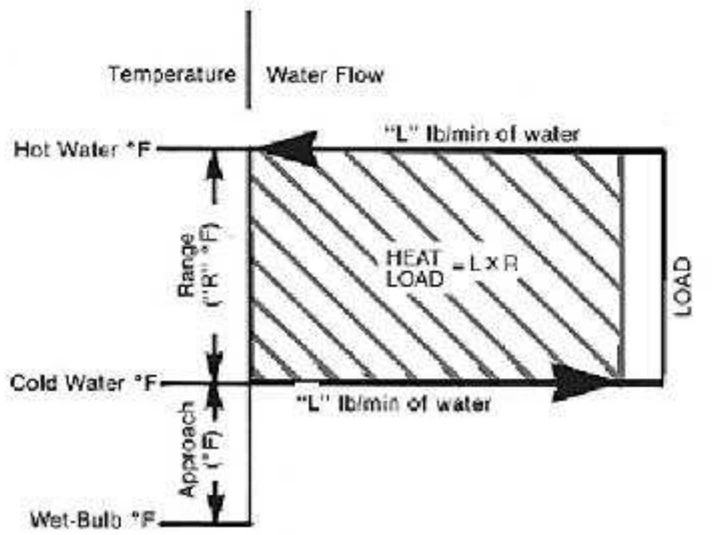


Figure 2.2 Range and approach schematic

The report mentioned ways to eliminate or control corrosion in the cooling tower parts. Using material that have passive layer like stainless steel is one way to prevent corrosion form. As a conclusion, the report recommends using stainless steel for the fill materials.

(Paolucci., 2002) analyzed the performance of a Cooling Tower. He formed a team to measure the temperature, relative humidity and velocity of the inlet and outlet of cooling tower in order to perform an analysis on the cooling produced. He uses several types of instruments to analyze the cooling towers properties (Paolucci, Cooling Tower Analysis, 2002). The four towers under study were:

- The Challenger Center cooling tower (CC)
- The Administrative Building cooling tower (AB)
- The Central Energy Plant (CEP-old) old cooling tower, and
- The Central Energy Plant (CEP-new) new cooling tower.

Both the AB and CEP are wet cooling towers while the CC is a dry cooling tower. The data that was recorded can be seen in Table 1 below.

Table 2.1 comparison of the four cooling tower (Paolucci., 2002)

	CC		AB		CEP Old		CEP New	
	INLET	OUTLET	INLET	OUTLET	INLET	OUTLET	INLET	OUTLET
Temp (°F)	82	97	89	86	98	81	98	85
RH (%)	70	44	53	88	7	60	7	53
Specific Volume (ft3/lb)	14.02	14.41	14.18	14.29	14.12	13.93	14.12	14.01
VFR (ft3/sec)	92		69		1418		725	
Capacity (tons)	**8**		**11**		**200**		**110**	

The conclusion that came out from this experiment is that dry cooling tower is not as efficient as the wet one. It also concluded that when the volumetric flow rate increases, the cooling capacity increases too. (Paolucci, Cooling Tower Analysis, 2002)

A recent study also showed that when airflow passes a wetted surface, there is a transfer of sensible and latent heat. If there is a difference in the partial pressure of water vapor in the air and that of the water, there will be a mass transfer. This transfer of mass causes a thermal energy transfer. This is because if some water is evaporated from the water layer, the latent heat of this vaporized water will be supplied to the air. The concept of enthalpy potential is a very useful one in quantifying the transfer of heat (sensible and latent) in those processes and components where there is a direct contact between the air and water. Heat transfer rate in the cooling tower is represented by the difference between the enthalpy of moist air at bulk water temperature and the enthalpy of the moist air. (Ramkumar Ramkrishnan, Experimental study of cooling tower performance using ceramic, 2013)

A study of water evaporation process was conducted by (Papaefthimiou VD, 2006). They work on developing a model to describe thermodynamically the water evaporation process inside a counter flow evaporative cooling tower. Schematic representation of energy contribution of cooling tower and air steam is shown in figure 2.3. The air from ambient is in direct contact with the falling water, they did their analysis based on the energy and mass balance between air and hot water. The water temperature, humidity ratio, and rate of change of air temperature along the cooling tower height were described. As per their results, the degree of saturation of inlet air affected the thermal performance of the cooling tower. They mentioned that the cooling capacity of the cooling tower increases with decreasing inlet air wet bulb temperature and the overall temperature of water fall is positively correlation with the increasing water to air mass ratio.

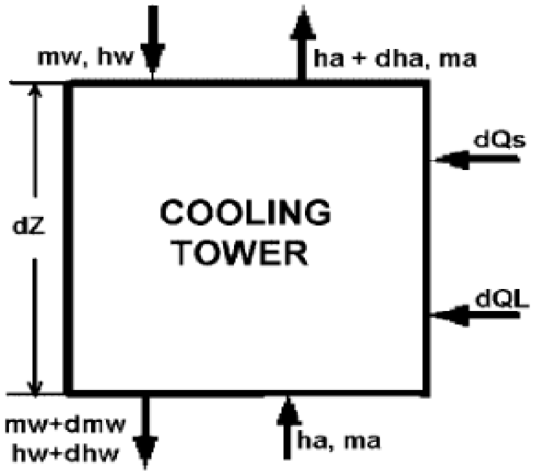


Figure 2.3 Representative schematic of energy contribution

Also, another study for the thermal effectiveness of the cooling tower was conducted by (Lemouari M, 2010). They studied the performance of a counter flow evaporative cooling tower by the heat rejected from the tower. They studied the effect of the flow rates of (air and water) .Also, the evaluate the inlet water temperatures on the thermal effectiveness of the cooling tower as well as the heat rejected by the tower from hot water to be cooled to the air discharged into the ambient. According to their results, the water to air mass flow rate ratio, as well as the inlet water temperature is very important to determine the performance of evaporative cooling towers.

Moreover, another study conducted by (Muangnoi T, 2007) who studied exergy. Exergy is the energy that is available to be used. After the system and surroundings reaches equilibrium. The exergy analysis used to investigate the performance of counter flow evaporative cooling tower. They write a mathematical equation related to heat and mass transfer principle. They proof the equation by experimental data analysis. According to the result, they showed that the lowest exergy destruction is located at the top of the tower.

Table 2.2 NTU_{Uncorr}. Equations for thermoplastic counter current wavy packing

Height (m)	Mass flow of air 0.07 kg/s	Mass flow of air 0.125 kg/s	Mass flow of air 0.18 kg/s
	Number of transfer unit without corrected end effect		
1.4	$NTU = 0.466\,(\dot{f}_w/\dot{f}_a)^{-0.551}$	$NTU = 0.485\,(\dot{f}_w/\dot{f}_a)^{-0.87}$	$NTU = 0.555\,(\dot{f}_w/\dot{f}_a)^{-0.47}$
1.05	$NTU = 0.422\,(\dot{f}_w/\dot{f}_a)^{-0.51}$	$NTU = 0.433\,(\dot{f}_w/\dot{f}_a)^{-0.84}$	$NTU = 0.549\,(\dot{f}_w/\dot{f}_a)^{-0.723}$
0.7	$NTU = 0.3891\,(\dot{f}_w/\dot{f}_a)^{-0..48}$	$NTU = 0.422(\dot{f}_w/\dot{f}_a)^{-0.79}$	$NTU = 0.491\,(\dot{f}_w/\dot{f}_a)^{-0.771}$
0.35	$NTU = 0.286\,(\dot{f}_w/\dot{f}_a)^{-0.44}$	$NTU = 0.317\,(\dot{f}_w/\dot{f}_a)^{-0.76}$	$NTU = 0.398\,(\dot{f}_w/\dot{f}_a)^{-0.58}$

An experimental investigation has been carried out on the counter flow-forced draft cooling tower. They made a model to optimize its performance and proposed using splash fills. The performance of the cooling tower using wire-mesh and splash fills (trays) was examined. The important performance parameters are considered for optimization with flow rates of water and air being taken as the design variables. Figure 2.4 shows the setup of cooling tower that used on the experiment. (Kuljeet Singh)

Figure 2.4 Forced draft cooling tower experimental setup (Kuljeet Singh)

This study reveals the different optimal operating points for various types of fills and out of these. As a result, the wire mesh type of fill has been found to be the most effectiveness fills operating under the study conditions. The conclusion that came out from this study that the proposed methodology is generalized and can be easily implemented to optimize the performance of any forced draft cooling tower with much larger temperature ranges. (Kuljeet Singh)

2.3 Comparative Study

A recent study conducted by (Bhupesh Kumar Yadav, 2015) was performed to compare analytical and experimental data of a cooling tower performance. The study revealed that the effectiveness (which is the ratio of range and the ideal range) of a designed model cooling tower is 52.94% (Bhupesh Kumar Yadav, 2015). Barile et al. studied the performance of a turbulent bed cooling tower. They found a correlation between water and air mass flow ratios.

Ceramic tile packing material (figure 2.5) was used as the exchange surface (fill material) in a model cooling tower. The experiment suggested that the ceramic fills provide a minimum restriction to the passage of the air (Ramkumar Ramkrishnan, 2013). It also showed that theoretical and experimental cooling tower effectiveness is within 5% error.

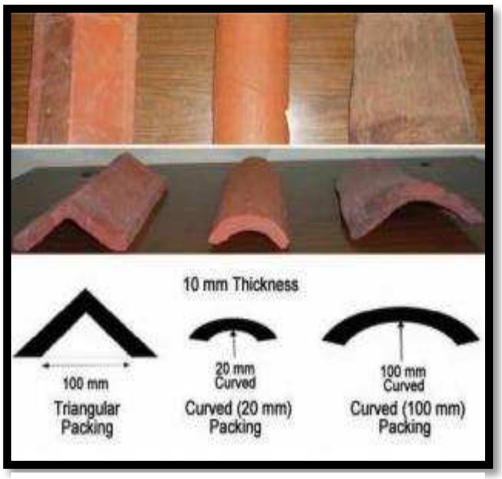


Figure.2.5 Ceramic tile packing (Ramkumar Ramkrishnan, 2013)

A report showed that the performance of a cooling tower depends on several parameters such as the range of cooling temperature, the inlet water temperature and the L\G variation ratio. At given operating conditions, the outlet water temperatures measure tower capabilities. The rate of increase in water temperature is quite small at low L\G ratios where G is the air mass flow rate, kg/s and L is water mass flow rate, kg/s (H. Marmouch, 2008).

The amount of heat exchange can be at higher rates if longer time (greater distance between fills) is employed, the longer contact time, the greater heat transfer (G.Srinivasan, 2016). This can be achieved by increasing the height of a cooling tower.

Chapter 3

System Design

3.1 Design Constraints

A Cooling tower is a heat transfer (exchanger) device that is used to discharge waste heat to the atmosphere. Designing & sizing such device are needed to determine the best type that fits the application requirements. To do so, some engineering standards and guidelines were used and reviewed to complete this project.

Several important factors need to be taken into consideration when designing a cooling tower. Our design factors are:

- The dry-bulb and wet-bulb temperatures of the air
- The temperature of warm water
- The efficiency of contact between air and water in terms of the volumetric mass transfer coefficient and the contact time between the air and the water
- The uniformity of distribution of the phases within the tower
- The air pressure drop
- The desired temperature of the cooled water

These factors are inferred from KLM Technology Group Engineering Design Guidelines.

By maintaining cooling towers with the engineering designed specifications, efficiency increases and life span increases too. This will positively impact the environment by saving energy resources. A 1C cooling water temperature increase may increase the A/C compressor electricity consumption by 2.7% and 1C drop in cooling water temperature can give a heat rate saving of 5 kCal/kWh in a thermal power plant, (KLM Technology Group).

Cooling tower sizing and selection should be carefully considered to meet the application requirements and operate with the designed range and efficiency. Different companies have been consulted for the optimum size that will achieve cooling of a minim 4 degrees Celsius. This was the target of this project. Table 3.1 is an example of readily designed towers with different operating requirements.

Table 3.1 Cooling tower capacity with different ambient temperatures

TTXL Model	Fan Power			Cooling Capacity at Indicated Operating Conditions GPM (m^3/hr)						
			HWT ℃ (℉)	26.67 (80)	29.44 (85)	32.22 (90)	33.33 (92)	35.00 (95)	41.67 (107)	44.44 (112)
	No. of Fans	Total Power kW	CWT ℃ (℉)	21.11 (70)	23.89 (75)	26.67 (80)	27.78 (82)	29.44 (85)	33.33 (92)	36.11 (97)
			WBT ℃ (℉)	15.56 (60)	18.33 (65)	21.11 (70)	23.89 (75)	25.56 (78)	26.67 (80)	32.22 (90)
i21929	2	5.8		**81.04** (357)	**93.78** (413)	**108.54** (478)	**88.70** (391)	**97.31** (428)	**130.50** (575)	**107.71** (474)
i21945	2	9.0		**100.73** (443)	**116.39** (512)	**134.50** (592)	**110.09** (485)	**120.67** (531)	**136.26** (600)	**133.52** (588)
i31929	3	8.7		**118.19** (520)	**136.73** (602)	**158.22** (697)	**129.28** (569)	**141.80** (624)	**190.22** (838)	**156.96** (691)

When the ambient temperature changed, the amount of cooled water changed as well. By looking over table 3.1, the optimum amount of water to be cooled in the range of hot water temperature of 41 corresponds to be approximately 575 m3/h.

Another company suggested a tool that has certain parameters from which you select the cooling tower size and design. Figure 3.1 shows a proposed size by Aggreko Cooling Tower Rental.

Figure 3.1 Cooling tower sizing tool

TTXL Factory has the below cooling tower specifications that corresponds to a temperature of 40° C for the warm water and wet bulb of 22° C. Figure 3.2 shows a suggested size with the following specifications:

Specifications		
	Metric	English
Nom. Dimensions (shell WxL)	213.4 cm x 411.5 cm	7'-00 x 13'-06"
No. Fans/Motors	2	2
Motors (total)	5.8 kW	8.0 hp
Inlet Dia.	One VanStone 6"	One VanStone 6"
Nominal Flow (35°C HWT/29.4°C CWT/25.6°C WBT) (95°F HWT/85°F CWT/78°F WBT)	118.0 m³/h	518 gpm
Minimum Flow	45.4 m³/h	200 gpm
Maximum Flow	136.0 m³/h	600 gpm
Shipping Weight	2,379 Kg	5,245 lb.
Operating Weight	4,360 Kg	9,609 lb.
Basin Capacity	2,025.2 L	535 gallons

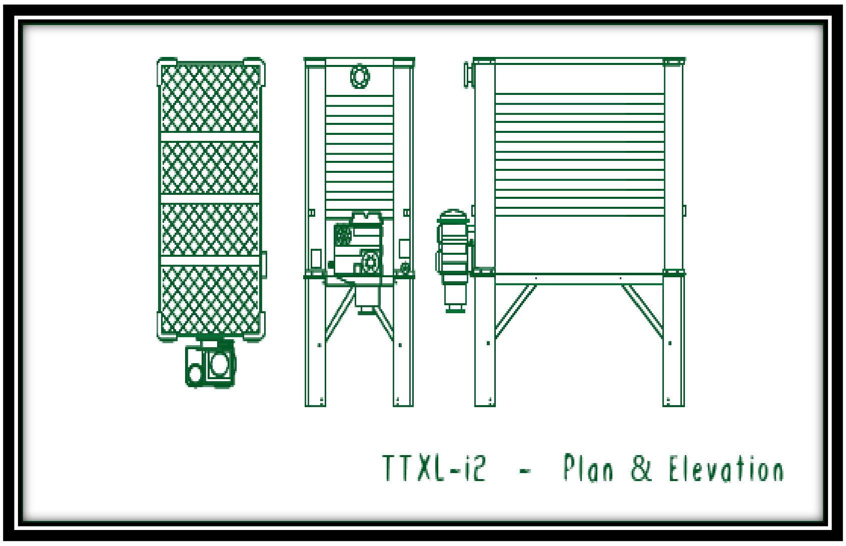
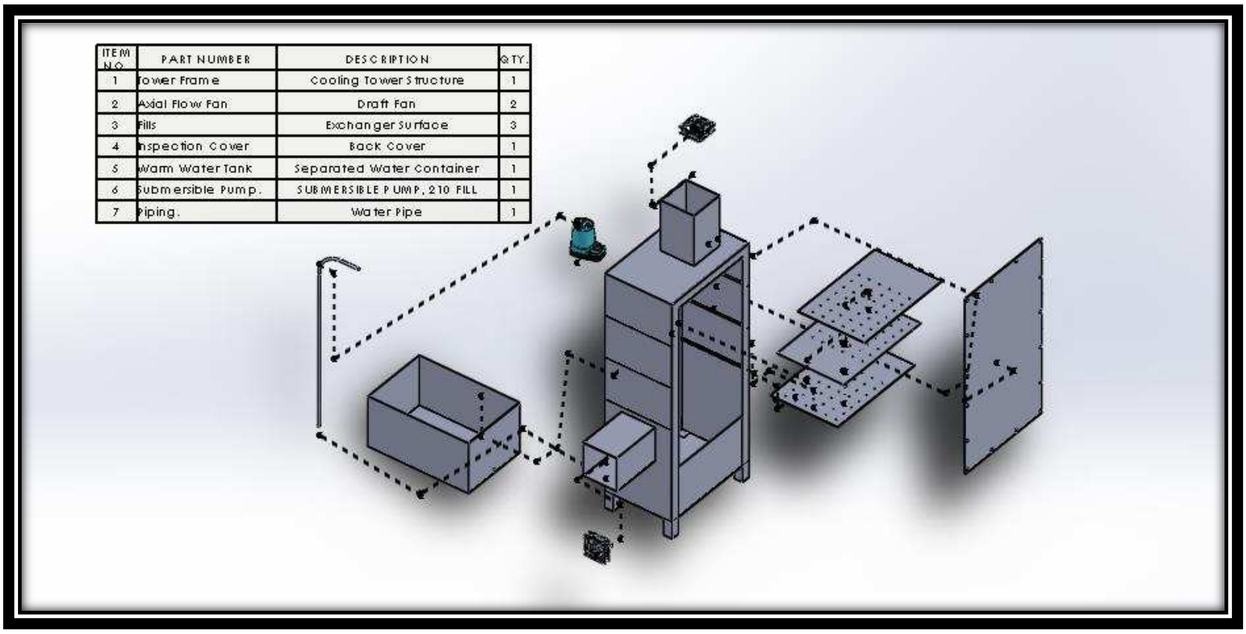


Figure 3.2 TTXL Assembled modular tower

Based on the above recommendations and after long discussion with many seniors, it was decided that the cooling tower be made with range of 4° to 5° C and the water flow rate as of the selected pump. The height is to be 1.3 m and the width to be 0.60 m with depth of 0.4 m to fit the requirement of reaching the temperature difference of 4 to 5 degree in range.

Corrosion environment is presented in cooling towers so frame should possess the proprieties that resist corrosion and temperature during process. The galvanized steel is better corrosion resistant than the uncoated steel as per the American Galvanizers Association. Also, Galvanized steel has lower cost when compare with other corrosion resistance metal like stainless steel. It is available in local market in different sizes and thicknesses. Also, it is easy to form it to the desired shape. In addition to that, the suitable type of electrode for galvanized steel is available in the local market for activities of assembly.



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Tower Frame	Cooling Tower Structure	1
2	Axial Flow Fan	Draft Fan	2
3	Fills	Exchanger Surface	3
4	Inspection Cover	Back Cover	1
5	Warm Water Tank	Separated Water Container	1
6	Submersible Pump.	SUBMERSIBLE PUMP, 210 FILL	1
7	Piping.	Water Pipe	1

Figure 3.3 Exploded view of the cooling tower assembly

Frame structure is made of galvanized steel (also called hot-dip zinc coated steel). It is an alloy of iron-zinc coated steel sheet. As per the American Galvanizers Association, the galvanized steel is 100 times better corrosion resistant than the uncoated steel. It is also 100% recyclable with conductivity of 113 W/m.K in solid state, (HDG Environmental Advantages, 2016). Engineering properties of galvanized steel are summarized in table 3.1.

Table 3.2 Properties of galvanized steel

Thermal	
Melting point	419.5C (787.1F)
Boiling point (760 mm Hg)	907C (1664.6F)
Vapor pressure	(419.5C) 1.39 x 10-1 mm Hg
Thermal Conductivity	
solid (18C)	113 W/m.K
solid (410.5C)	96 W/m.K
Volume coefficient of thermal expansion	
(20-400C)	0.89 x 10-6/K
(120-360C)	0.85 x 10-6/K
Contraction on freezing at 419.5C	4.48%
Volume change on freezing 46 C -> 0C	7.28%
Specific heat (20C)	0.382 kJ/kg.K
Latent heat of fusion (419.5C)	100.9 kJ/kg
Latent heat of vaporization (906C)	1.782 MJ/kg

Stainless Steel was used in our design for the fill (heat exchange surface) materials. It has high conductivity and thus greater heat transfer is achieved. Besides, it is corrosion resistant and it can withstand the scale formation. Since the cooling tower is pilot scaled, only three fills (trays) of stainless steel were used. The fills are equipped with small holes to allow smooth falling of water and air movement across the tower.

One of the standards being taken into consideration is Saudi Aramco Engineering Standard # 27-SAMSS-003. It states that a cooling tower should have the following material specifications (refer to table 3.2):

Table 3.3 Saudi Aramco Standard#27-SAMSS-003 Material Specification Standards for a Cooling Tower

No.	Component	Basic Material	Specification
1.	Drift eliminator	Douglas Fir Polyvinyl Chloride Glass Fiber Reinforced Polyester	CTI STD 114
2.	Piping	Carbon Steel RTR PVC HDPE	API SPEC 5L 01-SAMSS-034
3.	Mechanical Equipment Supports, Guards, Ladders and Safety Cages	Carbon Steel	ASTM A36
4.	Fan Bolts and Hardware	Stainless Steel	ASTM A194 - 8M ASTM A193 - B8M

Fans are mechanical devices that are used to move air. In cooling towers, they are employed to provide draft either forced or induced. This project incorporates both forced and induced fans to positively impact the efficiency of the cooling tower. A 92.32 cfm aluminum blade fan is used for both the forced and induced draft shown in figure 3.1.

Fan specifications and dimensions as well as other related technical data are summarized in below figure 3.2:

Figure 3.4 Axial flow fan

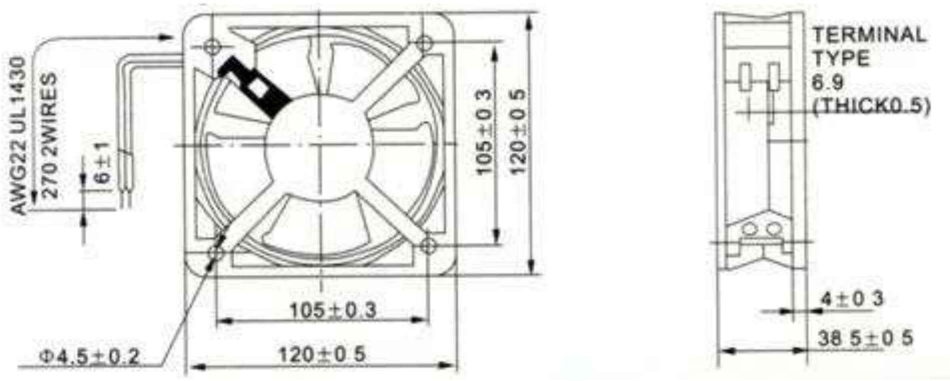


Figure 3.5 Fan outline drawing

General axial flow fan technical details:

Electric motor: Shaded pole type AC electric motor design.
Frame: High quality aluminum alloy outside frame Anti-corrosive and moisture proof structure
Impeller: UL-0 70% PBT+30%FRP
Bearing: self-lubricating bearing and ball bearing.
Insulation: Class B
Insulation Impedance: the case adds 500V DC to the coils, insulation impedance 100MΩ higher
Dielectric strength: 0.5mA 1500V/AC min
Safety protection: Impedance protection
Operating temperature: -10-+70℃
Storage temperature: -40-+70℃

Centrifugal submersible pump is used to transfer the warm water from the separated tank (which represents the water coming from power plant or A/C plant) to the top of the cooling tower. It is useful equipment that provides a head of 2.8 m with max flow rate 1800 L/h.

Features and specifications:

Voltage: 220V (Compatible with 230V/240V)
Frequency: 50/60HZ
Power: 75W
Head: 2.8 m
Flow: 1800L/H
Size: 102 * 98 * 100mm

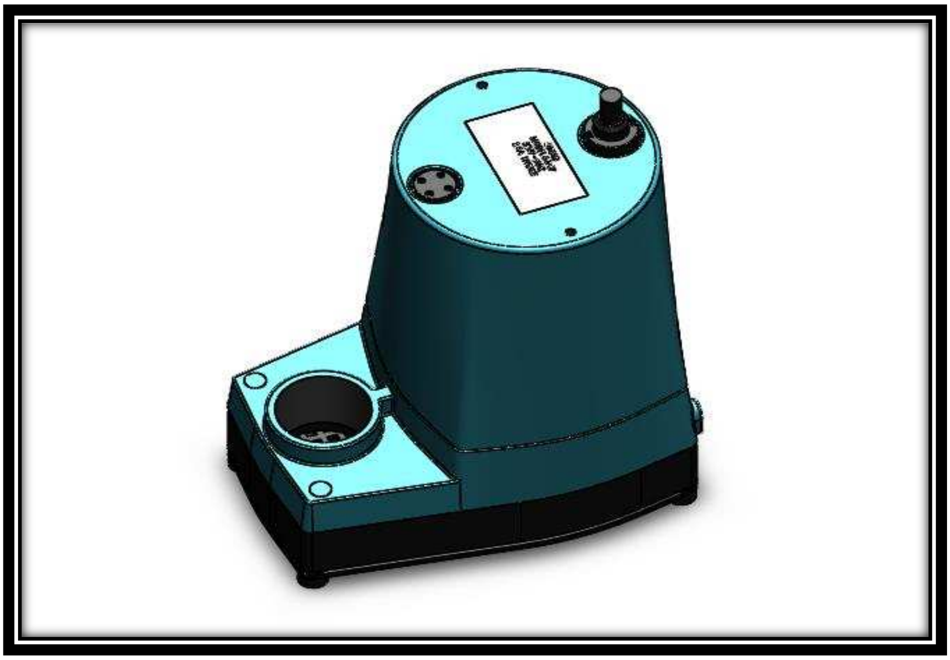


Figure 3.6 Submersible pump

3.2 Design Methodology

Designing a pilot scale counter-flow cooling tower requires several considerations to take care of and steps to follow in order to come up with a perfect design. The project was designed according to international standards and guidelines. One of the useful engineering tool that has been utilized is the Solidworks software. It helped us in determining the optimum size and dimensions of our cooling tower. The system design shown in figure 3.1 is the layout of our real project.

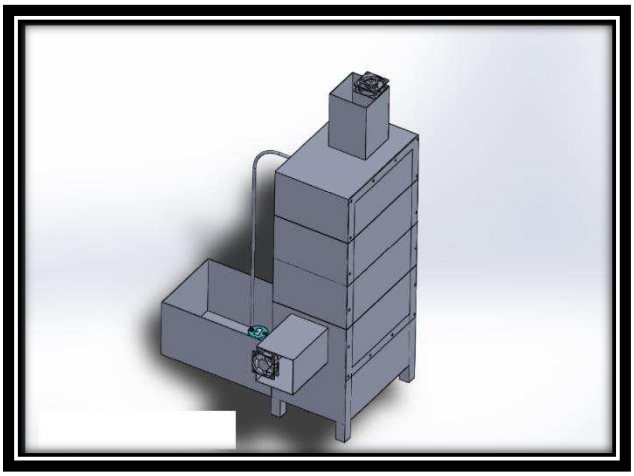


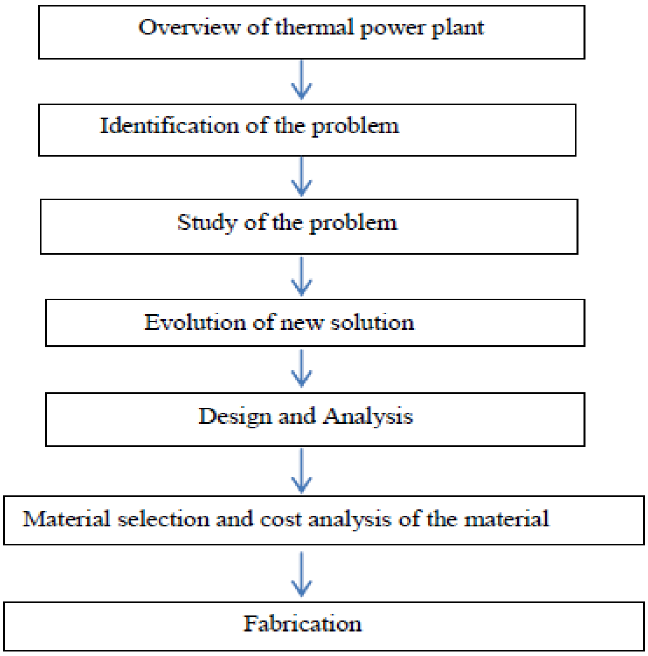
Figure 3.7 Layout of the assembled design

Previous studies were considered in the materials selection process and the best wall structural element was selected based on engineering standards of reputational companies. We have also done a Pugh chart comparison and it revealed the best choices available. We have chosen the stainless steel neglecting the bad effect of its weight. On the other hand, its thermal conductivity and corrosion resistance as well as its availability made it possible to be the best choice for this designs, Table 3.3 shows a Pugh chart.

Table 3.4 Pugh Chart for the fill material selection

	Stainless steel	Wood	Copper
Wight	-	+	+
Weldability with steel	+	-	-
Corrosion Resistance	S	S	S
Sheet availability	+	+	-
Thermal conductivity	+	-	+
Sum of -	1	2	2
Sum of +	3	2	2
Choice	*		

Selecting materials was carefully studied for this design. Several standards and codes have been reviewed to choose the best that fits our project. The methodology followed for this desgin depends upon the below diagram.



3.3 Product Subsystems and Components

Structural System

The design components consist of main structural components and subsystems. The frame is to support the whole tower assembly and provide space for the heat exchange to occur. The fills are fitted in the frame and the bottom basin is for collecting the cooled water. Both forced and draft fans are installed in the frame structure to move the air in counter flow pattern. Figure 3.2

Figure 3.8 Structural System

Plumbing System

Submersible pump is used to transfer warm water from a separated tank to the top of the cooling tower. PVC ½" hose is connected from the pump to the nozzle installed in the top of the tower. The water is then sprayed through the nozzle (sprinkler) to increase the surface contact area between air and water, see figure 3.4. The sprinkler sensing mechanism is destroyed so that it keeps running (spraying) the water at all times. Pump flow rate is 1800 L/h.

Figure 3.9 Sprinkler in operation

Figure 3.10 Water spray sprinkler

Instrumentation System

Two water proof sensors DS18B20 shown in figure 3.8 are used to measure the temperature of the warm water in the separated tank and the cooled water in the collection basin of the cooling tower. These sensors are accurate and have a display screen connected to them to display the temperature readings. Other air sensors TPM-10 shown in figure 3.9 are used to measure the temperature of the ambient air (inlet air) and the air leaving the cooling tower. They are also connected to display screen separately to show the air temperature readings.

Figure 3.11 Water temperature sensor

FEATURES

- Unique 1-Wire interface requires only one port pin for communication
- Multidrop capability simplifies distributed temperature sensing applications
- Requires no external components can be powered from data line. Power supply range is 3.0V to 5.5V
- Zero standby power required
- Measures temperatures from -55°C to +125°C. Fahrenheit equivalent is -67°F to +257°F ±0.5°C accuracy from -10°C to +85°C
- Thermometer resolution is programmable from 9 to 12 bits
- Converts 12-bit temperature to digital word in 750 ms (max.)
- User-definable, nonvolatile temperature alarm settings
- Alarm search command identifies and addresses devices whose temperature is outside of programmed limits (temperature alarm condition)
- Applications include thermostatic controls, industrial systems, consumer products, thermometers, or any thermally sensitive system

Figure 3.12 Air temperature sensor

FEATURES

- 12-hour / 24-hour displaying modes for selection
- This LCD hygrometer thermometer can display temperature, humidity and time simultaneously
- Desktop placing or wall hanging
- It has integral-hour alarm function
- It is ideal for constantly monitoring labs, fume hoods, walk-ins, plant areas, and storage facilities
- It has clock and calendar function (month and date)
- Fahrenheit and Celsius conversion
- It is durable and guaranteed

Specifications

• Using Environment Temperature	10℃---50℃
• Temperature Range	-50℃-+70℃
• Accuracy	+-1℃
• Battery	Two Button Battery (LR44,1..5V)
• Dimensions	1.8" x 1.5" x 0.59" / (4.6 x 2.66 x 1.5)cm (L x W x H)
• Color	Black
• Weight	1.41oz / 40g
• Using Environment	Humidity 5%-80%

3.4 Implementation

Reviewing and researching for possible solutions to enhance cooling tower performance and overcome its challenges were the first phase to implement this project. The decision was taken to use galvanized steel sheets for the frame structure and stainless steel for fills. As a result, assistance of group members was needed to weld the joints and construct the frame.

Submersible pump and fans were brought according to specified flow rates that are determined to withstand the tower structure size. All group members participated in the market survey and checked the availability of equipment that meets our needs. The program set up and instrumentation system is completed with the assistance of a specialist who is competent to do the job. Bill of materials of the cooling tower is shown in figure 3.7.

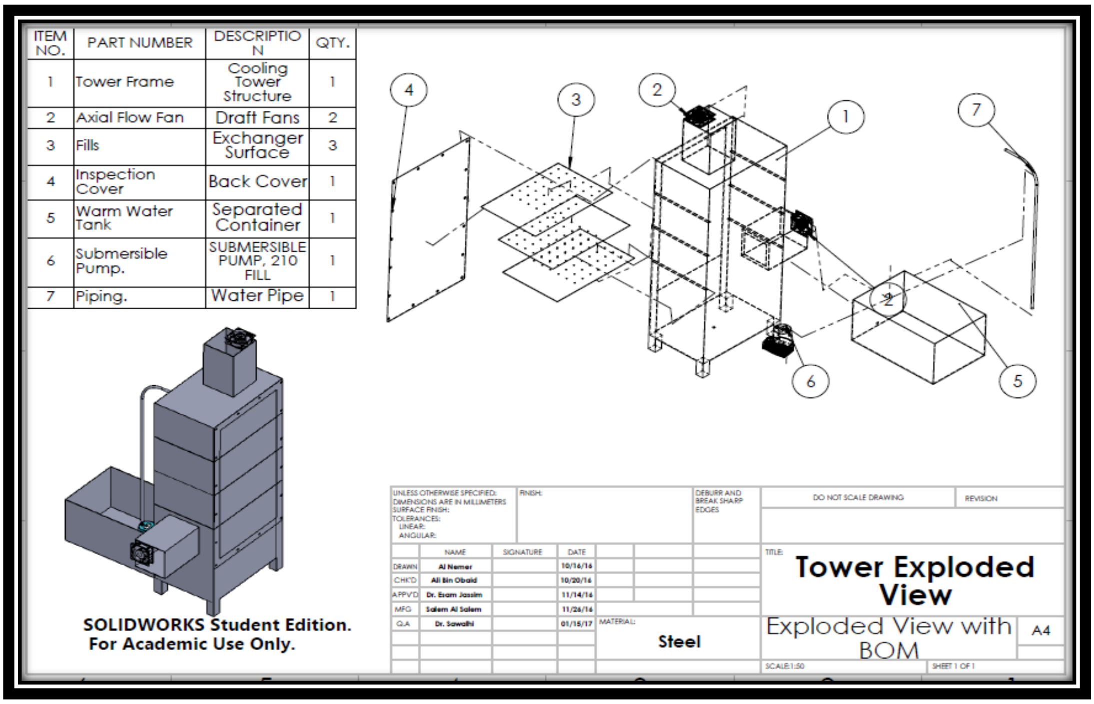


Figure 3.13 Bill of materials of the tower

Cooling towers are energy efficient and environmental friendly if designed perfectly. The size and type of a tower depends on the application for which it is going to be used. This project incorporates a pilot scale of both forced and induced fan draft with new fill arrangement. Having both forced and induced fan will definitely impact the performance of cooling tower. The zigzag water flow through the fills will also increase the time of water being cooled across the tower.

Chapter 4

System Testing & Analysis

4.1	Plumping and actual flow rate testing
4.2	Cooling Tower Performance Test
4.3	Overall Results and Discussion

4.1 Plumping and actual flow rate testing

The objectives of this test are:

- To check the tower for proper sealing (leak test)
- To check the pump's performance with current hose piping
- To check the water distribution through the nozzles

Procedure:

The cooling tower is completely insulated by vinyl. The separated water container is filled with water not exceeding the cooled water collection basin. The pump is connected to the power and switched on to observe any noticeable leakage across the tower.

*Note that you need to drain the water and power off the pump after test's completion.

4.2 Cooling Tower Performance Test

The objectives of this test are:

- To verify proper air flow across the cooling tower
- To notice any avoidable challenges
- To have an attempt test performance of the whole system including sensors
- To calculate the range, approach and efficiency of the cooling tower
- To predict the exit air and cooled water temperatures

Procedure:

The induced fan is connected to a power supply of 220V whereas the forced is 110V. Then the warm water tank is filled and the pump is primed. Make sure no obstacles could be sucked by the forced draft fan or any other unwanted object to enter the tower by the pump. Switch on the sensors prior to conducting the experiment. Record the temperature readings of the warm water and the ambient (inlet) air. The weather forecast of relative humidity should be recorded to get the wet bulb temperature from the psychrometric chart. Turn on the pump and fans simultaneously. Wait till the volume of collection basin is almost full (approximately 60L). Record the readings of the cooled water and the exit air temperatures. See experimental setup shown in figure 4.1.

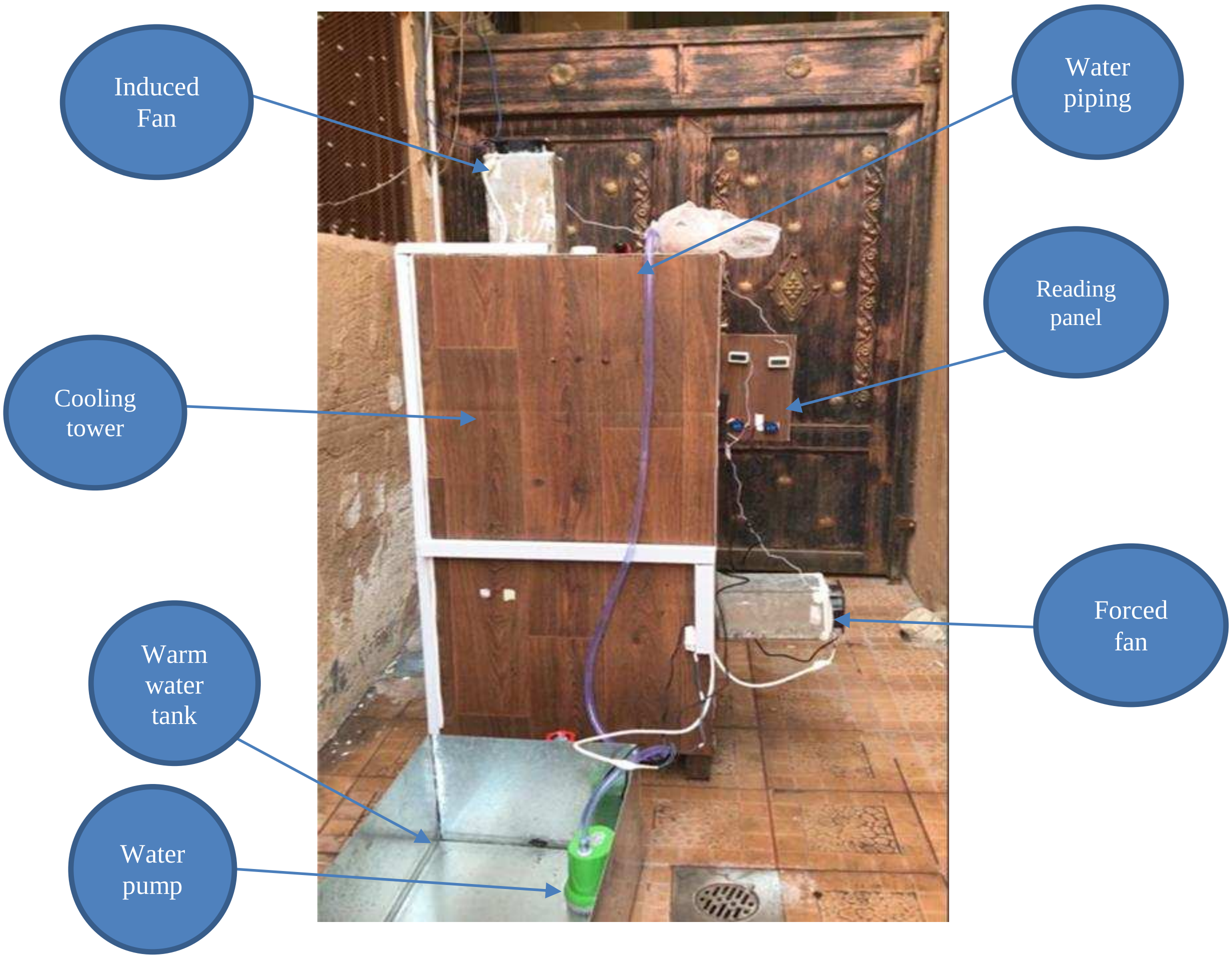


Figure 4.1 Experimental setup

Figure 4.2 Isometric view of real tower

4.3 Overall Results, Analysis and Discussion

When air flow passes a wetted surface there is a transfer of sensible and latent heat. If there is a difference in temperature between the air and the wetted surface, heat will be transferred. If there is a difference in the partial pressure of water vapor in the air and that of the water, there will be a mass transfer. This transfer of mass causes a thermal energy transfer because if some water is evaporated from the water layer, the latent heat of this vaporized water will be supplied to the air. The cooling tower effectiveness is the ratio of range to the ideal range:

Cooling Tower Approach:

The difference between the Cold Water Temperature (Cooling Tower Outlet)
And ambient Wet Bulb Temperature is called as Cooling Tower Approach.
Approach = Cold Water Temperature – Wet Bulb Temperature
Cooling Tower approach is the better indicator for the performance.

Cooling Tower Range:

The difference between the Hot Water Temperature (Cooling Tower Inlet) Temperature and Cold water (Cooling Tower Outlet) temperature is called Cooling Tower Range.
Range = Hot Water Temperature – Cold Water Temperature

Figure 4.3 Range & Approach of a cooling tower

$$Effectiveness\,(\varepsilon) = \frac{Range\,(R)}{Range\,(R) - Approach\,(A)}$$

$$\varepsilon = \frac{T_{w1} - T_{w2}}{T_{w1} - T_{wb1}}$$

$$Range\,(R) = T_{w1} - T_{w2}$$

$$Approach\,(A) = T_{w2} - T_{wb1}$$

Figure 4.4 Cooling tower formulas

Three cases of air drafts have been studied and tested in this cooling tower:

- Case (1) when only induced draft fan was used with flow rate of 92.32 cfm = 32.21 kg/s.
- Case (2) is when forced draft fan was only used with same flow rate as the induced one.
- Case (3) is studies when both fans are employed.

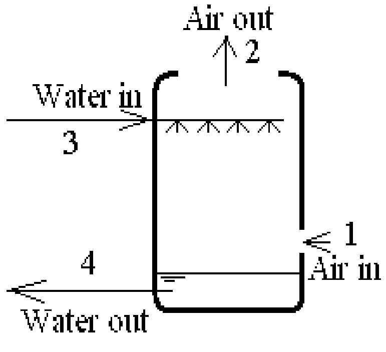


Figure 4.5 Cooling tower air & water flow

The magnitude of certain parameters needs to be measured to study the tower effectiveness of each case. Range, Approach, and efficiency as well as the evaporation loss rates are taken into consideration in this project. Range and Approach are critical parameters from which we can evaluate the performance and effectiveness of heat transfer rates in a cooling tower (figure 4.4). Thus, below calculations are measuring tools for our project. Range is the difference between inlet (warm) water and outlet (cooled) water. Approach is the difference between the outlet water temperature and the entering air wet bulb temperature. The higher approach the less efficient is the cooling tower whereas the higher range the high efficient the tower is.

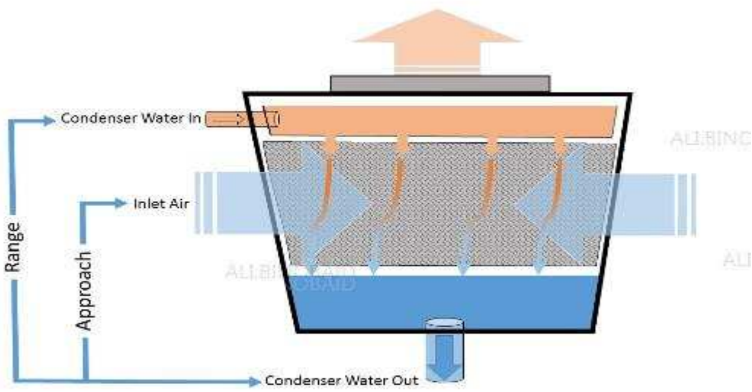


Figure 4.6 Diagram of range and approach

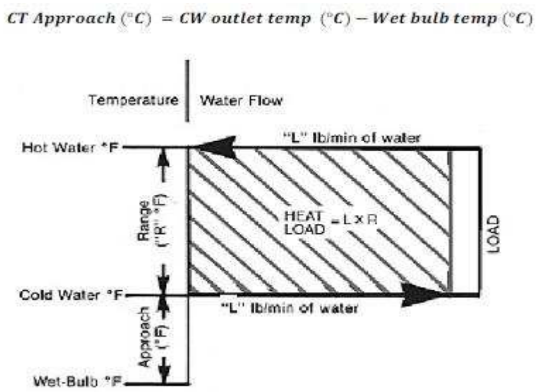


Figure 4.7 Range and approach schematic

Four trials were attempted to measure the temperature readings of each case. The calculations of Range, Approach, Efficiency & the Evaporation rate were carried out on the most ideal trial. In other words, the mean average of all trials has been selected to represent each parameter.

The air entering the cooling tower is denoted as Ta1 and the air exiting it is Ta2. Similarly, the water entering the tower is Tw1 and the exit is Tw2. Using these notations, temperature readings were recorded in tables 4.1, 4.2, 4.3. Further analysis of obtained results is explained below.

Case (1) Induced Fan Analysis:

In this system, a centrally located fan at the top, takes suction from the tower and discharges it to the atmosphere. The only difference between the induced draft cooling tower and forced draft cooling tower is that the fan is located at the top in the induced draft cooling tower.

Table 4.1 Case (1) temperature readings

Trial#	Ta1(C)	Tw1 (C)	Ta2 (C)	Tw2(C)
1	27	40.8	33	38.5
2	26.9	36.5	31.1	35
3	27.1	38.6	32.2	36
4	27.1	36.5	31.1	35.1
Average	27.02	38.1	31.95	36.15

Range = 38.1-36.15= 1.95 C

Approach= Cooled water-Wet bulb temperature, the corresponding wet bulb temperature is 21C (obtained from the Psychrometric Chart)

Approach=36.15-21= 15.15C

Efficiency = Range / (Range + Approach).

Efficiency= 1.95/ (1.95+15.15) = 11.4%

Case (2) Forced Fan Analysis:

In this system, fan is located near the bottom and on the side. This fan forces the air from bottom to top. An eliminator is used to prevent loss of water droplets along with the forced air.

Table 4.2 Case (2) temperature readings

Trial#	Ta1(C)	Tw1 (C)	Ta2 (C)	Tw2 (C)
1	27.8	39.3	33.5	35.1
2	29.1	36.6	32.2	34.5
3	29.2	39	33.7	35.1
Average	28.7	38.3	33.13	34.9

Range = 38.3-34.9 = 3.4 C

The wet bulb temperature corresponding to the average Ta1 is 22 C

Approach= 34.9-22= 12.9

Efficiency = Range / (Range + Approach).

Efficiency= 3.4/ (3.4+12.9) = 20.86 %

Case (3) Both Fans Analysis:

In this case, a combination of both forced and induced draft fans were used. They both work simultaneously to positively increase the volumetric flow rate of air across the tower.

Table 4.3 Case (3) temperature readings

Trial#	Ta1(C)	Tw1 (C)	Ta2 (C)	Tw2 (C)
1	26.2	40.2	30.4	34.6
2	27.2	36.8	31.5	34.8
3	27.1	41.2	32.4	35.5
4	23.5	37	28.9	32.5
Average	26	38.8	30.8	34.35

Range = 38.8-34.35= 4.45 C

The wet bulb temperature corresponding to the average Ta1 is 20 C

Approach= 34.35-20= 14.35

Efficiency = Range / (Range + Approach).

Efficiency= 4.5/ (4.5+14.35) = 23.9 %

Discussion

As per the obtained results, the induced fan has the lowest effect in heat transfer. The air flow is very weak across the tower. Hence, less efficient cooling is noticed. The rate of evaporation loss is the minimum compared to the other cases. Therefore, it is required for engineers and HVAC experts to further investigate the weakness of having only induced fans in cooling towers.

The efficiency of cooling depends on several parameters. This includes the terms "Range and Approach". The higher range is the good cooling tower is whereas the lower approach, the better rate of heat transfers. In this case, we have higher approach and less range which resulted in lower efficiency. One of the possible reasons of having less efficiency is due to having well insulated frame with no air entry portion other than the duct opening of the forced draft fan. The small holes on the fills can't allow large volume of air flow to pass through them.

The second case has achieved better results than the first one. The efficiency has reached up to 20.8% which represents almost double what was achieved in the induced draft experiment. The reason behind that is probably caused by the location of the fan. It is located in the above of the collection basin and right after the last cooling stage (fill). Evaporation loss has also increased and contributed to better cooling.

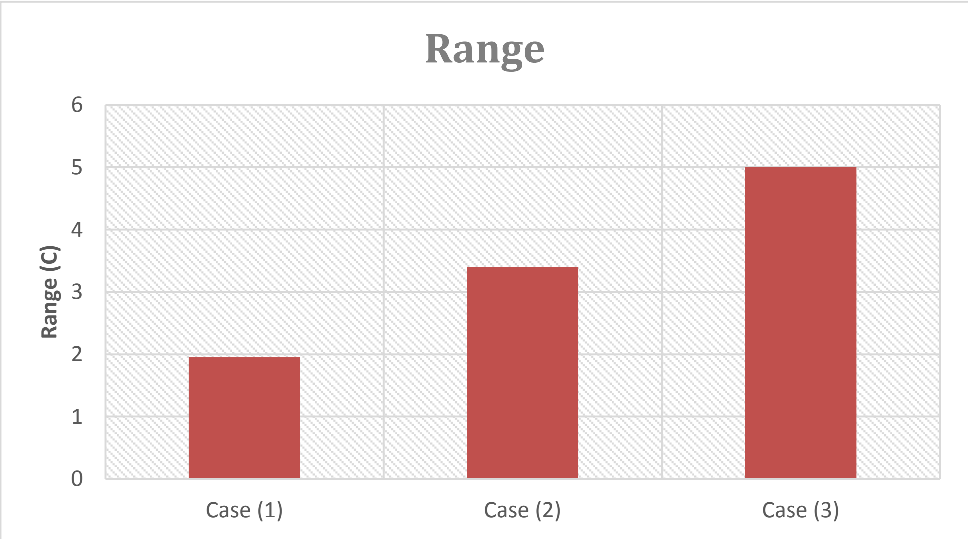


Figure 4.5 Comparison of Range of the three cases

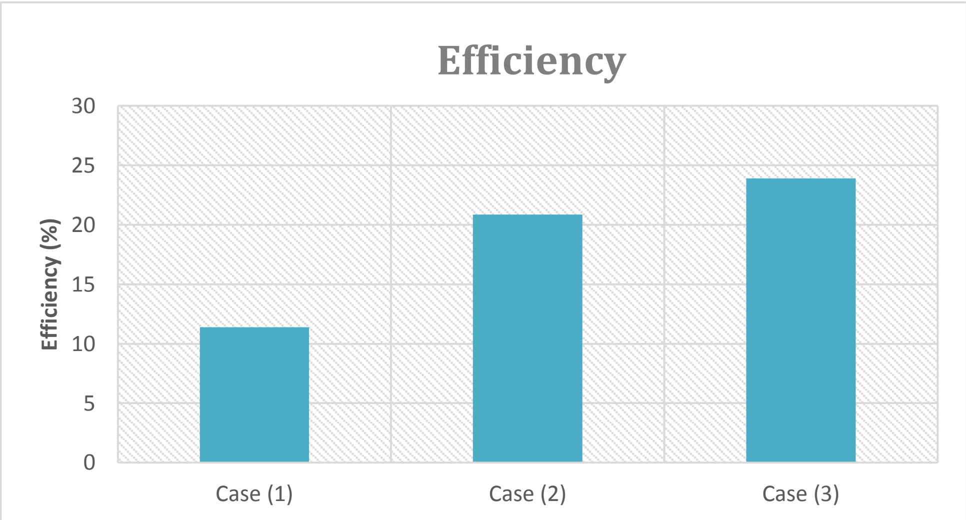


Figure 4.6 Comparison of efficiecy of the three cases

The cooling tower theory is based on the performance of a unit cooling tower with air and water quantities well defined. Its application to an actual cooling tower assumes that all unit cooling towers are working alike and in parallel. This of course is not the case. It depends on the design how closely the real cooling tower approaches the idealized cooling tower of equal units. In the actual tower each unit cooling tower works with a different inlet and exit water temperature.If overall average water inlet and exit temperature obtained in a test are used, then the theory descries the performance of some average unit cooling tower whose location is known.

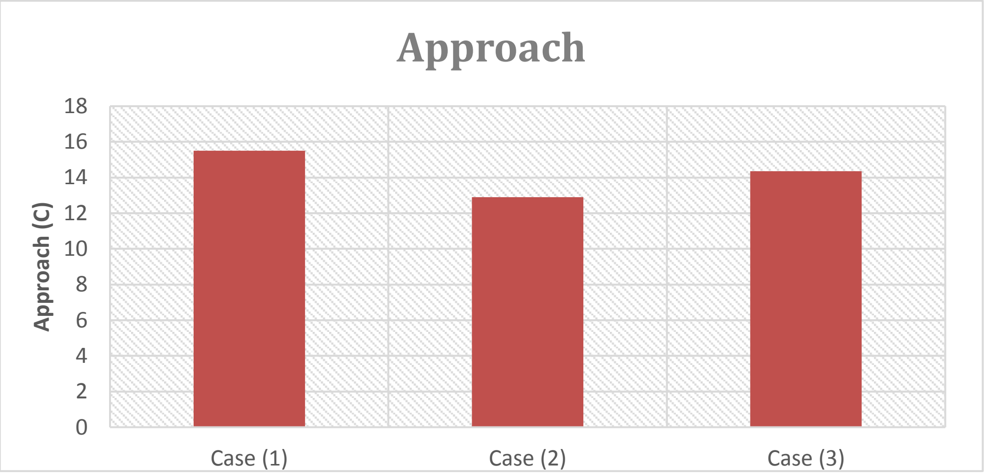


Figure 4.7 Comparison of Approach of the three cases

It is, of course, legitimate for a theory which attempts to describe a physical phenomena to suppress those factors whose effect on the overall results is small enough as to be within the degree of accuracy of the available testing procedures. Absolute exactitude is sacrificed for the sake of the clarity with which the effects of the essential factors on the phenomena are described. Figure 4.6 summerizes the achieved results for the three cases.

Figure 4.8 Summary of achieved results of the three cases

In comparison to these cases, case III is the highest in cooling range and efficiency as well as the evaporation loss rate. Having both forced and induced draft fans has achieved excellent results that met our expectations. The forced draft fan has allowed the air to pass effectively through the fills reaching to the top of the tower where the induced fan discharges it. The air is discharged to the atmosphere with some vapor content in it. Below charts are representations of our obtained data for the three cases.

The difficulty of obtaining consistent results in the testing of cooling towers is, or course, well known. One of the main factors that governs test results, the atmospheric wet-bulb entering the cooling tower pulsates during the test, is affected by changing wind conditions, and even is affected by the character of the environment in which the cooling tower is installed. A reasonable tolerance in the guarantee for a type of equipment as cooling towers represent, is therefore, unavoidable.

Chapter 5

Project Management

5.1	Project Plan
5.2	Contribution of Team Members
5.3	Project Execution Monitoring
5.4	Challenges and Decision Making
5.5	Project Bill of Materials and Budget

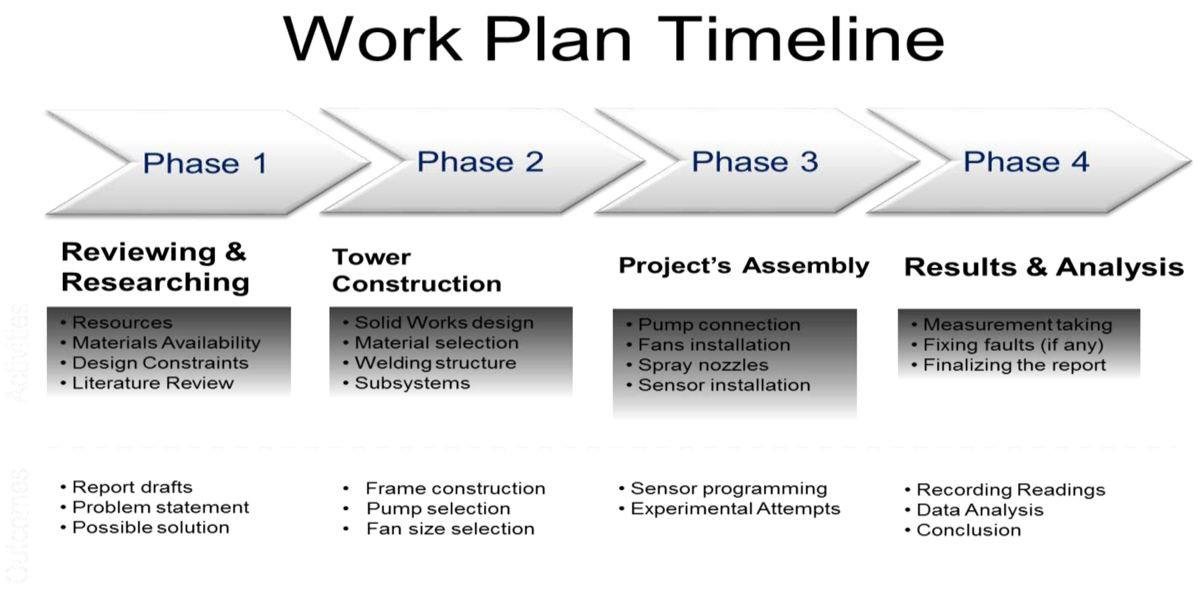
5.1 Project Plan

Managing project completion time is very essential for undergraduate students. In this project we set a flexible timeframe for all group members to complete the tasks in timely manner. Following is the table that shows the main tasks and their completion date.

Table 5.1 Project's Time frame

	Task	**Completion date**	**Budget and resources (Examples are given below)**
1	Literature review	27th of October	- Internet resources- Journals, HVAC experts, Work colleagues
2	System design	31st of October	CAD (solid works), Dr. Esam's recommendations, Cooling tower manufacturing companies' standards.
3	System Manufacturing and Assembly	20th of November	Approximately 4500-5000 SAR.
4	System Testing and Experiment Design	5th of December	Professor's assistance, technology utilization.
5	Analysis and Findings	20th of December	Compare experimental Vs. Theoretical data, feasibility study, cost effectiveness

The tasks are distributed among all group members. Biweekly reports explain the tasks assigned to individuals (see appendix 1). In addition, the Gantt chart (figure 5.1) for this project and timeline are shown below.



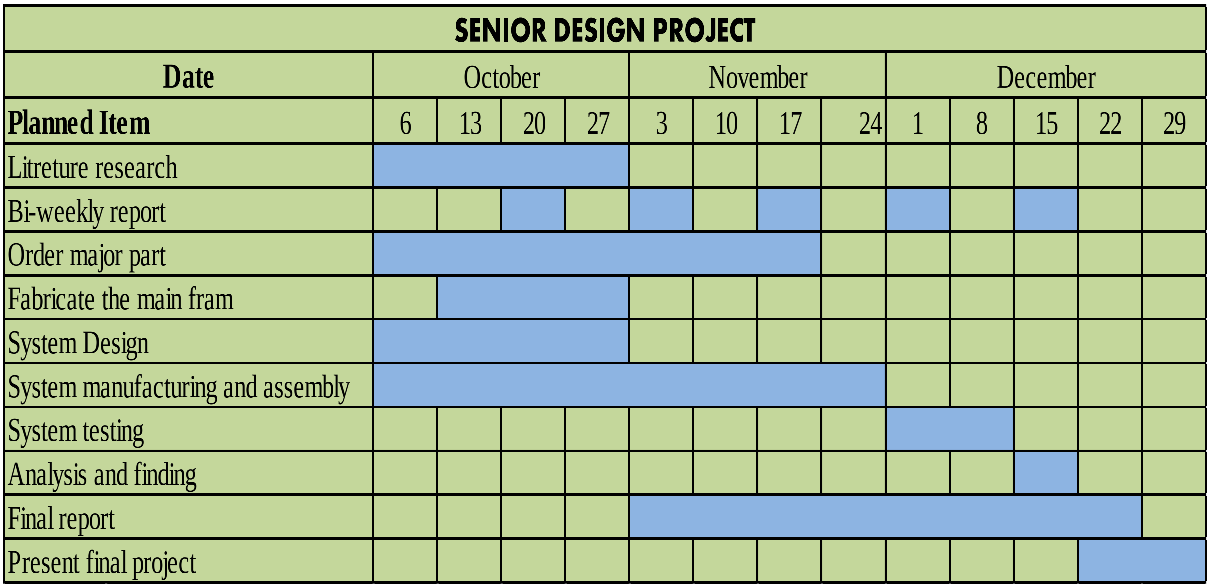


Figure 5.1 Gantt chart

5.2 Contribution of Team Members

All team members have positive contribution that resulted in successful completion of this project. In fact, they were enthusiastic to work together and interested in achieving the final product. The work was distributed evenly and fairly among team members. For example, Mohammad is a welder in Saudi Aramco and he is skillful in soildworks so he made the CAD design of this project and assisted in welding the structure of the tower's frame. Below table 5.2 shows exact task description for all of team members.

Table 5.2 Task distribution

#	Task description	Team member assigned
1.	Writing up the project report	All members
2.	Assembling the project	All members
3.	Meet Dr. Esam in weekly basis	All members
4.	Programing the sensors and instrumentation	Salem Al Salem
5.	Leakage test & market survey	Ali A Ben Obaid
6.	Welding works ,steel cutting & CAD design	Mohammed Al Nemer
7.	Buying necessary component (pump, fans, sensors) from the market	Husain Al Mubarak
8.	Conduct the experiments and record data	All members

5.3 Project Execution Monitoring

The project team members meet every Saturday of every week starting November 5th. The meeting is a useful tool that helped all members to stay updated and posed of the work progress done by individuals. Also, all members meet with the project advisor every Tuesday for any concerns or inquiries as well as recommendations related to the project. A WhatsApp group has been created for both group members and the advisor to stay connected at most of the time.

5.4 Challenges and Decision Making

In every engineering project, there are unexpected challenges that are experienced by engineers. In this project, we faced some problems that luckily were solved and revoked. Below are some the problems we faced and eventually were overcome.

Team members

All team members are employees and have many responsibilities other than the university. Juggling from work to the university and then going back home is difficult, but we overcome this challenge by time management. We specify every Saturday to work on the project including writing its reports as well as reading more about it in our free time.

Materials Selection

Choosing the right materials that fits our project requirements was another challenge. We wanted to select the best materials that could help us achieving our project's objectives. We were struggling whether to use wood, Aluminum or steel to construct our cooling tower. Finally, we reviewed many standards and guidelines of designing cooling towers and found out that stainless steel can be used in fill materials whereas carbon steel for the structural elements. One of team members is working as welder and has helped us constructing the frame structure.

Instrumentation

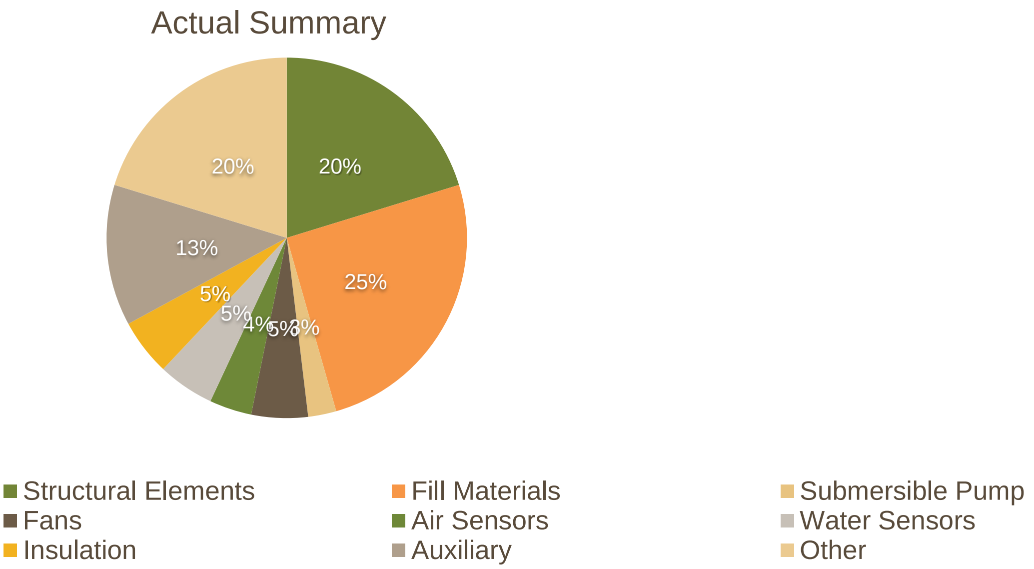
Due to the lack of knowledge in instrumentations, we were struggling which type of accurate sensor is suitable to us. We needed two air sensors and another two water sensors. We surveyed the local market and found that there is no availability of water proof sensors. Therefore, we ordered the parts from abroad.

5.5 Project Bill of Materials and Budget

Managing the pre-determined budget is a challenging for engineers. In this project, we were lucky that the budget didn’t exceed the planned one. We almost spent as planned. Below are the charts that specify the bill of materials with their cost.

DESIGN BUDGET

These graphs represent the actual expenses of the designed project but not limited to other hidden expenditures like transporting, surveying ...etc.



Summary by Category

Category	Budget	Actual	Difference
Structural Elements	SAR800.00	SAR800.00	SAR0.00
Fill Materials	SAR1,000.00	SAR1,000.00	SAR0.00
Submersible Pump	SAR100.00	SAR100.00	SAR0.00
Fans	SAR200.00	SAR200.00	SAR0.00
Air Sensors	SAR150.00	SAR150.00	SAR0.00
Water Sensors	SAR200.00	SAR200.00	SAR0.00
Insulation	SAR200.00	SAR200.00	SAR0.00
Auxiliary	SAR500.00	SAR500.00	SAR0.00
Other	SAR800.00	SAR800.00	SAR0.00
Total	SAR3,950.00	SAR3,950.00	SAR0.00

Chapter 6

Project Analysis

6.1 Life-long Learning

6.2 Impact of Engineering Solutions

6.3 Contemporary Issues Addressed

6.1 Life-long Learning

Senior design project is the milestone of the whole engineering degree courses. The knowledge gained by study is applied in it. In fact, our project is mainly about heat transfer and materials science. Additional skills that we learnt in this project are selection of sensors, time management, technical report writing, reviewing standards and codes. We went through different standards of international companies and organizations. We collected our information and data from trusted sites and journal articles. This has helped us in researching skills and improved our techniques in seeking for information.

Not only senior project has helped us in developing technical skills, but also it has helped us building our personalities through leadership and team working skills. The six core competencies have important roles of that, too. Being professional in all your works is a result of exercising these competencies.

In this project, we faced difficulties in time management as we all have families and responsibilities other than the Assessment III course. All team members are far from each other. Ali lives in Thoqabah and Husain has a room in Qurrayyah dormitory whereas Salem has an apartment in Qatif. Mohammad finds difficulties travelling from Dammam, too.

Whenever there is water. There is chance of leak! We couldn’t stop the leak in the beginning because of the metal joints. We put rubber gaskets between the metal surfaces to seal off, but unfortunately it didn’t work. Later we used adhesive sealant (silicone) to minimize the leak.

6.2 Impact of Engineering Solutions

By developing methods to increase cooling tower efficiency, we can significantly contribute in conservation of our environmental resources like water. Water is the life base of creations. Therefore, this project developed ways to conserve water vaporization and losses through the enhanced fill material and arrangement. Although implementing it could be costly, the benefits will be obtained are valuable.

As discussed previously, a one degree Celsius increase can consume power of 2.7% of an electrical compressor whereas reducing one degree Celsius in a cooling tower can save energy of 5 kCal/kWh. So, this represents the importance of a cooling tower in industry. This should motivate engineers further to look for possible ways to improve its efficiency without affecting natural resources and the environment. In the long term, many benefits can be obtained if proper methodology is employed.

6.3 Contemporary Issues Addressed

Eastern Province of Saudi Arabia is a critical region to focus on due to its economic resources. Most of Saudi Arabia's income depends on the power plants and refineries located in the Eastern Province. It is essential for us to study the performance of cooling tower typically used in the Eastern Region power plants, factories, buildings …etc. The weather in Eastern Province is variable and hence it affects the performance of cooling towers.

This project addressed the effect of humidity and cold weather temperature variations on cooling tower efficiency. Insulation was used to eliminate any external elements that contribute to deviating the project's outcomes. The vaporization caused by splashing the water over the cooling tower and ambient air is desirable whereas the one caused by external factor is not. Sun heat directed the tower frame can cause water to evaporate and hence more make up water is needed.

Chapter 7

Conclusion & Recommendations

7.1 Conclusion

7.2 Future Recommendations

7.1 Conclusions

For any engineering projects, existence of some challenges essentially requires analysis and methods to overcome. However, overcoming these challenges needs effective utilization of leadership skills and critical thinking of the problem as well. This may include the engineering knowledge that is gained through studying courses in the university. As it can be noticed from the results we gained, incorporating both forced and induced draft fans have positive impact on cooling tower performance. They contributed in increasing the efficiency of the cooling tower by enabling more volume of air to pass through the tower and hence more heat will be dissipated. The zigzag water flow pattern has made the water movement to slow down and longer time of water exposure to air is achieved. Stainless steel fills have higher conductivity and this helped us in achieving as excellent results as 4 C of cooling.

The senior design project is a milestone for engineering degree students. In fact, we have learned lots of useful information through conducting this experiment and writing up this thesis. In the past, we were not aware of the composition of galvanized and stainless steel and their thermal behavior and properties. The importance of a cooling tower in industries has motivated us to study its performance and look for possible ways to increase its efficiency.

7.2 Future Recommendations

For this project to give accurate results, we recommend that the temperature of the warm water tank be controlled and maintained to certain temperature. This can be done by having continuous heating to desired temperature. We also suggest having larger collection basin by having over flow piping to drain the flooding water to a separate container. Larger induced fan with higher flow rate is also recommended to have positive impact on the heat transfer rate.

Accurate measurement of air flow rate as well as water flow rate is also recommended. This will assist in evaluating and determining the heat dissipated in the system. Additionally, it is to set the required make-up water and substitute the evaporated amount of water. It is highly recommended to further look into possible engineering solutions to develop ways to overcome such challenges like the scale deposits on fills (exchange surface), corrosion, reducing water losses in cooling water systems and any other discoverable items that may be faced in future. One of the recommendations is to use Nano particle in the water to be cooled to enhance the heat transfer rates.

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Appendix A

Progress Reports

1 Biweekly Report#1

2 Biweekly Report#2

3 Biweekly Report#3

4 Biweekly Report#4

5 Biweekly Report#5

SDP – WEEKLY MEETING REPORT

Department of Mechanical Engineering
Prince Mohammad bin Fahd University

SEMESTER: ACADEMIC YEAR:	**FALL 2016-2017**	**Date:**	**October 20th, 2016**
PROJECT TITLE	**Design & Construction of a Pilot-Scale Cooling Tower**		
SUPERVISORS	**Dr. Esam Jassim**		

Member Name		Present/Absent	Arriving on time
Ali Ben Obaid	**201100293**	**Present**	**On time**
Salem Al Salem	**201100294**	**Present**	**On time**
Hussain Al Mubarak	**200901660**	**Present**	**On time**
Mohammed Al Nemer	**201100192**	**Present**	**On time**

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Gathering information for the presentation	All members		
2	Preparing the Power Point slides	Hussain		
3	Market survey on current cooling tower parts	Salem		
4	Writing up the objectives & Meeting#2 required information report	Ali		
5	Checking availability of required materials	Mohammad		

Task allocation for the next week:

#	Task description	Team member assigned
1	Literature Review Overview	All members
2	Gather together on Monday to discuss the required information for the literature review	All members
3	SolidWorks system design	Hussain Al Mubarak
4	Visiting workshops to check the ability to manufacture our project	Salem Al Salem
5	Typing & printing the final draft of the literature review	Mohammed Al Nemer
6	Connection point between members and the advisor	Ali Ben Obaid

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
F.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d.1 Develop a work plan and distribute tasks	Fails to develop a work plan and tasks are assigned ad hoc	Develops a work plan without much thought and tasks distribution is not balanced	Develops a good work plan and distributes tasks in a balanced way	Develops a realistic and well thought out work plan and distributes tasks in a balanced way and according to the skills and expertise of the team members
d. 2 Take responsibility in team efforts to complete the assigned tasks.	Does not perform assigned tasks; often misses meetings and, when present, does not have anything constructive to say; relies on others to do the work;	Performs assigned tasks but needs many reminders; attends meetings regularly but generally does not say anything constructive; sometimes expects others to do his/her work;	Performs all assigned tasks; attends meetings regularly and usually participates effectively; generally reliable;	Performs all tasks very effectively; attends all meetings and participates enthusiastically; very reliable.
d.3 Show respect to other team members.	Often argues with team mates; doesn't let anyone else talk; occasional personal attacks and "put-downs"; wants to have things done his way and does not listen to alternate approaches;	Usually does much of the talking; does not pay much attention when others talk, and often assumes their ideas will not work; no personal attacks and put-downs but sometimes patronizing; when others get through to him, works reasonably well with them;	Generally listens to others' points of view; always uses appropriate and respectful language; tries to make a definite effort to understand others' ideas;	Always listens to others and their ideas; helps them develop their ideas while giving them full credit; always helps the team reach a fair decision.

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Ali Ben Obaid**	4	4	4	4
2	**Salem Al Salem**	4	4	4	4
3	**Hussain Al Mubarak**	4	4	4	4
4	**Mohammed Al Nemer**	4	4	4	4

Comments on individual members

Name	Comments
Ali Ben Obaid	No comments
Salem Al Salem	No comments
Hussain Al Mubarak	No comments
Mohammed Al Nemer	No comments

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

Team#6

SEMESTER: ACADEMIC YEAR:	FALL 2016-2017	Date:	November 3^{rd} , 2016
PROJECT TITLE	Design & Construction of a Pilot-Scale Cooling Tower		
SUPERVISORS	Dr. Esam Jassim		

Member Name		Present/Absent	Arriving on time
Ali Ben Obaid	201100293	Present	Yes
Salem Al Salem	201100294	Present	Yes
Hussain Al Mubarak	200901660	Present	Yes
Mohammed Al Nemer	201100192	Present	Yes

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Second draft literature review proof reading	All members	100%	Report attached
2	Writing up the background with its references	Ali	100%	Report attached
3	SolidWorks system design & completing the previous work section of second draft	Mohammad	90%	Drawing attached
4	Following up the frame construction progress	Ali	100%	-------------
5	Writing up the comparative study section	Salem	100%	Report attached

Task allocation for the next week:

#	Task description	Team member assigned
1	Start preparing for the next presentation	All members
2	Gather together on Saturday to discuss the next step after constructing the frame (casing) and take photos.	All members
3	Finalize the SolidWorks system design	Mohammed Al Nemer Hussain Al Mubarak
4	Start working in chapter#3 section#1 of the final report	Salem Al Salem
5	Complete section#2 of chapter#3	Ali Ben Obaid
6	Meet Dr. Esam on Tuesday to discuss our progress	All members

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
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d.3 Show respect to other team members.	Often argues with team mates; doesn't let anyone else talk; occasional personal attacks and "put-downs"; wants to have things done his way and does not listen to alternate approaches;	Usually does much of the talking; does not pay much attention when others talk, and often assumes their ideas will not work; no personal attacks and put-downs but sometimes patronizing; when others get through to him, works reasonably well with them;	Generally listens to others' points of view; always uses appropriate and respectful language; tries to make a definite effort to understand others' ideas;	Always listens to others and their ideas; helps them develop their ideas while giving them full credit; always helps the team reach a fair decision.

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Ali Ben Obaid**	**4**	**4**	**4**	**4**
2	**Salem Al Salem**	**4**	**4**	**4**	**4**
3	**Hussain Al Mubarak**	**4**	**4**	**4**	**4**
4	**Mohammed Al Nemer**	**4**	**4**	**4**	**4**

Comments on individual members

Name	Comments
Ali Ben Obaid	No comments
Salem Al Salem	No comments
Hussain Al Mubarak	No comments
Mohammed Al Nemer	No comments

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

Team#6

SEMESTER: ACADEMIC YEAR:	FALL 2016-2017	Date:	November 20th , 2016
PROJECT TITLE	Design & Construction of a Pilot-Scale Cooling Tower		
SUPERVISORS	Dr. Esam Jassim		

Member Name		Present/Absent	Arriving on time
Ali Ben Obaid	201100293	Present	yes
Salem Al Salem	201100294	Present	yes
Hussain Al Mubarak	200901660	Present	yes
Mohammed Al Nemer	201100192	Present	yes

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Third draft literature review proof reading	All members	100%	Report attached
2	Writing up the design constraints	Ali	100%	Report attached
3	SolidWorks system design and finding out fan specifications	Mohammad	100%	Drawing attached
4	Frame construction works	Ali	100%	Photos attached
5	Writing up the methodology and implementation sections	Salem	100%	Report attached
6	Writing up the subsystems section of chapter#3	Husain	70%	--------------

Task allocation for the next week:

#	Task description	Team member assigned
1.	Start preparing for the next presentation	All members
2.	Finalize chapter#3 draft and proofread	Mohammed Al Nemer
3.	Buying the required sensors and controllers	Salem Al Salem
4.	Buying the fans	Ali A Ben Obaid
5.	Meet Dr. Esam on Tuesday to discuss our progress	All members
6.	Apply the thermal insulation on the tower	Mohammed Al Nemer
7.	Specify the required water flow rate and buying the required pump	Husain Al Mubarak
8.	Gather together on Saturday to discuss the next step after constructing the frame (casing), assemble the project and take photos	All members

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d.1 Develop a work plan and distribute tasks	Fails to develop a work plan and tasks are assigned ad hoc	Develops a work plan without much thought and tasks distribution is not balanced	Develops a good work plan and distributes tasks in a balanced way	Develops a realistic and well thought out work plan and distributes tasks in a balanced way and according to the skills and expertise of the team members
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d.3 Show respect to other team members.	Often argues with team mates; doesn't let anyone else talk; occasional personal attacks and "put-downs"; wants to have things done his way and does not listen to alternate approaches;	Usually does much of the talking; does not pay much attention when others talk, and often assumes their ideas will not work; no personal attacks and put-downs but sometimes patronizing; when others get through to him, works reasonably well with them;	Generally listens to others' points of view; always uses appropriate and respectful language; tries to make a definite effort to understand others' ideas;	Always listens to others and their ideas; helps them develop their ideas while giving them full credit; always helps the team reach a fair decision.

Indicate the extent to which you agree with the above statement, using a scale of 1-4 (1=None; 2=Low; 3=Moderate; 4=High)

#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Ali Ben Obaid**	**4**	**4**	**4**	**4**
2	**Salem Al Salem**	**4**	**4**	**4**	**4**
3	**Hussain Al Mubarak**	**4**	**4**	**4**	**4**
4	**Mohammed Al Nemer**	**4**	**4**	**4**	**4**

Comments on individual members

Name	Comments
Ali Ben Obaid	No comments
Salem Al Salem	No comments
Hussain Al Mubarak	No comments
Mohammed Al Nemer	No comments

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

Team#6

SEMESTER: ACADEMIC YEAR:	**FALL 2016-2017**	**Date:**	**December 1st , 2016**
PROJECT TITLE	**Design & Construction of a Pilot-Scale Cooling Tower**		
SUPERVISORS	**Dr. Esam Jassim**		

Member Name		Present/Absent	Arriving on time
Ali Ben Obaid	**201100293**	**present**	**yes**
Salem Al Salem	**201100294**	**present**	**yes**
Hussain Al Mubarak	**200901660**	**present**	**yes**
Mohammed Al Nemer	**201100192**	**present**	**yes**

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Presentation delivery	All members	100%	PPT attached
2	Completing report proof reading	Ali	100%	Report attached
3	Fan purchasing	Mohammad	100%	----------
4	Purchasing instruments	Salem	100%	Photos attached
5	Pump’s installing	Husain	100%	Report attached

Task allocation for the next week:

#	Task description	Team member assigned
1.	Start writing the next chapter	All members
2.	Assembling the project	All members
3.	Programing the sensors and instrumentation	Salem Al Salem
4.	Leakage test	Ali A Ben Obaid
5.	Meet Dr. Esam on Tuesday to discuss our progress	All members
6.	Apply the thermal insulation on the tower	Mohammed Al Nemer
7.	Complete the solidworks drawing as per Dr. Nader’s recommendations	Husain Al Mubarak
8.	Gather together on Saturday to have a first attempt of the experiment	All members

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
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#	Name	Criteria (d1)	Criteria (d2)	Criteria (d3)	Criteria (f1)
1	**Ali Ben Obaid**	**4**	**4**	**4**	**4**
2	**Salem Al Salem**	**4**	**4**	**4**	**4**
3	**Hussain Al Mubarak**	**4**	**4**	**4**	**4**
4	**Mohammed Al Nemer**	**4**	**4**	**4**	**4**

Comments on individual members

Name	**Comments**
Ali Ben Obaid	No comments
Salem Al Salem	No comments
Hussain Al Mubarak	No comments
Mohammed Al Nemer	No comments

	SDP – WEEKLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

Team#6

SEMESTER: ACADEMIC YEAR:	FALL 2016-2017	Date:	December 15th , 2016
PROJECT TITLE	Design & Construction of a Pilot-Scale Cooling Tower		
SUPERVISORS	Dr. Esam Jassim		

Member Name		Present/Absent	Arriving on time
Ali Ben Obaid	201100293	present	yes
Salem Al Salem	201100294	present	yes
Hussain Al Mubarak	200901660	present	yes
Mohammed Al Nemer	201100192	present	yes

Task progress report for the last week effort:

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Conducting the experiment on three cases	All members	100%	Results Attached
2	Completing report proof reading	Ali	100%	Report attached
3	Interpreting collected data	Mohammad	100%	Report Attached
4	Making graphs and charts on the report	Salem	100%	Report Attached
5	Completing the remaining sections of the final report	Husain	100%	Report attached

Task allocation for the next week:

#	Task description	Team member assigned
1.	Video Publishing	Mohammed Al Nemer
2.	Preparing the project's poster	Salem Al Salem
3.	Publishing the project's brochure	Husain Al Mubarak
4.	Finalizing the report	Ali A Ben Obaid
5.	Preparing the final presentation	All members

Outcome f: An understanding of professional and ethical responsibility.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
f.1 Demonstrate professionally responsibility at all times.	Fails to demonstrate responsibility for his actions and does not deal with others professionally	Shows some sense of responsibility for his actions but needs improvement in dealing with others professionally	Takes full responsibility for his actions and deals with others professionally	Demonstrates high moral and professional ethics, takes complete responsibility for his actions and is excellent in interacting and dealing with others

Outcome d: An ability to function on multidisciplinary teams.				
Criteria	**None (1)**	**Low (2)**	**Moderate (3)**	**High (4)**
d.1 Develop a work plan and distribute tasks	Fails to develop a work plan and tasks are assigned ad hoc	Develops a work plan without much thought and tasks distribution is not balanced	Develops a good work plan and distributes tasks in a balanced way	Develops a realistic and well thought out work plan and distributes tasks in a balanced way and according to the skills and expertise of the team members
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1	**Ali Ben Obaid**	**4**	**4**	**4**	**4**
2	**Salem Al Salem**	**4**	**4**	**4**	**4**
3	**Hussain Al Mubarak**	**4**	**4**	**4**	**4**
4	**Mohammed Al Nemer**	**4**	**4**	**4**	**4**

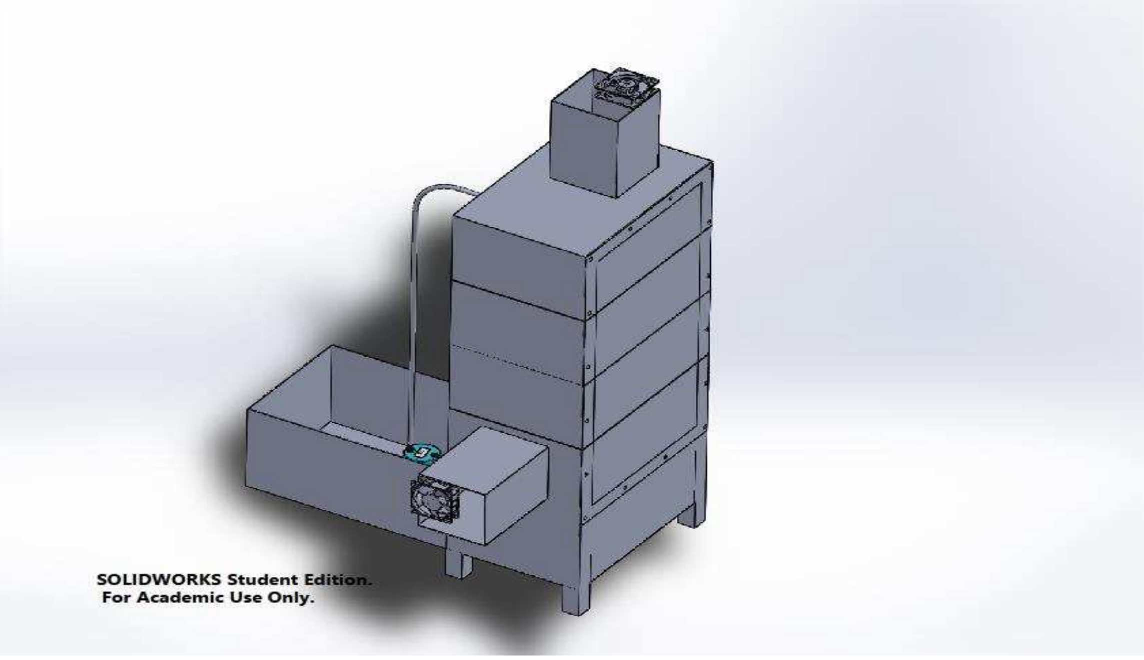
Comments on individual members

Name	Comments
Ali Ben Obaid	No comments
Salem Al Salem	No comments
Hussain Al Mubarak	No comments
Mohammed Al Nemer	No comments

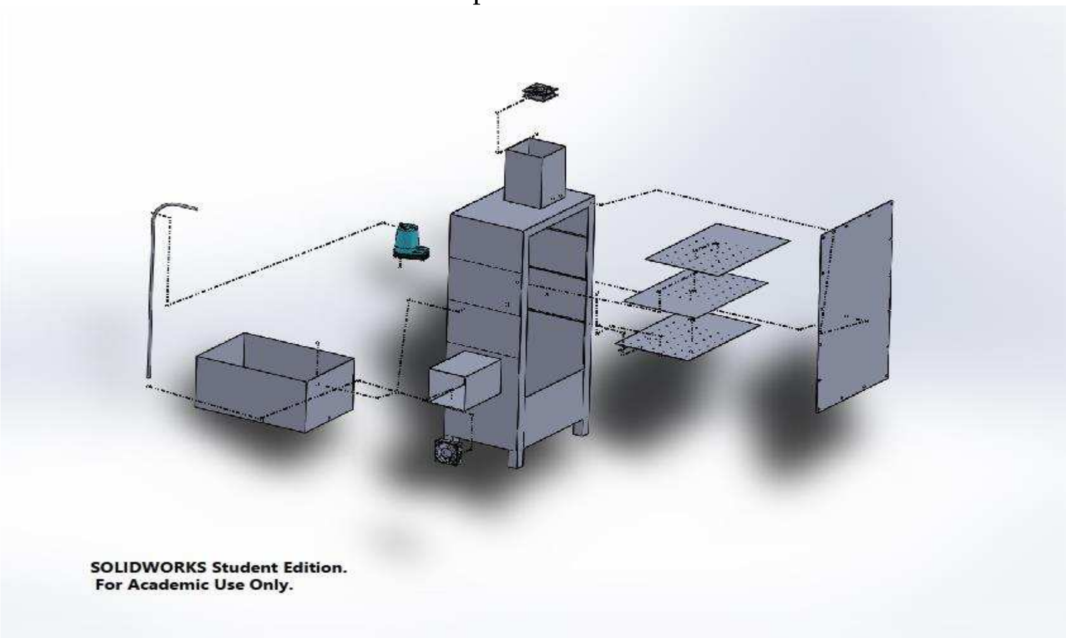
Appendix B

Bill of Materials

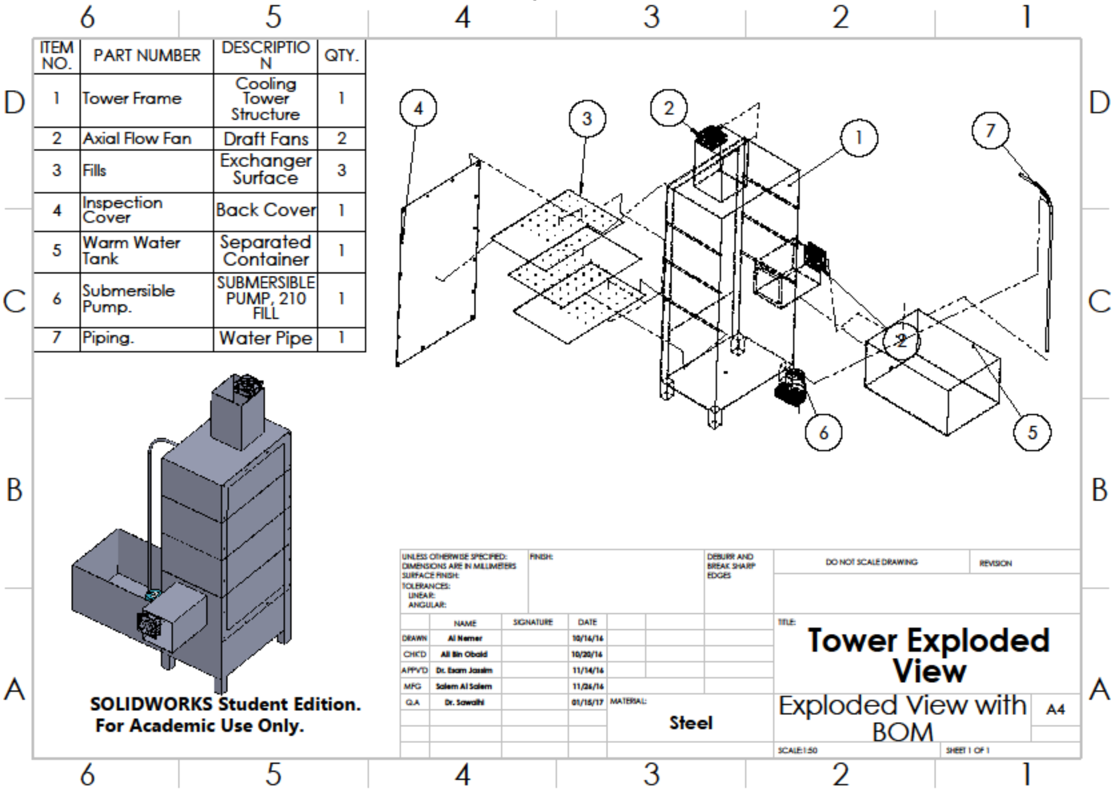
Assembled project



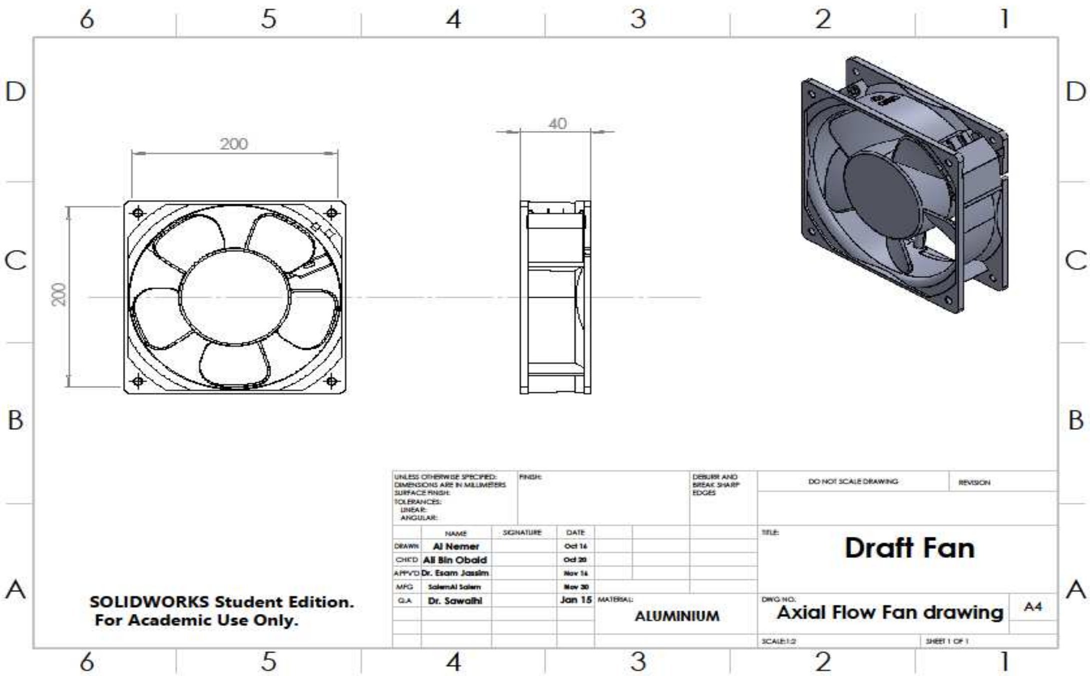
Exploded view



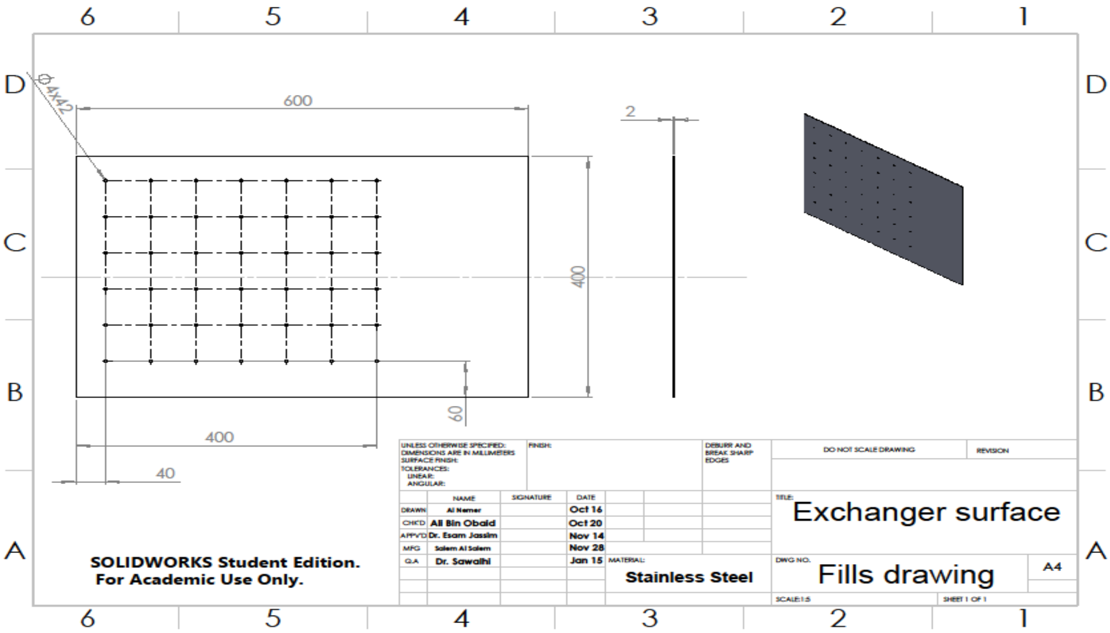
Assembly with BOM



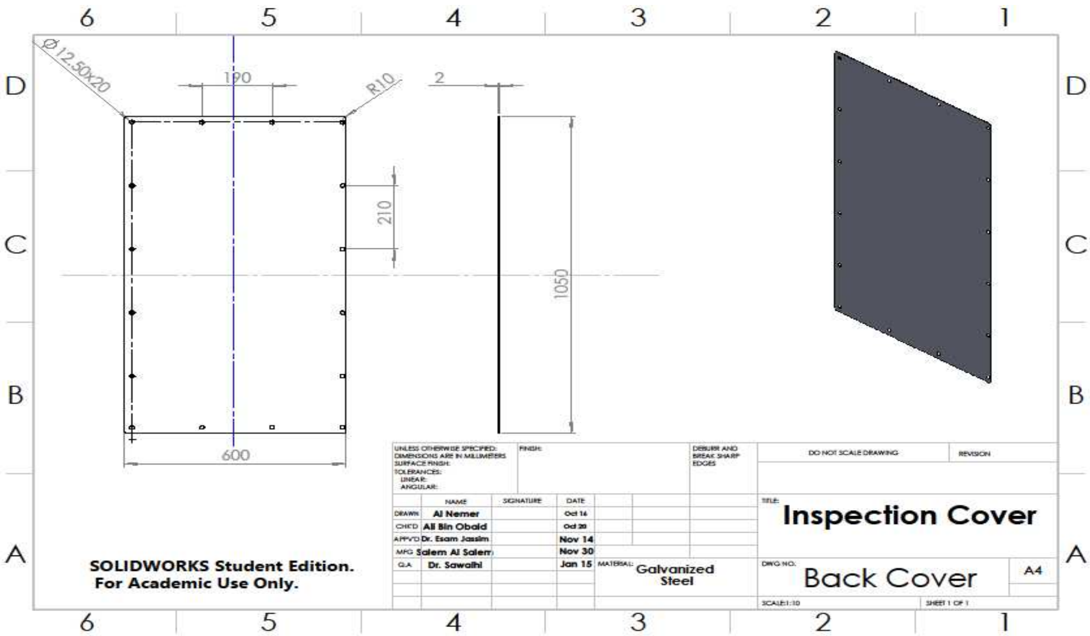
Axial flow fan drawing



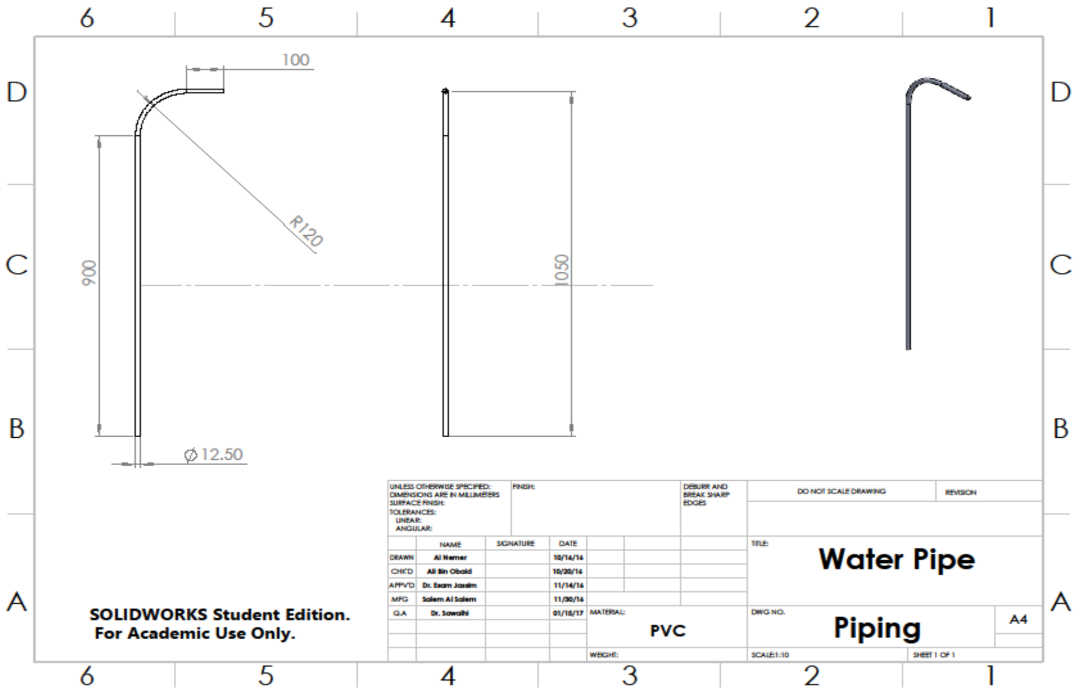
Fill drawing



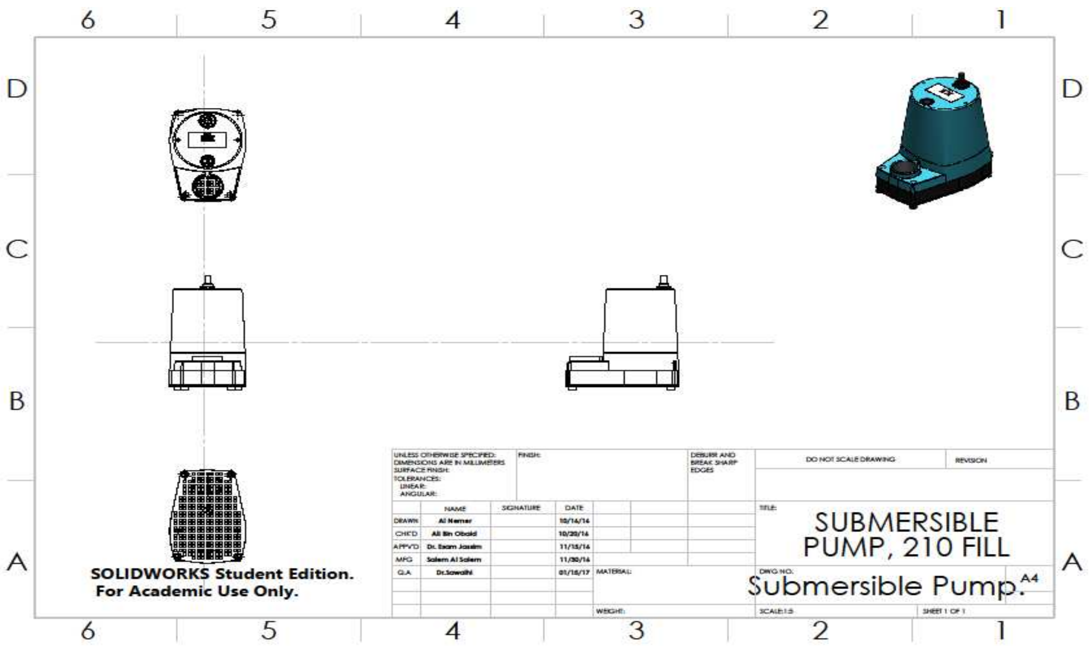
Inspection cover drawing



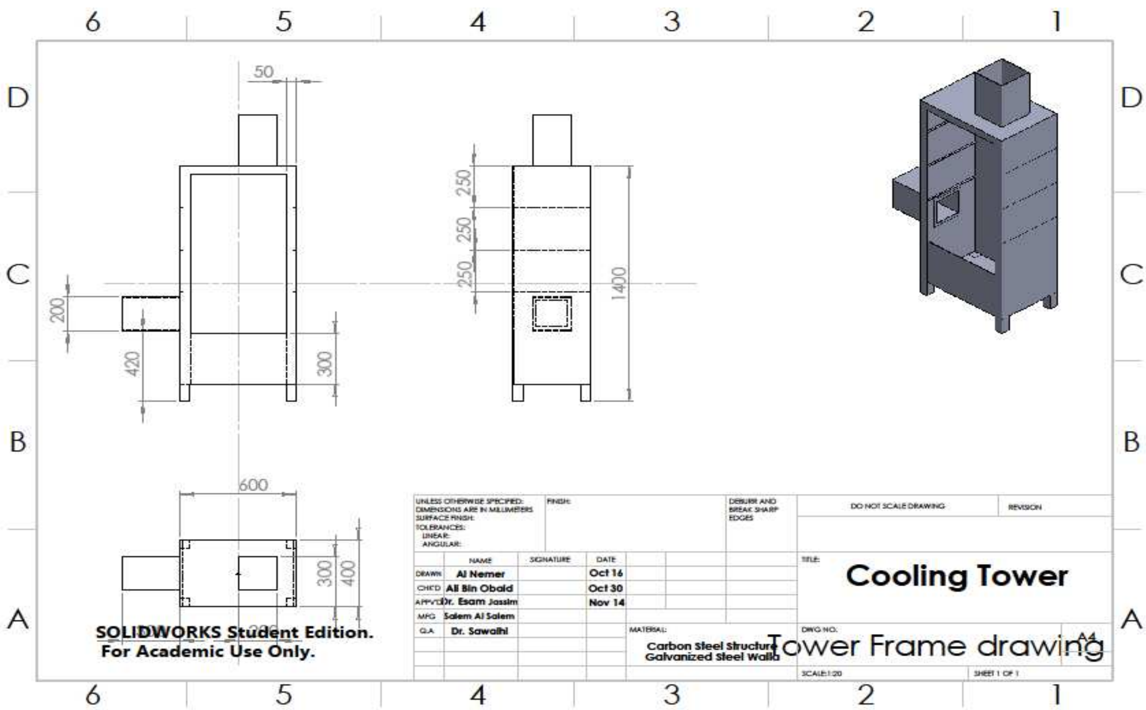
Piping drawing



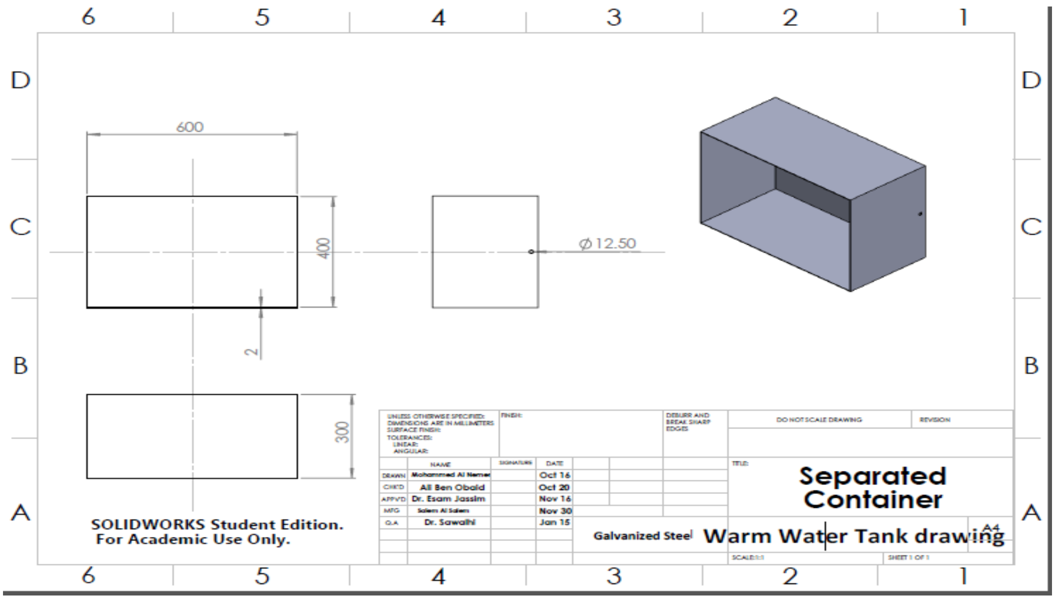
Submersible pump



Tower frame drawing



Warm water tank



Appendix C

Operation Manual

To safely and properly operate the system, follow the below steps:

- Fill in the separated tank with warm water (40-45 C) to a volume of 60L.
- Plug in the electrical power wire to a power source of 220V.
- Measure the warm water temperature and record.
- Turn on the pump and observe the water flowing properly.
- Measure and record the ambient air temperature.
- Turn on the required fan either induced or forced draft.

*Note: forced draft fan is 110V power supply voltage.

- Observe the system for any abnormalities.
- Do your calculations (if any).
- Make sure that cooled water outlet valve is open to drain the collection basin and maintain proper flow throughout the tower.
- Batteries of water sensors to be replaced with 1.5V once damaged or malfunctioned

Design & Construction of a Pilot-Scale Cooling Tower

Supervised By: Dr. Esam Jassim

Examiners :
Dr. Nader Sawalhi
Dr. Nader Nader

Team#6 Members:

1- Ali A Ben Obaid
201100293
2-Mohammed A Al Nemer 201100192
3-Salem H Al Salem
201100294
4-Hussain A Al Mubarak

Outlines

- Introduction
- Project’s Objectives
- Background & Literature Review
- Work Plan Timeline
- Work Performed
- Results & Analysis
- Conclusion
- Challenges

Introduction

- Eco-friendly device
- Economically effective
- Feasible to improve
- Interest to study heat transfer

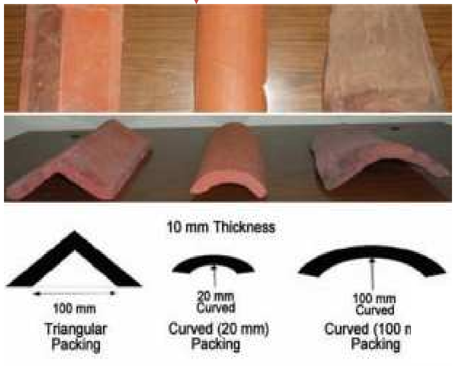
Project Objectives

Achieving greater heat transfer

Realistically modeled cooling tower

Utilizing both induced & forced draft fans

ackground & Literature Review



Work Plan Timeline

Phase 1

Reviewing & Researching

- Resources
- Materials Availability
- Design Constraints
- Literature Review

- Report drafts
- Problem statement
- Possible solution

Phase 2

Tower Construction

- Solid Works design
- Material selection
- Welding structure
- Subsystems

- Frame construction
- Pump selection
- Fan size selection

Phase 3

Project's Assembly

- Pump connection
- Fans installation
- Spray nozzles
- Sensor installation

- Sensor programming
- Experimental Attempts

Phase 4

Results & Analysis

- Measurement taking
- Fixing faults (if any)
- Finalizing the report

- Recording Readings
- Data Analysis
- Conclusion

Work Performed/Tasks

Mohammed

Salem

Hussain

Ali

All members

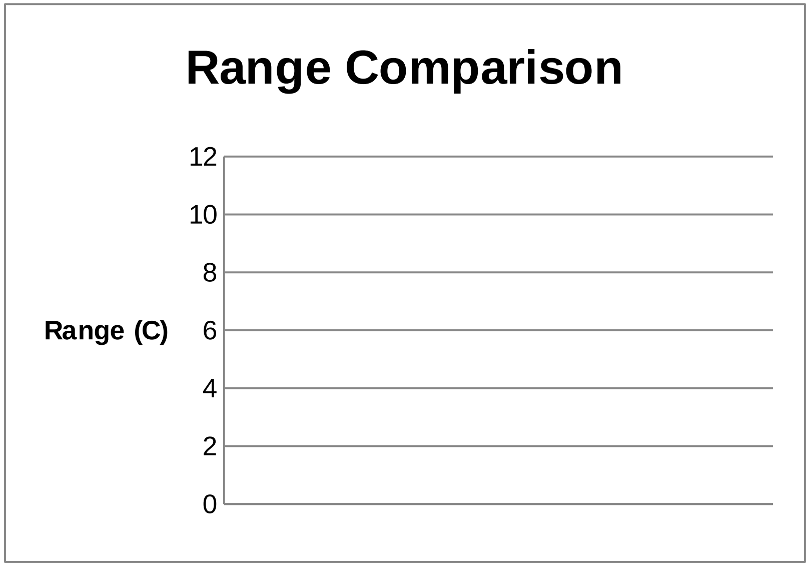
Experimental Setup & Conduct

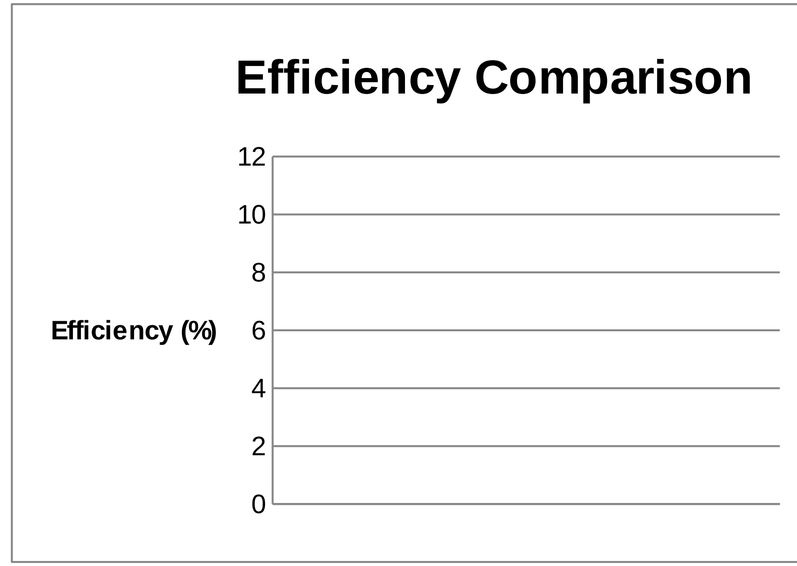
- **Range** is the difference between CW and HW

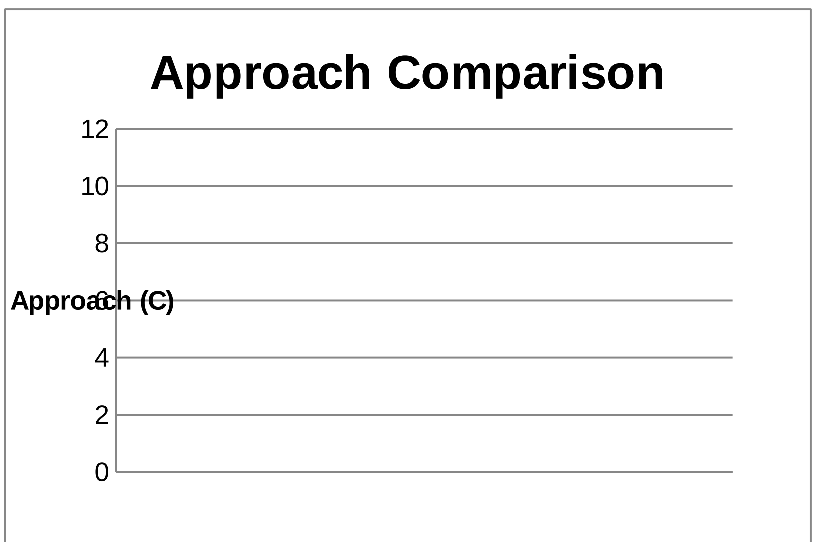
-**Approach** is the difference between wet bulb temperature and CW

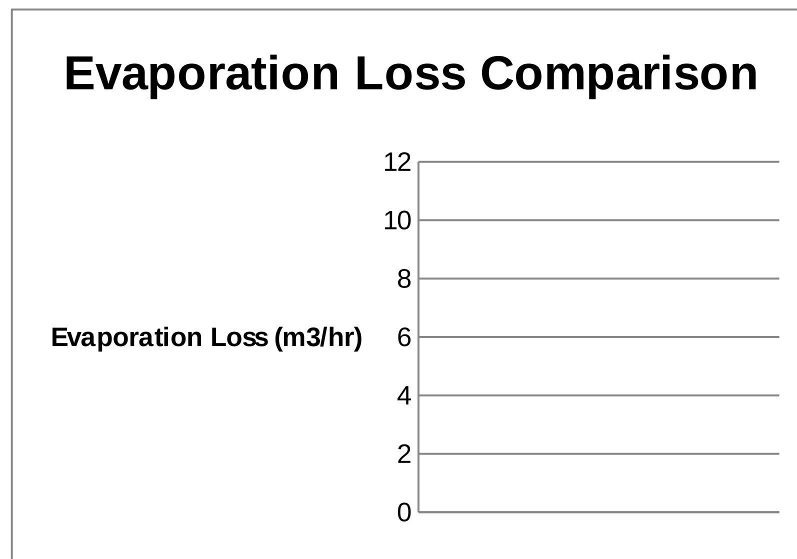
-**Efficiency** is Range / (Range + Approach)

-**Evaporation Rate** = 0.00085xRx1.8x C where R is range and C is water flow rate


Range Comparison
12
10
8
6
4
2
0
Range (C)


Efficiency Comparison
12
10
8
6
4
2
0
Efficiency (%)


Approach Comparison
12
10
8
6
4
2
0
Approach (C)


Evaporation Loss Comparison
12
10
8
6
4
2
0
Evaporation Loss (m3/hr)

Conclusion

Zigzag way water flow pattern

Using both fans resulted in positive impact

Stainless steel fills is effective

-Many benefits

Recommendations

Maintain the warm water temperature

Introduce air flow meter

Employ humidity sensor

Use higher air flow rate

Challenges

1. Material Selection
2. Leak!
3. Time management
4. Juggling from work to university to home

Special thanks to ME Faculty