An Open Source APP-HARDWARE setup to control the system for DATA CENTER COOLING

By

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Presented to the Faculty of the Graduate School of

The University of Texas at Arlington in Partial Fulfillment

Of the Requirements

For the Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

THE UNIVERSITY OF TEXAS AT ARLINGTON

December 2016

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Acknowledgements

I would like to personally thank you to my supervising Professor Dr. Dereje Agonafer for his encouragement, aid and mentoring for the duration of my research course and studies at University of Texas at Arlington. The pragmatic advice and support provided by him was the essential support because of which helped me to finish my thesis.

I would like to thank Dr. Andrey Beyle and Dr. Haji-Sheikh for taking time to serve on my thesis committee. Also, I would like to thank Mr. VARUN RAHUL for her invaluable support and timely inputs of Mr. Ashwin

I am obliged to Ms. Sally Thompson and Ms. Debi Barton for helping me out in all educational matters. They have been very kind and supportive whenever I needed their help.

I would like to thank all my friends in the EMNSPC team and in the University for assisting me throughout my time here at this University. Also I thank fiancé Prachi Gokhale-Darekar, Guruprasad Shinde and Ayush Khandelwal for staying with me thick and thin. Finally, I would like to thank my parents for their support, both emotionally and financially, without which I would not have been able to complete my degree.

December 06, 2016

Abstract

An Open Source APP-HARDWARE setup to control the system for DATA CENTER COOLING

By

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Control systems for data center cooling exists in the proprietary form and are often sold as part of the overall unit. They provide vital information related to the cooling systems and supply information on the temperature and humidity conditions inside the data center. Since most of these control systems software are proprietary they are expensive and hence not accessible to all. This project aims to develop a control system that operates on similar lines, but is economical and easily available. Developing a desktop or mobile based application not only gives the end user control over the cooling method (ex. DEC VS IEC) but also serves as a means to highlight ways in which one can reduce the usage of resources such as infrastructure, capital and energy

For optimal operation of the information technology (IT) module, the dry bulb temperature (T_{DB}) and relative humidity ($\emptyset$) at the inlet of a server must either be in the ASHRAE recommended zone or should be as specified by the IT equipment manufacturer. The main aim of the aforementioned tool is to communicate with the cooling system and to ensure that the conditions (temperature and relative humidity) inside the data center facility remain in the desired operating zone irrespective of the conditions outside the data center. The software tool is developed to be implemented on a modular data center with air-side economization, direct and indirect evaporative cooling capabilities.

The hardware used for this is an Agilent 34972A DAQ unit, Arduino MEGA 2650, SHT 11 temperature and humidity sensor and J type thermocouple (Two), and for the software; NI LabView 2015 and Matlab R2016a. The hardware is chosen to prepare two types of configurations; both achieving the same goal of data acquisition, but at different operating costs. While developing such a software tool, there will be a few points that will be thoroughly emphasized upon such as the flexibility of being used on any Operating System and portability i.e. it can be set up on any device that supports a display and has an interactive screen

The tool aims to control the amount and the duration for which this cooling is provided. Also, optimizing the switching time between the scenarios that require cooling and that don't can help us understand the efficiency with which the given cooling system can respond to inclement weather. This tool can help in deciding which cooling systems are best suited based on the location of the data center.

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Chapter 1

INTRODUCTION

1.1 Importance of DATA CENTER

Data centers are specialized units of which primary purpose is to store data, to process data, and transmission of data. Modern society thrive on data services like

Emails, online shopping, music streaming, digital medical records, social media et cetera these processes are depended on efficient data centers. Definition of data center as per Environmental Protection Agency (EPA) [1] - “Data Center applies to spaces specifically designed and equipped to meet the needs of high density computing equipment such as server racks used for data storage and processing. …

The Data Center locations are designed for computing and server functions; the volume of digital data developed, stored and transmitted, is increasing every day in last two decades. In 2011, as per IDC [2] report zettabyte limit was passed in 2010 and it was projected that the volume of information generated and replicated will pass 1.8 zettabyte in 2011,

A 9 times increase in 5 years. Spread of internet and increase in devices that use internet, has increased the volume of data use. Internet of things(IoT) has fuelled increase in use of internet as more people connected to it.[3] Data centers has two primary contents, first is ITE (IT Equipment) and second is supporting infrastructure.IT equipment consists of servers, storage hard disk ,processors .And supporting infrastructure consists of UPS, switch gear HVAC units ,et cetera.

P Delforge [4] published report for NRDC (National Resources Defense Council).As per this report data centers in 2010 consumed 1.1% to 1.5 % [5] of total global electricity and 1.7% to 2.2% of total USA electricity. He also estimated that 91 billion KWh of electricity was consumed in 2013 and predicted that it would reach 140 billion kWh by 2020.As a result of this increasing trend in consumption of data electricity- Data Center Industries, US government and other prominent companies focused their attention to improve data center efficiency and sustainability. In typical data center, 38% electricity is consumed by data center cooling as in figure below

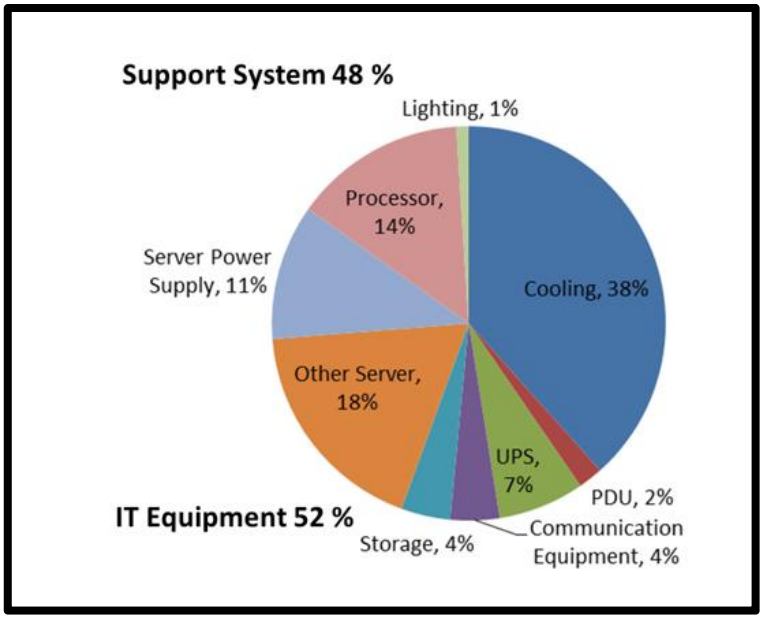

Figure 1.1 Electricity Break Down of Typical Data Center

1.2 Data Centers: Breakdown of Energy Consumption and Importance of Cooling

Power consumption or electricity consumption of data center is distributed into two main source-first is IT equipment consumption and supporting equipment like cooling systems. The heat is generated by the consumption of power by IT equipment [6.7].If Heat is not removed then equipment may not operate reliably, and may be required to shut down. Heat sinks Heat Pipes, vapor chambers and fans are provided to remove heat from

Air Cooled IT equipment .IT helps in drawing cold air in and it pushes hot air hot outside. As Modern day data centers consists many IT equipment, cold air is provided to data center by huge cooling systems to remove hot air. One can find many types of data center cooling systems ready in market and it has different effect on efficiency of data center.

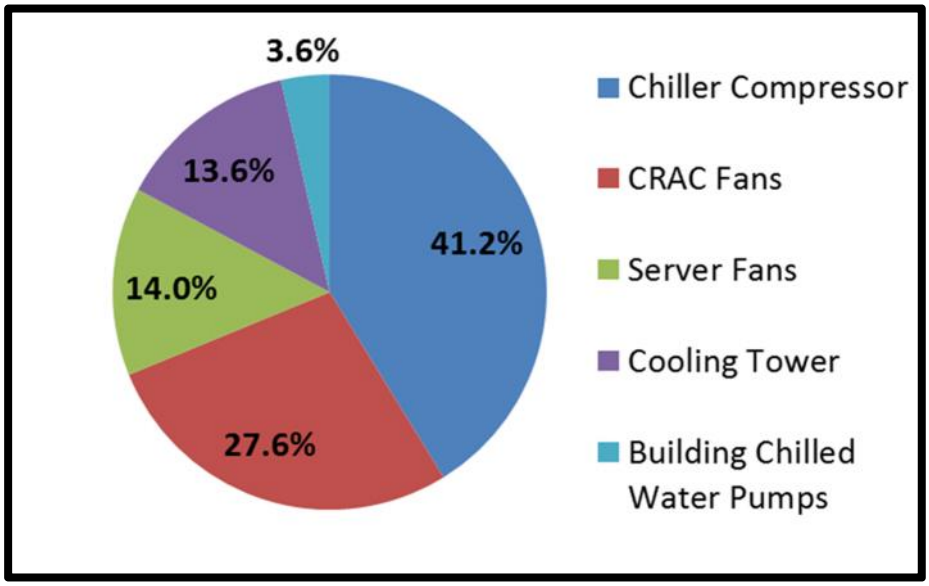

Figure 1.2 Distribution of electricity Consumed by HVAC system

Figure above shows the distribution of electricity consumed by different data center components. A generalized data center cooling system is made up of chiller compressors, CRAC fans, cooling tower building chilled water pumps et cetera. A significant portion of total electricity is consumed by chiller compressor. By cutting down the use of this chiller compressor considerable amount of energy can be saved. Alternative cooling methods like use of outside air and water-side economization and their application to data centers are studied further.

1.3 ASHRAE Thermal Guidelines for Data Processing Environment

Enthusiasm in improving efficiency of data center has gathered ASHRAE Technical Committee 9.9 different companies of data center, government agencies and research institutes. Ramifications of ITE on data center operational efficiency has explained by

Thermal Guidelines for Data Processing Environment. Performance and availability were the main focus for 2004 ASHRAE Thermal Guidelines for environmental specification of ITE, It wasn't emphasis on computation of efficiency of the ITE. [8]

As data centers ITE of different vendor and cooling system from data center a common operating condition was required that would allow the equipment to operate data center reliably.

The energy consumption by data center had growing worries, which made TC 9.9 update the Thermal Guidelines which considered the wider temperature and humidity ranges. Maintaining high reliability of ITE was main aim of 2008 update and also to operate the data center more efficiently. In 2008 temperature and humidity envelopes were widened with respect to 2004 or 2008 thermal guidelines. Two data center classes were also updated as number increased from two to four. Table 1-1 and Figure 1-2 show the 2011 Thermal Guidelines for Data Processing Environments – Expanded Data Center Classes and Usage. The Thermal Guidelines apply to the inlet air conditions to the IT equipment.

Since 2008 ASHRAE broaden the recommended range for temperature and humidity of inlet air conditions. This has been very helpful in increase in economizer hours and reduction in mechanical cooling. Data center cooling companies have realized that the outside air can be used to reduce the use of mechanized cooling and there is a future

scope to research more into alternate and renewable and sustainable cooling methods like air side economization and DEC like water side economization.

Chapter 2

Methods of Cooling Using Outside Air

2.1 Economizer

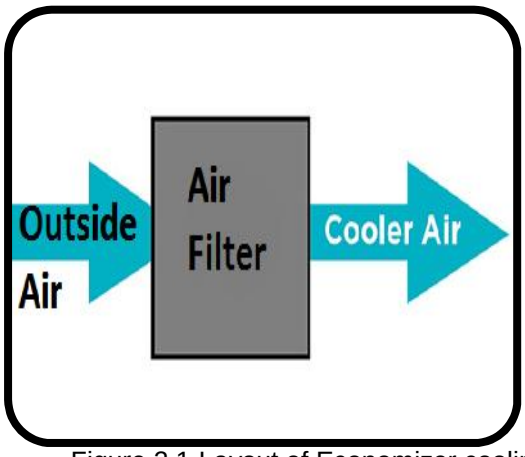

Figure 2.1 Layout of Economizer cooling

It is simplest method of data center cooling. When the properties of the outside air are same as ASHRAE recommended properties for data center, then the air is directly sent to data center .only air is filtered

2.2 Return Air.

When the outside air is cool, the return air coming from data center hot aisle is mixed with outside air. The final resultant air lies in ASHRAE recommended zone .As outside air is mixed return air to achieve the recommended conditions no mechanical cooling is required.

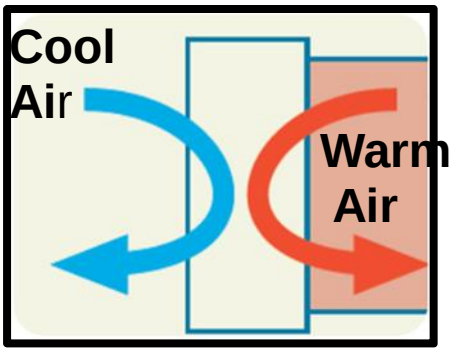

Figure 2.2 Return Air cooling method

2.3 Direct Evaporative Cooling

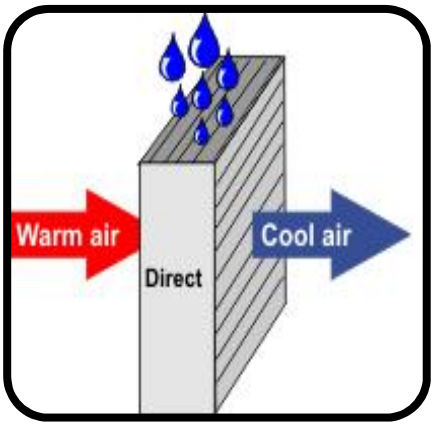

Figure 2.3 Direct Evaporative Cooling. [9]

In direct evaporative cooling, outside air is send through a medium .The medium is generally cellulose and water saturated media and it is cooled by evaporation. The resultant air is blown out by a blower. In Direct evaporative cooling, moisture is added to the air .The process continues until the air stream is close to saturation It is process where the dry bulb temperature is reduced, DEC is constant wet bulb process.

2.3.1 Advantages of DEC

- DX/chilled water cooling needs for fresh air .DEC reduces that requirement
- Mechanical cooling cost is reduced by 25% to 65%.

- As the mechanical cooling is less needed, the increasing the existing equipment is easy.
- Compressor life is increased
- Heat exchanger life is increased.

2.3.2 Temperature reduction achievable using direct evaporative cooling

The greater the difference between the wet bulb and dry bulb temperatures, the greater the achievable temperature reduction. Here's how to calculate temperature reductions achievable with direct, indirect, indirect/direct, and indirect/indirect evaporative cooling. These examples use a starting dry bulb (DB) temperature of 86 degrees F and wet bulb (WB) temperature of 66 degrees F. With direct evaporative cooling, the dry bulb temperature is reduced while the web bulb temperature remains the same.

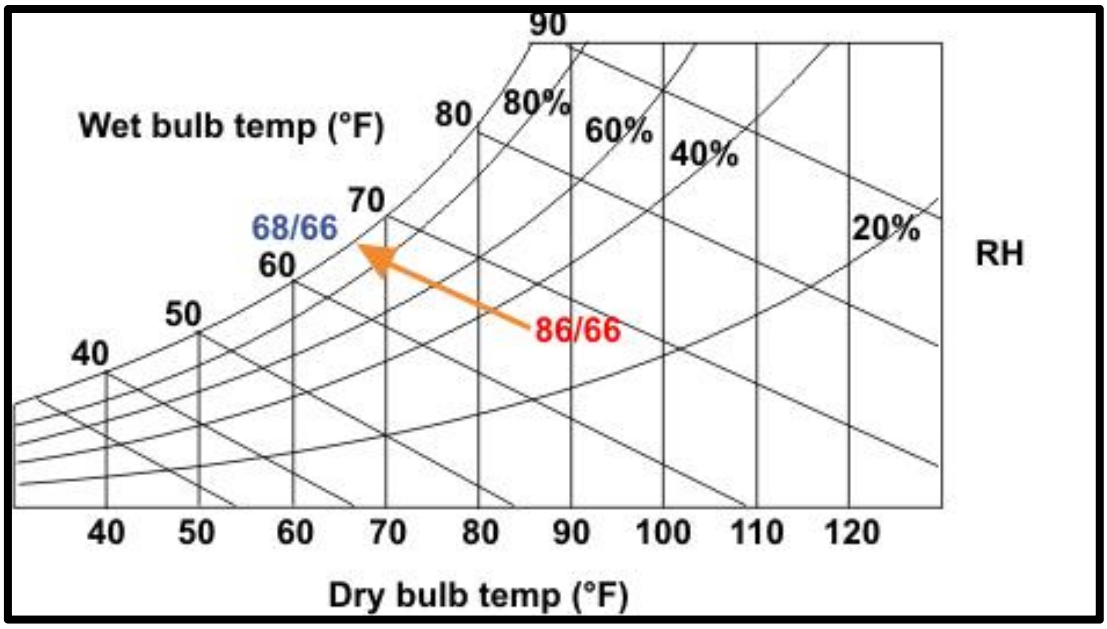

Figure 2.4 Process of DEC on Psychrometric Chart

- Temp drop achievable = (dry bulb - wet bulb) x (efficiency* of the media)

  Example: (86 degrees - 66 degrees) x .9 = 18 degrees

- Achievable temp = dry bulb - temp drop achievable

  Example: 86 degrees - 18 degrees = 68 degrees DB/66 degrees WB

- Starting DB: 86 degrees

  Ending DB: 68 degrees

2.3.3 Test Cities and Procedure:-

Albuquerque and Tucson are two cities selected for testing of DEC mode of software. Excel of weather data is sent into application for the month of June and July for these two cities. The test media for DEC are Celdek and Glassdek. Celdek has Saturation Efficiency or effectiveness 0.8 and Glassdek has 0.94 .Saturation Efficiency is calculated on standard data. Appendix D shows the weather data for two cities .The final temperature after DEC is calculated and it is plotted against days and with Inlet temperature.

Chapter 3

Methods of Data Collection

3.1 Introduction

In any cooling system, data measurement or data acquisition is the most important aspect. To gather data of outside air, primarily two approaches were used .first is data collection by Agilent DAQ (Data Acquisition System) and second is Arduino DAQ. Third method of input is an excel file .This method was used where physical data collection is not possible or primary data collection is failed and data is collected using other means.

3.2 Agilent DAQ

The company named Keysight-Agilent manufactures DAQ system that is data acquisition system. Industry uses Agilent DAQ system for data collection .This was the main reason behind the use of Agilent DAQ.

Figure 3.1 Agilent DAQ showing Temperature in Degree Centigrade

3.2.1 The specification of Agilent DAQ is as follows:-

- 3-slot mainframe with built-in 6½ digit DMM and 8 optional switch and control plug-in modules [10]
- Measures and converts -11 different input signals: temperature with thermocouples, RTDs and thermistors; dc/ac volts; 2- and 4-wire resistance; frequency and period; dc/ac current [10]

- IO options for easy connectivity to your PC: 34970A: GPIB, RS-232 34972A: LAN, USB [10]
- Graphical Web interface for point and click monitor and control (34972A)
- USB flash drive support to copy/log data in standalone applications (34972A) [10]
- Temperature Sensor-Thermocouple – 34970-61606 J type thermocouple

  Accuracy: – (1.0OC)

  Range: – (-250Oc to 1200OC)
- Bench Link Data Logger Software to configure and control tests, display results and collect data for further analysis [10]

3.2.2 The outside air properties measured:-

1. Tdb Dry Bulb Temperature
2. Twb Wet Bulb Temperature

3.2.3 Method of measurement –

The Dry Bulb temperature, means "air temperature", it is the most routine referred property. If it is referred to the temperature of the air then it is are commonly referring to the dry bulb temperature. It is called "Dry Bulb" because the air temperature is indicated by a thermometer not affected by the moisture of the air. Dry-bulb temperature - Tdb, is measured freely exposing thermometer to the air but shielded from radiation and moisture. The temperature is measured in degrees Celsius (oC) or degrees Fahrenheit (oF). On psychrometric chart the dry-bulb temperature is shown along the bottom axis of the psychrometric chart. Constant dry bulb temperatures appear as vertical lines in the psychrometric chart.

Twb- Wet Bulb Temperature. It is commonly known as the adiabatic saturation temperature. It is measured by using a thermometer with the bulb wrapped in wet muslin. It is the adiabatic evaporation process in which water from the thermometer bulb evaporates and the cooling effect is indicated by a "wet bulb temperature". Tdb is higher than Twb. The rate of evaporation from the wet bandage on the bulb, and the temperature difference between the dry bulb and wet bulb, depends on the humidity of the air. The evaporation from the wet muslin is reduced when air contains more water vapour.

Figure 3.2 -Set Up for Measuring Wet Bulb Temperature

3.3 Arduino DAQ

Arduino is an open-source project that created microcontroller-based kits for building digital devices and interactive objects that can sense and control physical devices .It is one of the most common hobby based board used in the world. It is sophisticated .It has good technical support and driver support.

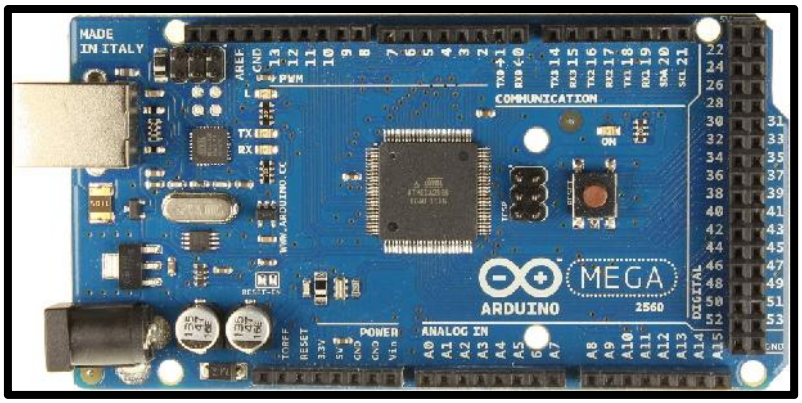

Figure 3.3 –Arduino Mega-2560 board.

Arduino board with DHT 11 makes Arduino DAQ, which is used to measure Tdb (Dry Bulb Temperature) and Relative Humidity. DHT sensor means Digital Humidity Temperature sensor.

3.3.1 The specification of Agilent DAQ is as follows:-

- Microcontroller - ATmega2560 [11]
- Operating Voltage - 5V [11]
- Input Voltage (recommended)- 7-12V [11]
- Input Voltage (limit) - 6-20V [11]
- Digital I/O Pins - 54 (of which 15 provide PWM output) [11]
- Analog Input Pins – 16 [11]
- Flash Memory -256 KB of which 8 KB used by boot loader [11]
- Length x Width x Weight -101.52 mm x 53.3 mm x 37 g. [11]
- Sensor - DHT 11 [11]

  Accuracy - Temperature +/- 2oC & humidity 5%

  Range - Temperature 0-50oC & humidity-20-80%

3.2.2 The outside air properties measured:-

Tdb Dry Bulb Temperature

RH Relative Humidity

3.2.3 Method of measurement

Tdb Dry Bulb Temperature-It measures the dry bulb temperature in similar way to Agilent DAQ

Relative Humidity - Humidity is the quantity of water vapor present in air. It is displayed as an absolute, specific or relative value. Relative humidity is expressed by either partial vapor and air pressure or density of the vapor and air, or by the actual mass of the vapor and air. Relative humidity is usually expressed in per cent and abbreviated by φ or RH.

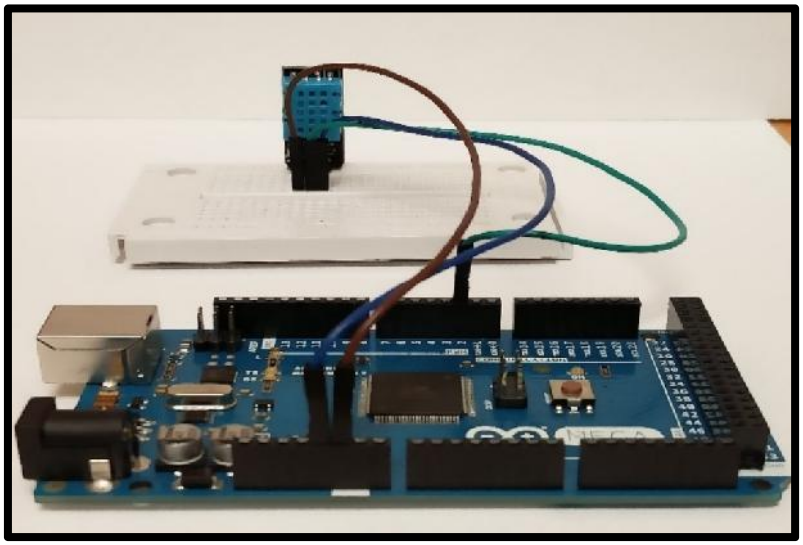

Figure 3.4 Arduino Mega board with DHT 11.

Chapter 4

Software part –Coding and control logic.

4.1 Introduction

Each software has two part .First is front end and second is back. Front end is where user enters input, it has Graphical User Interface (GUI). In computer engineering front end (frontend) and back end (backend) is distributed between the segregation between the presentation layer (the front end) – which is the interface between the user – and the data access layer (the back end). The front and back ends may be distributed among one or more systems.

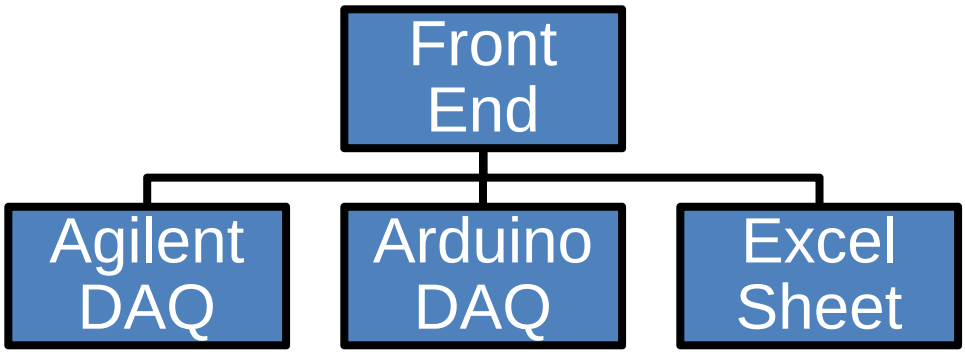

Figure 4.1 Different types of Front End of the app.

4.2 Front End

Front-end development, is known as user-side development. It is method of developing application using scripting language where user can see and interact. As the front end scripting languages changes constantly, developer has to update the knowledge it. The main Aim of designing is to make sure that when user open up the application, they see data in a way that is easy to interact and it should be related. Front is divided into three main categories as per input hardware. Each hardware input has different interface. First

is for Agilent DAQ, second is for Arduino DAQ and third is for Excel Sheet input. All three front designed using LabVIEW. LabVIEW has its own VI creator.

4.2.1 Agilent DAQ front end

When the hardware used is Agilent DAQ, this front pops up. It has three input as per image below. First two are temperature inputs (Tdb and Twb) coming from Agilent DAQ and third is Saturation Effectiveness for user to input. The graphs of Tdb and Twb are plotted showing trend in temperature variation.

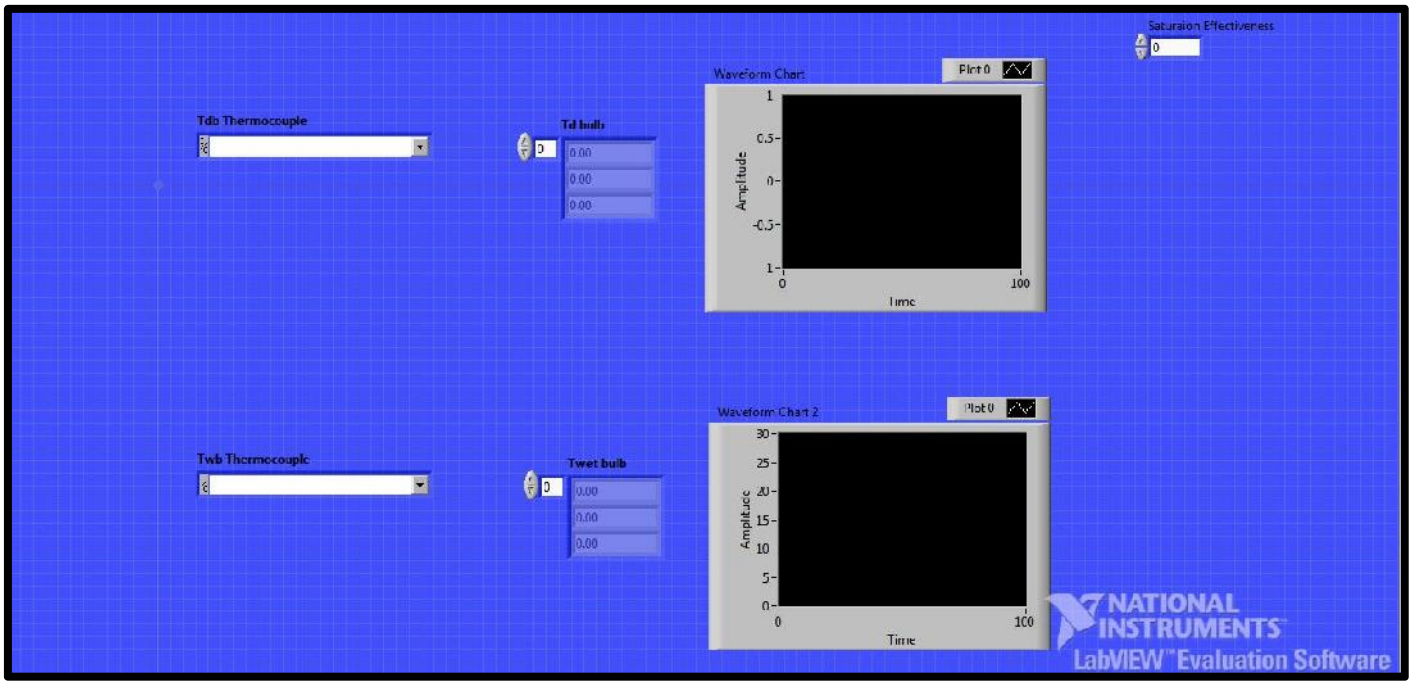

Figure-4.2 Front End –Software Interface for Agilent DAQ

4.2.2 Arduino DAQ front end

Arduino DAQ is used when the method of input is Arduino DAQ.As Arduino DAQ measures Tdb and RH, these two are the primary input along with Flow rate, IT load, it has

also other displays. These displays are used to indicate percentage of outside air required when economizer is used and also Region Number and standard Psychrometric Chart.

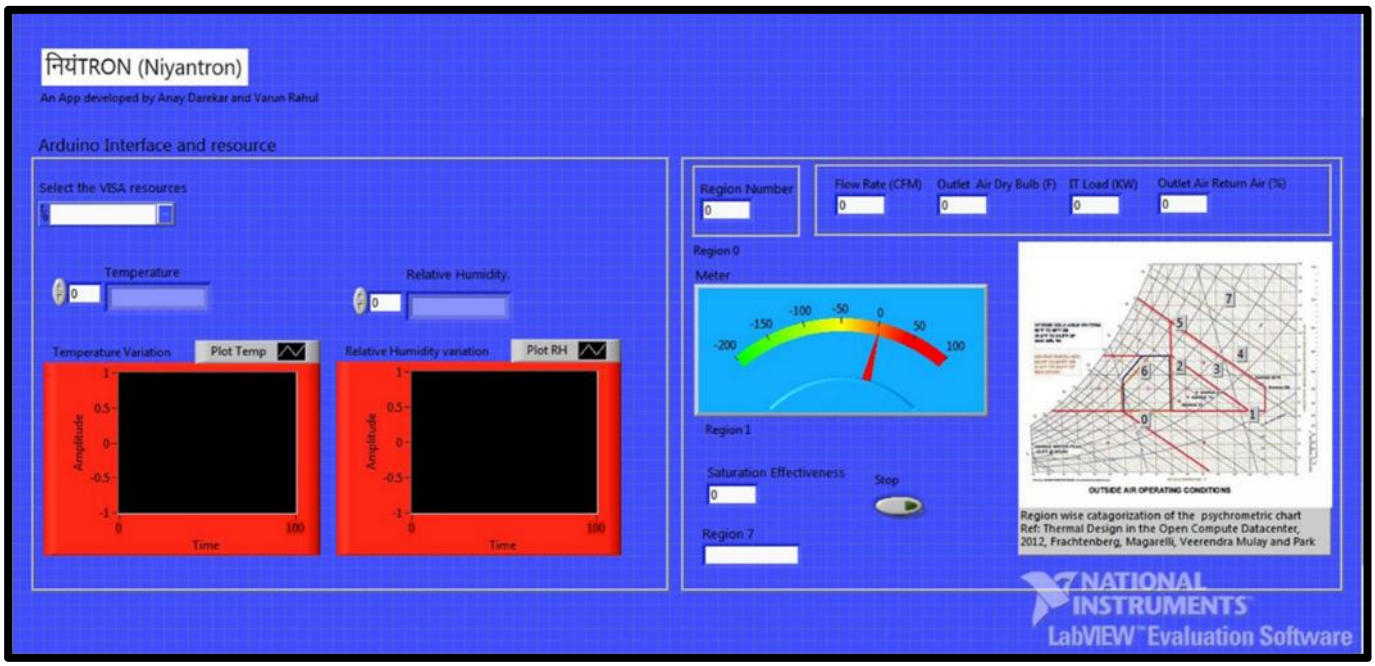

Figure 4.3 -Front End –Software Interface for Arduino DAQ

4.2.3 Excel Sheet front end

Excel front end is little bit different. The input is here excel file. It extracts data from excel file which is Tdb and RH. Plus it has also input box for Saturation effectiveness, flow rate and IT load for user to input. The front end will show plots of Tdb and RH.

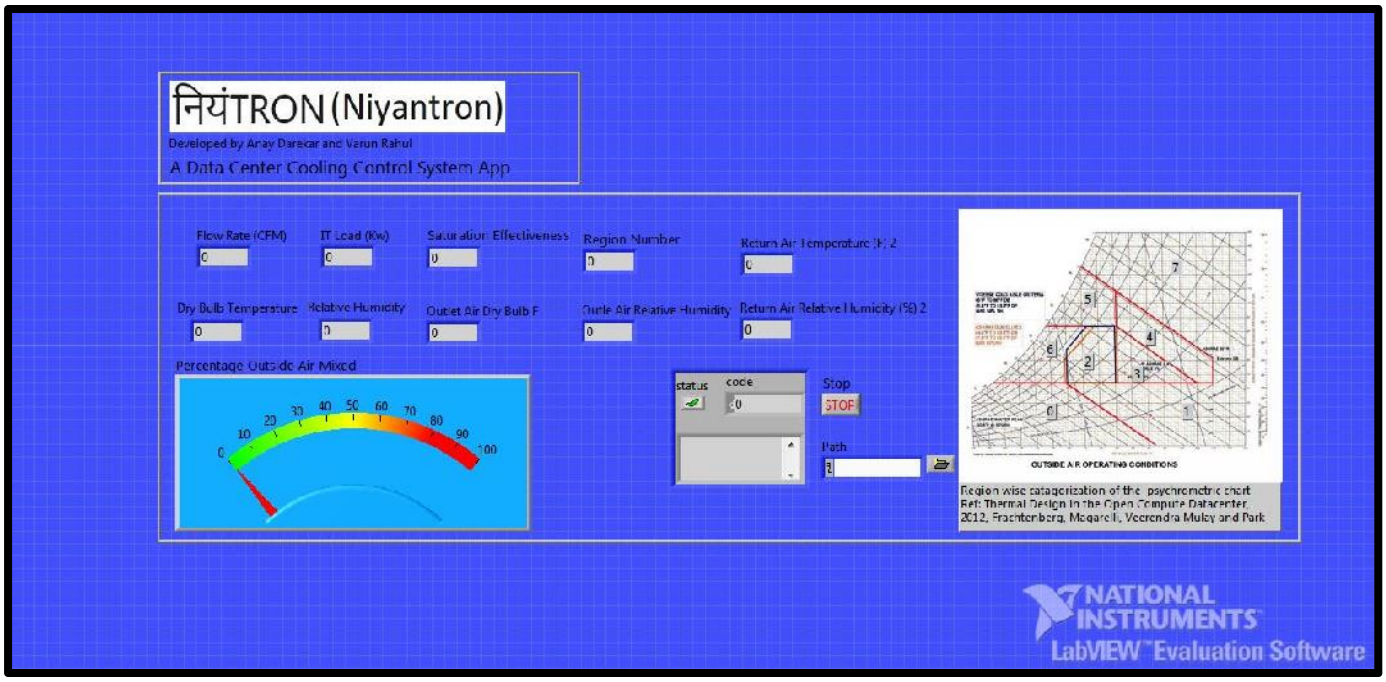

Figure 4.4 -Front End –Software Interface for Excel Input

Chapter 5

Coding and Logic

5.1 Introduction

Before starting the coding part, the psychrometric is divided into seven different regions .The regions are based on the cooling or heating process required to condition the outside air. [12][13] The regions are as per follows.

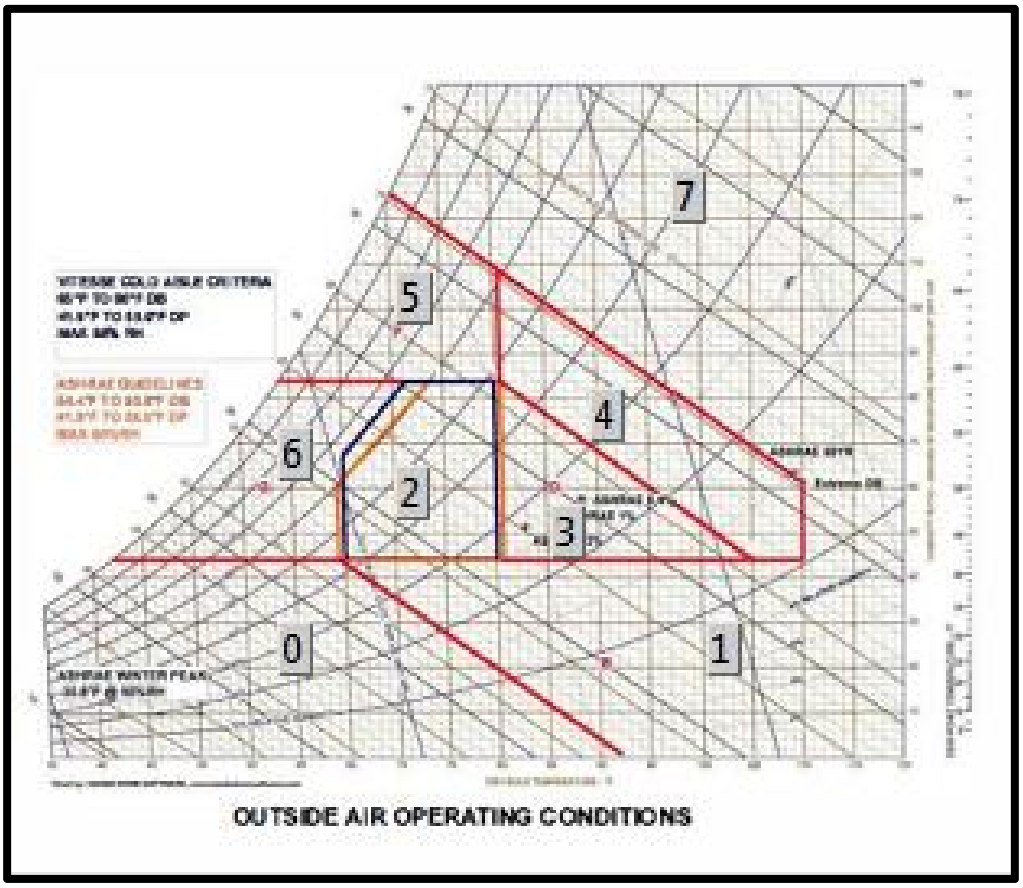

Figure 5.1 Psychrometric Chart Showing Different Regions

Region Number	Boundary Conditions	Cooling or Heating Process
0	(< 52°F DB and < 41.9°F DP):	Outside Air with Return Air
1	(> 52°F DB and < 41.9°F DP):	DEC
2	(> 65°F DB and > 41.9°F DP and <80°FDB and < 59.0°FDP and < 65%RH)	Recommended Zone (Economiser)
3	(> 80°F DB and > 41.9°F DP and <65. 76°FW B)	Economiser
4	(> 80°F DB and > 41. 9°F DP and > 65. 76°FW B)	Economiser + DEC or IEC
5	(80°FDB and > 59.0°FDP and > 65.76°FWB)	Economizer + DEC or IEC
6	(> 65°F DB and < 59.0°F DP and> 65 and < 63°FWB or > 65°FDB and> 41.9°FDP and> 65%RH and < 59.0°FDP or < 65.76°FDB	Economizer plus EC/H
7	Remaining region of Psychrometric Chart	Unacceptable Outside Air conditions

Table 5.1 –Different regions showing boundaries Psychrometric

Different regions has Tdb, Twb and Tdp as boundary limits.

5.2 Flow Chart for coding

Figure 5.2 –Flow chart of coding logic

As per the flow chart, the code is written and back end is programmed. First the data is acquired coming from hardware (Agilent DAQ or Arduino DAQ or Excel File Input). Data from hardware is then converted into programmable format so that the data is processed .Different data acquisition and conversion LabVIEW codes are shown below.

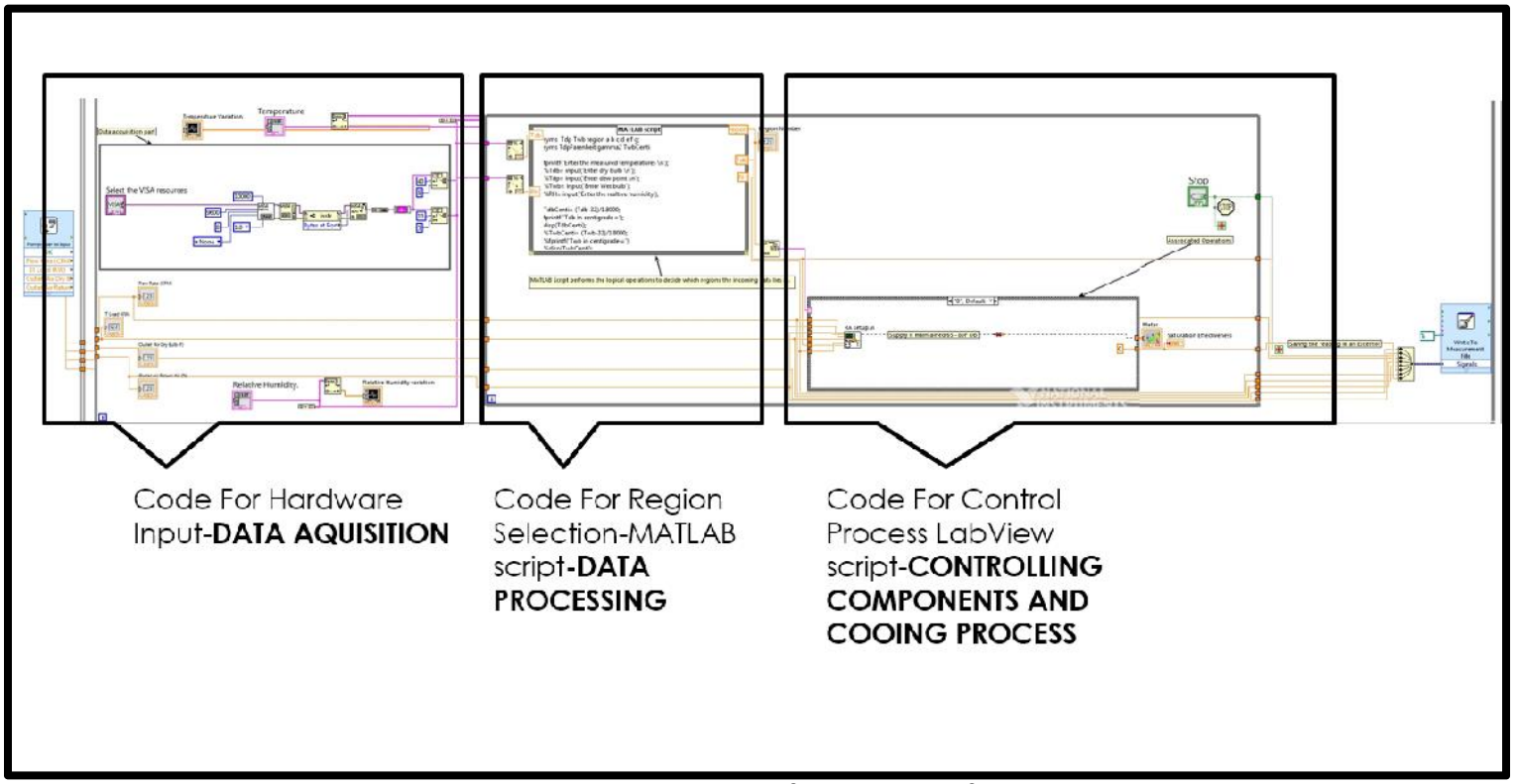

Figure 5.3 Distribution of Flow chart of coding logic

Figure above shows the distribution of flow chart on LabVIEW back end. Three different sections DATA ACQUISITION, DATA PROCESSING and CONTROLLING COMPONENTS & COOLING PROCESS. Data processing is pin pointing the location of the outside air temperature on psychrometric chart. And decide its air conditioning process. CONTROLLING COMPONENTS and COOLING PROCESS is process where the controlling of the actual components take place as per selected cooling method.

5.2.1 DATA ACQUISITION for Agilent DAQ

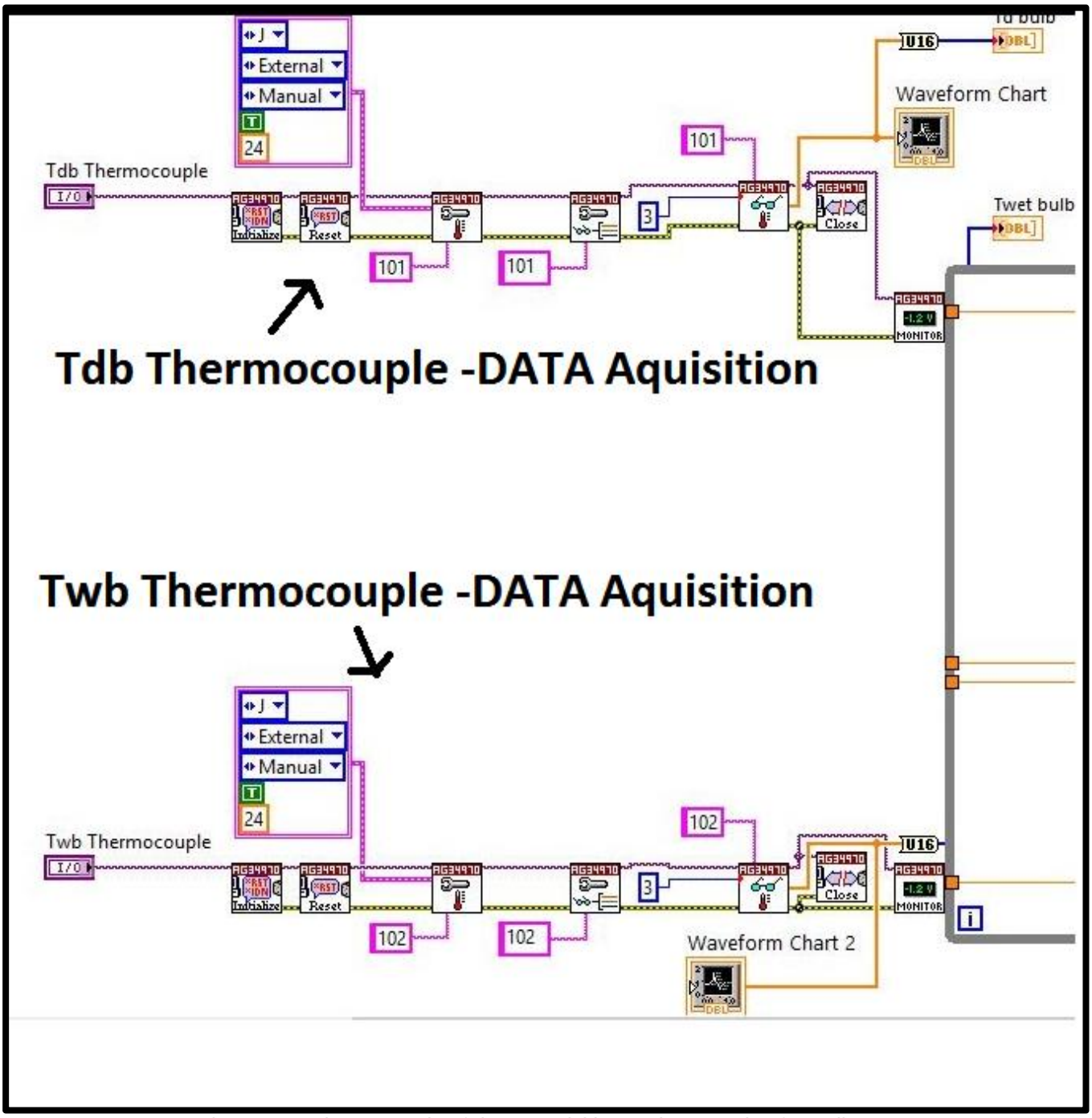

Figure 5.4 LabVIEW code of data acquisition and conversion for Agilent DAQ

5.2.2 DATA ACQUISITION for Arduino DAQ

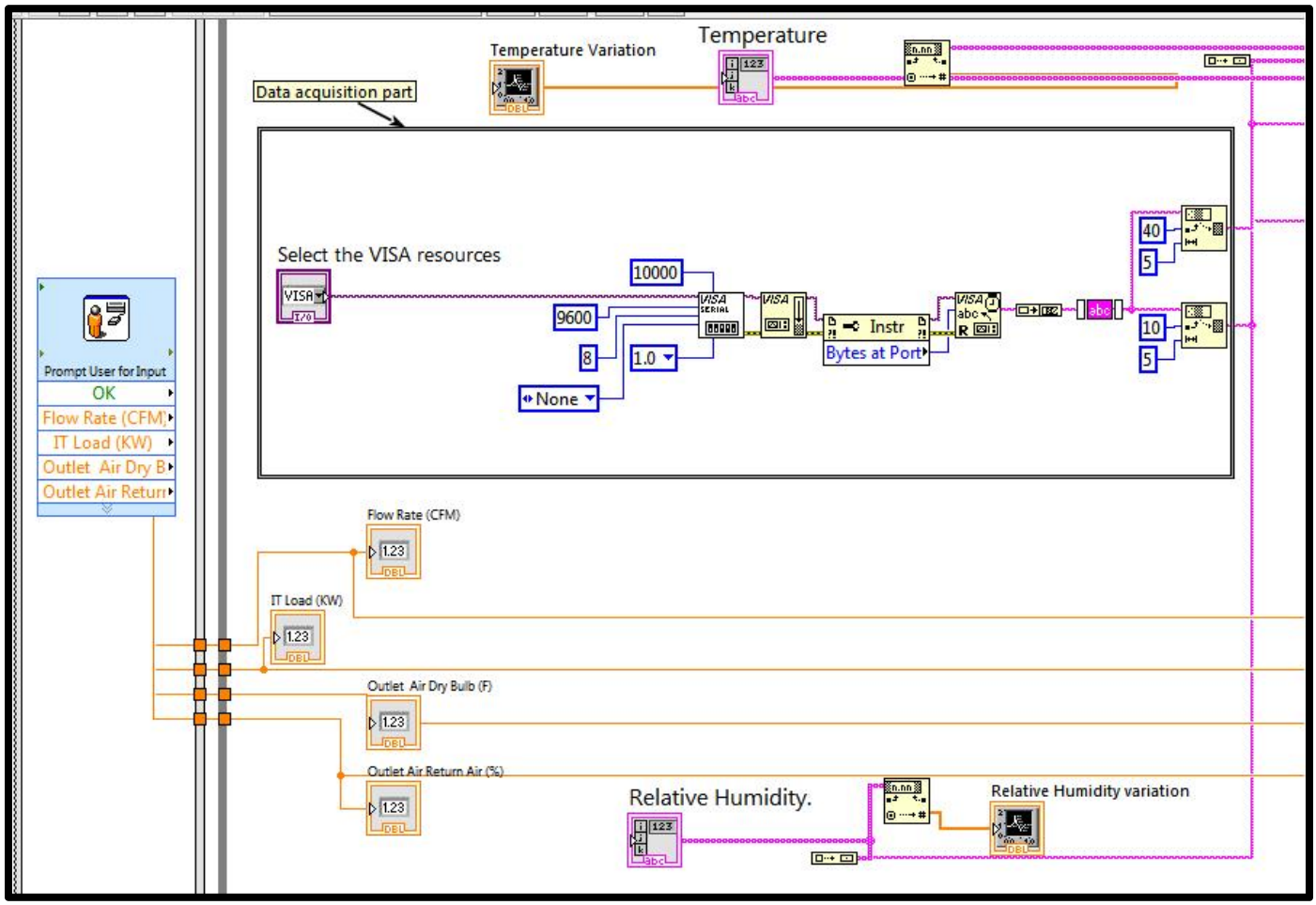

Figure 5.5 -LabVIEW code of data acquisition and conversion for Arduino DAQ

5.2.3 DATA ACQUISITION for Excel Sheet Input

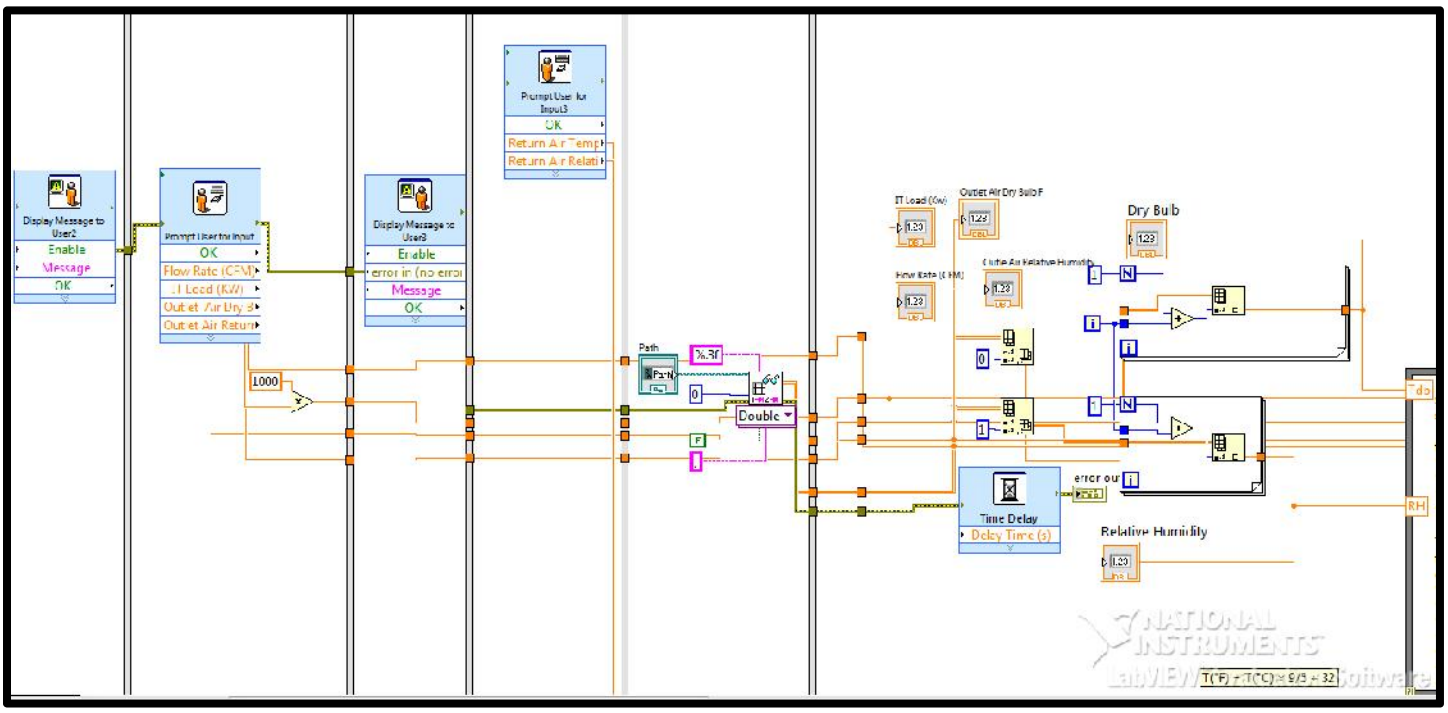

Figure 5.5 LabVIEW code of data acquisition and conversion for Excel File Input.

5.3 DATA PROCESSING

In Data Processing, data of outside air (Temperature and Relative humidity) is sorted and the location of outside air is pin pointed on the psychrometric chart. By the location of the point the region is selected and as per the region selected the air conditioning process. For data processing step, MATLAB code is embedded.

Coding in MATLB is flexible and simple. The Matlab Code is given in appendix. It gives number as an output which is then fed to CONTROLLING COMPONENTS and COOLING PROCESS.

5.4 CONTROLLING COMPONENTS and COOLING PROCESS

In this actual controlling of the components takes place. After getting the number coming from DATA PROCESSING, the region wise new window is popped showing different VIs from different processes. Each VI asks user to input different data as per cooling method and shows different outputs.

Different VIs are shown below.

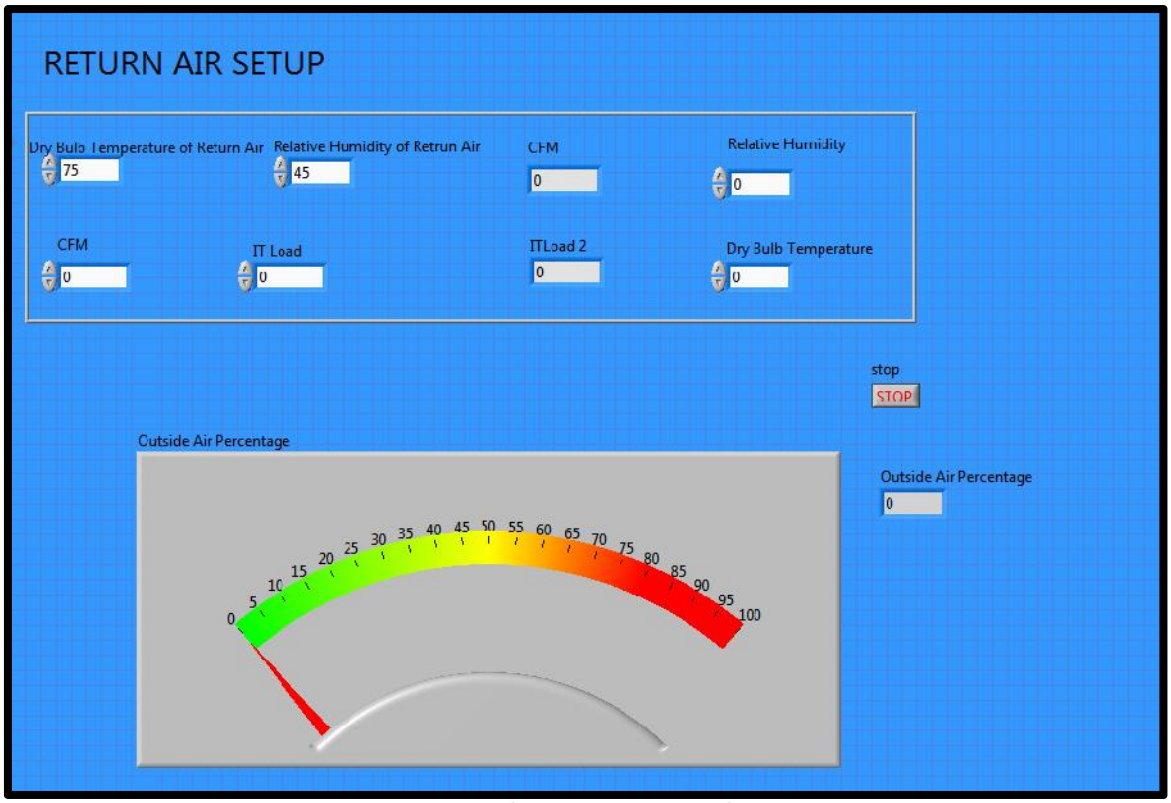

Figure 5.6 Return Air VI

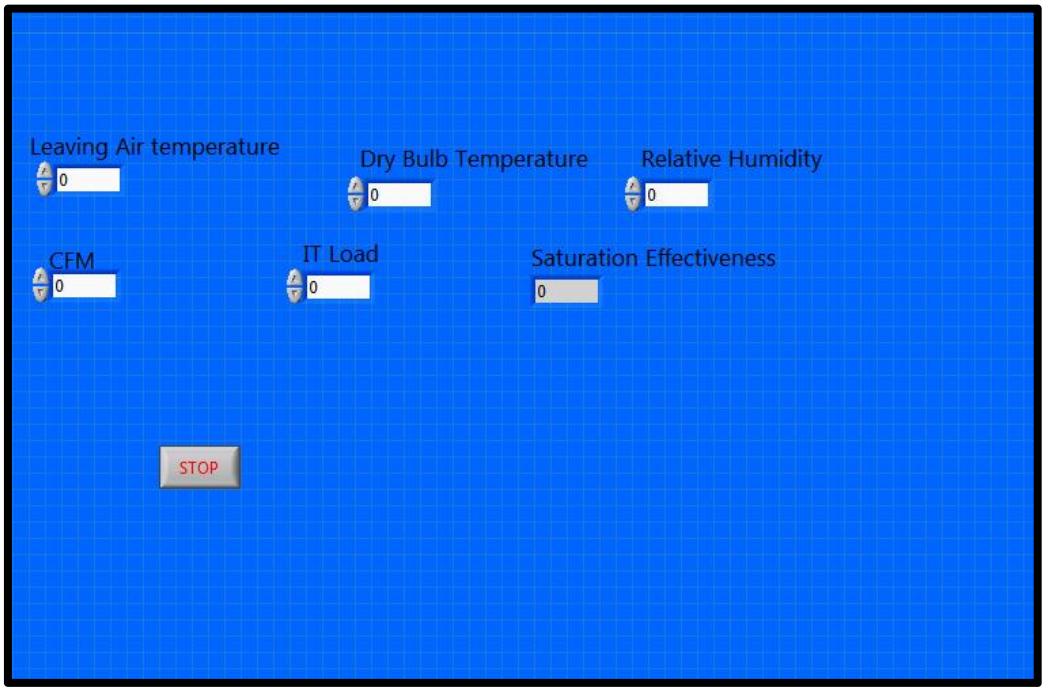

Figure 5.7 Direct Evaporative Cooling VI

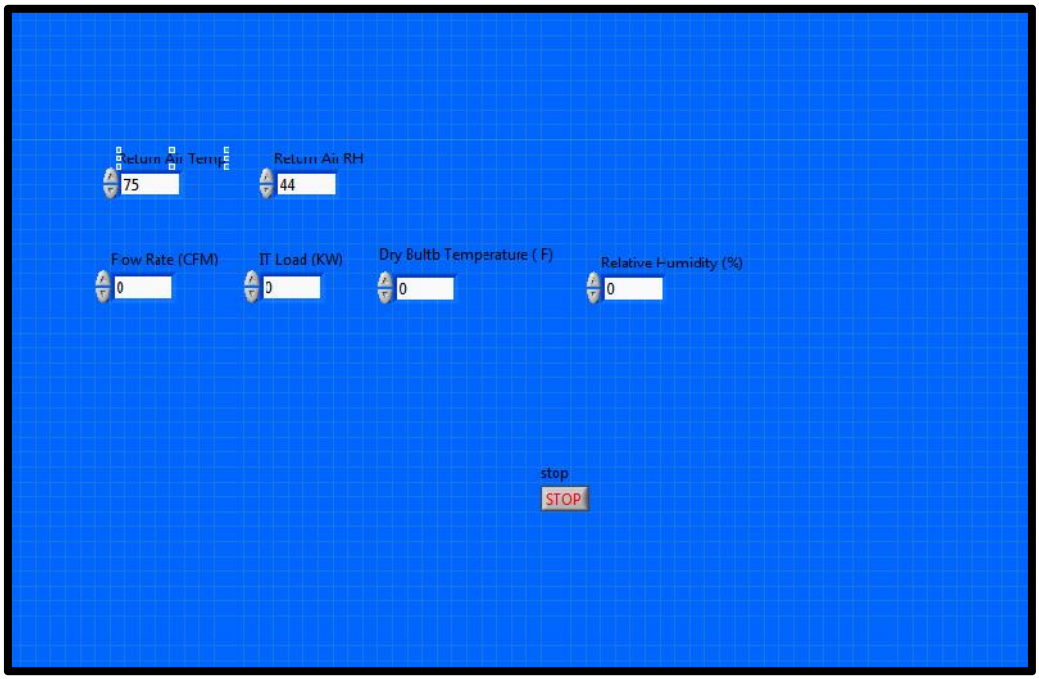

Figure 5.8 Economizer VI

Chapter 6

Proposed Demo Set Up

6.1 Introduction

The actual testing of software/app is the most essential step .Before testing it on actual data center, beta testing or previous testing is needed. That's where the demo set up comes in picture. Proposed demo setup is controlled by this app. It has three different regions. First is economizer. Second is mixing of outside air with return air and third is for direct evaporation chamber. The material for ducts is .The fans shown in figure are CPU cooling fans. Model number Silverstone AP121. And DEC media shown is either glassdek media or Celdek media. The Glassdek media has 0.94 saturation effectiveness and Celdek media has saturation effectiveness 0.8. The hot gun shown is used to replicate the effect of Hot Air coming from data center hot air aisle. The dampers and gears are manufacture using 3D printing .and servo motor used is maxon motor controlled using Arduino.

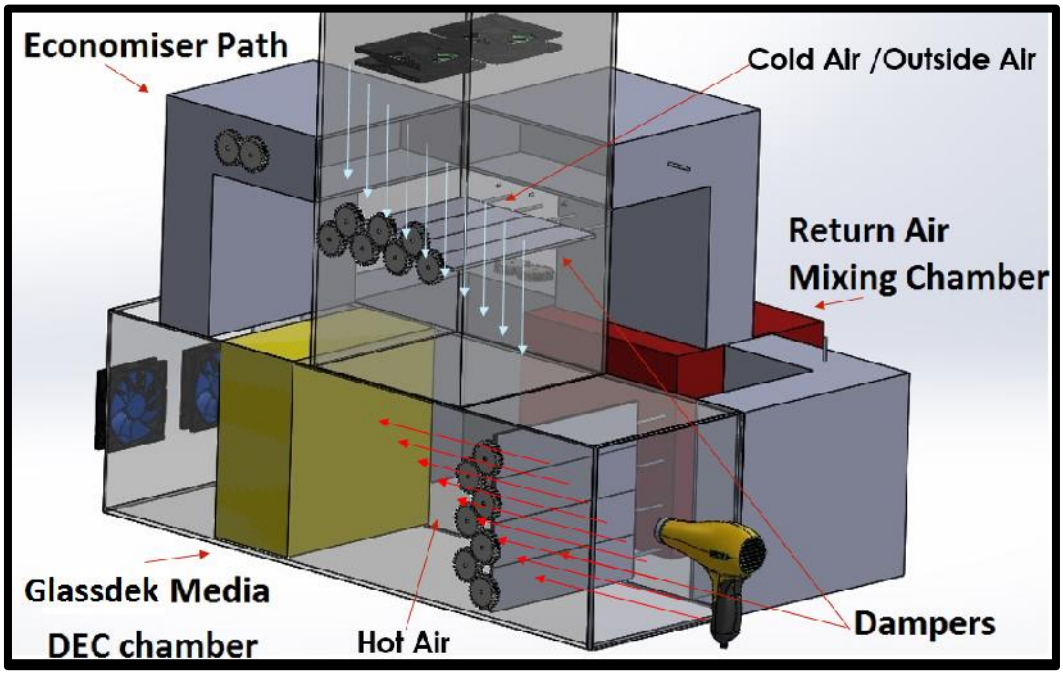

Figure 6.1 General Layout of Demo Setup

The figure above shows the proposed demo setup. There are dampers to control the flow of the air .When the cooling method is selected, the appropriate dampers are operated .The outside is coming from top. It is distribute into three chambers as per necessary cooling process.

6.2 Economizer

When the outside air properties are as per ASHRAE recommendations then the air is just filtered and directly passed to data center. In this process all other dampers are shut and only economizer dampers are open.

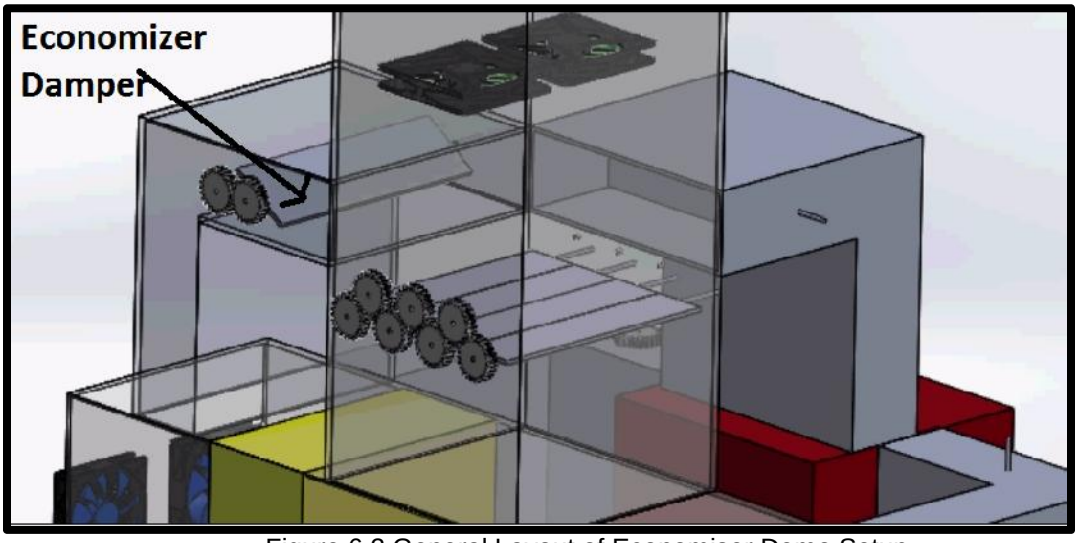

Figure 6.2 General Layout of Economiser Demo Setup

6.3 Return Air Mixing Chambers

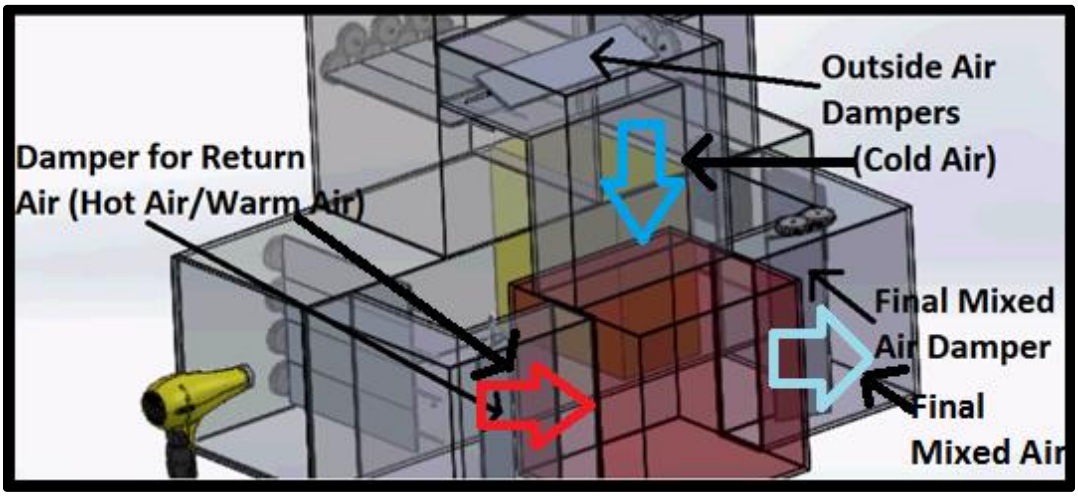

Figure 6.3 Return Air Mixing Chamber and its dampers.

When outside air is cold, the return air coming from IT equipment is used. Outside air is mixed with return air to condition and it brings the air into ASHRAE recommended zone. All other dampers are closed except Return air chamber as shown in figure.

6.4 Direct Evaporative Cooling Chamber.

When Outside air is dry and warm, DEC is used. The outside air is passed through DEC media. The dry bulb temperature is lowered and Twb & Relative Humidity is increased. The process is adiabatic.

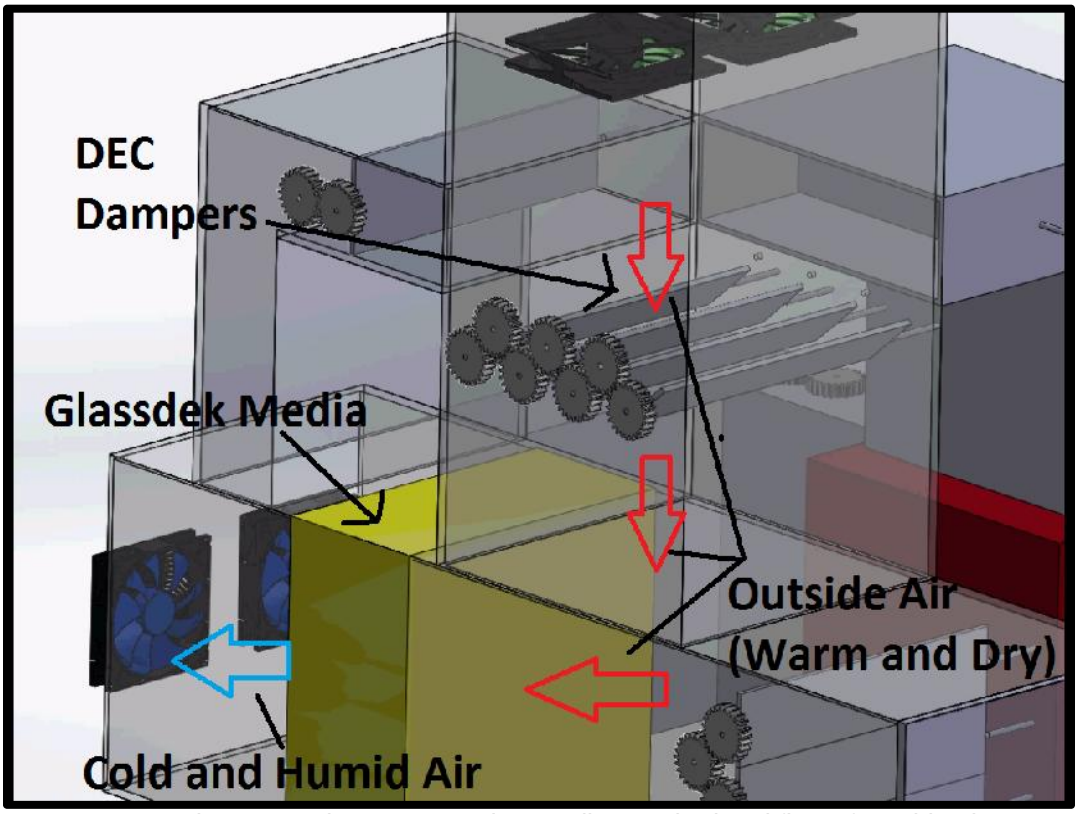

Figure 6.4 Direct Evaporative Cooling method and flow of outside air.

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6.4 Cost Analysis

- The Agilent DAQ [10]

  Base model : - $1300.00

  Supporting equipment (Multiplexer unit, thermocouples):- $400.00

  Total: - $1700.00

- Arduino DAQ- [11]

  The Board: - $45.00

  Sensors and Supporting Equipment $20.00

  Total:-$60.00

- Software Cost(Free) $0.00
- The proposed demo setup costs under $ 100.00. In addition to this, the app can be developed in under 400-420 man hours
- CPU Fans

  :-$4.99
- Servo Motor Arduino

  :-$11.00
- Outside Duct

  :-$25.00
- Hot GUN/Hair Dryer

  :-$15.00
- 3D printed parts –Dampers and Gears –Per gram cost

  :-$0.05
- Cooling Media

  $20.00

Chapter 7

RESULTS & CONCLUSION

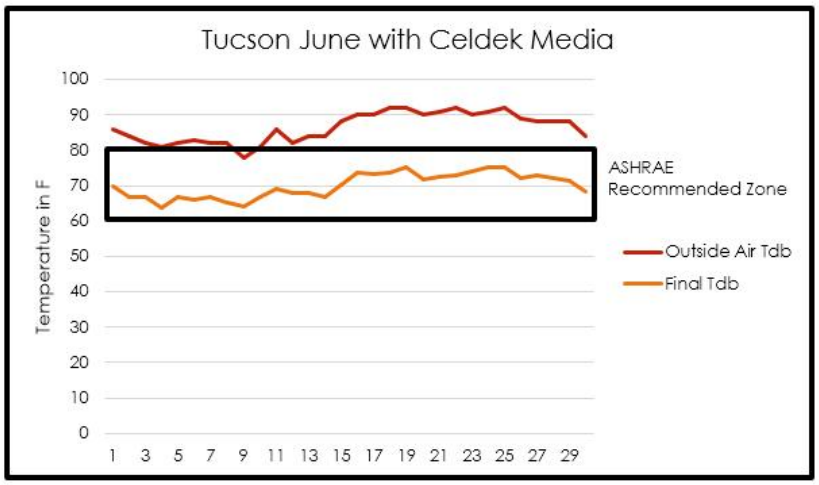


Figure 7.1 Tucson JUNE with Celdek Media

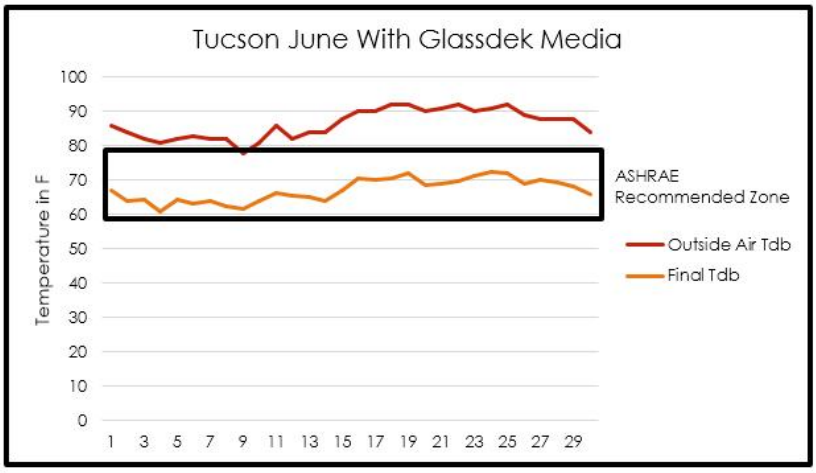


Figure 7.2 Tucson JUNE with Glassdek Media

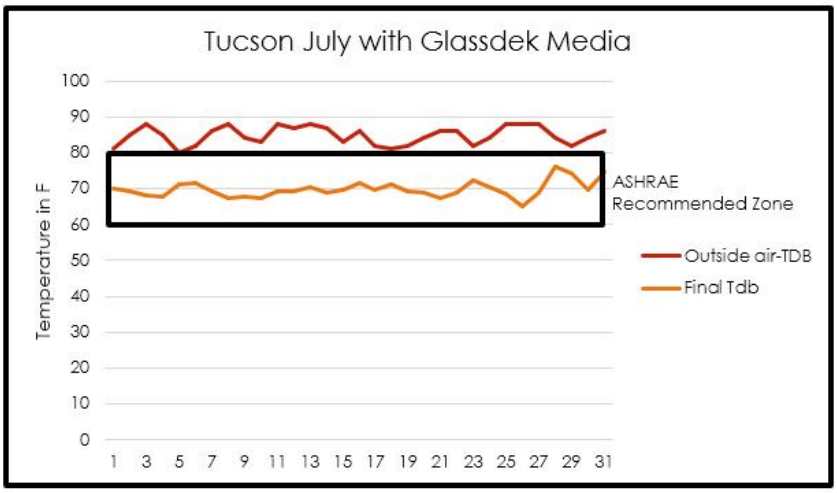


Figure 7.3 Tucson JULY with Glassdek Media

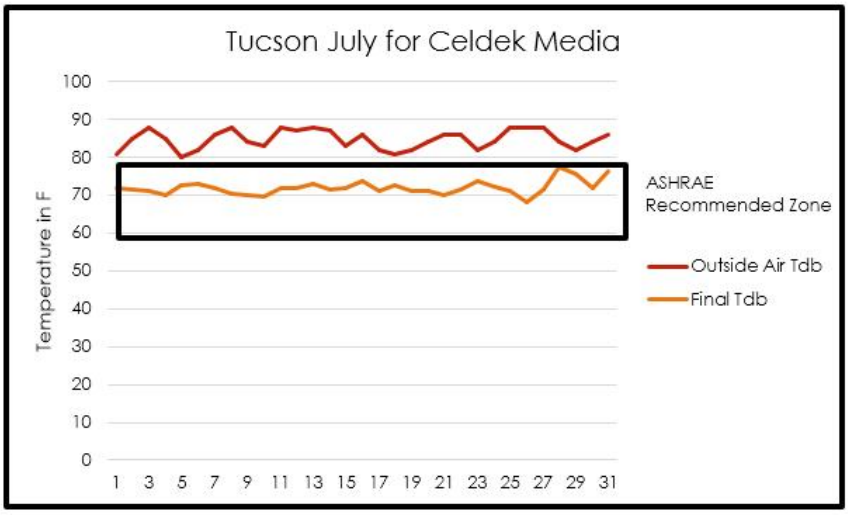


Figure 7.4 Tucson JULY with Celdek Media

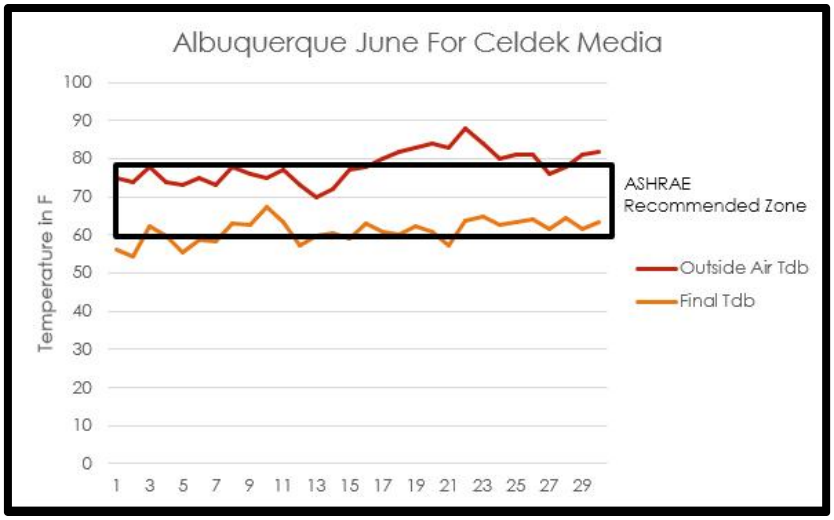


Figure 7.5 Albuquerque JUNE with Celdek Media

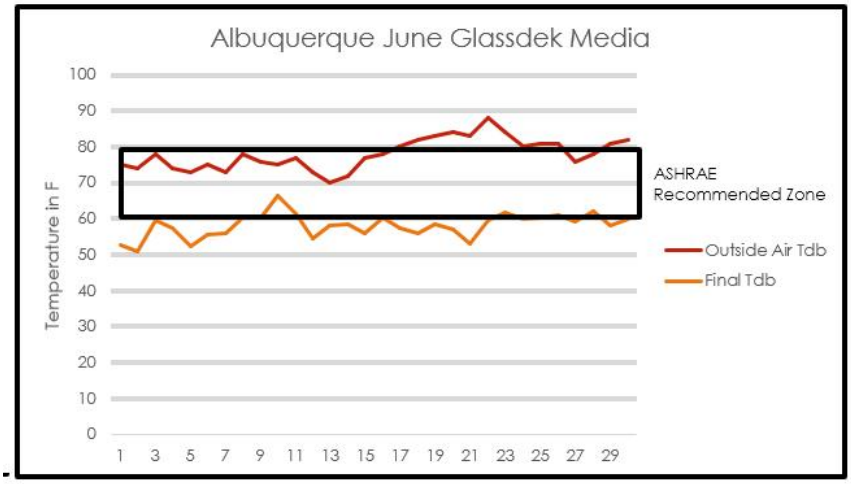


Figure 7.6 Albuquerque JUNE with Glassdek Media

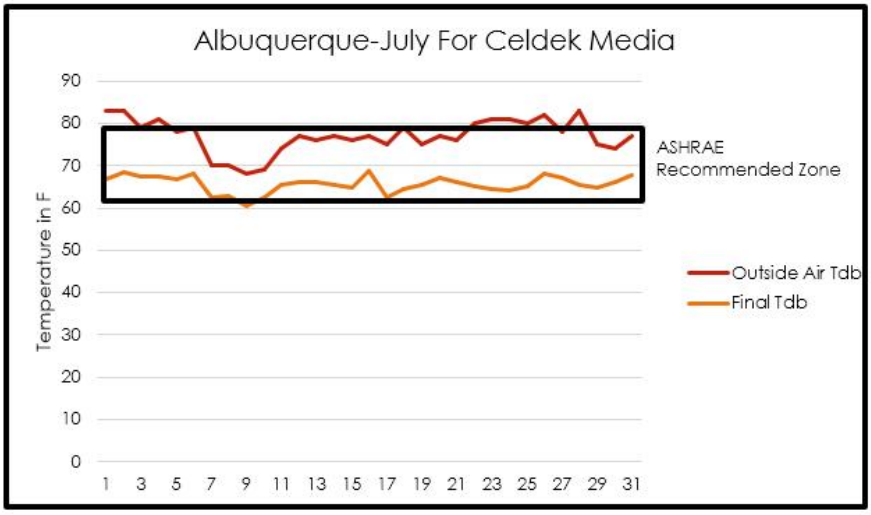
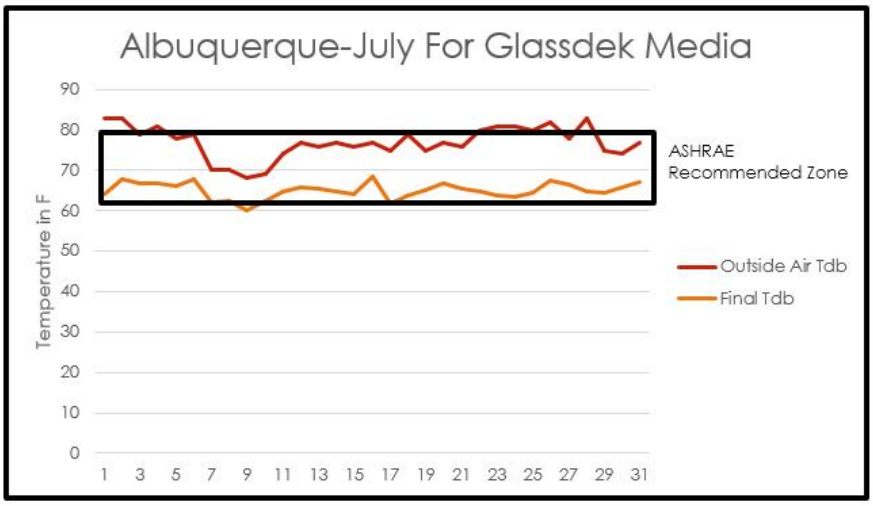


Figure 7.7 Albuquerque JULY with Celdek Media



- Figure 7.8 Albuquerque JULY with Glassdek Media

- Final Tdb after DEC falls in ASHRAE Recommended zone which shows that the process is perfect for Albuquerque and Tucson.
- Perfectly works with two cities or three cities and gives output
- The whole software is free of cost, only need to download the runtime libraries from respective websites of MATLAB and LABVIEW.
- Open Source System anyone can update and the version control makes better with every update. If effect of damper angle is published by someone the software is update accommodating that change making it more efficient.
- Total Cost is Less than $200 for Arduino DAQ. The Agilent costs around $2000.So over $1800 is saved in making basic Data Acquisition System.

Chapter 8

FUTURE WORK AND SCOPE

- More forms of cooling methods can be added. Current version has only three processes –return air, economiser and DEC. In future DX cooling and IEC cooling can be added
- This version is compatible with wired sensor .In future version it will be compatible with wireless sensors. Also Arduino comes with wireless capabilities. Wireless Arduino will be hooked to application.
- More sensor will be added for sensor fusion for control of temperature using IR sensor- IR sensor will be used to monitor aisle temperatures.
- This app is only mobile based .In future mobile based app for android and iOS will be developed
- Actual-physical demo model will fabricated and the software will be tested with Actual Stand Alone system.
- Data center outside USA will be added too.

```
#include "DHT.h"
#include <LiquidCrystal.h>

#define DHTPIN 22     // what pin we're connected to

#define DHTTYPE DHT11

DHT dht(DHTPIN, DHTTYPE);
LiquidCrystal lcd(8,9,4,5,6,7);

void setup(void) {
  lcd.begin(16, 2);
  lcd.print("Reading sensor");
  dht.begin();
}

void loop() {

  float temperature, humidity;

  humidity = dht.readHumidity();
  temperature = dht.readTemperature();
  delay(2000);

 lcd.clear();
char tempF[6];
 char humF[6];
 dtostrf(temperature, 5, 1, tempF);
 dtostrf(humidity, 2, 0, humF);

 lcd.print("T:");
 lcd.print(tempF);
 lcd.print((char)223);
 lcd.print("C ");
 lcd.print("H: ");
 lcd.print(humF);
 lcd.print("%");
}
```

Appendix B MATLAB code for sorting regions

```
%program for contolling cooling system
%define region and then use conditions to sort according to region.It is as
%per portland region.
%region 1
syms Tdb Tdp RH Twb region a b c d e f g;
clear all;
fprintf('Enter the measured temperatures \n');
%Tdb= input('Enter dry bulb \n');
%Tdp= input('Enter dew point \n');
%Twb= input('Enter Wet bulb');
if(Tdb<=52&&Tdp<=41.9&&Twb<46.8)
   %fprintf('REGION IS A \n');
   region=0;
%elseif
 %   fprintf('POINT LIES IN REGION B,C,D,G,E');
elseif (Tdb>52&&Tdp<41.9&&Twb<46.8)
   region=1;
   %fprintf('region is B \n')
elseif (Tdb>=65&&Tdb<80&&Tdp>41.9&&Tdp<59&&Twb<66.137)
   %fprintf('Region is C \n')
   region=2;
elseif(Tdb>80&&Tdb>80&&Twb<65.76)
   %fprintf('Region is D \n')
   region=3;
elseif(Tdb>80&&Tdp>41.9&&Twb>65.76)
   %fprintf('Region is E \n')
   region=4;
elseif(Tdb<80&&Tdp>59.0&&Twb>65.76)
   %fprintf('Region is F\ n')
   region=5;
else
   %fprintf('POINT LIES IN REGION G');
   region=6;
end
```

Appendix C

Psychrometric Chart 101

Psychrometry is the study of moist air and the changes in its conditions. The psychrometric chart graphically represents the relationship between air temperature and moisture content and is a basic design tool for mechanical engineers and designers.

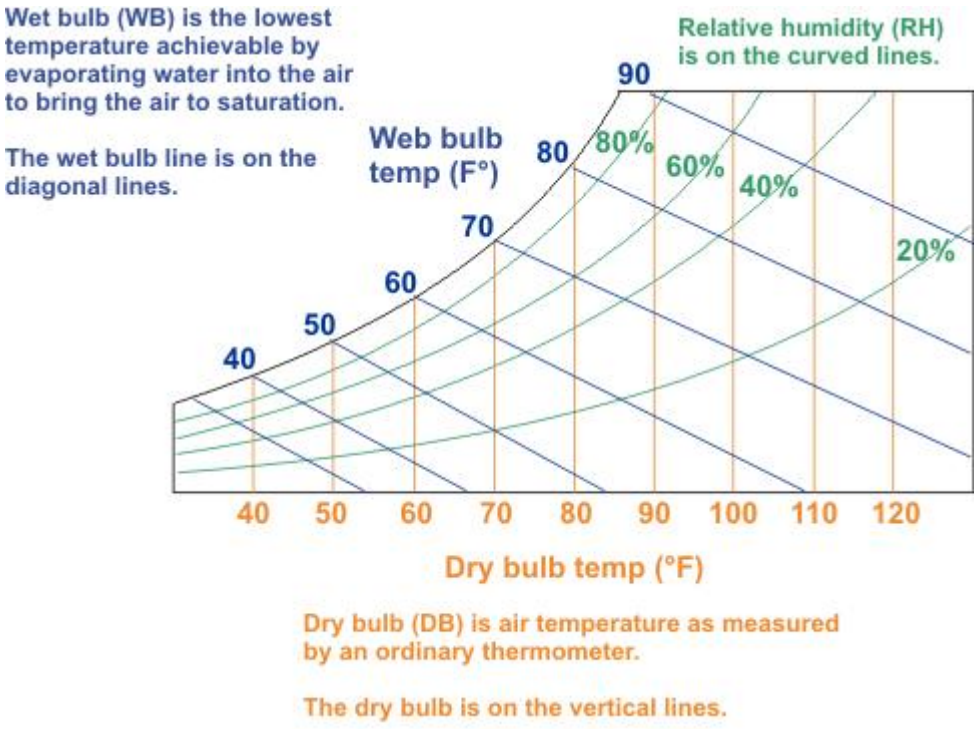


Figure 1 shows a basic psychrometric chart.

You can represent psychrometric processes (that is, any changes in the condition of the atmosphere) on the psychrometric chart. Common processes include:

- Sensible cooling/sensible heating
- Cooling and dehumidification/heating and humidification
- Humidification/dehumidification
- Evaporative cooling/chemical dehydration

Appendix D

Weather Data

- Month of June Albuquerque in Fahrenheit

Outside Air Tdb	Wet Bulb
75	51.46
74	49.6
78	58.39
74	56.4
73	51.21
75	54.51
73	54.7
78	59.3232
76	59.37
75	65.71
77	60.23
73	53.35
70	57.23
72	57.52
77	54.66
78	59.32
80	55.91
82	54.48
83	57.07
84	55.33
83	51.05
88	57.6367
84	60.21
80	58.57
81	58.87
81	59.89
76	58.09
78	61.18

- Month of July Albuquerque in Fahrenheit

81	56.7
82	58.61

Outside Air Tdb	Wet Bulb Temp
83	62.75
83	66.99
79	66.01
81	66.06
78	65.48
79	66.91
70	61.64
70	61.88
68	59.65
69	61.95
74	64.34
77	64.94
76	64.95
77	64.06
76	63.53
77	67.95
75	60.97
79	62.87
75	64.39
77	66.09
76	64.95
80	63.64
81	62.71
81	62.37
80	63.31
82	66.53
78	65.78
83	63.48
75	63.84
74	65.4
77	66.66

- Month of June Tucson in Fahrenheit

Outside Air Tdb	Wet Bulb
86	65.67
84	62.71
82	63.1
81	59.5
82	63.1
83	62
82	62.75
82	61.3
78	60.48
81	63.06
86	64.9
82	64.5
84	63.84
84	62.71
88	65.94
90	69.42
90	69.01
92	69.22
92	70.91
90	67.36
91	67.65
92	68.35
90	70.21
91	71.37
92	70.91
89	67.87
88	69.08
88	68.31
88	67.14
84	64.58

- Month of July Tucson in Fahrenheit

Outside Air Tdb	Wet Bulb
81	69.5
85	68.22
88	66.74
85	66.43
80	70.69
82	70.96
86	68.28
88	65.94
84	66.74
83	66.31
88	67.92
87	68.32
88	69.08
87	67.56
83	68.98
86	70.76
82	68.65
81	70.4
82	68.48
84	67.78
86	66.06
86	67.92
82	71.86
84	69.47
88	67.14
88	63.44
88	67.53
84	75.82
82	73.9
84	68.8
86	73.77

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