Low Cost Liquid Desiccant Dehumidification and Cooling System

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FINAL YEAR PROJECT REPORT

We hereby recommend that the dissertation prepared under our supervision by: Masna Bin Umeed (NUST 2012 01278 BSMME 11112F), Hassam Bashir (NUST 2012 01006 BSMME 11112F), Muhammad Rafay Aziz (NUST 2012 00959 BSMME 11112F) Titled: Low Cost Liquid Desiccant Dehumidification and Cooling System be accepted in partial fulfillment of the requirements for the award of Bachelors of Engineering in Mechanical Engineering degree with (_____ grade)

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Declaration

I/We certify that this research work titled "*Low Cost Liquid Desiccant Dehumidification and Cooling System"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

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Copyright Statement

Dedicated to our parents

Acknowledgments

I would thank ALLAH Almighty, who gave us knowledge and dedication to be able to complete this research.

Abstract

Our project is to provide air at 20 degree centigrade and 40-50% relative humidity which will be used to cool a room in Pakistan. Pakistan experiences very high temperatures and long humid spells during the summer. Often these spells leave thousands with heat strokes. People invest in products (water evaporation air coolers & compressor based air conditioners) to cope with the heat. However, water evaporation air coolers become ineffective in the humid conditions and compressor based air conditioners fall beyond the pay check of most population. We have built a Liquid Desiccant Dehumidification & Cooling system (LDDCS) which is cheaper and consume less electrical power than an average compressor based air conditioner. Our product has three major components, liquid desiccant dehumidifier to remove moisture content from the air and disinfect the air, liquid desiccant regenerator to expel the excess moisture to the environment outside and water based indirect evaporative air cooler to lower the temperature of the air. The LDDCS was examined under different room conditions condition. The data collected from this system is used to determine the results. This system provides us the air of 20 degree centigrade from 30 centigrade with 45% humidity. This system is cost effective and environment friendly.

Keywords:

- Indirect Evaporative cooling
- Liquid Desiccant Dehumidification
- Heat and mass transfer

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Symbols

Cpa specific heat of air (kJ kg1 1C1).

h1 specific enthalpy of process air at inlet of evaporative cooler (kJ kg1).

h2 specific enthalpies of process air at outlet of evaporative cooler (kJ kg1).

hv1 specific enthalpies of water vapor at inlet of evaporative cooler (kJ kg1).

hv2 specific enthalpies of water vapor at outlet of evaporative cooler (kJ kg1).

hfg latent heat of vaporization (kJ kg1).

Q sensible cooling capacity (kW)

Qt total cooling capacity (kW).

T dry bulb temperature of air (1C).

Tw wet bulb temperatures of air (1C).

Tdp dew point temperature of air (1C).

V volume flow rate of delivered air (m3 s1).

Win energy input (kW).

Chapter 1

Introduction

1.1 Background

In Hot weather is a serious problem in Pakistan. Pakistan experiences high temperatures and long humid spells during the summer. Temperature reach as high as 120 F during the afternoon. Often these spells leave thousands with heat strokes. During the summer of 2015 alone, around 2000 people died because of heat. People invest in products (water evaporation air cooler & compressor based air conditioners) to cope with the heat. However, water evaporation air coolers become ineffective in the humid conditions and compressor based air conditioners (costs $ 500 and consumer $100 worth of power per month) fall beyond the pay check of most population.

1.2 Aim and Objectives

Our project is to build a Liquid Desiccant Dehumidification & Cooling System which will be cheaper (costs $150) and consume less electrical power ($50 per month) than an average compressor based air conditioner. These characteristics will make our prototype accessible to middle and lower middle class of the country. It will also decrease the average household consumption considerably for people switching from compressor based air-conditioners since they take more than 50% of the total power of a household in Pakistan.

The following three main components were identified in order to achieve the overall aim of this research.

- Liquid desiccant dehumidifier to remove moisture content from the air and disinfect the air
- Indirect evaporative cooler to lower the temperature of the air using Maisotsenko Cycle
- Liquid desiccant regenerator to expel the captured moisture from desiccant solution to the environment outside

1.3 Project Methodology

We started our project with a market analysis to understand the existing cooling technologies and their underlying economics. We developed qualifying parameters for our project based on mechanical and cooling performance as well as economics. We beaconed into the literature review to understand the field of liquid desiccant dehumidification. Using the available information and our creativity we built the product and kept on improving it till suitable results were achieved.

Chapter 2

Literature Review

2.1 Alternative Cooling and Dehumidification Systems

With continuous depletion of natural resources to produce energy, alternative methods to provide the thermal comfort conditions and better indoor air quality must be explored. Main feature of these alternative methods is reduced energy consumption and enhanced efficiency. Desiccant dehumidification is also one of such candidates.

2.2 Introduction to Desiccant Cooling and Dehumidification Systems

Desiccant dehumidification is moisture removal using desiccant material. Main feature of these alternative methods is reduced energy consumption and enhanced efficiency. Desiccant dehumidification is also one of

2.2.1 Liquid Desiccant Dehumidification

With continuous depletion of natural resources to produce energy, alternative methods to provide the thermal comfort conditions and better indoor air quality must be explored. Main feature of these alternative methods is reduced energy consumption and enhanced efficiency. Desiccant dehumidification is also one of.

2.2.2 Liquid Desiccant Materials

A desiccant material attracts the water vapor towards itself and these materials are used where air of low dew point is needed. The strength of a liquid desiccant can be measured by its equilibrium vapor pressure, which is water vapor pressure that is in equilibrium with liquid desiccant material. The vapor pressure exponentially increases with the temperature of the water or desiccant and also increases as the water is absorbed by the desiccant, that is, equilibrium vapor pressure will be higher for a dilute liquid desiccant than a concentrated one.

Some other parameters which indicate desiccant materials performance are:

- Energy storage density

- Temperature for regeneration
- Boiling point elevation (BPE)
- Availability
- Cost

A good desiccant should have the following properties:

- Large saturation absorption capacity
- Low regeneration temperature
- Low Viscosity
- High heat transfer
- Non-volatile
- Non-corrosive
- Odorless
- Non-toxic
- Non-flammable
- Stable
- Inexpensive

Commonly used liquid desiccants in the industrial dehumidifiers are glycols and solutions of halide salts which include lithium chloride (LiCl), lithium bromide (LiBr), calcium chloride ($CaCl_2$), triethylene glycol and mixture of salts etc. The selection of a desiccant material will have a direct effect on the desiccant dehumidifier design.

2.3 Introduction to Evaporative Cooling

Desiccant dehumidification is moisture removal using desiccant material. Solid and Liquid and internal comfort conditions and better indoor air quality must be explored. Main feature of these alternative methods is reduced energy consumption and enhanced efficiency. Desiccant dehumidification is also one of

2.3.1 Direct Evaporative Cooling

With continuous depletion of natural resources to produce energy, alternative methods to provide the thermal comfort conditions and better indoor air quality must be explored. Main feature of these alternative methods is reduced energy

2.3.2 Indirect Evaporative Cooling

With continuous depletion of natural resources to produce energy, alternative methods to provide the thermal comfort conditions and better indoor air quality must be explored. Main feature of these alternative methods is reduced energy

2.3.3 Maisotsenko Cycle

In an indirect evaporative cooler (IEC), a primary (also called ‘product’) air stream is cooled by simultaneous heat and mass transfer between a secondary (also called ‘working’) air stream and a wet wall surface. The latent heat transport, in connection with the vaporization of the liquid film, plays an important role in the heat transfer process. Most commercially available IECs are equipped with standard cross-flow heat exchangers that have a stacked structure of heat and mass transfer plates. In principle, the structure allows the product air to flow over the dry side of a plate and the working air to flow perpendicular to the product flow direction over the opposite wet side of the plate. The wet side absorbs heat from the dry side by evaporating water and therefore cooling the dry side, while the latent heat of vaporizing water is given to the wet side air. In an ideal operation, the product air temperature on the dry side of the plate will reach the wet-bulb temperature of the incoming working air, and temperature of the working air on the wet side of the plate will increase to the incoming product air dry-bulb temperature and will reach 100% saturation. However, practical systems are far from ideal. It has been suggested that only 50 to 60 % of the incoming working air wetbulb temperature can be achieved for a typical indirect evaporative cooling device, while in most systems the working and product air come from the same source (i.e. ambient air) and therefore have the same temperature level. This type of exchanger has been comprehensively studied and developed, as suggested in the literature, with no great potential to further improve the cooling effectiveness (efficiency) of the exchanger.

In recent years, a new type of heat and mass exchanger utilizing the benefits of the Maisotsenko cycle has been developed. In this type of exchanger, part of the surface on the dry side is designed for the working air to pass through and the rest is allocated to the product air. Both the product and working air are guided to flow over the dry side along parallel flow channels. There are numerous holes distributed regularly on the area where the working air is retained and each of these allows a certain percentage of air to pass through and enter the wet side of the sheet. The air is gradually delivered to the wet side as it flows along the dry side, thus forming an even distribution of airstreams over the wet surface. This arrangement allows the working air to be pre-cooled before entering the wet side of the sheet by losing heat to the opposite wet surface. The pre-cooled air delivered to the wet side flows over the wet surface along channels arranged at right angles to the dry side channels, absorbing heat from the working and product air. As a result, the product air is cooled before being delivered to spaces where cooling is required, and the working air is humidified, heated and discharged to the atmosphere. Owing to effect of pre-cooling, the working air in the wet side (working air wet channel) has a much lower temperature and therefore, is able to absorb more heat from its two adjacent sides, i.e. the dry working air flow side and the dry product air flow side. As a result, the cooling (wet-bulb) effectiveness of the new structure would be higher than that in the traditional cross-flow exchanger.

Chapter 3

System Design

3.1 Introduction

System Design includes exploring number of candidate materials available in the market and then selecting an ideal candidate based on specific criteria for required job. Our system basically comprises of three major components.

- Dehumidifier
- Indirect Evaporative Cooler
- Desiccant Regenerator

3.2 Design and Configuration of Dehumidifier

In dehumidifier, air comes in direct contact with desiccant solution through a packing medium. Design of Dehumidifier includes

- Air and Desiccant Solution Configuration
- Choice of Packing Material
- Choice of Desiccant solution

3.2.1 Air and Desiccant Solution Configuration

Air and Desiccant Solution Configuration determines how air interacts with liquid desiccant solution. Different configurations of dehumidifier are possible for flow of air and desiccant solution. Each of them has been described below.

(i) Parallel Flow

In this configuration, air and liquid desiccant solution both flow parallel to each other in downwards direction. This configuration has been shown in the figure 3-1.

Merits	Demerits
• Easiest and simplest configuration • Very economical • No major issue of carryover of desiccant with air	• Vapor pressure difference between air and desiccant keeps on decreasing along the process hence effectiveness decreases • Less efficient

Table 3.1: Merit and Demerits of Parallel Flow

(ii) Counter Flow:

In this configuration, air and desiccant flow in opposite direction to each other. Usually air flows in upward direction while desiccant solution falls downwards direction, shown in figure 3-1.

Merits	Demerits
• Largest vapour pressure difference exist between air and desiccant solution • Very effective	• Minor issues related with carry-over of desiccant solution with air flow • Comparatively complex

Table 3.2: Merit and Demerits of Counter Flow

(iii) Cross Flow:

In cross flow configuration, flow direction of desiccant solution and air is perpendicular to each other. Desiccant flow from top to bottom while air passes perpendicular through it as shown in the figure 3-1.

Merits	Demerits
• Most effective Method • Good interaction between air and desiccant solution • Greater Surface contact	• Issues related with carryover of desiccant solution with air flow

Table 3.3: Merit and Demerits of Cross Flow

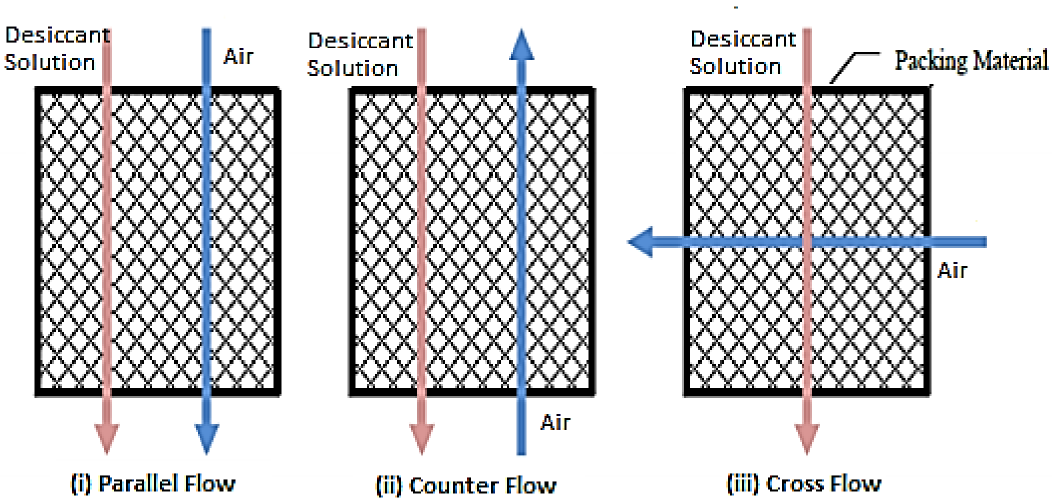


Figure 3-1 Configuration of Air and Desiccant Solution Based on direction of Interaction

3.2.2 Choice of Packing Material

Packing material is required for good surface interaction between air and desiccant solution in order to achieve mass and heat transfer between them. The different packing materials used in evaporative cooling pads are available in market. Most commonly used are,

- Khus Grass
- Wood wool
- Cellulose

Decision criterion to select good candidate was based on saturation efficiency. Saturation efficiency of cellulose pads is greatest among all as shown in figure 3-2.

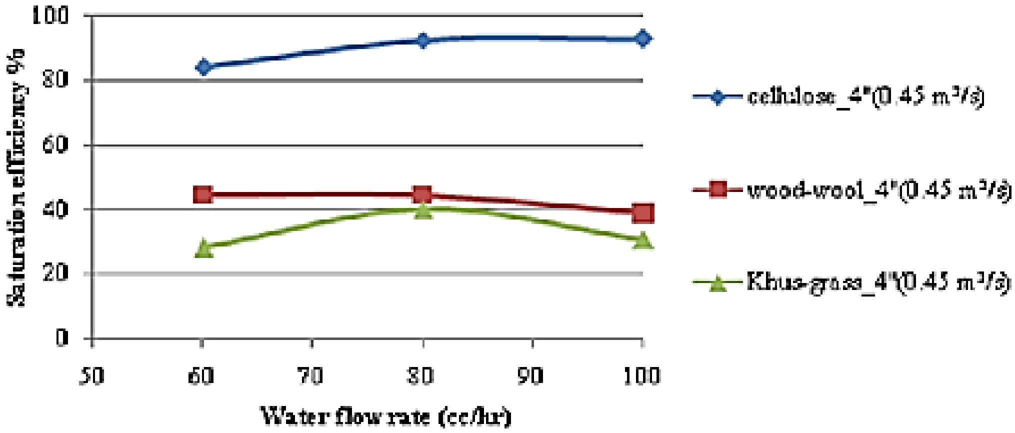


Figure 3-2 Saturation Efficiency Vs Water Flow rate

3.2.3 Choice of Desiccant solution

Desiccant materials are available in different forms and each of them has its own advantages and disadvantages. Commonly available desiccant materials include lithium chloride (LiCl), calcium chloride (CaCl2), lithium bromide (LiBr), triethylene glycol (TEG), silica gels, aluminium oxides, aluminium silicates etc.

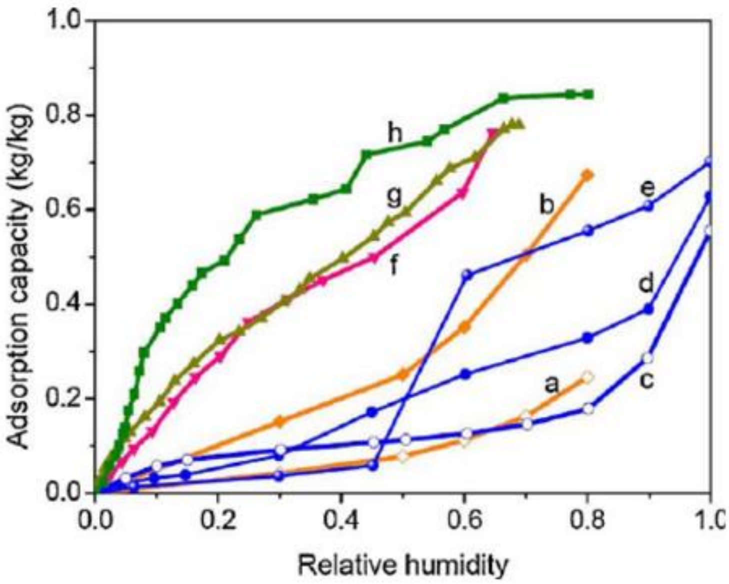


Figure 3-3 Adsorption capacity Vs Relative humidity

Given the properties of good desiccant, weighting factor was assigned to each characteristic depending upon the importance of the characteristic to the researchers. This data has been collected through difference resources with reference provided.

According to resources, the product of weighting factors and relative weight were summed for each characteristic and the candidate with the highest total was selected. Comparison was made for commonly available desiccant materials as follow

Characteristic (Max. Weight)	**LiCl**	**LiB**	**$CaCl_2$**	**Triethyle glycol**
Safety (1.0)	7.0	8.0	9.0	10.0
Corrosion (0.8)	8.0	8.0	7.2	8.0
Mass Transfer Potential at absorber (0.8)	8.0	8.0	8.0	8.0
Mass Transfer Potential at regenerator (0.8)	8.0	8.0	8.0	8.0
Heat of Mixing (0.6)	4.2	5.4	4.8	6.0
Cost (0.5)	3.5	2.5	5.0	4.5
Heat Transfer Potential (0.5)	5.0	4.5	5.0	2.5
Parasitic Power Losses (0.3)	3.0	3.0	2.7	1.5
Total	46.7	47.4	**49.7**	48.5

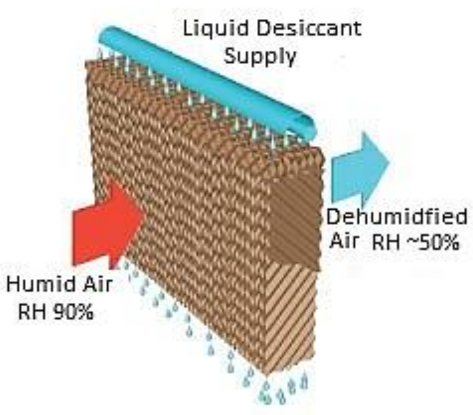
Table 3.4: Comparison between desiccant materials

Through this analysis, Calcium Chloride is best candidate for the application. It is one of the most efficient desiccant materials found in the found in nature. It is also non-toxic and environmentally friendly. Calcium Chloride has ability to attract the moisture several times its own weight in water. Moisture absorption of $CaCl_2$ is 150% its weight in water at relative humidity (RH) of only 50% and its absorption increases exponentially with increase in relative humidity, to 600% at 85% RH.

3.2.4 Overall Design Specifications

For dehumidifier, common evaporative cooling pads were used. They are made of fluted cellulose sheets glued together and are very effective in heat and mass transfer. Generally, these pads are used in direct evaporative cooling with water supply on top. However we used them as dehumidifier, liquid desiccant flows from top and air passing through. Liquid desiccant absorbs moisture through air as it passes through channels wetted with desiccant solution. Output is dehumidified air. Design specifications are given below.

Configuration:	Cross Flow
Packing Material:	Cellulose Pad
Desiccant:	Calcium Chloride ($CaCl_2$)



Height (H)	15 cm
Width (W)	17 cm
Depth (D)	5 cm

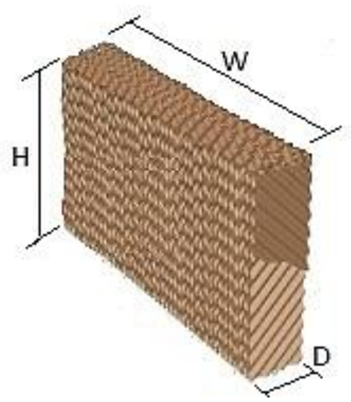


Figure 3-4 Design Specifications

3.2.5 Calculation of Cooling Load

Time	People (W)	Walls (W)	Windows (W)	Roof (W)	Grand Total (W)
9:00 AM	700	2519.843	522.6635	373.468793	4115.975
10:00 AM	700	2996.586	454.3797	540.693626	4691.659
11:00 AM	700	3263.907	443.6494	707.918459	5115.475
12:00 PM	700	3321.806	442.674	837.982218	5302.462
1:00 PM	700	3430.213	465.1101	968.045976	5563.369
2:00 PM	700	3271.298	473.8894	1060.94866	5506.136
3:00 PM	700	3217.095	443.6494	1098.10974	5458.854
4:00 PM	700	3108.688	410.483	1079.5292	5298.7
5:00 PM	700	3000.282	357.807	1023.78759	5081.876

Table 3.5: Cooling Load

Chapter 4

Conclusion and Future Work

4.1 Conclusions

4.1.1 Trnsys Results

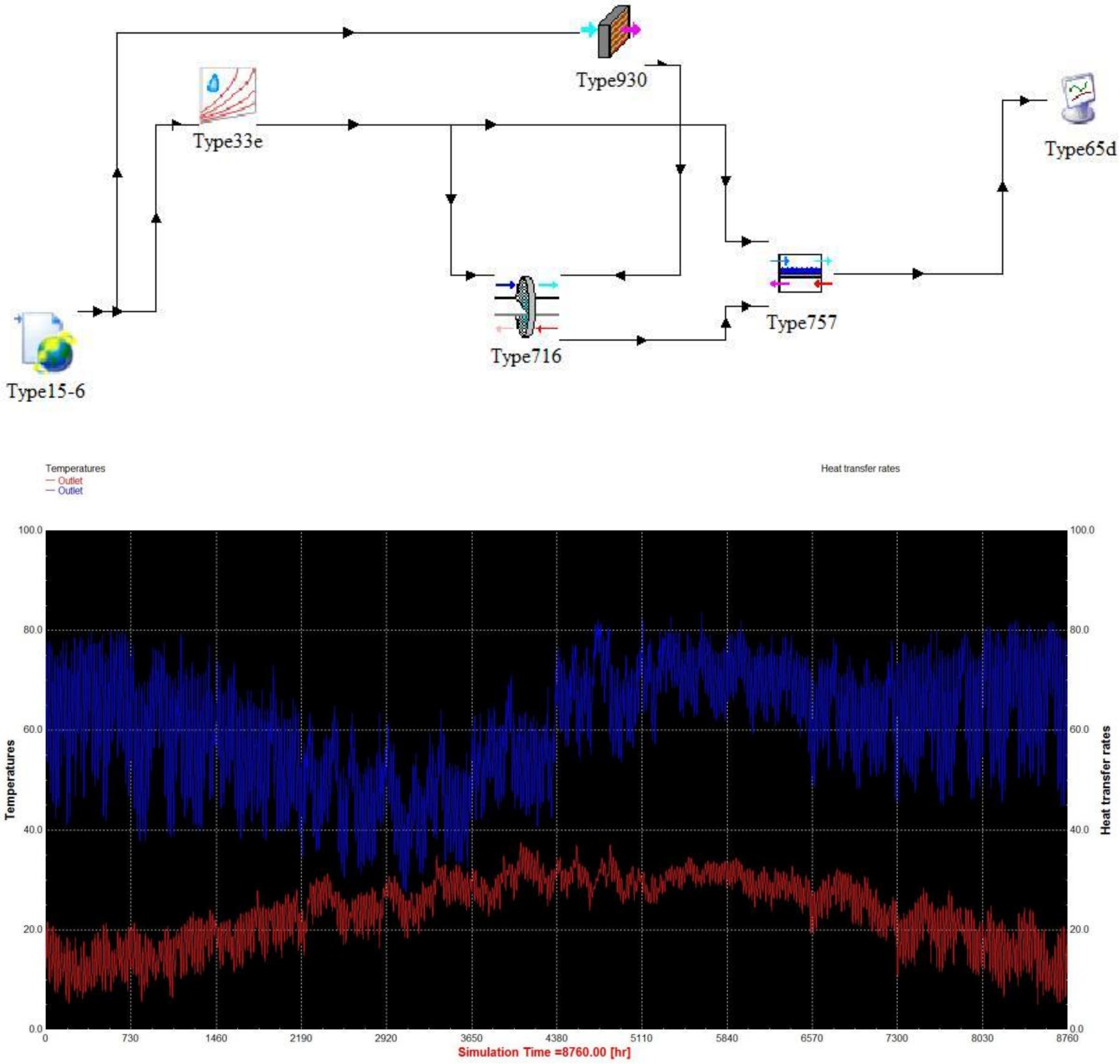


Figure 4-1 Trnsys Analysis

4.1.2 Prototype

Figure 4-2 Indirect Evaporative Cooling Chamber

Figure 4-3 Working Prototype

4.2 Results

Time/s	Outlet Air Temperature/Degree Celsius
0	31.6
30	31.0
60	30.2
90	29.5
120	28.0
150	26.9
180	26.0
210	24.4
240	23.1
270	22.3
300	21.7

Table 4.1: Results

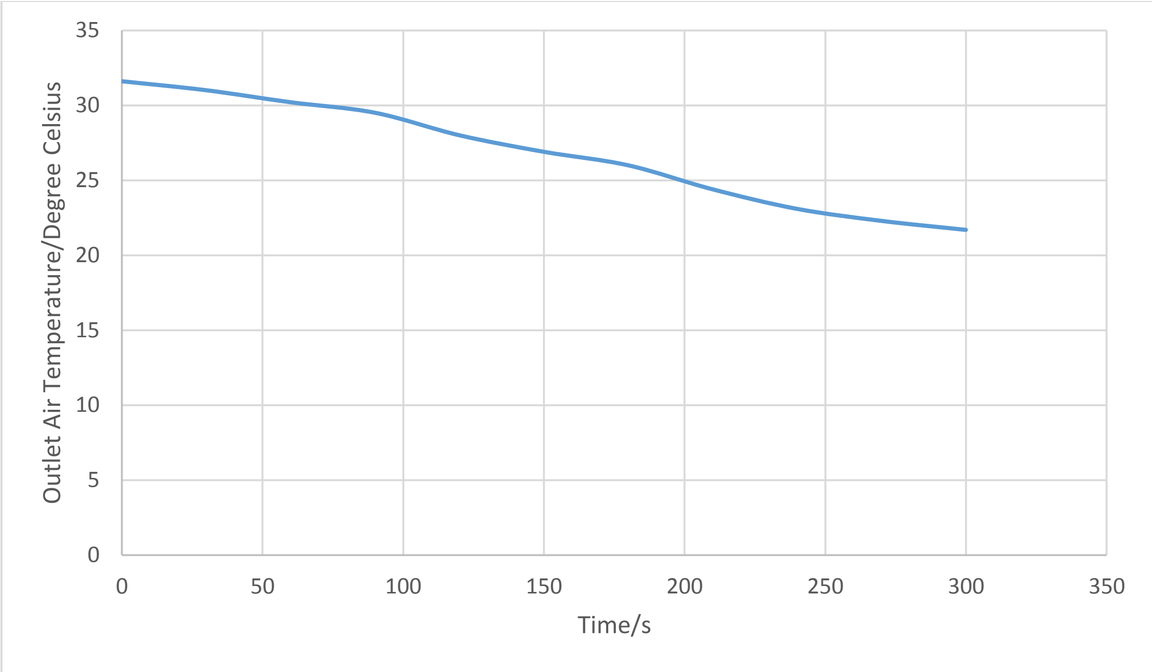


Figure 4-4 Outlet Air Temperature Vs Time

4.3 Future Work

1. Improvement of Design to make a consumer usable product.

2. Optimization for different climate conditions in different regions of Pakistan.

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