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CONCEPT DESIGN OF A GREENHOUSE COOLING SYSTEM USING MULTI-STAGE NANO-FILTRATION FOR LIQUID DESICCANT REGENERATION

Ameer Hayder Salman LAMI

Master's Thesis

Supervisor

Asst. Prof. Dr. Yaser ALAIWI

Istanbul, 2023

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The thesis titled CONCEPT DESIGN OF A GREENHOUSE COOLING SYSTEM USING MULTI-STAGE NANO-FILTRATION FOR LIQUID DESICCANT REGENERATION prepared and presented by AMEER HAYDER SALMAN LAMI has been **accepted unanimously** for the degree of Master of Science Thesis in Mechanical Engineering.

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Signature

DEDICATION

I dedicate this humble research to my dear parents who have done everything in their power since my childhood to push me forward for educational attainment, also my beloved wife and children who have devoted their efforts to creating the appropriate environment and creating an encouraging atmosphere to continue research and analysis, also to every researcher looking forward to collecting information, which I tried as much as possible to collect as much as possible how much can be related to the topic of research.

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ABSTRACT

CONCEPT DESIGN OF A GREENHOUSE COOLING SYSTEM USING MULTI-STAGE NANO-FILTRATION FOR LIQUID DESICCANT REGENERATION

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Agricultural greenhouses in warm climates grapple with a paramount challenge: excessive heat accumulation due to intense solar radiation. This issue has recently surged as the foremost concern for summer greenhouses, prompting ongoing research. Effective cooling strategies are imperative. Since the 18th century, it has revolutionized greenhouse cooling globally, remaining a staple technique. Other cooling methods exist. The current thesis delves into research on evaporative cooling in Iraq, applied to both summer and winter agricultural greenhouses. Compared to compression refrigeration, the multistage evaporative cooler curtails energy consumption, environmental pollutants, global warming effects, and manufacturing expenses. Suited for high humidity and temperature settings, it's viable for homes and substantial structures. Simulation findings showcase the developed evaporative cooler's prowess. Incorporating cooling stages markedly diminishes the out-dry bulb temperature by about 50% and specific humidity by roughly 80%. This innovation signifies a pivotal step towards environmentally friendly cooling solutions, ameliorating the pressing challenges posed by escalating temperatures.

Keywords: Evaporative Cooling, Multi-Stage Evaporative, Air- Water-Air Cooling System, Air-Water Heat Exchanger, ThermalAnalysis, Ansys.

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ABBREVIATIONS

CFD	:	Computational Fluid Dynamics
3D	:	Three Dimensional
CO_2	:	Carbon Dioxide
DEC	:	Direct Evaporative Cooling
IEC	:	Indirect Evaporative Cooling
ACR	:	Air Conditioning and Refrigeration
GHG	:	Greenhouse Gases
B.C	:	Before Christ
VPD	:	Vapour Pressure Deficit
Temp	:	Temperature
^{o}C	:	Degree Centigrade
EES	:	Engineering Equation Solver

1. INTRODUCTION

Most homes more than seventy-five percent have air conditioners. More than 8 percent of the nation's total power production is utilized for household air conditioning, which costs Americans $15 billion annually [1]. A typical house with air conditioning uses approximately two tons of power per year, or around 196 million metric tons of carbon dioxide (CO2) [2]. This energy usage may be decreased by 20–50 percent by switching to high-efficacy air conditioners and taking action to lessen household cooling demands [3].

It is crucial to understand that, as air conditioning has become the standard nationwide, cutting down on demand for it is often the simplest and least expensive method to keep comfortable throughout the summer [4]. This section discusses various cooling system kinds, when to update, how to choose a new system, and how to run the current system to achieve optimum efficacy after talking about how to manage heat out of the home. Without significant improvements in the energy efficiency of air conditioners & cooling equipment, their electricity demand could grow by up to 40% by 2030 [5].

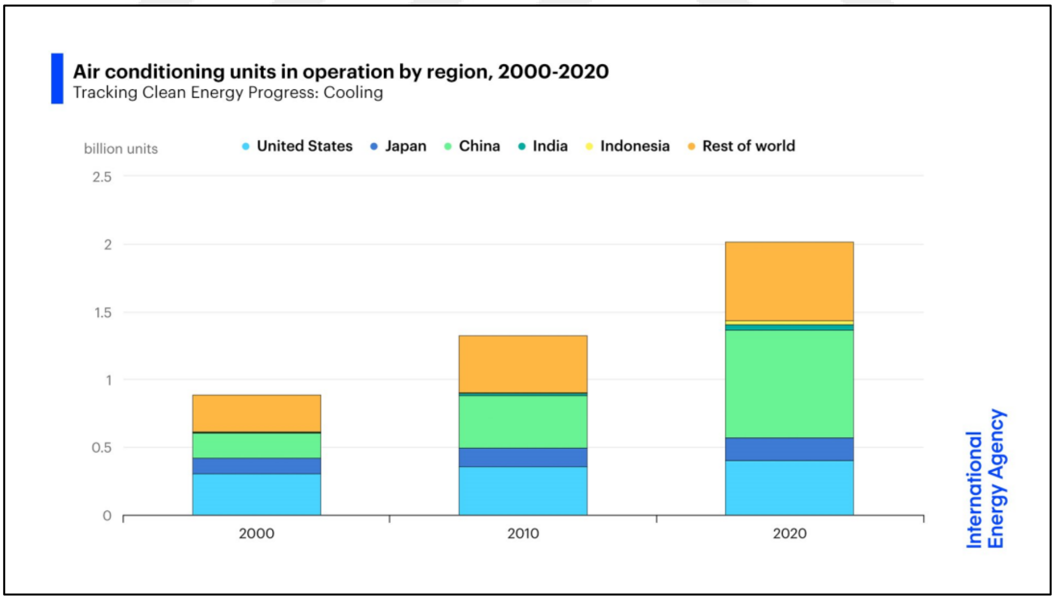


Figure 1.1: Air Conditioning Units in Operation by Region [5].

1.1 EVAPORATIVE COOLING SYSTEM

Evaporative coolers use water evaporation to cool the air [6]. This technique has been utilized in warmer climates for several years. The usage of evaporative cooling is expanding as global warming's consequences are also noticed in Europe [7]. Previously, Arabs utilized to hang wet clothes on windows and doors to take advantage of air cooling thru water evaporation. The water evaporates and the heat in the air is absorbed when the hot air travels thru the wetted material (in this example, the fabric), lowering the air's temp. Like this, people frequently travel to lakes or the coast on hot days in search of relief. In many respects, evaporative cooling mimics the milder temps often observed near huge bodies of water [8].

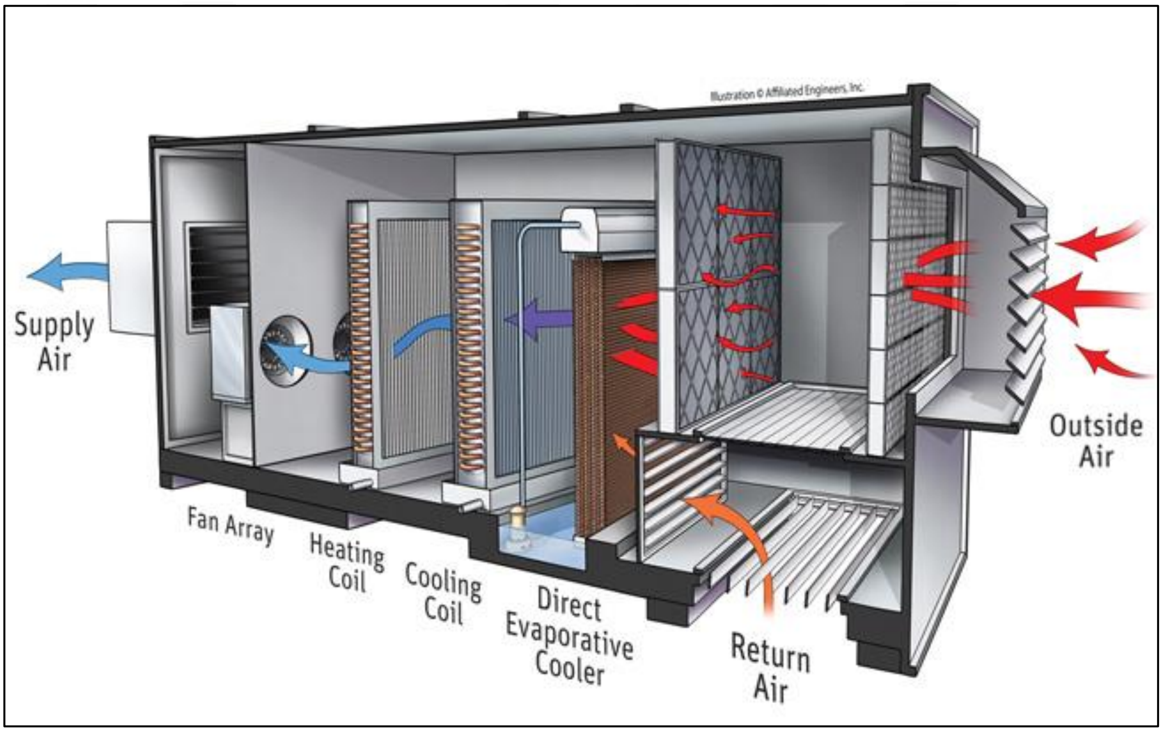


Figure 1.2: Evaporative Cooling System [9].

Evaporative cooling units only use water to cool the air. No chemical refrigerants are involved in the process. Moreover, when compared to refrigerated systems, evaporative air conditioners consume much less power, which results in extremely responsible environmental and energy-saving properties. Evaporative coolers consume the same amount of electricity regardless of how hot it is outside and continue to provide 100percent fresh, cold air inside. The opposite is true for cooling systems, which use more energy when the outside temp rises. Once the heat is at its worst, evaporative coolers' capacity to save costs increases [10]. In addition, they operate better when temps rise, which is another feature that sets them apart from refrigerated systems. Using little electricity, no compressor, and low running costs, evaporative cooling is the perfect solution for industrial and commercial environments that often have no cooling system installed [11]. Since the capital and operating expenses would be so high for end users in warehouses or industrial facilities, air conditioning does not represent a practical alternative. Evaporative coolers also utilize only fresh outside air. Outside air ventilation is widely recognized as a crucial element of a pleasant and healthy structure. Air from evaporative cooling units is entirely new; interior air is never circulated. The incoming air will automatically force the stale air outside the building via the doors, windows, or extract system, which may be a terrific way to enhance indoor air quality [12].

1.1.1 Types of Evaporative Cooling System

Evaporative air coolers are available in several types. Some fixed units blast air directly into the building, whereas others utilize duct systems to distribute air to various areas. Some fixed units are movable, while others must be mounted on the wall. Nevertheless, evaporative air cooler ducts are frequently bigger than standard ducts, and using the incorrect duct design will make the air cooler less efficient. Whichever cooler that needs depends on the environment in the house or business. Evaporative air coolers were available in two kinds [13]:

1.1.2 Direct Evaporative Cooling (DEC) System

When using direct evaporative cooling (DEC), outside air is blasted thru a material that has been saturated with water (often cellulose) and allowed to vaporize. A blower is utilized to move the cooled air [14]. Until the air stream is saturated, DEC adds moisture to the air stream. Whereas the wet bulb temp remains constant, the dry bulb temp drops.[15]. Dry bulb: A thermometer measures the reasonable air temp. Wet bulb: the lowest air temp that can be reached by adding water to the air to make it saturated.

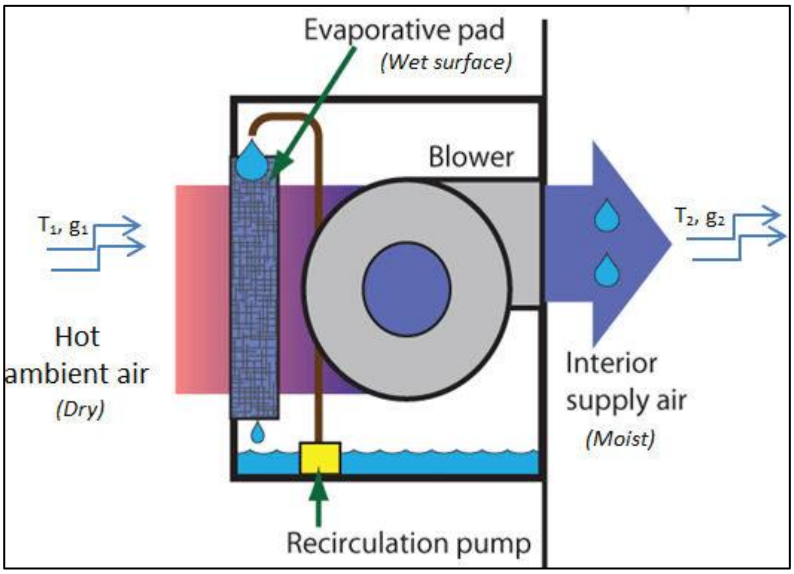


Figure 1.3: DEC System [6].

1.1.3 Indirect Evaporative Cooling System

A secondary (scavenger) air stream was cooled by water in Indirect Evaporative Cooling (IEC). The secondary air stream cools the main air stream as it passes thru a heat exchanger [16]. A blower moves the principal air stream that has been cooled. The main air stream does not become more humid due to IEC. The temps of the wet bulb and dry bulb are both lowered. When exhaust air is utilized as the secondary air stream in an indirect system, the heat exchanger may pre-heat outside air throughout the hot season [17].

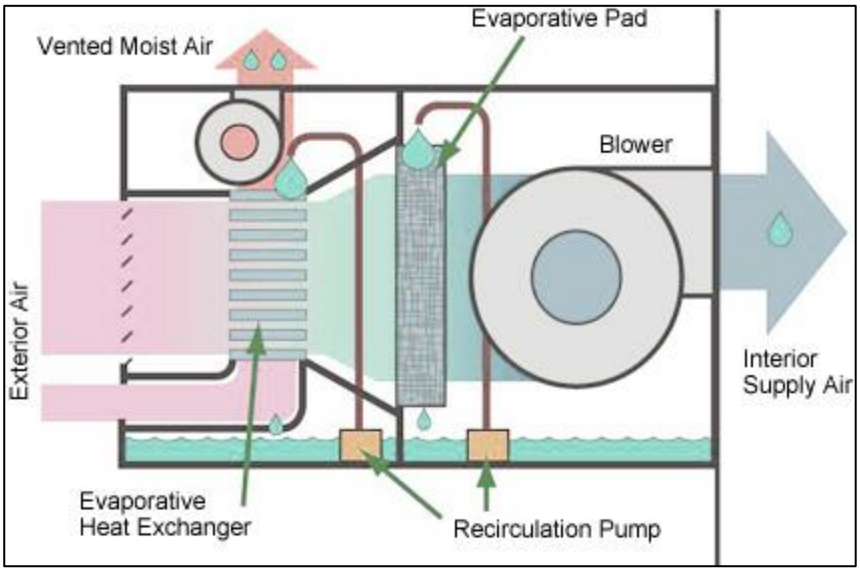


Figure 1.4: IEC System [18].

1.2 MULTI-STAGE EVAPORATIVE COOLING SYSTEM

An indirect evaporative cooling subsystem with either a vertical or horizontal set of exchanger channels is characterized as being part of a multi-stage hybrid evaporative cooler. A section of the horizontal heat exchanger tubes in the multi-stage hybrid evaporation system that consists of many stages is partly extended into the system's subsequent stage. The multi-stage hybrids evaporation cooling system with the vertical pair of heat exchanger channels consists of a first set that spans a sizable portion of the height of the hybrid evaporative cooling system's stage and a second set that spans around half of the stage's height. The IEC subsystem air may be cooled down without compromising its pressure flow thanks to a refrigeration system that is part of the multi-stage hybrids evaporative cooling system. [19].

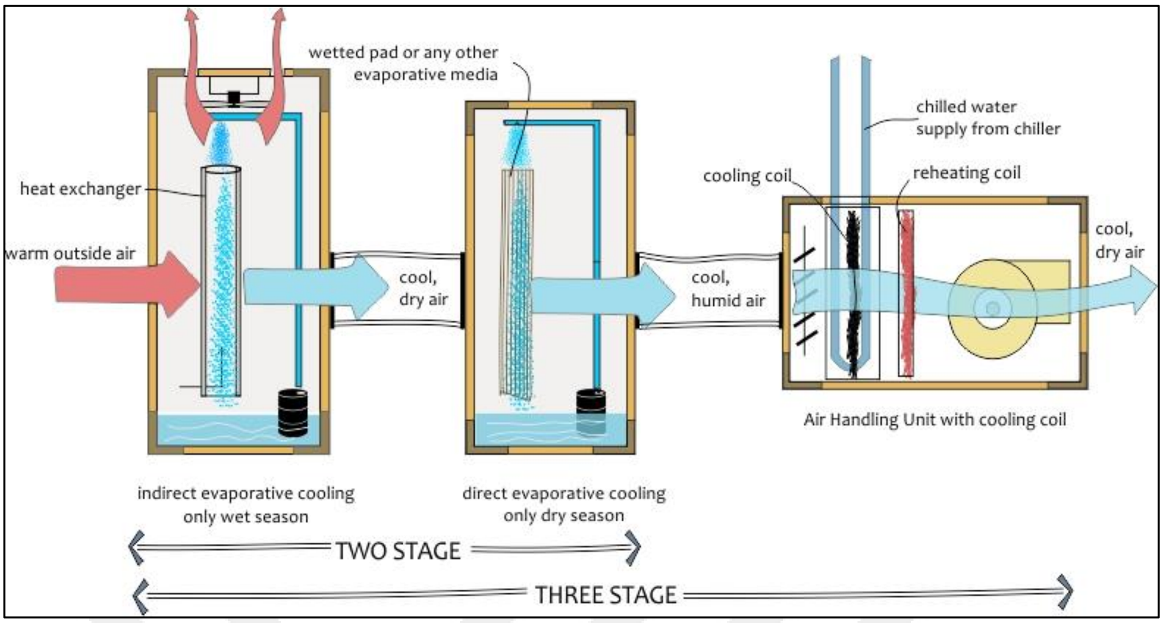


Figure 1.5: Multi-Stage Evaporative Cooling System [19].

1.2.1 Indirect/Direct Evaporative Cooling

The main air stream is cooled using IEC initially, followed by additional chilling using DEC in indirect/direct evaporative cooling [20].

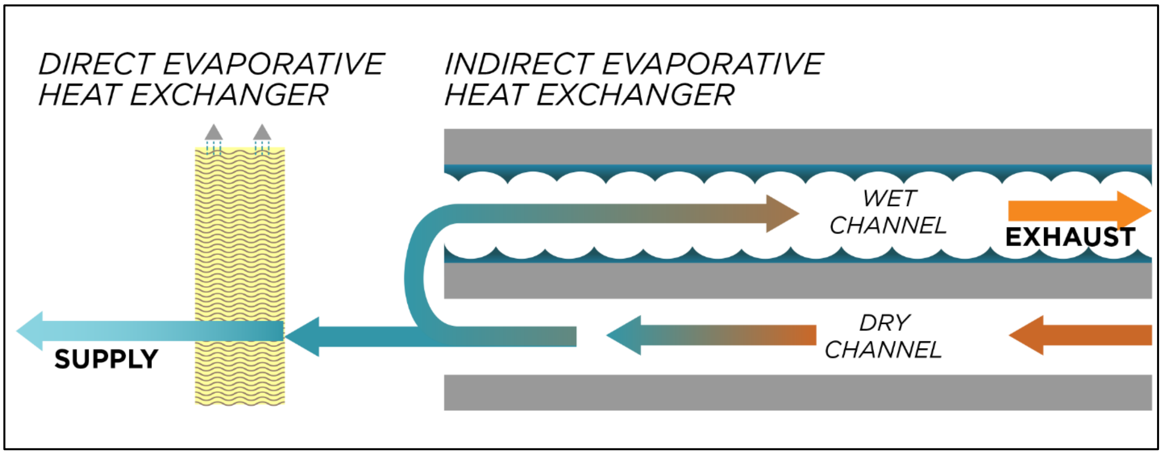


Figure 1.6: Indirect Direct Evaporative Cooling System [20].

1.2.2 Indirect/Indirect Evaporative Cooling

In the first step, indirect evaporative cooling is utilized to cool the main air stream. Water from the first cooling step enters the second stage via the coil's wet side. Minimal moisture is introduced to the main air stream, and more sensible heat is eliminated from it [21].

1.2.3 Advantages of Multi-Stages Cooling System

There are many advantages related to using a multi-stages cooling system instead of a single evaporative cooling system [22]:

i. For design conditions when DEC is insufficient, two cooling phases enable the use of energy-saving evaporative cooling technology.
ii. The capital cost is substantially cheaper, and the energy usage is around half that of air conditioning.
iii. Since they maintain better interior humidity ranges, two-stage systems often provide more comfort than compressor-based systems. In several applications, they may therefore take the role of mechanical refrigeration.
iv. Since only fresh air is utilized to cool the conditioned room, there have been no IAQ-related issues. Similar to ventilation, two-stage cooling systems are usually built for 25 to 40 air changes each hour.
v. Because no refrigerant has been utilized, the system is green.

1.2.4 Disadvantages of Multi-Stages Cooling System

Many disadvantages related to using a multi-stage cooling system along with advantages [23]:

i. In coastal locations with high relative humidity, it is less effective.
ii. Throughout the year, the cooled room experiences large temp variations based on the current ambient wet and dry bulb temps.

1.3 PROBLEM STATEMENT

Refrigerant and gas emissions linked to energy usage are the main effects of air conditioning and refrigeration (ACR) systems on the environment. The power plants that supply the energy, steam, or hot water needed to produce, transport, install, use, maintain, and eventually dispose of the equipment and associated devices are often where those gases are emitted. On-site, they may happen when equipment is powered by engines, turbines, or direct-fired absorption cycles. The running power industry's combustion emissions and refrigerant leaks have the greatest overall effects. The stratospheric ozone equilibrium is specifically impacted by the discharge or leakage of stable refrigerants that include chlorine, bromine, and other halogens, but their effects are often minimal.

Similar to this, GHGs are produced by both conventional refrigerants and combustion byproducts, most notably carbon dioxide (CO_2) and to a lesser degree nitrous oxide (N_2O). Multiple consequences of refrigerant leaks include ozone depletion after breakdown, direct action as greenhouse gases, and efficiency loss resulting to higher energy demand. Departures from the ideal charge, or—for refrigerant blends—charge and composition, cause performance losses. Therefore, choosing refrigerants with the fewest negative effects, limiting their release, and enhancing net efficiencies to reduce energy-related GHG emissions are the key concerns in addressing stratospheric ozone depletion and climate change for ACR systems.

1.4 AIMS AND OBJECTS

The current investigation aims to create an evaporative cooler by incorporating multiple heat exchanger stages (air-air and water-air) to indirectly and indirectly cool the input air before cooling directly inside the traditional evaporative cooler:

i. Creating a mathematical model for the system components by ANSYS software to simulate the performance of multi-stage evaporative cooling systems.
ii. Investigating the effect of inlet air Reynolds number Re and velocity percentage extracted air on sensible cooling.
iii. Investigating the effect of relative humidity and the distance between the heat exchanger plates on a Multi-stage Evaporative Cooling System.
iv. Determine the cooling system efficiency throughout February, July and October to track the system's performance under various weather temps.

1.5 THESIS LAYOUT

The current thesis consists of five chapters as follows:

a. Introduction contains background about the multi-stages evaporative cooling system, types of multi-stages evaporative cooling, and the issue faced by the multi-stages evaporative cooling system and its benefits.

b. Literature review related to multi-stages evaporative cooling system components, the differences between two multi-stages evaporative cooling systems, and the previous studies on the multi-stages evaporative cooling system.

c. Numerical Modelling with CFD methods for the multi-stages evaporative cooling system and some experimental works and tests that are usually used.

d. Represents the results obtained from the ANSYS Multi-physics software program, discusses those results, and compares the obtainable and experimental results.

e. Conclusions and recommendations for future work.

2. EVAPORATIVE COOLING CONCEPT AND LITERATURE REVIEW

2.1 INTRODUCTION

A physical phenomenon known as evaporative cooling occurs when a liquid evaporates, usually into the air around it, cooling the item or liquid that comes into touch with it. Once air that is not very humid travels over a wet surface, evaporative cooling happens; the higher evaporation rate and cooling. Over the years, several designs have been used. A very early type of evaporative cooling may be seen in paintings from early Ancient Egypt that show slaves fanning enormous, porous clay jars filled with water. The earliest artificial coolers were towers that captured wind, directed it thru water at the bottom and into a structure. As a result, the building was maintained cool at the time [24].

Evaporative cooling systems were first utilized by the New England textile business around 1800 B.C. to keep their mills cool [25]. The impact of employing a radiator, which lessens the impact of lag, was reduced and then totally eliminated in the 1930s by the Beardmore tornado airship engine [26]. Bricks have been utilised to build bamboo coolers, and the bricks are wrapped with hessian fabric. Along with the Almirah coolers, charcoal coolers have also been developed. A wetted carpet and a fan were employed to cool a nearby restaurant in New Delhi, India, according to Rusten's description of different forms of evaporative cooling utilised there in 1985. Less than 60000000 ft^2 were reportedly ever water cooled, despite the fact that the idea of cooling a roof with water has a long history [27]. Additionally, it was noted that evaporation is much accelerated when just a little quantity of water is applied to a roof comparing to what would happen if the whole roof surface were submerged in water [28].

In dry and hot climates, evaporative cooling has long been employed as a means of thermal comfort. The method includes chilling the air with water in both obvious and latent ways. The best circumstances for DEC are dry, below-average outside conditions. Once little to no humidification is needed, and if the external air humidity is within a reasonable range, an indirect evaporative system is utilised. To cool the air via sensible heating transfer, fresh, filtered air is sent into a dry component of the system. Evaporative cooling systems might be three or two stages in length.

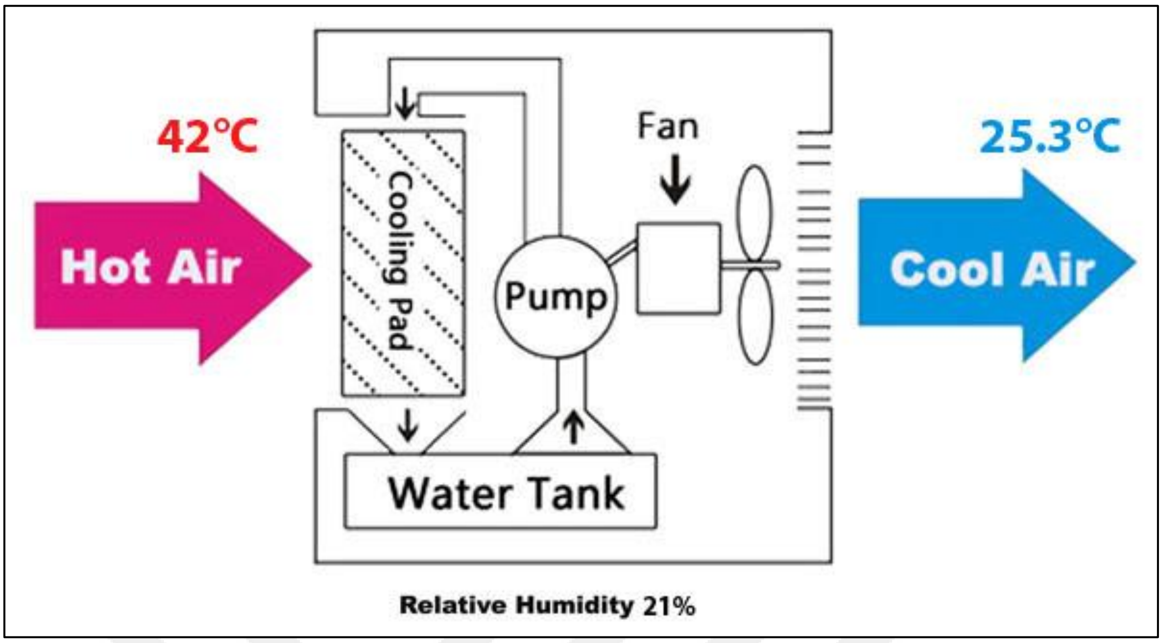


Figure 2.1: Working Principal Diagram of Evaporation Air Coolers.

2.1.1 Concept of Evaporative Cooling

The process of reducing a substance's temp because of the cooling effect from water evaporation is known as evaporative cooling. As water evaporates, sensible heat is converted to latent heat, resulting in a helpful cooling by lowering the ambient temp. From small-space cooling to large-scale industrial applications, this cooling effect has been applied on a variety of sizes [29].

In contrast to typical refrigeration and air conditioning systems, evaporative cooling may provide efficient cooling without the need for an external energy source. Simply soaking a surface and allowing the water to evaporate can effectively chill it [30]. Humans most noticeably experience this impact when they exercise since perspiration from their skin cools their bodies. The foundation for more sophisticated and motorised evaporative cooling systems was that simple kind of evaporative cooling [31].

The evaporative cooler operates on the premise that cooling results from water evaporating from a structure's surface [32]. The device's cooling also causes the air in the cooling chamber, where the evaporation occurs, to have a high relative humidity to the surrounding air. As a result, the environment in the chamber is more suited for storing fruits and vegetables.

Evaporative cooling occurs when dry air passes over a wet surface; the faster evaporation rate and the greater the cooling. The efficacy of an evaporative cooler is influenced by the surrounding air's humidity [33]. Because very dry air might absorb a lot of moisture, cooling was boosted. The worst-case scenario, when air is entirely saturated with water, prevents air from evaporating or cooling. The material that makes up an evaporation structure is frequently porous and gets water feeding. The substance was in contact with hot, dry air [34]. Because the water is evaporating into the air, the temp drops and the humidity rises [35].

In underdeveloped nations such Nigeria, and many countries in the middle east agriculture makes up the majority of the unofficial economic. Fruits and vegetable manufacturing is reportedly one of the most significant agriculturally based activities among the many different kinds [35]. Nevertheless, owing to inadequate infrastructure, subpar transport, and the perishable nature of the crops, farmers have not been receiving sufficient value for their products, resulting in a significant negative economic impact. The loss is significant throughout the post-harvest glut, and often part of the product must be given to animals or left to perish. Ndirika and Asota [36] assert that pathogenic attack, composition change, and moisture loss are the main causes of harm to various bio products. Once handling vegetables and fruits it's important to take into account the environment's relative humidity and temp. The rate of water loss and other metabolic processes will be slowed for freshly harvested food by any approach designed to raise the relative humidity of the storage environment (or lower the vapour pressure deficit (VPD) between the commodity and its environment) [37]. This will reduce the respiration processes and pathogen activities, which are the most harmful processes throughout vegetables and fruits preservation [38].

Though refrigeration is fairly common, it was shown that several vegetables and fruits, such tomatoes, bananas, and plantains, cannot be kept for an extended amount of time in a residential refrigerator because they are prone to chilling harm [39], [40]. Additionally, the low income of farmers in rural regions and the unstable power supply make refrigeration costly.

For the effective and low-cost storage of vegetables and fruits, FAO [41] recommended a method based on the evaporation cooling concept. The fundamental idea depends on cooling thru evaporation. Nevertheless, evaporation cooling systems are sometimes employed in preservation with a canopy over top [42].

The primary controlling mechanism of evaporation cooling is the transfer of heat and mass caused by the evaporation of water. Sensible heat is transformed into latent heat in this process. Specific heat is heat brought on by a rise or fall in temp. Although variations in sensible heat have an impact on temp, they have no impact on the physical condition of water. On the other hand, latent heat transmission only modifies a substance's physical state via condensation or evaporation [13]. Water transforms from a liquid to a vapour as it evaporation. The remaining liquid water and ambient air must be heated in order for this phase shift to occur. Consequently, the air's relative humidity rises and its temp drops. Wet-bulb temp (WBT), where at point the air would be totally saturated, is the highest cooling that could be accomplished [43].

2.2 THEORY AND BASIC PRINCIPLE OF EVAPORATIVE COOLING SYSTEM

A physical phenomenon known as evaporation cooling occurs when a liquid evaporates, usually into the air around it, cooling the item or liquid that comes into touch with it. The wet-bulb temp, as contrasted to the air's dry-bulb temp, is a gauge of the potential for evaporation cooling when considering water evaporating into air. The cooling impact of evaporation increases with the size of the temp difference between the two. Water evaporation has a noticeable cooling impact, and the quicker it happens, the cooler it becomes. There is no net evaporation of water in the air once the temps are the same, hence there is no cooling impact. This technique operates on the premise that if a specific location is conditioned and kept at a temp lower than the air temp around the space, some moisture from the exterior of the body should be released. In comparison to the surroundings, this keeps the space's temp low and its humidity level high. All of these needs are met by this evaporation cool chamber, which benefits small farmers in rural regions [44].

Evaporation coolers create cold air by directing hot, dry air over a wet pad. As the water in the pad dries up, it increases humidity whilst decreasing heat in the air. Water evaporation greatly cools the atmosphere by absorbing energy from its surroundings. Evaporation cooling occurs when dry air passes over a wet surface, the faster the evaporation rate, the higher the cooling. The efficacy of an evaporative cooler is influenced by the surrounding air's humidity. Very dry air might absorb a significant amount of moisture, which speeds up the cooling process. The worst-case scenario, when air is entirely saturated with water, prevents air from evaporating or cooling. By forcing water to evaporate and drip over the bricks or cooler pads, the evaporation-cooled storage structures implement the adiabatic cooling idea. The material utilized to build an evaporation cooler is frequently porous and may take in water. Dry, heated air is let in contact with the substance. Because of the water evaporating into it, the air gets cooler and more humid.

2.2.1 Evaporative Cooling with Psychrometric Chart

Rusten [45] asserts that evaporative cooling is an age-old and efficient technique of cooling water. He also mentioned how plants and animals employ this technique to lower their body temps. Rusten [45] listed the following circumstances under which evaporative cooling might occur:

a. High temps
b. Low humidity
c. Water that may be saved for usage
d. Access to air movement (from wind to electric fan)

It also revealed that heat or energy must be added in order for a liquid to turn into a vapour. Since the environment provides the energy needed to turn water into vapour, the environment is cooled as a result. Consequently, it is crucial to utilize the psychrometric chart to determine if evaporative cooling has occurred. Utilizing a particular graph known as a psychrometric chart, air variables may be succinctly described. Temps for wet and dry bulbs, dew point temp, specific volume, humidity proportion, relative humidity, and enthalpy [46] are among the characteristics shown on the graph.

The wet bulb temp, as contrasted to the air's dry-bulb temp, seems to be a gauge of the possibility of evaporative cooling when water evaporates into air. The cooling impact of evaporation increases with the size of the temp difference between the two. There is no net water evaporation in the air once the temps are the same, therefore there is no cooling impact [47].

The psychrometric chart specifies these factors at different phases and explains how to evaluate relative humidity and temp to get the best cooling efficacy when utilizing the evaporative cooling method [48].

The process of evaporation heating exchange, which makes use of the latent heating of evaporation and the enormous heating exchange that occurs when water evaporates, provides cooling. It takes advantage of the atmosphere's free latent energy. The psychometric graph illustrates how air and water interact (Figure 2.2). Water absorbs air like a sponge. The main distinction is that when air becomes hotter, this could retain more water [49]. Air flows all along line of constant energy D as it absorbs water. This chart may be utilized to determine the amount of cooling if the air's ambient conditions were specified [50].

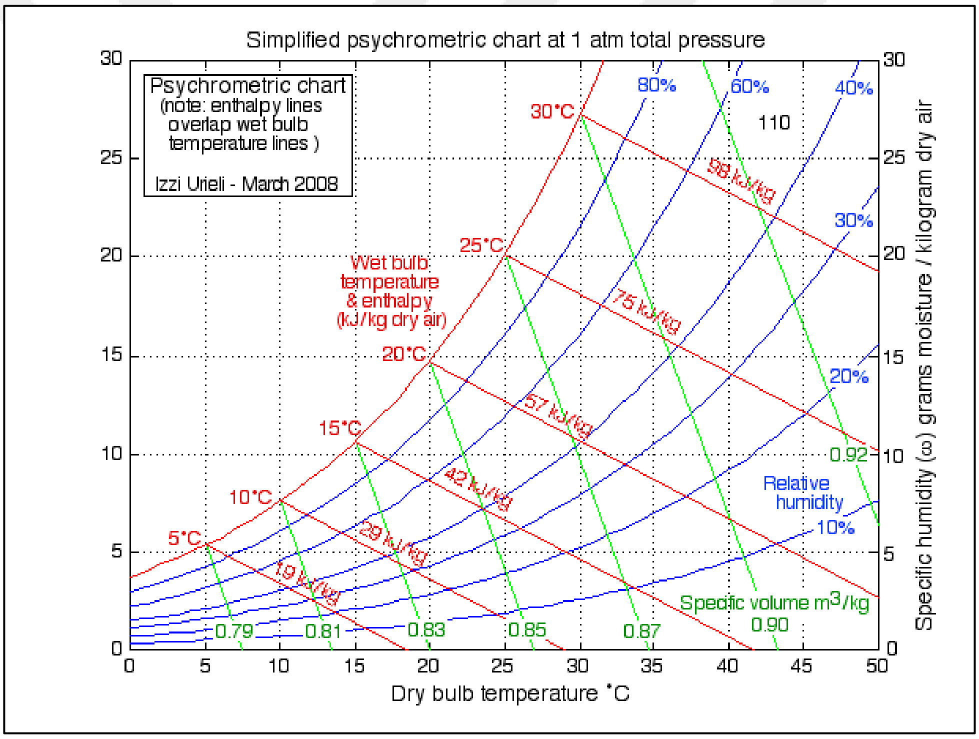


Figure 2.2: The Evaporative Cooling- Psychrometric Chart [51].

The dew point and dry bulb temp must be identical to the wet bulb temp for a perfect, 100percentage efficiency evaporative cooler [52]. Figures 2.2 and 2.3 psychometric graph serve as illustrations of what occurs once air passes thru an evaporation unit. The process A-B depicts a direct evaporation unit once the intake dry bulb temp was 30 degree centigrade and the wet bulb temp was 18 degree centigrade, with an initial differential of 12 degree centigrade. The depression will be 10.80 degree centigrade and the dry bulb temp of air exiting this unit would be 30-0.9x12= 19.2 degree centigrade (point B) once the direct unit's efficacy is 90 percent.

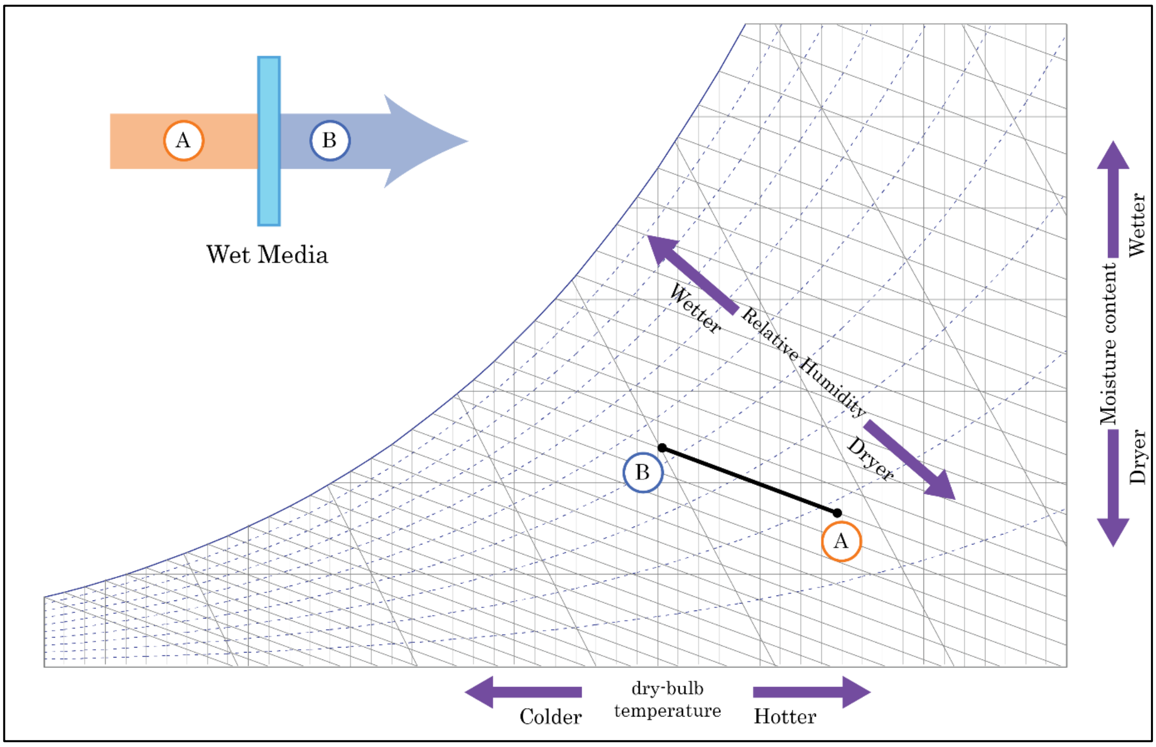


Figure 2.3: The Principle of Adiabatic Cooling.

2.2.2 Factors Affecting Evaporation

Evaporation is the process of conversion of a liquid phase into a gaseous phase. This process involves the presence of heat energy.

2.2.3 Temp

Another crucial element that affects how quickly liquids evaporate is temp. Thermodynamically, intermolecular and temp were intimately connected. The evaporation rate increases when the temp increases and vice versa. The kinetic molecules energy also increases on mean once temp rises, which is the cause. Consequently, more molecules escape from the liquid's surface, increasing the evaporation rate.

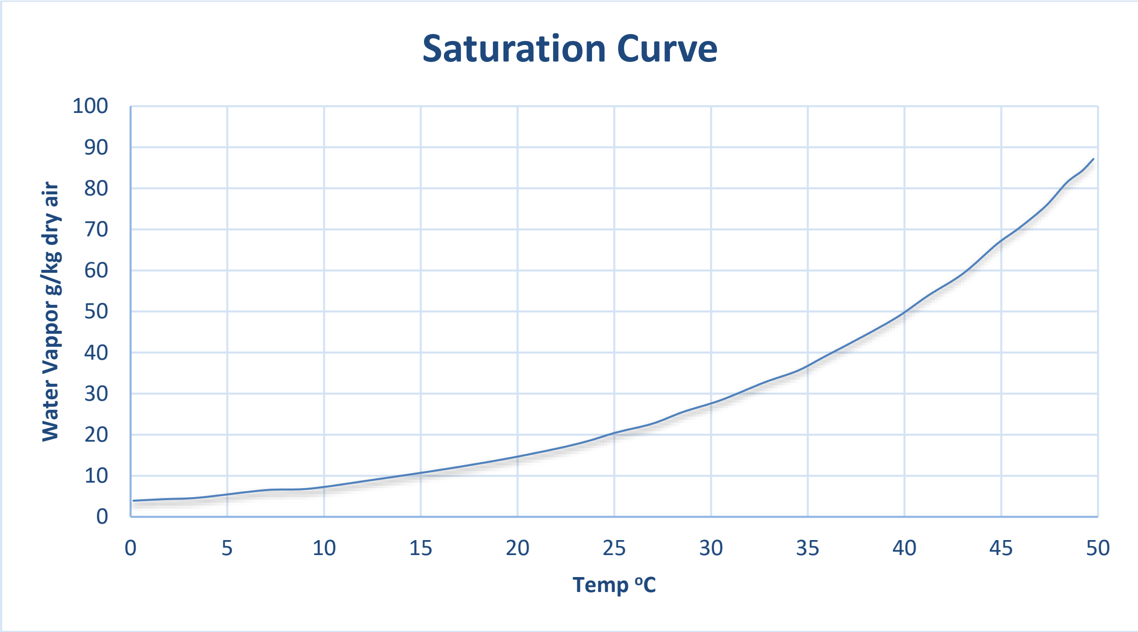


Figure 2.4: The Relationship Between Temp and Evaporation Rate.

2.2.4 Wind Speed

An essential aspect that affects the evaporation rate was air movement, whether it be natural (wind) or manufactured (fan). The air humidity nearest to the water surface (the moist region) increases when water has evaporated from wet surfaces. When any humid air stays in situ, as the humidity increases, the evaporation rate would begin to decrease. On the other hand, the evaporation rate would either increase or stay constant if the moist air near the water surface is continuously removed and replaced with drier air.

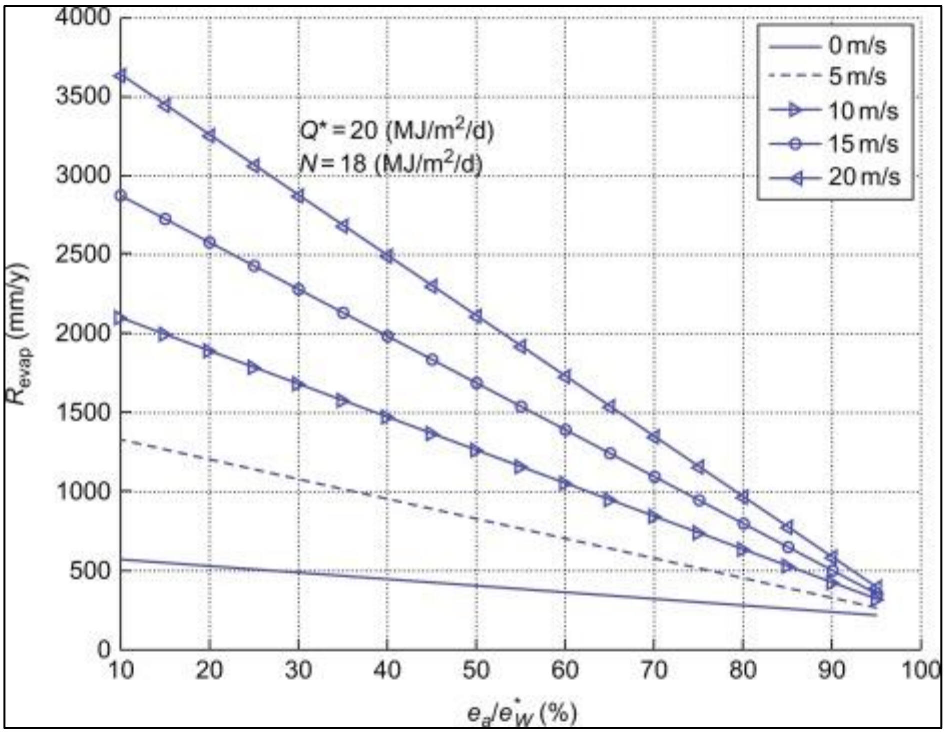


Figure 2.5: Evaporation Rate VS Saturated Vapor Pressure for Various Wind Speed.

2.2.5 Surface Area

It is referred to as the whole region that is exposed to the outside. The rate of evaporation increases with surface area, and vice versa. The reason for this is because more molecules may escape from surfaces with greater areas. Because of this, expanded clothing dries faster than unexpanded clothing. In a similar way, suppose we fill two pots—one open and the other narrow—each with one litre of water. Since there is greater surface area, evaporation would occur more quickly in pots with broader shapes.

2.2.6 Humidity

The relationship between evaporation rate and humidity is inverse. The evaporation rate rises as the relative humidity drops. Evaporation is also influenced by humidity, often known as the amount of water vapour in the air. The air is dryer and the rate of evaporation is greater the lesser the relative humidity. The air gets closer to saturation the more humid it is, and less evaporation may take place. Thus might conceive of their being more space for more water vapour to be stored in warmer air than in colder air because warm air could "keep" a greater content of water vapour.

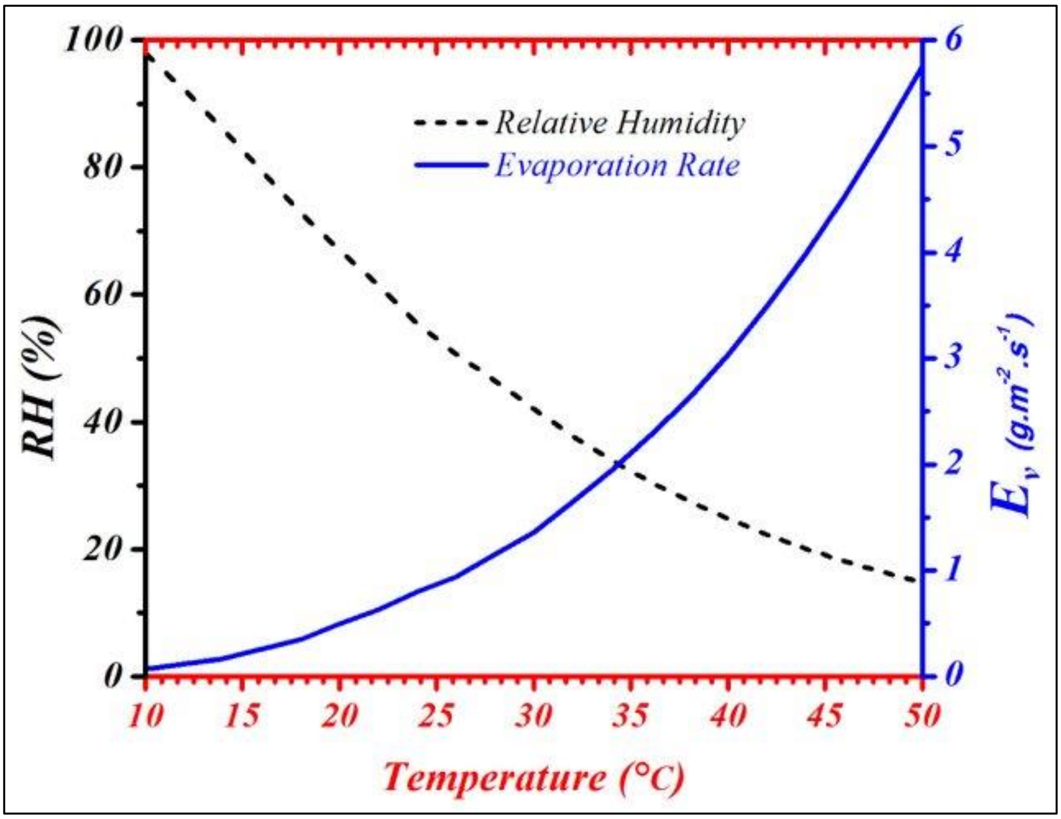


Figure 2.6: The Relationship Between Relative Humidity and Evaporation Rate [53].

2.3 METHODS OF EVAPORATIVE COOLING

The idea behind evaporative cooling seems to be that water absorbs heat, changing from a liquid state to steam and converting sensible heat into latent heat. Evaporative cooling has a number of major advantages, including affordability, energy efficiency, improved indoor air quality, and a decrease in CO2 emissions from power plants [54]. Studies on evaporative cooling systems have been undertaken by several researchers. A ceramic evaporative cooling system was created by Gómez et al. [55] and functions as a semi-indirect cooler by passing the water to be cooled via a cooling tower built of ceramic tubes. This kind of device enables the interior air to be determined due to a temp reduction of between 5 and 12 degrees Celsius. To increase the effectiveness of the evaporative cooling system at high humidity and lower air temp, Jain [56] created a two-stage evaporative cooling system. According to the findings, cooling efficiency increased by (100 to 110)%. El-Dessouky et al

[57] enhancement of a two-stage evaporative cooling system enhanced performance. in which the indirect and DEC units' indirect and DEC units were considered functions of the operating system together with the water flow rate and package thickness. Shaheen and Hmmadi [58] carried out a theoretical and practical analysis for a hybrid system made up of an evaporative air cooler and a refrigeration and air conditioning unit. This study intends to create fresh water, enhance the efficiency of the evaporative air cooler, and lower the moisture content of the air exiting the system. The impact of a number of variables, including intake temp, relative humidity, evaporator temp, and wetted pad thickness, was investigated. The findings revealed that when the relative humidity rose, the coil temp reduced, and the front air velocity reduced, the outlet temp drops by 1-3 and the volume of fresh water also increased. The findings also shown that when pad thickness increases, efficacy rises.

2.3.1 Categorization of Evaporative Cooling Systems

Based on the kind of mass and heating transfer that occurs between the air and water.

a. Direct evaporative coolers, where the working fluids (air and water) seem to be in direct contact, are one kind of evaporative cooler.

b. Indirect evaporative coolers, in which the working fluids are separated by a barrier or plates.

c. Combined System utilizes both indirect and direct evaporative coolers, as well as additional cooling cycles [4]. A basic categorization of the most common evaporative cooling system kinds for building cooling is shown in Figure 2.4.

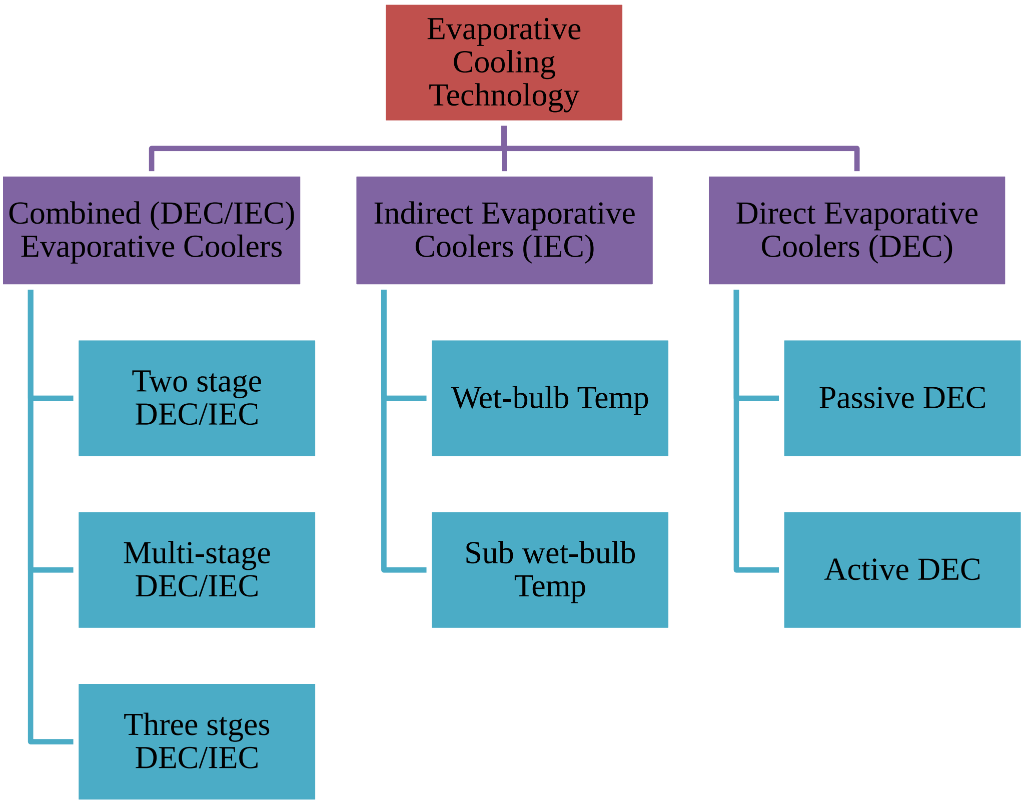


Figure 2.7: An Evaporative Cooling Systems Categorization [54].

There are several ways to chill the atmosphere. Among these, evaporative cooling is a well-known method. This cooling method results in a significant reduction in temp and a rise in humidity to an appropriate level for the short-term on-farm storage of perishables [59]. Additionally, it is utilised to pre-cool fruits and vegetables prior to transportation and cold storage [60]. The many techniques include:

2.3.2 Direct Cooling System

Direct evaporative cooling (DEC) is the process in which water evaporates into the air to be cooled while also humidifying, and adiabatic saturation is the thermal process. One of this process's key qualities is that it works better when the temp is greater, which implies if more cooling is required for thermal comfort. In evaporating water to raise the air's moisture content, DEC, which is often utilised with home systems, cools the air. It includes the passage of air over or thru a wet substance where evaporation and consequent cooling take place. Then, it is permitted for this moist, cooled air to go straight to the required location. In contrast to this method, indirect cooling employs heat exchangers to reduce the temp of the dry air using the cold, wet air generated by evaporative cooling. The cold wet air is subsequently released, and this cool dry air is utilised to chill the surroundings.

A straight line with consistently warm wet bulb temps is a direct evaporation cooling. Wet bulb temp and enthalpy stay constant during direct cooling operation, but dry bulb temp decreases as relative humidity and specific humidity rise. The efficiency of these systems ranges from 55 to 70%. How closely the supply air temp exiting the evaporation cooler approaches the external wet-bulb temp is a measure of effectiveness. In hot and dry areas where the design wet-bulb temp is 68 °F or below, direct evaporation cooling systems are appropriate. In some climes, the outside humidity is too high to allow for adequate cooling. This technique does have certain drawbacks, however. The entire amount of evaporative decrease that is feasible will often only be a tiny portion of the temp drop. This is principally caused by the substantial amount of water that must be cooled by a negligibly large surface area for evaporation. Large water containers could only hold a limited number of things [61]. Water is often held in this arrangement in either a watertight canvas bag or a porous clay container. Then, these containers are either hung up or put in a position where the wind may blow right by them. As warm, dry air passes by, the water in the container slowly seeps thru the clay or canvas material and evaporates off the surface. The evaporation process gradually cools the water..

2.3.3 Indirect Evaporative Cooling (IEC) System

Indirect evaporation cooling removes heat from the main air stream without adding moisture by using an air to air heat exchange. In one design, a string of horizontal tubes with moist exteriors receive hot, dry air from the outside. Warm, wet air is exhausted to the outside via a secondary air stream that passes over the coils' exterior. Thru the tubes, the outside air is cooled without gaining moisture. The efficacy of indirect evaporation cooling is approximately 75 percent. For certain applications, the high humidity that direct direct evaporative generates may not be acceptable. This issue is addressed by indirect evaporation cooling, which cools dry air by utilising the cool, moist air created by evaporation. The ideal atmosphere is subsequently cooled using the produced cold air. A heat exchanger is utilized to facilitate this coolness transfer [62].

All indirect evaporative cooling techniques need electricity to operate the water pump and fans. Indirect evaporation cooling only has a few uses because of this. Its main use is to chill buildings and rooms. In these circumstances, these cooling systems often cost less to acquire, construct, and run than traditional air conditioning systems. However, indirect evaporation cooling could not be utilised in all conditions, and the temp drop it may provide is not as significant as that provided by traditional mechanical cooling systems.

2.4 MULTI-STAGES EVAPORATIVE COOLING SYSTEM

According to [63], evaporative cooling (EC) systems produce increased humidity and lower temp by relying on the evaporation of water within the greenhouses. The greenhouses air must be cooled and its humidity expanded in order for the fluid to turn into vapour. This results in a transition from latent heat to sensitive heating. Depending on the kind of pads and the water flow used, they advise a variety of air velocities across the pads of 1 to 1.5 m/s, where the pressure loss was between 3.9 and 11.25 Pa.

A thorough mathematical model based on sensible and latent heat transmission was studied by [64]. The evaporative cooler's efficiency is predicted by the model under a variety of water supply conditions and operational factors. Cooler water, it was discovered, further lessens the decline in temp within the cooler. Indirect and direct coolers, two steps of evaporative cooling, were researched by Ambade [15]. Therefore, in this cooling system, hot incoming air is first passed thru a cooling pad, which serves as a heat exchanger when the air temp to be cooled falls. This air is then passed thru the cooling medium once more before being evaporated into the atmosphere. The findings indicated that saving water in five or six days provides the most benefit. It is the use of energy.

Increased ventilation rates can contribute to a reduction in interior temp. [65] looked on the operational performance and impact variable of a counter-stream regenerative evaporative cooler (REC). This was accomplished thru a focused testing procedure. Under various operating circumstances, the cooler's air flows at the outlet, input, and exhaust have been evaluated for humidity, flow rate, and temp. It demonstrates that the offered cooler's wet-bulb efficacy ranged from 0.55 to 1.06. By reducing intake air velocity and swiftly raising energy efficiency proportion (EER), cooler cooling capacity and intake air velocity were both substantially enhanced, as was wet-bulb efficacy.

[66] investigation of an indirect evaporative cooler (IEC) application in hot, humid environments has led to the proposal of a new hybrid air-conditioning system. To save energy, the entering natural air is pre-cooled using the IEC of the air-conditioning system. The secondary air in this system was made up of the cold, dry exhaust air from the air-conditioned space. However, condensation is likely to happen due to the high humidity of the clean air in humid areas, which has an influence on both sensible cooling and dehumidification.

A counter-flow regenerative evaporative cooler (REC) was designed, built, and put thru experimental testing by [67] at a research facility. The central mass and heat exchanger for the REC was created using layered sheets of aluminium with excellent wicking evaporation properties. When compared to traditional IEC, the newly developed REC system performs cooler. Experimental research was done on a counter-flow REC prototype's performance in a variety of Chinese outdoor air situations. The findings indicated that for each selected location, the REC may reduce cooling load by 53–100percent and electrical energy usage by 13–58percent annually. The effectiveness of an indirect evaporative cooler system with internal baffles as an air precooling unit and an evaporative condenser was investigated by [68]. The heated water is contained in serpentine pipes with an external thin film cotton layer in the test setup, which consists of an indirect evaporation cooling with inner baffles and an evaporation condenser.

The performance of a two-stages indirect/direct evaporation cooling system was created by [69]. This was accomplished by designing, building, and testing a two-stages evaporative cooling experimental setup that included an IEC stage (IEC) and a direct evaporation cooling stages (DEC). The system was already researched with regard to excess water usage in order to create comfortable conditions and electricity savings. The findings indicate that this technology has a great potential to provide comfort to areas in which standalone direct evaporative coolers are currently unable to. Despite a broad range of environmental circumstances, it is discovered that IEC and IEC/DEC efficacy vary between 55 and 61percent and 108 and 111 percent, respectively.

Both theoretical and experimental research on the effectiveness of multi-stage evaporative cooling systems is conducted by l-Badri and Farhan [70]. The indirect unit to lower the temp and the direct unit to moisten the air make up the majority of the experimental set-up. Air velocity, humidity, and Throughout the months of June and July, the experimental tests were regularly carried out to track the system's performance at varied temps ranging from 35 to 50 degree centigrade. For the Engineering Equation Solver (EES) software to evaluate the performance of multi-stage evaporative cooling systems, a mathematical model for the system components was created. The findings demonstrated that when the Reynolds number Re of the input air, the velocity fraction VAF extracted air for sensible cooling, the air temp at the product-in Tap,i, the air velocity at the product-in Vap,i, and the adiabatic efficacy Efad rise, so does the heat flux Qflux. But when the distance between the heat exchanger plates S and the relative humidity at the production RHap,i increase, it starts to decrease. Maximum performance is attained with just around 5mm of gap between the plates. Between experimental and anticipated data, when the outcomes, there has been a good deal of agreement. The experimental data's level of uncertainty fell between 4.14 to 6.15.

Iraq enjoys a longer summer than other nations due to its climate. The evaporative cooling system is appropriate for this environment since the air temps throughout this season exceeds 50 degree centigrade. Alhosainy and Aljubury [71] research on the two-stages evaporation cooling system, IEC, which consists of two heat exchangers and a groundwater flow rate of 5 L/min, is the first step. Direct evaporative cooling (DEC) that consists of 3-pads with groundwater flow rate of (4.5 L/min), is the second step. In Baghdad, the experimental work was conducted in the months of October, September, August, and July. The system's total evaporative efficacy (two coils with three pads, each pad measuring 3 cm) reached 167percent according to the findings, with a 26.2 degree centigrade temp differential between the supply and ambient. Whereas this increased to 122.7percent (one coil with three pads) when the supply and ambient temps were 16 degree centigrade apart, it decreased to 84.88percent and 84.36percent for IEC and DEC, respectively.

[72] examined the development of the evaporation cooler by integrating multistage heat exchanges (air - air and water - air) to chill the input air indirectly and directly before cooling directly within the traditional evaporation cooler. When compared to compression cooling system, the multistage evaporation cooler helps to minimise energy use, environmental

pollution, the effects of global warming, and cost of production. The multistage evaporative cooler was appropriate for use in homes and sizable structures with high relative humidity and temps. According to the experimental findings of the newly constructed evaporative cooler, introducing a cooling stage to a conventional cooler lowers the out-of-dry-bulb temp by approximately (50 percent) and increases specific humidity by around (70 percent).

The air conditioning (AC) unit primarily uses the vapour compression cycle as a refrigeration cycle. The Performance Coefficient (COP) must be raised in order to conserve energy. Making the system into a multi-stage vapour compression cycle is one possible option. One of the design considerations is the appropriate middle pressure between the low and high pressures. The ideal intermediate pressure of a two-stage vapour compression refrigeration cycle was researched by [73]. Consideration is given to the typical AC unit vapour compression cycle. R134a is the refrigerant in use. For the systems, the governing formulas were created. The issue has been resolved using an internal programme. Plotted as an intermediate function pressure were COP, the refrigerant mass flow rate, and compressor power. It has been demonstrated that there is an ideal intermediate pressure for achieving the highest COP. The suggested relationships for refrigerant R134a are required to be updated.

The examination of multi-stages and single-stage vapour compression refrigeration cycles is covered by [74]. It is taken into account that the AC unit uses a standard vapour compression cycle. Difluoromethane R32 is the refrigerant that is utilised. the analysis that utilized the modeling technique and the Aspen One programme. The refrigerant mass flow rate, compressor power, and COP are among the performance metrics. It has been demonstrated that multi-stage systems had a max COP. Based on the outcomes of the performance simulation, the multi-stage strategy for the air conditioning system is the most effective.

In a small chicken house in the summer, [75] explored the issue of a sudden temp decrease and its solutions using a cooling pad and fan system. Using field testing, the scope and dispersion of sudden temp drops in a commercial laying hen coop in north China have been examined. The findings revealed that after initiating the evaporation cooling system in the conventional ON/OFF mode, more than half of the poultry house has been cooled by more than 5 degree centigrade (the highest reaching 12.4 degree centigrade) in less than 25 minutes. Layers may experience harmful impacts from this mode. A multistage regulating approach of evaporation cooling system was designed to lessen this issue. The initial water supply system was changed by including a specifically created water repartition plate. The water repartitions plate may regulate how much of the pad is irrigated. Following the achievement of four degrees of moistened area—1/8, 1/4, 1/2, and the complete pad area—gradual cooling was accomplished. Thru changing the start temp and single-cooling rangse, the goal temp was progressively attained. Once this was done, it took hens a comparatively long time to adopt the cooling procedure. This regulatory strategy has undergone laboratory testing. The results shown that under multistage control, cooling and watering are done progressively. The first thru fourth stage cooling efficiencies have been 15.84, 30.53, 56.67, and 83.70 percent, respectively, and these values were in line with expectations. In conclusion, the multistage control strategy was successful in resolving the issue brought on by the evaporative cooling system's restrictive ON/OFF mode.

One of the most cost-effective methods for providing cooling was humidification-de humidification technology. Four packings are inserted into four distinct slots and a cam follower mechanism is employed to drive the new reciprocating packing humidification system that [76] concentrated on developing and building. To ascertain the impact on outlet variables like energy conversion rates and factors, humidification efficacy, and specific cooling capacity, inlet operating parameters like air velocity and camshaft rotation were modified. With better values for the performance parameters, the reciprocating multi-stages evaporative cooler outperforms the single-stage cooler. The evaporation rate, humidification efficiency (HE), and energy conversion factor (ECF) all decrease as the camshaft speed rises (ER). Air velocity raises ER and ECF while decreasing HE. The ECF attained is 2.9, which corresponds to an air velocity= 5.6 m/s and a camshaft speed of 10 rpm, and the greatest humidification efficiency is 72.6%. A multi-stages evaporating cooling system may save 7percent of energy as compared to traditional VCR-based cooling solutions. According to sensitivity study, the air flow rate has a bigger impact on output responses than camshaft rpm. To improve the multi-stages reciprocating cooler's performance, operating parameters have been modified. The findings showed that maintaining an air velocity of 5.3-6 m/s and a camshaft speed of 16-18 rpm improved the evaporation cooler's overall performance while using less energy.

In order to develop the suitable design for multi-stages IEC systems, [77] devised a performance assessment approach. The indirect evaporation cooler was already given a mathematical basis (IEC). Following validation, the mathematical model had been utilised to examine the assessment criteria while simultaneously taking into account the effects of the cooling capacity, pressure drop, and multi-stages IEC functioning in two modes. The Mode-2 IEC has a regenerative M-cycle system, whereas the Mode-1 IEC is a typical counter flow device. The IECs work in tandem with one another. The multi-stages system has the ability to increase cooling efficiency and lower exhaust air temp. Additionally, the multi-stages system exhibits a greater pressure drop, which causes a larger fan power usage. According to the study of performance assessment criteria, the recommended max stages for the Mode 1 and 2 IECs, respectively, are three stages and two stages.

A small counter flow heat exchanger with louvre fins on both sides was developed by [78] as a model for an indirect evaporative cooler. They showed that the cooler performance was overstated by their estimations by 20percent for intake air temps under 24 degree centigrade and by 10percent for higher inlet temps. The impacts of air stream direction in the channels of the indirect evaporative cooler (IEC) were examined by [79]. They discovered that employing the indirect evaporative cooler with counter-current design led to a greater performance. The IEC heat exchanger technique was described by [80] using the CFD approach. They looked at factors including input air temp, relative humidity, mass flow rate, and exchanger channel height. They came to the conclusion that lower output moisture content and temp could be achieved with lower intake relative humidity and temp. In order to explore the associated mass and heat transport properties in IEC with counter-flow configurations, [81] created a novel method. They looked closely at how various criteria affected the mean Nusselt and Sherwood values in their investigation. An experimental and computational investigation of the effectiveness of a counter-flow dew point evaporative cooling system was conducted by Pakari and Ghani [82]. They discovered that the cooling system's anticipated outlet temp from 1-dimensional and three d models and the experimental findings agreed rather well. A cross-flow heat exchanger-based indirect evaporative cooler was explored by [83]. They built a novel IEC system model in their research that took into account working circumstances as well as the impacts of secondary air humidification and surface wettability parameter.

A CFD model was utilised by [84] to take counter flow dew point evaporative coolers into account. The highest deviation predicted by the model from experimental data was 6 percent. The length and breadth of the cooling system's channels were the two dimensions that were examined in the model. A counter-cross flow plate heating recovery exchanger, which serves as an indirect evaporative air cooler, was the subject of a comparative research by [85]. According to their findings, the exchanger installed vertically had a lower exit temp than the exchanger set horizontally.

2.4.1 Greenhouses Evaporation Cooling System

Greenhouses are being built for the aim of producing high-quality crops, which cannot be done on open fields owing to the unfavorable weather conditions. Greenhouse farming in places with hot climates is characterized by high solar thermal load, which generates serious challenges within the atmosphere of the greenhouse and hinders plant development. This load is caused by the sun's intensity and position in the sky. Castilla et al. [86] report that the growth and quality of the crop grown within a greenhouse might be negatively impacted when temperatures fall below 12 degrees Celsius or rise over 30 degrees Celsius. In this sense, it is very essential to clear away any surplus heat load from the greenhouse if the weather is particularly warm. There is a wide variety of approaches that may be taken in order to keep a greenhouse at a temperature and humidity level that is conducive to healthy plant development. When temperatures are relatively mild in an area, the most frequent method used to modify the microclimate within a greenhouse is natural ventilation. Yet, at times of intense radiation, natural ventilation usually is unable to successfully remove the additional thermal load.

In order to solve this problem, you may install fan ventilation to operate as a replacement for the original method of removing excess heat. In some circumstances, shade nets placed either inside or outside the greenhouse are quite efficient in limiting the amount of solar radiation that enters the greenhouse while yet allowing for some solar radiation to get through. Likewise, despite the fact that the shade net lowers the heat load and the air temperature, there is a possibility that the plant's growth rate may slow down. A portion of the sun's energy is reflected back into the atmosphere when a roof is whitewashed, which lessens the greenhouse effect's heat burden. Evaporative cooling systems are the most effective method for the decrease in greenhouse surplus thermal load due to high levels of solar irradiation during hot times. This is because the other methods that were described are less effective than evaporative cooling systems. In order to maximize the effectiveness of evaporative cooling in greenhouses, natural ventilation or ventilation provided by fans is often used in conjunction with the process.

The transfer of heat and mass takes place between the air and the water during the evaporative cooling process. After the air's sensible heat has been absorbed by the water, and once that heat has reached the same level as the water's latent heat, the water will begin to evaporate. The temperature of the air drops because evaporation removes heat from the water and transfers it to the surrounding air. Dry air has a larger cooling impact than wet air does because evaporative cooling is dependent on the transfer of heat and mass between the air and the water. It is thus more effective in regions that experience hot and dry climates, but it may also be utilized in regions that experience high levels of humidity by combining appropriate desiccation medium [87].

A current concept of cooling efficiency was proposed by Abdel-Ghany et al. [88] for the use of fog cooling to greenhouse systems. They looked at how effective various fogging cycles were as a means of cooling the environment. The mass and energy balance of the heated air that was present within the greenhouse without being cooled led to the development of this term. They had also shown that an increase in evaporation rate lowered the air temperature, which led to an increase in the effectiveness of the cooling process. Ishigami et al. [89] evaluated the ventilation influence on plant microenvironment as well as the utilization of water (cooling and plant transpiration) in a semiarid fog-cooled greenhouse system. Their research was published in the journal Environmental Science & Technology. Tests were performed with two different configurations of roof and side vents to see which worked best. They discovered that the natural ventilation fog cooling approach was capable of keeping the greenhouse's interior temperature between 23 and 26 degrees Celsius in both vent scenarios. This was the case for natural ventilation. They observed that while the relative humidity rose, the ventilation rate and water consumption in the greenhouse reduced. This was despite the fact that the humidity itself had risen.

Li and Willits [90] conducted a research that compared a low pressure fogging system (4.05 bar) to a high pressure fogging system (40.5 bar) in order to gather data for their comparison.

They made the discovery that fogging systems operating at high pressure offered superior cooling than those operating at low pressure. This paper also presented the results of comparative research about the efficiency of evaporation and cooling. In a different piece of research, Katsoulas et al. [91] conducted an experiment to determine the influence of fogging on the microclimate within a greenhouse for the cultivation of soilless pepper crops. They conducted research on the impact that humidity management had on the climate of the greenhouse, the rate of crop transpiration, as well as the yield and fruit quality of the crop. They observed that the air temperature in the greenhouse and the temperature of the plant leaves were around 3 degrees Celsius lower under fog-cooled conditions compared to when there was no fog present.

Once again, Katsoulas et al. [92] investigated the impact of high-pressure fogging on the microclimate inside a greenhouse that was used for the cultivation of eggplants. The whole greenhouse was divided into two sections for the sake of taking measurements, with natural ventilation being used in one section while a fog chilling system was used in the other section. It was discovered that the temp of the compartment that was cooled by fog was between 2.5 and 3.5 degrees Celsius lower than the temp of the other compartment that was naturally cooled. The fog cooling brought the average temp of the fruit down by around 3 degrees Celsius and maintained a temp in the greenhouse that was below 32 degrees. Garcia et al. [93] conducted an experiment in which they compared the effectiveness of two strategies for cooling a plastic-covered greenhouse in the Mediterranean region: one used external moveable shade, while the other sprayed fog water. They carried out a number of tests in which various configurations of shade were considered in order to limit the amount of solar radiation that entered the greenhouse. According to their findings, the effectiveness of the cooling systems in each scenario is most likely comparable when compared to fixed shade.

In their study, Perret et al. [94] exhibited a Quonset greenhouse that included humidification and dehumidification systems that had been constructed appropriately. Two humidifiers and two dehumidifiers, also known as condensers, were installed in the greenhouse. The humidifiers were responsible for increasing the relative humidity of the air while simultaneously lowering the temp. The dehumidifiers were responsible for bringing the air's temp down below its dew point. Davies and Paton [95] developed a CFD model that was calibrated using a prototype seawater greenhouse that was built in the United Arab Emirates. The calibration of the model could be able to make predictions about the temperatures and airflow within. According to Davies [96], liquid desiccators and solar regeneration are both viable options that may be considered for the purpose of reducing the temp inside of an evaporatively cooled greenhouse. He suggested a plan that was similar to the conventional fan-pad system but also included the installation of a desiccant pad in front of the first evaporator pad. He conducted an experiment in the environment of the Gulf in Abu Dhabi and claimed that a liquid-desiccant cooling system could reduce the temp of the greenhouse by 5 degrees Celsius more effectively than the conventional fan-pad technique.

Mahmoudi et al. [97] developed a model for the enhancement of the production of fresh water by using a passive condenser. This model was used to improve the process. The plants benefited from the greenhouse's cool environment, which was supplied for them. The real pump driven system was shown to have a lower capacity to generate fresh water when compared to the simulated findings obtained from the passive condenser. Wong et al. [98] construct a conceptual design of the mechanical equipment necessary to cool, store heat, and heat a greenhouse operation using an aquifer thermal energy storage (ATES) system. They created a thorough thermal energy model for a greenhouse by utilizing the TRNSYS software. Their model is capable of simulating the energy performance of both the conventional (open) and the "closed" greenhouse energy operation in the environment of Canada.

For greenhouse usage, Abbouda and Almuhanna [99] created a two-stage evaporative cooling system that includes a direct evaporative cooling (DEC) unit that includes the cooling pad and an indirect cooling unit that includes the cooling coils unit (CCU). In the CCU, the heat load of the hot air was transferred as it was passing through the cooling coil, but in the DEC, heat is absorbed during the evaporation of the supplied water. It was discovered that the CCU was capable of delivering the only hourly mean temp reduction of 8.1 degrees Celsius, with an efficiency of 47.4%. On the other hand, the DEC's efficacy was calculated to be 75.12% on an hourly average basis. Likewise, the hourly mean air temp in the greenhouse was lowered by 19.1 degrees Celsius during the daytime and by 9.0 degrees Celsius during the night when the combined cooling mode (both CCU and DEC) was used.

A theoretical model was developed by Lychnos and Davies [100] analyze the performance study of a greenhouse that was paired with a solar power regenerator, MgCl2 desiccators, and an evaporative pad. The model had been constructed for both the regenerator and the desiccators, and its findings demonstrated a healthy fit with the experimental values that had been undertaken throughout the warm summer months. According to what they found, in comparison to the conventional evaporative cooling system, the desiccators with pad system were able to lower the average daily maximum temperatures by 5.5–7.5 degrees Celsius during the warm season.

An dry location in Oman served as the setting for the experimental examination that Al-Busaidi and Al-Mulla [101] carried out on two distinct greenhouses, namely a saltwater greenhouse (SWGH) and a conventional greenhouse (CGH). Both of the greenhouses included fans and an evaporative cooling system that used pads, however the SWGH used saltwater rather than fresh water to meet the need for the greenhouse's temperature control. In addition, a desalination unit was included into the cooling SWGH system. This allowed for the production of fresh water, which was used to irrigate the cucumber plants that were grown within the greenhouse. It was found that SWGH was able to lower the temp of the greenhouse by 4.8 degrees Celsius, whereas conventional greenhouses were only able to reduce the temp by 7.4 degrees Celsius. It was also seen that CGH was unable to keep the relative humidity within the building at more than 60% of the time, but SWGH was able to do so.

A solar desiccant evaporative cooling system was created and developed by Abu-Hamdeh et al. [102]. This system is intended to be capable of cooling the greenhouse in high humid climatic conditions. They determined that the suggested cooling method had the potential to lower the interior temp by around 6 degrees Celsius when compared to the more conventional method of cooling, which included the evaporation of water. Aljubury et al. [103] introduced a two-stage evaporative cooling system (indirect-direct cooling system; IDEC) for the purpose of safeguarding plants contained inside a greenhouse situated in a desert area where the temp of the surrounding air regularly climbs to 50 degrees Celsius. The cooling system had one indirect evaporative cooling (IEC) heat exchanger in addition to three pads that were each staged in three different ways. In order to study the microclimate within the greenhouse, they devised a technique called indirect-direct evaporative cooling, or IDEC for short. Both the indirect heat exchanger and the wetting pads made use of geothermal water. Geothermal water was employed as a cooling fluid. They discovered that the efficiency of evaporative cooling provided by the IDEC system had been enhanced to 108%, in contrast to the efficiency provided by direct evaporative cooling (DEC), which was 77.5%. In the end, the researchers came to the conclusion that the IDEC, which used ground water as a coolant, had caused a decline in greenhouse temp of almost 12.1 degrees Celsius to 21.6 degrees Celsius and an increase in relative humidity of 8% to 62percent in comparison to the circumstances outside.

Banik and Ganguly [104] created a thermal model of a desiccant aided dispersed fan-pad ventilated greenhouse system in order to estimate the air's temp within the greenhouse. They used reference model research that was already published in the literature to validate the model. It was discovered that during a hot and humid season, a greenhouse was able to achieve a temperature reduction of 4.3 degrees Celsius below the ambient temperature, but a standard fan-pad system only achieved a temperature reduction of 2.5 degrees Celsius below the ambient temperature. In addition to this, they included a cumulative cash flow model in their analysis so that they could determine the payback time and the Net Present Value of the greenhouse system.

3. SIMULATION MODEL DESCRIPTION

3.1 INTRODUCTION

This chapter provides basic information about CFD simulations for manufacturing applications that include cooling system. In-depth presentations of the ideas and simulations are also made.

3.2 MODELLING STRATEGY

In this thesis, the utilizations are simulated and examined using a structured approach. The method may be broken down into the three following major phases (Figure 3.1).

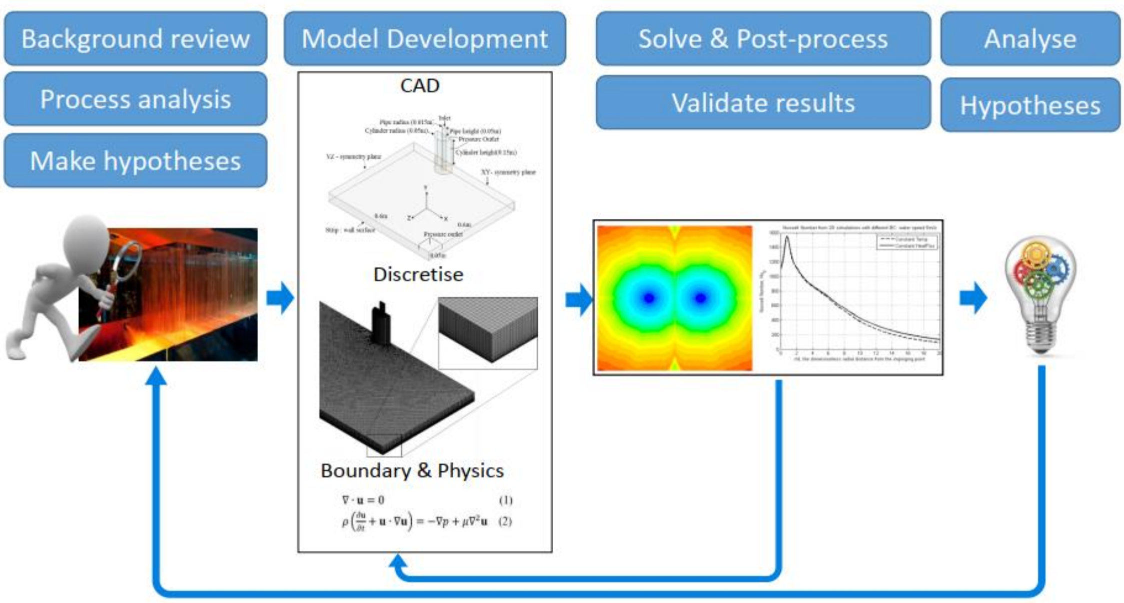


Figure 3.1: Modelling Strategy.

3.2.1 Various CFD Methods

High-fidelity CFD simulations for industry sectors are carried out using two alternative methods, depending on Eulerian and Lagrangian parameters, respectively. Meshes-based CFD techniques are those created using the Eulerian reference frame. In this method, the mathematical domains W was specified utilizing meshes components (Figure 3.2a), and the Navier-Stokes formulas are indeed a collection of very nonlinear formulas that have been calculated across the whole meshes. The RANS formulas, that are time-averages variations of the fundamental Navier-Stokes formula, were analyzed in this thesis. Reynolds Osborne put out the concept of using the Reynolds decomposition to divide the flow parameters into average (time-average) and estimations to construct the RANS formulas (Reynolds, 1895). As the most popular method of modelling turbulent flows in the majority of commercial CFD systems, RANS formulas were primarily utilised to represent turbulent flows. The Navier-Stokes equations may be solved using other methods, including DNS (directly numerical simulations) and LES (large eddies simulation). Nevertheless, these methods are mathematically considerably more taxing than the RANS method, hence they are not the first choice for significant industrial R&D challenges. The formulas used in the RANS modelling technique are explained in detail. In this thesis, the most widely used meshes-based FVM approach is used.

Mesh-free particle-based CFD techniques are those created using the Lagrangian frame. According to this method, the fluid was depicted as a collection of fluid particles with characteristics including mass, location, velocity, and temp (Figure 3.2b). This method solves the initial batch of Navier-Stokes formulas, but the interfacial tension between the particles causes the convective of the particle to automatically happen. In the original Navier-Stokes momentum formulas, the nonlinear convective components are therefore ignored. In this thesis, SPH, the most well-liked Lagrangian mesh-free particle approach, has been used. The SPH version of the Navier-Stokes formulas is addressed by approximating them utilizing SPH kernel approximations operations.

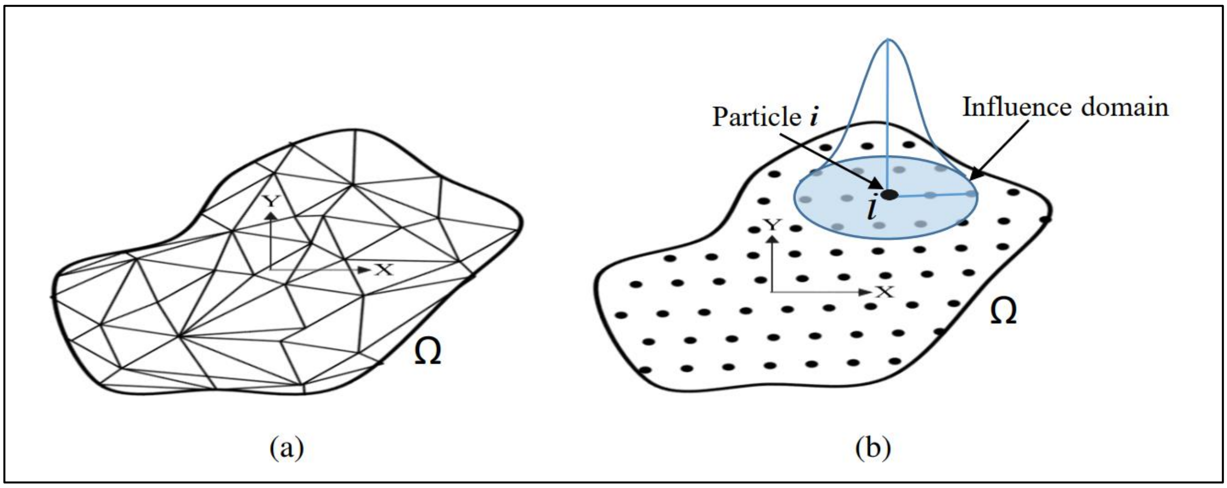


Figure 3.2: Various Discretization Methods for Computational Fluid Dynamics: (A) Meshes (B) Particles.

3.2.2 Governing Formulas

The primary principles of a set of transport formulas used to simulate any fluid movement are momentum and mass conserving. To describe heating transmission, other formulas should also be addressed, such as the energy conservation formula, turbulence formulas, and component transport formulas for combustion. Below is a presentation of the momentum and mass formulas. The following is how the conservation of mass formula may be expressed:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{3.1}$$

The next formula describes the momentum conserved in the initial Navier-Stokes formula:

$$\frac{\partial}{\partial t}(\rho u_i) + \underbrace{\frac{\partial}{\partial x_j}(\rho u_j u_i)}_{\text{convective term}} = -\frac{\partial p}{\partial x_i} + \underbrace{\frac{\partial}{\partial x_j}\left(\mu \frac{\partial u_i}{\partial x_j}\right)}_{\text{diffusive term}} + F_i \tag{3.2}$$

whereas, external force is Fi, dynamics viscosity is μ , pressure is p tensor symbolization velocity is ui and density is x_j.

3.2.3 Transfer Energy Formula

The energy conserving formula looks like this:

$$\rho c_p(\frac{\partial T}{\partial t} + \underbrace{u_i \frac{\partial T}{\partial x_i}}_{\text{convective term}}) = \frac{\partial}{\partial x_i}\left(\kappa \frac{\partial T}{\partial x_i}\right) + \phi \tag{3.3}$$

whereas, energy thermal is expressed by *T*, specific capacity of heating is *cp*, thermally conductive properties is *k* and the viscously dissipation is *f* or the internal heating rate produced/ volume unit.

3.2.4 Transportation Formula for Mixture Fraction

Under the presumption of equal mass diffusion coefficients of the species participating in the systems, the mixed fraction idea is utilized to describe combustion. The transportation formula for each species is then combined into a single transportation formula for the mixed fraction $f = \frac{Z_i - Z_{i,ox}}{Z_{i,\text{ fuel}} - Z_{i,ox}}$ as following:

$$\frac{\partial}{\partial t}(\rho f) + \frac{\partial}{\partial x_i}(\rho u_i f) = \frac{\partial}{\partial x_i}\left(\frac{\mu}{\sigma}\frac{\partial f}{\partial x_i}\right) + S_m + S_{user} \tag{3.4}$$

whereas, s is referring to constant value and dynamic viscosity is presented by μ.

3.3 MODEL DESCRIPTION

Greenhouses located in regions with warm summers often have a difficult time producing crops during the summer months due to the fact that the temp within the greenhouse increases over the range that is suitable for growing [96]. Cooling methods are necessary to permit cultivation at any time of the year; yet, traditional cooling technologies like as vapour compression and evaporative cooling have severe drawbacks that prevent their widespread use. Evaporative cooling is only a viable option in regions that have a plentiful supply of water and takes a significant amount of energy to operate. Compressing vapors often involves the use of refrigerants that contribute to climate change. Vapor compression. As a result, there is not currently a market for water- and resource-efficient greenhouses that are suitable for hot climes [105]. In order to fill this significant void, there is a pressing need for more efficient thermal processes that use less water.

In the current investigation, 10-row chilled water-cooling coils with dimensions of 75 cm in length, 0.0125 m in diameter, and 5 cm between each coil have been employed. For implementing the boundary conditions, the complete coil set was contained in a rectangular cube with dimensions of 2 metres long by 0.75 metres wide by 1 metres high. Figure 3.1 [106] depicts the indirect evaporative cooling system's geometry, and Figure 3.2 shows the system's geometry from the side.

There are two models: The first one consists of three stages (air fan-water pad-air fans), while the second one consists of (air fan-water pad).

3.3.1 Air Fan

In three stages cooling system, a big air fan has been placed in the ceiling of the evaporation cooling system unit in order to give enough space for entering the hot air into the system, as well as when change the system from three stages to two stages cooling system just close or remove the ceiling fan.

While in both three and two stages cooling system, the second fans was (two small fans) in order to give high opportunity for air path to move on.

Figure 3.3: Air Fan [107].

3.3.2 Multi-Pipes Heat Exchanger

A twin pipe heat exchanger is a particular kind of pipe with a central conductive barrier that prevents an annulus shape from being formed by both flowing liquids and an adjacent pipe. The working fluid is carried by the inner half of the pipe, which serves as a conductor. The inner tube serves as a conduit for the ensuing heat exchange. When the cold flow travels thru the outer shell, the heated flow travels through the inner tube. Double pipe exchangers are often used in high-pressure and high-temp applications because of their strong structure and capacity to expand. When the hot flow surpasses the cold flow, they could also undergo temp cross throughout counterflow. A twin pipe heat exchanger is often employed in situations where the more common shell and tube exchangers are ineffective at transferring the required amounts of heat. To raise the temperature, it may be employed either in parallel or in series.

Figure 3.4: Multi-Layers Heat Exchanger [108].

3.3.3 Water Pad

In order to reduce the air temperature, wet curtain (water curtain) cooling primarily employs water in the evaporation process to absorb heat from the air. Used in practice along with a negative pressure fan, a wet curtain is installed on one end of an airtight building's gable or side wall, and a fan is installed on the opposite end. This creates a negative pressure that forces outdoor air to flow through the wet curtain's porous surface, reducing the temperature of the indoor air by 10 to 15 degree centigrade while also burning a lot of calories.

At the heart of the cooling pad cooling process is the finished paper pad, which has a thin layer of water film on the surface of corrugated fiber. Once outdoor hot air is drawn through the paper by a suction fan, the water on the water film would then absorb the heat and turn into steam, causing the indoor temperature to drop more than 5 or 10 degrees as a result.

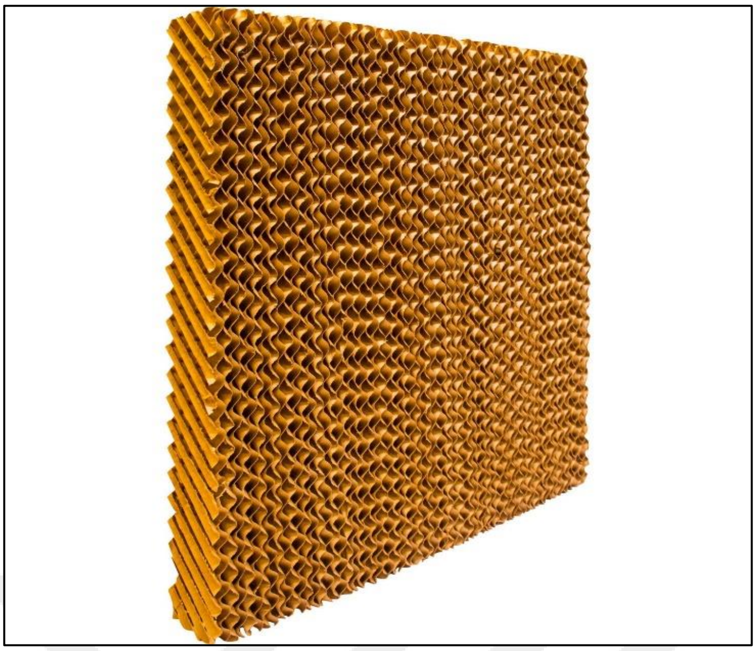


Figure 3.5: Water Pad Honeycomb Shape.

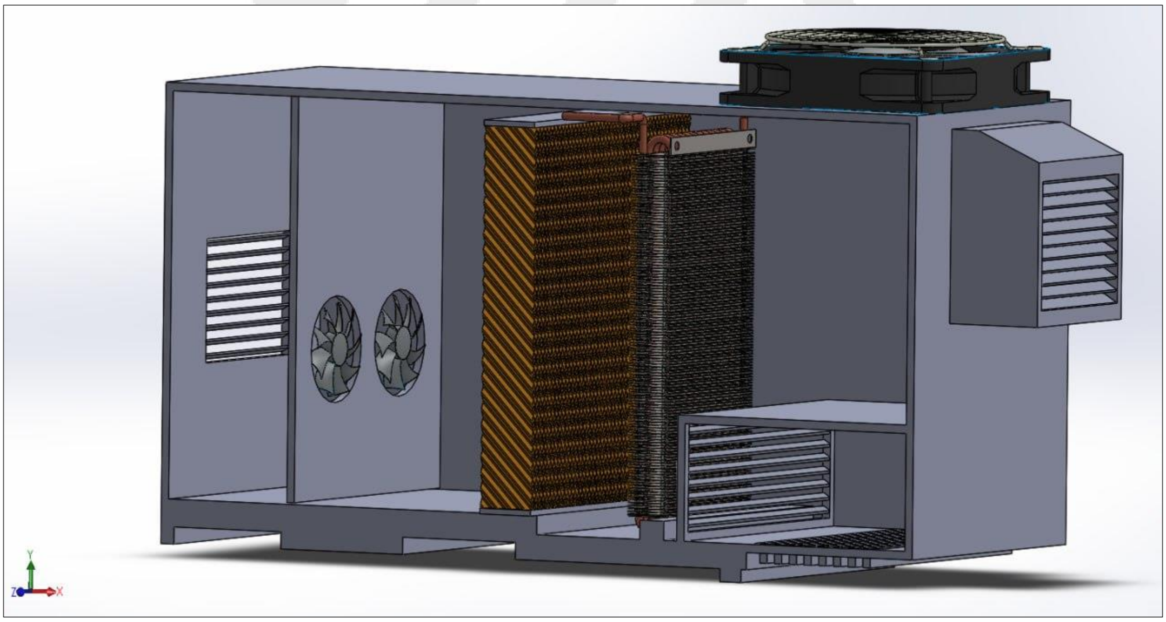


Figure 3.6: Three Stages Evaporation Cooling Model.

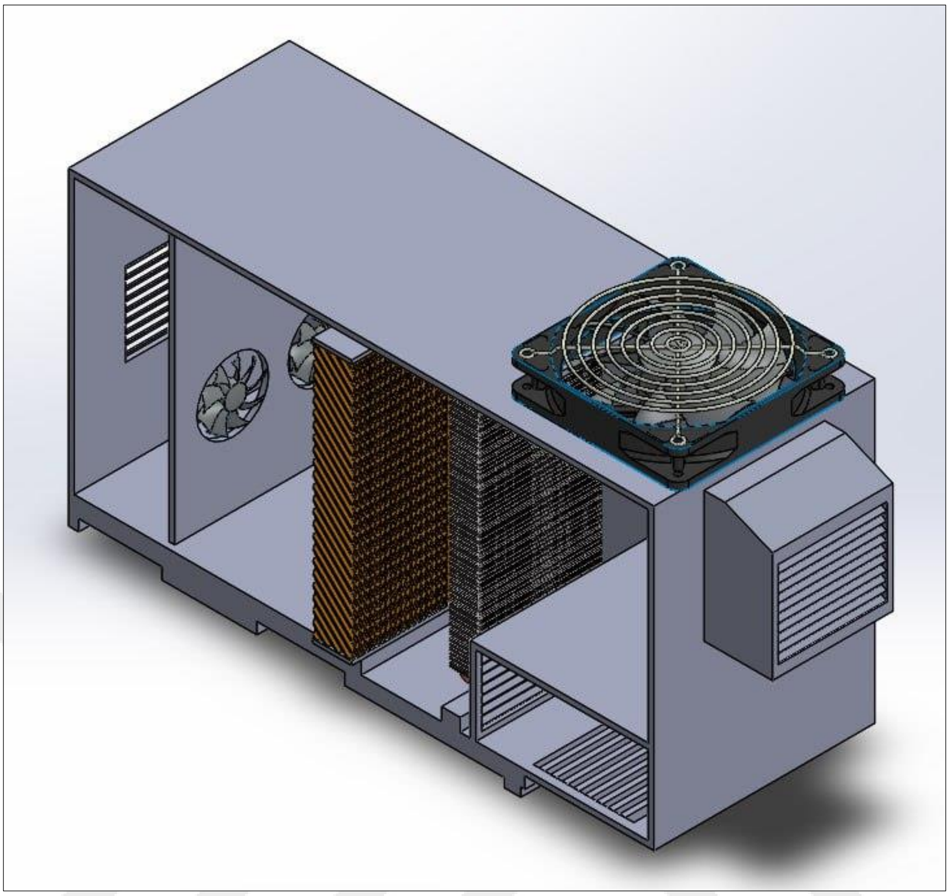
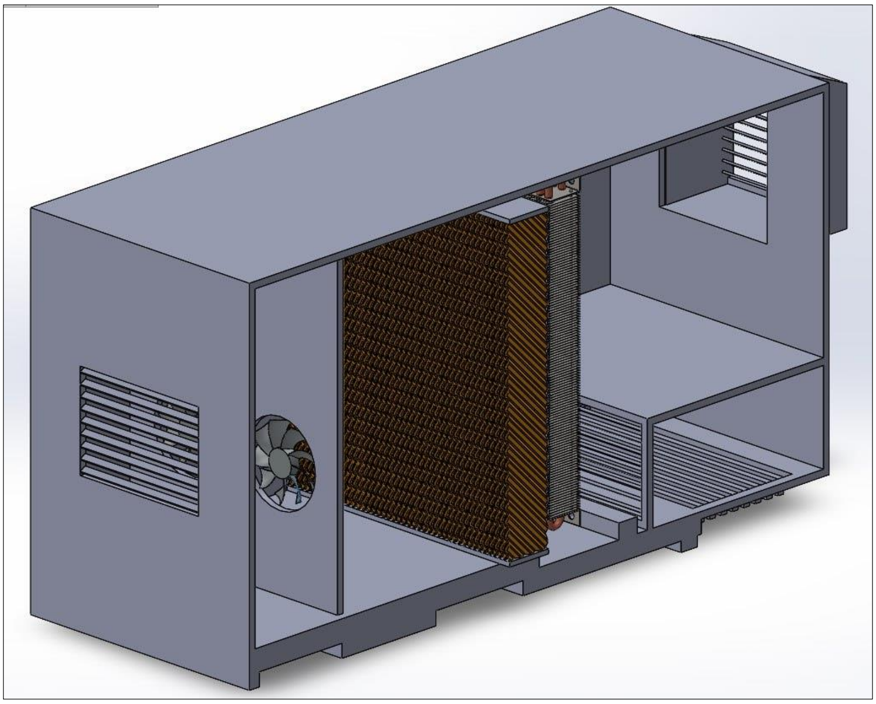


Figure 3.6: Three Stages Evaporation Cooling Model “Figure Continued”.



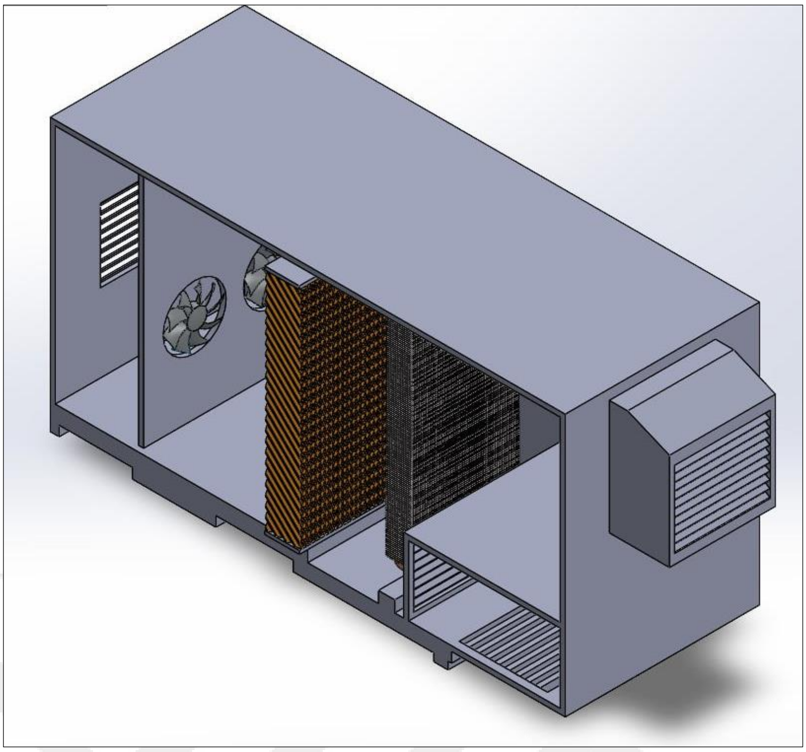
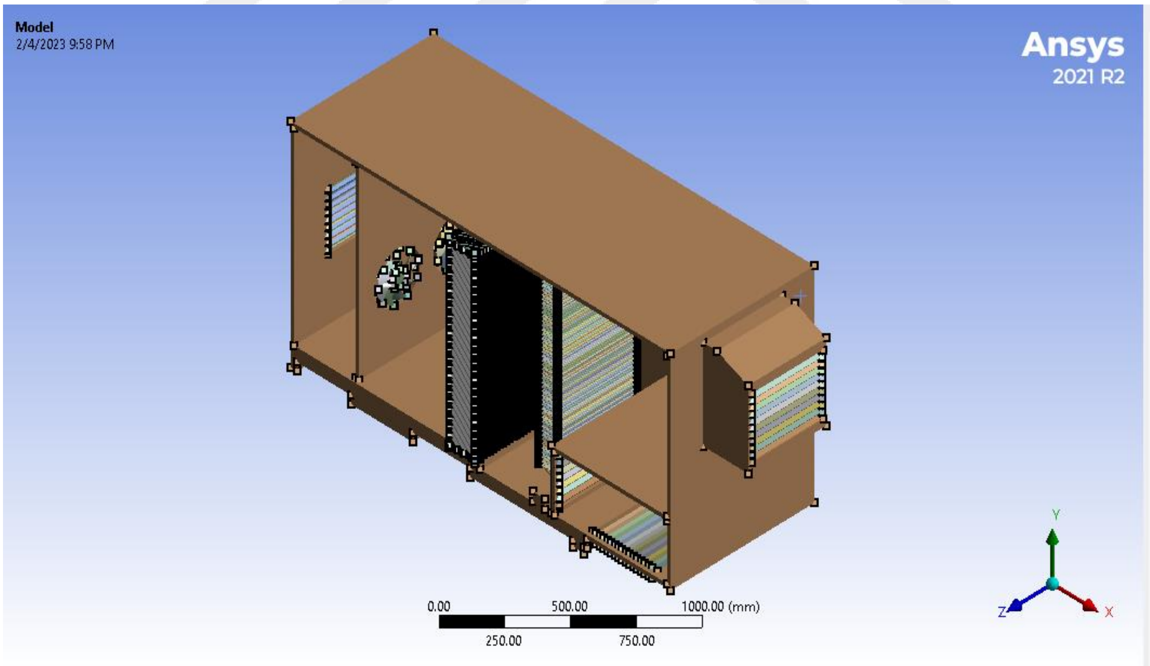


Figure 3.7: Two Stages Evaporation Cooling Models.



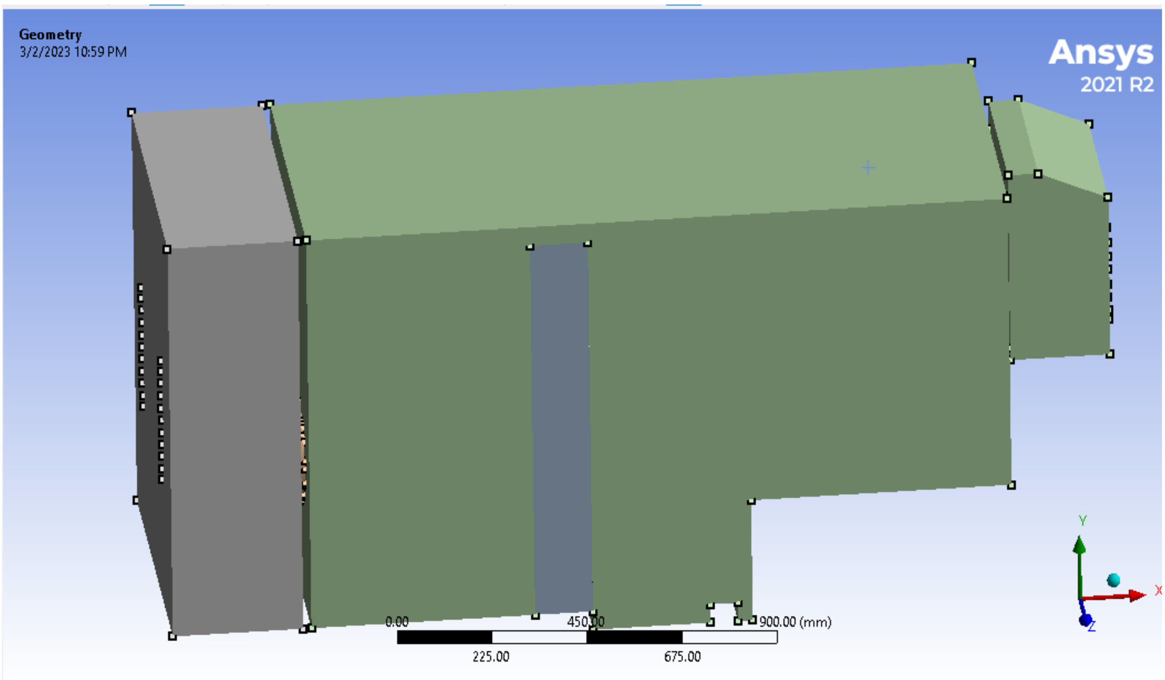


Figure 3.8: The (IEC) System Geometry [106].

Table 3.1: Model Geometry

Object Name	Geometry
State	Fully Defined
Type	SpaceClaim
Length Unit	Meters
Bounding Box	
Length X	2258.1 mm
Length Y	1000. mm
Length Z 770. mm	
Properties	
Volume	1.3872e+009 mm³
Scale Factor Value	1.
Statistics	
Bodies	5
Active Bodies	5
Nodes	409867
Elements	2212351
Object Name	Geom
State	Meshed
Graphics Properties	

Table 3.1: Model Geometry "Tables Continued".

Visible	**Yes**
Definition	
Suppressed	No
Assignment	
Coordinate System Default	Coordinate System
Bounding Box	
Length X	2258.1 mm
Length Y	1000. mm
Length Z 770. mm	
Properties	
Volume	1.3872e+009 mm³
Statistics	
Nodes	409867
Elements	2212351
Mesh Metric	None

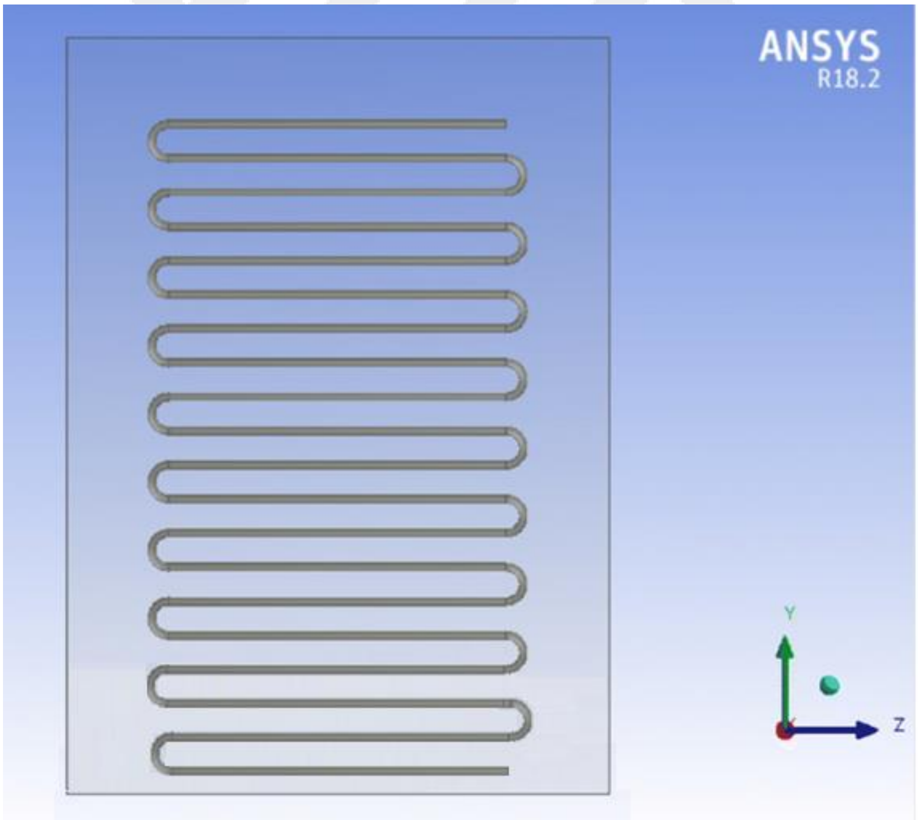


Figure 3.9: The (IEC) System Geometry Side-View for Heat Exchanger [106].

3.4 GOVERNING EQUATIONS

The flow was regarded as incompressible, turbulent, and three-dimensional in the current investigation. The ANSYS CFD code Fluent can handle species transport problems as well as energy, momentum, and continuity formulas. The momentum and continuity formulas applied in this situation are represented by formulas (3.1) and (3.2), respectively. Furthermore, we investigate the acceleration caused by droplet particles and viscous forces [109].

$$\frac{\partial \rho}{\partial \mathrm{t}} + \nabla \cdot (\rho \vec{\mathrm{v}}) = S_{DPM} + S_{\mathrm{Other}} \tag{3.5}$$

Whereas ρ = fluid density phase, $\vec{v}$ = velocity in vector formula, S_{DPM} = discreting phase model source, S_{other} = extra mass source.

$$\frac{\partial \overline{\rho \vec{v}}}{\partial \mathrm{t}} + \nabla \cdot (\rho \overline{v \vec{v}}) = -\nabla \mathrm{p} + \nabla \tau + \rho \mathrm{g} + F_{DPM} \tag{3.6}$$

whereas DPM force acceleration is F_{DPM}, gravitational acceleration is g, statical pressure is P, and stress tensor is τ .

In ANSYS Fluent 18.2, the species transportation formula is used to simulate the movement of water vapour in the atmosphere. The species transport formula is expressed in formula (3.3).

$$\frac{\partial \rho \mathrm{Y}_i}{\partial \mathrm{t}} + \nabla \cdot \left(\rho \vec{\mathrm{Y}_\iota}\right) = -\nabla \cdot \vec{\mathrm{J}_\iota} + \vec{\mathrm{S}_\iota} \tag{3.7}$$

whereas: species created by DPM is known as S_i, flux diffusion is J_i, local fractional mass for every species is presented by Y_i.

The energy formula shown in Equation (3.4) controls how heating is transferred [109].

$$\frac{\partial \rho \mathrm{E}}{\partial \mathrm{t}} + \nabla \cdot (\vec{v}(\rho \mathrm{E} + \mathrm{p})) = \nabla \cdot \left(\mathrm{k}_{eff} \nabla \mathrm{T} - \sum_j h_j \vec{\mathrm{J}}_i + \bar{\tau}_{eff} \cdot \vec{v} \right) \tag{3.8}$$

Whereas: enthalpy is characterized by E, effective thermally conductive is K_{eff}, flux diffusion is *Ji* since species.

The flow simulation that use the allowing species transfer formula and k-k turbulence model was already done utilizing the governing formulas mentioned above. The k-εk-ε turbulence model's formulas were just as following:

Kinetics energy for turbulent (k) [110]:

$$\rho\frac{\partial \mathrm{k}}{\partial \mathrm{t}}+\rho\bar{\mathrm{u}}_{\mathrm{j}}\frac{\partial \mathrm{k}}{\partial \mathrm{x_j}}=\tau_{\mathrm{ij}}\frac{\partial \bar{\mathrm{u}}_{\mathrm{j}}}{\partial \mathrm{x_j}}-\rho\varepsilon+\frac{\partial}{\partial \mathrm{x_j}}\left[(\mu+\mu_{\mathrm{t}}/\sigma_{\mathrm{k}})\frac{\partial \mathrm{k}}{\partial \mathrm{x_j}}\right] \tag{3.9}$$

The ratio at which turbulent energy is dissipated (ε)[109]:

$$\rho\frac{\partial \varepsilon}{\partial \mathrm{t}}+\rho\bar{\mathrm{u}}_{\mathrm{j}}\frac{\partial \varepsilon}{\partial \mathrm{x_j}}=\mathrm{C}_{\varepsilon 1}\frac{\varepsilon}{\mathrm{k}}\tau_{\mathrm{ij}}\frac{\partial \bar{\mathrm{u}}_{\mathrm{i}}}{\partial \mathrm{x_j}}-\mathrm{C}_{\varepsilon 2}\rho\frac{\varepsilon^2}{\mathrm{k}}+\frac{\partial}{\partial \mathrm{x_i}}\left[(\mu+\mu_{\mathrm{t}}/\sigma_{\varepsilon})\frac{\partial \varepsilon}{\partial \mathrm{x_j}}\right] \tag{3.10}$$

3.5 GRID GENERATION AND NUMERICAL METHOD

Tetrahedral mesh was employed in the current work for the computing area's inlet and outflow areas. Further, to achieve high calculation accuracy, fine meshes were used for the most sensitive sections. Figures 3.3 and 3.4 show the grid from both the top and side, respectively.

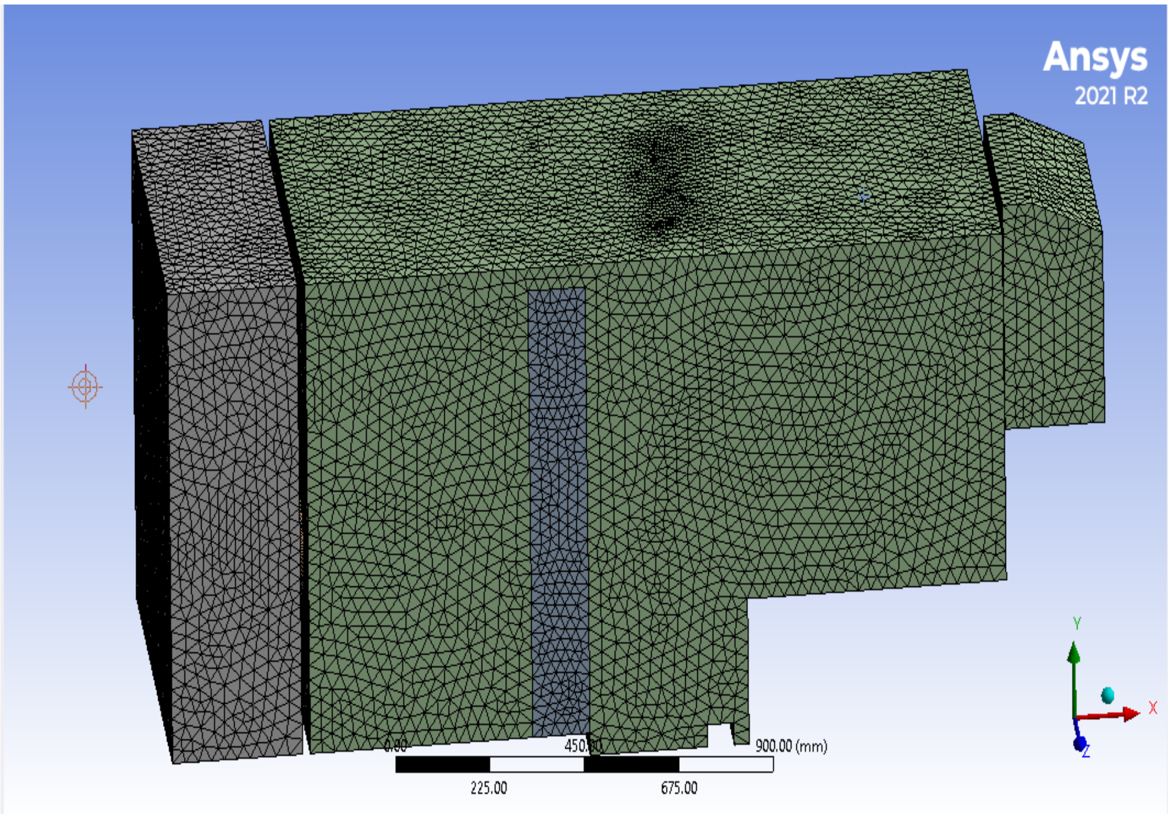


Figure 3.10: The Entire View of The Grid.

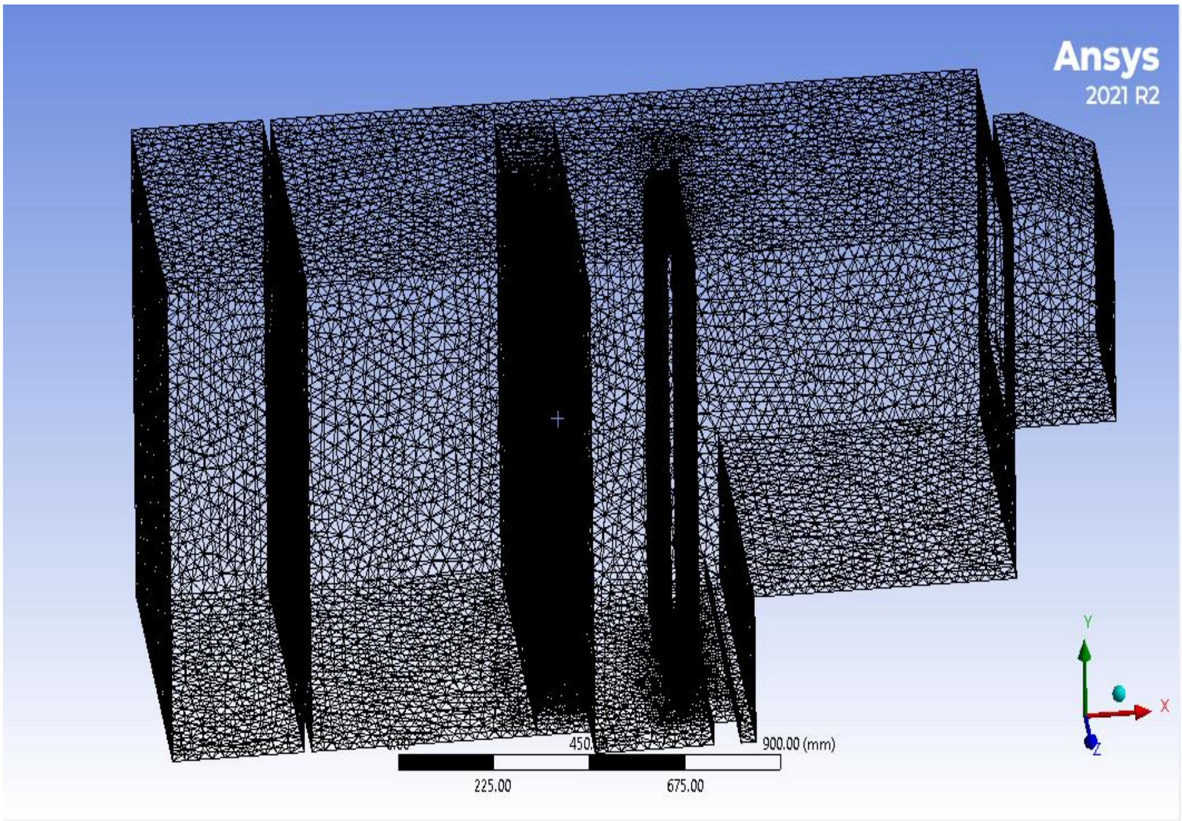


Figure 3.10: The Entire View of The Grid “Figure Continued”.

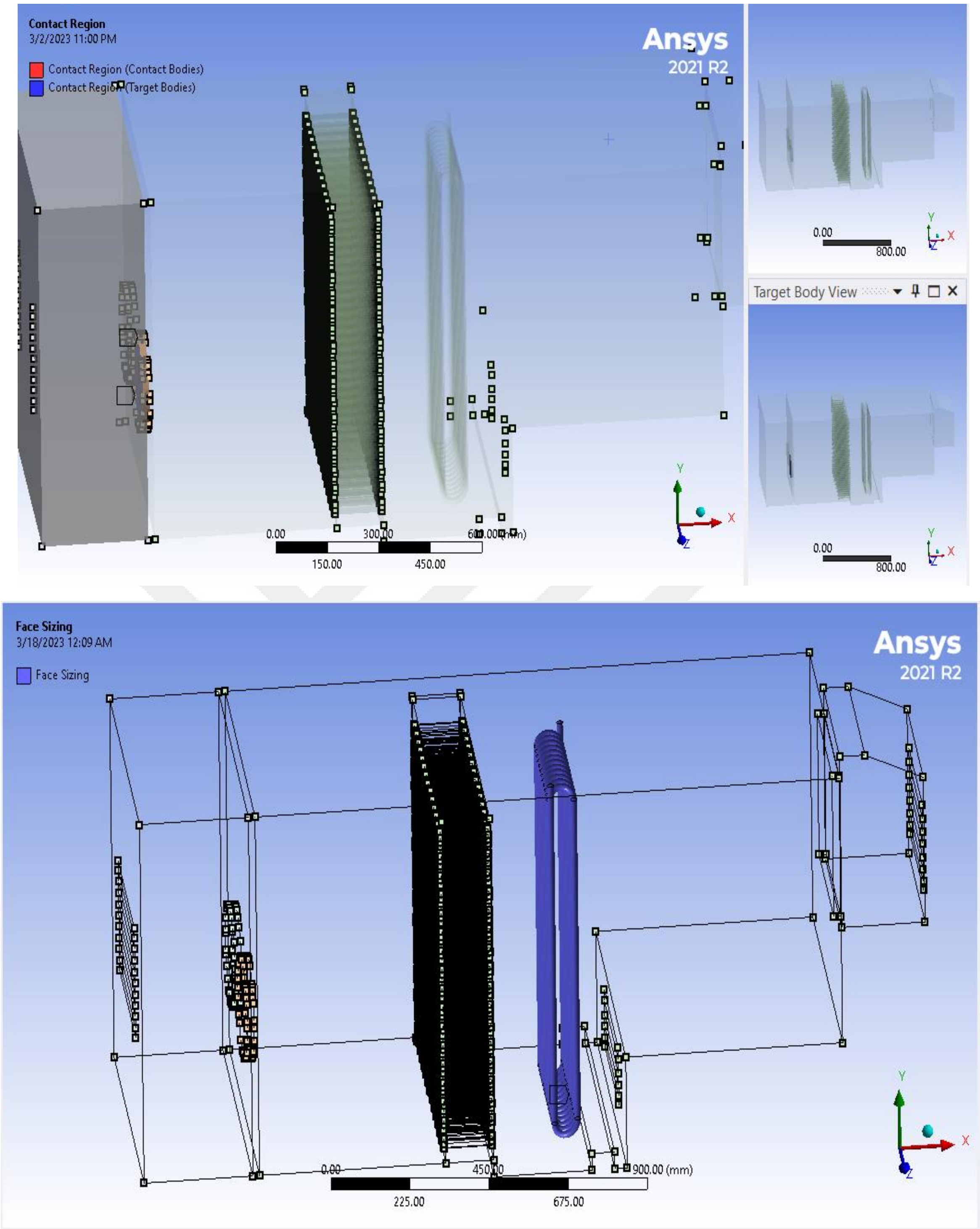


Figure 3.11: The Grid’s Lateral View.

Table 3.2: Mesh Details.

Object Name	***Mesh***
State	Solved
Display	
Display Style	Use Geometry Setting
Defaults	
Physics Preference	CFD
Solver Preference	Fluent
Element Order	Linear
Element Size	30.0 mm
Export Format	Standard
Export Preview Surface Mesh	No
Sizing	
Use Adaptive Sizing	No
Growth Rate	Default (1.2)
Max Size Default	(60.0 mm)
Mesh Defeaturing	Yes
Defeature Size Default	(0.15 mm)
Capture Curvature	No
Capture Proximity	No
Bounding Box Diagonal	2586.9 mm
Average Surface Area	5585.4 mm^2
Minimum Edge Length	2.6176 mm
Quality	
Check Mesh Quality	Yes, Errors
Target Skewness	Default (0.900000)
Smoothing	Medium
Mesh Metric	None

Table 3.2: Mesh Details "Tables Continued"

Inflation	
Use Automatic Inflation	None
Inflation Option	Total Thickness
Number of Layers	5
Growth Rate	1.2
Maximum Thickness	Please Define
Inflation Algorithm	Pre
View Advanced Options	No
Advanced	
Number of CPUs for Parallel Part Meshing	Program Controlled
Straight Sided Elements	
Rigid Body Behavior	Dimensionally Reduced
Triangle Surface Mesher	Program Controlled
Topology Checking	Yes
Pinch Tolerance Default	(0.27 mm)
Generate Pinch on Refresh	No
Statistics	
Nodes	409867
Elements	2212351

Table 3.3: Mesh Information Summary for FFF.

Domain	Nodes	Elements
air_ _1	15777	81024
air_ _2	383531	2037922
fan_1	1949	7957
fan_2	2055	1308
water	19767	84140
All Domains	423079	2212351

3.5.1 Bounding Conditions

The bounding conditions are defined to the intake velocities for the inlet and the outlet pressures for the outlet side. The coils were also given the no-slip boundary conditions. The working fluids have been thought to be water, which has a density=998.2 kg/m^3 and a viscosity= 0.001003 kg/m^3, and air, which has a density=1.225 kg/m^3 and a viscosity of 1.7894 10-5 kg/m^3. With a moisture content of 34.9 percent, the warm air intake temp is 300 Kelvin and the temp of the water is 275 Kelvin. The boundary situation for the coils' input portion has been adjusted to inlet velocity, while the boundary situation for the coils' outlet part was set to outlet pressures (Figure 3.5). With a water entry velocity of 0.5 m/s, the Reynolds number ranged from 6300-12,640 for various coils sizes, leading to the assumption that the flow was turbulent.

Utilizing ANSYS Fluent 18.2, the numerical analysing has been performed depending on the CFD codes that are utilised to represent the complicated behaviours of mass and heating flow [111]–[113] and were also employed in a number of issues [114], [115]. Formulas for energy, momentum, and continuity were discretized using the upwind second-order approach. Additionally, pressure computation was second-order, and the SIMPLE method was employed for pressure-velocity couplings. For all formulas, the convergence conditions were regarded as smaller than 106. The Reynolds-Average Navier-Stokes (RANS) formulas regulate the flow because of the great Reynolds number flow within the coils. In accordance with the recommendations of other research for comparable flows [116], [117], the turbulence behaviour within the coil were modelled utilizing a typical k-ε turbulence model.

3.5.2 Grid Independence Study and Validation

In order to determine if the final grid with cell counts of 794,000, 525,0000, 287,000, and125,00 was enough for calculating the water outlet temp, a grid independence investigation has been carried out. The findings of the smallest grid and the grids with $525x10^3$ cell hardly differed from one another. Thus, the grids with $525x10^3$ cell has been utilised to acquire the findings in order to choose an appropriate grid size to reduce computation time and improve accuracy. Grids independence is seen in full in Figure 6. Additionally, the values of the water outlet temp and the air outlet temp were comparison with the experimental findings of [106] at a number of Reynolds=6320 so as to confirm the computational findings. As could be observed, the numerical simulation's findings and the experimental findings data were in excellent accord [106].

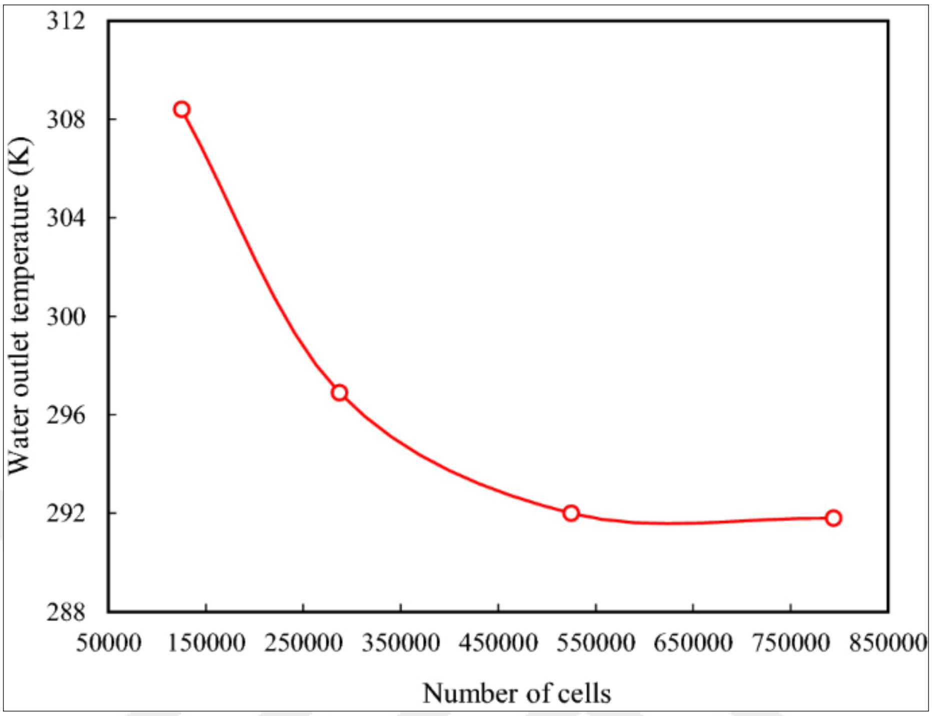


Figure 3.12: The Independence Grid Details.

3.6 SELECTED SITE OF STUDY

Iraq, officially known as the Republic of Iraq, is located in Western Asia. To the north, it shares a border with Turkey; to the east, it shares a border with Iran; to the southeast, it shares a border with the Persian Gulf and Kuwait; to the south, it shares a border with Saudi Arabia; to the southwest, it shares a border with Jordan; and to the west, it shares a border Baghdad is both the nation's capital and its biggest city. The vast bulk of the country's total population of 40 million people.

There are two distinct climate zones in Iraq: the dry, hot lowlands, which include the alluvial plains and the deserts, and the wetter, cooler northeast, which is located at a higher elevation and has lower average temperatures. Agriculture that is sustained by precipitation alone is only feasible in the northeast; in other regions, irrigation is required. In the lowlands, there are only two distinct seasons: summer and winter, with just a few weeks of in-between transitional weather. The summer, which begins in May and continues until October, is marked by cloudless sky, very high temperatures, and low relative humidity; throughout the months of June through September, there is no precipitation that happens. Temperatures over 123 degrees Fahrenheit (51 degrees Celsius) have been reported in Baghdad during the summer months of July and August. Mean daily temperatures during those months hover around 95 degrees Fahrenheit (35 degrees Celsius). In the summer, there is a significant difference in temperature between night and day.

The pathways of westerly air depressions that travel across the Middle East throughout the winter move southward, delivering rain to southern Iraq. The typical annual precipitation in the lowlands varies from 4 to 7 inches (100 to 180 mm); almost all of this precipitation falls between November and April. Yearly totals fluctuate greatly from year to year, but the mean annual precipitation is between these two extremes. December and February are the months during which the lowlands experience winter. Temperatures are normally temperate; however, it is possible to experience both very hot and extremely cold weather, including frost. Temps in Baghdad during the wintertime vary from roughly 2 to 15 degrees Celsius, which is 35 to 60 degrees Fahrenheit. Depending on the previous information of the location and climate of Iraq the following parameters have been selected to investigated in the simulated application of the evaporation cooling case.

Table 3.4: Selected Parameters for Investigating.

Parameter	Values
Temperature (C)	February=12.5 July= 45 October=37
Reynolds number	1000, 2500, 10000
Fan air velocity	1 m/s, 2 m/s
Relative humidity	15% , 52%

4. RESULTS AND DISCUSSION

A numerical simulation was conducted to enhance the efficacy of the indirect evaporative cooling (IEC) system utilizing a mixed mode of spraying arrangement. The objective was to gain a better understanding of the system's performance. The present model is designed to assess the sensible cooling effect generated by the combined action of forced air circulation and evaporation in the context of IEC systems for greenhouse applications. This chapter will present a report on numerical techniques, model verification, and simulation results.

4.1 ITERATION FOR THE SELECTED SYSTEMS

The construction of numerical simulations necessitates a proficient understanding on the part of the researcher [118]. To ensure accuracy, researchers have devised tools for code users to verify the correctness of their actions. As one gains familiarity with numerical codes, their level of expertise and self-assurance in the field tends to increase [119]. Consequently, the scientist formulates procedures to expedite their workflow and verify its accuracy.

Upon confirming the feasibility of a steady state scenario, it is imperative to assess the convergence of the solution, detect any anomalies, and ensure the iteration curves exhibit seamless behavior [120]. These observations indicate that the mesh is effectively capturing the flow characteristics. During the initial 5 to 10 iterations, it can be observed that the solution exhibits non-smooth behavior [121]. However, as the iteration process advances, the curves for velocities and pressure gradually become smoother. In a channel flow scenario, it is typical to observe greater fluctuations in the u velocity component during the iterative process when the flow is directed along the x-axis [122]. This phenomenon is expected due to the higher energy of the flow in the x-axis direction. Conversely, the v and w velocity components tend to exhibit similar behavior. Typically, the pressure iteration curve exhibits distinguishable characteristics from the iteration curves of u, v, and w. It is imperative to ensure the smoothness of the pressure curve throughout the iteration process to ascertain the adequacy of the coarse mesh selected [123]. If the pressure fluctuation persists, it may be necessary to employ a medium or fine mesh.

In relation to the maximum number of iterations, it is important to note that the purpose of iterations is to obtain the optimal converged solution [124]. For instance, it is not uncommon to observe initial iterations exhibiting non-smooth behavior, but as the number of iterations increases, convergence stabilizes and remains constant. Consequently, selecting several iterations beyond this point, such as 20, would be unnecessary and would only serve to prolong simulation calculation time without yielding any additional benefits. This could potentially impede progress towards meeting project deadlines [125].

Upon conducting 300 computations and executing the relevant computations, the resultant iteration graph was visualized within the Fluent interface [126]. The residual velocity graphs for 300 iterations in the direction of continuity, (x, y & z)-velocity, k and omega are depicted in Figure 4.1 and 4.2.

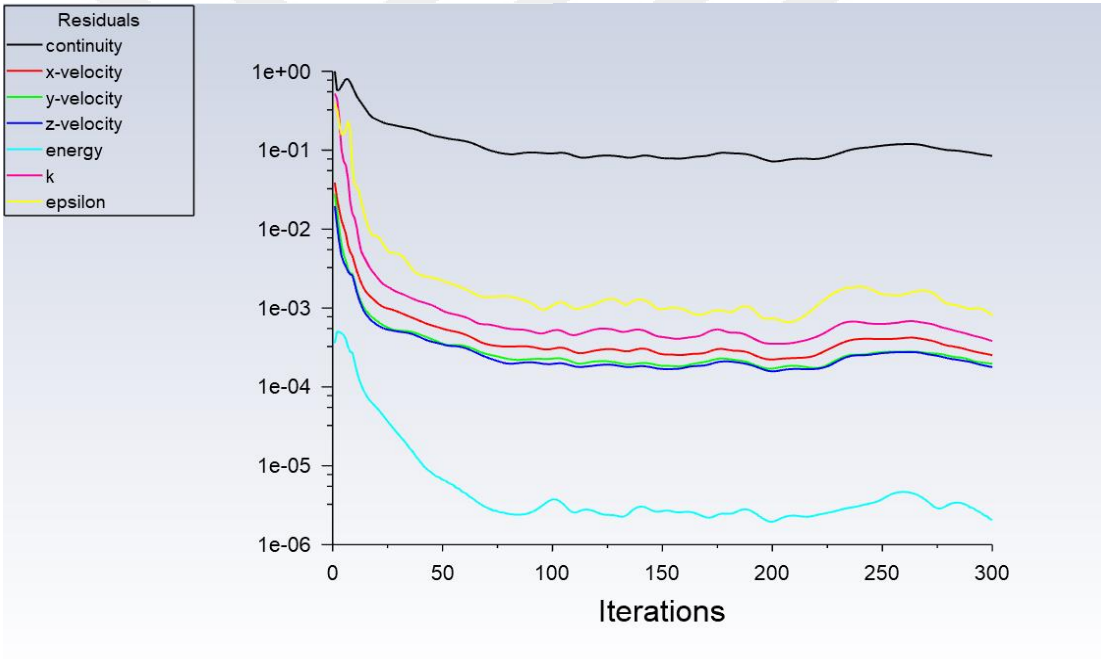


Figure 4.1: Residual Velocity Graphs of 300 Iteration for Model One With Three Stages Cooling System.

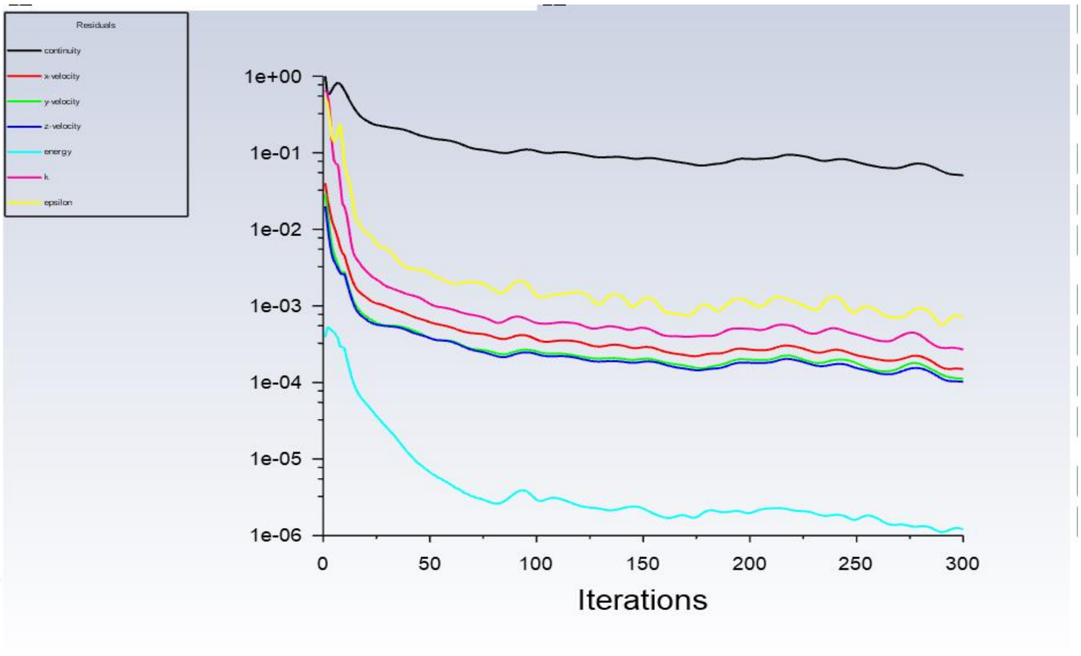


Figure 4.2: Residual Velocity Graphs of 300 Iteration for Model Two with Two Stages Cooling System.

4.2 VELOCITY STREAMLINE

A streamline refers to a geometric line that is tangent to the direction of instantaneous velocity, which is a vector quantity characterized by both magnitude and direction. To depict this phenomenon in a fluid dynamics context, one could envision the movement of a designated fluid particle within a flow [127]. One potential method involves the utilization of fluorescent dye to label a droplet of water, which can subsequently be subjected to laser illumination to induce fluorescence. Assuming a brief exposure time relative to the velocity's rate of change, a short streak would be observed as the drop moves in accordance with the local velocity field [128]. The streak's length would be V \Delta t, and its direction would be tangential to the instantaneous velocity direction. By marking numerous droplets of water in this manner, the flow's streamlines will become discernible [129], [130]. Since the flow can only proceed in one direction at a given point, the velocity at any point in the flow possesses a singular value. As a result, the crossing of streamlines is precluded, except for instances where the velocity magnitude is zero, such as at a stagnation point [131].

There exist alternative methods to render the flow discernible. An approach that can be employed to visualize the trajectory taken by the fluorescent droplet is through the utilization of a long-exposure photograph [132]. The trajectory is commonly referred to as a pathline, which bears resemblance to the visual effect produced by capturing a prolonged exposure of vehicular headlights on a highway during nighttime [133]. The phenomenon of pathline intersection is a plausible occurrence, as can be inferred from the analogy of a freeway. In the event of a vehicle changing lanes, the pathline delineated by its lights may intersect with another pathline traced by an adjacent vehicle at a distinct moment [134].

Streamlines can serve as an alternative means of representing flow patterns. A streamline can be defined as the locus of particles that have traversed a specific point at a previous instant in time [135]. As an illustration, in the event of a continuous release of fluorescent dye from a stationary location, the dye forms a streamline as it progresses in the downstream direction [136]. To extend the metaphor of a freeway, the line refers to the aggregate of the luminous signals emanating from the automobiles that have traversed a common toll plaza. In the event that fluid particles exhibit a uniform motion, a solitary line ensues, whereas in the case of non-uniform motion, the line may intersect itself [137].

4.2.1 Model with Air-Water-Air

The rate of change of displacement over time, commonly referred to as velocity. The concept of streamline is beneficial in observing the smooth and efficient flow of steam across the stage. The analysis of streamline motion proves to be a valuable tool in examining the flow behavior within the given stage. The optimal configuration of the stage ought to feature a continuous and streamlined motion of the steam, devoid of any interruptions or discontinuities.

Figure 4.2 – 4.4 show the streamline distribution of cooling three stages evaporating system with three different temperatures (12.5, 37 and 45) degree centigrade. In three stages evaporative cooling system the velocity streamline values vary based on the inlet temperatures.

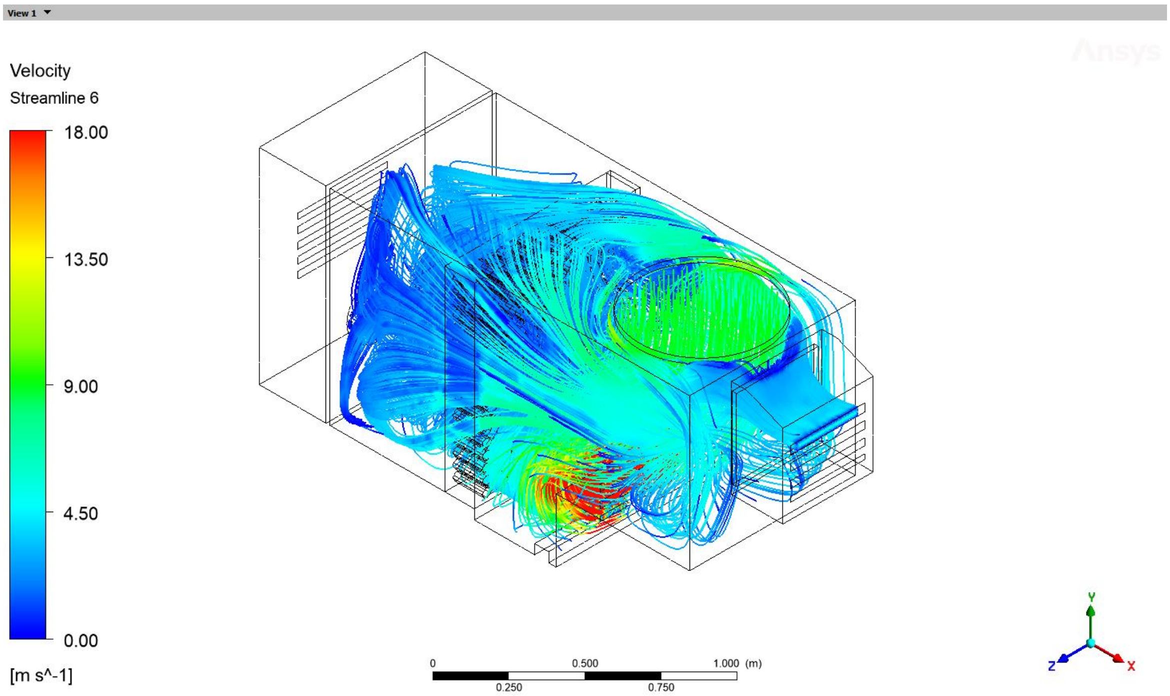


Figure 4.3: Velocity Streamline for Model Two with 12.5 Degree Centigrade.

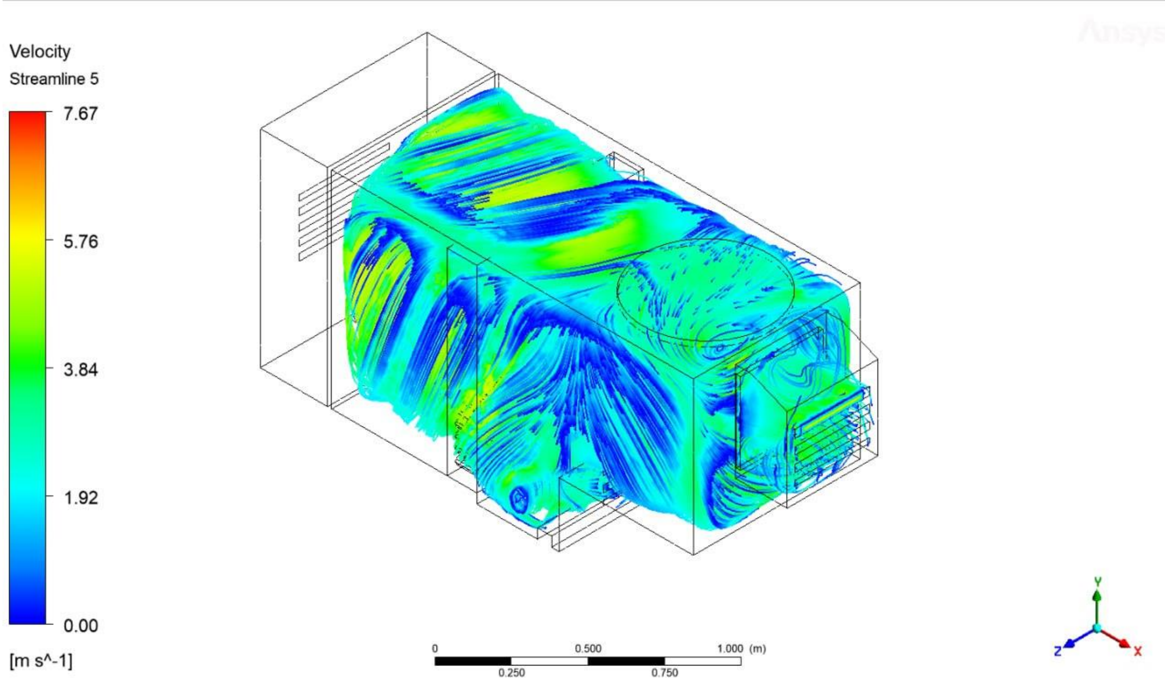


Figure 4.4: Velocity Streamline for Model Two with 37 Degree Centigrade.

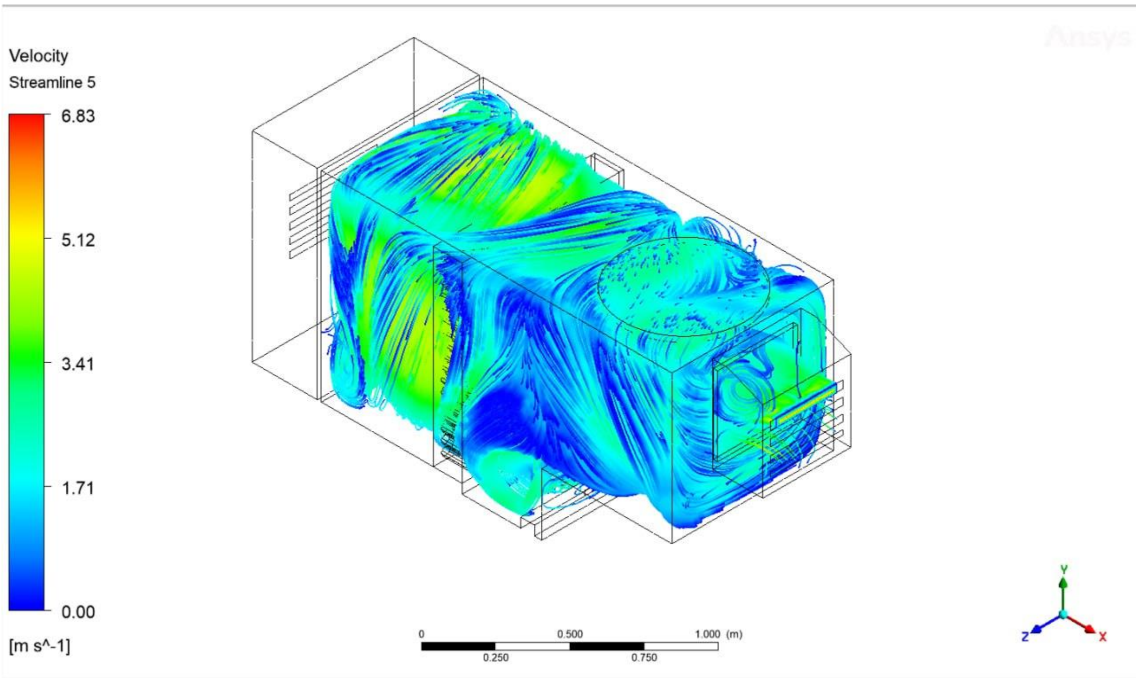


Figure 4.5: Velocity Streamline for Model Two with 45 Degree Centigrade.

From figure 4.6 demonstrates that the velocity streamline values are reduced from 20.32 to 6.83 m/s with increasing the weather temperature from 12.5 to 45 degrees centigrade and mostly return to increase the weather velocity in cold temperatures.

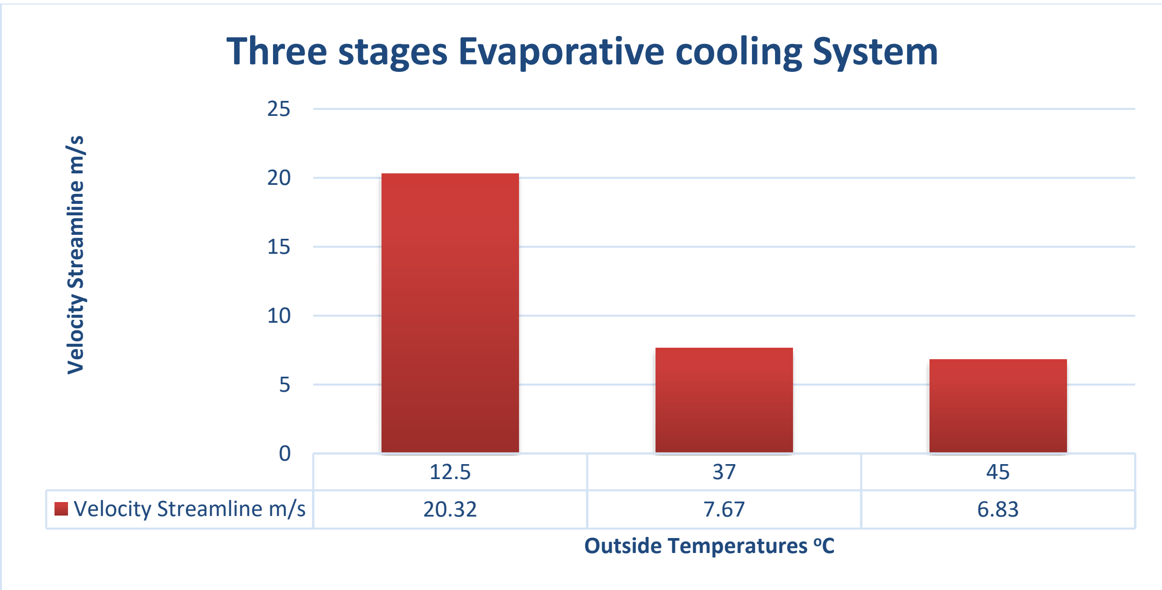


Figure 4.6: Velocity Streamline for Model Two with Three Stages Evaporative Cooling System at Three Months.

4.2.2 Model with Water-Air

Figure 4.7 – 4.9 show the streamline distribution of cooling three stages evaporating system with three different temperatures (12.5, 37 and 45) degree centigrade. In two stages evaporative cooling system the velocity streamline values are constant in spite of changing the inlet temperatures.

From figure 4.10 demonstrates that the velocity streamline values have not changed in two stages evaporative cooling system and increasing the weather temperature from 12.5 to 45 degrees centigrade are changed due to absence of water pad that change the surrounding environment.

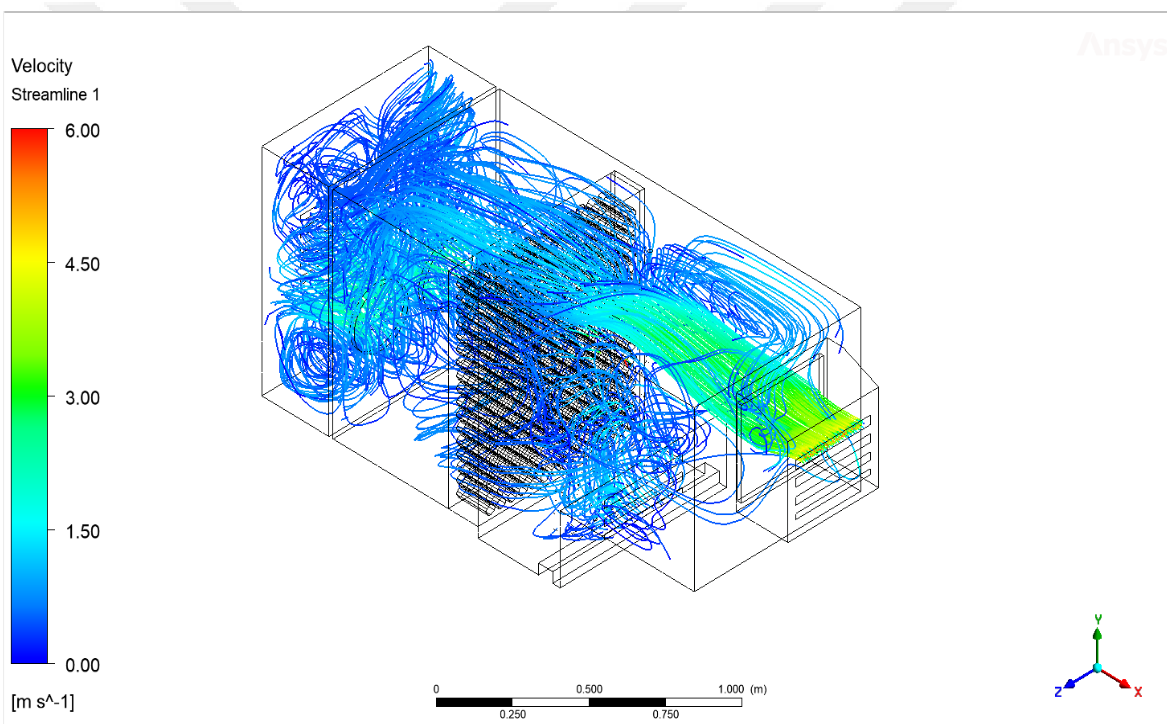


Figure 4.7: Velocity Streamline for Model One with 12.5 Degree Centigrade.

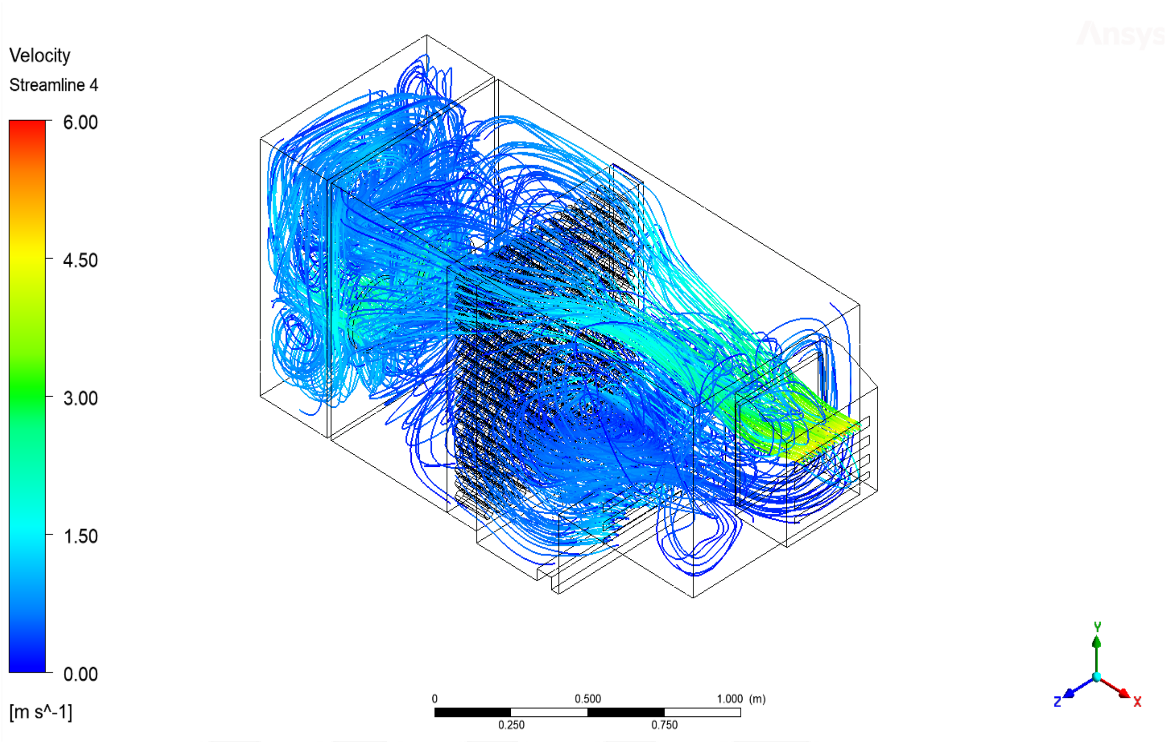


Figure 4.8: Velocity Streamline for Model One With 37 Degree Centigrade.

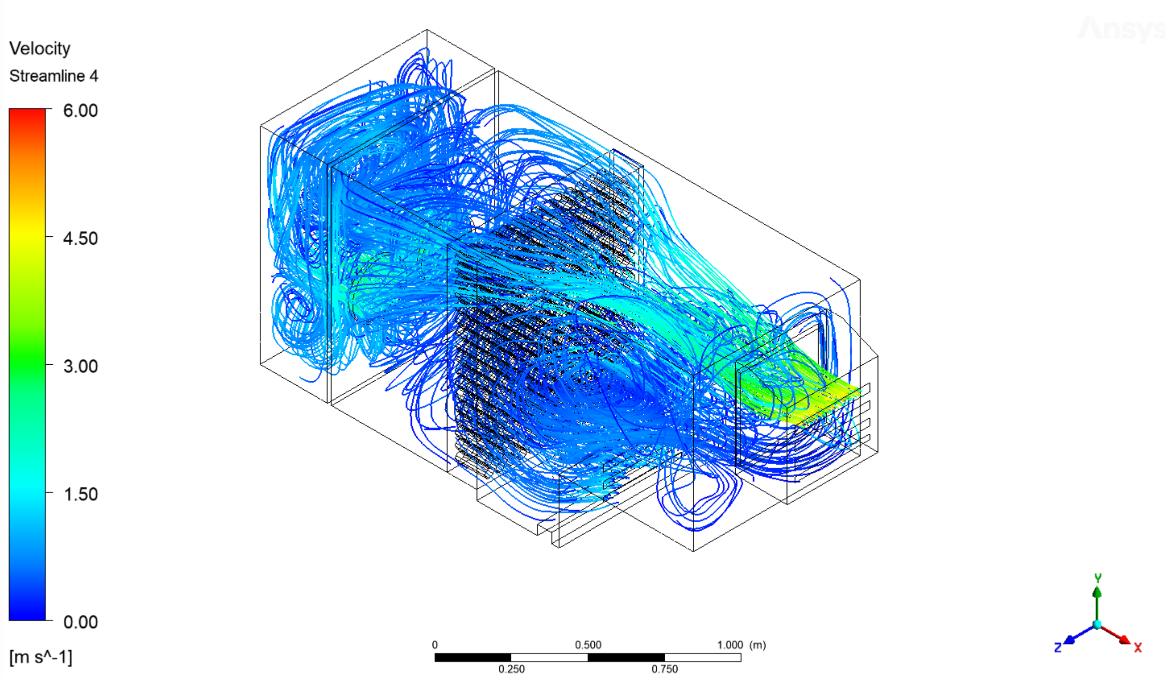


Figure 4.9: Velocity Streamline for Model One with 45 Degree Centigrade.

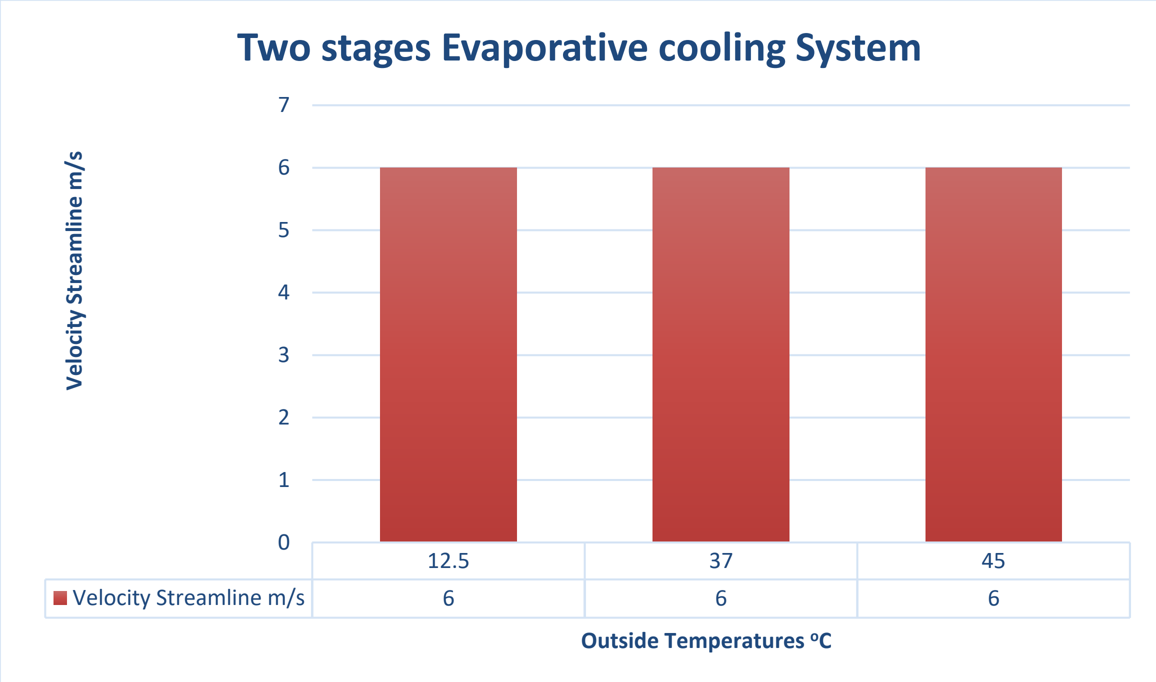


Figure 4.10: Velocity Streamline For Model Two with Two Stages Evaporative Cooling System at Three Months

4.3 VELOCITY VOLUME RENDERING

The observed relationship between inlet design and height with flow uniformity and average velocity is in accordance with expectations. Nevertheless, the elimination of spatter particles lacks clarity. The findings suggest that there is no direct correlation between an increased local velocity and the elimination of spatter particulates from the processing area. The observed phenomenon may be attributed to the formation of a recirculation zone within the chamber, causing the particles to evade the bulk flow as a result of their initial velocities [138]. The recirculation zone of the argon flow has the potential to confine particulates within the machine, impeding their effective removal from the build chamber and resulting in their deposition in other regions of the chamber [139]. Regrettably, an effective quantification of the recirculation zone is currently unattainable. The spatter particulates could have been eliminated from the process area, but their removal from the system through the outlet may not have been entirely successful.

4.3.1 Model with Air -Water-Air

Figure 4.11 – 4.13 show the velocity volume rendering distribution of cooling three stages evaporating system with three different temperatures (12.5, 37 and 45) degree centigrade. In three stages evaporative cooling system the velocity volume rendering values vary based on the inlet temperatures.

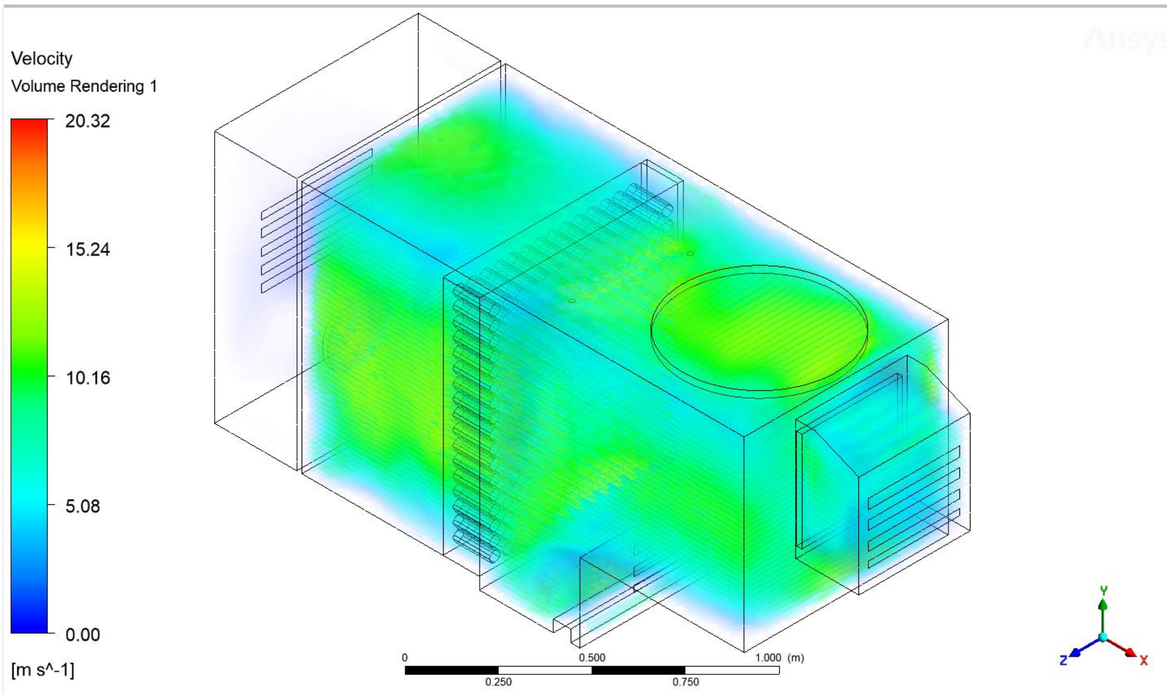


Figure 4.11: Velocity Volume Rendering for Model Two with 12.5 Degree Centigrade.

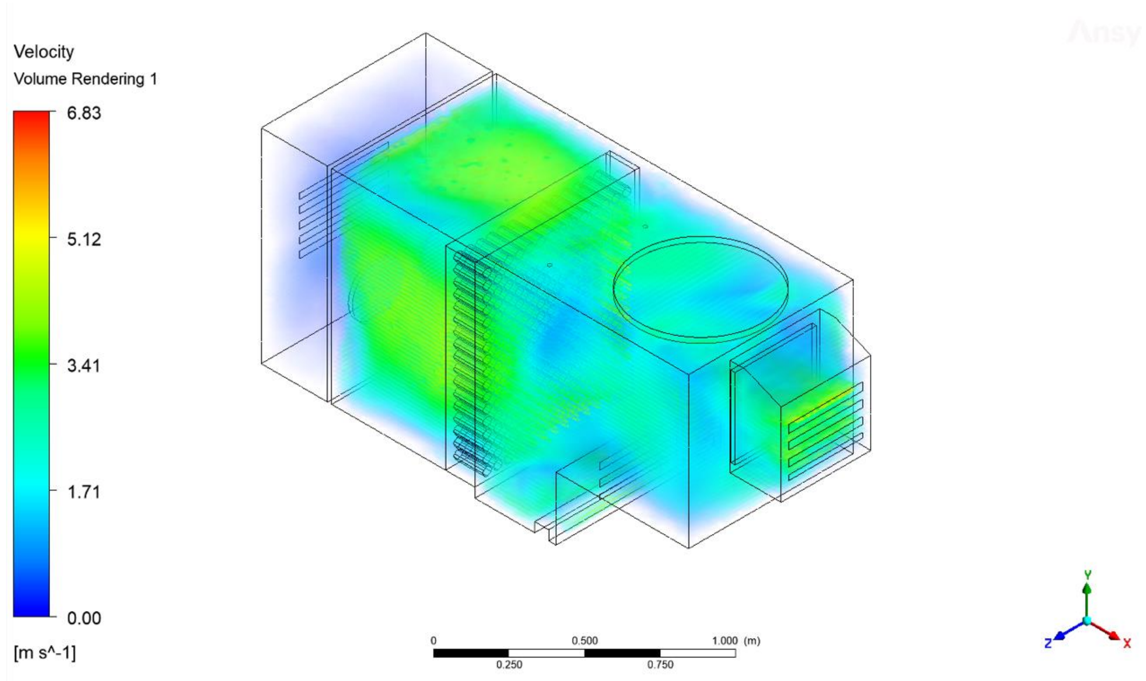


Figure 4.12: Velocity Volume Rendering for Model Two with 37 Degree Centigrade.

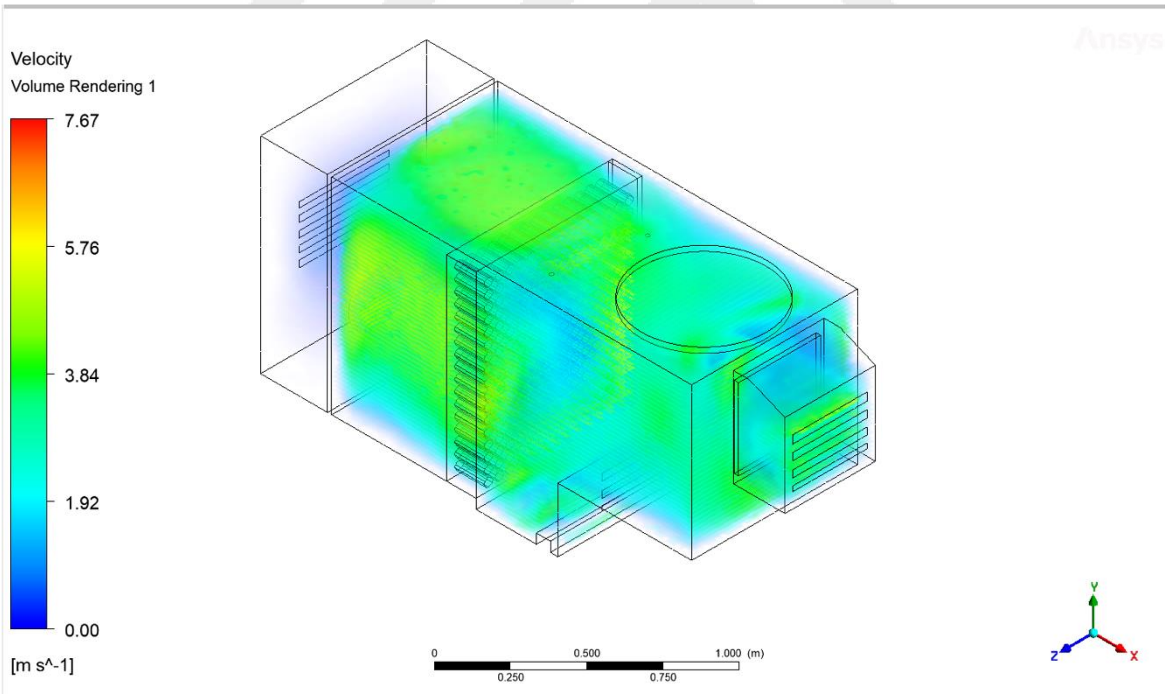


Figure 4.13: Velocity Volume Rendering for Model Two with 45 Degree Centigrade.

4.3.2 Model with Water-Air

Figure 4.14 – 4.16 demonstrate that the velocity volume rendering values have not changed in two stages evaporative cooling system and increasing the weather temperature from 12.5 to 45 degrees centigrade are changed due to absence of water pad that change the surrounding environment.

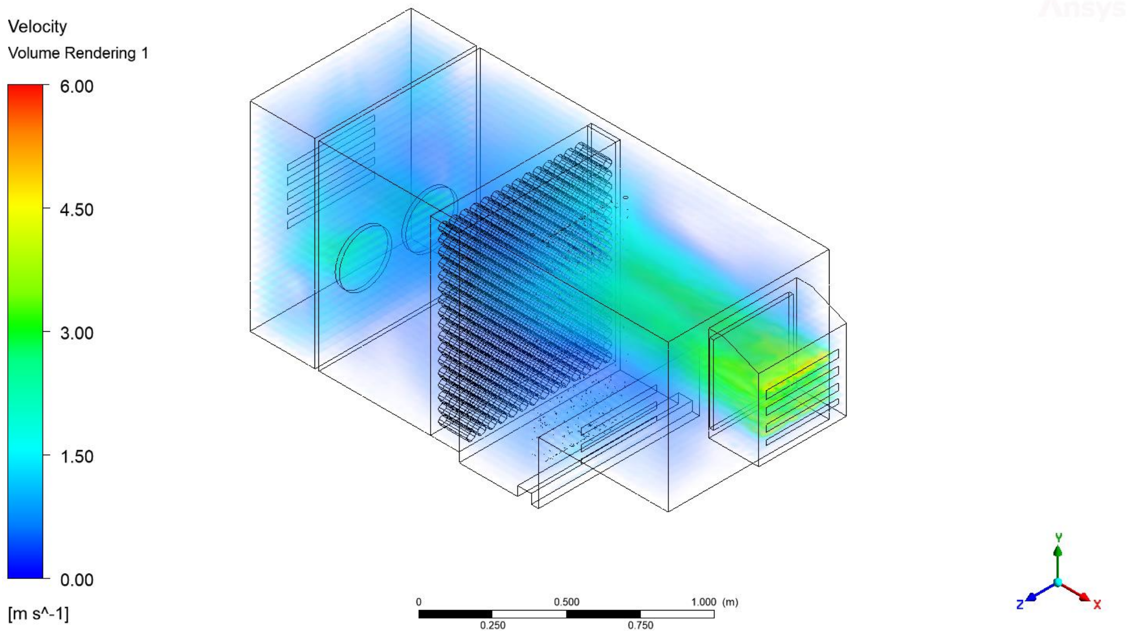


Figure 4.14: Velocity Volume Rendering 1 for Model Two with 12 Degree Centigrade.

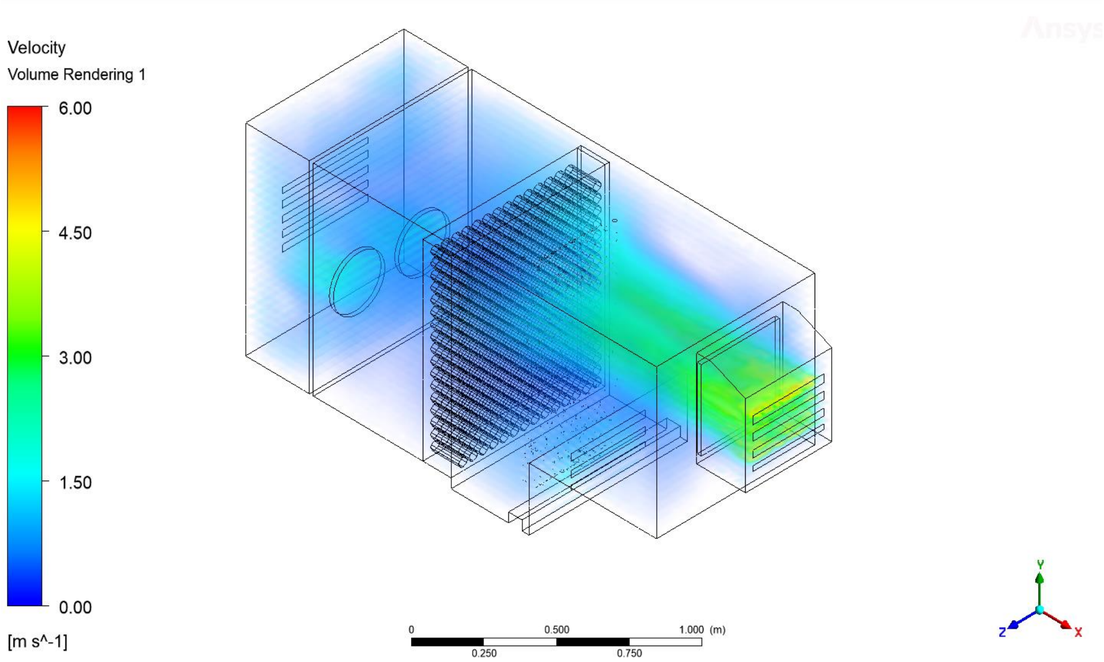


Figure 4.15: Velocity Volume Rendering 1 For Model Two with 37 Degree Centigrade.

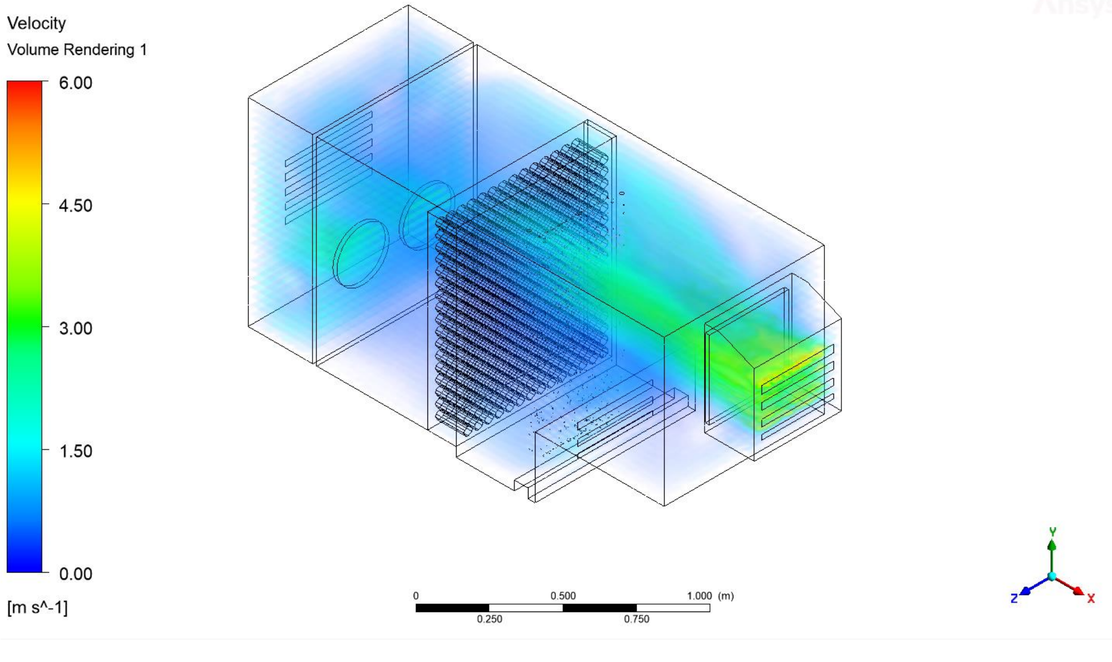


Figure 4.16: Velocity Volume Rendering 1 for Model Two with 45 Degree Centigrade.

4.4 VELOCITY COUNTER

4.4.1 Model with Air -Water-Air

Figure 4.17 – 4.19 show the velocity counter distribution of cooling three stages evaporating system with three different temperatures (12.5, 37 and 45) degree centigrade. In three stages evaporative cooling system the velocity volume rendering values vary based on the inlet temperatures.

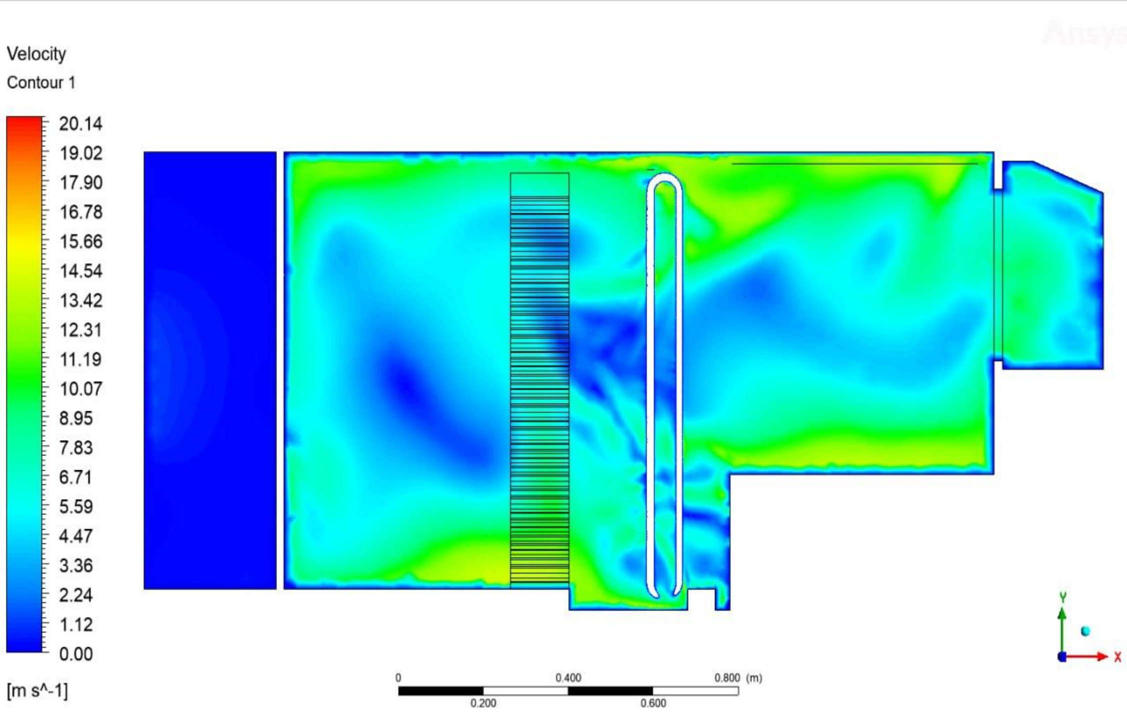


Figure 4.17: Velocity Counter 1 for Model Two with 12.5 Degree Centigrade.

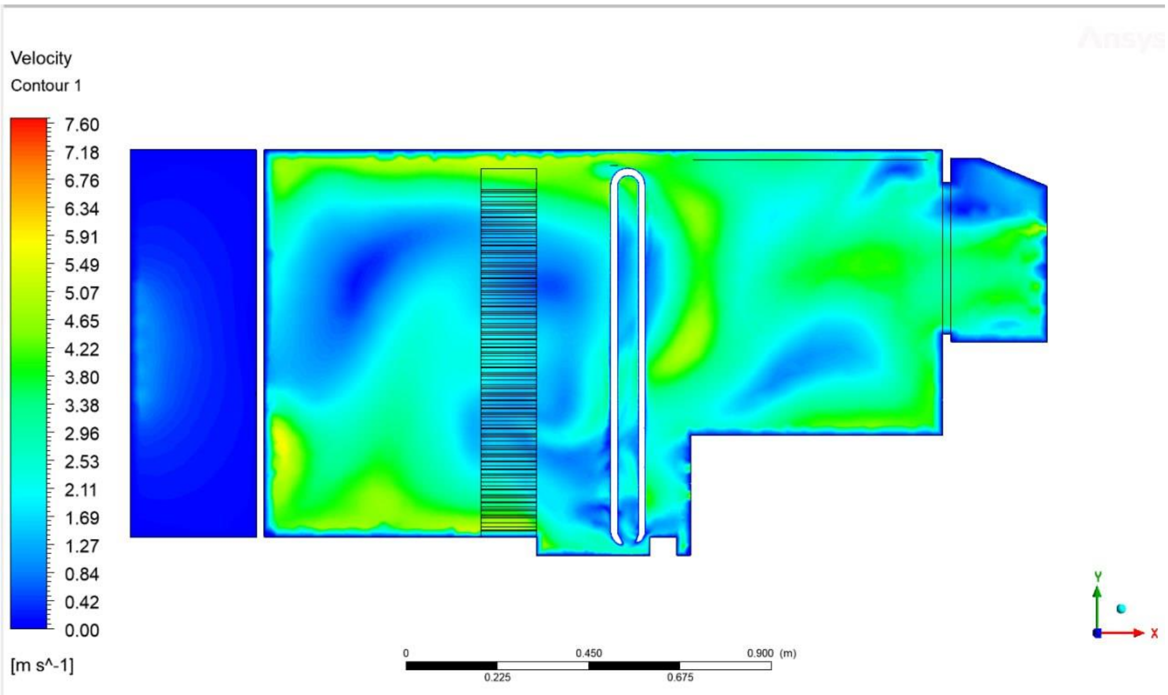


Figure 4.18: Velocity Counter 1 for Model Two with 37 Degree Centigrade.

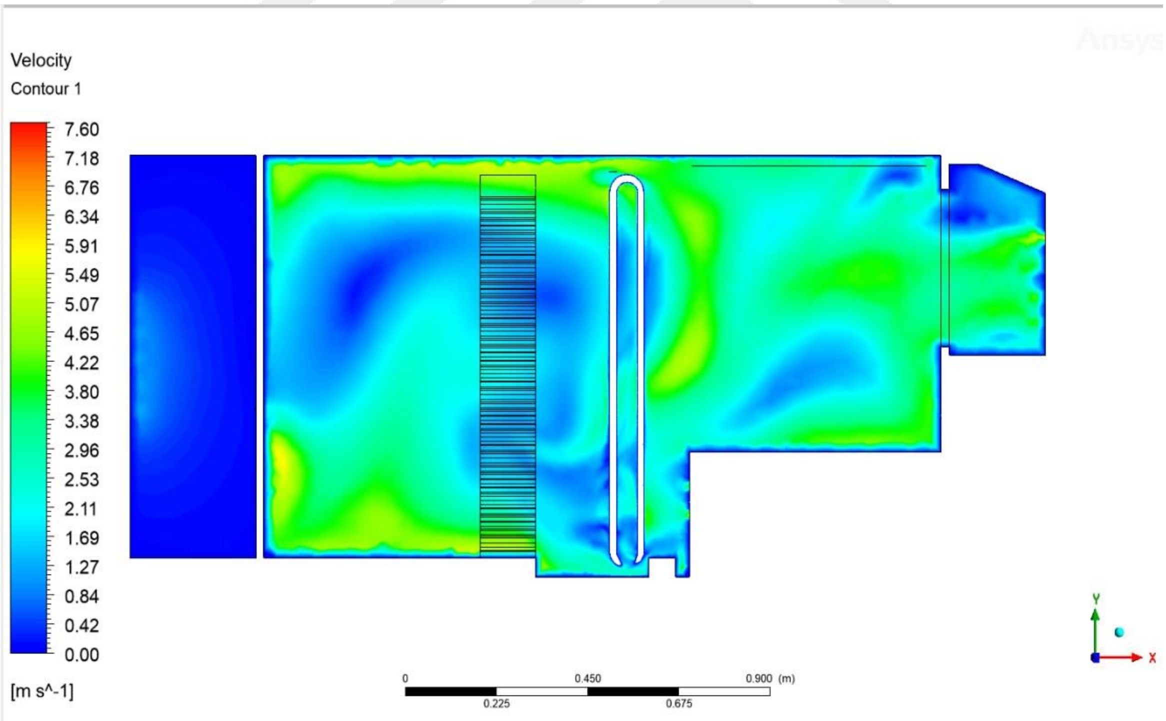


Figure 4.19: Velocity Counter 1 for Model Two with 45 Degree Centigrade.

4.4.2 Model with Water-Air

Figure 4.20 – 4.22 show the velocity counter distribution of cooling two stages evaporating system with three different temperatures (12.5, 37 and 45) degree centigrade. In two stages of evaporative cooling system the velocity counter values are reduced with increasing the weather temperatures from 12.5 to 37 degree centigrade constant, but increasing the weather temperature to 45 has no effective change on velocity counter.

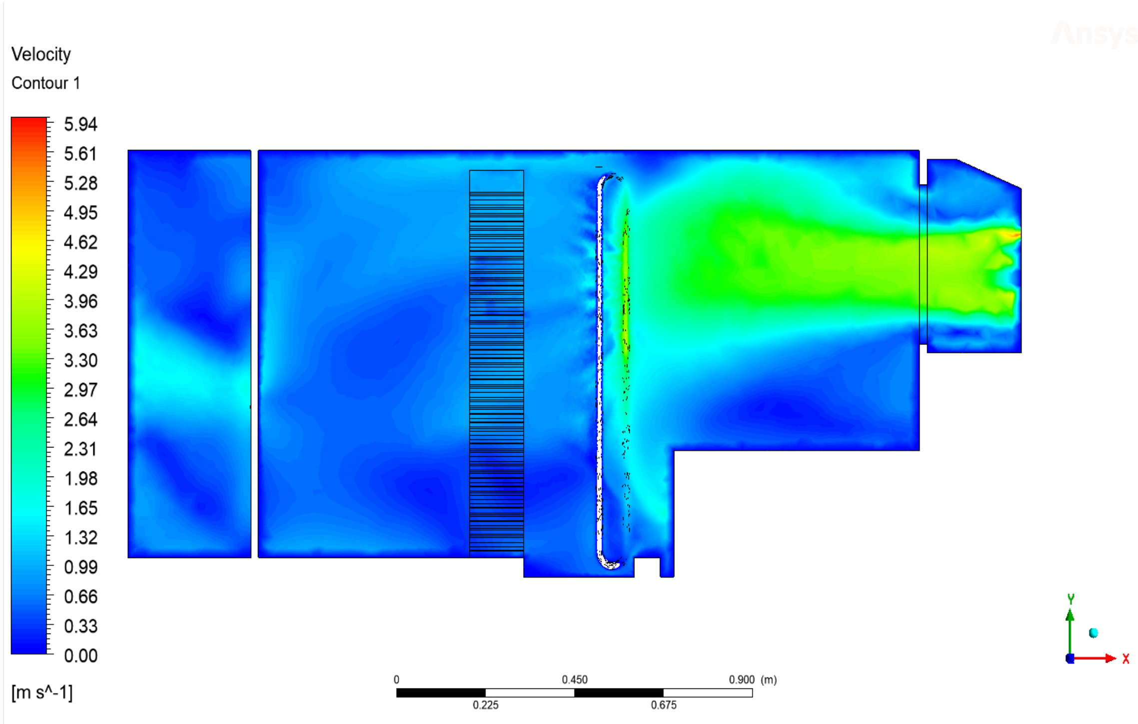


Figure 4.20: Velocity Counter 1 For Model two with 12.5 Degree Centigrade.

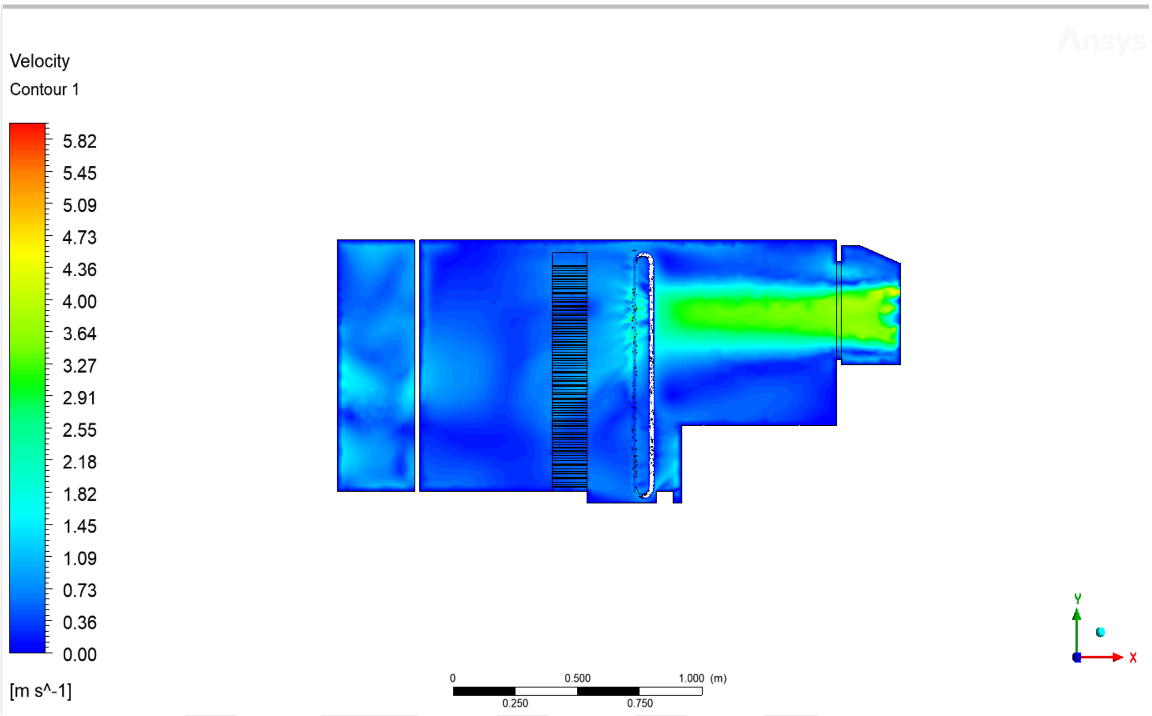


Figure 4.21: Velocity Counter 1 for Model Two with 12.5 Degree Centigrade.

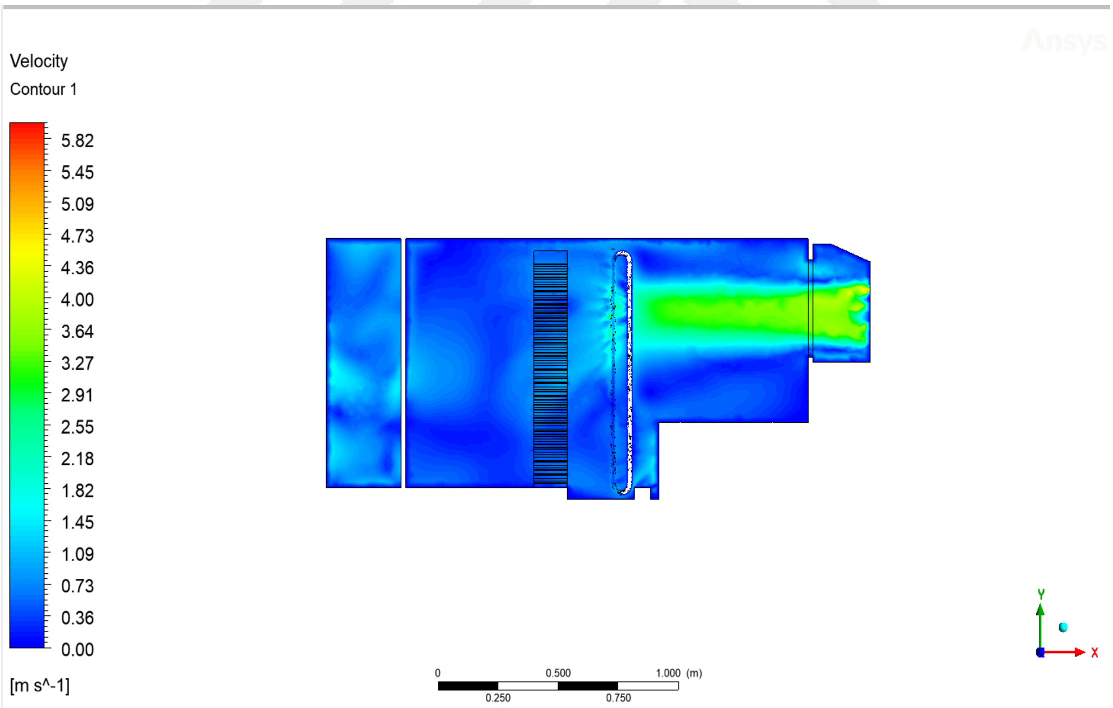


Figure 4.22: Velocity Counter 1for Model Two with 12.5 Degree Centigrade.

4.5 TEMPERATURE DISTRIBUTION

4.5.1 Model with Air -Water-Air

With three stages evaporative cooling, the temperature distribution counter for three selected months is shown in figure 23-25. Based on simulation results increasing the input temperature with similar inlet velocity 6m/s the reduction in the temperatures were increase with increased the inlet temperature. In February with 12.5ºC, the cooling system was reduced the temperature to 11.59 ºC, while with increasing the temperature in October and July (37, 45 ºC) show reduction to 50% and more. And the obtained results from ANSYS software show good correlation between increasing temperature and reduction temperature when using two stages evaporative cooling system as shown in figure 26.

Table 4.1: Summary of Temperature Results Summary of Temperature Results with Three Stages Evaporative Cooling System at Three Months

Cases	Input Temperature	Outlet temperature		
		Min	Average	Max
1	12.5	0.15	6.343	11.16
2	37	0.15	20.88	37
3	45	0.15	22.37	39.65

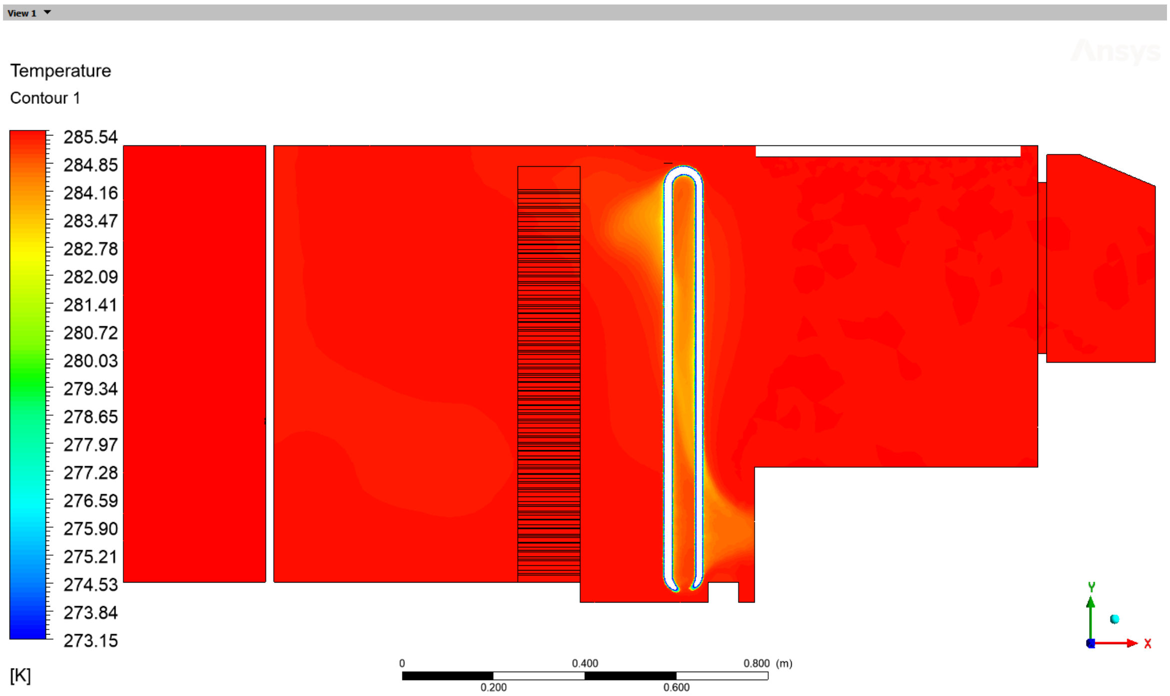


Figure 4.23: Temperature Counter 1 for Model One with 12.5 Degree Centigrade.

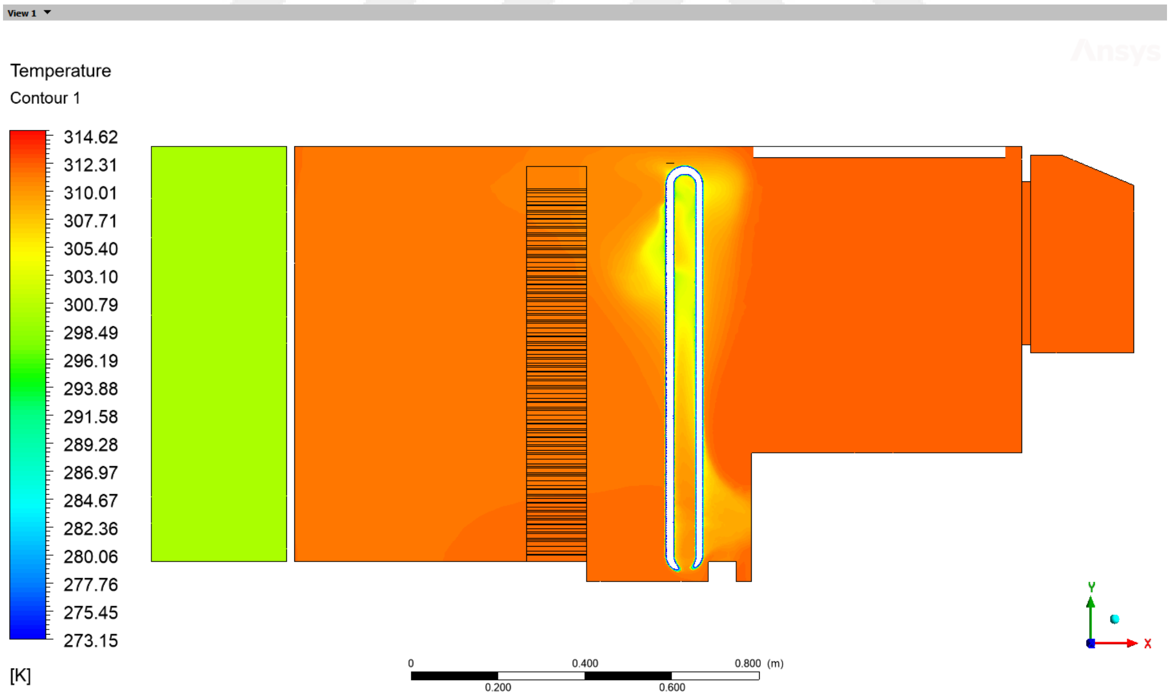


Figure 4.24: Temperature Counter 1 for Model One With 37 Degree Centigrade.

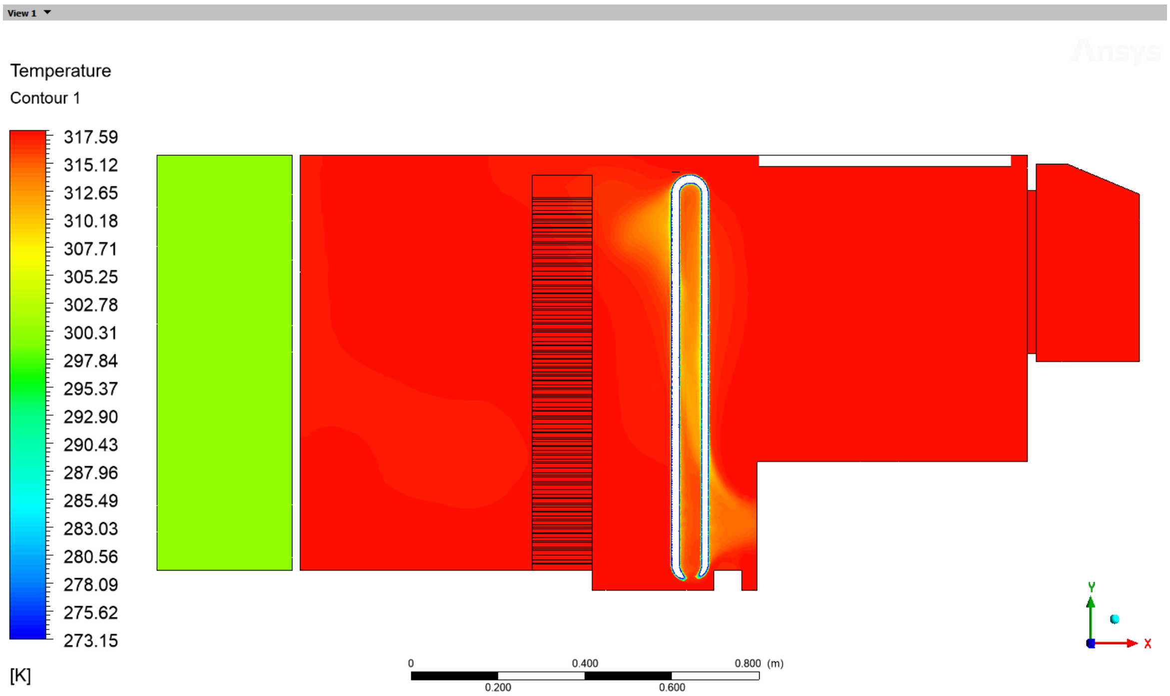


Figure 4.25: Temperature Counter 1 for Model One With 45 Degree Centigrade.

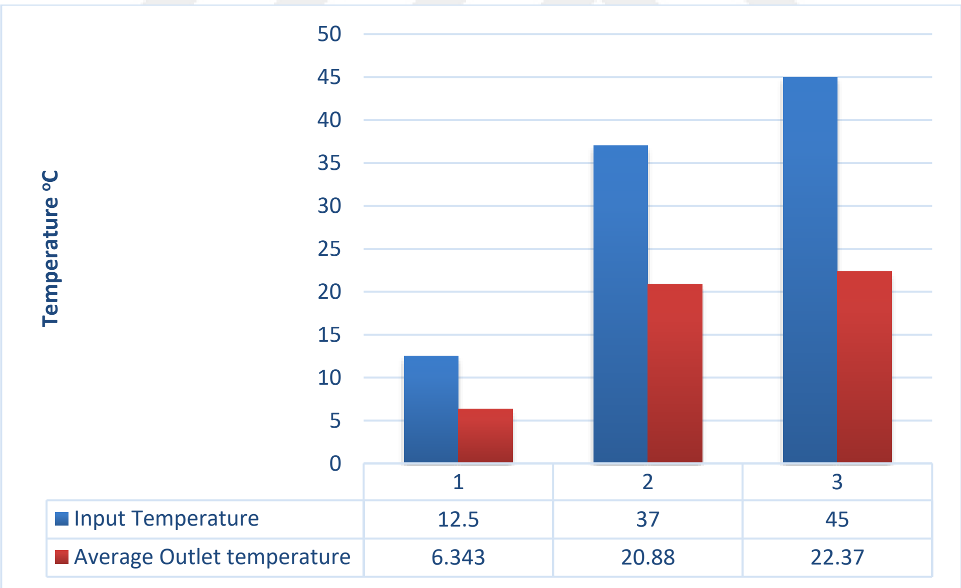


Figure 4.26: Temperature Distribution for Model One with Three Stages Evaporative Cooling System at Three Months

4.5.2 Model with Water-Air

With two stages evaporative cooling, the temperature distribution counter for three selected months is shown in figure 4.27-4.29. Based on simulation results increasing the input temperature with similar inlet velocity 6m/s the reduction in the temperatures were increase with increased the inlet temperature. In February with 12.5ºC, the cooling system was reduced the temperature to 11.59 ºC, while with increasing the temperature in October and July (37, 45 ºC) show reduction to 50% and more. And the obtained results from ANSYS software show good correlation between increasing temperature and reduction temperature when using two stages evaporative cooling system as shown in figure 4.30.

Table 4.2: Summary of Temperature Results Summary of Temperature Results with Two Stages Evaporative Cooling System at Three Months

Cases	Input Temperature	Outlet temperature		
		Min	Average	Max
1	12.5	0.15	11.59	12.54
2	37	0.15	18.41	36.66
3	45	0.15	21.91	43.67

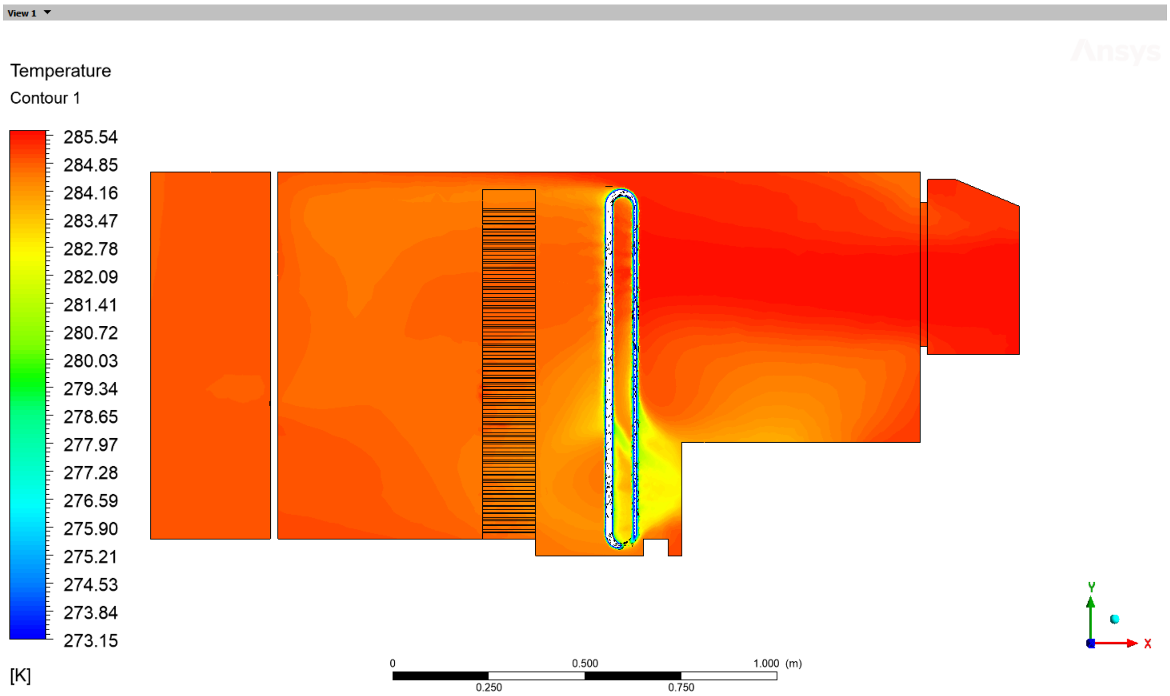


Figure 4.27: Temperature Counter 1 for Model Two with 12.5 Degree Centigrade.

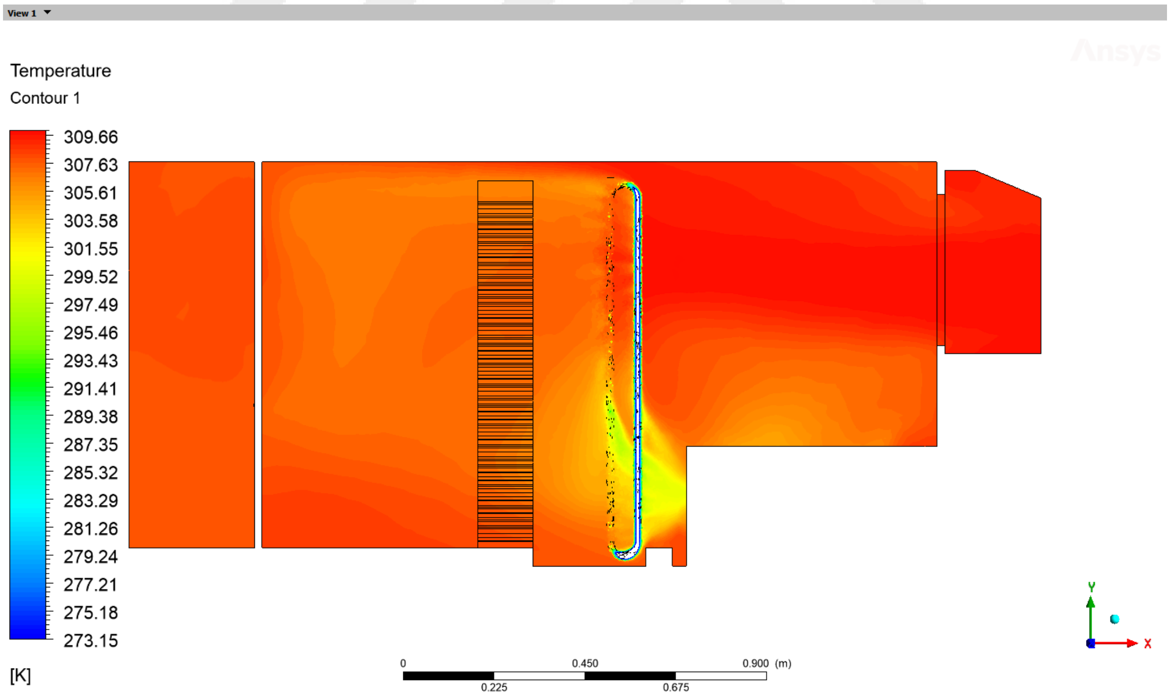


Figure 4.28: Temperature Counter 1 for Model Two with 37 Degree Centigrade.

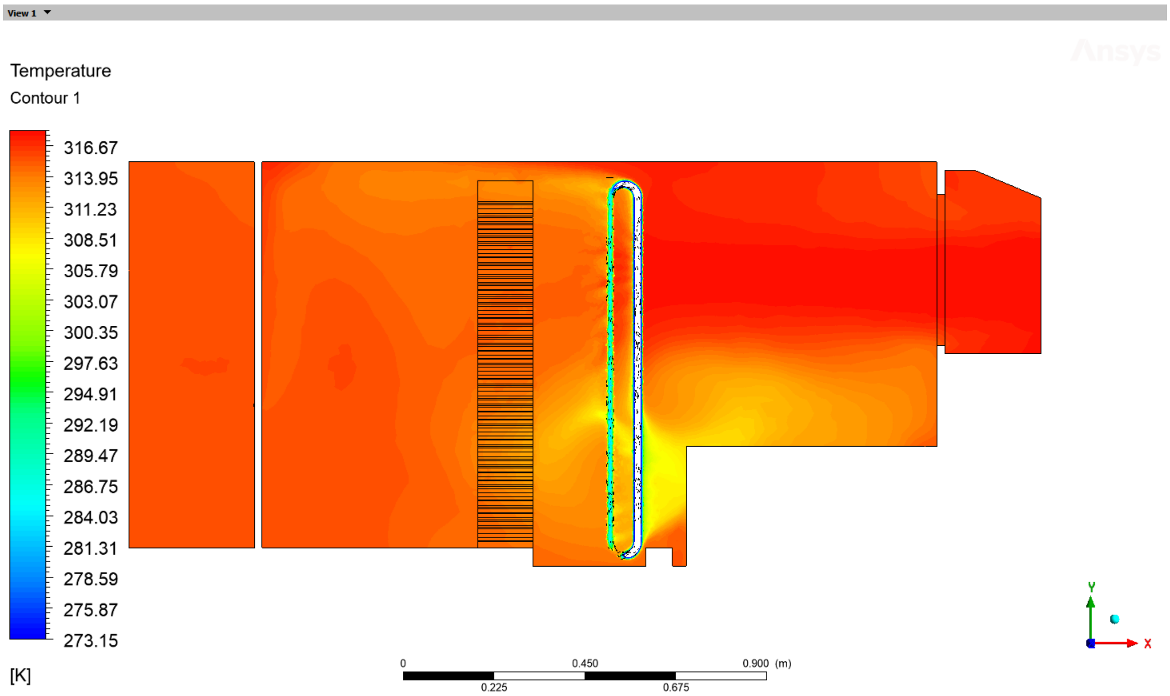


Figure 4.29: Temperature Counter 1 for Model Two with 45 Degree Centigrade.

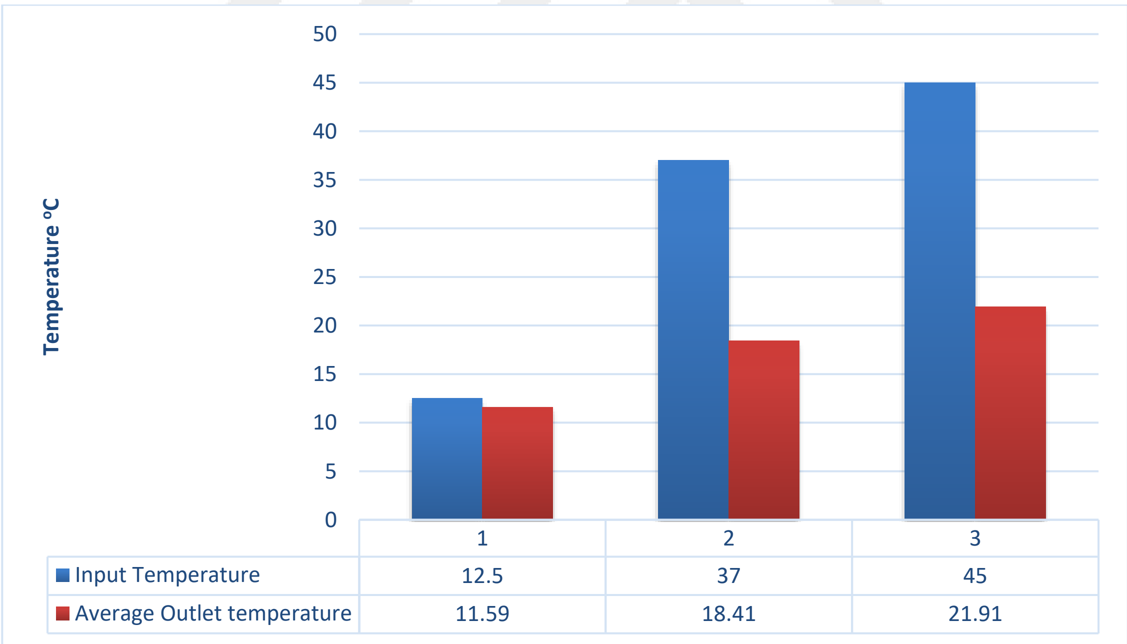


Figure 4.30: Temperature Distribution for Model Two with Two Stages Evaporative Cooling System at Three Months

4.6 TEMPERATURE VECTOR

4.6.1 Model with Air -Water-Air

The temperature vector gives an indication about the places that increase temperature or decreased it, Figures 4.31-4.33 show that the highest temperature is records in the entrance and this value increased significantly before heat-exchanges, while it reduced after it and reduced significantly after water pad due to working the pad on drop down the temperature of outside weather.

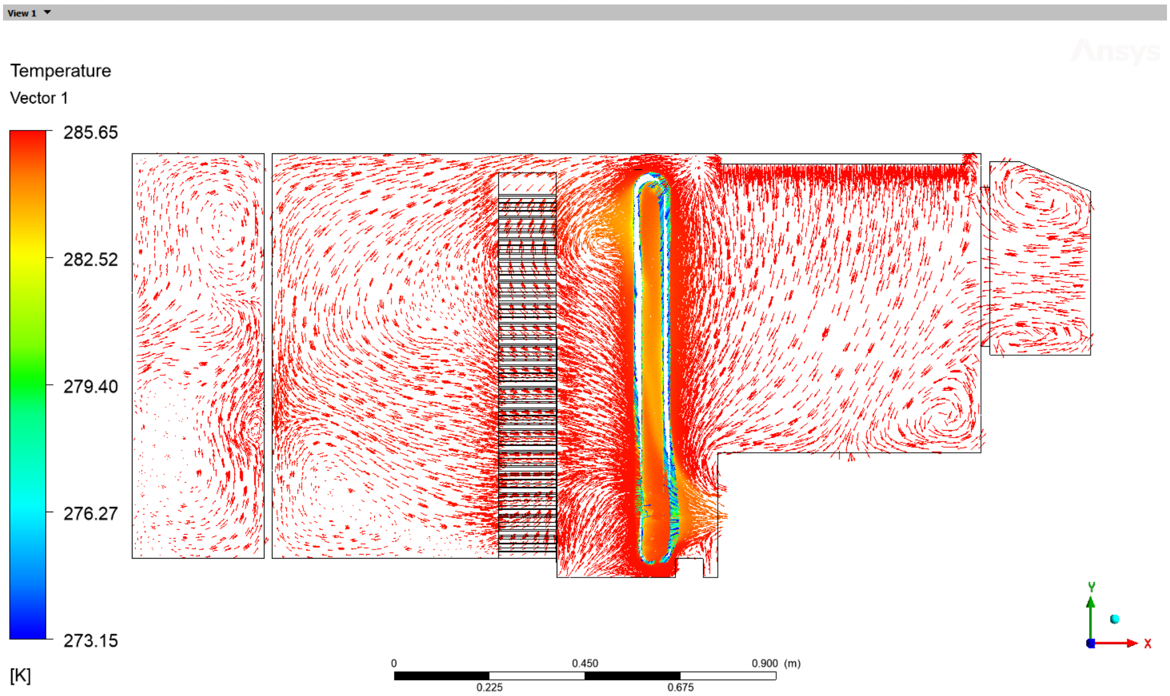


Figure 4.31: Temperature Vector 1 for Model One with 12.5 Degree Centigrade.

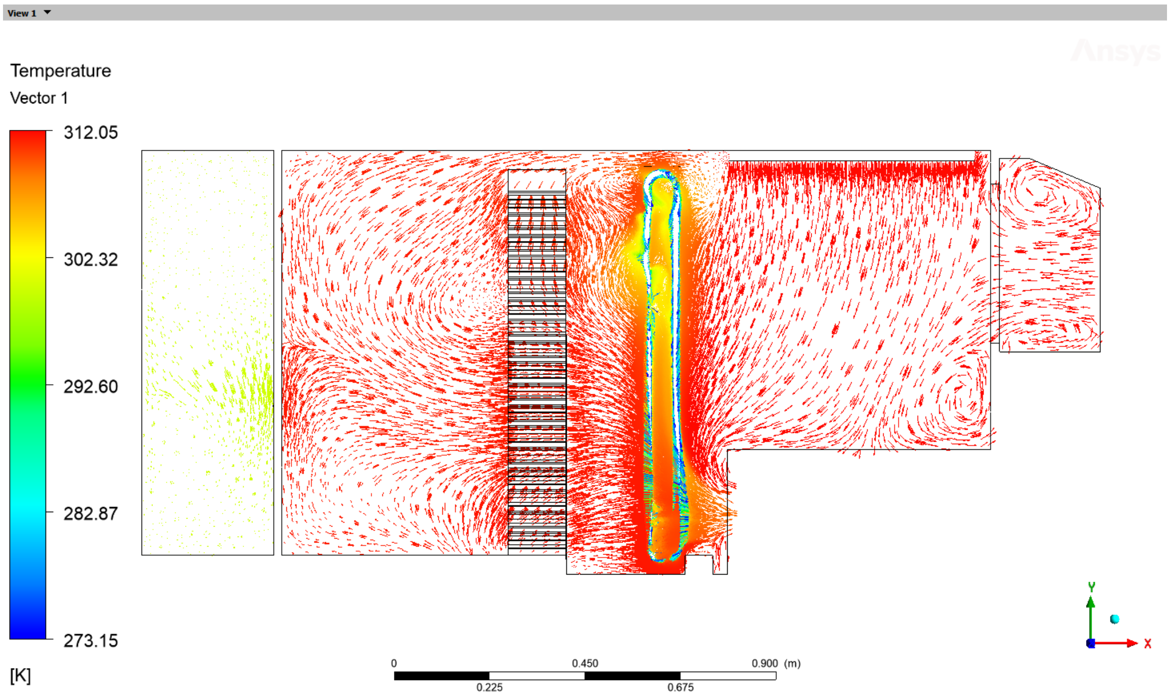


Figure 4.32: Temperature Vector 1 for Model One with 37 Degree Centigrade.

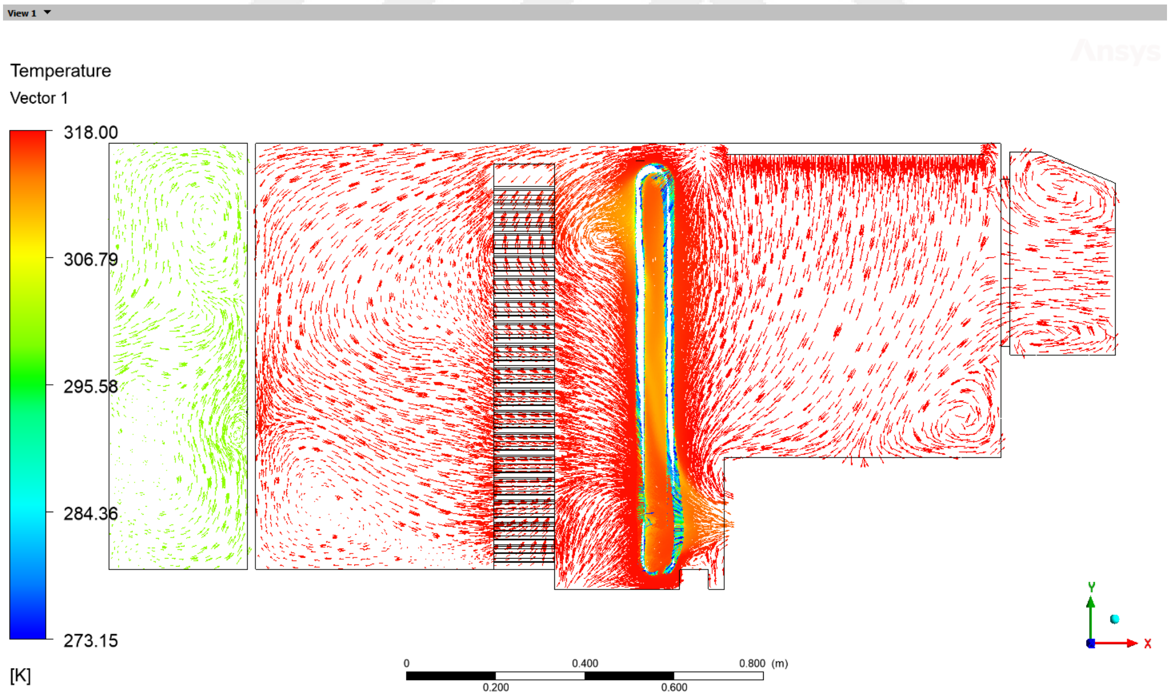


Figure 4.33: Temperature Vector 1 for Model One With 45 Degree Centigrade.

4.6.2 Model with Water-Air

The temperature vector gives an indication about the places that increase temperature or decreased it, Figures 4.34-4.36 show that the highest temperature is records in the entrance and this value increased significantly before heat-exchanges, while it reduced after it and reduced significantly after water pad due to working the pad on drop down the temperature of outside weather.

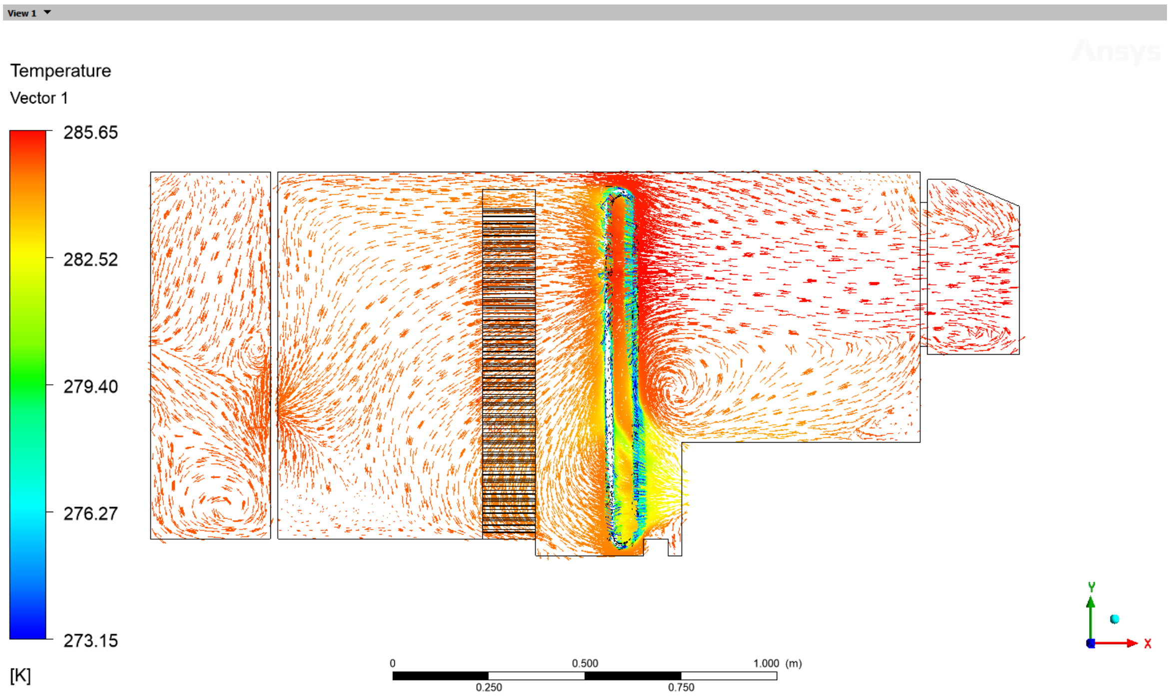


Figure 4.34: Temperature Vector 1 for Model Two with 12.5 Degree Centigrade.

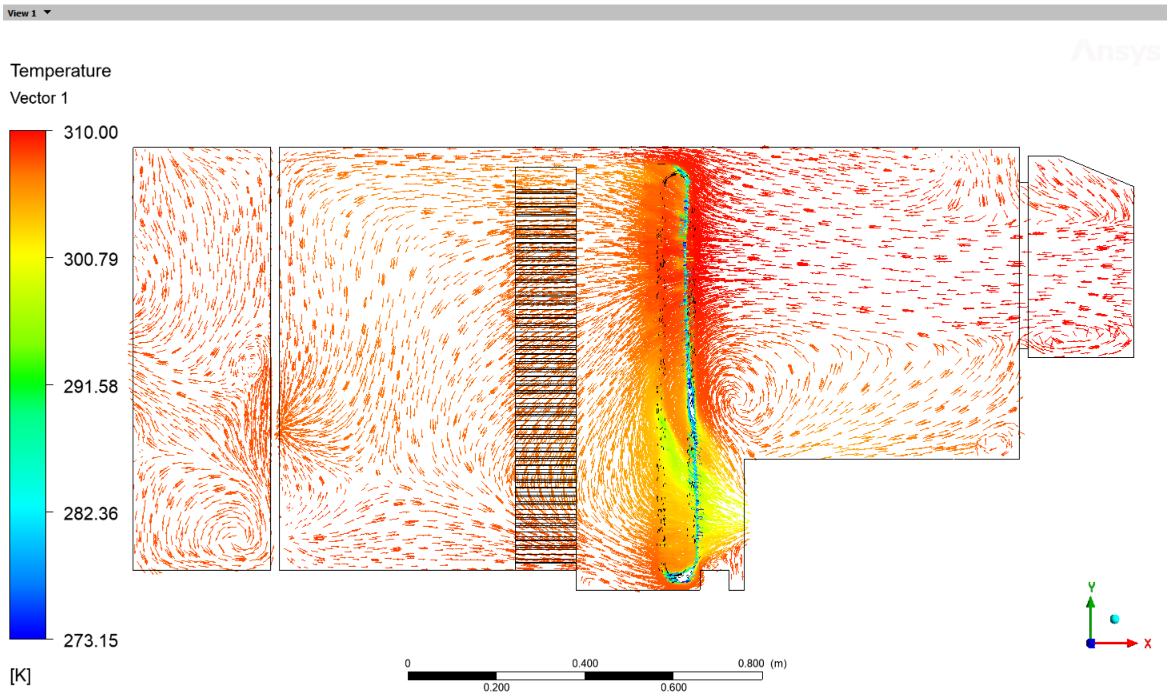


Figure 4.35: Temperature Vector 1 for Model Two with 37 Degree Centigrade.

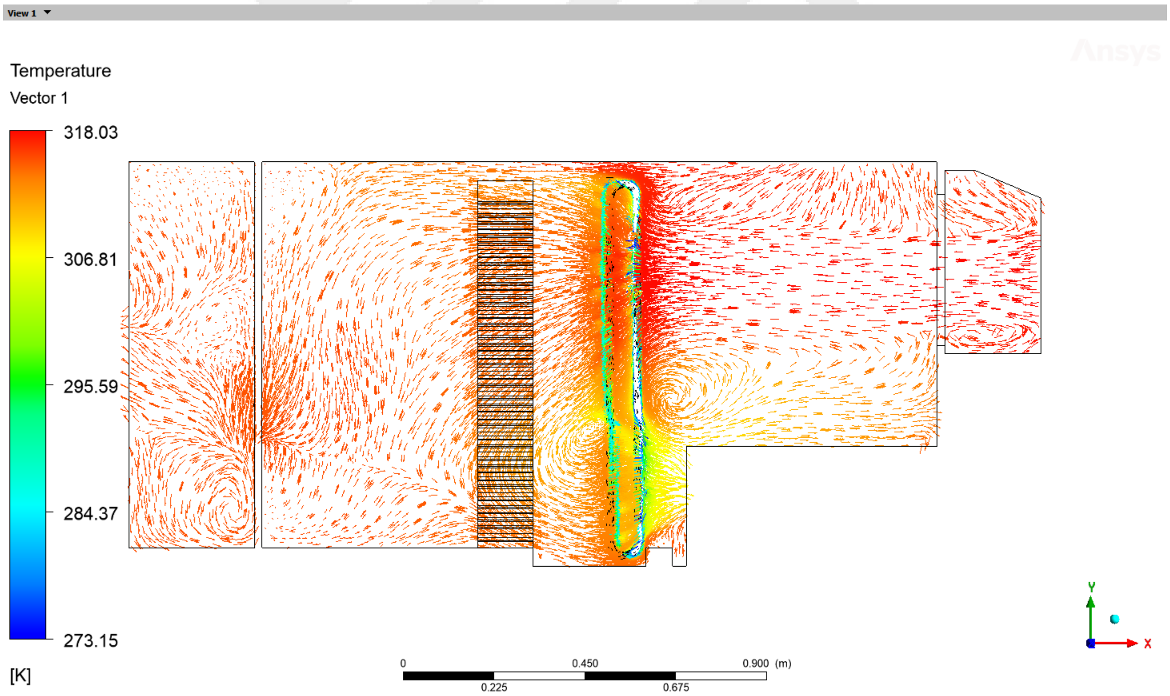


Figure 4.36: Temperature Vector 1 For Model Two with 45 Degree Centigrade.

4.7 THE CHANGES REYNOLDS NUMBER

The Reynolds number is a dimensionless quantity used in fluid mechanics to characterize the flow of a fluid over a surface or through a pipe. The Nusselt number variations in relation to the Reynolds number for the chosen heat exchanger, which has a diameter of d=0.01905, are depicted in Figure 4.37. The Nusselt number exhibited a significant increase with an increase in Reynolds number for the chosen coil diameters, as depicted in the presented figure.

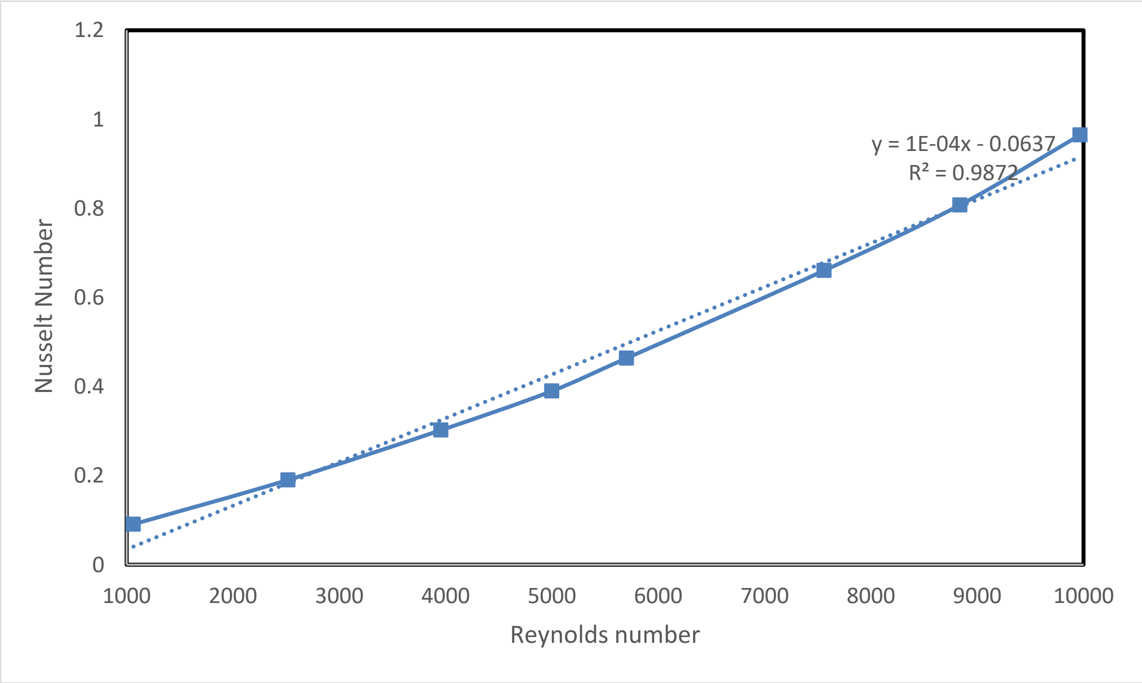


Figure 4.37: The Relationship Between Nusselt Number and Reynolds Number for the Selected Multi-Layers Heat Exchanger.

4.8 THE EFFECT OF RELATIVE HUMIDITY

As well known the weather in Iraqis very extreme and there is a massive difference in weather temperatures among the year seasons [140]–[142], figure 4.38 show that the lower temperatures are recoded in the first two months in the year and the highest values recoded in the July and August. While Figure 4.39 shows the relationship between relative humidity and weather temperatures and the relationship between them is negative one and increasing the temperature led to decrease the relative humidity percentage.

Efficiency of cooling system for the two selected system have been shown in figures 4.40, 4.27 and 4.28, the cooling system efficiency in three stages is better than two stages.

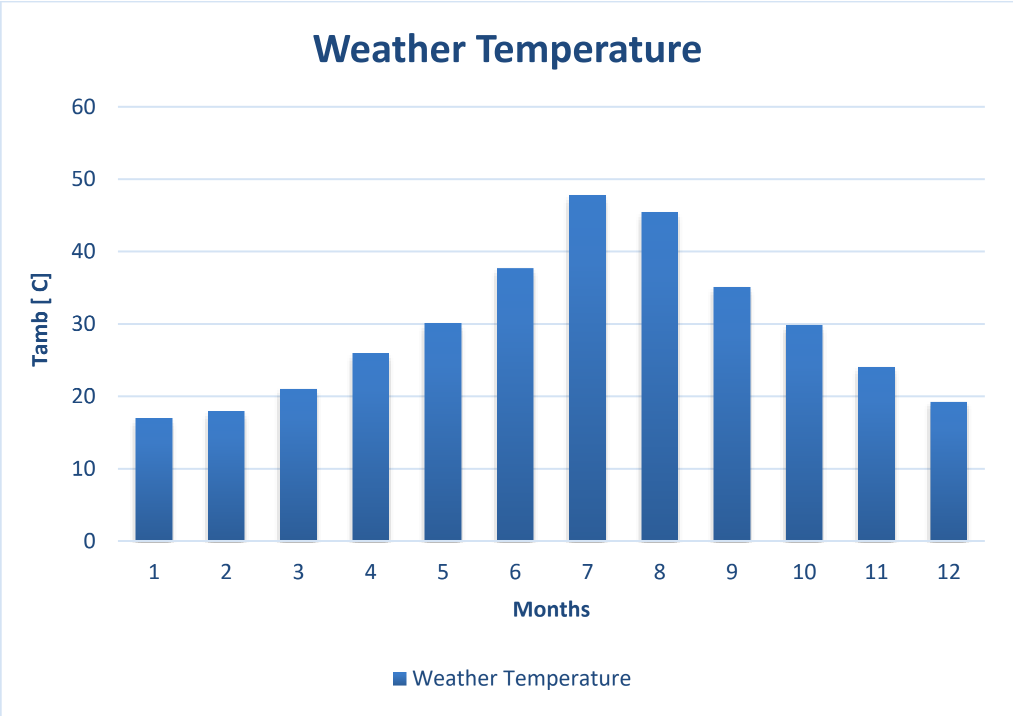


Figure 4.38: Weather Temperature in Iraq Within One Year

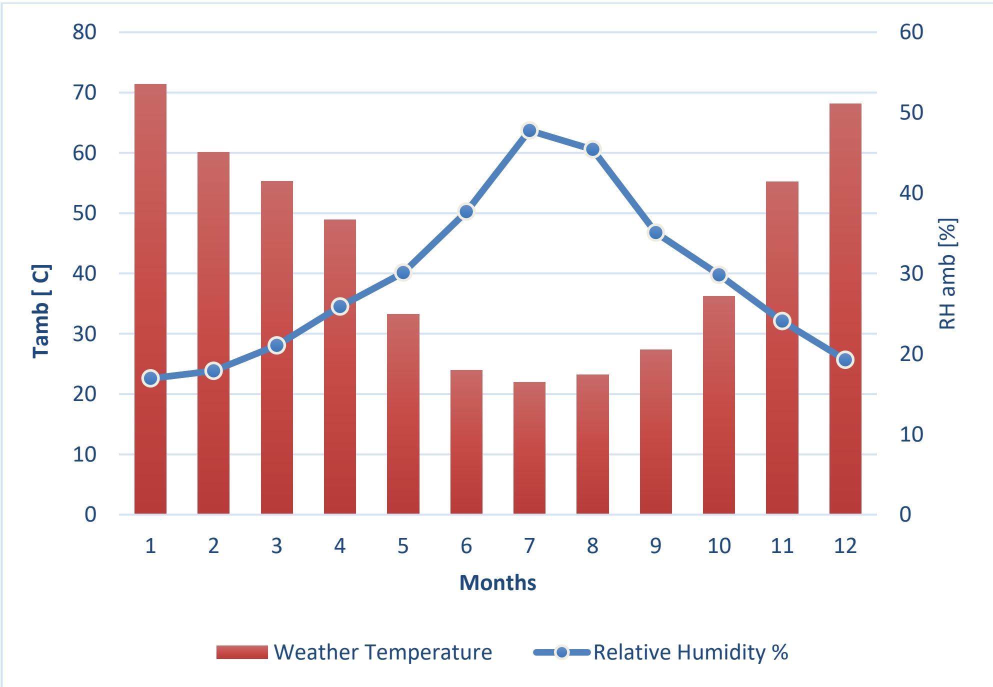


Figure 4.39: The Relationship Between Relative Humidity and Weather Temperatures.

Table 4.3: The Effect of Relative Humidity on the Outlet Temperature for Three Stages Evaporative Cooling System.

Cases	Inlet-Temp	Relative humidity	Outlet Temp	Efficiency of Cooling System
Case 1	12.5	15%	6.343	49%
Case 2	12.5	52%	8.9	29%
Case 3	45	15%	22.37	50%
Case 4	45	52%	30.21	33%
Case 5	37	15%	20.88	44%
Case 6	37	52%	25	32%

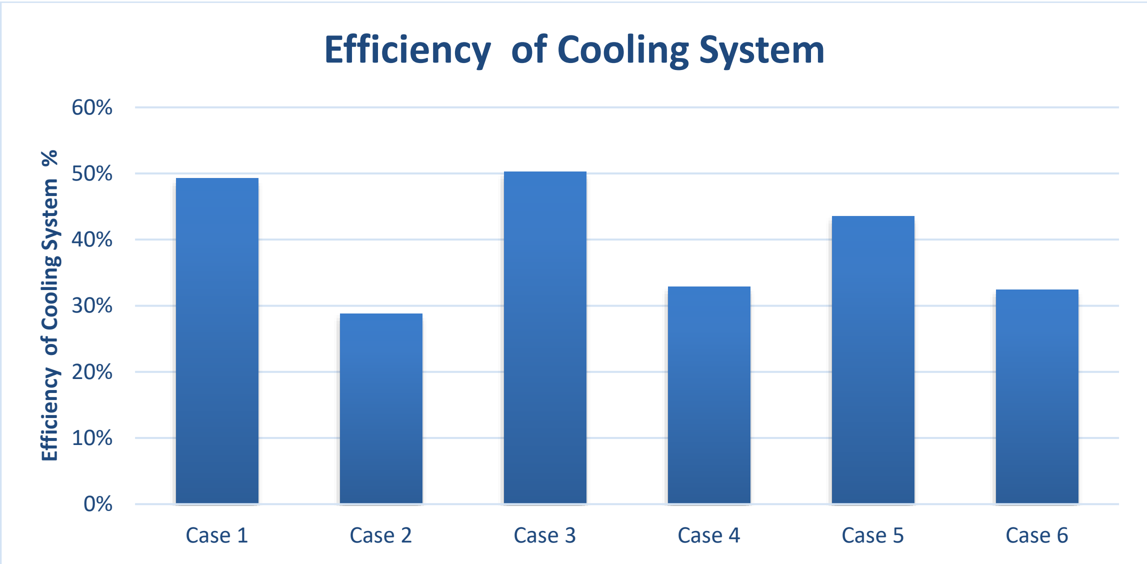


Figure 4.40: Efficiency of Cooling System for Three Stages Evaporative Cooling System

Table 4.4: The Effect of Relative Humidity on the Outlet Temperature for Two Stages Evaporative Cooling System

Cases	Inlet-Temp	Relative humidity	Outlet Temp	Efficiency of Cooling System
1	12.5	15%	11.59	7%
2	12.5	52%	12.21	2%
3	45	15%	21.91	51%
4	45	52%	33.3	26%
5	37	15%	18.41	50%
6	37	52%	28	24%

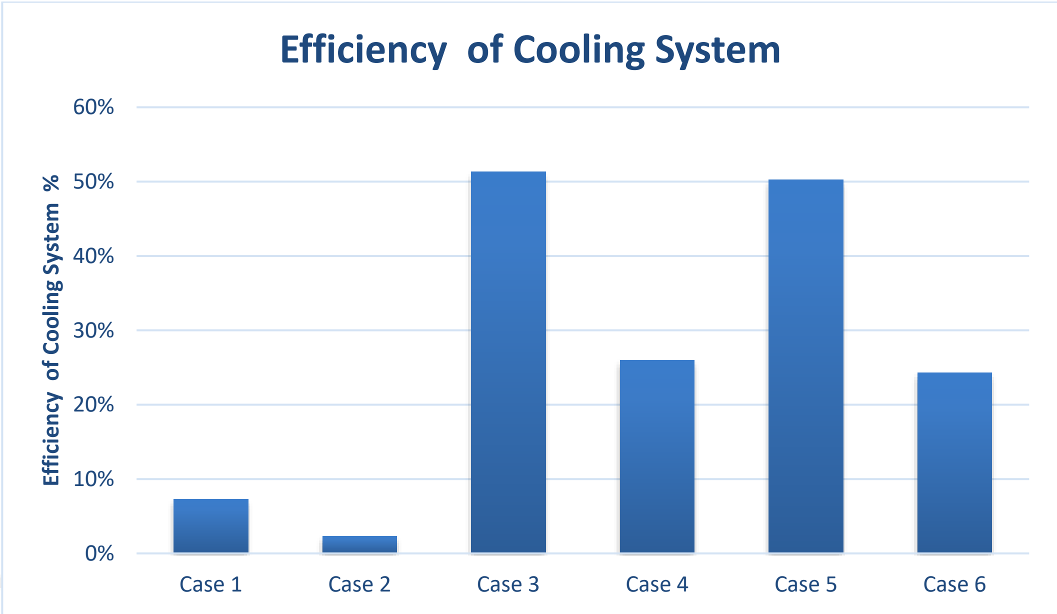


Figure 4.41: Efficiency of Cooling System for Two Stages Evaporative Cooling System

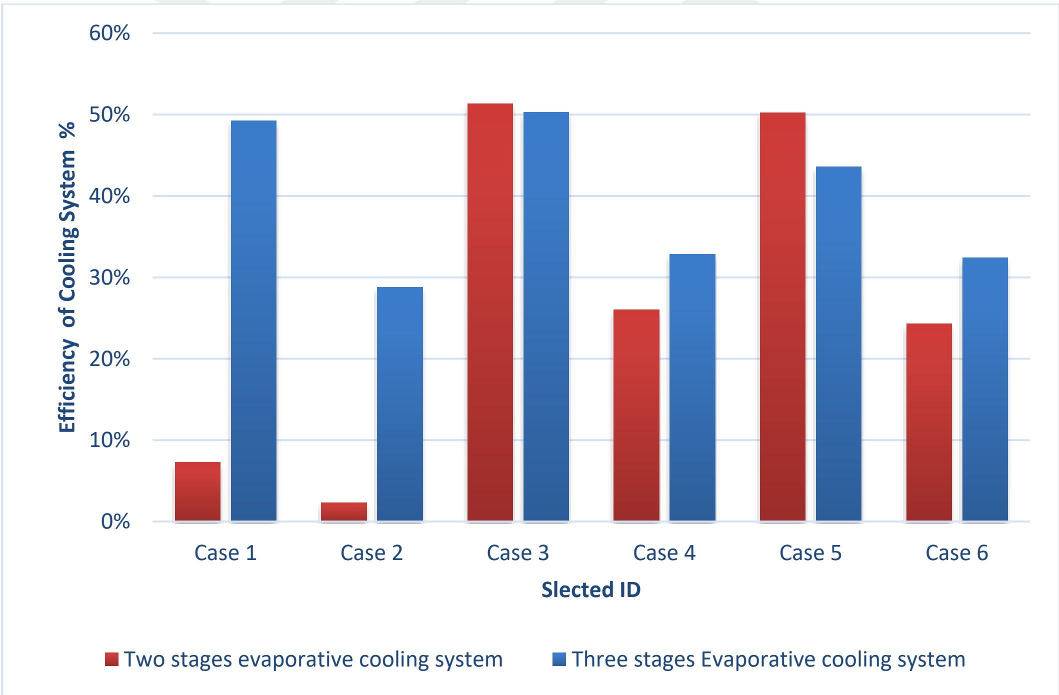


Figure 4.42: Comparative Between the Two Selected Models for Evaporative Cooling System.

5. CONCLUSION AND FUTURE RESEARCH

5.1 CONCLUSION

The focus of the present thesis was on fan-pad cooling, fan-pad-fan evaporation cooling, and other potentially useful cooling systems such as desiccated pad evaporative cooling, two-stage and three-stage evaporative cooling, and greenhouses. The study placed a strong emphasis on the most important aspects of evaporative cooling as well as the performance characteristics of the systems. According to the findings of the research, evaporative cooling is not used in greenhouses on its own but rather in conjunction with other methods, like ventilation and shade. There are various benefits and drawbacks associated with using each kind of evaporative cooling system.

The selection of a suitable cooling system is mostly determined by the climatic conditions of the surrounding area, in addition to the design and construction of the greenhouse. The analysis demonstrates that evaporative cooling systems were regularly changed and improved according to the climatic circumstances to obtain better cooling performance. This has been done to produce better cooling results. This progress has been made possible because of the development of applicable theory and practice.

The evaporative cooling system has also been developed for areas that are extremely hot and dry (climates like those found in deserts). In such climates, two-stage evaporative cooling is much more effective at creating an appropriate microclimate inside of a greenhouse than direct evaporative cooling is.

It has been discovered that the evaporative cooling system is a method that has been shown to be highly effective for the purpose of greenhouse cooling. Evaporative cooling with desiccation pads can decrease the greenhouse temp to between 4.3 and 7.5 degrees Celsius lower than that of the air temp. Two-stage evaporative cooling utilizing geothermal water can effectively cool the greenhouse environment by around 8 to 21.4 degrees Celsius lower than that of the air temp. Direct evaporative cooling is able to cool the greenhouse environment by 2 to 12 degrees Celsius lower than that of the air temp.

5.2 SUGGESTIONS FOR FUTURE RESEARCH

According to the results of a cursory examination of the relevant published material, it has been determined that a significant amount of investigation is still required into the indirect method of evaporative cooling and the mixed mode, which is a mixture of the direct and indirect modes. There is a significant amount of untapped potential for more study that can be carried out in the hot and humid tropics and subtropics. After an examination of the evaporative cooling system, the following subject areas are suggested for further investigation as possible areas of use in greenhouses.

a. The design of the photovoltaic evaporative cooling system and its control

b. Development of an evaporative cooling system for greenhouses, using solar chimneys to help in ventilation.

c. Alter the scale of the existing system to study how well it works across a large region.

d. Integrated management of the shade screen and the evaporative cooling system to provide the cooling system with environmentally friendly energy.

e. System design of regenerative evaporative cooling with identical design and units - Design and development of passive evaporative cooling in addition to cooling unit and heating on to lower the overall humidity of the system.

f. The use of alternative forms of energy, such as solar and geothermal, to provide either direct or indirect evaporative cooling The afore-mentioned ideas, if put into practice in the context of greenhouse applications, would encounter a great deal of difficulty, which might be the topic of more investigation.

REFERENCES

[1] P. Nejat, F. Jomehzadeh, M. M. Taheri, M. Gohari, and M. Z. A. Majid, "A global review of energy consumption, CO2 emissions and policy in the residential sector (with an overview of the top ten CO2 emitting countries)," *Renew. Sustain. energy Rev.*, vol. 43, pp. 843–862, 2015.

[2] E. G. McPherson, *Carbon dioxide reduction through urban forestry: guidelines for professional and volunteer tree planters*, vol. 171. US Department of Agriculture, Forest Service, Pacific Southwest Research Station, 1999.

[3] H. H. Masjuki, T. M. I. Mahlia, and I. A. Choudhury, "Potential electricity savings by implementing minimum energy efficiency standards for room air conditioners in Malaysia," *Energy Convers. Manag.*, vol. 42, no. 4, pp. 439–450, 2001.

[4] V. L. Erickson, M. Á. Carreira-Perpiñán, and A. E. Cerpa, "OBSERVE: Occupancy-based system for efficient reduction of HVAC energy," in *Proceedings of the 10th ACM/IEEE international conference on information processing in sensor networks*, IEEE, 2011, pp. 258–269.

[5] C. Koronen, M. Åhman, and L. J. Nilsson, "Data centres in future European energy systems—energy efficiency, integration and policy," *Energy Effic.*, vol. 13, no. 1, pp. 129–144, 2020.

[6] O. Amer, R. Boukhanouf, and H. G. Ibrahim, "A review of evaporative cooling technologies," *Int. J. Environ. Sci. Dev.*, vol. 6, no. 2, p. 111, 2015.

[7] W. R. Keatinge and G. C. Donaldson, "The impact of global warming on health and mortality," *South. Med. J.*, vol. 97, no. 11, pp. 1093–1100, 2004.

[8] U. Berardi, P. La Roche, and J. M. Almodovar, "Water-to-air-heat exchanger and indirect evaporative cooling in buildings with green roofs," *Energy Build.*, vol. 151, pp. 406–417, 2017.

[9] P. Nicoll, N. Thompson, and V. Gray, "Forward osmosis applied to evaporative cooling make-up water," *Power Plant Chem.*, vol. 14, no. 10, p. 632, 2012.

[10] I. Sarbu, "A review on substitution strategy of non-ecological refrigerants from vapour compression-based refrigeration, air-conditioning and heat pump systems,"

Int. J. Refrig., vol. 46, pp. 123–141, 2014.

[11] S. D. White, P. Kohlenbach, and C. Bongs, “Indoor temperature variations resulting from solar desiccant cooling in a building without thermal backup,” *Int. J. Refrig.*, vol. 32, no. 4, pp. 695–704, 2009.

[12] M. El Hourani, K. Ghali, and N. Ghaddar, “Effective desiccant dehumidification system with two-stage evaporative cooling for hot and humid climates,” *Energy Build.*, vol. 68, pp. 329–338, 2014.

[13] J. Watt, *Evaporative air conditioning handbook*. Springer Science & Business Media, 2012.

[14] N. Shah, “Cfd analysis of direct evaporative cooling zone of air-side economizer for containerized data center,” 2012.

[15] A. P. Ambade, “Study, Design and Analysis of Two Stages Evaporative Cooling System,” *Int. J. Sci. Res. Dev.*, vol. 3, no. 01, pp. 2061–2321, 2015.

[16] M. MEDOJEVIĆ and D. Obradovića, “SOLAR COOLING TECHNOLGIES AND THEIR APPLICATION REGARDING THE SOLAR POTENTIAL OF AP VOJVODINA”.

[17] G. J. Bom, *Evaporative air-conditioning: applications for environmentally friendly cooling*, vol. 23. World Bank Publications, 1999.

[18] B. Porumb, P. Ungureşan, L. F. Tutunaru, A. Şerban, and M. Bălan, “A review of indirect evaporative cooling technology,” *Energy procedia*, vol. 85, pp. 461–471, 2016.

[19] L. A. Schlom and A. J. Becwar, “Multi-stage hybrid evaporative cooling system.” Google Patents, Aug. 03, 2010.

[20] R. Shirmohammadi and N. Gilani, “Effectiveness enhancement and performance evaluation of indirect-direct evaporative cooling system for a wide variety of climates,” *Environ. Prog. Sustain. Energy*, vol. 38, no. 3, p. e13032, 2019.

[21] U. Sajjad *et al.*, “A review of recent advances in indirect evaporative cooling technology,” *Int. Commun. Heat Mass Transf.*, vol. 122, p. 105140, 2021.

[22] L. Guan, M. Bennett, and J. Bell, “Evaluating the potential use of direct evaporative cooling in Australia,” *Energy Build.*, vol. 108, pp. 185–194, 2015.

[23] P. M. Cuce and S. Riffat, “A state of the art review of evaporative cooling systems for building applications,” *Renew. Sustain. Energy Rev.*, vol. 54, pp. 1240–1249, 2016.

[24] O. Nematollahi, P. Alamdari, and M. R. Assari, “Experimental investigation of a dual purpose solar heating system,” *Energy Convers. Manag.*, vol. 78, pp. 359–366, 2014.

[25] B. Riangvilaikul and S. Kumar, “An experimental study of a novel dew point evaporative cooling system,” *Energy Build.*, vol. 42, no. 5, pp. 637–644, 2010.

[26] I. Firth, “Cooler?.,” *Phys. Educ.*, vol. 6, no. 1, pp. 32–41, 1971.

[27] G. N. Tiwari and H. N. Singh, “Solar energy conversion and photoenergy system–vol. 11–solar distillation,” *Cent. energy Stud. Indian Inst. Technol. India*, 1992.

[28] A. Carrasco, R. Pittard, S. N. Kondepudi, and S. Somasundaram, “Evaluation of a direct evaporative roof-spray cooling system,” 1987.

[29] M. J. Chegere, “Post-harvest losses reduction by small-scale maize farmers: The role of handling practices,” *Food Policy*, vol. 77, pp. 103–115, 2018.

[30] S. Jaber and S. Ajib, “Evaporative cooling as an efficient system in Mediterranean region,” *Appl. Therm. Eng.*, vol. 31, no. 14–15, pp. 2590–2596, 2011.

[31] B. G. Vainer, “FPA-based infrared thermography as applied to the study of cutaneous perspiration and stimulated vascular response in humans,” *Phys. Med. Biol.*, vol. 50, no. 23, p. R63, 2005.

[32] V. P. Shatsky, Z. V Vysotskaya, and V. A. Gulevsky, “TO THE QUESTION ABOUT WORK OF WATER-EVAPORATING COOLERS.,” *Sci. Her. Vor. State Univ. Archit. Civ. Eng.*, 2009.

[33] D. V. K. Samuel and V. Beera, “Evaporative cooling system for storage of fruits and vegetables-a review,” *J. Food Sci. Technol.*, vol. 50, no. 3, pp. 429–442, 2013.

[34] S. Cao *et al.*, “Advances in solar evaporator materials for freshwater generation,” *J. Mater. Chem. A*, vol. 7, no. 42, pp. 24092–24123, 2019.

[35] B. Akande and Y. Diei-Ouadi, *Post-harvest losses in small-scale fisheries*. Food and Agriculture Organization of the United Nations, 2010.

[36] V. I. O. Ndirika and C. N. Asota, "An evaporative cooling system for rural storage of fresh tomato," *J. Agric. Eng. Technol.*, vol. 2, no. 4, pp. 56–66, 1994.

[37] N. Katsoulas, A. Baille, and C. Kittas, "Effect of misting on transpiration and conductances of a greenhouse rose canopy," *Agric. For. Meteorol.*, vol. 106, no. 3, pp. 233–247, 2001.

[38] H. Barre, *Environmental and functional engineering of agricultural buildings*. Springer Science & Business Media, 2012.

[39] R. Shewfelt, "Quality characteristics of fruits and vegetables," *Minimal Process. foods Process Optim. An iterface. CRC Press. Boca Rat.*, pp. 171–189, 1994.

[40] W. A. Olosunde, J. C. Igbeka, and T. O. Olurin, "Performance evaluation of absorbent materials in evaporative cooling system for the storage of fruits and vegetables," *Int. J. Food Eng.*, vol. 5, no. 3, 2009.

[41] L. Garibaldi, "The FAO global capture production database: a six-decade effort to catch the trend," *Mar. Policy*, vol. 36, no. 3, pp. 760–768, 2012.

[42] C. Kittas, T. Bartzanas, and A. Jaffrin, "Temperature gradients in a partially shaded large greenhouse equipped with evaporative cooling pads," *Biosyst. Eng.*, vol. 85, no. 1, pp. 87–94, 2003.

[43] P. La Roche, "Passive Cooling Systems," in *Carbon-Neutral Architectural Design*, CRC Press, 2017, pp. 323–367.

[44] S. M. Dadhich, H. Dadhich, and R. Verma, "Comparative study on storage of fruits and vegetables in evaporative cool chamber and in ambient," *Int. J. Food Eng.*, vol. 4, no. 1, 2008.

[45] E. Rusten, *Understanding evaporative cooling*. Volunteers in Technical Assistance (VITA), 1985.

[46] J. T. Liberty, B. O. Ugwuishiwu, S. A. Pukuma, and C. E. Odo, "Principles and application of evaporative cooling systems for fruits and vegetables preservation," *Int. J. Curr. Eng. Technol.*, vol. 3, no. 3, pp. 1000–1006, 2013.

[47] L. Shashua-Bar, D. Pearlmutter, and E. Erell, "The cooling efficiency of urban landscape strategies in a hot dry climate," *Landsc. Urban Plan.*, vol. 92, no. 3–4, pp. 179–186, 2009.

[48] A. Alahmer, M. A. Omar, A. Mayyas, and S. Dongri, "Effect of relative humidity and temperature control on in-cabin thermal comfort state: Thermodynamic and psychometric analyses," *Appl. Therm. Eng.*, vol. 31, no. 14–15, pp. 2636–2644, 2011.

[49] L. Han, W. Shi, B. Wang, P. Zhang, and X. Li, "Energy consumption model of integrated air conditioner with thermosyphon in mobile phone base station," *Int. J. Refrig.*, vol. 40, pp. 1–10, 2014.

[50] X. Cui, K. J. Chua, and W. M. Yang, "Numerical simulation of a novel energy-efficient dew-point evaporative air cooler," *Appl. Energy*, vol. 136, pp. 979–988, 2014.

[51] R. M. Lazzarin, "Introduction of a simple diagram-based method for analyzing evaporative cooling," *Appl. Therm. Eng.*, vol. 27, no. 11–12, pp. 2011–2025, 2007.

[52] J. R. Camargo, "Evaporative cooling: water for thermal comfort," *Ambient. e Agua-An Interdiscip. J. Appl. Sci.*, vol. 3, no. 2, pp. 51–61, 2008.

[53] H. Esmaeilzadeh, M. Rivard, E. Arzi, F. Légaré, and A. Hassani, "Smart textile plasmonic fiber dew sensors," *Opt. Express*, vol. 23, no. 11, pp. 14981–14992, 2015.

[54] V. Vakiloroaya, B. Samali, A. Fakhar, and K. Pishghadam, "A review of different strategies for HVAC energy saving," *Energy Convers. Manag.*, vol. 77, pp. 738–754, 2014.

[55] E. V. Gómez, F. J. R. Martínez, F. V. Diez, M. J. M. Leyva, and R. H. Martín, "Description and experimental results of a semi-indirect ceramic evaporative cooler," *Int. J. Refrig.*, vol. 28, no. 5, pp. 654–662, 2005.

[56] D. Jain, "Development and testing of two-stage evaporative cooler," *Build. Environ.*, vol. 42, no. 7, pp. 2549–2554, 2007.

[57] H. El-Dessouky, H. Ettouney, and A. Al-Zeefari, "Performance analysis of two-stage evaporative coolers," *Chem. Eng. J.*, vol. 102, no. 3, pp. 255–266, 2004.

[58] M. Q. Shaheen and S. H. Hmmadi, "Combined evaporative air cooler and

refrigeration unit for water purification and performance enhancement of air cooling system," *Univ. Thi-Qar J. Eng. Sci.*, vol. 10, no. 1, pp. 79–90, 2019.

[59] S. N. Jha and S. K. Kudos, "Determination of physical properties of pads for maximizing cooling in evaporative cooled store," *J. Agric. Eng.*, vol. 43, no. 4, pp. 92–97, 2006.

[60] S. B. Maini and J. C. Anand, "Evaporative cooling system for post harvest management of horticultural crops," *Agric Mark*, vol. 35, no. 3, pp. 34–39, 1992.

[61] I. F. Odesola and O. Onyebuchi, "A review of porous evaporative cooling for the preservation of fruits and vegetables.," 2009.

[62] M. Singh and K. G. Naranyahgkeda, "Investigation and development of indirect evaporative cooling using plastic heat exchanger," *Mech Eng Bull*, vol. 14, no. 7, pp. 61–65, 1999.

[63] A. Franco, D. L. Valera, A. Madueno, and A. Peña, "Influence of water and air flow on the performance of cellulose evaporative cooling pads used in Mediterranean greenhouses," *Trans. ASABE*, vol. 53, no. 2, pp. 565–576, 2010.

[64] E. ROGDAKİS, İ. KORONAKİ, and D. TERTİPİS, "Estimation of the water temperature influence on direct evaporative cooler operation," *Int. J. Thermodyn.*, vol. 16, no. 4, pp. 172–178, 2013.

[65] Z. Duan, C. Zhan, X. Zhao, and X. Dong, "Experimental study of a counter-flow regenerative evaporative cooler," *Build. Environ.*, vol. 104, pp. 47–58, 2016.

[66] Y. Chen, H. Yang, and Y. Luo, "Parameter sensitivity analysis of indirect evaporative cooler (IEC) with condensation from primary air," *Energy Procedia*, vol. 88, pp. 498–504, 2016.

[67] Z. Duan, X. Zhao, C. Zhan, X. Dong, and H. Chen, "Energy saving potential of a counter-flow regenerative evaporative cooler for various climates of China: Experiment-based evaluation," *Energy Build.*, vol. 148, pp. 199–210, 2017.

[68] A. E. Kabeel, M. M. Bassuoni, and M. Abdelgaied, "Experimental study of a novel integrated system of indirect evaporative cooler with internal baffles and evaporative condenser," *Energy Convers. Manag.*, vol. 138, pp. 518–525, 2017.

[69] A. Sharma and H. Darokar, “Two Stage Indirect/Direct Evaporative Cooling,” *Int. J. Theor. Appl. Res. Mech. Eng.*, vol. 7, no. 1, pp. 41–46, 2018.

[70] A. R. Al-Badri and Z. M. Farhan, “A Study on Thermal Effectiveness of Multi-Stages Evaporative Air Cooling,” *Wasit J. Eng. Sci.*, vol. 8, no. 2, pp. 1–14, 2020.

[71] A. H. M. Alhosainy and I. M. A. Aljubury, “Two Stage Evaporative Cooling of Residential Building Using Geothermal Energy,” *J. Eng.*, vol. 25, no. 4, pp. 29–44, 2019.

[72] A. Mohammed;, W. Aqeel;, and B. Nabhan;, “Experimental study of a multi-stage evaporative cooler,” *Univ. Thi-Qar J. Eng. Sci.*, vol. 7, no. 1, pp. 1–8, 2016.

[73] H. Ambarita and H. V Sihombing, “The optimum intermediate pressure of two-stages vapor compression refrigeration cycle for Air-Conditioning unit,” in *Journal of Physics: Conference Series*, IOP Publishing, 2018, p. 12098.

[74] H. V Sihombing, H. Ambarita, W. Naibaho, and E. Y. Setiawan, “Effect of multi–stages vapor compression refrigeration cycle using refrigerant R32 for Air-Conditioning unit,” in *IOP Conference Series: Materials Science and Engineering*, IOP Publishing, 2020, p. 12017.

[75] G. Han, X. Feng, and S. Zhao, “A Multistage Regulation Method for the Pad and Fan Cooling System,” *Fisheries*, vol. 7, no. 1, pp. 1–5, 2018.

[76] S. Kumar, S. V. K. Reddy, and S. S. Salins, “Experimental investigation on the humidification parameters of the reciprocating multistage evaporative Cooler-A novel approach,” *Int. J. Therm. Sci.*, vol. 177, p. 107539, 2022.

[77] X. Cui, X. Yang, Q. Kong, X. Meng, and L. Jin, “Performance evaluation and comparison of multistage indirect evaporative cooling systems in two operation modes,” *Int. J. Energy Res.*, vol. 44, no. 12, pp. 9298–9308, 2020.

[78] G. Boxem, S. Boink, and W. Zeiler, “Performance model for small scale indirect evaporative Cooler.,” in *Clima 2007, Helsinki, Finland*, FINVAC, 2007.

[79] N. M. SHARIATI and N. Gilani, “An investigation of indirect evaporative coolers, IEC with respect to thermal comfort criteria,” 2009.

[80] Y. You, H. Jiang, and J. Lv, “Analysis of influence of IEC heat exchanger based on

CFD method," *Energy Procedia*, vol. 158, pp. 5759–5764, 2019.

[81] Y. Wan, C. Ren, and L. Xing, "An approach to the analysis of heat and mass transfer characteristics in indirect evaporative cooling with counter flow configurations," *Int. J. Heat Mass Transf.*, vol. 108, pp. 1750–1763, 2017.

[82] A. Pakari and S. Ghani, "Comparison of 1D and 3D heat and mass transfer models of a counter flow dew point evaporative cooling system: Numerical and experimental study," *Int. J. Refrig.*, vol. 99, pp. 114–125, 2019.

[83] S. De Antonellis, C. M. Joppolo, P. Liberati, S. Milani, and F. Romano, "Modeling and experimental study of an indirect evaporative cooler," *Energy Build.*, vol. 142, pp. 147–157, 2017.

[84] Y. Wan, J. Lin, K. J. Chua, and C. Ren, "Similarity analysis and comparative study on the performance of counter-flow dew point evaporative coolers with experimental validation," *Energy Convers. Manag.*, vol. 169, pp. 97–110, 2018.

[85] W.-Y. Li, Y.-C. Li, L. Zeng, and J. Lu, "Comparative study of vertical and horizontal indirect evaporative cooling heat recovery exchangers," *Int. J. Heat Mass Transf.*, vol. 124, pp. 1245–1261, 2018.

[86] N. Castilla and J. Hernandez, "Greenhouse technological packages for high-quality crop production," in *XXVII International Horticultural Congress-IHC2006: International Symposium on Advances in Environmental Control, Automation 761*, 2006, pp. 285–297.

[87] A. Fouda and Z. Melikyan, "A simplified model for analysis of heat and mass transfer in a direct evaporative cooler," *Appl. Therm. Eng.*, vol. 31, no. 5, pp. 932–936, 2011.

[88] A. M. Abdel-Ghany and T. Kozai, "Cooling efficiency of fogging systems for greenhouses," *Biosyst. Eng.*, vol. 94, no. 1, pp. 97–109, 2006.

[89] Y. Ishigami, T. Tetsuka, and E. Goto, "Analysis of the aerial environment of a tomato greenhouse equipped with different fog cooling systems," *J. Agric. Meteorol.*, vol. 70, no. 2, pp. 127–131, 2014.

[90] S. Li and D. H. Willits, "Comparing low-pressure and high-pressure fogging systems in naturally ventilated greenhouses," *Biosyst. Eng.*, vol. 101, no. 1, pp. 69–77, 2008.

[91] N. Katsoulas, C. Kittas, G. Dimokas, and C. Lykas, “Effect of irrigation frequency on rose flower production and quality,” *Biosyst. Eng.*, vol. 93, no. 2, pp. 237–244, 2006.

[92] N. Katsoulas, D. Savvas, I. Tsirogiannis, O. Merkouris, and C. Kittas, “Response of an eggplant crop grown under Mediterranean summer conditions to greenhouse fog cooling,” *Sci. Hortic. (Amsterdam).*, vol. 123, no. 1, pp. 90–98, 2009.

[93] M. L. Garcia, E. Medrano, M. C. Sanchez-Guerrero, and P. Lorenzo, “Climatic effects of two cooling systems in greenhouses in the Mediterranean area: External mobile shading and fog system,” *Biosyst. Eng.*, vol. 108, no. 2, pp. 133–143, 2011.

[94] J. S. Perret, A. M. Al-Ismaili, and S. S. Sablani, “Development of a humidification–dehumidification system in a quonset greenhouse for sustainable crop production in arid regions,” *Biosyst. Eng.*, vol. 91, no. 3, pp. 349–359, 2005.

[95] P. A. Davies and C. Paton, “The Seawater Greenhouse: background, theory and current status,” *Int. J. Low-Carbon Technol.*, vol. 1, no. 2, pp. 183–190, 2006.

[96] P. A. Davies, “A solar cooling system for greenhouse food production in hot climates,” *Sol. energy*, vol. 79, no. 6, pp. 661–668, 2005.

[97] H. Mahmoudi, N. Spahis, S. A. Abdul-Wahab, S. S. Sablani, and M. F. A. Goosen, “Improving the performance of a Seawater Greenhouse desalination system by assessment of simulation models for different condensers,” *Renew. Sustain. Energy Rev.*, vol. 14, no. 8, pp. 2182–2188, 2010.

[98] B. Wong, L. McClung, A. Snijders, D. McClenahan, and J. Thornton, “The application of aquifer thermal energy storage in the Canadian greenhouse industry,” in *International Symposium on High Technology for Greenhouse Systems: GreenSys2009 893*, 2009, pp. 437–444.

[99] S. K. Abbouda and E. A. Almuhanna, “Improvement of evaporative cooling system efficiency in greenhouses,” *Int. J. Latest Trends Agric. Food Sci.*, vol. 2, no. 2, pp. 83–89, 2012.

[100] G. Lychnos and P. A. Davies, “Modelling and experimental verification of a solar-powered liquid desiccant cooling system for greenhouse food production in hot climates,” *Energy*, vol. 40, no. 1, pp. 116–130, 2012.

[101] H. A. Al-Busaidi and Y. A. Al-Mulla, "Crop water requirement inside conventional versus seawater greenhouses," in *International Conference on Agricultural Engineering: New Technologies for Sustainable Agricultural Production and Food Security 1054*, 2013, pp. 73–79.

[102] N. H. Abu-Hamdeh and K. H. Almitani, "Solar liquid desiccant regeneration and nanofluids in evaporative cooling for greenhouse food production in Saudi Arabia," *Sol. Energy*, vol. 134, pp. 202–210, 2016.

[103] I. M. A. Aljubury and H. D. Ridha, "Enhancement of evaporative cooling system in a greenhouse using geothermal energy," *Renew. energy*, vol. 111, pp. 321–331, 2017.

[104] P. Banik and A. Ganguly, "Performance and economic analysis of a floricultural greenhouse with distributed fan-pad evaporative cooling coupled with solar desiccation," *Sol. Energy*, vol. 147, pp. 439–447, 2017.

[105] D. Misra and S. Ghosh, "Evaporative cooling technologies for greenhouses: a comprehensive review," *Agric. Eng. Int. CIGR J.*, vol. 20, no. 1, pp. 1–15, 2018.

[106] X. Zhou and J. E. Braun, "Transient modeling of chilled water cooling coils," 2004.

[107] M. Roffi, F. J. T. E. Ferreira, and A. T. De Almeida, "Comparison of different cooling fan designs for electric motors," in *2017 IEEE International Electric Machines and Drives Conference (IEMDC)*, IEEE, 2017, pp. 1–7.

[108] S. Al-Musaedi, Z. Asadi, D. D. Ganji, and M. Javidan, "Simulation of melting and solidification processes of organic phase change materials used in storing heat energy in multi-layers heat exchanger," *J. Energy Storage*, vol. 50, p. 104687, 2022.

[109] A. Fluent, "Release 15.0, theory guide," *ANSYS Inc, Canonsbg.*, 2013.

[110] H. K. Versteeg and W. Malalasekera, *An introduction to computational fluid dynamics: the finite volume method*. Pearson education, 2007.

[111] H. Fatahian, H. Salarian, M. E. Nimvari, and E. Fatahian, "Numerical study of thermal characteristics of fuel oil-alumina and water-alumina nanofluids flow in a channel in the laminar flow," *IIUM Eng. J.*, vol. 19, no. 1, pp. 251–269, 2018.

[112] A. A. S. Lima, A. A. V Ochoa, J. A. P. Da Costa, and J. R. Henríquez, "CFD simulation of heat and mass transfer in an absorber that uses the pair ammonia/water

as a working fluid," *Int. J. Refrig.*, vol. 98, pp. 514–525, 2019.

[113] Y. Qian, Z. Han, J.-H. Zhan, X. Liu, and G. Xu, "Comparative evaluation of heat conduction and radiation models for CFD simulation of heat transfer in packed beds," *Int. J. Heat Mass Transf.*, vol. 127, pp. 573–584, 2018.

[114] E. Fatahian, A. L. Nichkoohi, and H. Fatahian, "Numerical study of the effect of suction at a compressible and high Reynolds number flow to control the flow separation over Naca 2415 airfoil," *Prog. Comput. Fluid Dyn. an Int. J.*, vol. 19, no. 3, pp. 170–179, 2019.

[115] C. Yue, Q. Zhang, Z. Zhai, and L. Ling, "CFD simulation on the heat transfer and flow characteristics of a microchannel separate heat pipe under different filling ratios," *Appl. Therm. Eng.*, vol. 139, pp. 25–34, 2018.

[116] H. Montazeri, B. Blocken, and J. L. M. Hensen, "Evaporative cooling by water spray systems: CFD simulation, experimental validation and sensitivity analysis," *Build. Environ.*, vol. 83, pp. 129–141, 2015.

[117] B. Gebrehiwot *et al.*, "CFD modeling of indirect/direct evaporative cooling unit for modular data center applications," in *International Electronic Packaging Technical Conference and Exhibition*, American Society of Mechanical Engineers, 2013, p. V002T08A054.

[118] M. Zyda, "From visual simulation to virtual reality to games," *Computer (Long. Beach. Calif).*, vol. 38, no. 9, pp. 25–32, 2005.

[119] S. A. Ward and R. H. Halstead, *Computation structures*. MIT press, 1990.

[120] H. Guo *et al.*, "Label-Efficient Interactive Time-Series Anomaly Detection," *arXiv Prepr. arXiv2212.14621*, 2022.

[121] M. Aboubacar and M. F. Webster, "A cell-vertex finite volume/element method on triangles for abrupt contraction viscoelastic flows," *J. Nonnewton. Fluid Mech.*, vol. 98, no. 2–3, pp. 83–106, 2001.

[122] M. K. Borg, D. A. Lockerby, and J. M. Reese, "A multiscale method for micro/nano flows of high aspect ratio," *J. Comput. Phys.*, vol. 233, pp. 400–413, 2013.

[123] T. Mostafaie, F. M. Khiyabani, and N. J. Navimipour, "A systematic study on meta-

heuristic approaches for solving the graph coloring problem," *Comput. Oper. Res.*, vol. 120, p. 104850, 2020.

[124] H. L. Stone, "Iterative solution of implicit approximations of multidimensional partial differential equations," *SIAM J. Numer. Anal.*, vol. 5, no. 3, pp. 530–558, 1968.

[125] S. W. Mahfoud and D. E. Goldberg, "Parallel recombinative simulated annealing: A genetic algorithm," *Parallel Comput.*, vol. 21, no. 1, pp. 1–28, 1995.

[126] J. Tu, G. H. Yeoh, C. Liu, and Y. Tao, *Computational fluid dynamics: a practical approach*. Elsevier, 2023.

[127] B. J. Kirby, *Micro-and nanoscale fluid mechanics: transport in microfluidic devices*. Cambridge university press, 2010.

[128] W. D. Bachalo, "Experimental methods in multiphase flows," *Int. J. Multiph. flow*, vol. 20, pp. 261–295, 1994.

[129] W. Merzkirch, *Flow visualization*. Elsevier, 2012.

[130] S. A. Gbadebo, N. A. Cumpsty, and T. P. Hynes, "Three-dimensional separations in axial compressors," in *Turbo Expo: Power for Land, Sea, and Air*, 2004, pp. 457–469.

[131] N. Gregory, J. T. Stuart, and W. S. Walker, "On the stability of three-dimensional boundary layers with application to the flow due to a rotating disk," *Philos. Trans. R. Soc. London. Ser. A, Math. Phys. Sci.*, vol. 248, no. 943, pp. 155–199, 1955.

[132] F. Lemoine and G. Castanet, "Temperature and chemical composition of droplets by optical measurement techniques: a state-of-the-art review," *Exp. Fluids*, vol. 54, pp. 1–34, 2013.

[133] B. L. Abernathy, "A method of sequence design for urban streets evaluated in case studies." Massachusetts Institute of Technology, 1963.

[134] L. Holland, C. Davenport, and E. Chappell, *Mastering AutoCAD Civil 3D 2014: Autodesk Official Press*. John Wiley & Sons, 2013.

[135] H. Hægland, H. K. Dahle, G. T. Eigestad, K.-A. Lie, and I. Aavatsmark, "Improved streamlines and time-of-flight for streamline simulation on irregular grids," *Adv.*

Water Resour., vol. 30, no. 4, pp. 1027–1045, 2007.

[136] B. Cantwell, D. Coles, and P. Dimotakis, "Structure and entrainment in the plane of symmetry of a turbulent spot," *J. Fluid Mech.*, vol. 87, no. 4, pp. 641–672, 1978.

[137] R. P. Batycky, *A three-dimensional two-phase field scale streamline simulator*. stanford university, 1997.

[138] M. Sommerfeld and H.-H. Qiu, "Characterization of particle-laden, confined swirling flows by phase-doppler anemometry and numerical calculation," *Int. J. Multiph. flow*, vol. 19, no. 6, pp. 1093–1127, 1993.

[139] X. Zhang, B. Cheng, and C. Tuffile, "Simulation study of the spatter removal process and optimization design of gas flow system in laser powder bed fusion," *Addit. Manuf.*, vol. 32, p. 101049, 2020.

[140] Y. Osman, N. Al-Ansari, M. Abdellatif, S. B. Aljawad, and S. Knutsson, "Expected Future Precipitation in Central Iraq Using LARS-WG Stochastic Weather Generator," *Engineering*, vol. 06, no. 13, pp. 948–959, 2014, doi: 10.4236/eng.2014.613086.

[141] Z. M. Mohammed and W. H. Hassan, "Climate change and the projection of future temperature and precipitation in southern Iraq using a LARS-WG model," *Model. Earth Syst. Environ.*, vol. 8, no. 3, pp. 4205–4218, 2022.

[142] A. S. Hassan, K. N. Zeki, and N. S. Salih, "Determination the quantity of extreme rainfall and calculation of the climatology mean for Baghdad City," *Iraqi J. Sci.*, pp. 447–455, 2018.