IMPROVING AIR-CONDITIONING SYSTEMS NUMERICALLY BY USING DIRECT EVAPORATIVE COOLING IN SEVERELY HOT WEATHER

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I certify that in my opinion the thesis submitted by Jaafar Hattab Furaig SALEEM titled “IMPROVING AIR-CONDITIONING SYSTEMS NUMERICALLY BY USING DIRECT EVAPORATIVE COOLING IN SEVERELY HOT WEATHER ” is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

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Jaafar Hattab Furaig SALEEM

ABSTRACT

M. Sc. Thesis

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Karabuk University
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Direct evaporative cooling (DEC) systems use water evaporation to cool air through a moist pad or filter. These systems are known for their low energy consumption. This study aims to improve the operation of DEC systems in extremely hot conditions. The goal is to develop cost-effective and environmentally friendly cooling solutions while reducing energy use, ensuring the systems are correctly constructed and sized for the specific building and climatic conditions.

It employs ANSYS software, a robust computational fluid dynamics (CFD) technique, and EES software for simulation. The simulation process will be divided into two phases, the first of which is represented by the presence of injectors, which have been divided into three sections to see the softness in the process of chilling the air entering from outside, which is represented by three distinct speeds. The number of turns of the second section, represented by a tube coming from the condenser in the heat exchanger, will be altered to see the improvement in receiving the cooling gas. Thus, the total number of instances employed is 27 cases added to the two sections, representing 54 cases, followed by the application of these cases with the EES software to determine the value of improvement in the COP. The number of twists in the cooling tubes and the number of nozzles were purposely adjusted to investigate how they affected system efficiency. The system's structure is made up of a coil and tube type heat exchanger with a changeable length and number of turns. The second part of the simulation process is represented by the air entry area and the water spraying process with variable number of nozzles, where 5, 9, and 13 turns of the cooling tube were used, and this represents the second part of the simulation process to know the thermal effect on the heat exchange process between the fluids, while the first part is represented by the air entry area and the water spraying process with variable number of nozzles, where 15, 24, and 35 nozzles were used. The duct's measurements were 20 cm in width, 10 cm in height, and 25 cm in total length. On the duct width, the roll diameter was 60 mm.

The results reveal that system geometry, specifically the air entrance region and the water spraying procedure, has a considerable influence on thermal dynamics and fluid flow within a heat exchanger. The number of coils turns and nozzles can have a significant impact on system performance, as illustrated by the distinct temperature and velocity curves. Furthermore, to handle complicated geometrical configurations and deliver significant insights, the study made full use of ANSYS' powerful simulation capabilities. At an inlet velocity of 2.0, the design with 35 injectors and 13 coil turns scored the maximum COP of 4.537, suggesting that it is the best configuration for the given system. It reaches a maximum temperature of 55.27 degrees Celsius. At a velocity of 1 m/s, the coil turns in the temperature chart reach a peak, whereas the COP chart has the lowest values at the same velocity. Also, the highest COP for the system is 4.537, which occurs at 35 injectors and 13 coil turns. The study's findings could open the way for further improvement of such systems, perhaps increasing their efficiency. The study highlights the significance of computational tools in understanding and improving complicated thermal systems such as heat.

Keywords : Coil and tube heat exchanger, coefficient of performance, air-conditioning systems, direct evaporative cooling.

Science Code : 91431

ÖZET

Yüksek Lisans Tezi

AŞIRI SICAK HAVALARDA DOĞRUDAN EVAPORATİF SOĞUTMA KULLANARAK İKLİMLENDİRME SISTEMLERININ SAYISAL İYİLEŞTİRİLMESİ

Jaafar Hattab Furaig SALEEM

Karabük Üniversitesi
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Doğrudan buharlaştırmalı soğutma (DEC) sistemleri, nemli bir ped veya filtre aracılığıyla havayı soğutmak için suyun buharlaşmasını kullanır. Bu sistemler düşük enerji tüketimleriyle bilinirler. Bu çalışma, DEC sistemlerinin aşırı sıcak koşullarda çalışmasını iyileştirmeyi amaçlamaktadır. Amaç, enerji kullanımını azaltırken uygun maliyetli ve çevre dostu soğutma çözümleri geliştirmek, sistemlerin belirli bina ve iklim koşulları için doğru şekilde inşa edilmesini ve boyutlandırılmasını sağlamaktır. Simülasyon için güçlü bir hesaplamalı akışkanlar dinamiği (CFD) tekniği olan ANSYS yazılımını ve EES yazılımını kullanmaktadır. Simülasyon süreci iki aşamaya ayrılacaktır; bunlardan ilki, üç farklı hız ile temsil edilen dışarıdan giren havanın soğutulması sürecindeki yumuşaklığı görmek için üç bölüme ayrılmış olan enjektörlerin varlığı ile temsil edilmektedir. Isı eşanjöründeki kondenserden gelen bir tüp ile temsil edilen ikinci bölümün dönüş sayısı, soğutma gazının alınmasındaki iyileşmeyi görmek için değiştirilecektir. Böylece, kullanılan toplam örnek sayısı iki bölüme eklenen 27 örnektir ve 54 örneği temsil eder, ardından COP'deki iyileşme değerini belirlemek için bu örnekler EES yazılımı ile uygulanır. Soğutma tüplerindeki büküm sayısı ve nozul sayısı, sistem verimliliğini nasıl etkilediklerini araştırmak için bilinçli olarak ayarlanmıştır. Sistemin yapısı, uzunluğu ve dönüş sayısı değiştirilebilen bobin ve tüp tipi bir ısı eşanjöründen oluşmaktadır. Simülasyon sürecinin ikinci kısmı, hava giriş alanı ve değişken sayıda nozul ile su püskürtme işlemi ile temsil edilmektedir; burada soğutma tüpünün 5, 9 ve 13 dönüşü kullanılmıştır ve bu, akışkanlar arasındaki ısı değişim süreci üzerindeki termal etkiyi bilmek için simülasyon sürecinin ikinci kısmını temsil ederken, birinci kısım hava giriş alanı ve değişken sayıda nozul ile su püskürtme işlemi ile temsil edilmektedir; burada 15, 24 ve 35 nozul kullanılmıştır. Kanalın ölçüleri 20 cm genişlik, 10 cm yükseklik ve 25 cm toplam uzunluktur. Kanal genişliğinde rulo çapı 60 mm idi.

Sonuçlar, sistem geometrisinin, özellikle hava giriş bölgesi ve su püskürtme prosedürünün, bir ısı eşanjörü içindeki termal dinamikler ve akışkan akışı üzerinde önemli bir etkiye sahip olduğunu ortaya koymaktadır. Bobin dönüşlerinin ve nozulların sayısı, farklı sıcaklık ve hız eğrilerinde gösterildiği gibi sistem performansı üzerinde önemli bir etkiye sahip olabilir. Ayrıca, karmaşık geometrik konfigürasyonları ele almak ve önemli bilgiler sunmak için çalışmada ANSYS'nin güçlü simülasyon yeteneklerinden tam olarak yararlanılmıştır. Giriş hızı 2,0 olan 35 enjektörlü ve 13 bobin dönüşlü tasarım, 4,537'lik maksimum COP değerine ulaşarak söz konusu sistem için en iyi konfigürasyon olduğunu göstermiştir. Maksimum 55,27 santigrat derece sıcaklığa ulaşır. Sıcaklık grafiğindeki bobin dönüşleri 1 m/s hızda zirveye ulaşırken, COP grafiği aynı hızda en düşük değerlere sahiptir. Ayrıca, sistem için en yüksek COP değeri 4,537 olup 35 enjektör ve 13 bobin dönüşünde gerçekleşmektedir. Çalışmanın bulguları, bu tür sistemlerin daha da iyileştirilmesinin önünü açabilir ve belki de verimliliklerini artırabilir. Çalışma, ısı gibi karmaşık termal sistemlerin anlaşılmasında ve iyileştirilmesinde hesaplama araçlarının önemini vurgulamaktadır.

Anahtar Kelimeler : Bobin ve borulu ısı eşanjörü, performans katsayısı, iklimlendirme sistemleri, doğrudan evaporatif soğutma.

Bilim Codu : 91431

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SYMBOLS AND ABBREVITIONS

SYMBOLS

$\sum\dot{m}_{in}$: The total mass flow entering per unit time
$\sum\dot{m}_{out}$:The total mass flow exiting per unit time
$\dot{Q}$: The heat transfer per unit time
$\dot{W}$: Work done by the control volume per unit time
h_{in} : Specific enthalpy per the mass entering the system
h_{out} : Specific enthalpy per mass leaving the system
$\bar{\tau}$: The stress tenser
μ : The viscosity
μ_t : The eddy viscosity
E : Energy
$\dot{E}$: Entropy
$\dot{m}$: Mass flow
ψ : Exergy
V : Volume
$\dot{V}$: Volume flow rate
$\vec{V}$: Velocity
$\vec{V}^T$: Inlet velocity
ρ : Density
p : Pressure
I : Length
k : Thermal conductivity
k : The turbulent kinetic energy
ε : Turbulent dissipation
C : Constant
T : Temperature
T' : Inlet temperature

ABBREVITIONS

DEC : Direct evaporative cooling
EES : Engineering Equation Solver
CFD : Computational Fluid Dynamics
COP : Coefficient of performance

PART 1

INTRODUCTION

1.1. GENERAL

Particularly in areas with extremely hot climates, air conditioning has become an essential part of our daily lives. Air conditioning units are increasingly in demand in these areas and are now seen more as a necessity than a luxury. However, conventional air conditioning systems use a lot of energy, which not only has an impact on the environment but also drives up consumer electricity bills [1]. To get around these issues, researchers are looking into alternative air conditioning systems that are more environmentally friendly and energy-efficient. One of these options is direct evaporative cooling (DEC), which uses water evaporation to cool the air. Since they are known to be more economical and energy-efficient than conventional air conditioning systems, DEC systems have grown in popularity recently [2]–[4].

This topic primarily focuses on how DEC systems can be used to numerically improve air conditioning systems in extremely hot weather. The various benefits and drawbacks of DEC systems, the numerical models used to assess their performance, and how these models can be used to optimize DEC systems for various applications will all be covered in this discussion.

1.2. THE CHALLENGES OF TRADITIONAL AIR CONDITIONING SYSTEMS IN SEVERELY HOT WEATHER

In regions with very hot climates, traditional air conditioning systems have a number of challenges. The major problem is the substantial energy consumption needed to chill the air. This increased energy demand results in higher carbon emissions, which contribute to climate change and global warming [5]. Additionally, standard air conditioners are not designed to work well in hot and muggy conditions, which can result in a decrease in cooling capability and an increase in energy consumption [6], [7].

Additionally, refrigerants that are harmful to the environment are routinely used in traditional air conditioners. These refrigerants, like hydrofluorocarbons (HFCs), contribute to ozone depletion and global warming. As a response to these issues, researchers are researching towards more sustainable and ecologically friendly refrigerants [8], [9].

Another problem with traditional air conditioning systems is the cost of installation and maintenance. These systems need intricate pipes, ducts, and compressors, all of which can be costly to build and operate. Additionally, because they depend on electricity, conventional air conditioners are susceptible to power outages, which can be a problem in hot weather [5].

The need for alternative air conditioning systems that are more economical, economical, and environmentally friendly is highlighted by these difficulties [10, 11]. We will go over direct evaporative cooling systems in detail in the following sections as a potential answer to these problems. Lundgren-Kownacki [12] explained the Challenges of using air conditioning in hot climate as shown in figure (1-1).

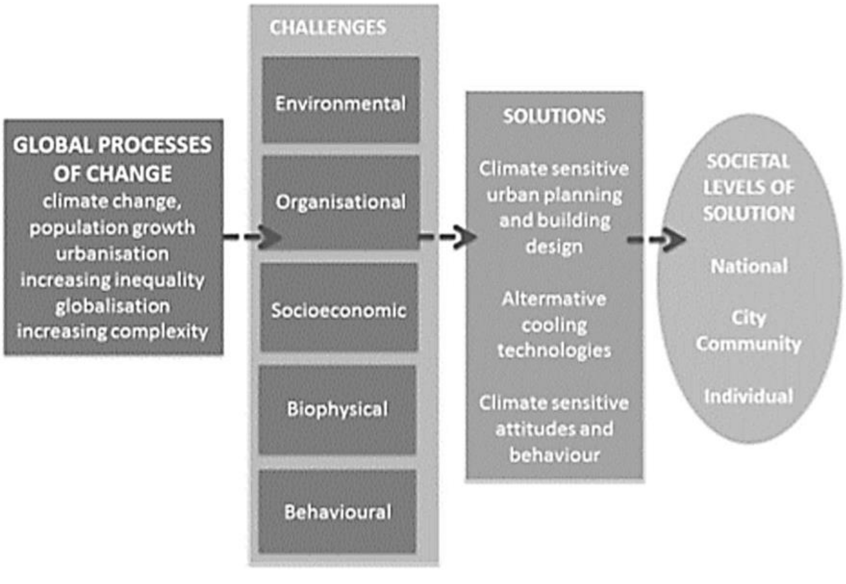


Figure 1.1. The relation between global processes of change, challenges related to AC [12].

1.3. THE ADVANTAGES AND LIMITATIONS OF DIRECT EVAPORATIVE COOLING SYSTEMS

Direct evaporative cooling (DEC) systems use water evaporation to cool the air. These devices function by forcing heated air through a damp pad or filter, which cools the air as the water evaporation takes place. DEC systems are known to be more energy-efficient and cost-effective than traditional air conditioning systems, and they have several advantages and limitations as shown in table (1-1). DEC systems offer several advantages over traditional air conditioning systems, including energy efficiency, sustainability, and improved indoor air quality [13], [14]. However, these systems also have some limitations that must be considered when designing and implementing them. By optimizing the design and operation of DEC systems, it may be possible to improve air conditioning systems numerically in severely hot weather [15].

Table 1.1. The advantages and limitations of direct evaporative cooling systems.

Advantages	Limitations
1. Energy-efficient: DEC systems use less energy than traditional air conditioning systems since they do not rely on compressors or refrigerants. This leads to lower energy bills and reduced carbon emissions. 2. Sustainable: DEC systems use water as a cooling agent, which is a sustainable and renewable resource. This makes DEC systems an environmentally friendly alternative to traditional air conditioning systems. 3. Healthier indoor air quality: DEC systems add moisture to the air, which can improve indoor air quality by reducing the risk of dry eyes, skin, and throat. 4. Cost-effective: DEC systems are generally less expensive to install and maintain than traditional air conditioning systems since they require less complex infrastructure.	1. Limited effectiveness in humid climates: DEC systems work best in dry climates, where the air is not already saturated with moisture. In humid climates, DEC systems can be less effective since the air is already saturated with moisture, reducing the rate of evaporation. 2. Limited cooling capacity: DEC systems have a limited cooling capacity and may not be able to provide sufficient cooling in extremely hot weather conditions. 3. DEC systems need routine maintenance to make sure that the moistened pads or filters are clean and operating properly. Failure to maintain these parts may result in decreased efficiency and higher energy usage. 4. Water usage: DEC systems need a steady supply of water, which can be a problem in areas with a lack of water.

1.4. THE NUMERICAL MODELS USED TO ANALYZE DEC SYSTEM PERFORMANCE

Water evaporation is used in direct evaporative cooling (DEC) systems to cool the air. These machines work by pumping warm air through a damp pad or filter, which causes the water to evaporate and cool the air. DEC systems are renowned for using less energy.

One such numerical model is the psychrometric model, which represents the thermodynamic properties of air and water vapor. This model can predict the cooling capacity and energy consumption of DEC systems across a range of operational and environmental conditions, including as air temperature, humidity, and airflow rate. Lai et al. [16] explanation's of this model is shown in figure (1-2).

The heat and mass transfer model is another numerical representation that explains how heat and mass are transferred from the air to the moistened pads or filters in DEC systems. The effectiveness of the cooling process can be predicted using this model, which can also be used to identify areas where the system design needs to be improved. Wu et al. [17] used this method in there study.

Computational fluid dynamics (CFD) models are also commonly used to analyze DEC system performance. These simulations help designers optimize the ductwork and fan designs for greater efficiency. They also replicate the airflow patterns and heat transfer in the system. Kapilan et al [18] used ANSYS CFD in their study to modeling the direct evaporative cooling.

Numerical models are powerful tools for analyzing the performance of DEC systems and optimizing their design and operation for improved energy efficiency and cooling capacity. In the next sections, we'll look at how these models might be used to numerically improve air conditioning systems in extremely hot climates.

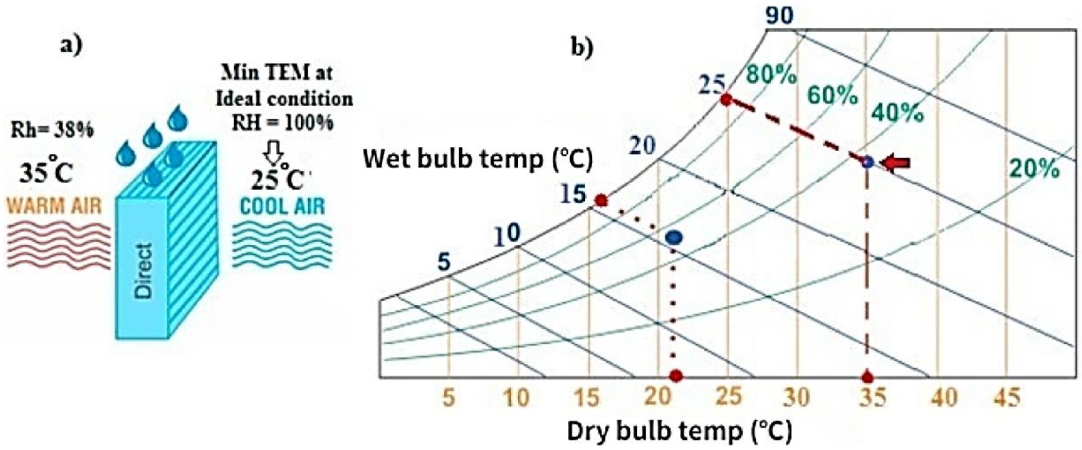


Figure 1.2. System diagram of direct evaporative cooling.

1.5. HOW NUMERICAL MODELS CAN BE USED TO OPTIMIZE DEC SYSTEMS FOR DIFFERENT APPLICATIONS

When it's really hot outside, direct evaporative cooling (DEC) systems can function better thanks to numerical modeling. Designers and engineers can optimize the system design and operation for improved energy efficiency and cooling capacity by using numerical models to simulate the behavior of DEC systems under various operating conditions [19].

To optimize the design of the moistened pads or filters in DEC systems, one method is to use numerical models. The best thickness, porosity, and material qualities for increased cooling efficiency can be found by analyzing the heat and mass transfer between the air and the pads or filters. For instance, a study published in the Journal of Energy and Buildings discovered that increasing the pad thickness considerably enhanced the cooling performance of a DEC system [20].

Another strategy is to improve the airflow patterns in DEC systems using numerical models. Computational fluid dynamics (CFD) models can be used to analyze the airflow and heat transfer in the system and identify potential areas for ducting and fan design advancement. For instance, a study that appeared in the International Journal of Energy Research discovered that a DEC system's cooling capacity significantly increased by optimizing the ductwork and fan design [21].

Numerical models can also be used to forecast how DEC systems will perform under various operating parameters and weather scenarios. This can assist engineers and designers in maximizing the cooling capacity and system efficiency during design and operation. For instance, a study that used numerical models to analyze a DEC system's performance in a hot, humid climate identified the best operating conditions for increased cooling effectiveness.

Overall, numerical modeling shows great promise to improve the performance of DEC systems under extremely hot conditions. In areas with extremely hot climates, it might be possible to reduce energy consumption, lower carbon emissions, and improve indoor comfort by optimizing the design and use of these systems using numerical models.

1.6. THE POTENTIAL FOR DEC SYSTEMS TO IMPROVE AIR CONDITIONING SYSTEMS NUMERICALLY IN SEVERELY HOT WEATHER

Direct evaporative cooling (DEC) systems offer a number of benefits over traditional air conditioning systems in extremely hot conditions. These benefits consist of:

1. Energy efficiency: Because DEC systems rely on evaporating water for cooling instead of mechanical refrigeration, they use significantly less energy than conventional air conditioning systems. According to the US Department of Energy, DEC systems can consume up to 50% less energy than standard air conditioning systems [22].
2. Lower carbon emissions: DEC systems produce fewer carbon emissions because they use less energy than conventional air conditioning systems. Due to this, DEC systems are a more eco-friendly choice for cooling buildings in extremely hot weather.
3. The use of fresh outdoor air by DEC systems to cool buildings can enhance indoor air quality by lowering the concentration of allergens and pollutants. On the other hand, conventional air conditioning systems circulate indoor air, which may cause allergies and toxins to build up [23].

4. Cost-effectiveness: Because DEC systems are usually less expensive to construct and maintain than traditional air conditioning systems, they are a cost-effective solution for cooling buildings in exceptionally hot weather [23].
5. Flexibility: Buildings utilized for commercial, industrial, and residential purposes can all use DEC systems. To boost cooling capacity, they can also be utilized in conjunction with other cooling systems such evaporative coolers or mechanical refrigeration [22].

In extremely hot situations, DEC systems have a variety of benefits over conventional air conditioning systems. Utilizing these systems might result in savings on cooling costs, indoor air quality, carbon emissions, and energy utilization.

1.7. THE IMPORTANCE OF SUSTAINABLE AIR CONDITIONING SYSTEMS IN THE CONTEXT OF GLOBAL WARMING AND CLIMATE CHANGE

In extremely hot weather, direct evaporative cooling (DEC) systems have a number of advantages over conventional air conditioning systems, but they also face a number of difficulties that must be overcome. These challenges include:

1. High relative humidity: In areas with high relative humidity, DEC systems might not work as well to cool buildings because the air is already moist, which limits the possibility of evaporative cooling. To address this issue and maintain indoor comfort, designers might need to include more mechanical refrigeration or dehumidification systems [24].
2. Water quality: DEC systems require a consistent flow of clean water to function properly. In areas with poor water quality, such as those with high concentrations of dissolved solids or pollutants, the efficacy of DEC systems may be compromised. Water treatment systems might need to be added to address this issue and guarantee that the water used in DEC systems is of a high enough standard.
3. Maintenance: To ensure the efficient operation of DEC systems, regular maintenance is required. Over time, the moistened pads or filters in these

systems may gather dust, dirt, or other debris, reducing their cooling capacity. To maintain optimal system performance, these components must be cleaned and replaced on a regular basis [23].

4. Design of the system: DEC systems need to be planned and sized for the particular building and climatic conditions in which they will be used. Undersized or poorly designed systems may not have enough cooling capacity, resulting in discomfort and higher energy costs.

1.8. OBJECTIVE OF THE PRESENT WORK

In order to enhance the performance of air conditioning systems in extremely hot weather, the current work explores the use of direct evaporative cooling (DEC). DEC systems must be designed and sized appropriately for the specific building and climatic conditions in which they will be used. The ultimate objective is to create cost-efficient and environmentally friendly cooling solutions for areas with extremely hot climates while lowering energy consumption. The following points can serve as a summary of the study's goals:

1. To investigate the feasibility of using direct evaporative cooling (DEC) to improve air conditioning systems in severely hot weather conditions.
2. To create numerical models for analyzing DEC systems' performance under various circumstances and to optimize their design parameters for particular applications.
3. To compare the performance of DEC systems with traditional air conditioning systems, and to evaluate their potential for reducing energy consumption and environmental impact.
4. To make recommendations for the design, installation, and operation of DEC systems in real-world applications based on the results of numerical simulations and experimental data.

PART 2

LITERATURE REVIEWS

2.1. INTRODUCTION

In regions with extremely hot weather, demand for air conditioning systems has steadily increased in recent years. It is well known that conventional air conditioning systems consume a lot of energy, which raises power costs and harms the environment. Researchers have been seeking for more environmentally friendly and energy-efficient alternatives to traditional air conditioning systems in response to these problems. One such alternative that has gained popularity is direct evaporative cooling (DEC), as it is both cost- and energy-efficient. This literature study will primarily focus on examining the use of DEC in numerically enhancing air conditioning systems in extremely hot weather situations, including its advantages and disadvantages, numerical modeling methodologies, and optimization methods for different applications. The study will compare the performance of DEC systems to that of traditional air conditioning systems and offer recommendations for the design and operation of DEC systems.

2.2. DIRECT EVAPORATIVE COOLING (DEC)

Dizaji et al. [24] used the Maisotsenko cycle to HVAC systems (M-cycle). The researchers' new technique for chilling air has a lot of potential. This method makes it feasible to lower the temperature of the air circulation to the dew point, which was previously impractical. The researchers employed a range of techniques, such as experimental procedures, statistical design methods, and analytical solutions, to assess the M-cycle properties of this method. The study organized and compared these methods and provided an evolutionary viewpoint for analytical solutions of M-cycle. The M-cycle parameters were systematically analyzed as shown in figure (2-1), and A thorough overview of the outcomes was provided. The report provided an overview of the M-cycle market's present situation and suggested areas for further investigation.

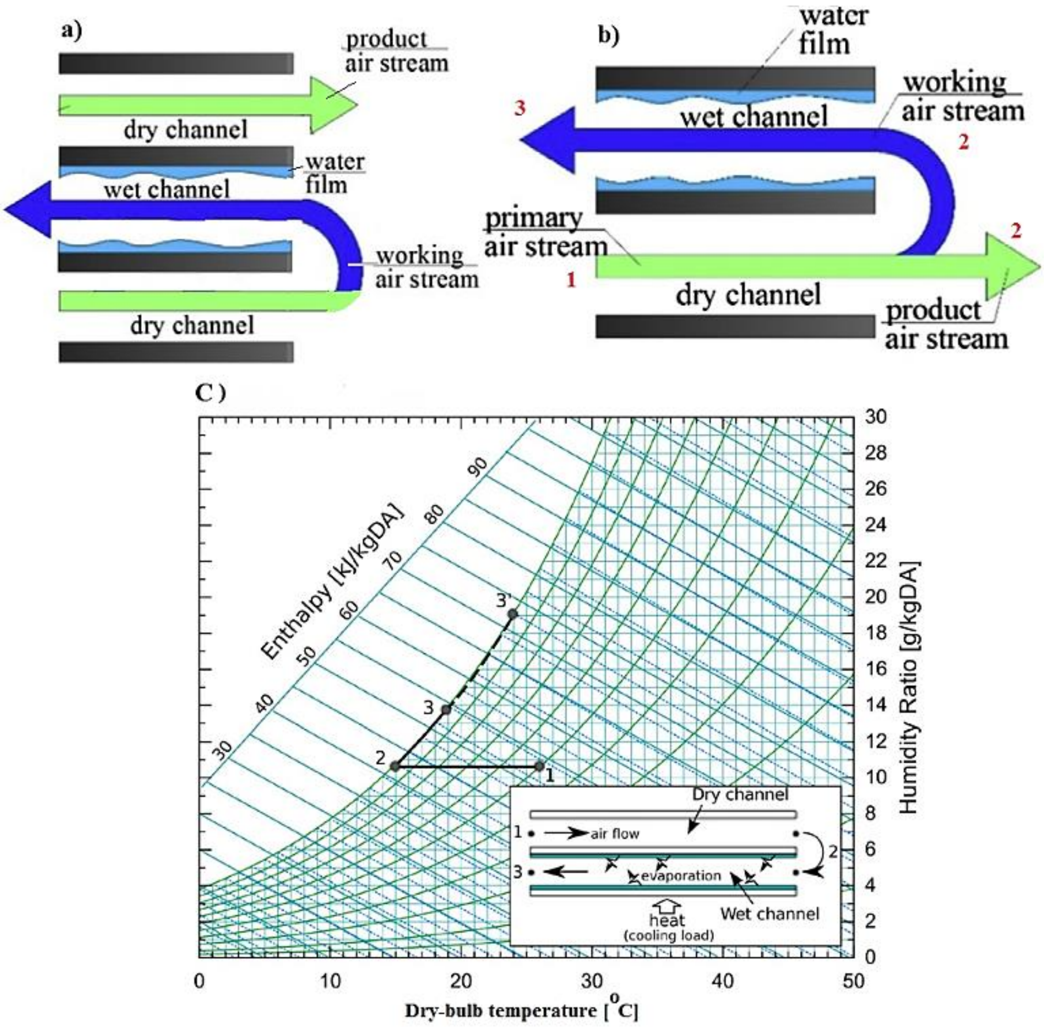


Figure 2.1. M-cycle two main counter flow indirect evaporation method [25].

Heidarinejad et al. [26] studied the cooling efficiency of a two-stage indirect/direct direct evaporative system in a variety of simulated climatic settings. As seen in figure (2-2), the system comprises of an indirect evaporative cooling step followed by a direct evaporative cooling process (2-2). The effectiveness of the system was tested under different outdoor conditions using two air simulators. The findings indicate that the new system is capable of providing comfortable conditions in a large area of Iran, when direct evaporative cooling by itself is insufficient to keep you cool in the heat. The system was able to save more than 60% of power consumption compared to mechanical vapor compression systems, with only a 55% increase in water usage compared to direct evaporative cooling systems. As an energy-efficient and environmentally-friendly alternative, This technology can function as a bridge between direct evaporative cooling and mechanical compression of vapor.

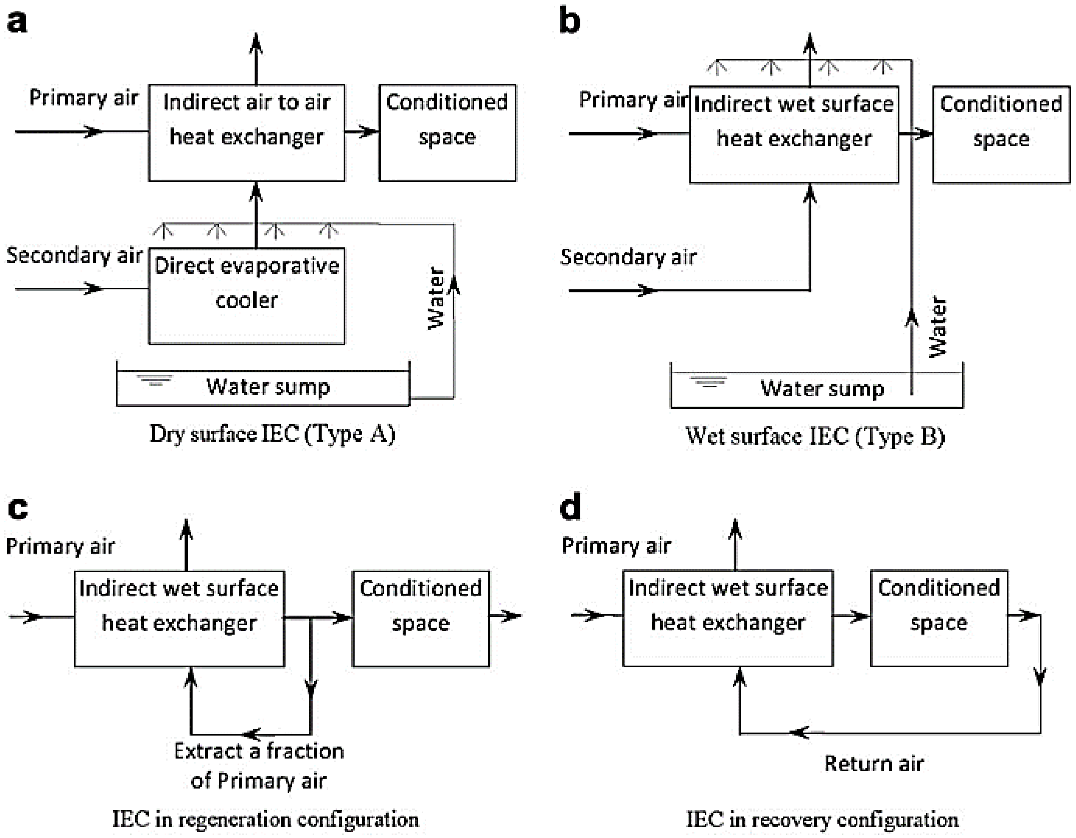


Figure 2.2. Schematic diagram of various IEC configurations [26].

Al-Badri et al. [27] investigated the efficacy of mixing direct evaporative air cooling (DEC) with chilled water to increase DEC performance in humid conditions. To analyze DEC's efficiency, they developed a prediction model based on heat and mass balance between air and water, and the experimental setup is shown in Figure (2-3). Their research found that the mass flow rate ratio was the most important component in DEC's performance, and that by chilling the water and lowering the mass flow rate ratio, DEC's performance could be significantly enhanced even in high-humidity environments. These findings point to the possible application of DEC in areas with extremely humid weather.

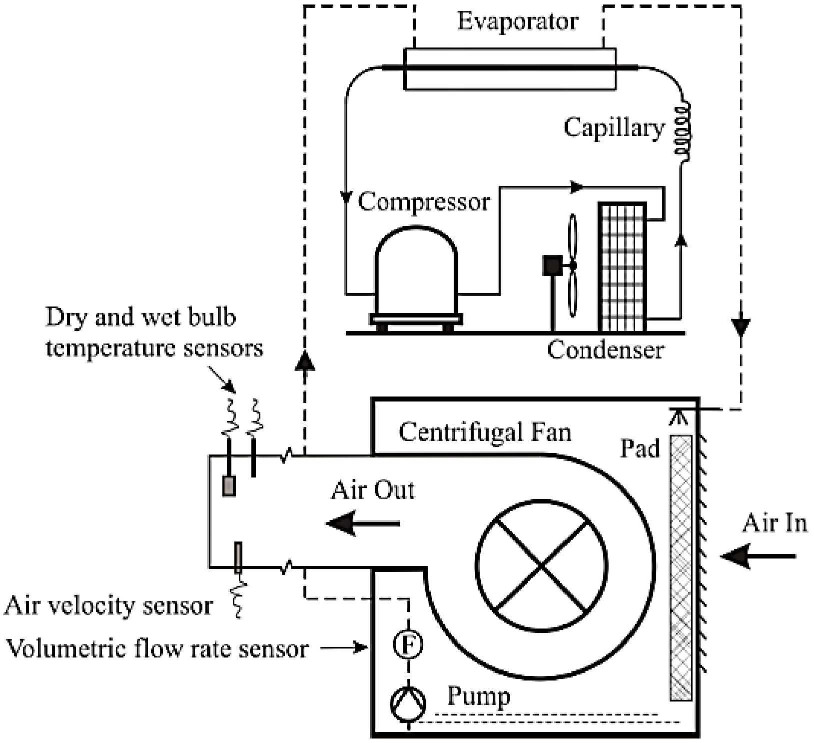


Figure 2.3. Experimental setup [27].

Camarg et al. [28] highlighted the advantages of using evaporative cooling systems as a cost-effective alternative to conventional mechanical vapor compression systems for air conditioning. Evaporative cooling employs water and air as working fluids, causing mass and heat transfer processes that result in the water evaporation and a subsequent reduction in air temperature. Figure (2-4) explained the DEC system used in their study. The paper outlines the principles of direct evaporative cooling systems and the mathematical equations used to determine their effectiveness. The results of experimental tests conducted on a direct evaporative cooler are presented to determine convective heat transfer coefficient and compare them to the mathematical model. Overall, the paper highlights the potential of evaporative cooling systems as a cost-effective alternative for air conditioning.

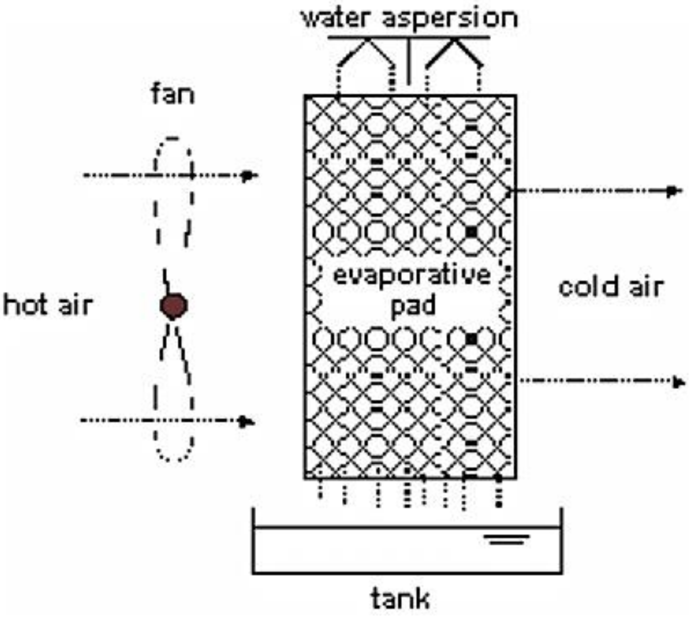


Figure 2.4. Direct evaporation cooler [28].

Dhamneya et al. [29] investigated the thermodynamic performance of direct evaporative cooling systems using different configurations of cooling media, specifically Aspen fibers. The researchers analyzed the effect of inlet air temperature, humidity, and mass flow rate on the performance characteristics of the system as explained in figure (2-5). The study's findings indicate that the saturation efficiency of all the developed top flow and ordinary lateral flow configurations is comparable, except for the triangle top flow configuration, which exhibited the highest saturation efficiency of 97% for Case-I. The triangular configuration of an evaporative cooling system had a maximum saturation efficiency of 97%, 88%, zero, and 89% for Case-I, Case-II, Case-III, and Case-IV, respectively, outperforming ordinary and other top flow DEC systems.

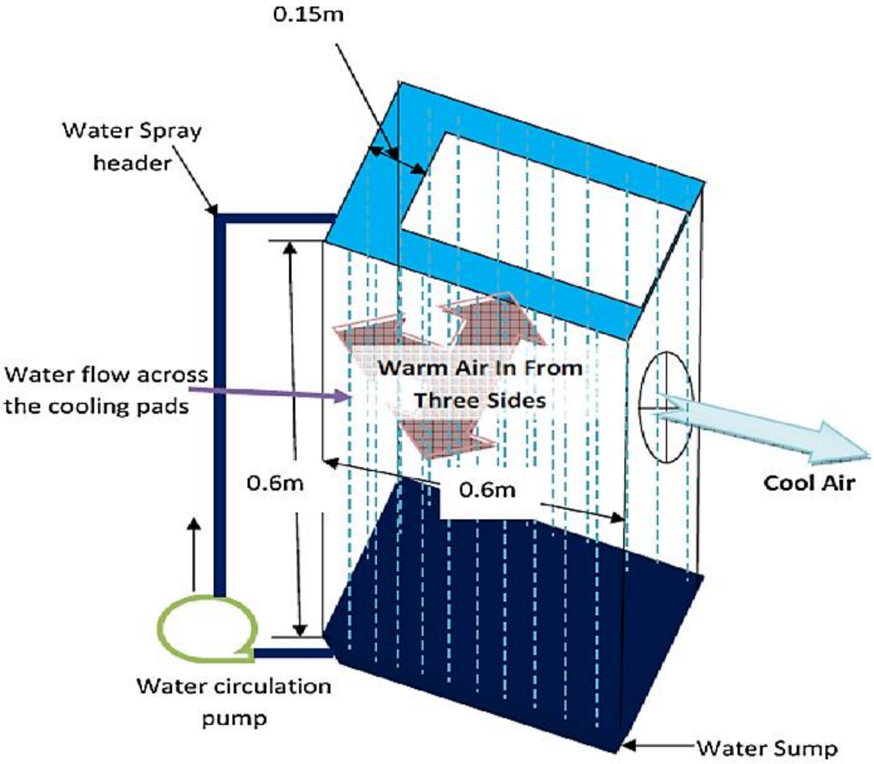


Figure 2.5. Ordinary cooling media [29].

Zhao et al. [30] investigated the application of direct evaporative cooling (DEC) in a battery thermal management system to cool lithium-ion (Li-ion) batteries (BTMS). The research looks at the impact of relative humidity and airflow rate on the effectiveness of the DEC system and compares the results to standard air cooling and natural convection cooling. Tests are conducted on both individual batteries and a 9-cell battery pack, as seen in figure (2-6). The results reveal that the DEC system efficiently reduces the maximum temperature and temperature differential inside the battery pack, potentially allowing for greater utilization of Li-ion batteries under difficult working situations. A DEC tunnel is also built to boost cooling performance even further.

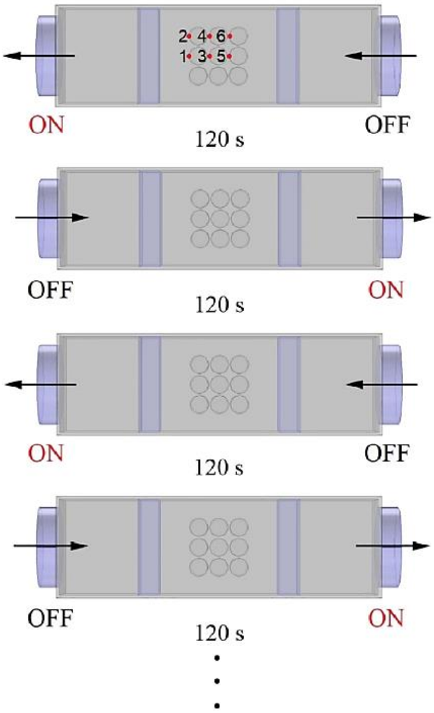


Figure 2.6. Schematic diagram of the reciprocating airflow [30].

Chiesa et al. [31] investigated the viability of adopting passive direct evaporative cooling (DEC) to increase interior thermal comfort in the Mediterranean region. The study used three distinct approaches to evaluate the feasibility of DEC in different sites, taking into consideration characteristics such regulated natural ventilation, internal heat gains, and thermal insulation. Thermal simulations for a prototype office building were performed in 60 towns reflecting various Mediterranean climatic zones. They evaluated several building designs in order to investigate the impact of design characteristics on the possibility for effective space cooling. The data show that DEC has a large potential for low-energy cooling, notably in the Eastern Mediterranean and southern Spain, and that its performance is heavily controlled by critical parameters that influence cooling demand. The study also suggests novel ways for analyzing the geo-climatic feasibility of DEC on an hourly basis, proving their practicability and giving assessment tools for designers who consider DEC technologies early in the design process.

Tewari et al. [32] studied the thermal comfort of office buildings in the Indian composite climate during the summer season by employing Direct Evaporative Cooling (DEC) systems. The researchers used the data of thermal monitoring of office buildings in Jaipur during peak summer months from April to July 2016 to calibrate thermal simulation models produced with EnergyPlus. They also used Taguchi design to create an L16 orthogonal array of control factors and their corresponding levels for simulation runs. According to the CCATCZ and ASHRAE Standard 55-2013 thermal comfort zones, respectively, the results revealed that DEC might prevent around 42% and 52% of thermal discomfort hours throughout the summer season. A good agreement (R2 > 0.90) between onsite measurements and computed values of indoor temperature was discovered when two additional buildings were used for field validation. This finding suggests the potential usefulness of this methodology for forecasting and enhancing the thermal performance of office buildings using DEC systems in the Indian composite climate.

AL-Juwayhel et al. [33] studied during Kuwait's scorching summer, the thermal performance of four different types of evaporative air conditioning systems was assessed. The systems under investigation included a one-stage direct evaporative cooler (DEC), a one-stage indirect evaporative cooler (IEC) connected to an external cooling tower, two-stage indirect/direct evaporative coolers (IEC/DEC), and a three-stage evaporative cooling and mechanical vapor compression (IEC/DEC-MVC) system. Thermal effectiveness and energy efficiency ratio (EER), two measures, were utilized to assess the systems. IEC/DEC had the greatest EER, followed by DEC, IEC/DEC-MVC, and IEC, according to the results. The efficacy of DEC was the lowest, followed by DEC/IEC, IEC, and IEC/DEC-MVC. The study also created two correlations for each system, one for EER and the other for the efficacy and the water to air mass flow ratio (L/G or Re). These correlations can help with evaporative cooling unit design and optimization.

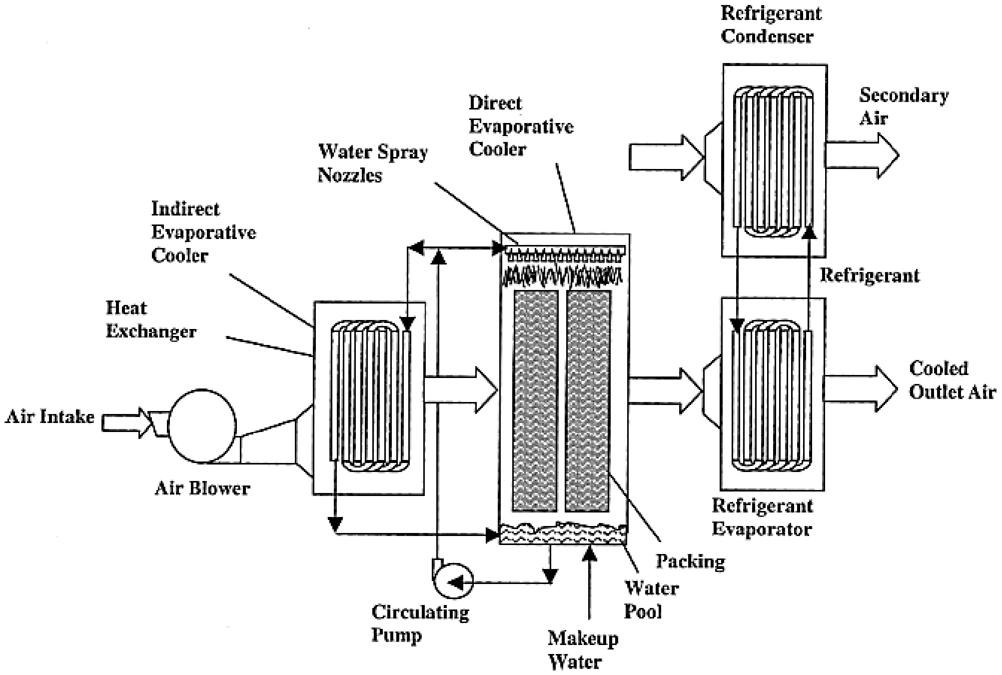
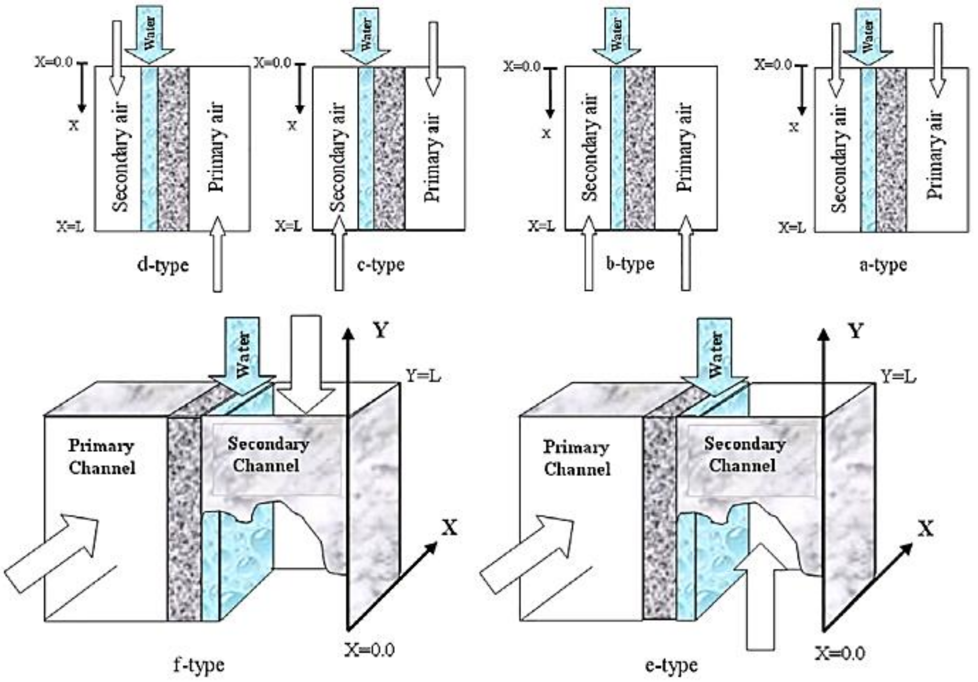


Figure 2.7. Indirect/ direct evaporative cooler [33].

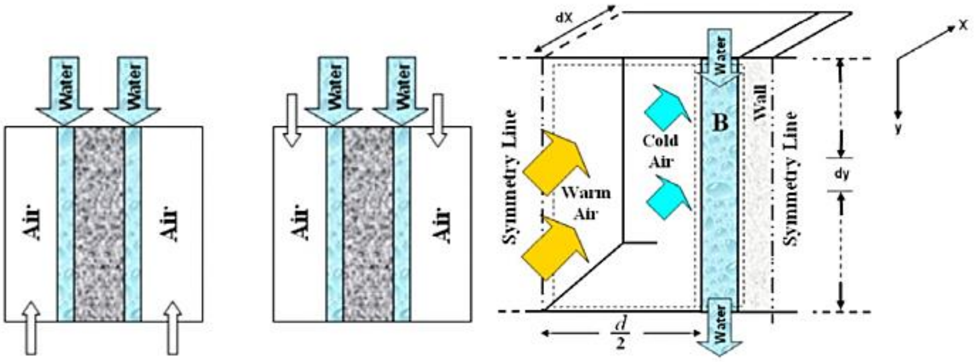
Chiesa et al. [34] examined the potential of direct evaporative cooling (DEC) in reducing discomfort hours in Southern Europe and the Mediterranean. The research analyzes 20 urban locations across the area and calculates cooling degree hours and virtual climatic discomfort hours. The study uses a sample building and simulates both a baseline (free running) and a DEC case for every location. Night ventilation is also simulated for comparison. The chosen DEC model is the direct CelDekPad, which is compatible with EnergyPlus. The study conducts a psychrometric analysis and identifies comfort boundaries to help designers consider DEC and night ventilation in the early design phases.

Xuan et al. [35] studied extensive overview of the evaporative cooling research and use in China. Despite the positive outcomes, few people are aware of them because the majority of publications are in Mandarin. The study describes the thermodynamic properties and operating theories of many forms of evaporative cooling, including direct, indirect, and semi-indirect. It then reviews the experimental and theoretical research on feasibility studies, performance testing, optimization, and mass and heat transfer analysis. The practicality of evaporative cooling in various climates, the effectiveness of different evaporative cooling equipment, and important factors and approaches for increasing efficiencies are also covered in the article. In Part II, the study discusses the typical evaporative cooling equipment and systems utilized in China.

Shirmohammadi et al. [36] conducted a study on optimizing evaporative cooling systems using a finite difference method. The efficacy of the system was investigated in relation to plate spacing, airflow velocity, and wettability factor. The findings showed that using narrow channel width, lowering the relative humidity of the air in the secondary channel, using materials with high wettability factors on the surface, and raising the airflow velocity ratio between the secondary and primary channels can all increase the effectiveness of evaporative cooling systems. The study proposed nine cooling systems, and the co-current DEC and the cross-flow indirect evaporative cooler with f-type had the highest efficiency at 73% and 40%, respectively. The paper suggests combining these two systems to create an indirect/direct evaporative cooling system that can be used for various climates in Iran. The study's findings can be applied globally to identify appropriate evaporative cooling systems for different climates.



Schematic of indirect evaporative cooler.



Schematic of direct evaporative coolers.

Figure 2.8. Evaporative cooling systems [36].

Camargo et al. [37] presented the basic principles of the evaporative cooling process for human thermal comfort, Figure (2-9) explained the DEC used in their study. The results showed good agreement between the experimental and theoretical models, with an average deviation of 8%. The study also found that the efficiency of the direct evaporative cooling system is affected by factors such as the air velocity and the water flow rate. A higher air velocity and water flow rate result in higher cooling efficiency. The study concluded that the DEC system can be a cost-effective and energy-efficient solution for thermal comfort in dry and hot weathers. However, the system may not be suitable for hot and humid climates where the effectiveness of the cooling process is reduced due to the high humidity levels.

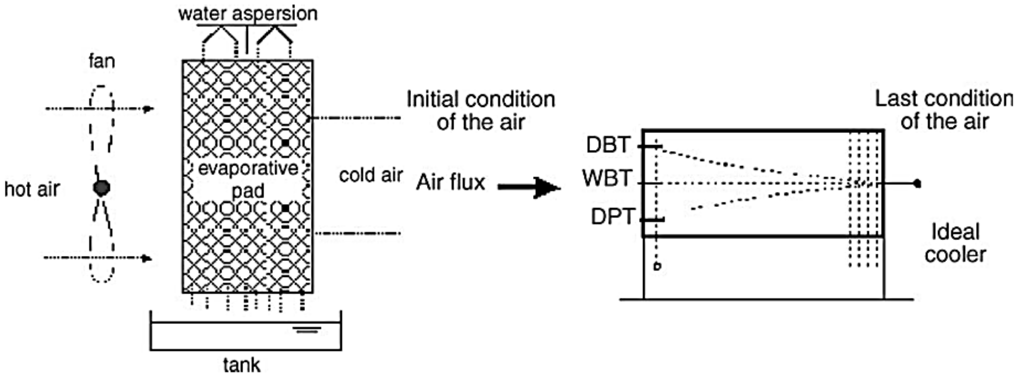


Figure 2.9. Direct evaporative cooling system used by [37].

Eidan et al. [38] used direct evaporative cooling to improve the efficiency of a small air conditioning system. Using an evaporative cooling cycle, where the air passes over wet pads before going through the condenser, the cooling system was set up to replicate extremely hot weather conditions with a dry bulb temperature of up to 55 °C (2-10). The study looked at four factors: compressor auto-shutdown in hot weather, cooling capability, compressor coefficient of performance (COP), and energy savings. The outcomes demonstrated a considerable increase in the air conditioning system's overall performance. With each degree of temperature drop, the refrigeration capacity rose by 5% to 7.5%, and the electrical current was reduced by 0.12A to 0.16A. Furthermore, even with a 16% voltage decrease, the compressor might still function, potentially solving the issue of summertime electricity dips in places like Iraq.

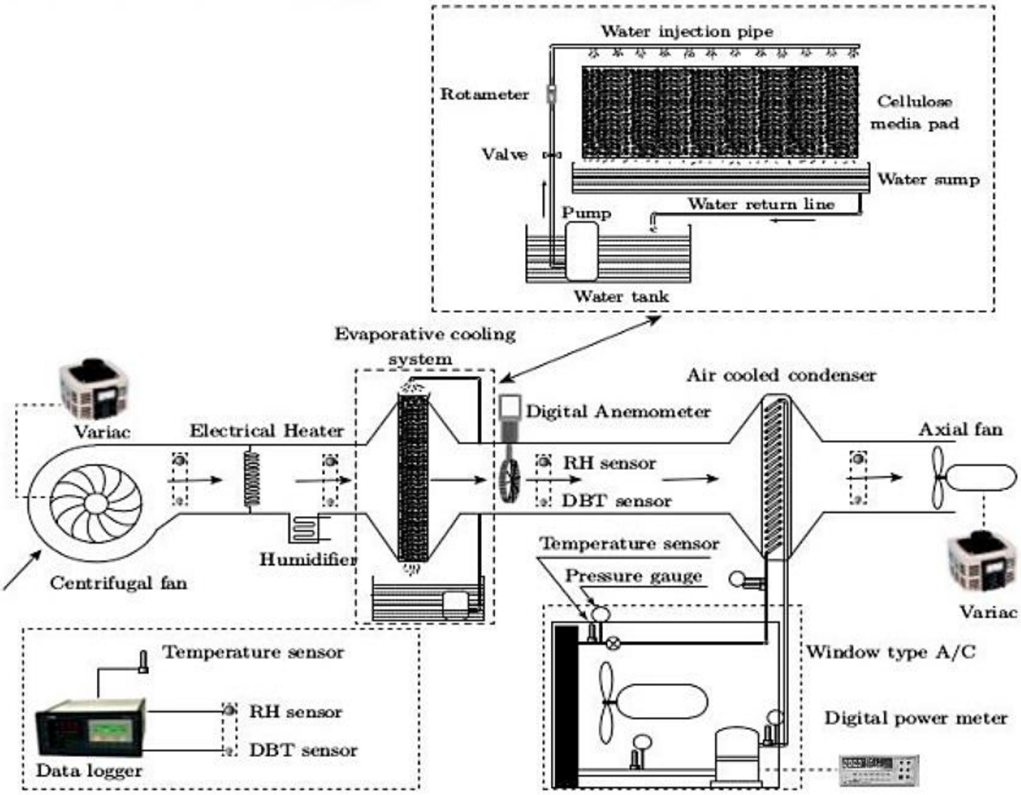


Figure 2.10. Experimental rig of Eidan et al. [38].

Salins et al. [39] were interested in how Celdek packing performed in evaporative cooling under different operating circumstances. As shown in figure, they employed mathematical modeling to forecast the outlet humidity ratio, Dry bulb temperature (DBT), cooling efficiency, and cooling impact by adjusting air velocities, intake DBT, inlet relative humidity, and pad thickness for three different wettability levels of Celdek packing (2-11). According to the research findings, increasing pad thickness and material wettability enhanced cooling effect, saturation efficiency, DBT, and humidity ratio. Increases in input airflow rate and RH, on the other hand, resulted in decreases in DBT, humidity ratio, and cooling efficiency. Celdek 7090 with a thickness of 0.3 m and wettability of 630 m2/m3 provided the optimum performance, with a maximum DBT of 6°C, RH of 55%, saturation efficiency of 90%, and cooling impact of 7000 Watts.

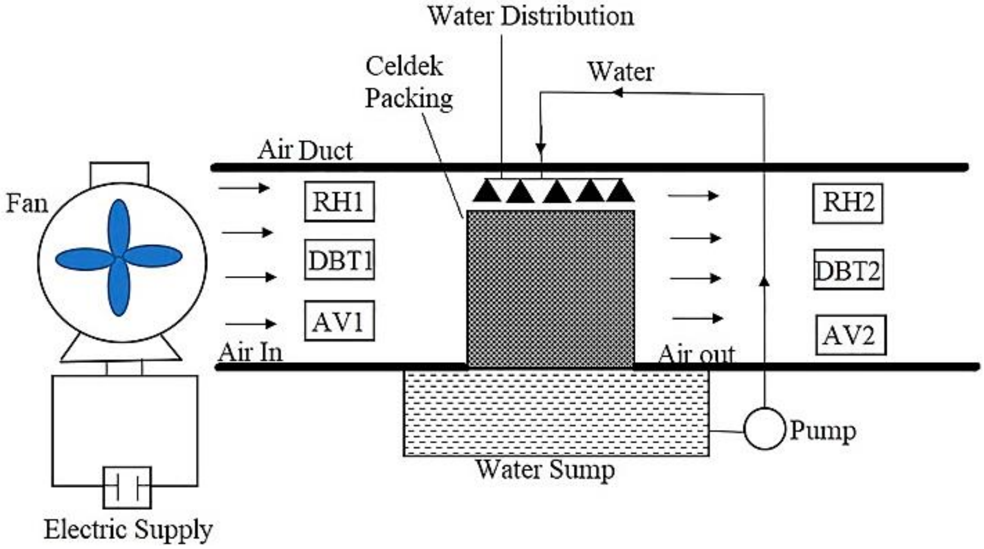


Figure 2.3. Evaporative cooling system used by Salins et al. [39].

Mousavi et al. [40] conducted research to evaluate the feasibility of using an evaporative cooling system in a Sustainable Farming Compartment (SFC) as a substitute for wastewater reuse in the United Arab Emirates (UAE), where water is scarce and costly. The SFC was tested in a laboratory and in the field in harsh weather conditions, and the temperature decrease and humidity change were measured. Figure (2-12) show the experimental prototype used in their study. The results obtained from the experiment indicated that the SFC has the ability to reduce the temperature significantly by 7-16°C, provided the initial relative humidity is 51%. The modeling energy, which involved numerical solution, was able to validate the experimental results. The optimal cooling performance of the system was evaluated through parametric studies of system components, and an optimized design for the SFC with an evaporative cooling system was suggested. The study aims to promote sustainable farming practices in the UAE by providing an alternative to expensive and energy-concentrated water sources.

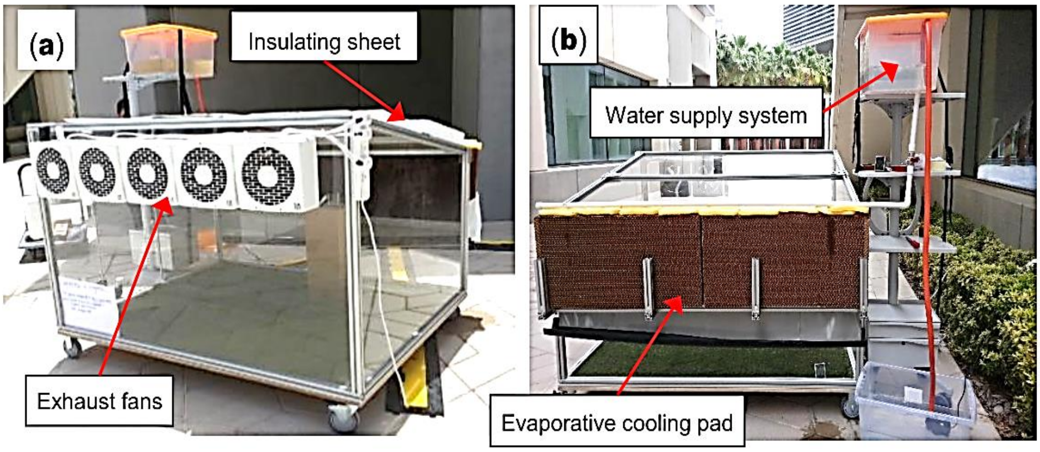


Figure 2.4. Evaporative cooling system used by Mousavi et al. [40].

Moshari et al. [41] conducted numerical simulations to examine the performance of different evaporative coolers, including counter and cross flow with (REC) system and (IEC) system with a cross-flow. The simulations utilized a set of equations for heat and mass transfer, which were discretized using Finite Difference Method (FDM) and solved iteratively in MATLAB. The authors observed good agreement when comparing their simulation findings to experimental data for Cross Flow IEC, Counter and Cross Flow REC. They employed contour plots to depict the two-dimensional temperature distribution in Cross-Flow REC's wet channel. The research also looked at the impacts of pre-cooling on REC performance and compared it to a four-stage IEC. The results revealed that Counter-Flow REC has the lowest inlet air temperature and the maximum wet-bulb efficacy when compared to Cross-Flow REC and four-stage IEC with the identical research settings, with about 30% greater wet-bulb efficiency.

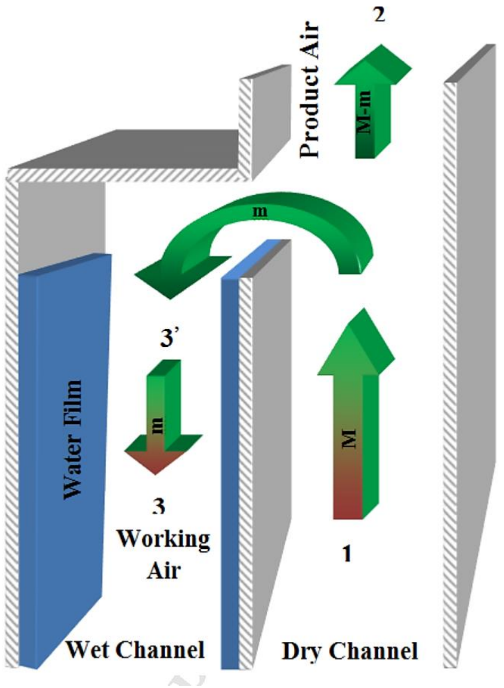


Figure 2.5. Regenerative Cross- and Counter-Flow Evaporative Coolers (REC) [41].

In order to estimate the heat and mass transport properties in a plate-type cross-flow indirect cooling system while taking surface wettability into consideration, Adam et al. [42] developed a mathematical model. The system's performance was evaluated using three parameters: average output temperature of the product air stream, cooling capacity rate, and wet-bulb efficiency. The model was validated using publicly available data. The results showed that the system's cooling capacity and wet-bulb efficiency were both improved by increasing the surface wettability factor. The performance of the system for heat and mass transfer was also found to depend on the air inlet temperature, intake velocity, mass flow rate, and working air humidity ratio.

Fan et al. [43] performed a numerical analysis of the impacts of mechanical vibration and magnetic fields on the evaporative cooling process in space stations using the direct simulation Monte Carlo method. According to the study, lowering the acceleration levels was necessary to avoid significant atomic losses caused by high mechanical vibrations during the cooling process. Additionally, the study explored the impact of magnetic fields on the cooling process and found that increasing the s-wave scattering length through feshbach resonance could significantly increase the phase space density of atoms. In addition, the work modelled a two-stage crossed beam evaporative cooling process under physical effects, yielding encouraging results for future cold atom studies on space stations.

Jradi and Riffat [44] aimed to improve the performance of an IEC system by modifying its exchanger to cool air below its wet bulb temperature and towards its dew point temperature. As shown in Figure, they created a novel technology called a psychrometric energy core (PEC) that employs a cross-flow heat and mass exchanger for air-conditioning applications in buildings (2-14). The study included a numerical analysis that used a thorough model constructed in MATLAB to forecast the distribution of air temperature and humidity throughout the dry and wet channels. Using published data and experimental results, the model was verified. At an intake air temperature of 30 °C, 50% relative humidity, and a working-to-intake air flow ratio of 0.33, the system achieved a wet bulb effectiveness of 112% and a dew point effectiveness of 78%. The authors conducted a parametric analysis to evaluate the influence of various operational factors and improve the performance of the cooling system in order to reach thermal comfort levels in buildings.

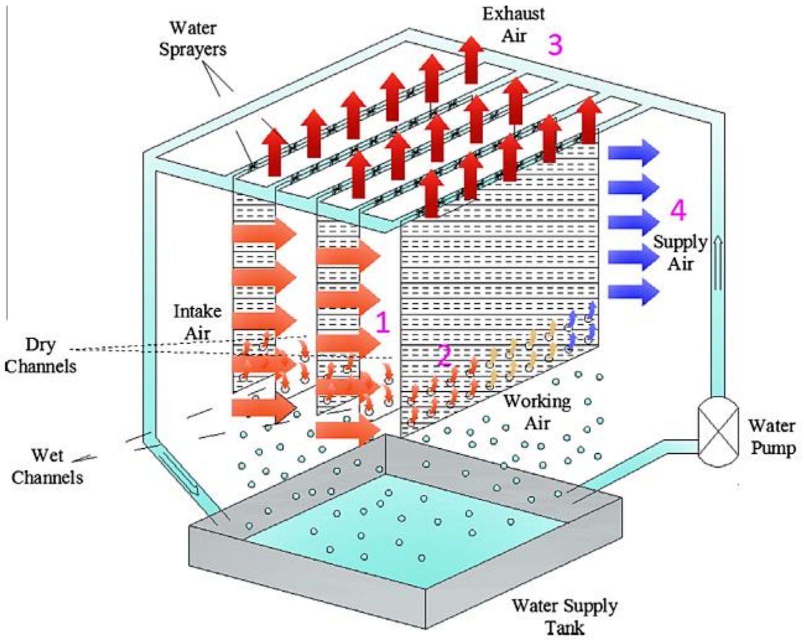


Figure 2.6. Dew point evaporative cooler [44].

Cui et al. [45] studied a novel dew-point evaporative air conditioner that can cool air to temperatures below ambient wet-bulb temperature and towards dew-point temperature. Separate working and product channels make up the counter-flow closed-loop system, as depicted in figure (2-15). The study used a Eulerian-Lagrangian computational fluid dynamics (CFD) model to investigate the performance of the evaporative air cooler under various conditions, and the results were validated against experimental data. The study discovered that intake air condition, airflow velocity, airflow passage size, and product-to-working airflow ratio all had an effect on cooler performance. The novel dew-point evaporative air conditioner with lower air velocity, smaller channel height, bigger length-to-height ratio, and lower product-to-working airflow ratio achieved a higher wet-bulb and dew point efficacy.

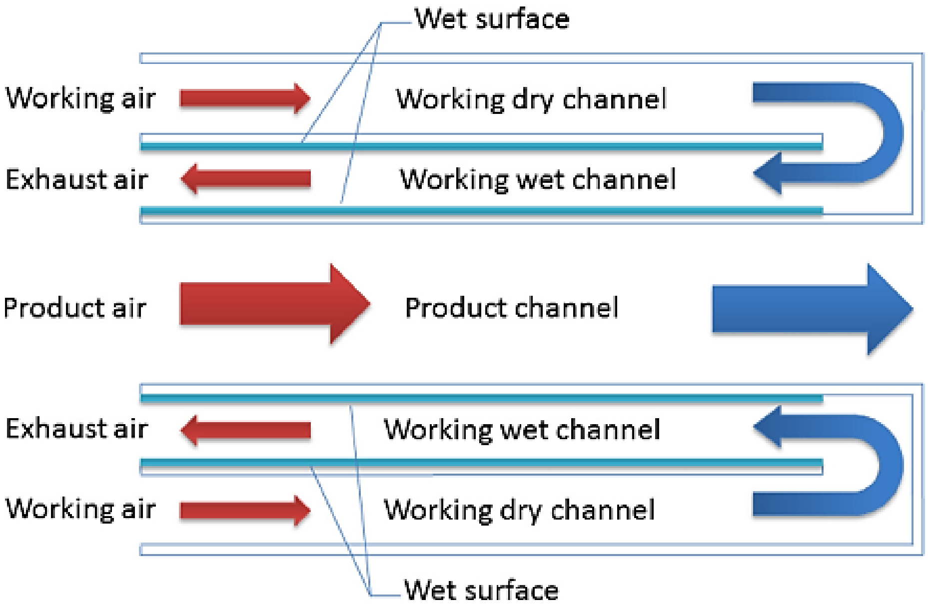


Figure 2.7. Schematic of dew point evaporative cooler used by Cui et al. [45].

Zhou et al. [46] presented research on a novel cooling system known as combination cross-regenerative cross flow (C-RC) thermoelectric aided indirect evaporative cooling (TIEC), which utilizes indirect evaporative cooling and thermoelectric cooling technologies to enhance its cooling performance. They created a model for the system's heat and mass transfer analysis and utilized it to optimize its performance and compare it to a regenerative cross flow TIEC system under various situations. The performance of the system was also examined in relation to various primary air properties, mass flow rate ratios, and wet channel length ratios. The system has the ideal mass flow rate and wet channel length ratios, which results in the highest COP, according to the findings. This study provides helpful information about the functionality and optimization of the C-RC TIEC system, which can be used to create cooling systems that are more effective.

In order to cool direct evaporative air, Khafaji et al. [47] carried out a numerical analysis of the heat and mass transfer mechanism in forced laminar convection between two parallel plates with wet walls. The Navier-Stokes equations, as well as the diffusion and energy equations, were all solved using a 2D approach. The incoming air temperature (T0) was kept constant at 30°C while the study looked at the effects of changing the Reynolds number (Re) from 50 to 1000 and the relative humidity at the inlet (0) from 0 to 50%. The evaporative cell's characteristics were to be optimized. The findings demonstrated that the saturation zone moved downward along the flow as the Reynolds number rose. Additionally, as the Reynolds number and relative humidity at the inlet increased, the thermal hydraulic efficiency decreased. The work's overall conclusion emphasizes the importance of fine-tuning the evaporative cell's properties for effective forced laminar convection direct evaporative air cooling in a channel between two parallel plates with wet sides.

A numerical study of the evaporative dew point cooling, an unique kind of cooling system, was reported by Riangvilaikul and Kumar [48]. The system's performance was assessed in the study under various inlet air conditions, such as dry, moderately humid, and humid climates, as well as the effects of different operating parameters, including velocity, system size, and the working air to intake air ratio. The researchers developed a model of the system to simulate the heat and mass transfer processes and validated the model's predictions against experimental data and literature. The study also optimized the system parameters and explored its effectiveness under various inlet air conditions. Overall, the findings suggest that the dew point evaporative cooling system could be a viable alternative to traditional vapor compression air conditioning systems, especially in hot and arid environments for sensible cooling of ventilation air.

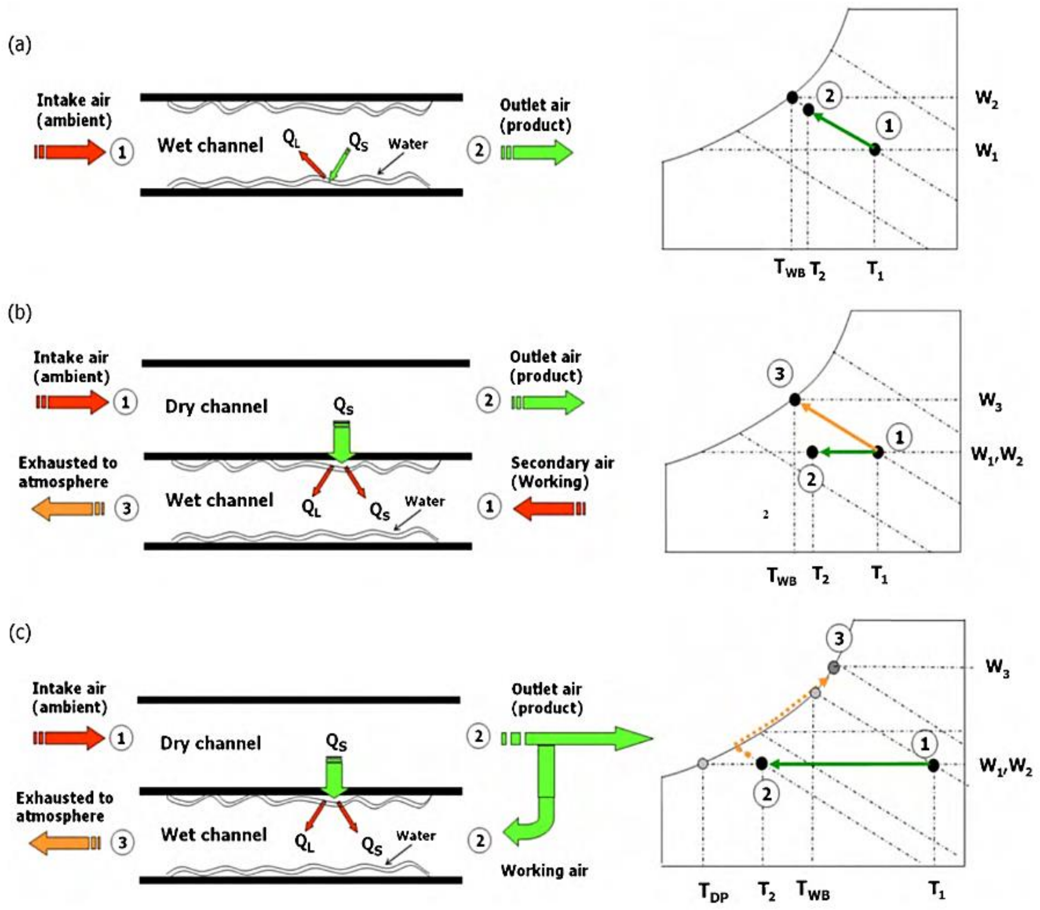


Figure 2.8. The comparison between direct, indirect, dew point evaporative cooling used by Riangvilaikul and Kumar [48].

Sheng and Nnanna [49] studied the impact of three system factors on direct evaporative cooling (DEC) system cooling performance. DEC cools air as it flows through a wetted media by evaporating water, which helps lower the energy usage of HVAC&R systems. The velocity of the frontal air, the frontal air's dry-bulb temperature, and the temperature of the entering water while holding all other factors constant. They gathered information at various levels of each parameter and evaluated the trends to discover the link between each parameter and cooling efficiency. The researchers discovered that, within certain limitations, the cooling effectiveness of DEC systems improves with frontal air dry-bulb temperature, but declines with frontal air velocity and incoming water temperature. In addition, an empirical link was established between supply frontal air velocity and cooling efficiency for DEC systems in a typical environment.

2.3. CONCLUDING REMARKS

It is evident from the research mentioned here that evaporative cooling technologies have the potential to offer a sustainable and energy-efficient replacement for conventional HVAC systems. The use of direct and indirect evaporative cooling systems can significantly reduce the energy consumption of buildings in hot and dry climates, while solid desiccant indirect evaporative cooling can also be effective in humid climates.

The studies also emphasize how crucial it is to maximize these systems' design and operation parameters for optimum performance and efficiency. Evaporative cooling system characteristics such as input air temperature and humidity, air velocity, water flow rate, and system architecture may have an impact on the effectiveness of cooling and energy efficiency.

According to the research, evaporative cooling systems have a bright future in terms of environmentally friendly building construction and maintenance. To fully realize the potential of these technologies and to enhance their performance for a range of building types and climates, additional study is necessary.

The DEC method has been demonstrated to be a successful method for reducing energy consumption in HVAC systems based on the studies mentioned earlier. Frontal air velocity, dry-bulb temperature, and incoming water temperature have all been evaluated for their effects on cooling performance in the studies, and empirical correlations between these parameters and cooling efficiency have been established. Additionally, some studies have evaluated the use of pre-cooling and post-cooling sections in the DEC system to enhance overall performance, as well as the effects of various wetted media on DEC performance. Overall, the studies point to DEC as a potential replacement for conventional HVAC systems, particularly in dry and arid environments.

PART 3

METHODOLOGY

3.1. INTRODUCTION

A heat exchanger is an essential part of refrigeration systems that enhances overall performance and energy effectiveness. It is intended to dissipate heat from one fluid to another without coming into direct contact, resulting in efficient cooling. With the help of references, this introduction will go over the advantages of using a heat exchanger in a refrigeration system. Improved energy efficiency is one of the main benefits of adding a heat exchanger to a refrigeration system. Heat from the refrigerant can be efficiently transferred to the environment or to other fluids in the system by using the heat exchanger. The workload on the compressor is lessened as a result of this process, which also improves the system's overall efficiency [50] A heat exchanger can help refrigeration systems have less of an impact on the environment. Lower energy requirements and lower greenhouse gas emissions are the results of the heat exchanger's improved energy efficiency and facilitation of heat transfer. Heat exchangers assist in achieving sustainability objectives and reducing the effects of climate change by reducing energy consumption [51]. In the system, heat exchangers also aid in avoiding refrigerant contamination. The purity and integrity of the refrigerant are guaranteed because as it passes through the heat exchanger, it is kept apart from the surrounding air and other fluids in the system. By avoiding any potential cross-contamination, the refrigeration system's functionality and dependability are maintained [52]. Heat exchangers are made to maximize the efficiency of heat transfer between the refrigerant and the fluid around it. They offer a sizable surface area for heat exchange, making efficient and quick cooling possible. The refrigeration system can quickly achieve the desired cooling effect thanks to this improved heat transfer process, cutting down on cooling cycle times and improving overall system performance. Numerous advantages come from using a heat exchanger in a refrigeration system, including improved energy efficiency, decreased environmental impact, prevention of refrigerant contamination, increased heat transfer effectiveness, and flexibility in system design. Because of these benefits, heat exchangers are essential parts of refrigeration systems, enhancing both their overall efficiency and sustainability.

3.2. EES SOFTWARE

A dependable software application called EES (Engineering Equation Solver) is frequently used to resolve and analyze challenging engineering problems including thermodynamics, fluid mechanics, heat transfer, and other topics. Engineers and academics can benefit from EES since it has a simple user interface and a large library of integrated equations and thermophysical properties. With the help of a reference, this introduction will give a general overview of the EES package and its capabilities. F-Chart Software engineers created the EES package, a computer tool with many features for successfully resolving engineering challenges. Users can precisely model and simulate a range of engineering systems using an equation-solving engine and a flexible thermodynamic property database. One of the key benefits of EES is the huge collection of equations and property data. The system's equations are a representation of a wide range of engineering phenomena, including as energy balance, mass balance, fluid motion, heat transfer, and combustion processes. These equations may be combined into user-defined models without the need for time-consuming computations, simplifying the study of complex systems. Along with equations, EES also offers a huge collection of thermodynamic characteristics. As a result, it is feasible to access a broad variety of thermophysical properties, including those of single components, mixtures, gases, liquids, and solids. Calculations and simulations are made easier for users since they have access to accurate and reliable property values for a range of materials. The user-friendly interface of EES makes installation and issue resolution less complicated. In the context of the program, which resembles a spreadsheet, users may define variables, enter data, and generate equations using a straightforward syntax. Iterative optimization and speedy analysis are made possible by the program's automated equation solution and real-time presentation of the findings. EES also offers parametric and sensitivity analyses that enable users to examine how changing input parameters may affect system performance. The forecast of engineering system performance, process evaluation, and design optimization all benefit greatly from this characteristic. The EES package is a powerful software tool that engineers and researchers can utilize to assist them in resolving difficult engineering challenges. EES offers an effective and dependable platform for modeling and analyzing a variety of engineering systems thanks to its ability to solve equations, extensive thermodynamic property database, user-friendly interface, and analysis features [53].

General Mass, Energy, and Exergy Equations

The conservation of mass equation for system:

$$\sum\dot{m}_{in} = \sum\dot{m}_{out} \tag{3.1}$$

where:

$\sum\dot{m}_{in}$: the total mass flow entering per unit time.
$\sum\dot{m}_{out}$: the total mass flow exiting per unit time.
The energy balance for each component is based on the first law of thermodynamics for system [54]:

$$\dot{Q} + \dot{W} = \sum\dot{m}_{out}h_{out} - \sum\dot{m}_{in}h_{\mathrm{in}} \tag{3.2}$$

where:

$\dot{Q}$: the heat transfer per unit time.
$\dot{W}$; Work done by the control volume per unit time.
h_{in} : specific enthalpy per the mass entering the system.
h_{out}: specific enthalpy per mass leaving the system.

Unlike mass and energy, entropy is not conserved in open and closed systems, as entropy is produced due to irreversibility. In open systems, the entropy balance can be expressed as[55]:

$$\dot{E} = \dot{m}\psi \tag{3.3}$$

3.3. ANSYS PACKAGE

Studies in Computational Fluid Dynamics (CFD) are conducted to get more knowledge about the flow. k-ε model is used to highlight the impact of the turbulence model by solving a two-transport equation. Therefore, these Cartesian coordinate systems may be solved using numerical solution methods (x, y, and z). The geometry in three dimensions is produced.

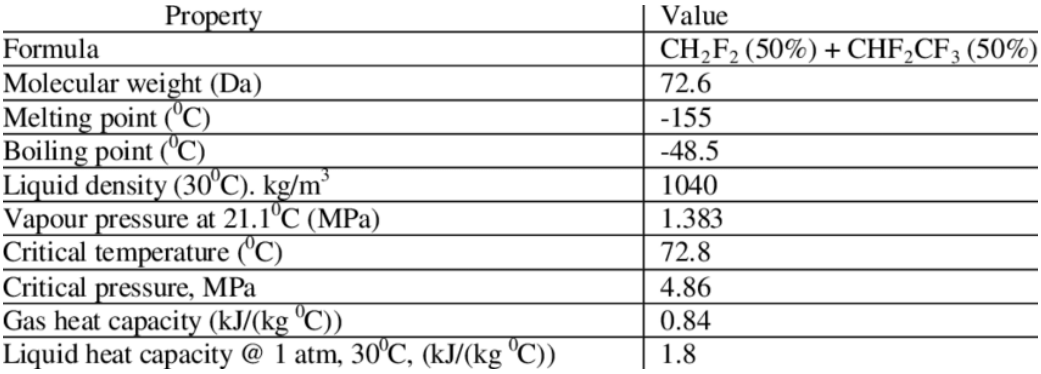
ANSYS version (19), will be implemented here to generate the system geometry, grid it, and run the simulations.

3.1.1. Assumptions

In the current study, R140A is considered as the running liquid and the characteristics of flow are assumed to be:

1. Steady flow, three dimensional,
2. Newtonian,
3. Incompressible, and
4. Turbulent.

Table 3.1. R140A properties [56].



Property	Value
Formula	CH_2F_2 (50%) + CHF_2CF_3 (50%)
Molecular weight (Da)	72.6
Melting point (^{0}C)	-155
Boiling point (^{0}C)	-48.5
Liquid density (30^{0}C). kg/m^3	1040
Vapour pressure at 21.1^{0}C (MPa)	1.383
Critical temperature (^{0}C)	72.8
Critical pressure, MPa	4.86
Gas heat capacity (kJ/(kg ^{0}C))	0.84
Liquid heat capacity @ 1 atm, 30^{0}C, (kJ/(kg ^{0}C))	1.8

3.1.2. Governing Equations

The governing equations to be solved are the continuity, momentum and the equation of the energy.

Mass Conservation (Continuity)

$$\nabla \cdot (V) = 0 \tag{3.4}$$

Momentum Equation

$$\nabla \cdot (\rho \dot{V} \dot{V}) = -\nabla p + \nabla \cdot (\bar{\tau}) \tag{3.5}$$

The stress tenser $\bar{\tau}$ is given by:

$$\bar{\tau} = \mu \left[\left(\nabla \vec{V} + \nabla \vec{V}^T \right) - \frac{2}{3} \nabla \cdot \vec{V} I \right] \tag{3.6}$$

Energy Equation

$$\nabla \cdot (\dot{V}(\rho E)) = \nabla (k \nabla T - \rho C \dot{V} T') \tag{3.7}$$

3.1.3. Turbulence Model

The typical $(k-\varepsilon)$ model is often employed in the modeling of heat transfer because it is cheap and logically accurate across a broad spectrum of turbulent flows. In the $(k-\varepsilon)$ model, two additional transport equations for the turbulent kinetic energy (k) and turbulent dissipation rate (ε) are solved and the eddy viscosity (μ_t) is computed as a function of k and ε [57].

3.1.4. ANSYS Package

Two modules are used to solve the flow equations:

1- The main component is the preprocessor module, which is the part of the code responsible for making the grid and the geometry.
    a) Modeling of geometry.
    b) Mesh generation.
    c) Boundary condition.
2- The Navier-Stokes equations, including the continuity, momentum, and energy equations, and the turbulent flow model are all solved in the second module, Solution.

3.1.5. System Geometry

The structure of the system shown in Figure (3.1) consists of a coil and tube type heat exchanger with a variable length in the number of turns. Where 5, 9 and 13 turns of the cooling tube were used, and this represents the second part of the simulation process to know the thermal effect on the heat exchange process between the fluids [58], while the first part is represented by the air entry area and the water spraying process with variable number of nozzles, where 15, 24 and 35 nozzles were used. As for the dimensions of the duct, it was 20 cm in width, 10 cm in height, and the total length was 25 cm. The roll diameter was 60 mm on the duct width.

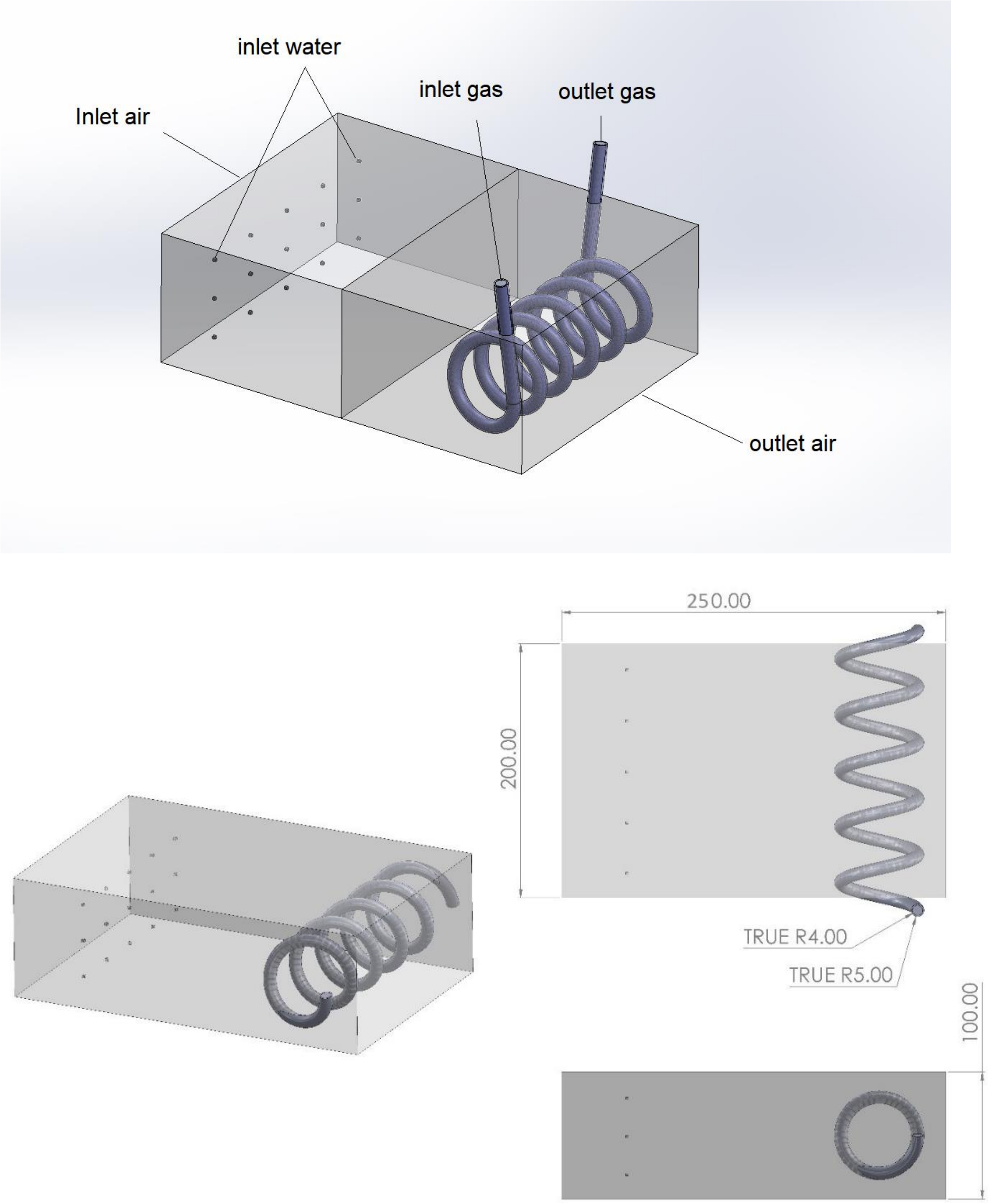


Figure 3.1. geometry shape.

3.1.6. Mesh Generation

Since unstructured grids tend to work well for complicated geometries, a tetrahedron grid was employed in this investigation. In ANSYS, users just need to provide input in a single phase to generate a mesh for a solid geometry or a 3D model. In this work, a total of (3701221) cells were collected see fig (3.2).

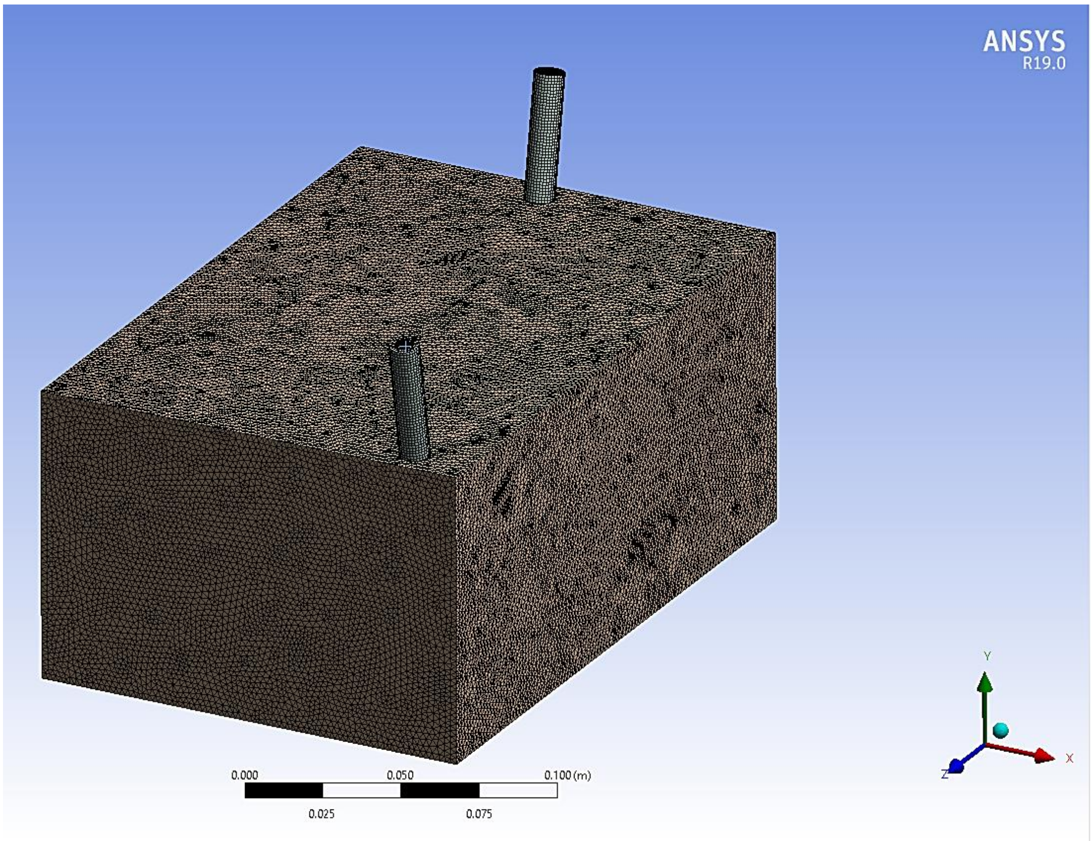


Figure 3.2. Mesh generated.

The simulation process requires the work of complex algorithms to solve the matrices contained in the domain, and therefore an accurate mesh must be made to solve the equations. And then work the reliability of the mesh for a solution to reach a stable state with the results. Because of the multiplicity of models that have been simulated, it is necessary to make more than one mesh and more than one mesh reliability. The value of the element was 3701221 when the Average temperature gas in outlet reached 53.903m/s as in Table 3.2.

Table 3.2. Mesh independency.

case	**element**	**node**	**Average temperature gas in outlet °C**
1	2162567	393564	55.734
2	2524690	519076	54.210
3	3025365	623482	53.964
4	3412354	734210	53.909
5	3701221	877558	53.903

3.1.7. Boundary Conditions

Where the pressures and temperatures extracted from the EES program were entered the results sources for the CFD program, which is considered as a boundary condition.

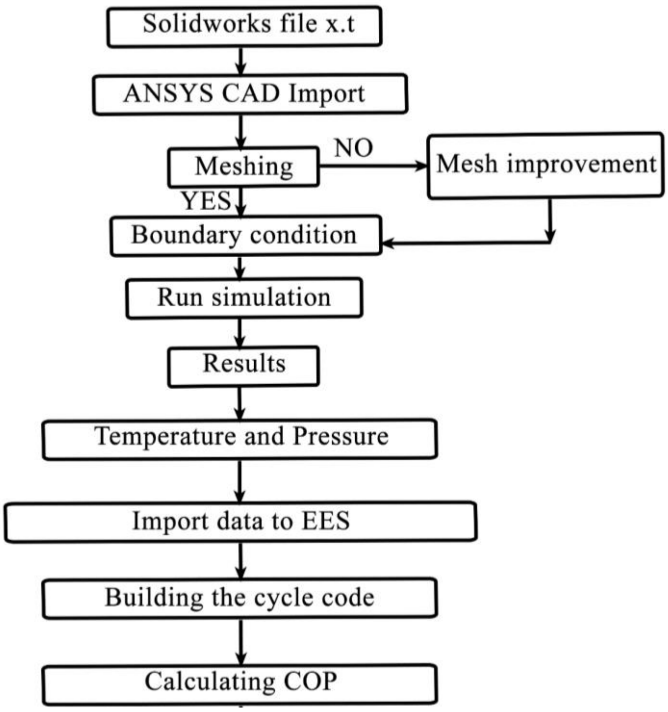


Figure 3.3. Flow chart.

3.1.8. Initial Conditions

Since the flow field can't be determined until after iteration has begun, a best estimate is required before any progress can be made toward a solution. All parameters in this study are set relative to the inlet boundary conditions of the inner pipe.

3.1.9. Problem Solution

A volume of the control depended technique that comprises of the accompanying advances, which can be utilized for arrangement:

1. A network is created on the field.

2. Sets of conditions like speed, pressure, and preserved scalars, arithmetical are built by the combination on each control volume of the overseeing conditions.
3. The Discretized Conditions are linearized and tackled iteratively.

ANSYS is the arrangement calculation utilized by Familiar and is embraced in the current work. The overseeing conditions are addressed successively (i.e., isolated from each other). Since the overseeing conditions are non-direct (and coupled), numerous cycles might be finished before a merged arrangement is gotten.

3.1.10. Solution Parameters

The solution parameters include the following:

A. Precision Solver Type

The usual methods for locating precision solvers are limited to the single and double. For an infinitely precise computer, the residuals would vanish when the solution converges to zero. In a real computer, the residuals tend to converge to a small number (known as "rounding off") before they stop fluctuating (known as "leveling off").

B. Iterations Number

This is the highest digit of iterations done before the solver terminates.

3.1.11. Convergence Criteria

Solution of the fluid flow equations is iterated in CFD until convergence is achieved. Once the answer has not changed beyond the bounds of the chosen convergence criterion, the iterations will cease. The error residuals, defined as the difference between a variable's value in two successive iterations normalized by the highest absolute residual for the first five iterations, are the most often used approach to test for solution convergence. When the residuals for all of the aforementioned fluid flow equations fall below a tolerance level of 10-6, we say that the solution has converged.

PART 4

RESULTS AND A DISCUSSION

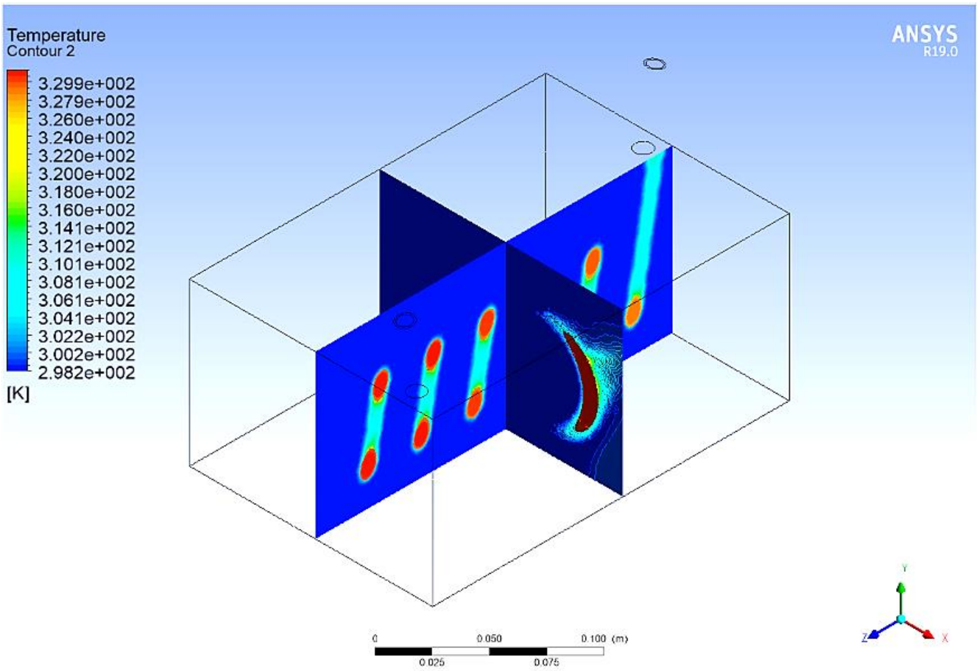
4.1. INTRODUCTION

In computational fluid dynamics (CFD) analysis, it is essential to comprehend the relationship between the geometry of the system and the heat transfer efficiency [59]. This study undertook a comprehensive investigation into how alterations to particular parameters of a coil and tube type heat exchanger, specifically the number of nozzles and cooling tube turns, affect the system's performance. The analysis considered various scenarios in which the number of nozzles was 15, 24, and 35, and the number of cooling tube turns was 5, 9, or 13. The ANSYS software facilitated the generation of an unstructured tetrahedron grid, which was useful for managing the complex geometries of the system. Using this technology, patterns in the temperature and velocity contours resulting from these modifications were discernible, laying the groundwork for the subsequent discussion of results.

4.2. ANALYSIS OF TEMPERATURE CONTOURS

Figures 4.1 to 4.9 depict the temperature contour analysis of a system with different nozzles, turns in the cooling tube, and inlet velocities of 0.5, 1, and 2 m/s. The number of turns and nozzles affect the temperature contour, according to the ANSYS simulation. The heat is dispersed most evenly when there are 13 turns and 35 nozzles, respectively. This shows that adding turns and nozzles can enhance temperature distribution and heat exchange efficiency, which will enhance the heat exchanger system's functioning and efficiency. Changing the structure could increase the effectiveness of the heat exchange process.

The observed outcomes can be attributed to the increased heat transfer surface area and the number of tubes turns and nozzles. More turns provide longer paths for fluid exchange, while more nozzles improve fluid distribution and dispersion. However, trade-offs such as increased pressure drop and intricate designs may occur. Future research should concentrate on optimizing these parameters to achieve the most effective design with the fewest compromises. To optimize system design for maximum efficiency and cost-effectiveness, it is essential to strike a balance between these variables.



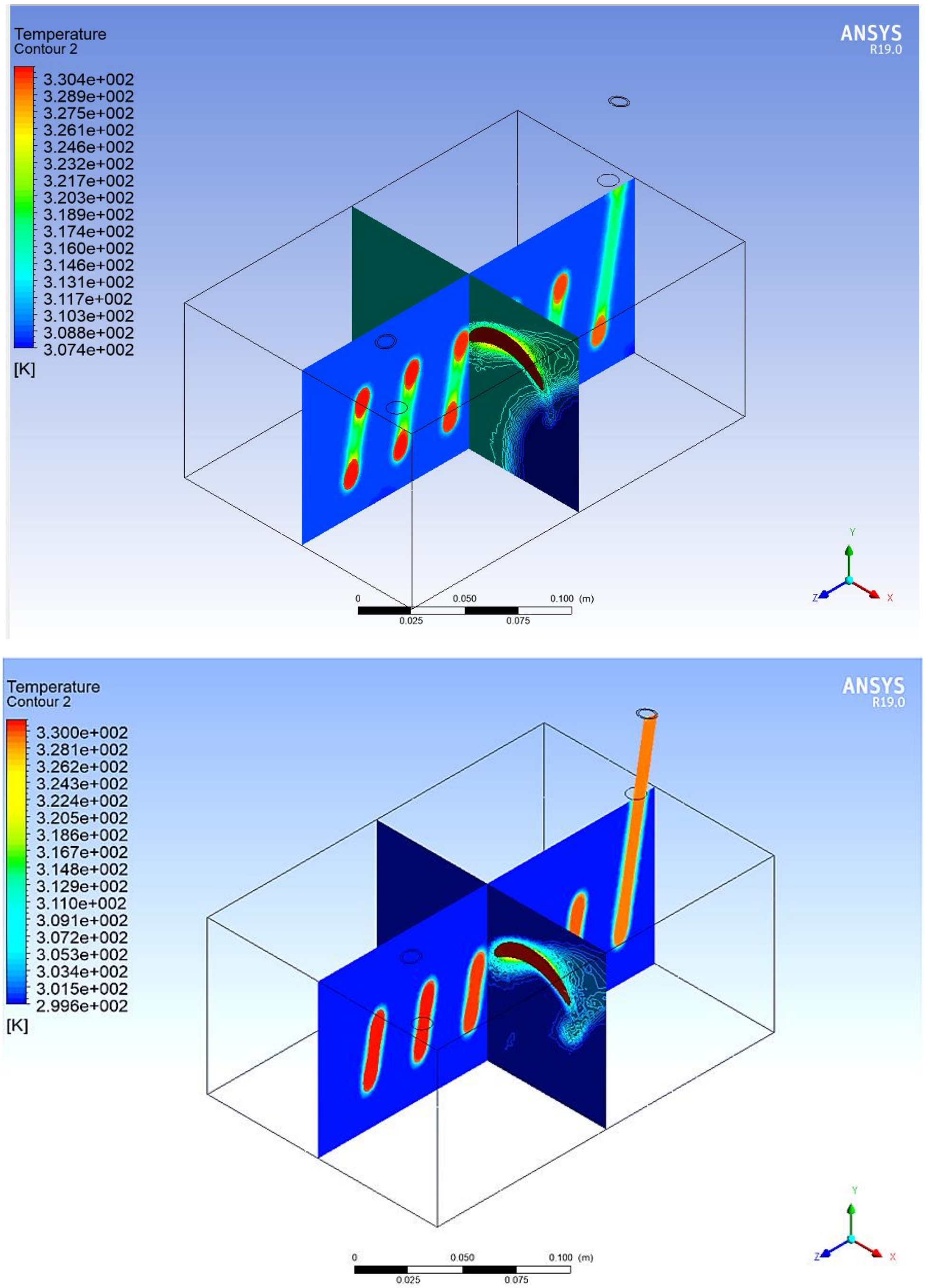


Figure 4.1. Temperature Contour Analysis for a System with 15 Nozzles and 5 Turns in the Cooling Tube, with Inlet velocity 0.5,1, 2 m/s.

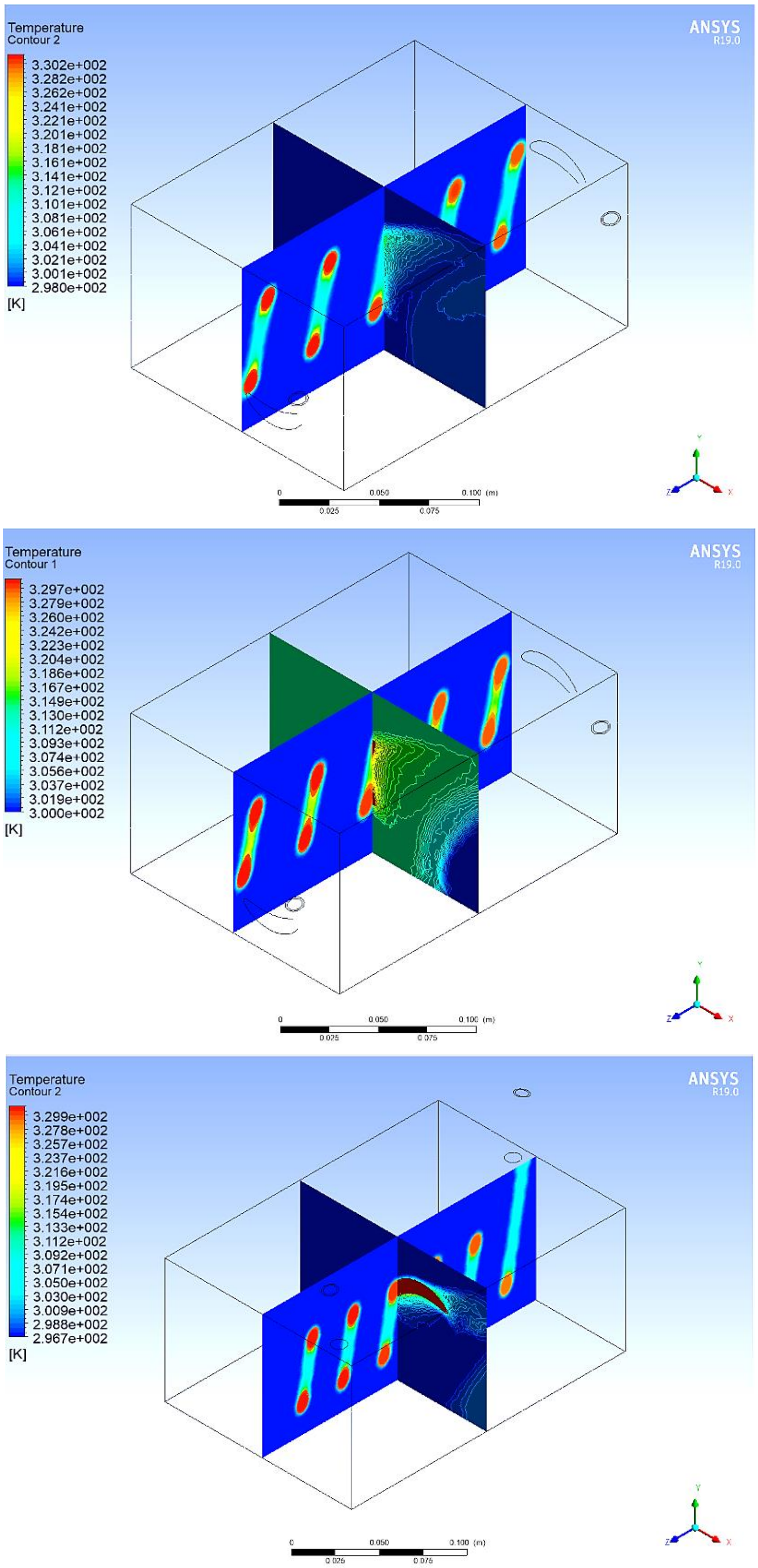


Figure 4.2. Temperature Contour Analysis for a System with 24 Nozzles and 5 Turns in the Cooling Tube, with Inlet velocity 0.5, 1 and 2 m/s.

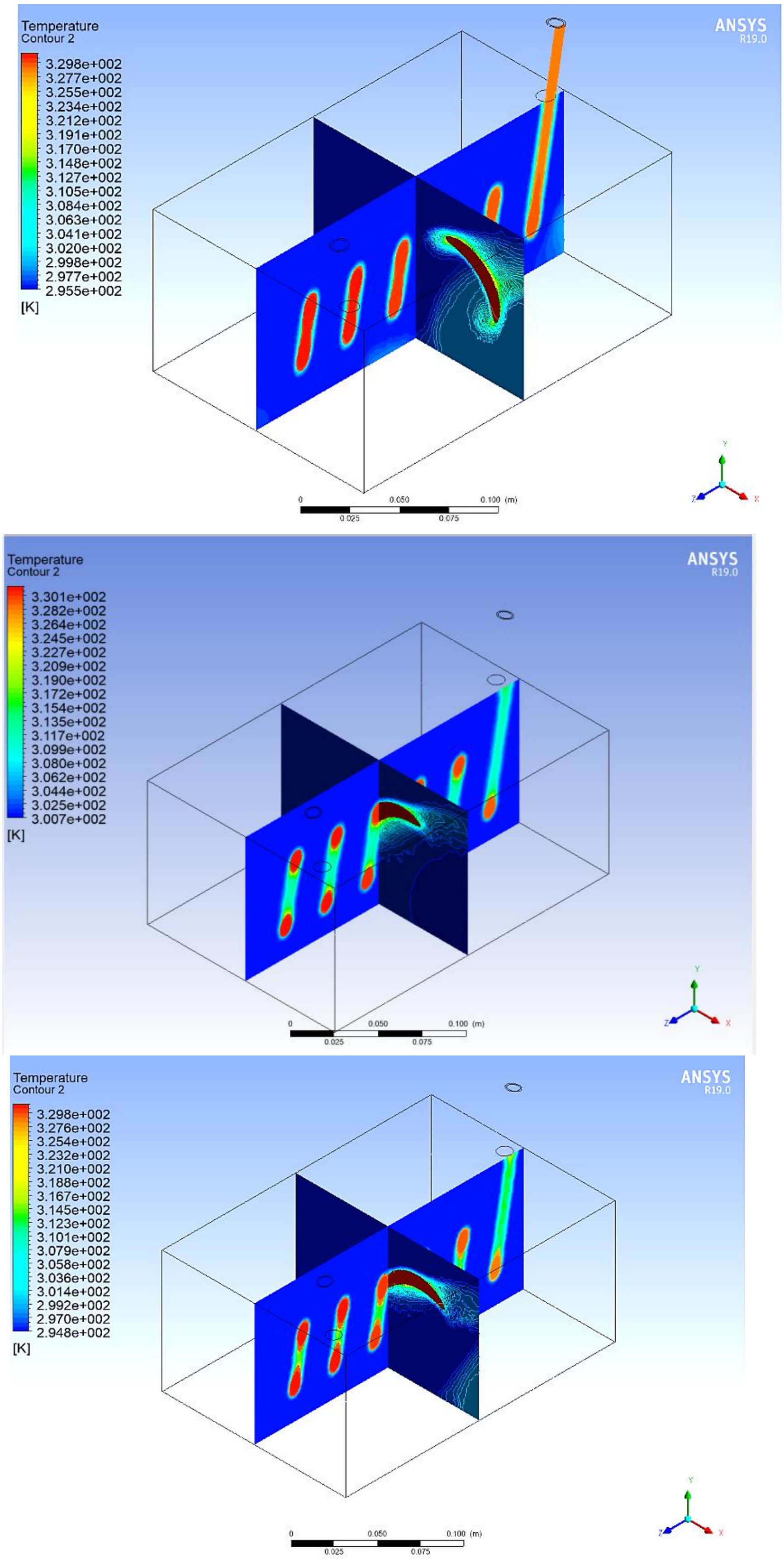


Figure 4.3. Temperature contour analysis for a system with 35 nozzles and 5 turns in the cooling tube, with inlet velocity 0.5, 1and 2 m/s.

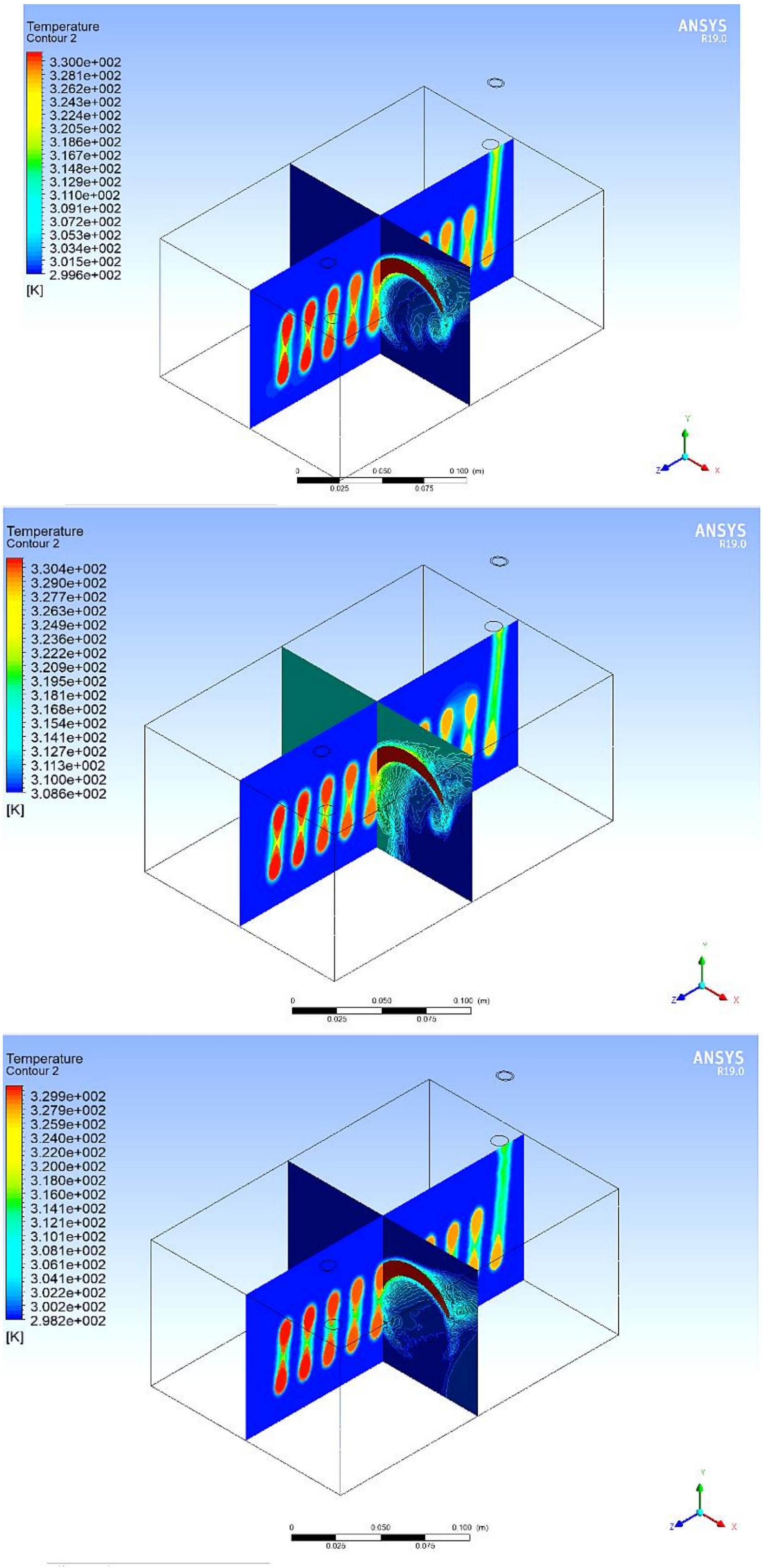


Figure 4.4. Temperature contour analysis for a system with 15 nozzles and 9 turns in the cooling tube, with inlet velocity 0.5, 1 and 2 m/s.

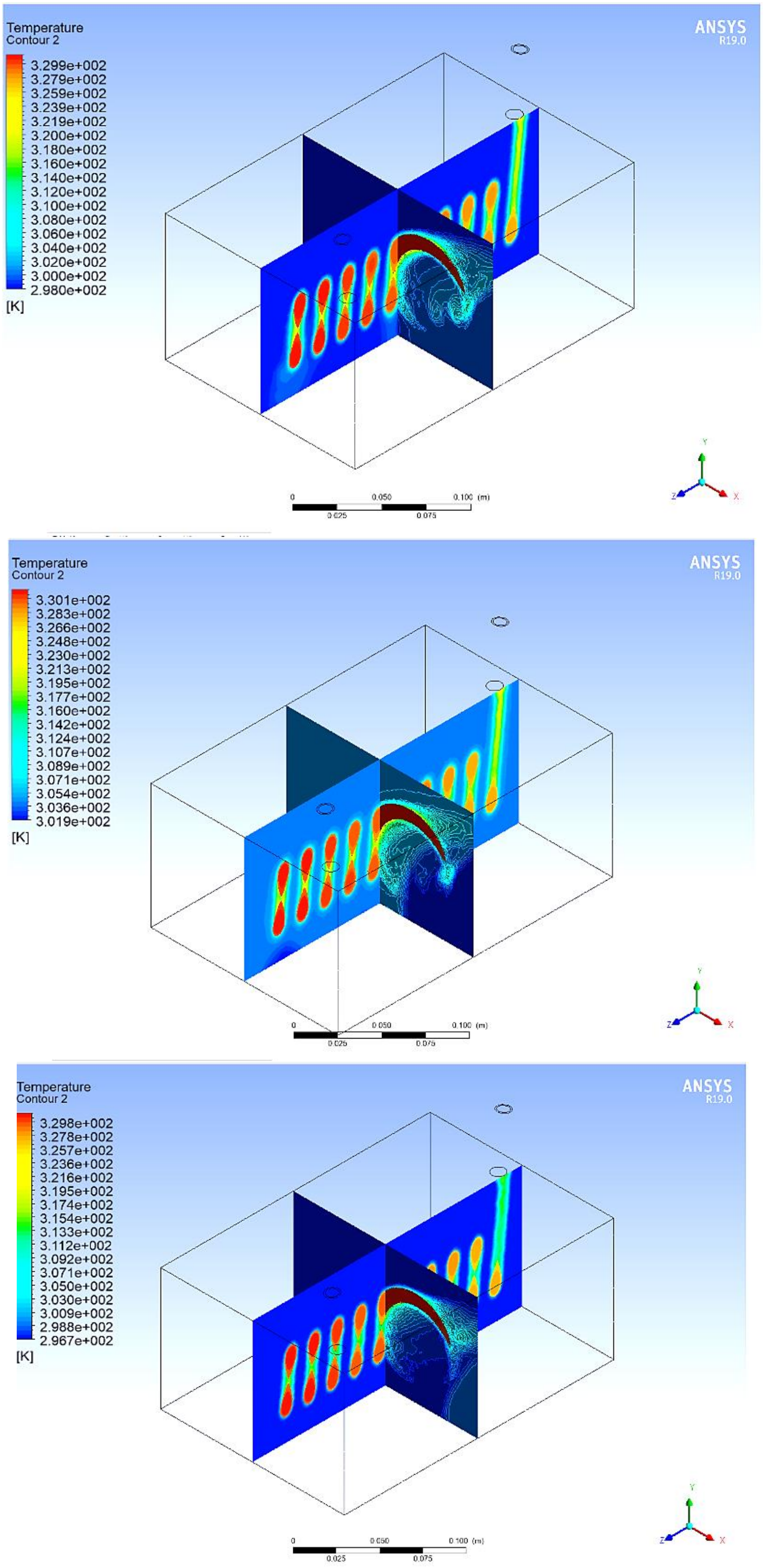


Figure 4.5. Temperature contour analysis for a system with 24 nozzles and 9 turns in the cooling tube, with inlet velocity 0.5, 1 and 2 m/s.

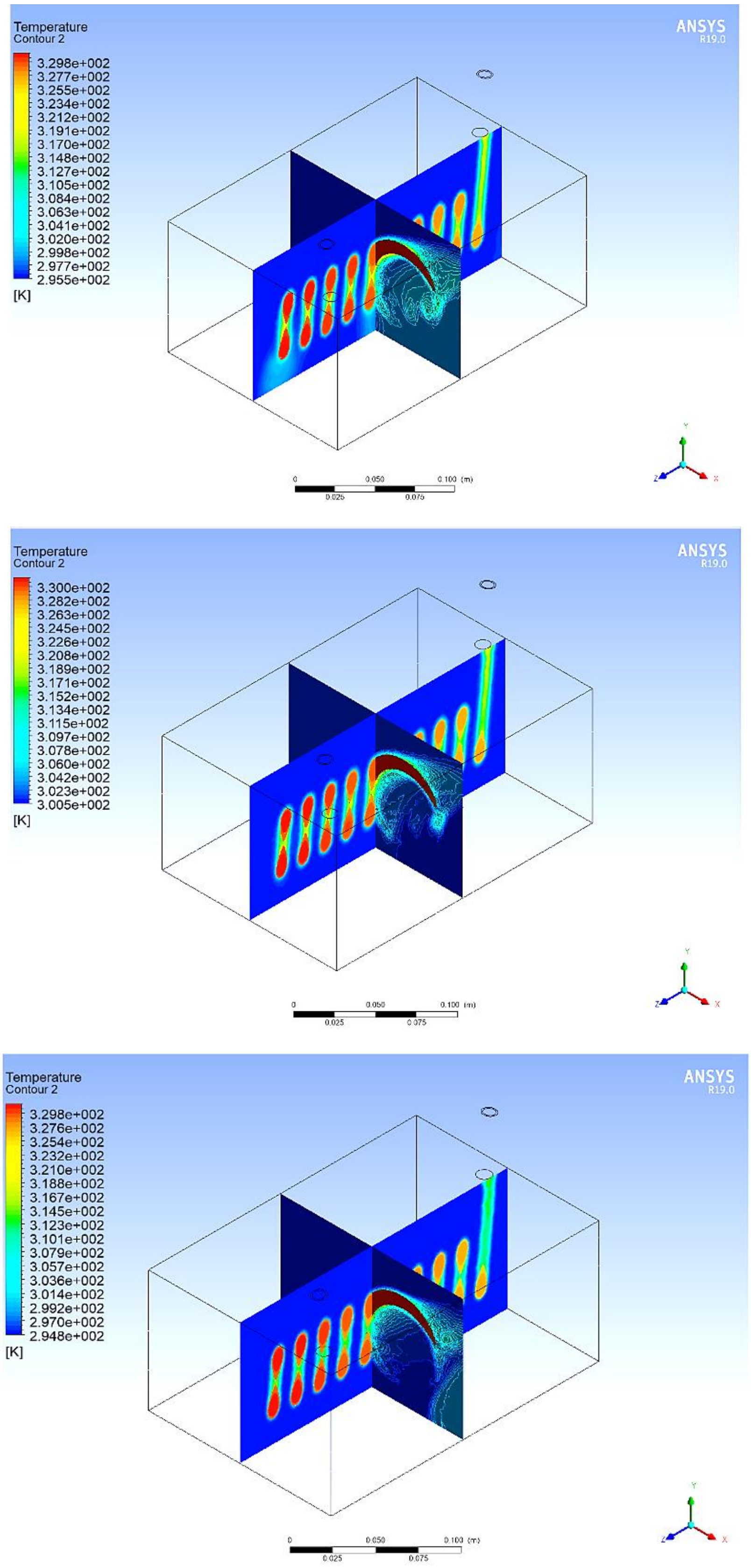


Figure 4.6. Temperature contour analysis for a system with 35 nozzles and 9 turns in the cooling tube, with inlet velocity 0.5, 1 and 2 m/s.

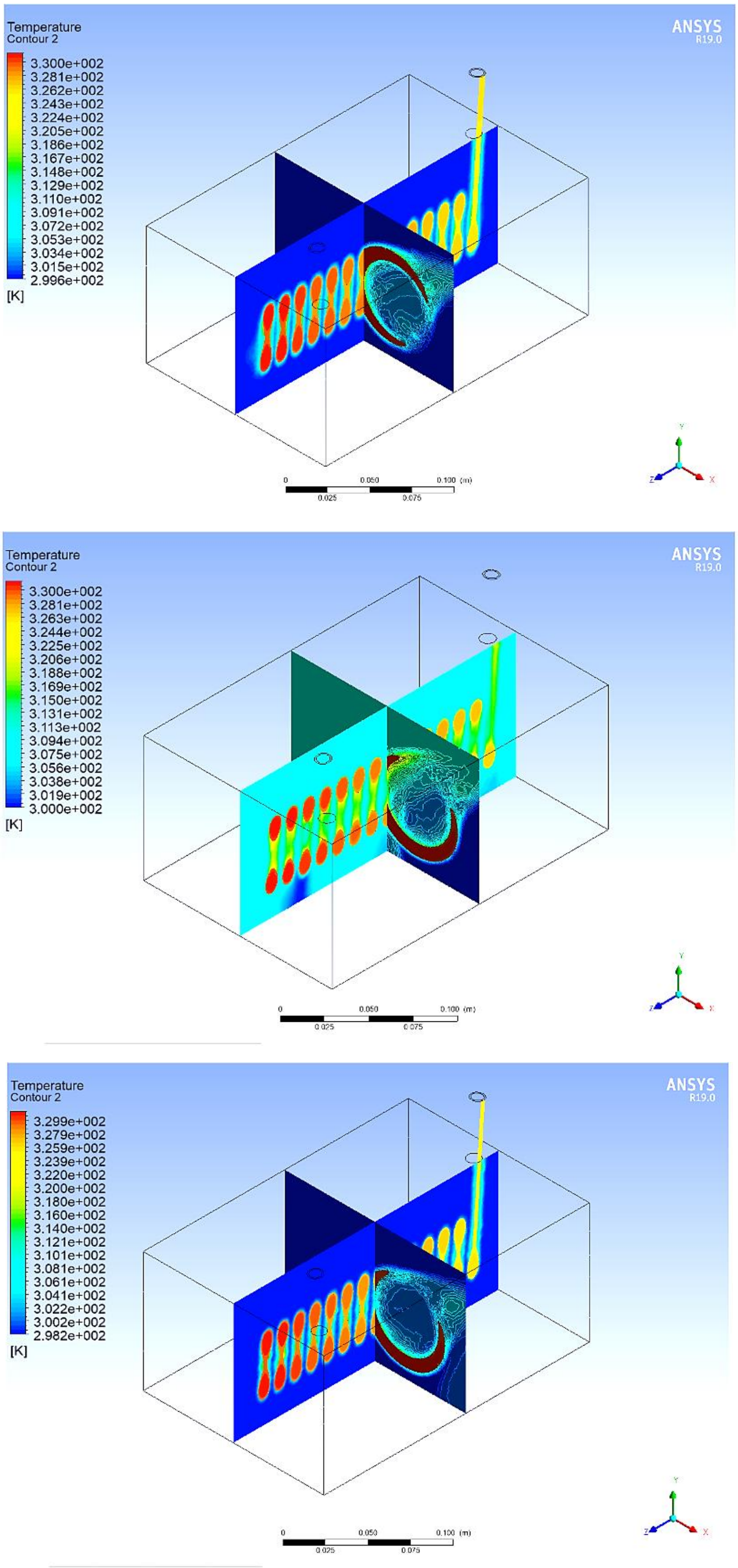


Figure 4.7. Temperature contour analysis for a system with 15 nozzles and 13 turns in the cooling tube, with inlet velocity 0.5, 1 and 2 m/s.

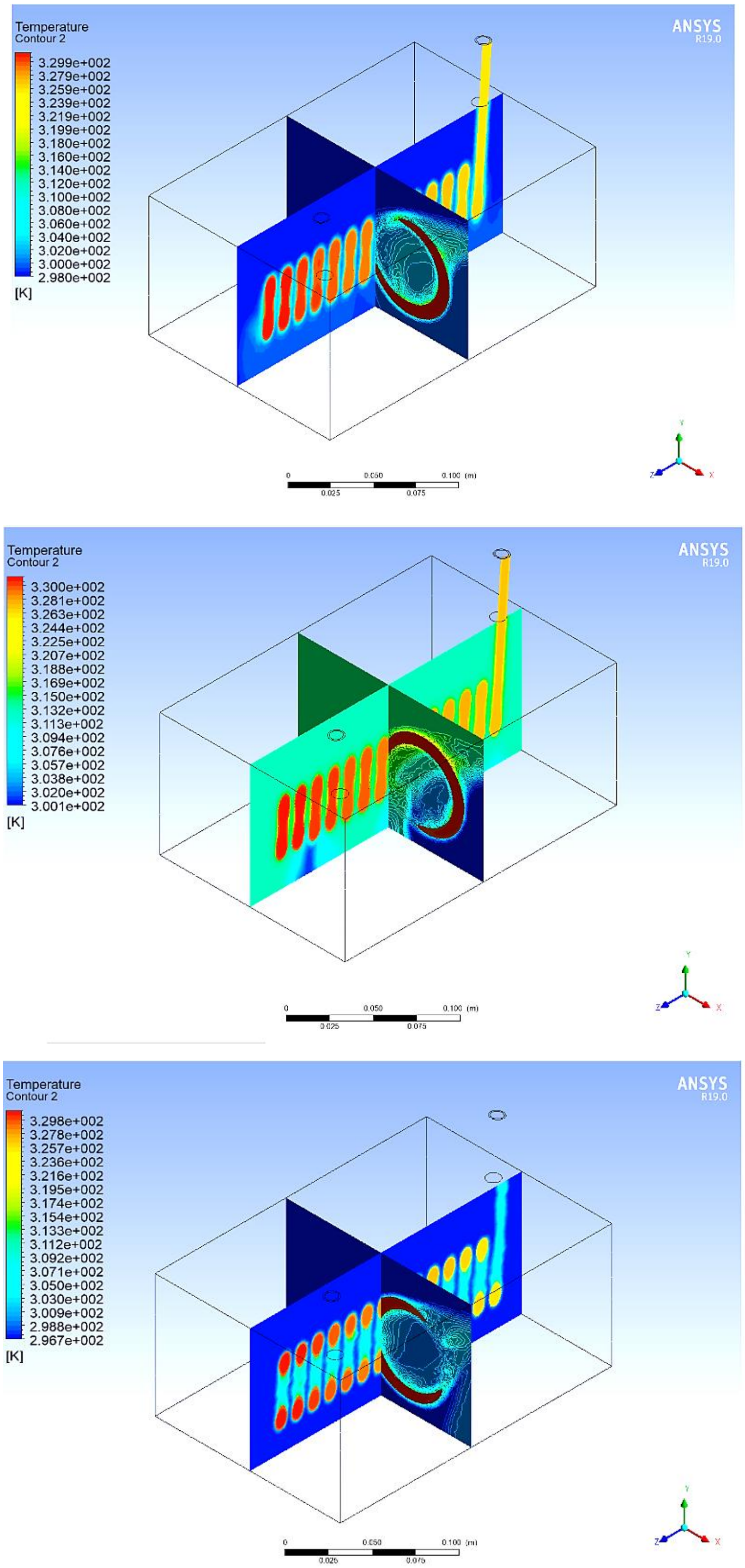


Figure 4.8. Temperature Contour Analysis for a System with 24 Nozzles and 13 Turns in the Cooling Tube, with Inlet velocity 0.5, 1 and 2 m/s.

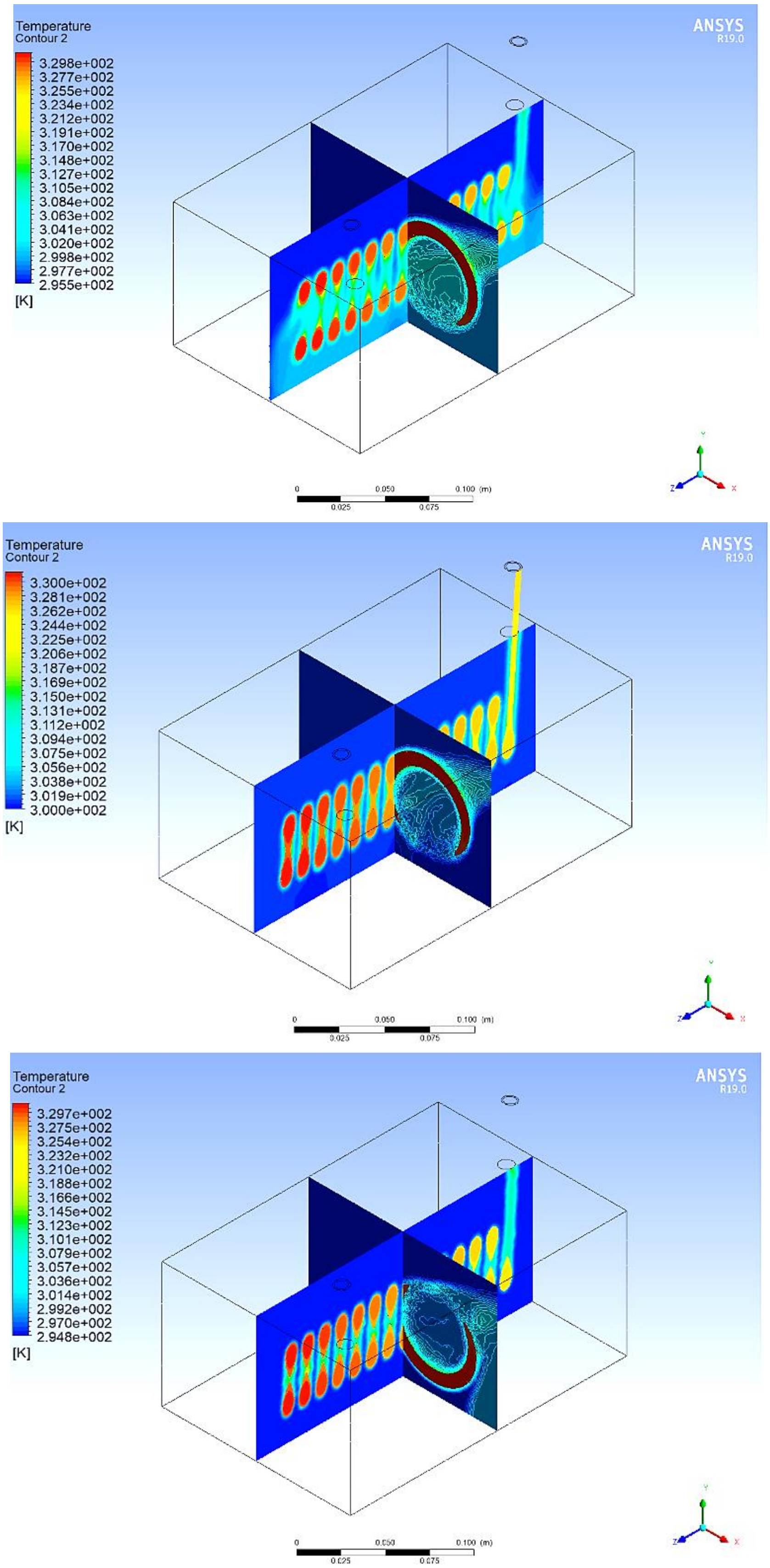
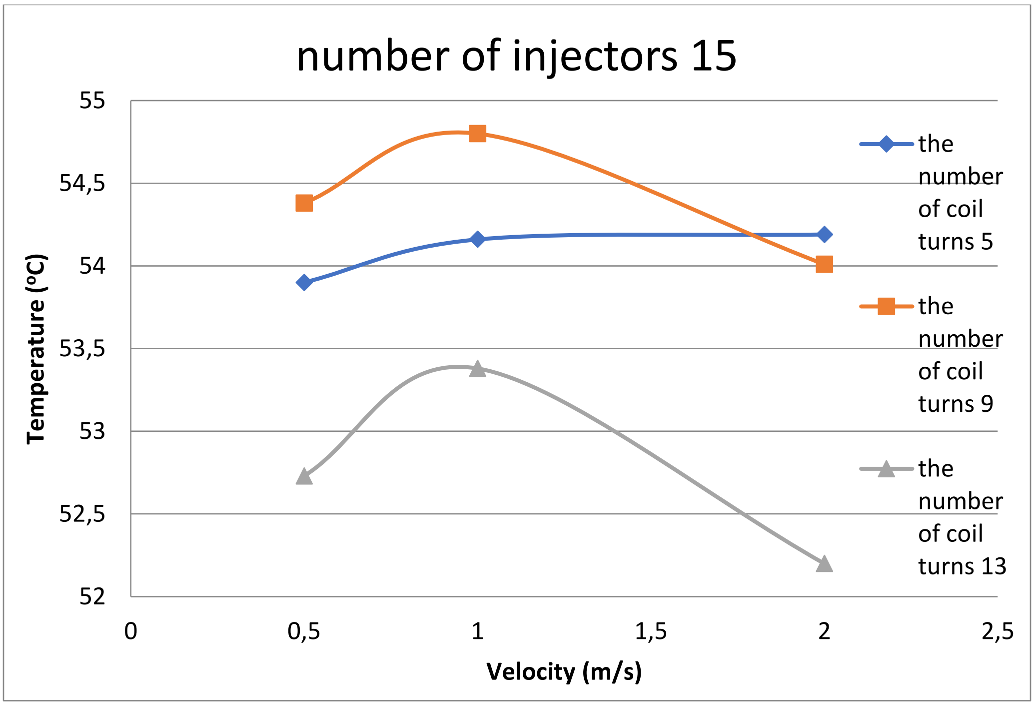
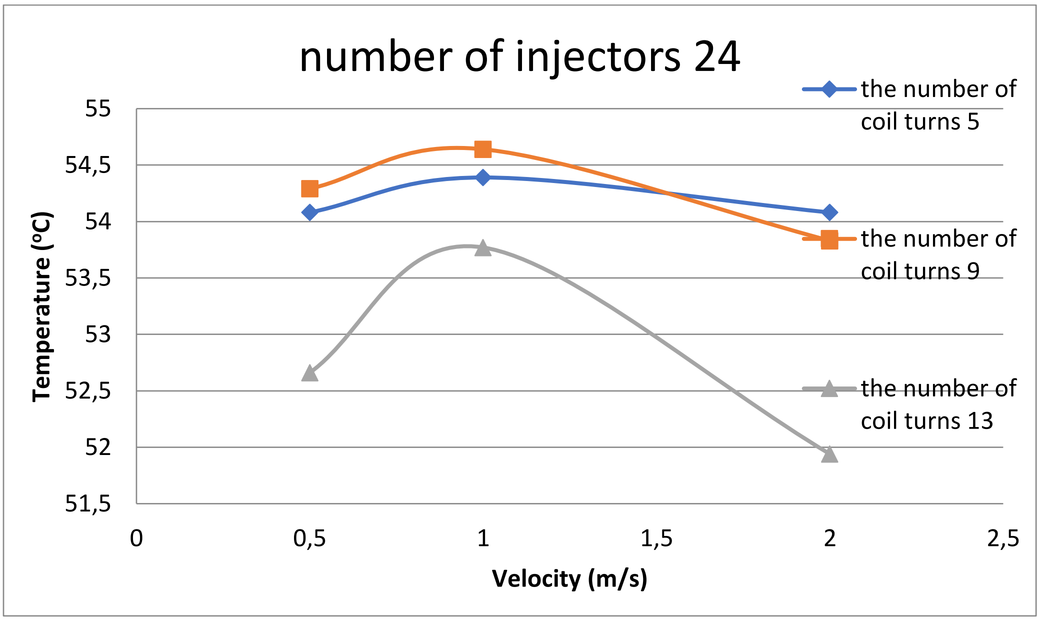


Figure 4.9. Temperature contour analysis for a system with 35 nozzles and 13 turns in the cooling tube, with inlet velocity 0.5, 1 and 2 m/s.

4.2.1. Temperature with Velocity

Figure 4.10 below indicate an increasing in temperature degrees for three injectors cases, where at the number of injections 15 the maximum number of coil turns is 9 also the three coils started at 0.5 m/s with different temperatures range. By increasing in velocity, the temperature increases also until reaches to peak point bat 1 m/s as shown





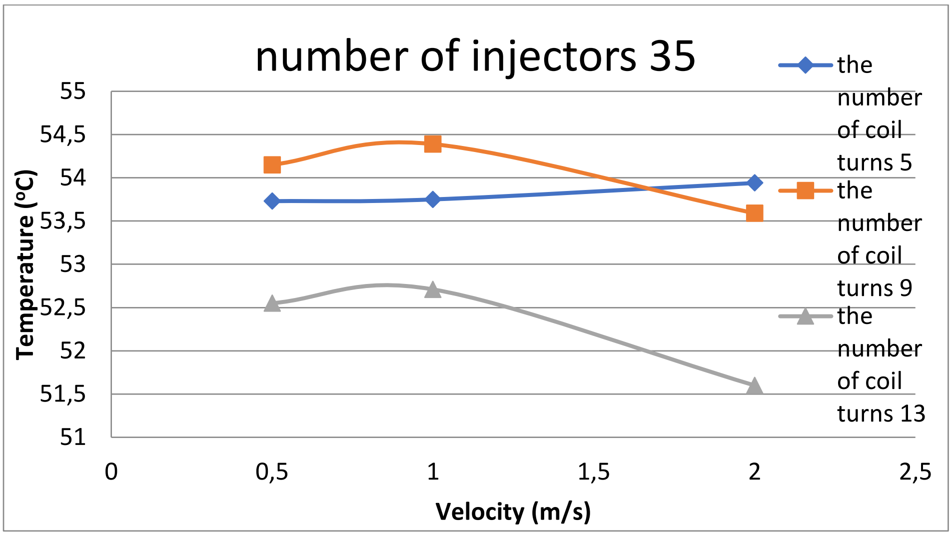


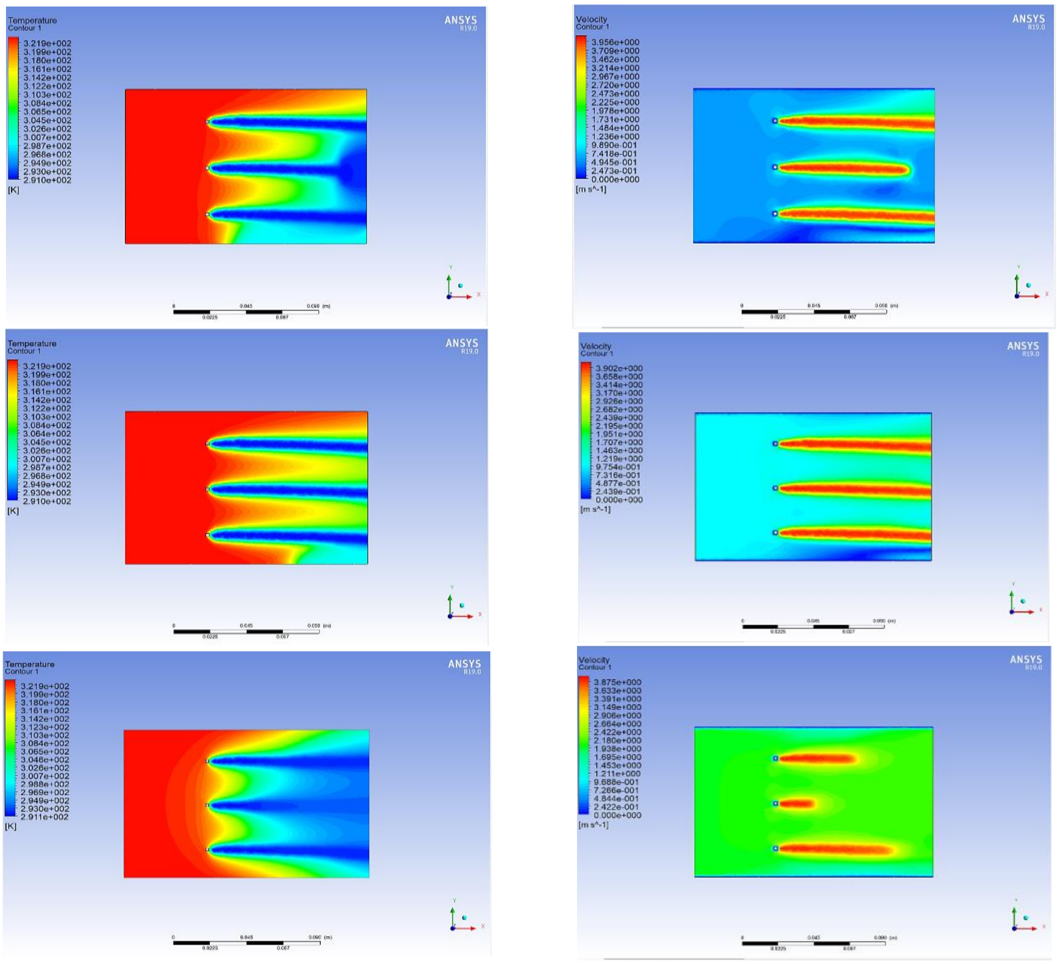
Figure 4.10. Number of coils turns with temperature

The figure show that the highest and lowest values of coil turns are happen at 15 injection numbers while at 24 injections can notice that the coil 13 reaches over 53.5 ºC when compared with the other charts.

4.3. INFLUENCE OF AIR ENTRY GEOMETRY AND WATER SPRAYING PARAMETERS ON THERMAL DYNAMICS

Figures 4.11–4.13 show temperature and velocity contour variation with air velocity and the number of nozzles. The simulations revealed a consistent pattern of temperature distribution within the system. At slower speeds, the temperature contours displayed a more uniform distribution of heat. This can be attributed to the longer residence time of the air inside the system, allowing for sufficient heat exchange with the cooling tubes. In contrast, at higher speeds, the temperature contour appeared to gradient, indicating a lower degree of heat exchange because of a shorter interaction time between air and cooling tubes. The temperature distribution was also impacted by various nozzle configurations. Due to the larger surface area of the air and water spray, the use of 35 nozzles produced a more uniform temperature contour than the use of 15 or 24 nozzles, indicating a more effective heat exchange process. The velocity contour also showed a similar trend. The system's airflow was generally consistent and maintained a laminar flow pattern at lower velocities, allowing for effective heat exchange. However, as air velocity increased and the amount of time the air spent interacting with the cooling tubes decreased, a more turbulent flow pattern developed, potentially lowering the efficiency of heat exchange. The velocity profile was also significantly influenced by the quantity of nozzles used. There was less chance of hotspots or areas of poor heat transfer within the system with more nozzles because the air velocity was distributed more evenly. Contrarily, fewer nozzles led to a less even distribution of air velocity, potentially leading to areas of reduced heat exchange efficiency.

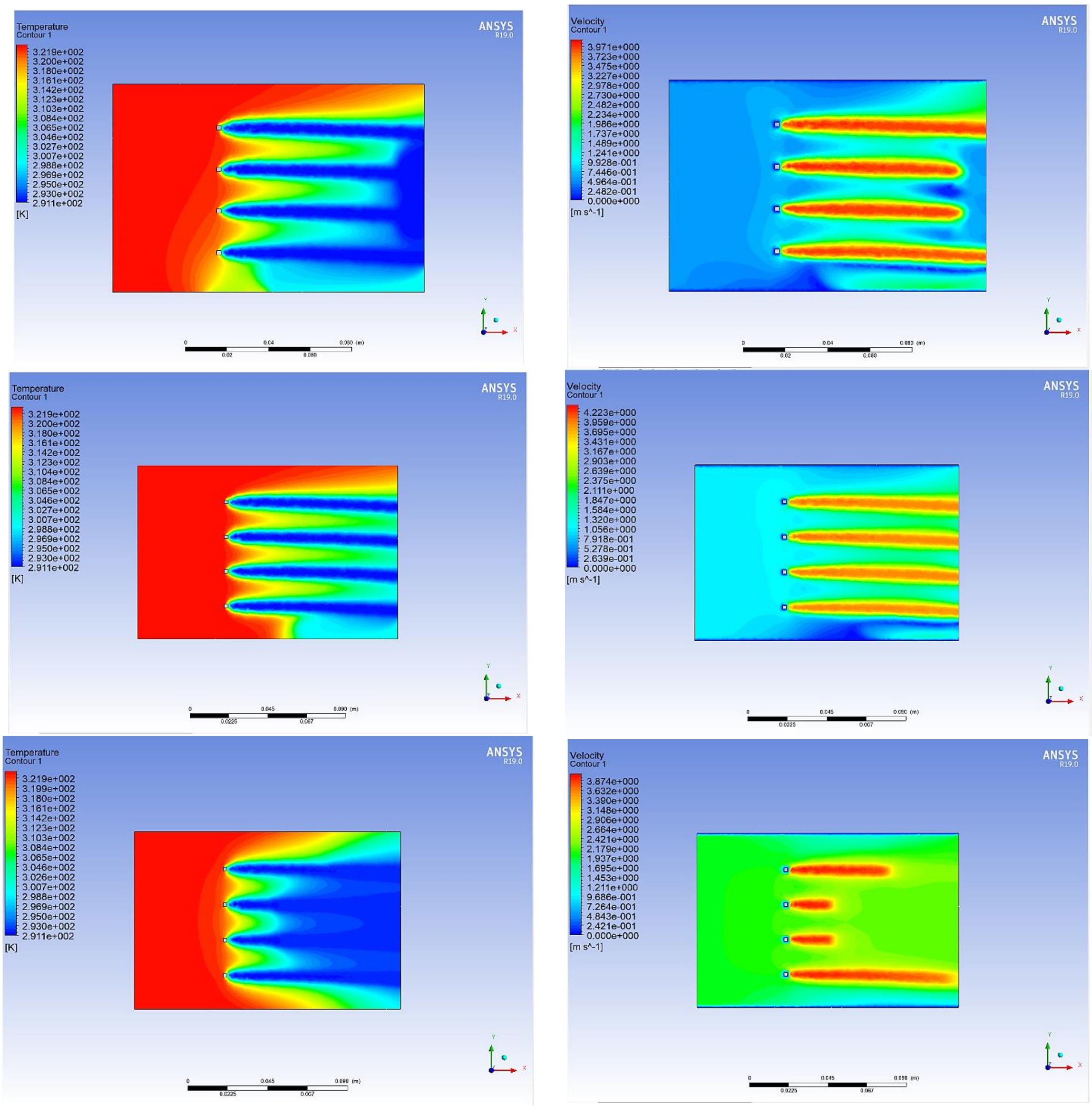
These results can be used to improve the system's design, maximizing air and water distribution within the system and improving heat transfer efficiency. The ideal number of nozzles and air velocity can be established with the aid of these temperature and velocity contours, resulting in a more energy-efficient system.



Temperature

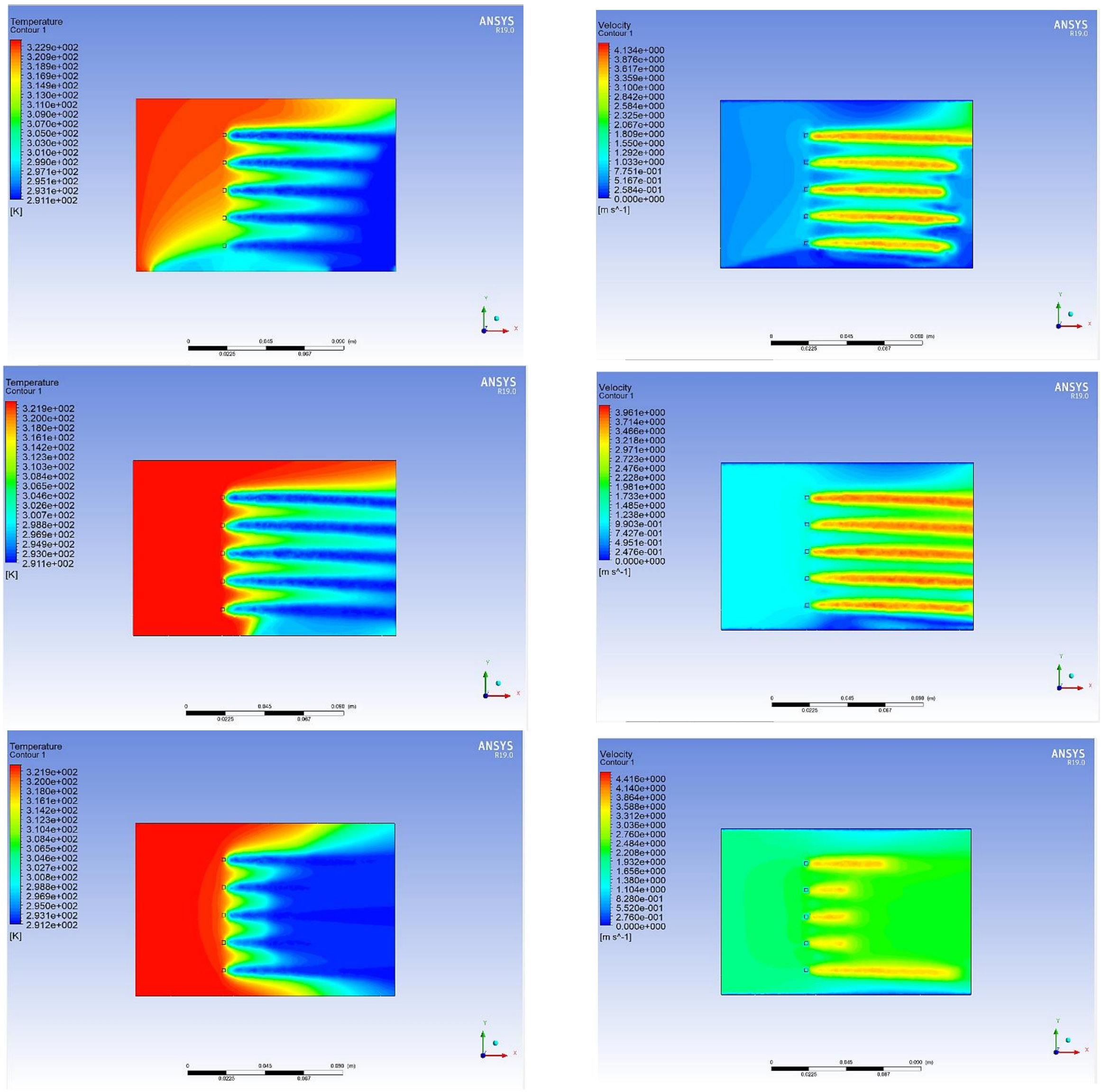
Velocity

Figure 4.11. Temperature and velocity contour variation with 15 nozzles and different air velocity, 05,1, and 2 m/s.



Temperature Velocity

Figure 4.12. Temperature and velocity contour variation with 24 nozzles and different air velocity, 05,1, and 2 m/s.



Temperature Velocity

Figure 4.13. Temperature and velocity contour variation with 35 nozzles and different air velocity, 05, 1 and 2 m/s.

4.4. EVALUATING SYSTEM EFFICIENCY: ANALYSIS OF COEFFICIENT OF PERFORMANCE (COP)

Table 4.1's coefficient of performance (COP) table demonstrates how the effectiveness of the system at various inlet velocities depends on the number of injectors and coil turns used. The system that produces the highest COP (4.537) at an inlet velocity of 2 m/s has 35 injectors and 13 coil turns, making it the most effective under these circumstances. Adding injectors and more coil turns may have enhanced efficiency by increasing the surface area for heat exchange.

Even though adding turns and injectors often increases COP, it's still crucial to keep this in mind. For example, when the number of turns increases, the COP significantly reduces for both 15 and 24 injectors at an inlet velocity of 1 m/s. This could be the result of a pressure drop caused by the additional revolutions, which could reverse the efficiency benefits.

It's interesting to note that the COP at higher speeds seems to increase as the number of injectors increases from 15 to 24, then to 35, regardless of the number of coil turns. This may imply that the number of injectors has a greater influence on the coefficient of performance (COP) at these higher velocities, possibly as a result of the faster rate of heat exchange caused by the larger amount of water sprayed.

The information reveals an intricate connection between the number of injectors, the number of coil spins, the speed of the inlet, and the system's coefficient of performance (COP). While there is a tendency for more turns and injectors to boost efficiency, other elements like pressure drops and evaporation rates can also have a large impact on the COP.

Table 4.1. Coefficient of performance (COP) for various inlet velocities, injector and coil turn configurations.

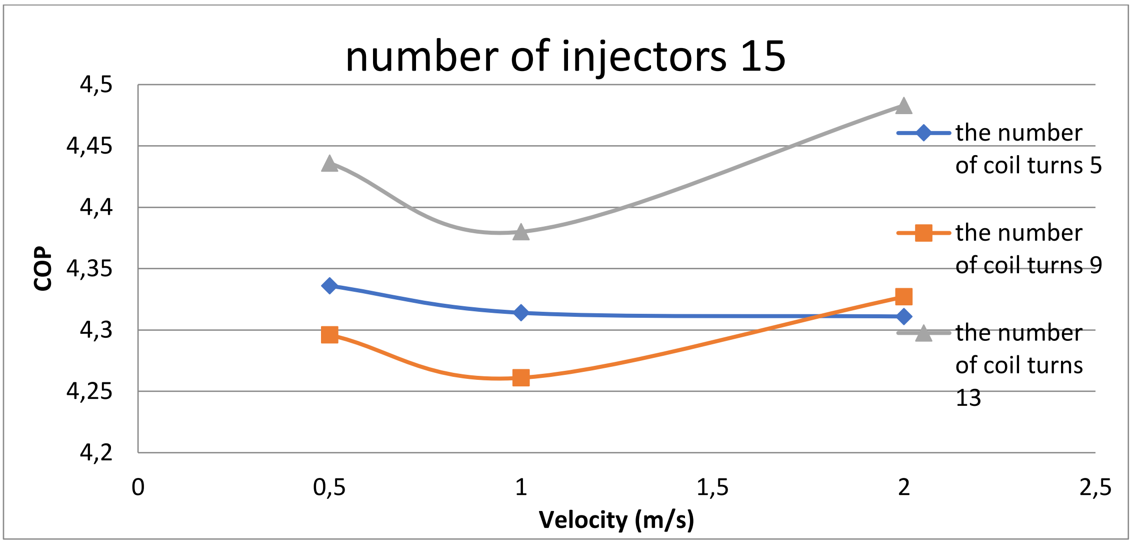
Inlet Velocity	**No. of Injectors / Coil Turns**	**15/5**	**15/9**	**15/13**	**24/5**	**24/9**	**24/13**	**35/5**	**35/9**	**35/13**
0.5	COP	4.336	4.296	4.436	4.321	4.303	4.442	4.35	4.315	4.452
1.0		4.314	4.261	4.38	4.295	4.274	4.347	4.348	4.295	4.438
2.0		4.311	4.327	4.483	4.321	4.342	4.506	4.332	4.362	4.537

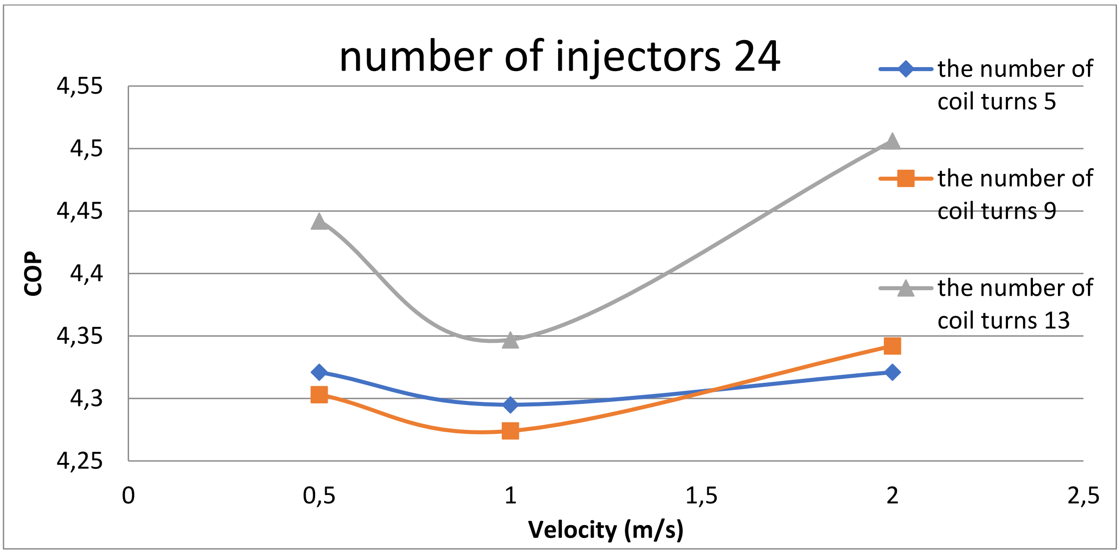
Last but not least, the outcomes are due to the increased heat transfer surface area caused by additional turns and nozzles. The fluid's journey is lengthened by more tube turns, increasing the surface area and time available for heat transmission. Similarly, an increase in the number of nozzles may improve fluid distribution and dispersion, resulting in more efficient heat transfer. However, trade-offs must be considered, such as a higher pressure drop due to more turns or a more complex and potentially more expensive design due to an increased number of nozzles. Future research should concentrate on optimizing these parameters to produce the most effective design with the fewest alternatives.

In a coil and tube type heat exchanger, the number of turns in the cooling tube and the number of nozzles play an important role in the efficiency of the heat exchange process. Engineers and designers can optimize the heat exchanger's structure for greater efficiency and performance if they comprehend the effects of these parameters. Despite the promising results, additional research is required to fully comprehend these complex interactions, and the optimal balance of these variables may be dependent on the heat exchanger's application and constraints.

4.4.1. COP with Velocity

The coefficient of performance is computed at three numbers of injections, which are (15, 24, and 35) in the same numbers of coils turns. The best injection is 35, which indicated that the three turns are higher in values than other turns, as shown below.





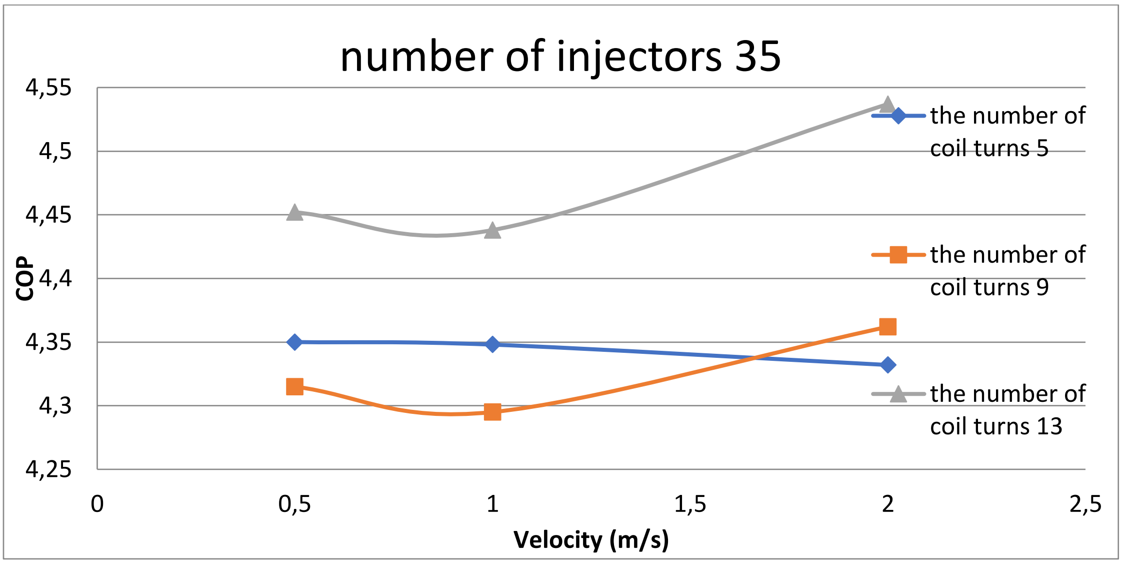


Figure 4.14. Number of coils turns with COP.

From figures 4.14, it can be obtain that the max COP reach approximately to 4.54, which is at 13 turns, while the 9 turns increase over 4.35.

There are big different between the 13 and 9 and 5 turns, which denote that when the turns increase the coil rotate in high speed and that leads to increases in COP.

4.5. VALIDATION WITH OTHER WORK

The study of polydisperse evaporating spray is difficult because of the influence of numerous physical factors. Few research have looked into the effect of water spray systems on heat exchangers, despite the fact that many have used CFD models to look into the cooling performance of these systems. The creation of a novel and straightforward method to replicate polydisperse-evaporating sprays over intricate 3D geometries is of tremendous interest for industrial applications. In order to examine the impact of water spray on heat exchangers and to propose a CFD water spray model, this research is the first contribution to the creation of a CFD numerical tool. The spray production and its dispersion in airflow are the two stages of the spray model. The spray development step represents the period of time between the injection of the droplets and the point at which the droplet velocity reaches the air velocity. The droplet trajectory analysis provides access to this position and the spray dimension, and the integration of the droplet size decrease equation yields the amount of liquid water evaporated. Boundary conditions are provided in this first section for the second step of the 3D CFD program Code_Saturne. The k-ε turbulence model is used in this CFD code to solve the Navier-Stokes equations for the spray. The liquid potential temperature, L, the total water specific humidity, qw, which are conservative factors for the evaporation processes, and the total number, Nc, of droplets are introduced as the three transport variables. A source term technique is used to incorporate droplet evaporation into the Nc equation. In order to represent and track the evolution of the droplet spectra, a lognormal law was also employed.

Good agreement is noticed between Fabien et al. work, figure 4.15 and the present work, figure 4.16.

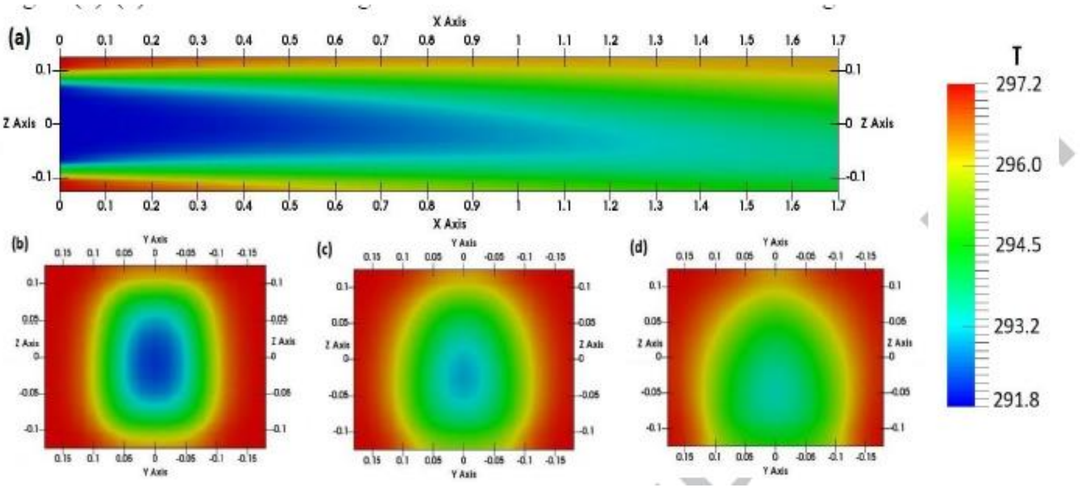
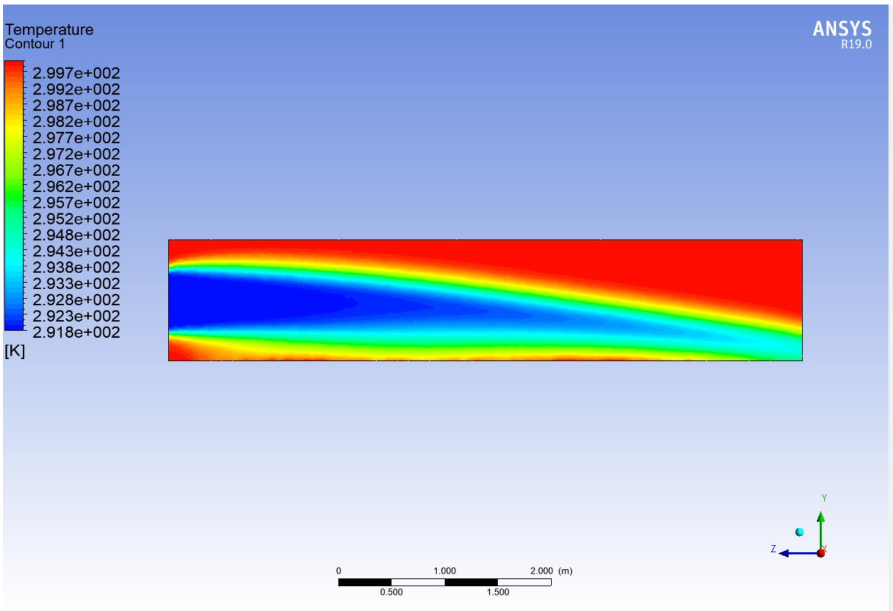


Figure 4.15. Air temperature field at y=0 m, x=0.5 m, x=1 m and x=1.5 m (Fabien et al. work).



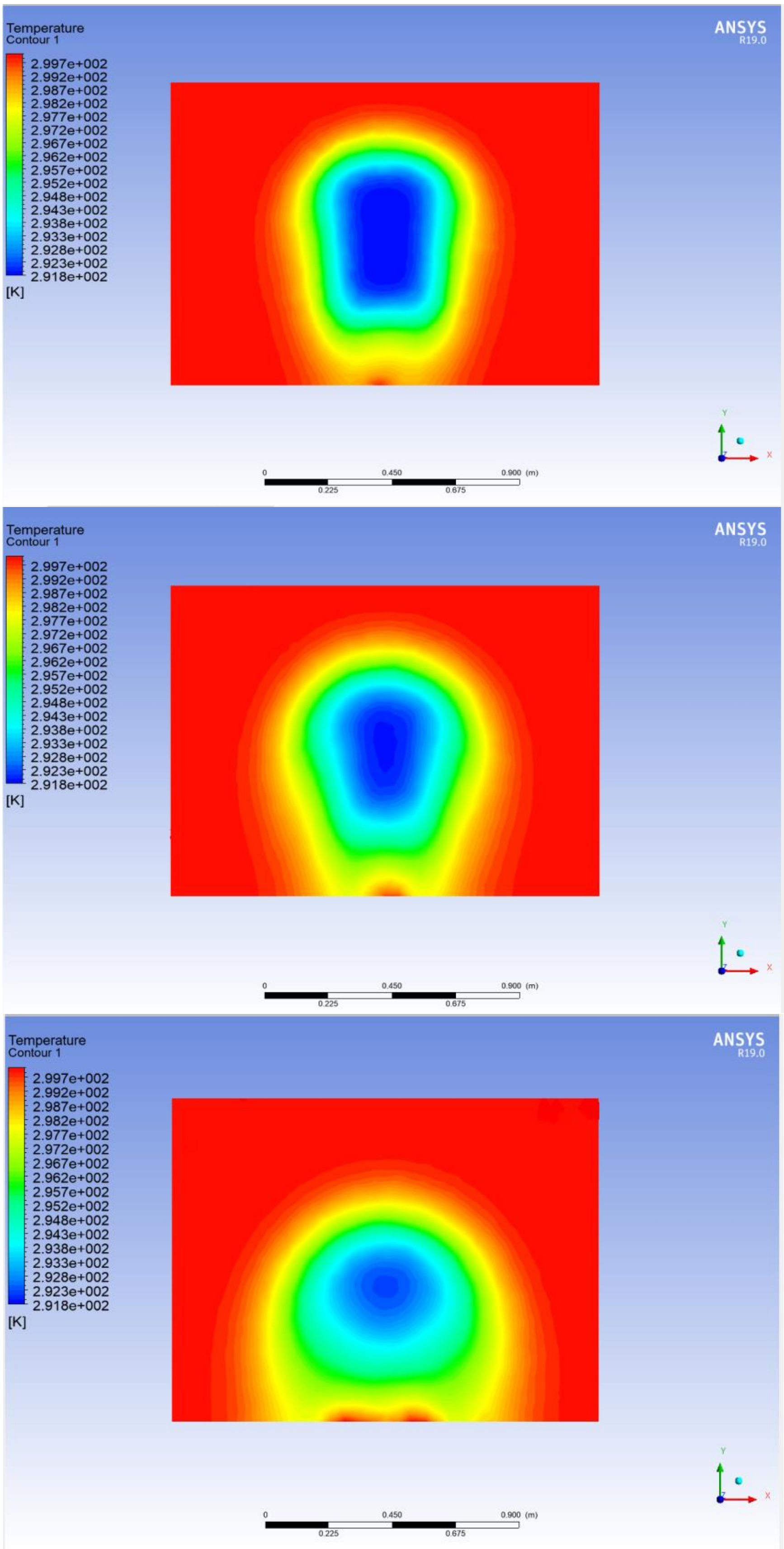


Figure 4.16. Air temperature field at y=0 m, x=0.5 m, x=1 m and x=1.5 m (present work).

PART 5

CONCLUSIONS AND RECOMMENDATIONS

As this investigational study on system geometry and its effects on the performance of a coil-and-tube type heat exchanger nears its conclusion, several noteworthy observations and insights emerge that merit summarization. The research was predicated primarily on the concept of analyzing complex geometrical configurations using ANSYS's robust simulation capabilities.

By meticulously varying the number of coils turns and the number of nozzles, the study examined the complex effects of these parameters on the performance of the system. Indicated by distinct temperature and velocity contours, the results demonstrated that these geometrical features have a substantial impact on the thermal dynamics and fluid flow within the heat exchanger. Consequently, the system geometry, specifically the air entry area and the water spraying process, plays a crucial role in the heat exchange process.

This investigation's findings have significant implications for the design and optimization of heat exchangers. The results demonstrate that the strategic modification of certain geometrical parameters may improve the overall performance and efficiency of such systems.

5.1 CONCLUSIONS

The following key points can be drawn as a conclusion:

1. The thermal dynamics and fluid flow within a heat exchanger are significantly influenced by system geometry, specifically the air entry area and the water spraying process.

2. As evidenced by the distinct temperature and velocity contours, the number of coils turns and nozzles can have a profound effect on the system's performance.
3. The study made effective use of ANSYS's robust simulation capabilities to handle complex geometrical configurations and provide valuable insights.
4. The configuration with 35 injectors and 13 coils turns achieved the highest COP of 4.537 at an inlet velocity of 2.0, indicating that it is the optimal configuration for the given system.
5. The max temperature degree reaches it is 55.27 ^{o}C. At the velocity 1 m/s conclude that the coil turns in temperature chart reaches to peak point while in COP chart be at lowest values at the same velocity.
6. Highest COP for the system 4.537 which is occur at number of injectors 35 and coil turns 13.
7. The findings of the study could pave the way for further optimization of such systems, which could increase their efficiency.
8. The research demonstrates the importance of computational tools for comprehending and enhancing complex thermal systems such as heat.

5.2. RECOMMENDATIONS

A number of suggestions can be made to improve our understanding of how system geometry affects heat exchanger performance based on the results of the extensive simulation study done with ANSYS. These suggestions broaden the range of applications for the findings and may prove helpful for upcoming investigations and applications.

1. The coil turn and nozzle count parameters could be further optimized, leading to a more effective system, with the help of extensive research.
2. The study can be expanded to look at how different fluids affect how well the system works.
3. The impact of varying the size of the duct on the heat exchange process of the system should be analyzed.
4. Future research should investigate how geometrical variations influence the performance of a system under transient conditions.

5. The impact of variations in pressure conditions in conjunction with the geometrical changes could be a topic worthy of study.
6. Although simulation provides robust insights, testing and validation of the findings in the real world are essential for their practical application.

These recommendations, taken together, may open new avenues of research and practical applications in the design and optimization of coil and tube type heat exchangers.

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RESUME

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