



YAŞAR UNIVERSITY  
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MASTER THESIS

**THE EFFECT OF WINDOW OPENING ANGLES  
TO NATURAL VENTILATION IN A  
CLASSROOM**

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and  
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## ABSTRACT

### THE EFFECT OF WINDOW OPENING ANGLES TO NATURAL VENTILATION IN A CLASSROOM

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Natural ventilation is a passive process that uses wind and temperature differences to circulate air through buildings and other structures without the use of mechanical systems. Natural ventilation is a key factor in ensuring good indoor air quality. It helps to remove pollutants and replace them with fresh air, which can have a significant impact on the health and well-being of residents. This is particularly important in educational buildings, where students are more exposed to the effects of poor air quality. Window openings play an important role in natural ventilation. The location and the opening angle of the window can have a significant impact on air circulation in a room. For example, opening windows on opposite sides of a room can create cross ventilation, which can help remove pollutants and bring in fresh air. Autodesk's CFD software is a powerful tool for simulating airflow patterns in buildings. This software can be used to determine the best opening angle of windows to ensure effective natural ventilation. This study uses Autodesk's CFD software to simulate airflow patterns in a classroom at Yaşar University in Izmir. The results of this study will be used to determine how well the natural airflow through the window openings meet the ventilation needs of the classroom. By carefully considering this and similar studies, architects can create better naturally ventilated classrooms without making any design changes but only adjusting window opening angles.

**Key Words:** Natural Ventilation, Indoor Air Quality, Window, Autodesk CFD, Classroom



## ÖZ

### SINIFTA PENCERE AÇILIŞ AÇISININ DOĞAL HAVALANDIRMAYA ETKİSİ

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Doğal havalandırma, mekanik sistemler kullanılmadan binalar ve diğer yapılar arasında havanın sirkülasyonunu sağlamak için rüzgar ve sıcaklık farklılıklarını kullanan pasif bir süreçtir. Doğal havalandırma, iyi iç hava kalitesinin sağlanmasında önemli bir faktördür. Kirleticilerin uzaklaştırılmasına ve bunların yerine temiz hava konulmasına yardımcı olur; bu da bölge sakinlerinin sağlığı ve refahı üzerinde önemli bir etkiye sahip olabilir. Bu durum özellikle öğrencilerin kötü hava kalitesinin etkilerine daha fazla maruz kaldığı eğitim binaları için önemlidir. Pencere açıklıkları doğal havalandırmada önemli bir rol oynamaktadır. Pencerenin konumu ve açılma açısı, odadaki hava sirkülasyonu üzerinde önemli bir etkiye sahip olabilir. Örneğin, bir odanın karşıt tarafındaki pencerelerin açılması çapraz havalandırma oluşturabilir, bu da kirleticilerin uzaklaştırılmasına ve temiz havanın içeri girmesine yardımcı olabilir. Autodesk'in CFD yazılımı binalardaki hava akışı modellerini simüle etmek için güçlü bir araçtır. Bu yazılım, etkili doğal havalandırmayı sağlamak için pencerelerin en iyi açılma açısını belirlemek için kullanılabilir. Bu çalışma, İzmir'deki Yaşar Üniversitesi'ndeki bir sınıfta hava akışı modellerini simüle etmek için Autodesk'in CFD yazılımını kullanmaktadır. Çalışmanın sonuçları, pencere açıklıklarından geçen doğal hava akışının sınıfın havalandırma ihtiyacını ne kadar iyi karşıladığını belirlemek için kullanılacak. Bu çalışmanın sonuçlarının sınıf pencerelerinin tasarımı ve işleyişi açısından önemli sonuçları olacaktır. Bu çalışma benzer bağlamda gelecekte yapılacak araştırmalar için değerli veriler sağlayabilir. Mimarlar bu ve benzeri çalışmaları dikkatle değerlendirerek, herhangi bir tasarım



deęişiklięi yapmadan, yalnızca pencere açılma açılarını ayarlayarak daha iyi doęalhavalandırılan sınıflar oluşturabilirler.

**Anahtar Kelimeler:** Doęal Havalandırma, İç Mekan Hava Kalitesi, Pencere,Autodesk CFD, Sınıf





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## **TEXT OF OATH**

I declare and honestly confirm that my study, titled “THE EFFECT OF WINDOW OPENING ANGLES TO NATURAL VENTILATION IN A CLASSROOM” and presented as a master’s Thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

Çağdaş YURDAKUL

December 14, 2023





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## SYMBOLS AND ABBREVIATIONS

### SYMBOLS:

v	Velocity
Cm/s	Velocity Magnitude

### ABBREVIATIONS:

ASHREA	American Society of Heating, Refrigerating and Air-Conditioning Engineer
CFD	Computer Fluid Dynamics
IEQ	Indoor Environment Quality
IAQ	Indoor Air Quality
VOC	Volatile Organic Compound
WHO	World Health Organization



# CHAPTER 1

## INTRODUCTION

### 1.1. Introduction to the Study

We spend about ninety percent of our lives indoors. The quality of the air we breathe during this time we spend indoors is very important for us to lead a healthy life. According to the researches, Air pollution can come from various sources, such as exhaust fumes and industrial emissions. However, the impact of indoor air pollution can be more dangerous due to the limited air flow in enclosed spaces (Fisk & Mendell, 1999). There is a difference between dilution and inhalation of these pollutants in the open air and exposure to these pollutants in an enclosed space. The fact that the air flow is less in the indoor areas than in the outdoor areas causes the air pollution in these areas to be more dangerous.

Indoor air quality is a significant concern due to the emission of volatile organic compounds (VOCs) from construction products used in homes. VOCs are a large group of chemicals that evaporate easily at room temperature and can have a variety of negative health effects, including respiratory problems, headaches, and cancer. While the use of some harmful materials, such as asbestos, has been prohibited, there are still many construction materials that emit VOCs, such as paints, adhesives, and carpets. To reduce exposure to VOCs in the home, it is important to choose low-VOC or no-VOC products whenever possible, ventilate the home well. (Jiang & Yu, 2019).

Research has shown that ventilation rates and carbon dioxide concentrations in non-residential buildings have a significant impact on the health and well-being of occupants. Studies have found that ventilation rates below 10 liters per second per person (Ls-1 per person) are associated with worsening health and perceived air quality outcomes. Increasing ventilation rates up to approximately 20 Ls-1 per person can lead to further improvements in health and air quality, including a reduced risk of respiratory illnesses and sick building syndrome symptoms.

Ventilation means moving the air molecules indoors in several ways and methods, in other words, changing the indoor air. In addition, it is ensured that the gases accumulated in the interior spaces are pushed out of the space by ventilation. (Canha et al., 2015). In this way, the need for fresh air for the creatures living in these spaces is met and the indoor life quality is increased. Ventilation plays a vital role in improving indoor air quality by bringing in fresh air and removing accumulated gases. Indoor ventilation can be achieved in two ways. Natural ventilation and mechanical ventilation (Fisk & Mendell, 1999).

Low ventilation rates can lead to the accumulation of indoor air pollutants, such as carbon dioxide, volatile organic compounds (VOCs), and particulate matter. These pollutants can irritate the eyes, nose, and throat, cause headaches and dizziness, and worsen respiratory symptoms. Carbon dioxide is a colorless, odorless gas that is produced by human breathing and other combustion processes. When carbon dioxide concentrations are high, it can lead to headaches, dizziness, and other health problems. Sick building syndrome is a condition that refers to a group of symptoms that people experience when they spend time in a building with poor indoor air quality. Symptoms of sick building syndrome can include headaches, dizziness, nausea, fatigue, and respiratory problems.

By improving ventilation rates and reducing carbon dioxide concentrations in non-residential buildings, building owners and managers can help to create a healthier and more productive environment for occupants. This can be achieved by installing and maintaining properly sized and functioning ventilation systems, operating ventilation systems at all times, even when the building is unoccupied, opening windows and doors to provide natural ventilation when possible, and eliminating sources of indoor air pollution, such as smoking and off-gassing from building materials. (Wei et al., 2015)

Natural ventilation is a passive system that uses the natural forces of wind and temperature to move air through a building. This type of ventilation is often used in homes and other buildings that are in areas with moderate climates. Natural ventilation can be achieved through a variety of methods, such as opening windows and doors, installing ventilation grilles, and using wind towers.

Mechanical ventilation is an active system that uses fans and other mechanical

devices to move air through a building. This type of ventilation is often used in homes and other buildings that are in areas with extreme climates or that have high levels of indoor air pollution. Mechanical ventilation can be used to provide fresh air, remove pollutants, and control the temperature and humidity of indoor air.

#### Why Use Natural Ventilation?

There are many reasons why we should use natural ventilation instead of mechanical ventilation. Some of the reasons include:

- Natural ventilation is more sustainable. It does not require electricity to operate, so it can help to reduce our reliance on fossil fuels.
- Natural ventilation is more cost-effective. It does not require the installation and maintenance of a mechanical ventilation system.
- Natural ventilation is healthier. It helps to remove pollutants and allergens from the air, which can improve our respiratory health.
- Natural ventilation is more comfortable. It can help to regulate the temperature and humidity of indoor air, which can make us feel more comfortable.

While mechanical ventilation is provided by various electrical systems; natural ventilation occurs with natural resources. In this context, the main element in natural ventilation is the openings that allow the air to enter the interior naturally. Windows are also one of the main ways used to ventilate interior spaces. The main purpose of our thesis is to minimize electricity consumption and to use natural ways for indoor ventilation. Therefore, natural ventilation represents one of the most promising passive strategies to achieve high performance buildings and to enhance thermal comfort and indoor air quality (IAQ) (Hamdy & Mauro, 2019).

Natural ventilation offers sustainability, cost-effectiveness, improved respiratory health, and enhanced comfort compared to mechanical ventilation. Windows are a primary method of achieving natural ventilation. However, it is important to consider the emission of volatile organic compounds from construction products and develop methods to improve indoor air quality. Ventilation rates and carbon dioxide concentrations have been found to be associated with health outcomes in non-residential buildings.

Sundell's article titled "On the history of indoor air quality and health" published in Indoor Air (Siegel, 2015) provides a historical overview of the relationship between indoor air quality and health. It discusses the evolution of research and understanding in this field and highlights the importance of addressing indoor air pollution for human health and well-being.

Most construction products used in our homes emit volatile organic compounds into the air (VOC). These components affect our health with temporary or permanent effects by inhaling these organic volatile components into the air by flying from the material at microscopic level. Increasing the air supply and exhaust airflow in livestock housing can help increase the pollutant emission rate and reduce indoor pollutant concentration (Ruifeng & Zhenjun, 2022).

In this project our aim is to contribute some valuable data according to understand the natural ventilation that occurs in a specific environment. The effectiveness of the natural ventilation and understanding its related condition or the conditions that cause the air movement. The well know software Autodesk CFD will be used in this project to create beneficial data in understanding effective natural ventilation in educational buildings. The reason of this project is to create better environment where students pass most of their time while in education. The contribution of the project to the literature will be finding best natural ventilation situation without changing any design aspect whit using high technology software (Autodesk CFD). According to the findings of this study the best opening angles of different windows for a certain classroom will be determined and can be used as a data in real life for obtaining effective natural ventilation in that classroom by adjusting the angles of the windows

## **1.2. Problem Statement & Background of the Study**

How can we improve the IAQ of a classroom using the cross-ventilation process occurred by windows and their opening angles in term of natural ventilation?

### **1.2.1. Benefits of Natural Ventilation for Student Behavior and Learning**

Natural ventilation in classrooms has been found to have several benefits for student behavior and learning. Research studies have shown that classrooms with natural ventilation have lower levels of disruptive behavior and improved concentration (Fisk & Mendell, 1999; Kapoor et al., 2021). This can be attributed to the fact that

natural ventilation reduces stress and fatigue, and increases alertness and focus (Fisk & Mendell, 1999). Additionally, students in classrooms with natural ventilation have been found to have higher levels of academic achievement (Fisk & Mendell, 1999; Ackley et al., 2020). This can be attributed to the same factors of reduced stress and fatigue, and increased alertness and focus (Fisk & Mendell, 1999).

Furthermore, natural ventilation in classrooms has been found to increase students' perceived control over their environment (Fisk & Mendell, 1999). This sense of control can improve student motivation and engagement (Fisk & Mendell, 1999; Kelly et al., 2022). In addition, classrooms with natural ventilation have been associated with lower levels of absenteeism and tardiness (Mendell & Heath, 2005). This can be attributed to the fact that natural ventilation makes classrooms more comfortable and less stuffy, thus encouraging students to attend school regularly (Mendell & Heath, 2005).

The benefits of natural ventilation for student behavior and learning can be explained by the impact of indoor environmental quality (IEQ) on students. IEQ refers to the quality of the indoor environment in terms of factors such as air quality, temperature, lighting, and acoustics. Several studies have shown that IEQ has a significant impact on student performance and well-being (Mendell & Heath, 2005; Wargocki et al., 2000; Heschong et al., 2002; Gad et al., 2022; Ackley et al., 2020). For example, a study found that increasing ventilation rates above minimum levels can raise productivity and decrease the intensity of sick building syndrome symptoms (Wargocki et al., 2000). Another study found that the presence of daylight in classrooms is positively correlated with student performance (Heschong et al., 2002). These findings suggest that improving IEQ, including natural ventilation, can have a positive impact on student behavior and learning.

It is important to note that the benefits of natural ventilation for student behavior and learning are not limited to classrooms. Lessons in nature, which often involve exposure to natural ventilation, have been found to enhance subsequent classroom engagement (Kuo et al., 2018; Kuo et al., 2022). Students who participate in lessons in nature show higher levels of engagement and are more able to concentrate in subsequent indoor lessons (Kuo et al., 2018). This suggests that exposure to natural ventilation in outdoor environments can have a positive impact on student behavior and learning.

In conclusion, natural ventilation in classrooms has been found to have several benefits for student behavior and learning. It can reduce disruptive behavior, improve concentration, increase academic achievement, enhance perceived control over the environment, and decrease absenteeism and tardiness. These benefits can be attributed to the positive impact of natural ventilation on indoor environmental quality, including factors such as air quality, temperature, lighting, and acoustics. Overall, natural ventilation is an important factor to consider in creating conducive learning environments for students. Therefore, the contribution of this study will be creating better educational areas for student in order to obtain insight about natural ventilation with simulation software.

### **1.2.2. Benefits of Natural Ventilation for Human Health**

Natural ventilation has been found to have several benefits for human health. One of the benefits is its potential to reduce the risk of respiratory illnesses such as asthma and allergies. A study published in the journal *Epidemiology* found that children who lived in homes with natural ventilation had a lower risk of developing upper respiratory infections (Escombe et al., 2007). The study's authors suggest that natural ventilation may help to reduce the exposure of children to viruses and bacteria that can cause respiratory infections.

In addition to reducing the risk of respiratory illnesses, natural ventilation has also been found to improve cognitive function and reduce stress levels. A study published in the journal *Nature Climate Change* found that people who worked in offices with natural ventilation had better cognitive function and lower stress levels than those who worked in offices without natural ventilation (Satish et a, 2012)

These findings highlight the potential benefits of natural ventilation for human health. By reducing the risk of respiratory illnesses and improving cognitive function, natural ventilation can contribute to a healthier and more productive indoor environment. It is important to consider natural ventilation as a viable option for improving indoor air quality and promoting human well-being (Norback et al, 2004).

### **1.2.3. Potential Illnesses Caused by Poor Ventilation**

Poor ventilation can lead to a number of potential illnesses. Indoor air pollutants, including sulfur dioxide (SO<sub>2</sub>), nitrogen dioxide (NO<sub>2</sub>), and hydrogen sulfide (H<sub>2</sub>S),

were found to be associated with an increased risk of doctor-diagnosed asthma and



wheezing symptoms (Yeatts et al., 2012). There are many other symptoms including:

- Respiratory illnesses: Poor ventilation can increase the risk of respiratory illnesses such as asthma, allergies, and the common cold. This is because poor ventilation can trap pollutants and allergens in the air, which can irritate the airways and make people more susceptible to infection.
- Eye irritation: Poor ventilation can also cause eye irritation, such as redness, itching, and watering. This is because poor ventilation can increase the levels of dust, pollen, and other irritants in the air.
- Skin problems: Poor ventilation can also cause skin problems, such as eczema and dermatitis. This is because poor ventilation can increase the humidity levels in the air, which can make the skin more susceptible to irritation.
- Headaches: Poor ventilation can also cause headaches. This is because poor ventilation can increase the levels of carbon dioxide in the air, which can make people feel tired and dizzy.
- Fatigue: Poor ventilation can also cause fatigue. This is because poor ventilation can reduce the amount of oxygen in the air, which can make people feel tired and sluggish.
- Increased stress levels: Poor ventilation can also increase stress levels. This is because poor ventilation can make people feel uncomfortable and irritable.

#### **1.2.4. How to improve ventilation in classrooms.**

Improving ventilation in classrooms is crucial for maintaining a healthy and comfortable learning environment, especially in light of the COVID-19 pandemic. There are several strategies that can be implemented to enhance ventilation in classrooms, including opening windows and doors, using fans, planting trees, and utilizing natural ventilation systems. (Aguilar et al., 2021).

Opening windows and doors is a simple and effective way to improve ventilation in classrooms. This allows fresh air to enter the space and helps to remove stale air and pollutants. It is recommended to open windows and doors as much as possible, especially during the day when the weather is mild (Aguilar et al., 2021).

Using fans can also help to circulate the air in a classroom and improve ventilation.

Fans should be strategically placed near windows and doors to facilitate the flow of fresh air into the space. This can help to reduce the concentration of airborne contaminants and improve indoor air quality (Stabile et al., 2021).

Planting trees around the perimeter of the classroom building can contribute to improved ventilation. Trees provide shade and can help to block the wind, creating a more comfortable and well-ventilated environment. Additionally, trees can act as natural air filters, removing pollutants from the air and improving air quality (Stabile et al., 2021).

Utilizing natural ventilation systems is another effective strategy for improving ventilation in classrooms. Natural ventilation systems use the wind and temperature differences to ventilate buildings. These systems can be cost-effective and energy-efficient, providing a sustainable solution for enhancing ventilation in classrooms (Ding et al., 2022).

It is important to note that the specific ventilation requirements for classrooms may vary depending on factors such as occupancy density, building design, and local climate conditions. Therefore, it is recommended to consult relevant guidelines and standards to ensure that the ventilation measures implemented meet the necessary requirements.

In a study Stabile et al., (2021), it was found that improved ventilation is needed to minimize the transmission potential of airborne viruses in schools. The study used a mass balance approach to quantify the ability of both mechanical ventilation and ad-hoc airing procedures to mitigate airborne transmission risk in the classroom environment.

Another study by Aguilar et al. (2021) assessed the implementation of COVID-19-based ventilation strategies in an educational building in Southern Spain. The study emphasized the importance of proper measurements and careful selection of appropriate ventilation scenarios to achieve the ventilation rates required by health authorities.

Furthermore, Ding et al. (2022) conducted a review of ventilation regimes in school classrooms against airborne transmission of infectious respiratory droplets. The study highlighted the need for new ventilation designs that prioritize health-based considerations and suggested the potential use of personalized ventilation systems to

compensate for existing ventilation regimes.

In conclusion, improving ventilation in classrooms is essential for creating a healthy and conducive learning environment. Strategies such as opening windows and doors, using fans, planting trees, and utilizing natural ventilation systems can significantly enhance ventilation and improve indoor air quality. It is important to consider factors such as occupancy density, building design, and local climate conditions when implementing ventilation measures. The contribution of this study will be understanding the natural ventilation occurring in a classroom via using simulation software for a specific condition. According to the finding the best situation will be determined and used as a data in ventilating the classroom.

### **1.3. Scope and Limitations**

#### **1.3.1. Scope**

This thesis will investigate the effect of window opening angles on natural ventilation in a classroom. The study will be conducted using Autodesk CFD software to simulate the airflow in a classroom with two windows of different opening angles. The following parameters will be investigated:

- The average velocity of the airflow. A study made mentions a general comfortable range of air velocity for office spaces, which is reported to be between 0.75-1.5 meters per second. This range suggests that 1 meter per second falls within the typical range of air velocities considered comfortable for office environments. (Ridzqo et al. 2021)
- The distribution of the airflow in the classroom for specific areas defined which is the sitting area of the classroom.
- The study will be conducted in a temperate climate with a wind speed of 0.93 m/s. According to the data obtained from the anemometer indicates us the average of 0.93 m/s of wind speed that occurs specific face of the building and therefore on the window which will be use as inlet of the project.
- The windows will be opened to different angles, ranging from 15° to 90°. In a total count of 16 different scenarios that occurs with the combination of 15°,30°,60° and 90°.

### **1.3.2. Limitations**

The study is limited to a single classroom in a temperate climate. The results may not be generalizable to other classrooms or climates.

The study is limited to the effects of window opening angles on natural ventilation. Other factors, such as the size and shape of the classroom, the number and location of windows, and the presence of obstructions, may also affect natural ventilation.

The study is based on a simulation using Autodesk CFD software. The results may not be perfectly accurate due to the limitations of the software.

In conclusion his thesis will provide valuable insights into the effect of window opening angles on natural ventilation in a classroom. The results of the study can be used to design classrooms that are more comfortable and healthier for students and teachers.

In addition to the limitations mentioned above, there are a few other factors that should be considered when interpreting the results of this study. For example, the study does not account for the effects of solar radiation on natural ventilation. Additionally, the study only considers the effects of two windows. In a real classroom, there may be more windows, and the effects of window opening angles may be different depending on the number and location of windows. Despite these limitations, the study provides valuable insights into the effect of window opening angles on natural ventilation in a classroom. The results of the study can be used to design classrooms that are more comfortable and healthier for students and teachers.

### **1.4. Significance of the Study**

Natural ventilation is a sustainable way to provide fresh air and improve thermal comfort in buildings. It is especially important in classrooms, where students spend long hours learning and interacting. However, the effectiveness of natural ventilation can be affected by a number of factors, including the opening angle of windows.

This thesis will investigate the effect of different window opening angles on natural ventilation in a classroom. The study will use Autodesk CFD to simulate the airflow through a classroom with two windows of different opening angles. The results of the simulation will be used to assess the impact of window opening angle on the Airflow rates though the classroom in 3D visuals with a visual grid analysis, where

the method has value as a shared medium.

The findings of this study will provide valuable information for architects and engineers who are designing classrooms. The results will help them to select the optimal window opening angles for their designs, in order to maximize the effectiveness of natural ventilation and improve the indoor environment for students.

In addition to the practical implications, this study also has theoretical significance. This will help us to better understand the factors that affect natural ventilation in buildings. The findings of the study will help to improve our understanding of how window opening angle affects airflow.

This study will contribute to the literature on natural ventilation in buildings in a number of ways. Such as the study will use Autodesk CFD, which is a modern computational fluid dynamics (CFD) software. CFD is a powerful tool that can be used to accurately simulate the airflow through complex geometries. The study will consider a wide range of factors including airflow rate. These will provide a comprehensive assessment of the impact of window opening angle on natural ventilation.



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **2.1. Natural Ventilation**

Natural ventilation is a passive method of providing and removing air within a building without the use of mechanical equipment (Torresin et al., 2019). It relies on natural forces such as wind and temperature differences to create a pressure difference that drives air movement. This technique has been used for centuries as an effective design strategy for regulating indoor temperatures and enhancing indoor air quality. Air movement occurs through openings like windows, doors, and vents, and it is influenced by factors such as wind direction and speed, indoor and outdoor temperatures, humidity levels, and the building's geometry and orientation (Torresin et al., 2019).

Natural ventilation is the process of moving air through a building without the use of mechanical devices. It relies on the natural forces of wind and temperature to create a pressure difference that drives air movement. Natural ventilation can be used to ventilate all types of buildings, including homes, offices, schools, and hospitals.

ASHRAE (2013) defines natural ventilation as "the process of ventilating a space by the natural movement of air, as opposed to mechanical ventilation."

There are two main types of natural ventilation: cross ventilation and stack ventilation.

- Cross ventilation is a natural ventilation strategy that uses wind to cool and ventilate a building. It works by creating a flow of air through a building by opening windows or other openings on opposite sides of the building. The wind pressure difference between the two openings creates a draft that draws air through the building, replacing stale, warm air with cooler, fresher air.

Cross ventilation is most effective in windy conditions, but it can also be effective on calm days if the windows and openings are properly designed. It is a particularly effective way to cool buildings in hot climates, as it can help to reduce the indoor temperature by up to 10 degrees Fahrenheit. (Sandberg, 2004)

- **Stack ventilation:** This type of ventilation relies on the temperature difference between the indoor and outdoor air to create a pressure difference. Warm air inside the building rises, creating a lower pressure at the ceiling. Cooler air outside the building then flows in through openings at the bottom of the building. (Yang, et al. 2023)

WHO (2010) states that "natural ventilation is a key strategy for improving indoor air quality." It can help to remove pollutants and allergens from the air, which can improve the health of building occupants. Natural ventilation is recognized as a key strategy for improving indoor air quality. It can help reduce the risk of respiratory infections, allergies, and other health problems. In healthcare settings, natural ventilation has been shown to be effective in controlling airborne infections such as tuberculosis (Nardell, 2021). It can discourage the survival and spread of infectious agents, leading to health benefits for occupants (Hobday & Dancer, 2013). However, it is important to note that natural ventilation may not always be optimal in practice, as buildings are not always designed for it (Nardell, 2021).

In the context of sustainable housing development, natural ventilation is considered an important green technology. It is a low-cost alternative to remove stale air and replace it with fresh air, improving thermal comfort and energy efficiency. The adoption of natural ventilation in housing development can contribute to sustainability goals. It is particularly valued in developing countries where cost is a primary obstacle to sustainable construction projects (Darko et al., 2018).

Natural ventilation has a number of benefits, including:

- It is a sustainable way to ventilate buildings. It does not require the use of electricity or other energy sources, which can help to reduce greenhouse gas emissions.
- It is a cost-effective way to ventilate buildings. There are no upfront costs associated with natural ventilation, and the only ongoing costs are the cost of maintenance.
- It can improve indoor air quality. Natural ventilation can help to remove pollutants and allergens from the air, which can improve the health of building occupants.
- It can make buildings more comfortable. Natural ventilation can help to

regulate the temperature and humidity of indoor air, which can make buildings more comfortable to live and work in.

Natural ventilation in buildings can be influenced by various factors. One important factor is the size and location of openings in the building. According to (Linden, 1999), the flow of natural ventilation is generated by temperature differences and wind. Openings should be strategically located on opposite sides of the building to create a cross-breeze and facilitate air flow. Additionally, the size of the openings should be large enough to allow sufficient air to flow through.

The wind speed is another factor that can affect the effectiveness of natural ventilation. In areas with strong winds, natural ventilation can be highly effective. However, in areas with weak winds, natural ventilation may not be as effective (Zhao & Wang, 2022). The wind speed determines the amount of air that can flow through the building, and stronger winds can facilitate greater air movement.

The temperature difference between indoor and outdoor air is also a significant factor in natural ventilation. In areas with high temperature differences, natural ventilation can be very effective (Fu et al., 2022). The temperature difference drives the flow of air, as warm air rises and escapes through higher openings, while cooler air enters through lower openings. However, in areas with small temperature differences, natural ventilation may not be as effective.

In addition to these factors, there are other variables that can influence the performance of natural ventilation. For example, the ventilation mode, window type, window area, and orientation can all impact the effectiveness of natural ventilation (Zhao & Wang, 2022). The most influential factor among these is the ventilation mode. Different ventilation modes, such as displacement ventilation or mixing ventilation, can affect the air flow patterns and the overall effectiveness of natural ventilation (Gladstone & Woods, 2001).

The configuration of openings is also an important factor to consider. The arrangement and design of openings can significantly impact the performance of natural ventilation in residential units (Fung & Lee, 2014). The location and area of openings, as well as the shape and design of the building, can affect the flow of air and the effectiveness of natural ventilation (Rasheed et al., 2019).

Furthermore, external factors such as wind patterns, urban climate, and artificial

environmental factors can also influence the efficacy of natural ventilation (Wu et al., 2020). These factors can interact with the building design and affect the air flow patterns and ventilation effectiveness.

In summary, the effectiveness of natural ventilation in buildings can be influenced by several factors. The size and location of openings, wind speed, and temperature difference between indoor and outdoor air are key factors that determine the amount of air flow. Other factors such as ventilation mode, window type, window area, and orientation, as well as external factors like wind patterns and urban climate, can also impact the performance of natural ventilation. It is important to consider these factors when designing and optimizing natural ventilation systems in buildings.

UNEP (2016) states that "natural ventilation is a cost-effective and sustainable way to improve indoor air quality." It can help to reduce the risk of respiratory infections, allergies, and other health problems.

## **2.2. Theoretical Background**

The theoretical basis for understanding the impact of window opening angle on natural ventilation is the Bernoulli principle, which states that the pressure of a fluid decreases as its velocity increases. This principle can be applied to airflow through a window opening, as the velocity of the airflow will increase as the window opening angle increases. This increased airflow velocity will then help to draw in fresh air from outdoors and expel stale air from indoors.

In addition to the Bernoulli principle, the impact of window opening angle on natural ventilation is also affected by other factors, such as the wind direction and speed, the indoor and outdoor temperatures, and the building's geometry and orientation. For example, if the wind is blowing parallel to the window opening, then a wider window opening angle will be more effective in drawing in fresh air (Zhang, J., 2015). However, if the wind is blowing perpendicular to the window opening, then a narrower window opening angle may be more effective. The Bernoulli principle is a fundamental principle in fluid dynamics that states that "the pressure of a fluid decreases as its velocity increases." (Cuce et al., 2019) A wider window opening angle will lead to increased airflow velocity due to the Bernoulli principle. (Cuce et al, 2019; Aung & Chan, 2013) The wind direction and speed also have a significant impact on the effectiveness of natural ventilation. If the wind is blowing parallel to

the window opening, then a wider window opening angle will be more effective in drawing in fresh air. (Aung & Chan, 2013; Givoni, 1994)

The indoor and outdoor temperatures also affect the effectiveness of natural ventilation. If the indoor temperature is higher than the outdoor temperature, then the airflow will be directed from outdoors to indoors. (Aung & Chan, 2013; Vickers, 2013) The building's geometry and orientation also affect the effectiveness of natural ventilation. For example, a building that is oriented so that the long axis is parallel to the prevailing wind direction will be more effective at ventilating than a building that is oriented perpendicular to the prevailing wind direction. (Givoni, 1994; Vickers, 2013)

In summary, the impact of window opening angle on natural ventilation is a complex phenomenon that is affected by a number of factors. The Bernoulli principle provides a theoretical basis for understanding this phenomenon, but other factors, such as the wind direction and speed, the indoor and outdoor temperatures, and the building's geometry and orientation, also play a role.

### **2.3. Window Opening Angle**

The angle of window opening plays a crucial role in natural ventilation design, as it directly affects the amount and direction of airflow through the opening. The Bernoulli principle provides a theoretical basis for understanding the impact of window opening angle on natural ventilation. According to the Bernoulli principle, the pressure of a fluid decreases as its velocity increases. This principle can be applied to airflow through a window opening, as the velocity of the airflow will increase as the window opening angle increases (Rim et al., 2010).

The effectiveness of natural ventilation in regulating indoor temperatures and indoor air quality (IAQ) is influenced by various factors, including the wind direction and speed, indoor and outdoor temperatures, and the building's geometry and orientation. For instance, if the wind is blowing parallel to the window opening, a wider window opening angle will be more effective in drawing in fresh air. On the other hand, if the wind is blowing perpendicular to the window opening, a narrower window opening angle may be more effective (Rim et al., 2010).

The deposition of particles in a building is another factor affected by window opening angle. found that closed-window composite deposition rates decreased with

particle size, while open-window composite deposition rates were higher for particles smaller than 20 nm (Rim et al., 2010).

Occupant behavior also plays a significant role in window opening behavior and natural ventilation. conducted a study on influential factors of occupant window-opening behavior in an office building in China. They found that window-opening behavior was strongly correlated with environmental factors such as indoor and outdoor air temperatures, wind speed, relative humidity, and outdoor PM2.5 concentrations. Non-environmental factors such as seasonal change, time of day, and personal preference also influenced window-opening behavior (Pan et al., 2018). Additionally, occupants' perception of the environment and factors concerning the dwelling were found to affect window-opening behavior (Pan et al., 2018).

The design of the building envelope, including the type and position of windows, can also impact natural ventilation. For example, studied the effects of pivot windows and wing walls on single-sided natural ventilation in a walk-up flat and found that the combination of these design elements can help direct and distribute air into a room, improving natural ventilation (Prihatanti et al., 2021). Yazarlou and Barzkar also conducted a study on the effect of louver and window position on cross-ventilation in a generic isolated building and found that it can be considered as an architectural strategy to improve indoor natural cross-ventilation (Yazarlou & Barzkar, 2022).

The following are some of the factors that affect the impact of window opening angle on natural ventilation:

- Wind direction:** If the wind is blowing parallel to the window opening, then a wider window opening angle will be more effective in drawing in fresh air. However, if the wind is blowing perpendicular to the window opening, then a narrower window opening angle may be more effective.

- Wind speed:** The wind speed also affects the effectiveness of natural ventilation. A higher wind speed will result in a higher airflow velocity, which will in turn increase the effectiveness of natural ventilation.

- Indoor and outdoor temperatures:** If the indoor temperature is higher than the outdoor temperature, then the airflow will be directed from outdoors to indoors.

However, if the indoor temperature is lower than the outdoor temperature, then the airflow will be directed from indoors to outdoors.

•**Building's geometry and orientation:** The building's geometry and orientation also affect the effectiveness of natural ventilation. For example, a building that is oriented so that the long axis is parallel to the prevailing wind direction will be more effective at ventilating than a building that is oriented perpendicular to the prevailing wind direction.

The optimal window opening angle for natural ventilation will vary depending on the specific building and environment. However, in general, a wider window opening angle will be more effective in drawing in fresh air and expelling stale air.

In addition to the factors mentioned above, the impact of window opening angle on natural ventilation can also be affected by the size of the window opening, the type of window, and the presence of other factors, such as trees or buildings, that can obstruct the airflow. It is important to consider all of these factors when designing a natural ventilation system. By carefully considering the window opening angle, the designer can help to ensure that the system is as effective as possible.

#### **2.4. Previous Studies on Natural Ventilation and Window Opening Angle**

Previous studies have extensively investigated the impact of window opening angle on natural ventilation and indoor environmental quality. These studies have been conducted in various settings, including classrooms, offices, hospitals, and homes. The findings from these studies suggest that the optimal window opening angle for a particular building or environment depends on several factors, such as indoor and outdoor temperatures, wind direction and speed, building geometry and orientation, and the specific pollutants present (Pan et al., 2018; Park & Choi, 2018; Yoon et al., 2022; Liu et al., 2023; Yoo et al., 2022).

For example, a study examined the effect of different window opening angles on airflow patterns and indoor air quality in a university classroom. The study found that a window opening angle of 30 degrees provided the most effective natural ventilation in terms of improving indoor air quality and reducing indoor CO<sub>2</sub> levels (Pan et al., 2018).

Other studies have focused on specific indoor environments, such as hospitals and offices. Cao et al. (2020) found that a window opening angle of 60 degrees was the most effective in reducing the concentration of pollutants in a hospital room (Pan et al., 2018). On the other hand, Lee et al. (2015) found that a window opening angle of 30 degrees was the most effective in improving thermal comfort in an office building (Pan et al., 2018). These findings highlight the importance of considering the specific building and environment when determining the optimal window opening angle.

Overall, the research on the impact of window opening angle on natural ventilation and indoor environmental quality is still ongoing. While there is no one-size-fits-all solution, the available evidence suggests that the optimal window opening angle for a particular building or environment will vary depending on a number of factors, including temperature, wind conditions, building characteristics, and pollutant levels (Pan et al., 2018; Park & Choi, 2018; Yoon et al., 2022; Liu et al., 2023; Yoo et al., 2022). Further research is needed to better understand these factors and develop guidelines for optimizing window opening angles in different contexts.

This study will determine and suggest some specific opening angle for a specific environment for obtaining the best natural ventilation scenario in an available classroom without making any design changes but only opening necessary windows in determined angles.

## **2.5. Methodology**

Computational fluid dynamics (CFD) is a numerical method used to simulate the flow of fluids. It has various applications in different fields, including natural ventilation in buildings and the analysis of airflow patterns (Guo et al., 2015; Afshin et al., 2016; Pirouz et al., 2021). CFD simulations can provide valuable insights into the impact of different factors on fluid flow, such as window opening angles in buildings (Guo et al., 2015; Afshin et al., 2016). Autodesk CFD is a commercial CFD software widely used by engineers and scientists for modeling and simulating fluid flows (Guo et al., 2015).

In the context of natural ventilation in buildings, CFD simulations can be used to optimize the design of window opening angles. By simulating the airflow through a building with different window opening angles, engineers and designers can study the impact of these angles on the airflow velocity, temperature distribution, and pressure distribution within the building (Guo et al., 2015; Afshin et al., 2016). For example, a study using Autodesk CFD simulated the airflow through a building with different window opening angles and found that the airflow velocity increased as the window opening angle increased (Afshin et al., 2016). These simulations can help designers optimize the window opening angle for natural ventilation in buildings, leading to improved energy efficiency, reduced carbon emissions, and improved indoor air quality (Guo et al., 2015).

Analyzing the outcome of Computational Fluid Dynamics (CFD) simulations is a crucial step in understanding the behavior of fluid flows in various applications. CFD simulations provide valuable insights into the aerodynamics, airflow patterns, temperature distribution, and other important parameters in different fields such as wind turbines, building design, industrial processes, and more. In this synthesis, we will explore several references that discuss the analysis of CFD simulation outcomes and provide insights into the methodologies and applications.

One relevant reference is the article by (Zahle et al., 2014), which presents a comprehensive aerodynamic analysis of a 10 MW wind turbine rotor using 3D CFD simulations. The study focuses on analyzing the rotor performance and deriving airfoil aerodynamic characteristics for use in aero-elastic simulation tools. The authors compare the 3D CFD airfoil data derived using the Azimuthal Averaging Technique (AAT) with airfoil data based on 2D CFD simulations and engineering models. This reference is relevant as it provides insights into the analysis of CFD simulation outcomes in the context of wind turbine aerodynamics.

Pirouz et al. (2021) present a study on the role of HVAC design and windows on indoor airflow patterns and air changes per hour (ACH). The authors use CFD simulations to analyze the airflow patterns and determine optimal placement and safer locations for occupants to decrease health risks. This reference is relevant as it demonstrates the application of CFD simulations in analyzing airflow patterns and optimizing ventilation systems.

Goubergrits et al. (2009) present a study on using wall-PIV (Particle Image Velocimetry) as a near-wall flow validation tool for CFD simulations. The authors compare the results of wall-PIV flow visualization with CFD flow simulations under steady flow conditions. This reference is relevant as it discusses the validation of CFD simulation results using experimental techniques.

Zhang (2023) discusses the parameter correction method of CFD based on the Approximate Bayesian Computation technique. The author emphasizes the need to adjust and modify CFD models considering uncertainties to improve the prediction accuracy and confidence level of CFD simulations. This reference is relevant as it addresses the challenges of uncertainties in CFD simulations and proposes a method for improving prediction accuracy.

Gan et al. (2022) present a framework for integrating Building Information Modeling (BIM) and virtual reality (VR) with CFD simulations for interactive aerodynamic design and wind comfort analysis of modular buildings. The authors highlight the importance of visual experience in improving building ventilation and supporting informed decision-making in the early stages of design. This reference is relevant as it demonstrates the integration of CFD simulations with BIM and VR technologies for building design optimization.

Hiyama & Kato (2011) discuss the optimization of variables in air conditioning control systems using simulations that integrate CFD analysis and the response factor method. The authors propose a method that calculates sensitivities from heat sources to an arbitrary point in an indoor environment and integrates them into simulations with unsteady boundary conditions. This reference is relevant as it addresses the optimization of variables in HVAC systems using CFD simulations.

Srinivasan & Malkawi (2005) discuss real-time simulations using learning algorithms for immersive data visualization in buildings. The authors highlight the use of CFD simulations in building performance analysis, including natural ventilation design, smoke and fire prediction, and indoor air quality assessment. This reference is relevant as it emphasizes the application of CFD simulations in analyzing building performance.

Zhai (2006) analyzes the application of CFD in building design and reviews the developing trends in applying CFD to building design. The author discusses the

importance of CFD simulations in understanding airflow patterns, thermal distribution, and other factors in building design. This reference is relevant as it provides an overview of the application of CFD simulations in building design.

Wei & Ye (2020) discuss the experimental and numerical analysis of fluid-solid-thermal coupling in an electric fuel pump. The authors highlight the advantages of CFD simulations in obtaining simulation results that cannot be provided by experiments alone. This reference is relevant as it emphasizes the application of CFD simulations in analyzing fluid-solid-thermal interactions.

In conclusion, analyzing the outcome of CFD simulations involves post-processing, visualization, and interpretation of the simulation results. The selected references provide insights into various aspects of CFD simulation analysis, including aerodynamics, airflow patterns, temperature distribution, optimization, validation, and application-specific considerations. These references highlight the importance of scientific visualization and their method of these visualizations to create results differencing according to need and situations.

Autodesk CFD offers several advantages over other alternatives in the field of computational fluid dynamics (CFD). One of the key advantages is its accuracy. Autodesk CFD utilizes various numerical methods that are known for their accuracy and robustness. These methods have been extensively used in different industries to solve fluid flow and heat transfer problems. The accuracy of Autodesk CFD is demonstrated by its ability to provide results that correlate well with experimental data (Hung, 2021).

Another advantage of Autodesk CFD is its flexibility. It can be used to solve a wide range of problems, from simple to complex. The software offers a variety of features that allow users to customize their simulations according to their specific needs. This flexibility makes Autodesk CFD suitable for various applications in different industries.

Ease of use is another notable advantage of Autodesk CFD. The software has a user-friendly interface that makes it easy for users to create and run simulations. Even those who are new to CFD can quickly learn how to use Autodesk CFD. This ease of use is beneficial for both beginners and experienced users, as it allows for efficient workflow and reduces the learning curve.

Integration with other Autodesk products is another advantage of Autodesk CFD. It seamlessly integrates with other Autodesk software, such as Autodesk Fusion, Autodesk AutoCAD, Autodesk Inventor and Autodesk Revit. This integration allows users to simulate the performance of their designs in a virtual environment, providing valuable insights and optimization opportunities. (Autodesk CFD, 2023)

In addition to these advantages, Autodesk CFD offers a range of other features that make it a preferred choice for CFD applications. It provides a wide range of pre-built models and components, allowing users to quickly set up simulations. The software also includes a powerful meshing engine, which is essential for generating high-quality meshes for accurate simulations. Autodesk CFD offers a variety of post-processing tools that enable users to analyze and visualize simulation results effectively. Furthermore, the software provides a comprehensive documentation library, which serves as a valuable resource for users to understand and utilize its features effectively.

While Autodesk CFD offers numerous advantages, it is important to note that there are other CFD software alternatives available in the market. Some popular alternatives include ANSYS Fluent, COMSOL Multiphysics, and OpenFOAM. Each of these alternatives has its own strengths and weaknesses. For example, ANSYS Fluent is known for its accuracy and flexibility, while COMSOL Multiphysics is recognized for its ability to simulate a wide range of physical phenomena. OpenFOAM, on the other hand, is an open-source CFD software that offers flexibility and versatility (J Yan, et al, 2020).

The choice of the best CFD software depends on the specific needs and requirements of the user. If a powerful and accurate software that is easy to use is desired, Autodesk CFD is a suitable option. However, if flexibility and versatility are the primary considerations, COMSOL Multiphysics or OpenFOAM may be more proper choices (Pashchenko, 2019).

Overall, Autodesk CFD is a powerful and versatile CFD software package that is a good choice for a variety of engineering problems. The two-equation turbulence model is a relatively simple and computationally efficient model that can be very effective in predicting the behavior of turbulent flows in many cases.

The k-epsilon turbulence model is commonly used in Computational Fluid Dynamics (CFD) simulations to analyze natural ventilation in buildings. This model allows for the prediction of turbulence kinetic energy and turbulence dissipation rate, which are important parameters in understanding the airflow patterns and effectiveness of natural ventilation (Gladstone & Woods, 2001).

In the context of interior architecture, natural ventilation plays a significant role in achieving thermal comfort and maintaining indoor air quality. Vernacular architecture, such as the traditional houses in Sistan, Iran, often incorporates natural ventilation strategies that have been optimized over time (Heidari et al., 2017). Computational Fluid Dynamics (CFD) simulations can be used to study the airflow and temperature levels in these spaces, providing insights into the effectiveness of natural ventilation strategies (Khan, 2022).

The application of CFD in building design has gained prominence in recent years. It allows architects and engineers to analyze and optimize natural ventilation systems, among other aspects of building performance. CFD simulations can provide valuable information on airflow patterns, temperature distribution, and the impact of design parameters on natural ventilation effectiveness (Zhai, 2006).

In hot-arid climates, enhancing the performance of natural ventilation is crucial for achieving thermal comfort and reducing energy consumption. Spatial configurations, such as the layout and arrangement of openings, can significantly impact the airflow patterns and effectiveness of natural ventilation systems (Selim et al., 2023). CFD simulations can be used to evaluate different spatial configurations and optimize natural ventilation strategies in hot-arid climates.

Overall, the k-epsilon turbulence model, in conjunction with CFD simulations, can provide valuable insights into the performance of natural ventilation in interior architecture. By analyzing airflow patterns, temperature distribution, and the impact of design parameters, architects and engineers can optimize natural ventilation systems to achieve thermal comfort, maintain indoor air quality, and reduce energy consumption.

In addition to the advantages mentioned above, Autodesk CFD also offers several other features that make it a good choice for engineering applications, such as:

- A wide range of meshing tools

- A variety of post-processing tools
- The ability to simulate multiphase flow
- The ability to simulate combustion
- A comprehensive library of turbulence models

In conclusion, Autodesk CFD offers several advantages over other alternatives in the field of computational fluid dynamics. Its accuracy, flexibility, ease of use, and integration with other Autodesk products make it a preferred choice for various CFD applications.

The CFD simulations were conducted using the following steps:

1. The building geometry was modeled in Autodesk AutoCAD
2. The model transferred to Autodesk Fusion.
3. The model is transferred to simulations Autodesk CFD
4. The material of the model was specified
5. The boundary conditions were specified.
6. The mesh of the model was specified
7. The CFD k- epsilon solver was used to solve the Navier-Stokes equations.
8. The results of the simulations were analyzed.

The CFD simulations provided valuable insights into the impact of window opening angle on natural ventilation in buildings. The results of the simulations can be used to help designers optimize the window opening angle for natural ventilation in buildings.

The following boundary conditions were specified for the simulations:

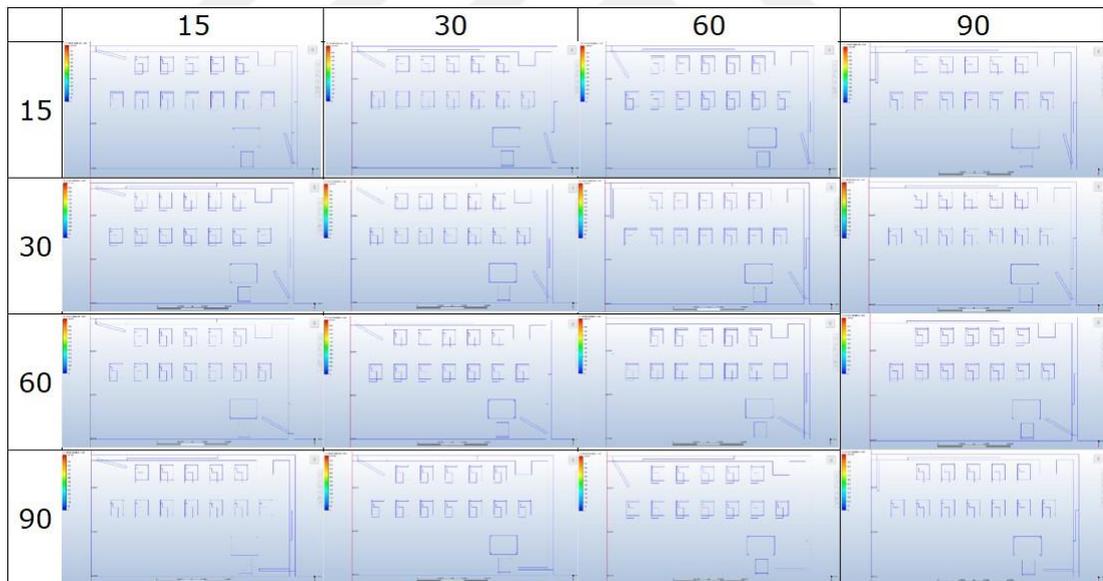
- The indoor air temperature was set to 20°C.
- The outdoor air temperature was set to 20°C.
- The wind speed was set to 0,93 m/s.
- The window opening angles were 15°, 30°, 60° and 90°.
- A list of different opening angle conditions created using 15°, 30°, 60° and 90°. Their combinations which are 15°-15°, 15°-30°, 15°-60°, 15°-90° , 30°-

15° , 30°-30° , 30°-60° , 30°-90° , 60°-15° , 60°-30° , 60°-60° , 60°-90° , 90°-15° , 90°-30° , 90°-60° , 90°-90° were modeled to test. Total of different 16 models.

**Table 1.** Window Opening Angles Combinations.

ANGLES	15	30	60	90
15	15,15	15,30	15,60	15,90
30	30,15	30,30	30,60	30,90
60	60,15	60,30	60,60	60,90
90	90,15	90,30	90,60	90,90

**Table 2.** Window Opening Angles Combinations Top Views



The reason of the opening angles and pivot opening situation comes from an advised project that was occurring in CUHADAROĞLU Holding Company in 2017 the insight of the project was to obtain CFD result for a basic automation system that will be affecting the interior natural ventilation by opening two opposite windows in different angles. According to this demand the angles of the project determined as 15°, 30°, 60° and 90°. This experiment would pass in a second phase to process the optimal range. The result of this project will give us insights to understand and focus

to the optimal values. The opening type and other values can be tested as well but the most common window opening type is the pivot opening that is more applicable to residential building which was the aim of the company.

The main objective is to analyze the outcomes of the simulations therefore our aim is to define the velocity of the air, its distribution throughout the classroom and its effect to internal air molecules. The analysis of airflow velocity in a classroom is an important step in ensuring the health and comfort of students and teachers. By understanding how air flows through the room, we can identify areas where there may be moving air or drafts and make adjustments to the ventilation system to improve air quality.

To measure airflow velocity, we can use a variety of devices, including hot-wire anemometers, laser Doppler velocimeters, and ultrasonic anemometers. These devices measure the speed of air molecules at a specific point in space. In this case we are using CFD software to understand air dynamics. Once we have measured the airflow velocity with Autodesk CFD, we can create a velocity map of the classroom. This map will show us how air flows through the room and identify areas where air velocity occurs. We can use the airflow velocity data to compare different window opening angles. This will help us to determine which window opening angles provide the best airflow and air quality in the classroom.

The classification method that we use to compare different window opening angles will depend on the specific data that we have collected. However, we may want to consider factors such as the average airflow velocity, the distribution of airflow, and the number of areas with moving air or drafts.

By analyzing the airflow velocity in a classroom, we can make informed decisions about how to improve air quality and ensure the health and comfort of students and teachers.

Here are some additional considerations for analyzing airflow velocity in a classroom:

- The time of day can affect airflow velocity. For example, airflow velocity may be lower in the morning when the classroom is first occupied, and higher in the afternoon when the students are more active.

- The type of activity that is taking place in the classroom can also affect airflow velocity. For example, airflow velocity may be higher when students are exercising,

and lower when they are sitting quietly.

-The presence of furniture and other objects in the classroom can also affect airflow velocity. For example, airflow velocity may be lower in areas where there is a lot of furniture, and higher in areas where there is more open space.

By taking all of these factors into account, we can get a more accurate picture of how airflow velocity affects the classroom environment. This information can then be used to make informed decisions about how to improve air quality and ensure the health and comfort of students and teachers.

The simulations were run for a period of 10 minutes. The results of the simulations were used to calculate the airflow velocity, temperature, and pressure distribution in the building. The CFD simulations were conducted on a high-performance computing cluster. The simulations took approximately 24 hours to complete.

The results of the CFD simulations were analyzed using a visual outcome by grid method. The grid method is applied to the design of the classroom to understand where to focus. In this case the grid will be focusing on student sitting area. The visuals and color changes is visualized in desired area to understand the effect of the velocity of air on focus areas. The CFD simulations provided valuable insights into the impact of window opening angle on natural ventilation in buildings. However, it is important to note that the results of the simulations are only valid for the specific building and conditions that were modeled.



## **CHAPTER 3**

### **CASE STUDY**

#### **3.1. Site Selection and Description**

In this section, we will present a case study of a classroom in Yaşar University located in İzmir, Turkey. The classroom is named Y115 and it is only 32 square meters.

An anemometer located on the external side of the classroom to understand the prevailing wind direction and the speed of wind that occurs. The data received from the anemometer will indicate the average stats that will be used in software.

Two large windows that open on diagonally opposite sides of the classroom will be our main object to test the ventilation simulations.

The selection of this type of classroom refers to its location and condition. This type of classroom provide us a two front wall that has windows on it according to the shape and its location the windows can ensure a better ventilation option than one faced classrooms. The anemometer that exits on the outside wall near the window can give us a more precise data about wind velocity that occurs on the side of the classroom.

The classroom was evaluated using CFD simulations. The simulations showed that the classroom is able to achieve natural ventilation rates that are sufficient to meet the ventilation requirements of the occupants. The simulations also showed that the classroom is able to maintain comfortable indoor temperatures throughout the year. The case study demonstrates that it is possible to design small classrooms that are highly efficient in terms of energy use and that provide a comfortable indoor environment without the need for mechanical ventilation. However, the classroom can also be operated with one of the windows closed.

The CFD simulations showed that the classroom was able to maintain comfortable indoor temperatures even when one of the windows was closed. However, the simulations also showed that the classroom was able to achieve higher ventilation rates when both windows were open. The results of the CFD simulations suggest that

it is possible to operate a classroom with one of the windows closed, but the classroom will be more comfortable and energy-efficient if both windows are open.

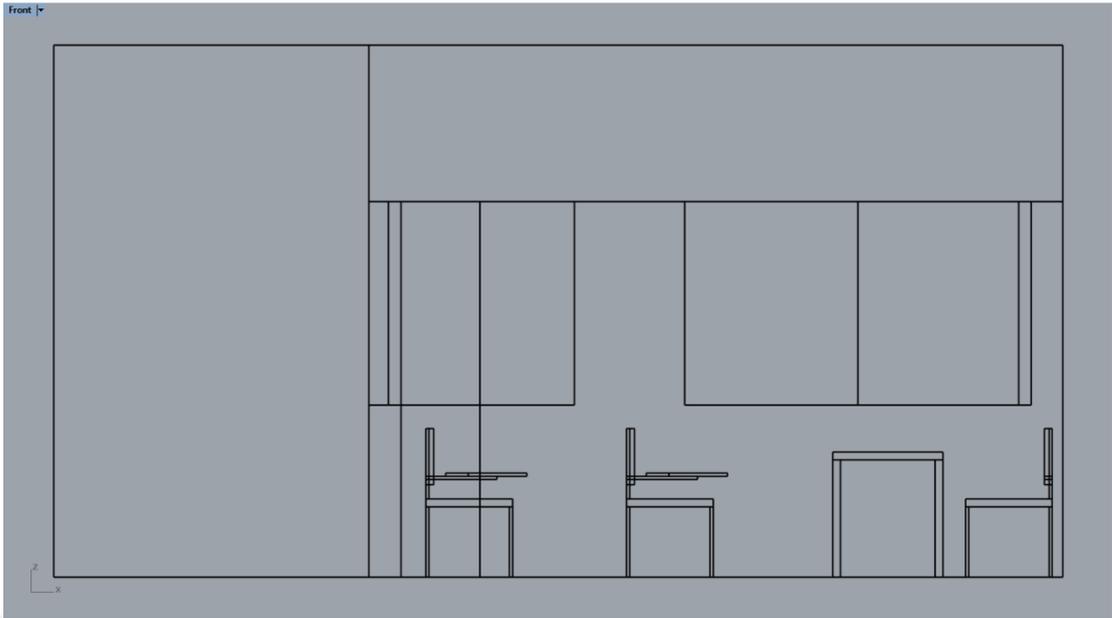
The case study presented in this section provides valuable insights into the potential of natural ventilation. The findings of the case study suggest that natural ventilation can be a viable option for providing a comfortable and energy-efficient indoor environment in small classrooms. The case study also highlights the importance of careful design in order to maximize the benefits of natural ventilation. The classroom that was studied was designed with a number of features that are intended to promote natural ventilation, such as two large windows that open on opposite sides of the classroom. These features helped to ensure that the classroom was able to achieve natural ventilation rates that were sufficient to meet the ventilation requirements of the occupants.

Overall, the case study presented in this section provides valuable insights into the potential of natural ventilation. The findings of the case study suggest that natural ventilation can be a viable option for providing a comfortable and energy-efficient indoor environment in small classrooms. However, it is important to note that the results of the case study are only valid for the specific classroom that was studied. The results may not be valid for other classrooms or conditions.

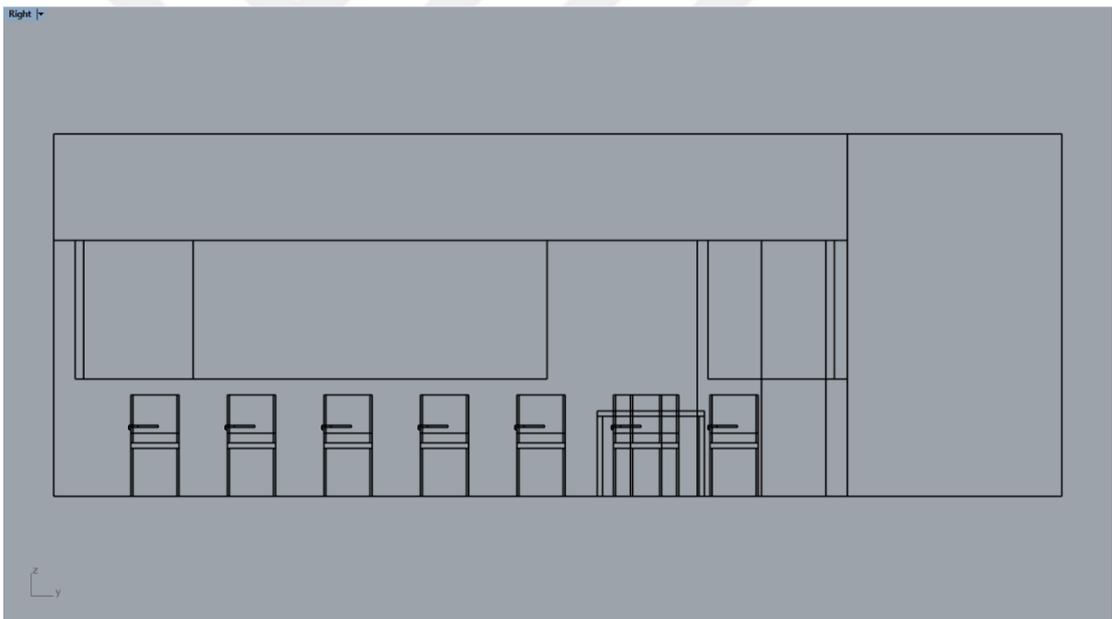
## **3.2. Available Data**

### **3.2.1. Architectural drawings**

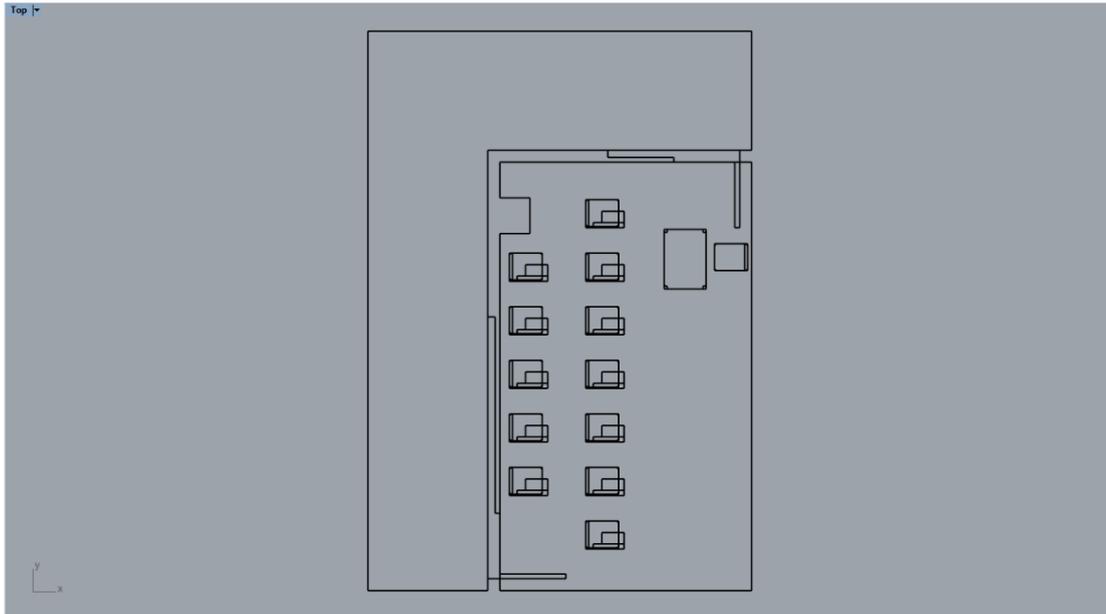
The architectural drawings of the classroom were obtained from the school district. The drawings provided detailed information on the dimensions of the classroom, the location and size of the windows, and the orientation of the building. The drawings also included information on the materials used in the construction of the building, as well as the insulation and air sealing details. This information was used to identify the features of the classroom that were intended to promote natural ventilation, such as the two large windows that open on opposite sides of the classroom. The architectural drawings were also used to calculate the volume of the classroom, which was necessary for the analysis of the collected data.



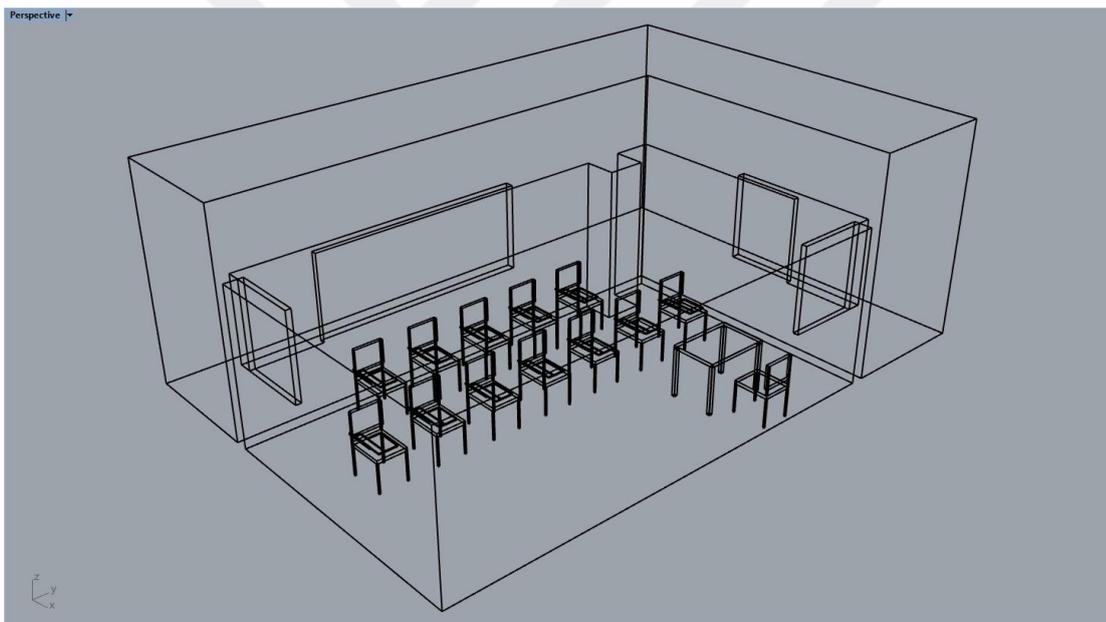
**Figure 1.** Front View



**Figure 2.** Right View



**Figure 3.** Top View



**Figure 4.** Perspective View 3D Model (Rhino 6)

### 3.2.2. Weather data.

Weather data for the study period was obtained from the anemometer. The weather data included information on the outdoor air temperature, relative humidity, wind speed, and wind direction. This information was used to assess the impact of outdoor environmental conditions on the indoor environmental conditions and natural ventilation performance of the classroom. The weather data was also used to

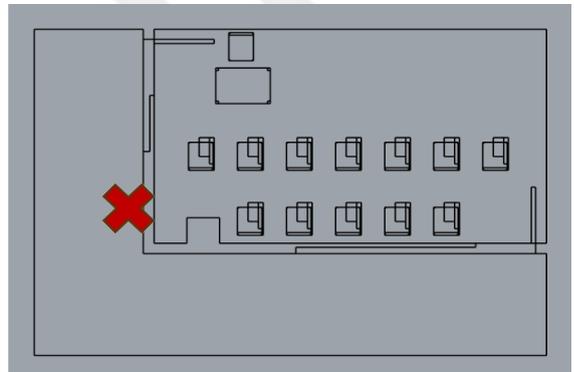
calculate the outdoor air exchange rate, which was necessary for the analysis of the collected data.



**Figure 5.** Real Photo Of The Anemometer Attached Outside Of The Classroom

**Table 3.** Anemometer Velocity DATA (Between May 16- April 17)

MONTH/YEAR	AIR VELOCITY (m/s)
MAY 16	0,897515173
JUN 16	0,956352322
JULY 16	1,146754091
AUG 16	1,099291377
SEP 16	0,97072494
NOV 16	0,85652082
OCT 16	0,81299804
DEC 16	0,880427241
JAN 17	1,021055158
FEB 17	1,034685406
MAR 17	0,775993022
APR 17	0,777059418
<b>AVARAGE</b>	<b>0,935781417</b>



**Figure 6.** Location Of The Anemometer Outside Of Classroom Wall. (-0.9 m below the window)

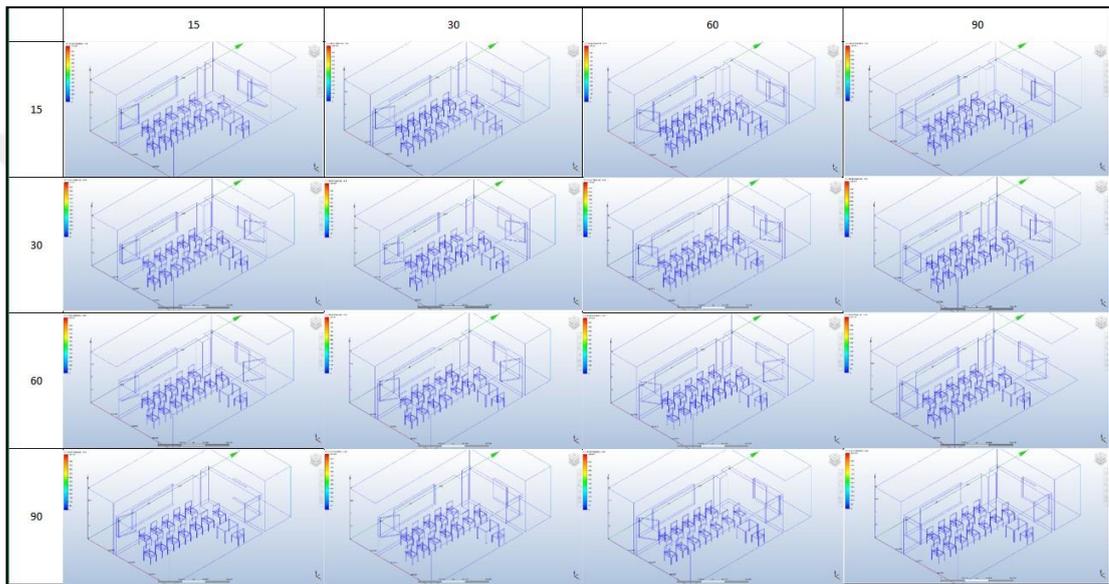


## CHAPTER 4

### RESULTS AND DISCUSSION

#### 4.1. Measured Data and Simulation

This chapter contain every scenario that has been tested thought Autodesk CFD. These scenarios are the combination of different window opening angles. The following images are the outcomes of the simulation scenarios that are listed below.

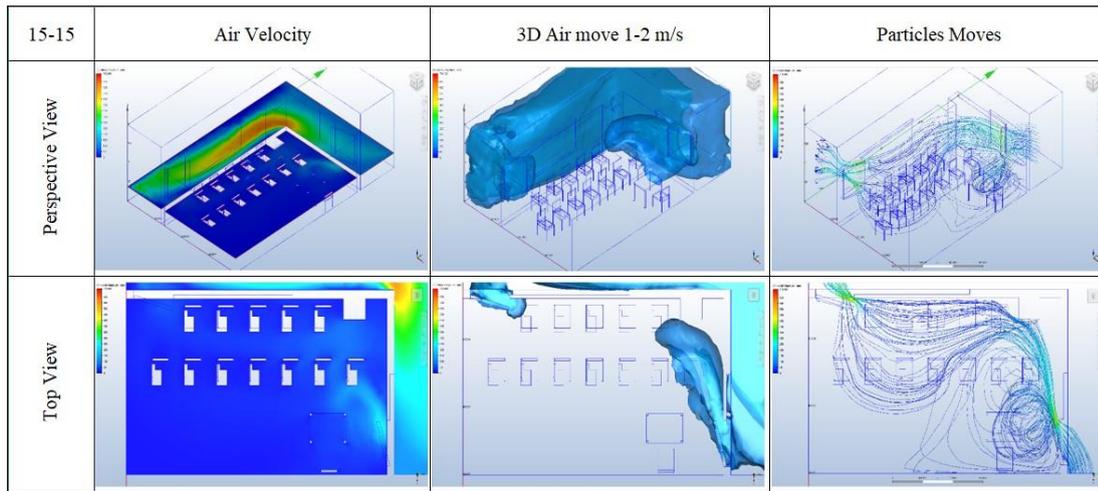


**Figure 7.** Classroom cross ventilation scenarios 3D Scenarios

##### 4.1.1. 15°- 15°

**Table 4.** Scenario 1 CFD Setup

Scenario 1	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	15
Window 2 angle	15
Meshing method	CFD Automatic
Total Node	82969
Total element	287627
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

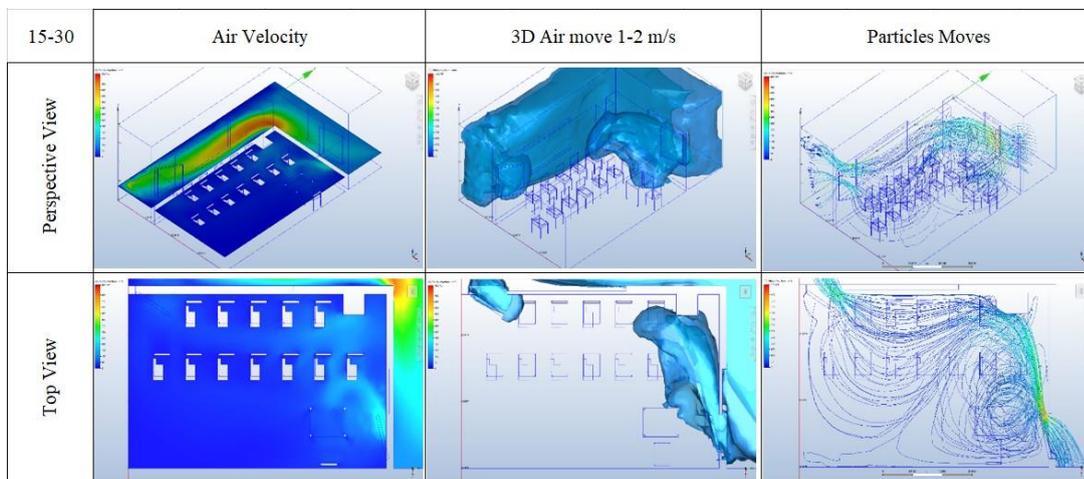


**Figure 8.** 15°-15° Outcomes

**4.1.2. 15°- 30°**

**Table 5.** Scenario 2 CFD Setup

Scenario 2	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	15
Window 2 angle	30
Meshing method	CFD Automatic
Total Node	82859
Total element	287470
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

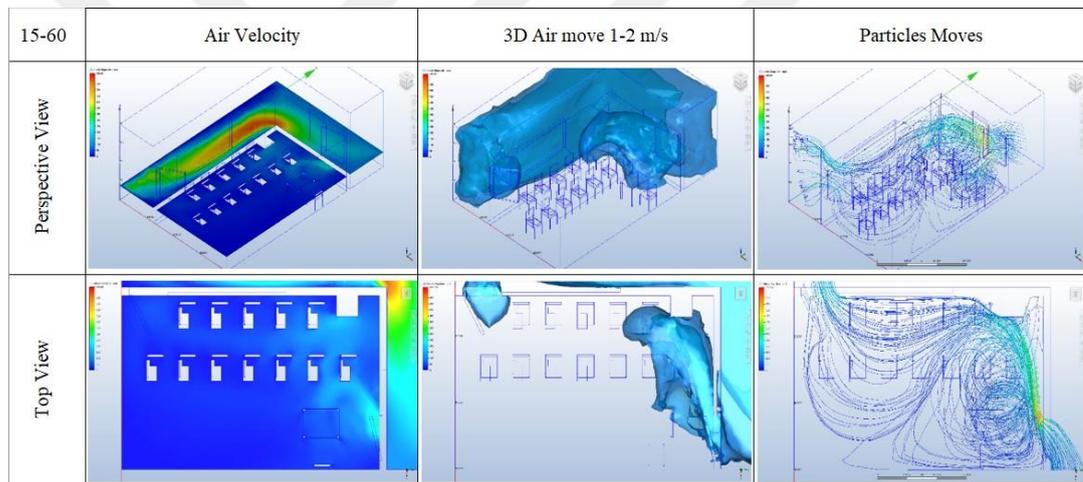


**Figure 9.** 15°-30° Outcomes

### 4.1.3. 15°- 60°

**Table 6.** Scenario 3 CFD Setup

Scenario 3	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	15
Window 2 angle	60
Meshing method	CFD Automatic
Total Node	82282
Total element	284530
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

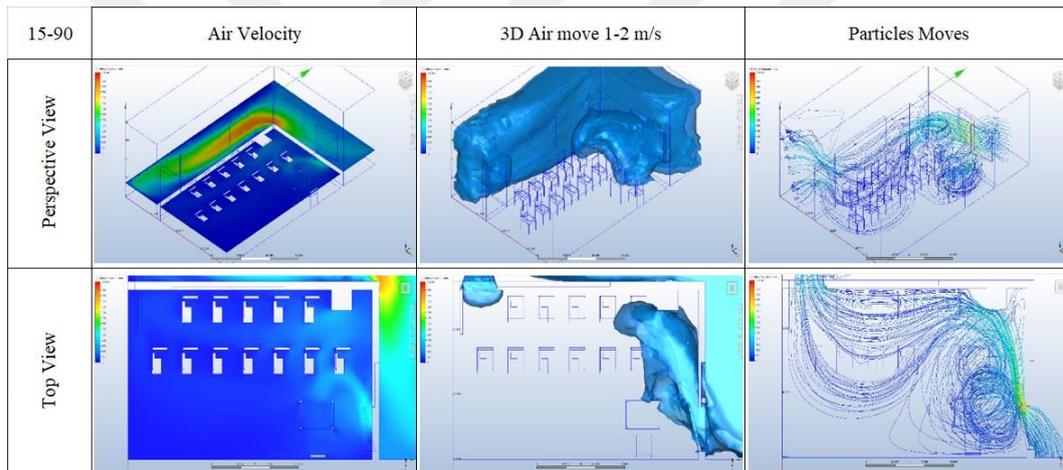


**Figure 10.** 15°-60° Outcomes

#### 4.1.4. 15°- 90°

**Table 7.** Scenario 4 CFD Setup

Scenario 4	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	traditional
Window 1 angle	15
Window 2 angle	90
Meshing method	CFD Automatic
Total Node	83039
Total element	287728
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

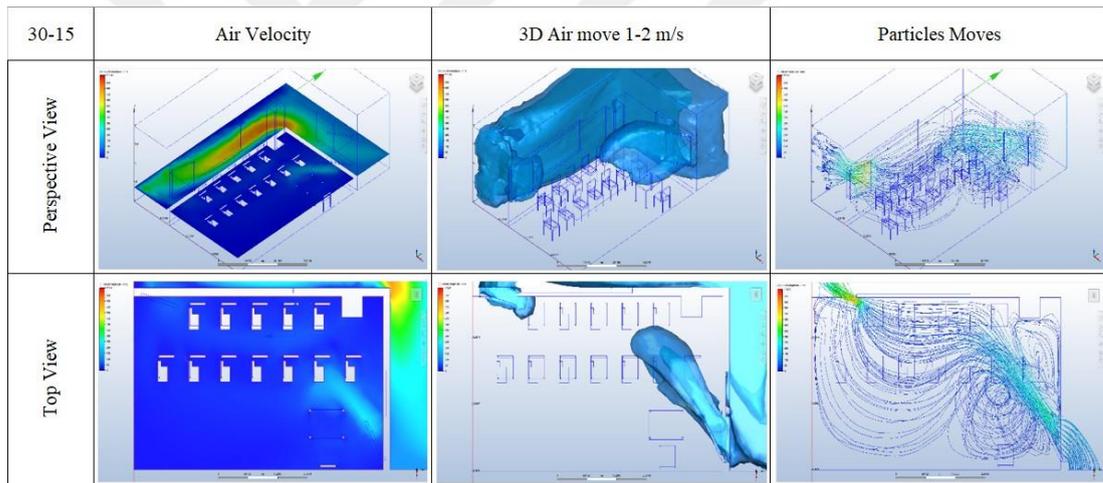


**Figure 11.** 15°-90° Outcomes

4.1.5. 30°- 15°

**Table 8.** Scenario 5 CFD Setup

Scenario 5	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	30
Window 2 angle	15
Meshing method	CFD Automatic
Total Node	82889
Total element	287728
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

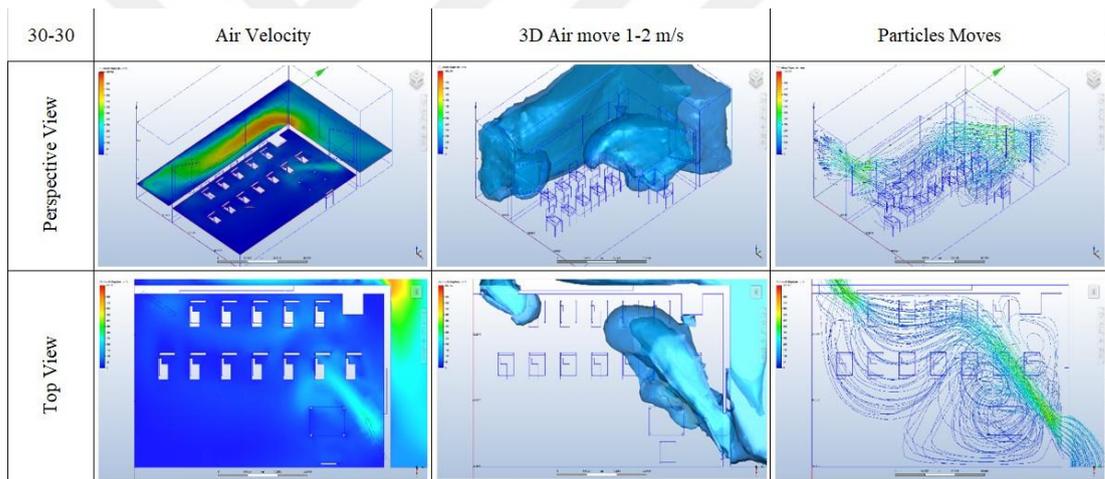


**Figure 12.** 30°-15° Outcomes

4.1.6. 30°- 30°

**Table 9.** Scenario 6 CFD Setup

Scenario 6	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	30
Window 2 angle	30
Meshing method	CFD Automatic
Total Node	82844
Total element	288007
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

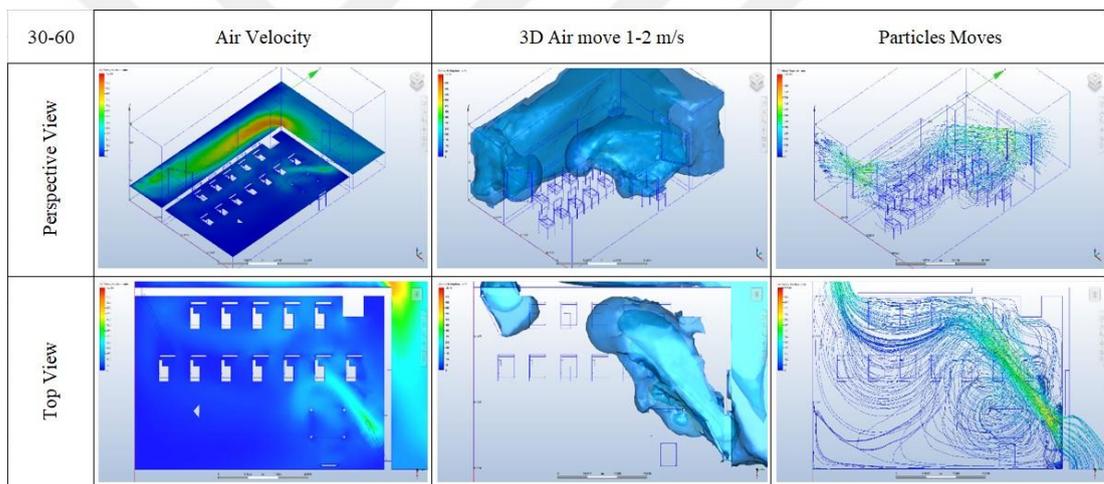


**Figure 13.** 30°-30° Outcomes

#### 4.1.7. 30°- 60°

**Table 10. Scenario 7 CFD Setup**

Scenario 7	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	30
Window 2 angle	60
Meshing method	CFD Automatic
Total Node	82581
Total element	285920
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

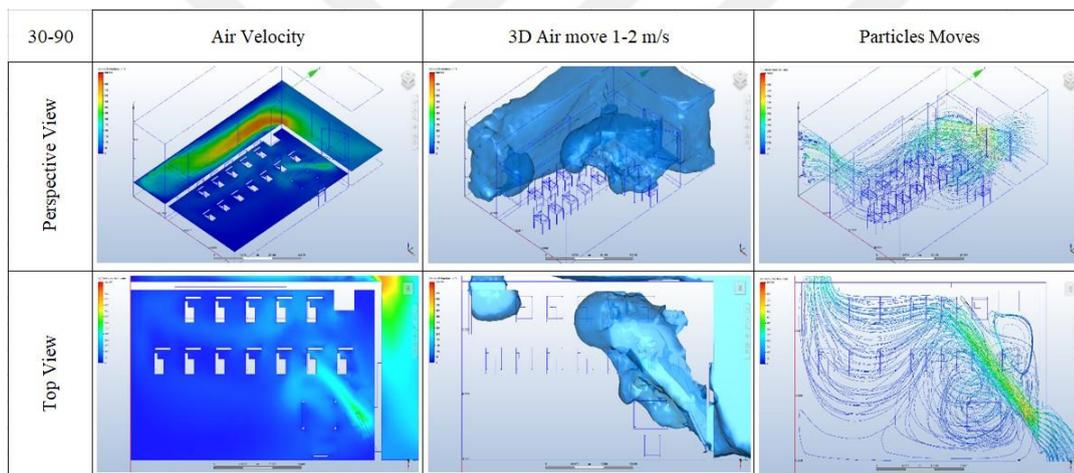


**Figure 14. 30°-60° Outcomes**

#### 4.1.8. 30°- 90°

**Table 11.** Scenario 8 CFD Setup

Scenario 8	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	30
Window 2 angle	90
Meshing method	CFD Automatic
Total Node	83004
Total element	288039
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

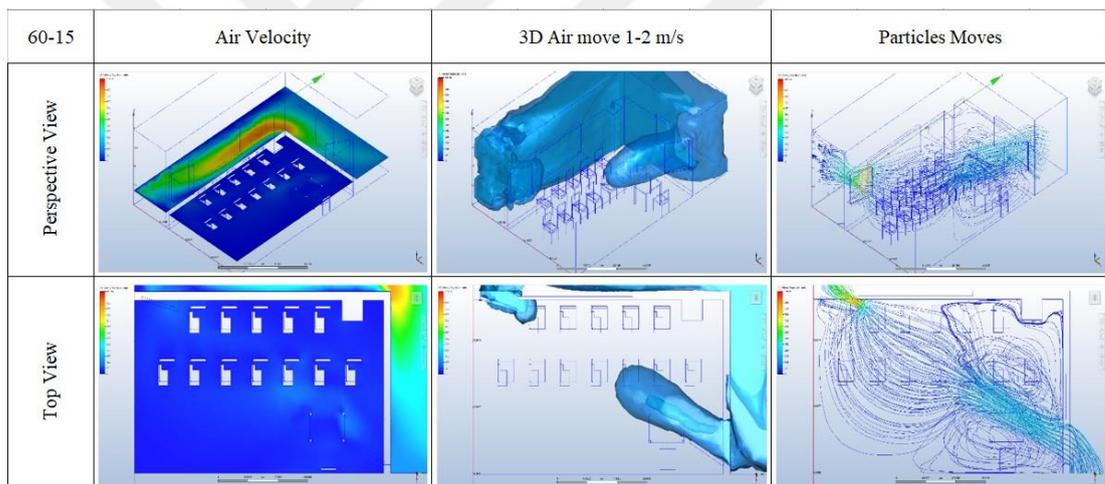


**Figure 15.** 30°-90° Outcomes

4.1.9. 60°- 15°

**Table 12.** Scenario 9 CFD Setup

Scenario 9	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	60
Window 2 angle	15
Meshing method	CFD Automatic
Total Node	82122
Total element	283810
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1



**Figure 16.** 60°-15° Outcomes

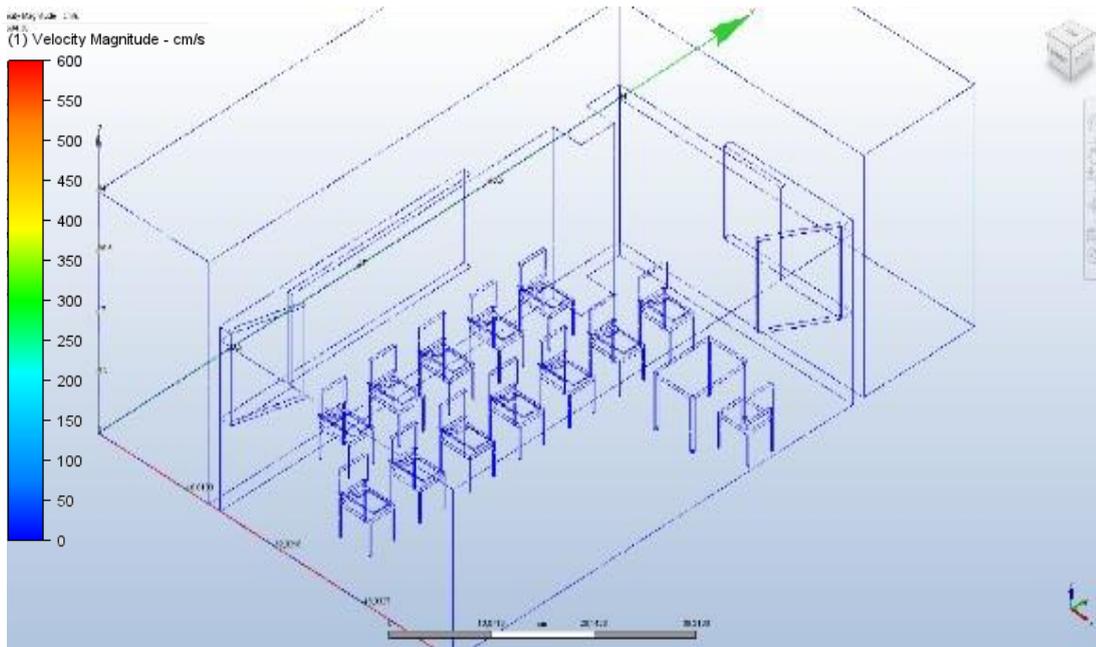


Figure 17. 60°-15° Perspective – Empty

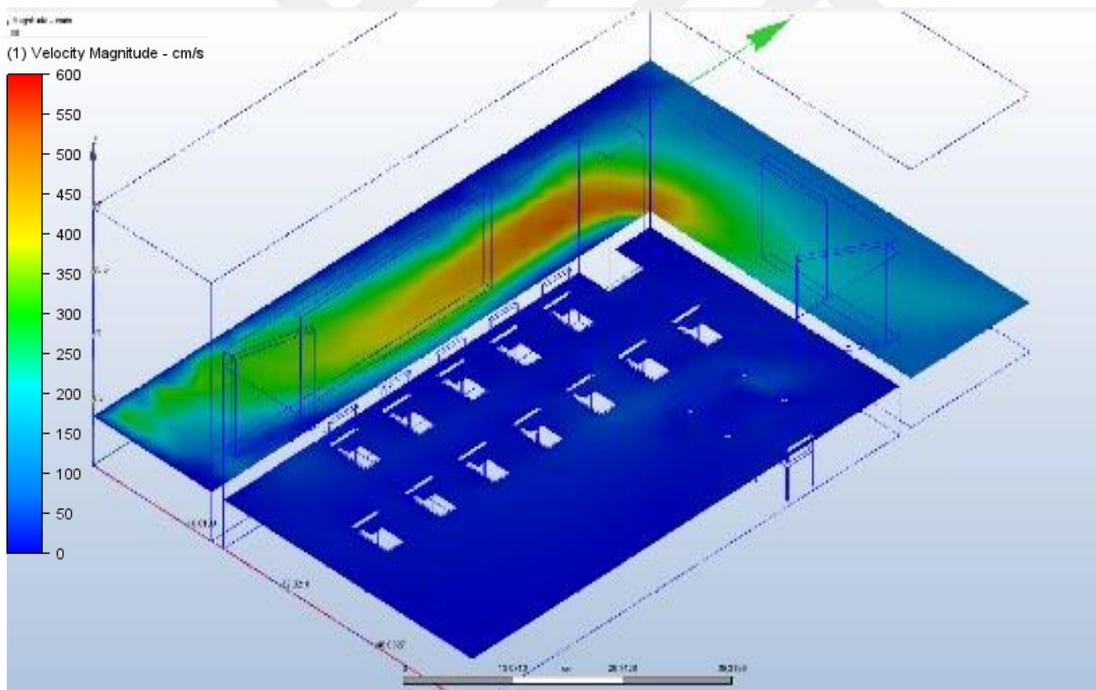
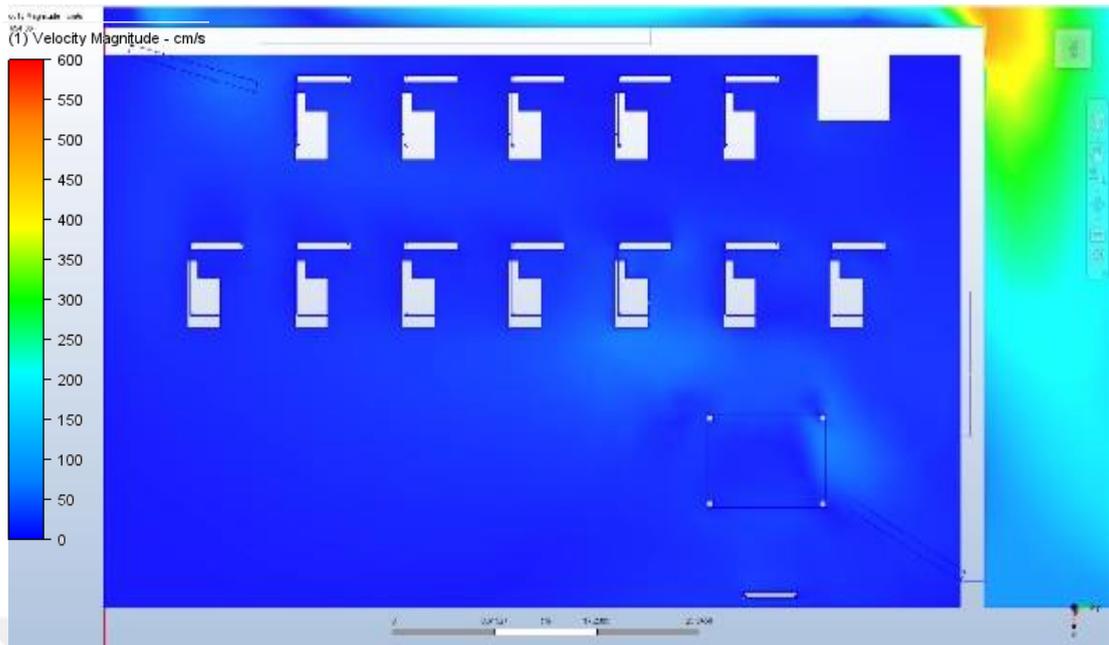
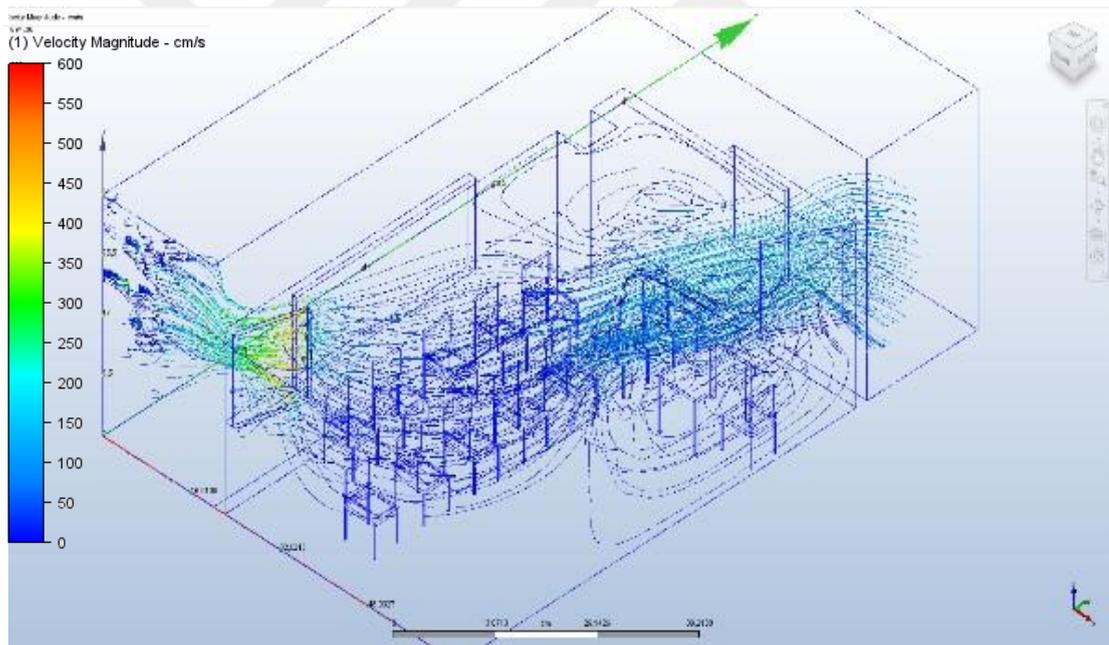


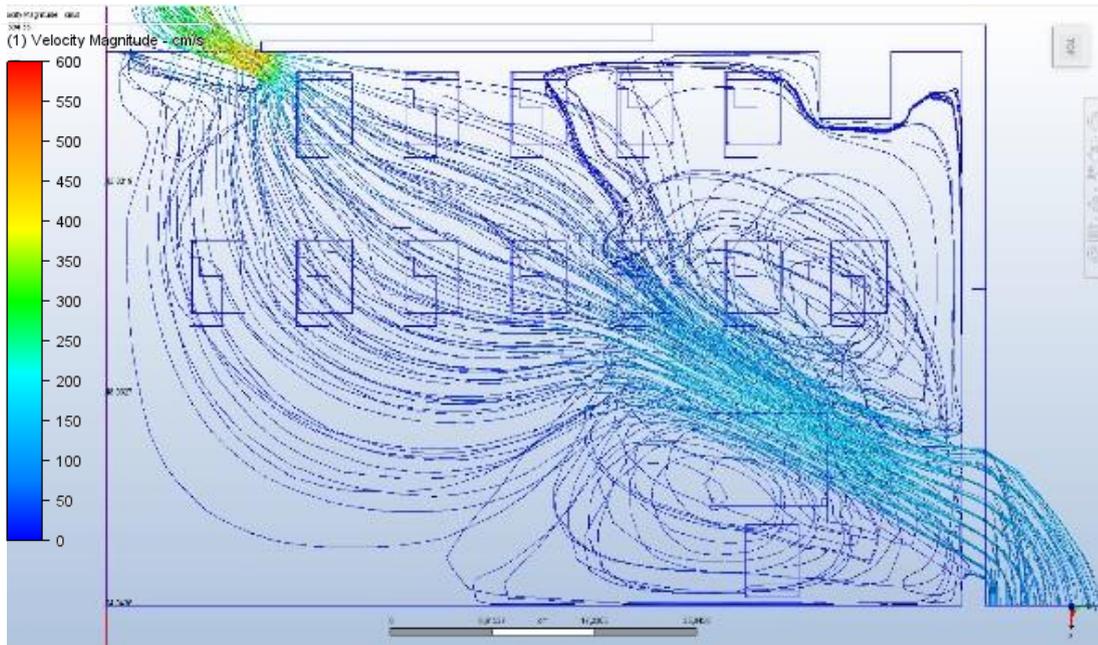
Figure 18. 60°-15° Perspective -Velocity



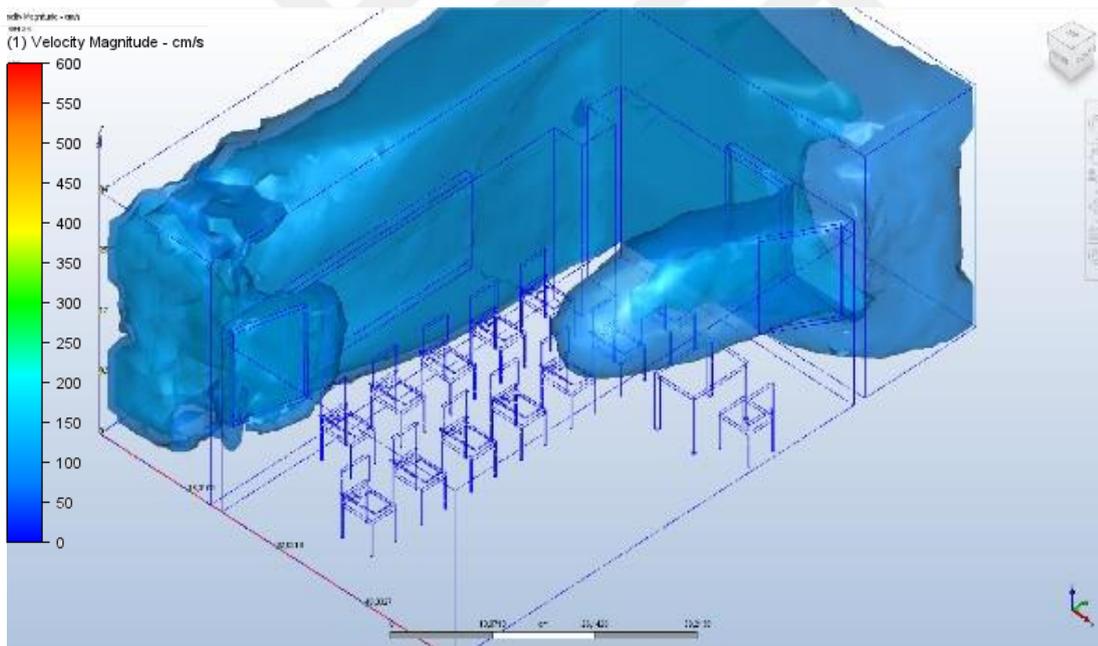
**Figure 19.** 60°-15° Top View - Velocity



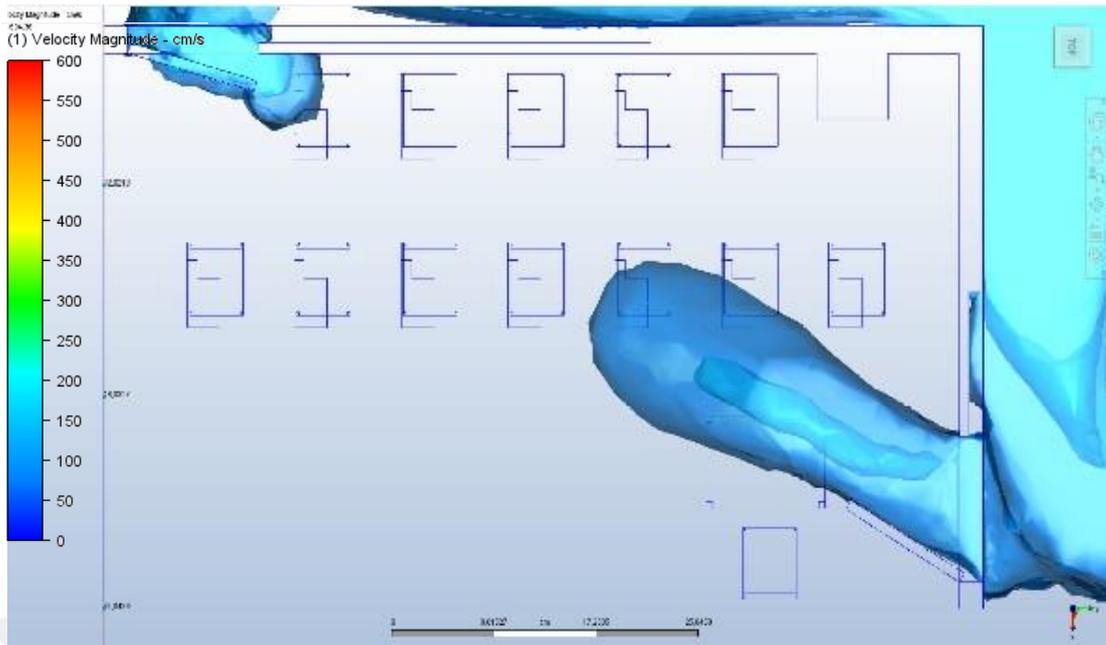
**Figure 20.** 60°-15° Perspective- Particles



**Figure 21.** 60°-15° Top View – Particles



**Figure 22.** 60°-15° Perspective - 3D Air 1-2 m/s

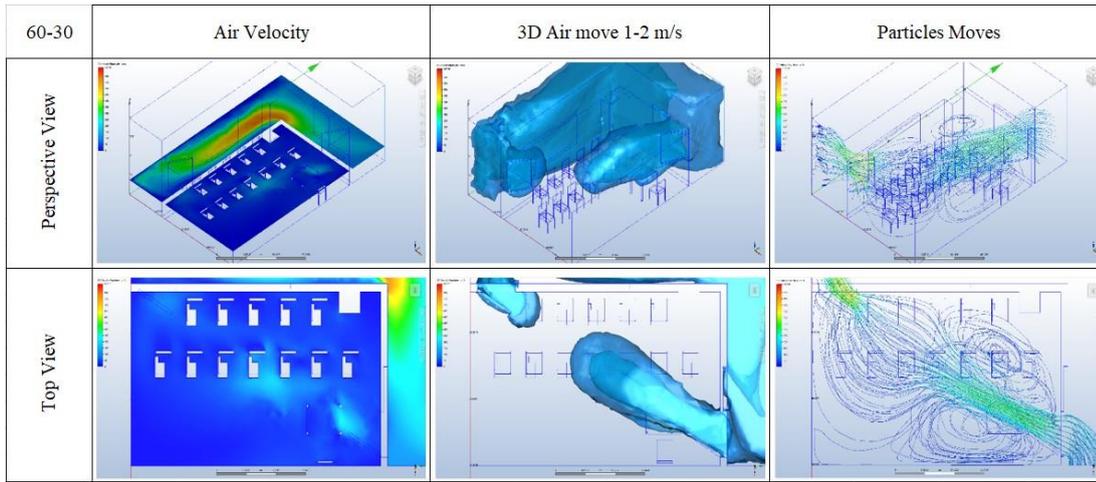


**Figure 23.** 60°-15° Top View - 3D Air 1-2 m/s

#### 4.1.10. 60°- 30°

**Table 13.** Scenario 10 CFD Setup

Scenario 10	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	60
Window 2 angle	30
Meshing method	CFD Automatic
Total Node	82131
Total element	284262
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

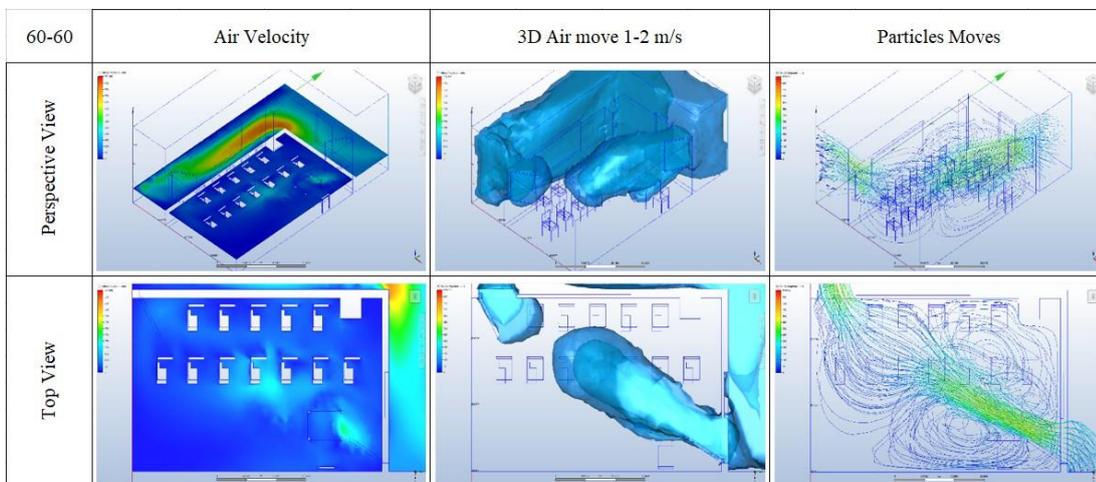


**Figure 24.** 60°-30° Outcomes

**4.1.11. 60°- 60°**

**Table 14.** Scenario 11 CFD Setup

Scenario 11	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	60
Window 2 angle	60
Meshing method	CFD Automatic
Total Node	85078
Total element	296292
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

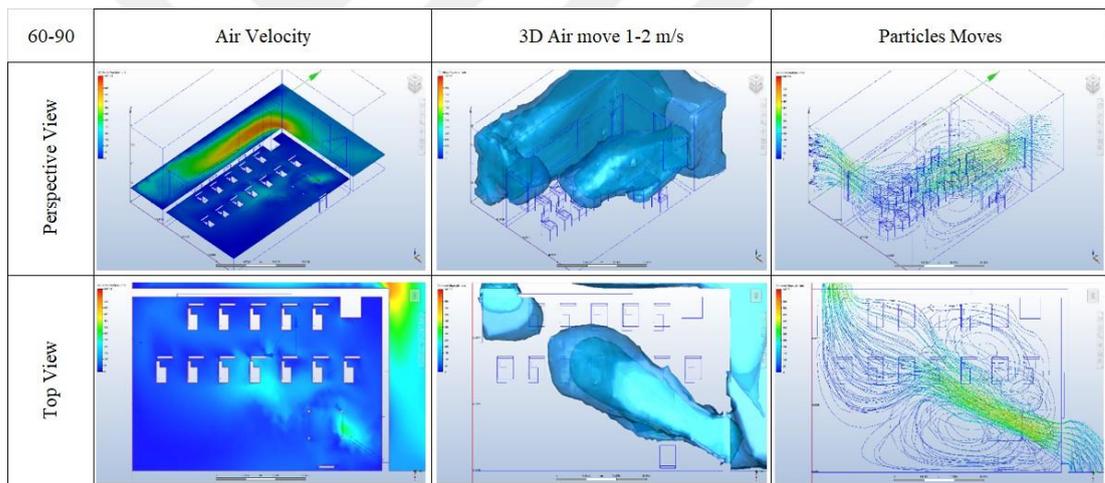


**Figure 25.** 60°-60° Outcomes

4.1.12. 60°- 90°

**Table 15.** Scenario 12 CFD Setup

Scenario 12	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	60
Window 2 angle	90
Meshing method	CFD Automatic
Total Node	82237
Total element	283989
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

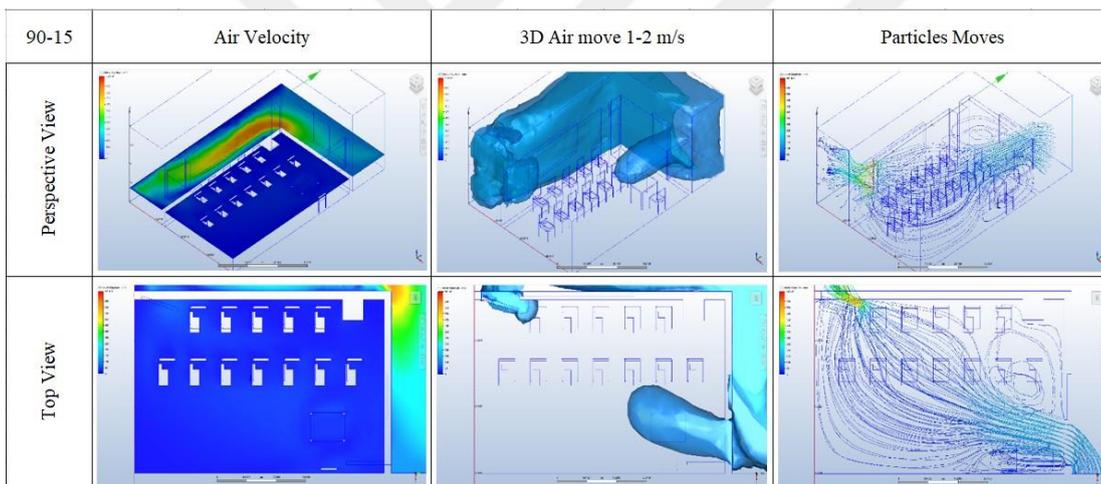


**Figure 26.** 60°-90° Outcomes

#### 4.1.13. 90°- 15°

**Table 16.** Scenario 13 CFD Setup

Scenario 13	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	90
Window 2 angle	15
Meshing method	CFD Automatic
Total Node	83172
Total element	288108
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1



**Figure 27.** 90°-15° Outcomes

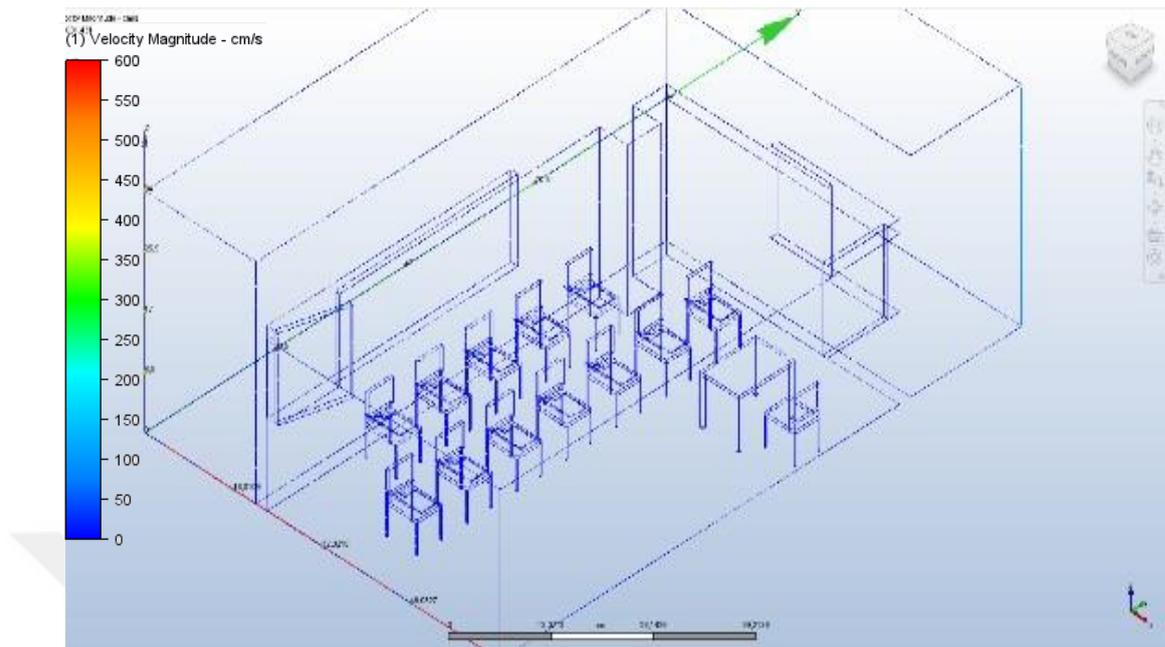
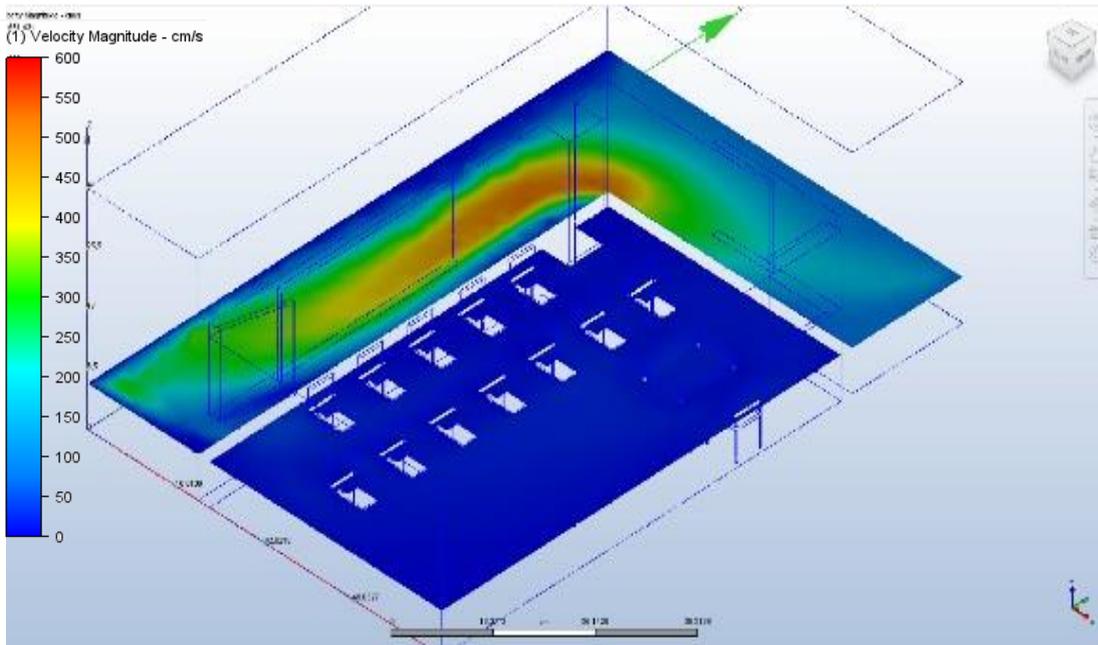
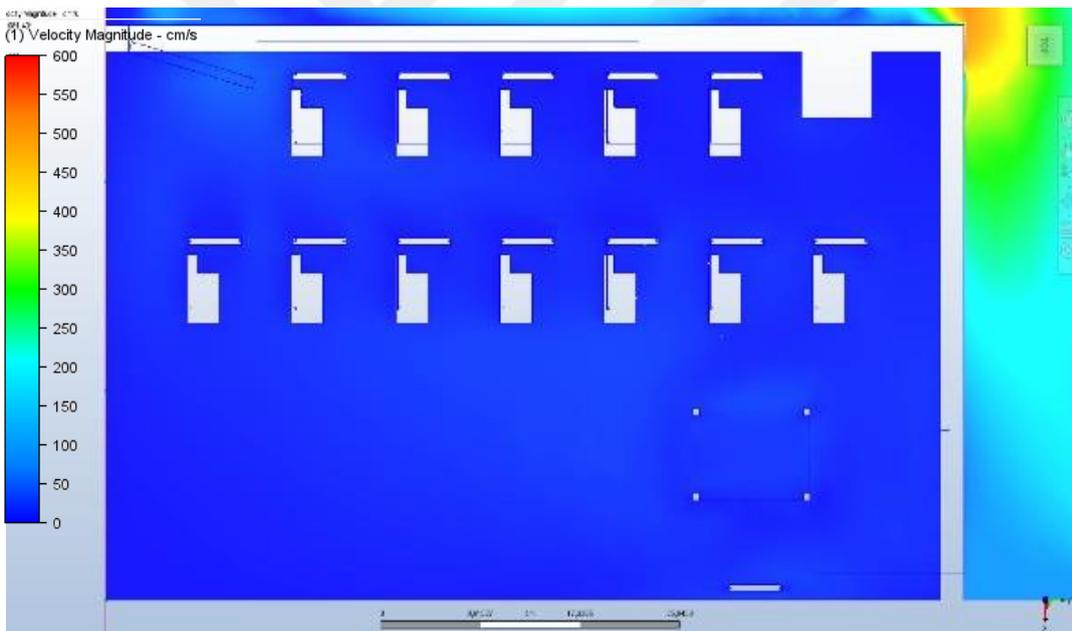


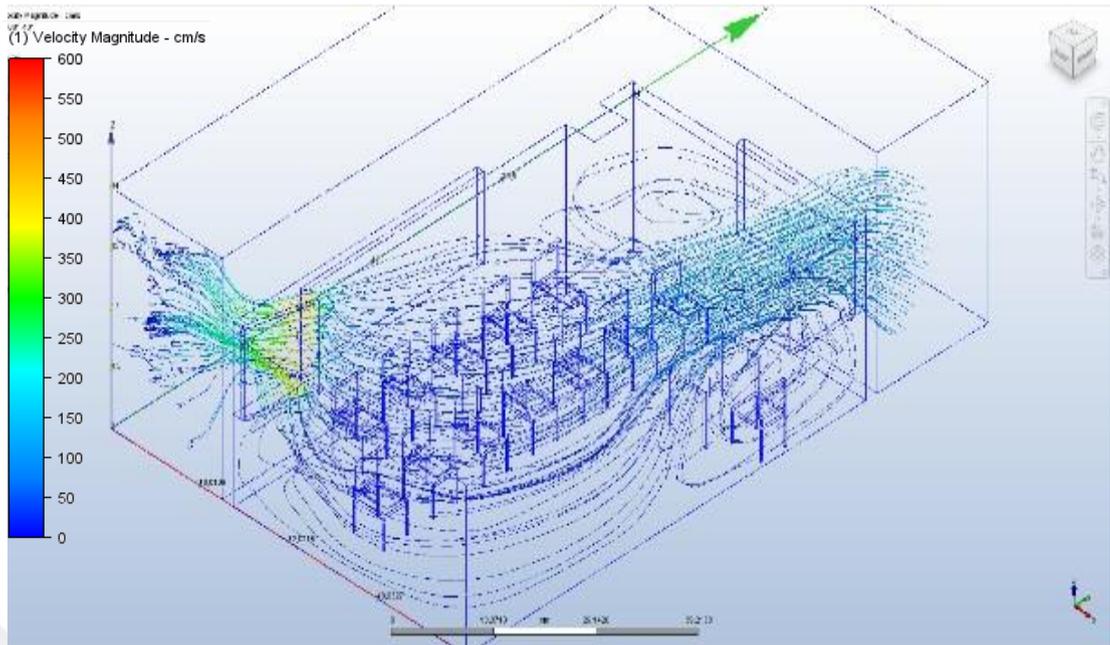
Figure 28. 90°-15° Perspective – Empty



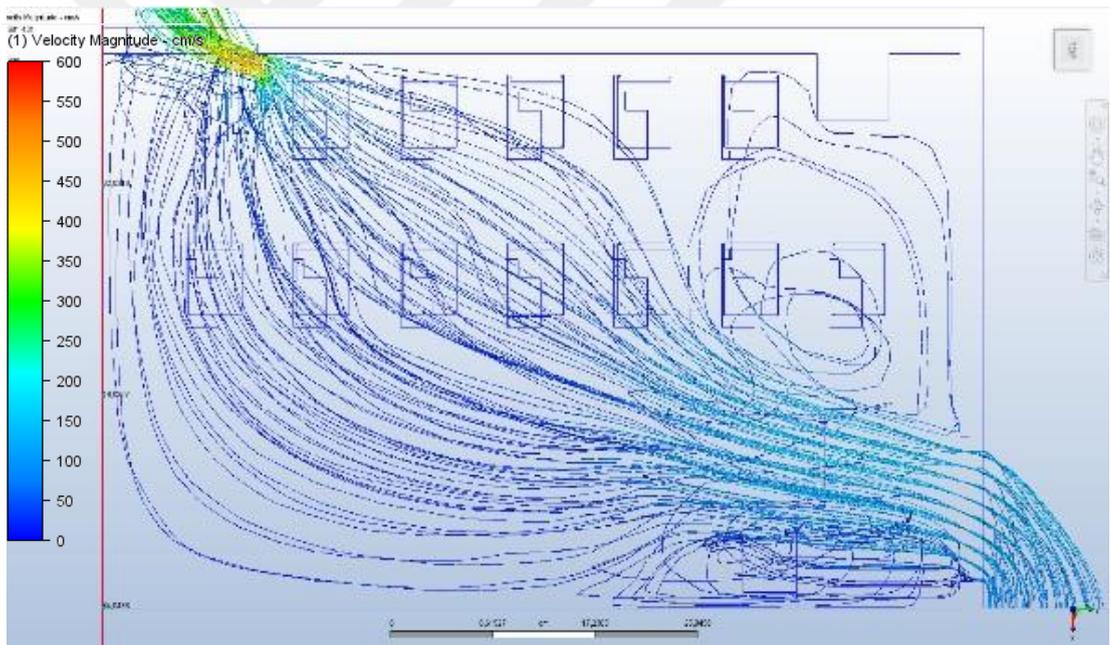
**Figure 29.** 90°-15° Perspective -Velocity



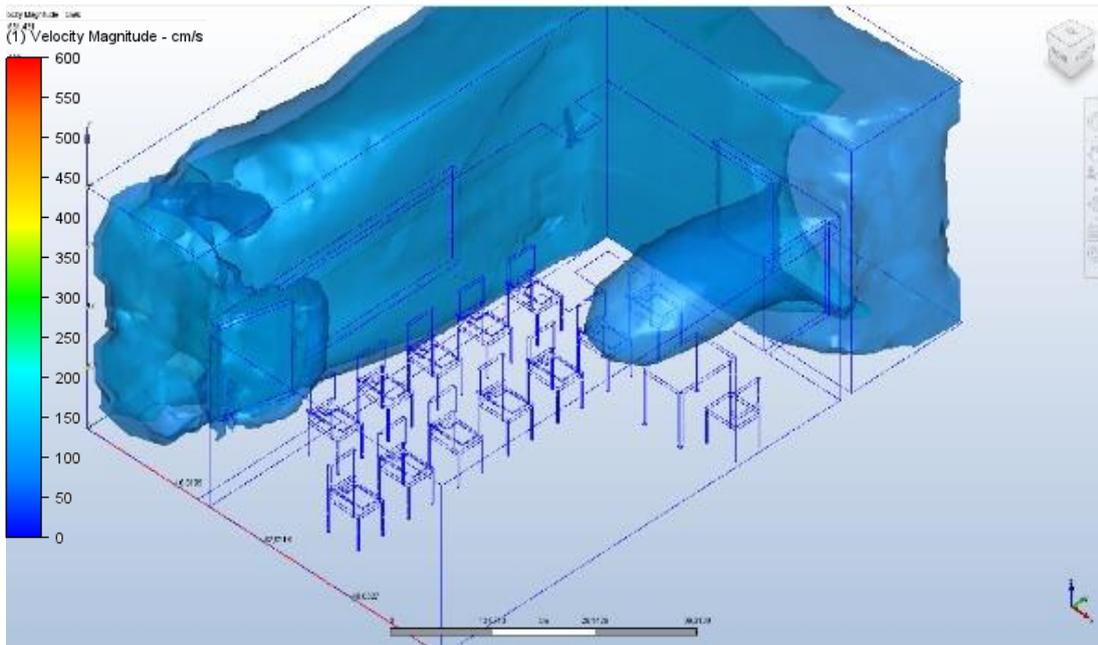
**Figure 30.** 90°-15° Top View –Velocity



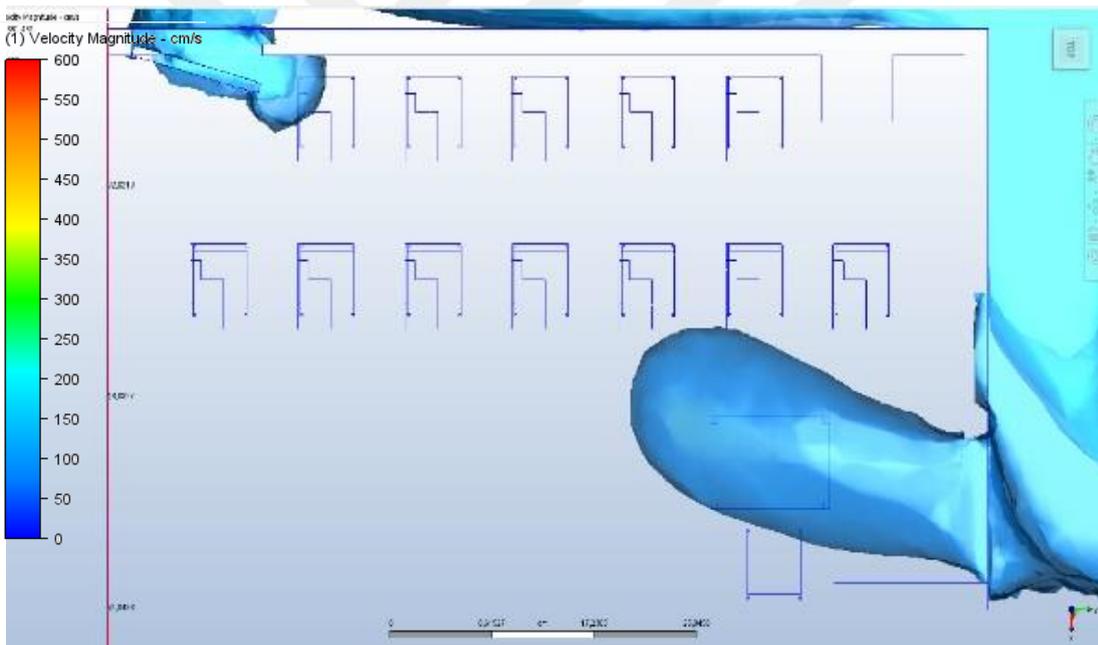
**Figure 31.** 90°-15° Perspective- Particles



**Figure 32.** 90°-15° Top View – Particles



**Figure 33.** 90°-15° Perspective - 3D Air 1-2 m/s

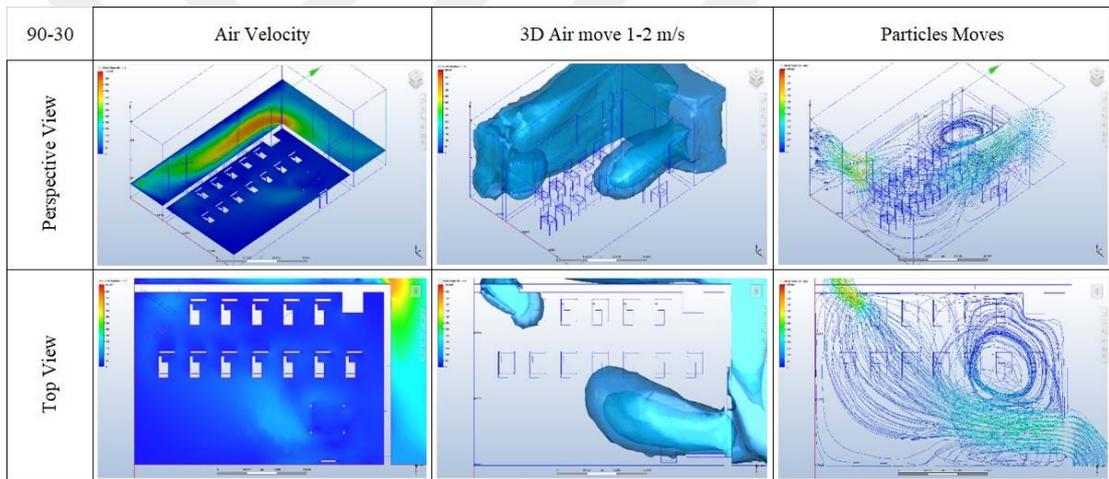


**Figure 34.** 90°-15° Top View - 3D Air 1-2 m/s

4.1.14. 90°- 30°

**Table 17.** Scenario 14 CFD Setup

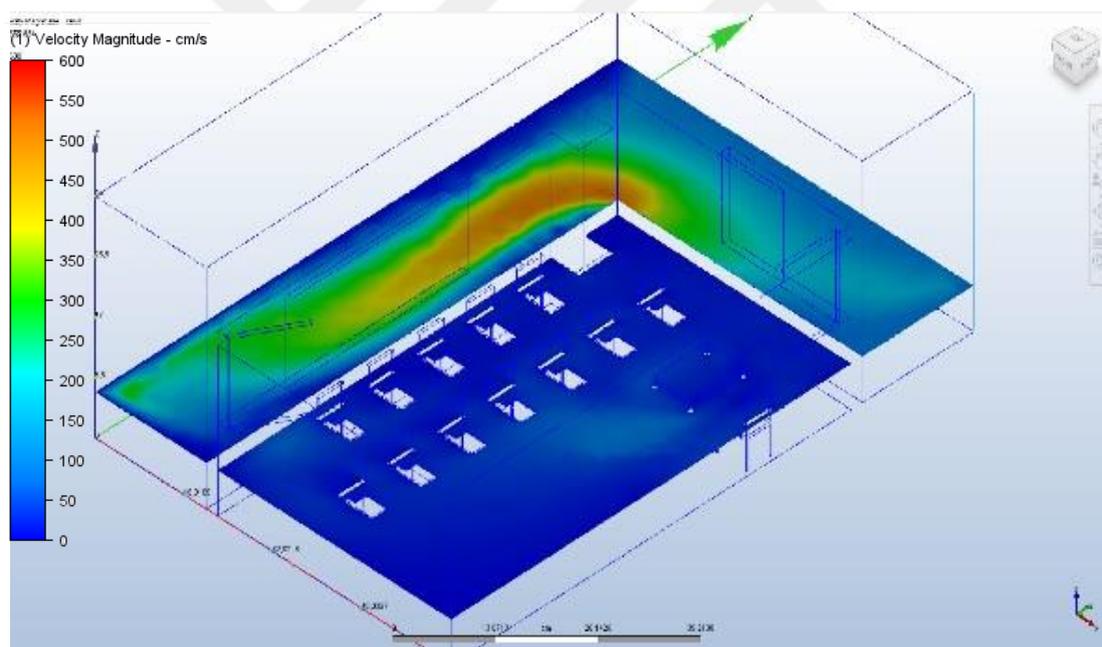
Scenario 14	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	90
Window 2 angle	30
Meshing method	CFD Automatic
Total Node	83216
Total element	288725
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1



**Figure 35.** 90°-30° Outcomes



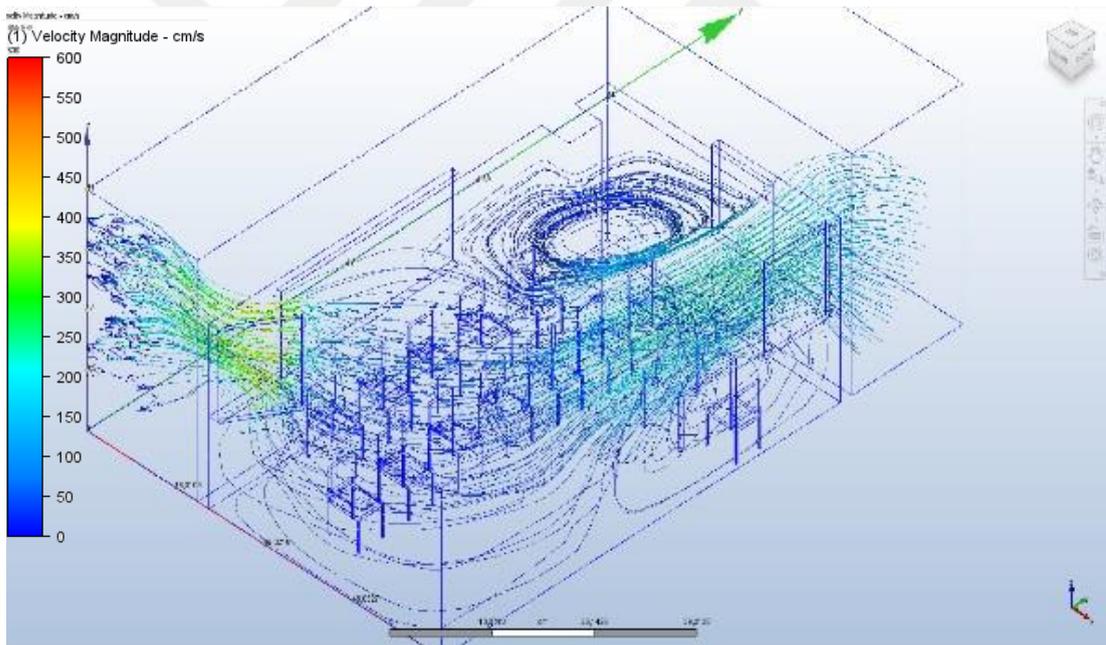
**Figure 36.** 90°-30° Perspective – Empty



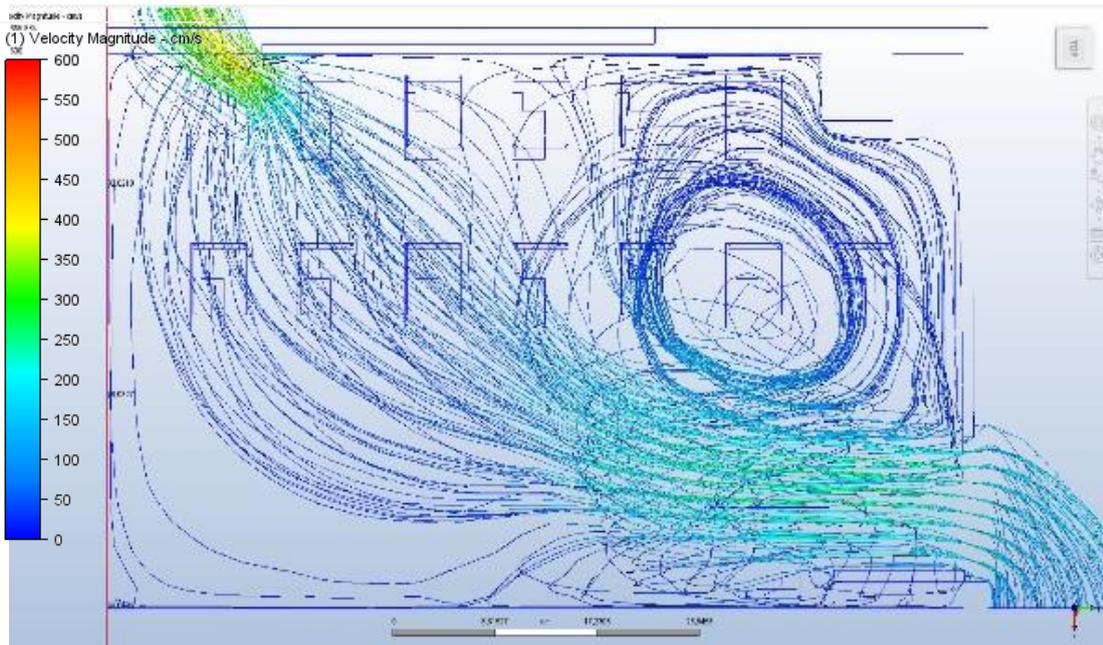
**Figure 37.** 90°-30° Perspective -Velocity



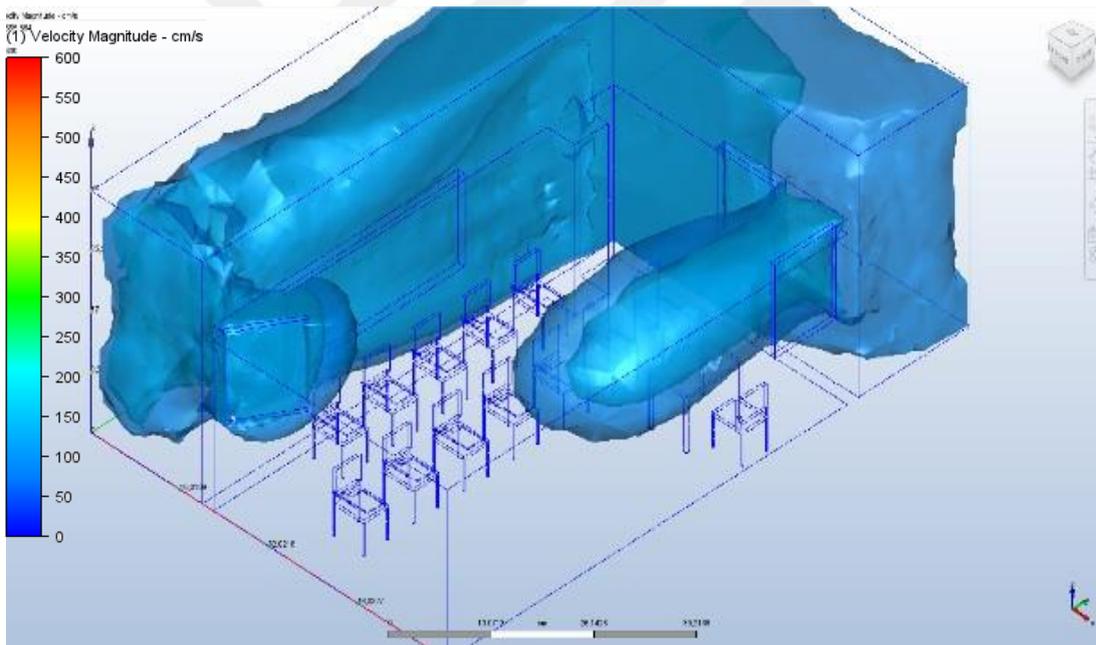
**Figure 38.** 90°-30° Top View-Velocity



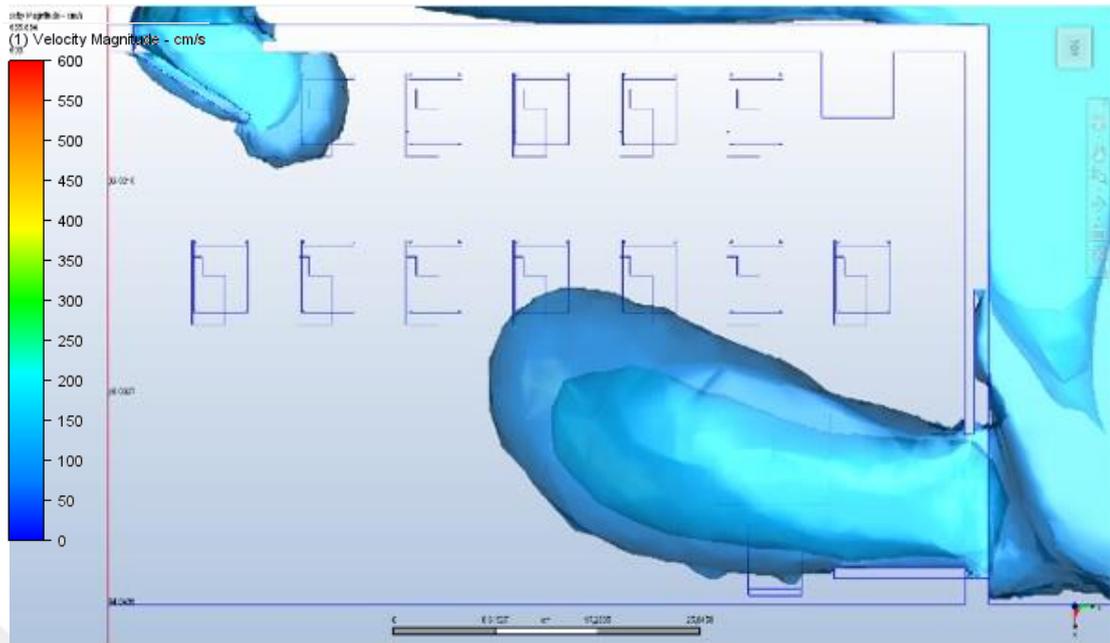
**Figure39.** 90°-30° Perspective-Particle



**Figure 40.** 90°-30° Top View-Particles



**Figure 41.** 90°-30° Perspective -3D Air 1-2 m/s

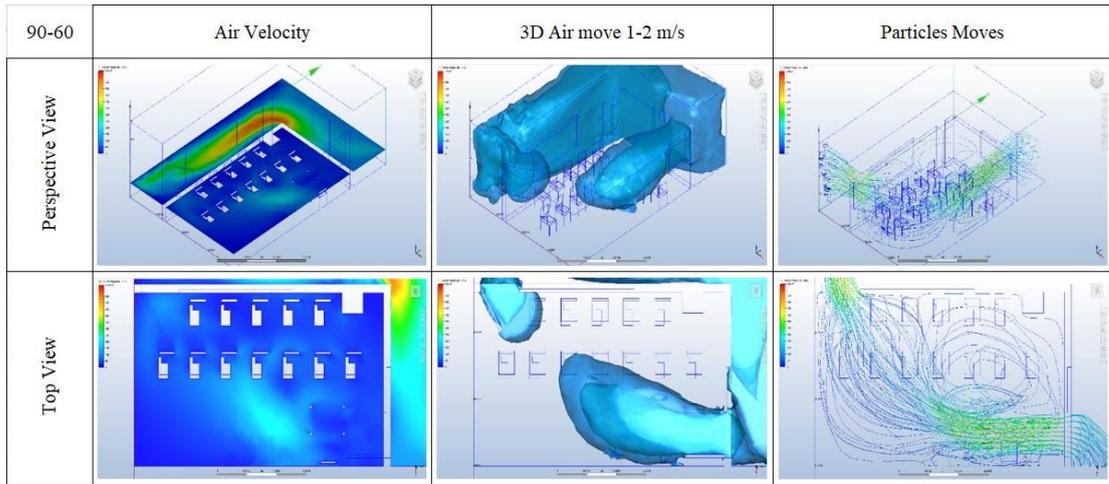


**Figure 42.** 90°-30° Top View - 3D Air 1-2 m/s

#### 4.1.15. 90°- 60°

**Table 18.** Scenario 15 CFD Setup

Scenario 15	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	90
Window 2 angle	60
Meshing method	CFD Automatic
Total Node	82629
Total element	285582
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1

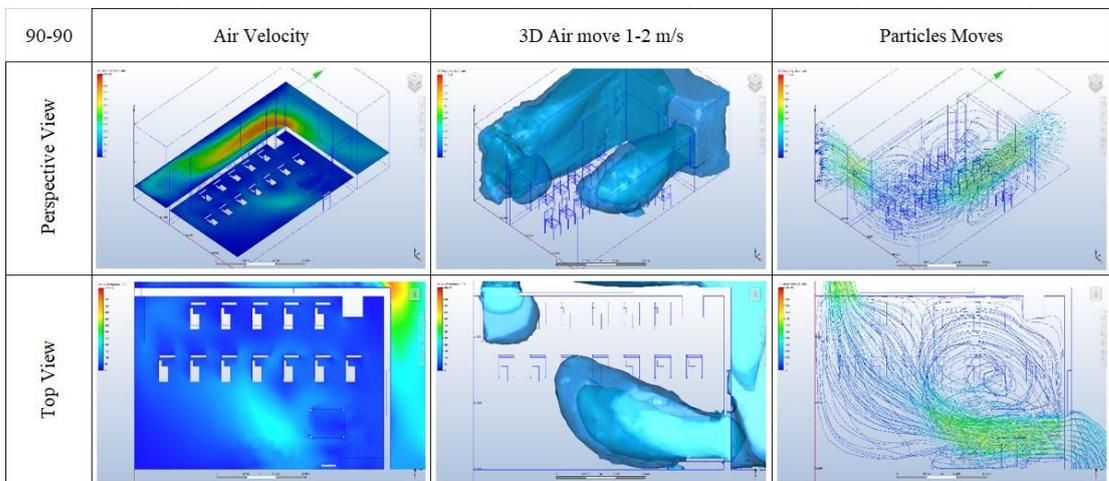


**Figure 43.** 90°-60° Outcomes

**4.1.16. 90°- 90°**

**Table 19.** Scenario 16 CFD Setup

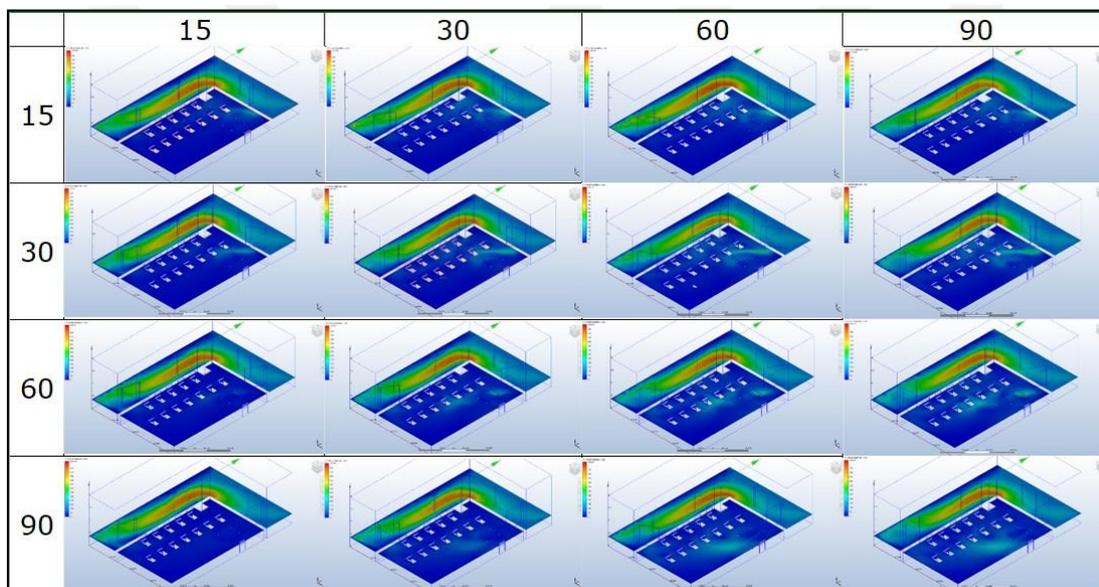
Scenario 16	
Solve model	k-epsilon
Air velocity	0,93
Window opening type	Traditional (Pivot)
Window 1 angle	90
Window 2 angle	90
Meshing method	CFD Automatic
Total Node	83238
Total element	288086
Plane	x-y
Plane height	75 cm
Trace starting point	Window 1



**Figure 44.** 90°-90° Outcomes

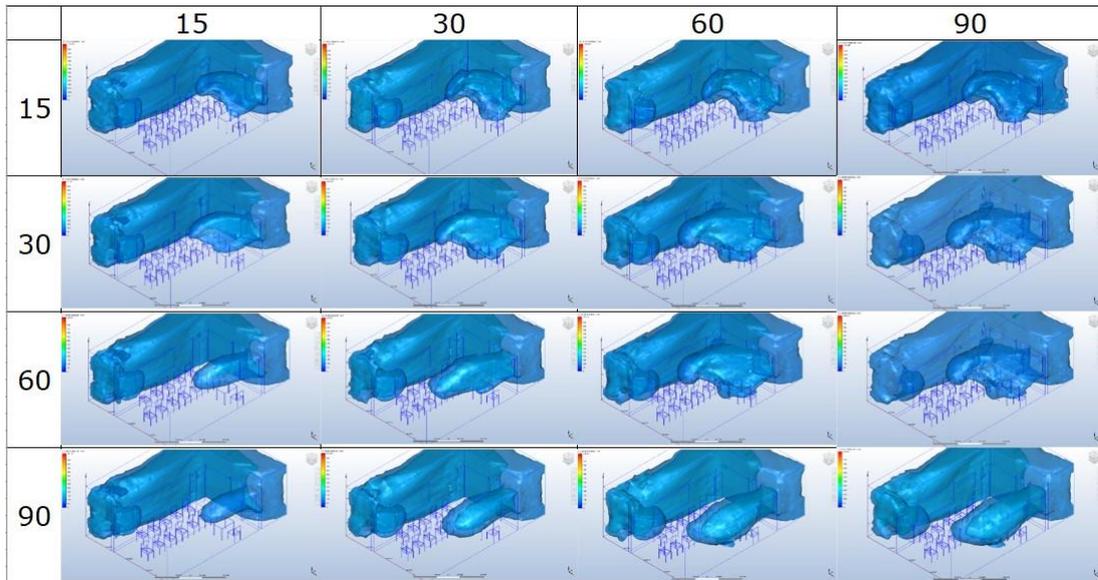
## 4.2. Analysis of Airflow Velocity

The airflow velocity analysis can be done by using the output that CFD scenarios creates. The output of CFD include the velocity of the particles in the air, their movement trough x, y and z axis. Different visualization of the outcomes refers to different approaches to the scenario. For instance, one of these visualizations is made by adjusting a plane in x and y axis. The heigh of this plane is equal to the height of the seminar chair's small table (75cm) which will inform us the velocity of the air occurring to the surface of the tables. Our objective is to find best scenarios that will be suitable for interior spaces as office which referred 1m/s. according to velocity plane we want to see less dark blue in desired locations.



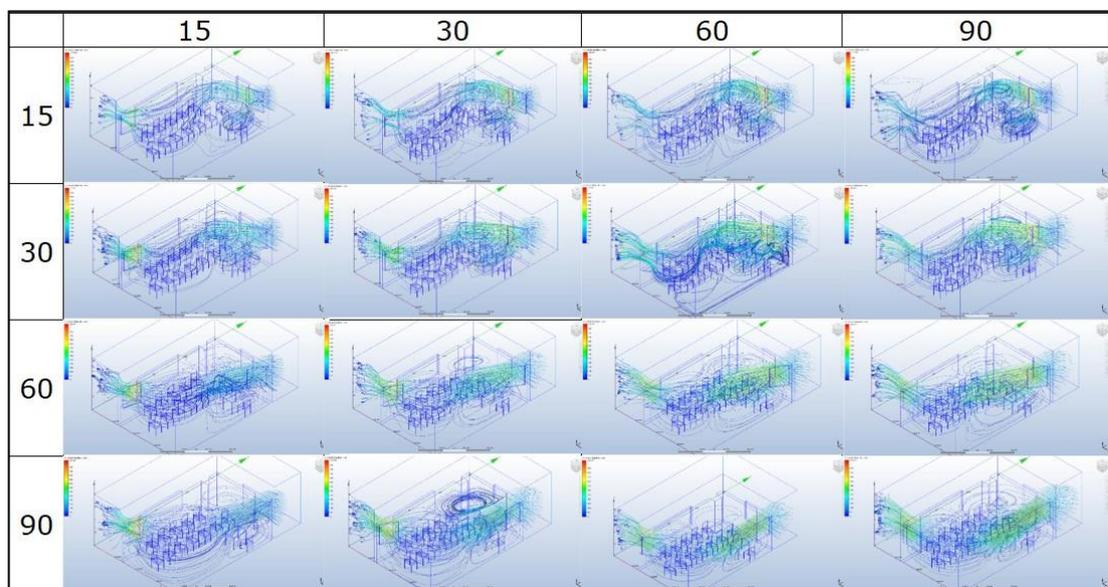
**Figure 45.** Velocity On Plane Scenarios

Making comment for only on plane velocity will not reveal all the conditions of the scenario therefore another visualization method should be considered. One of the other visualization methods is to visualize the volume of air in x, y and z axis in a 3D clouded way. This method is referring to the air movement in between specific velocity (1m/s-2m/s) which help us to understand the velocity of air occurring the scenario in the classroom interior volume. In this visualization method we consider that the blue volume doesn't reach to students sitting area so we can say that this area will not be disturbed with the air velocity.



**Figure 46.** 3D Air Movement 1-2 M/S Scenarios

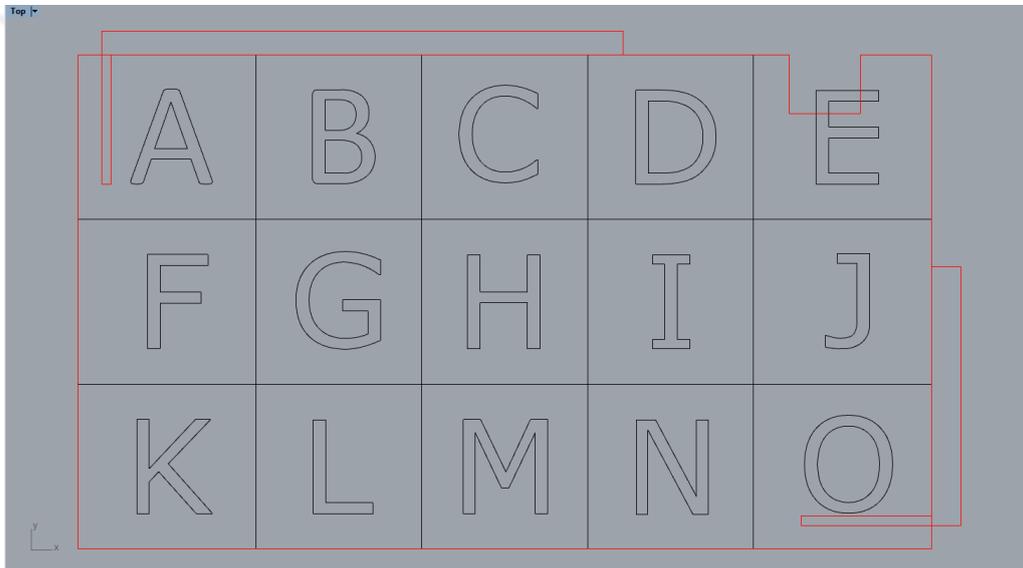
One different visualization method is particle trace visualization. In this method we can see the particle movement through the classroom interior still the velocity of the particles are important to understand the movement of the air and if this movement is disturbing or not. According to this method we can comment on the situation on the air particles if they are moving through the classroom or not. The bluer particle movement the best for avoiding disturbing air velocity.



**Figure 47.** Particle Velocity and Allocation Scenarios

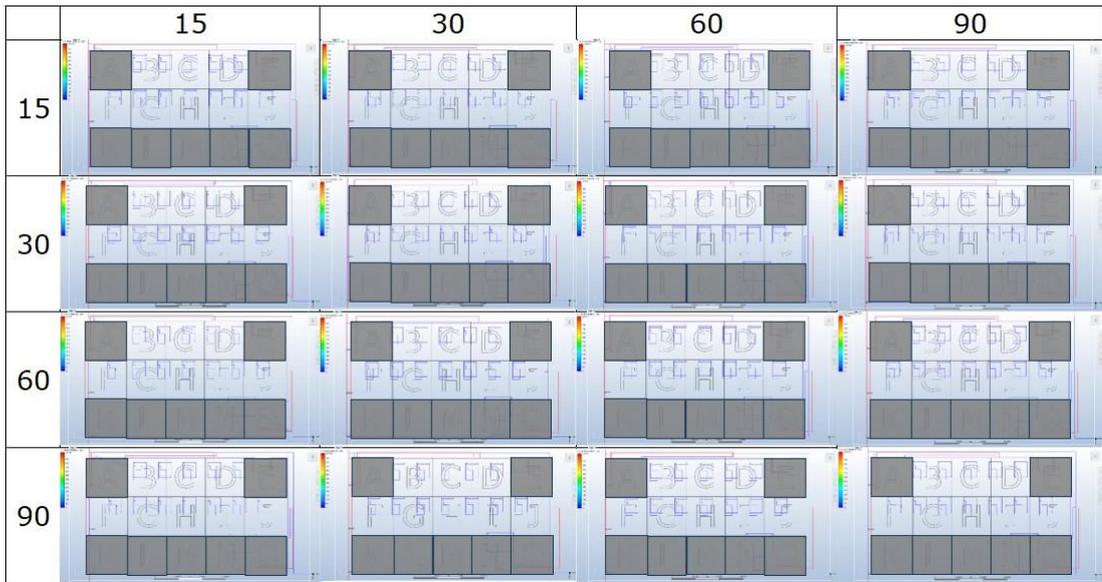
### 4.3. Comparison of Different Window Opening Angles

We can create a classification method in order to understand which options the best and which options are the worst in between the simulation outcomes. The grid system analysis is a technic that is used to do more estimated interpretation in destinated areas. This helper can be used to observe differentiations according to grid, we can observe and evaluate according to the visuals that occur in that area. Visuals having color changes (velocity actually) is counted and evaluated in three different visualization method. In this project we want to understand the locations that students uses mostly (student chairs) therefore we will be focusing in B, C, D, F, G, H, I and J locations.

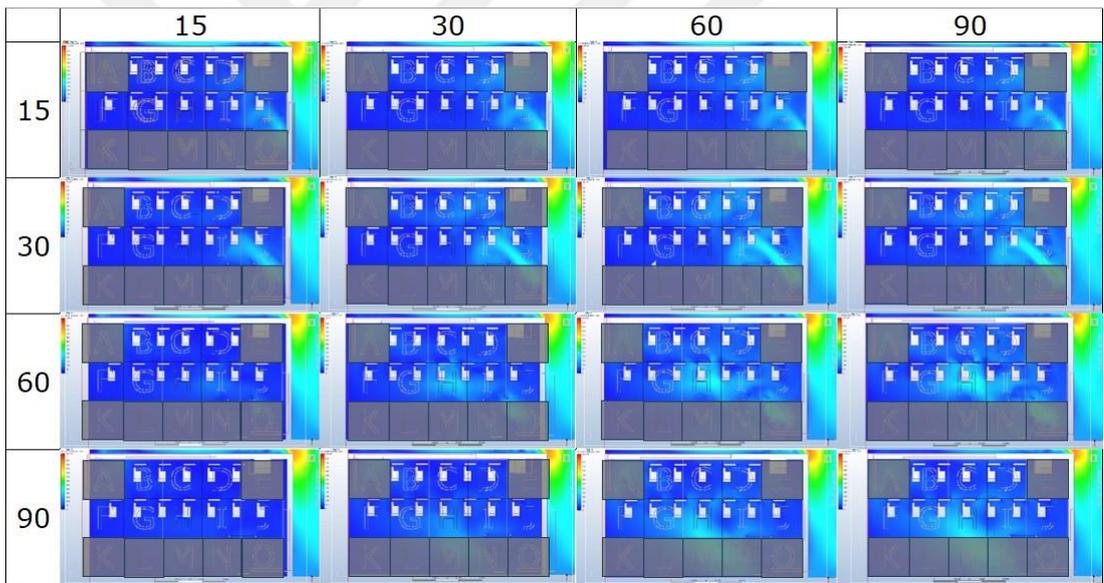


**Figure 48.** Grid-Locations

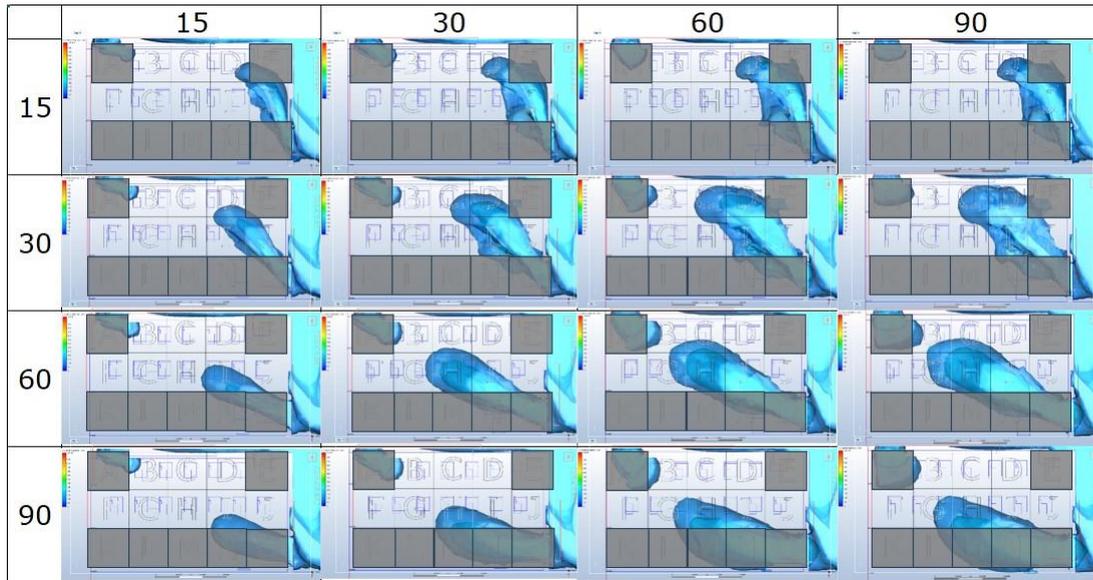
Applying the grid on the visuals is a simple method suggested that will help us to understand the scenarios and make better comment on occurring situations. We applied the grid to 3 different visualization method that was mentioned earlier and according to this we can understand and find best situations.



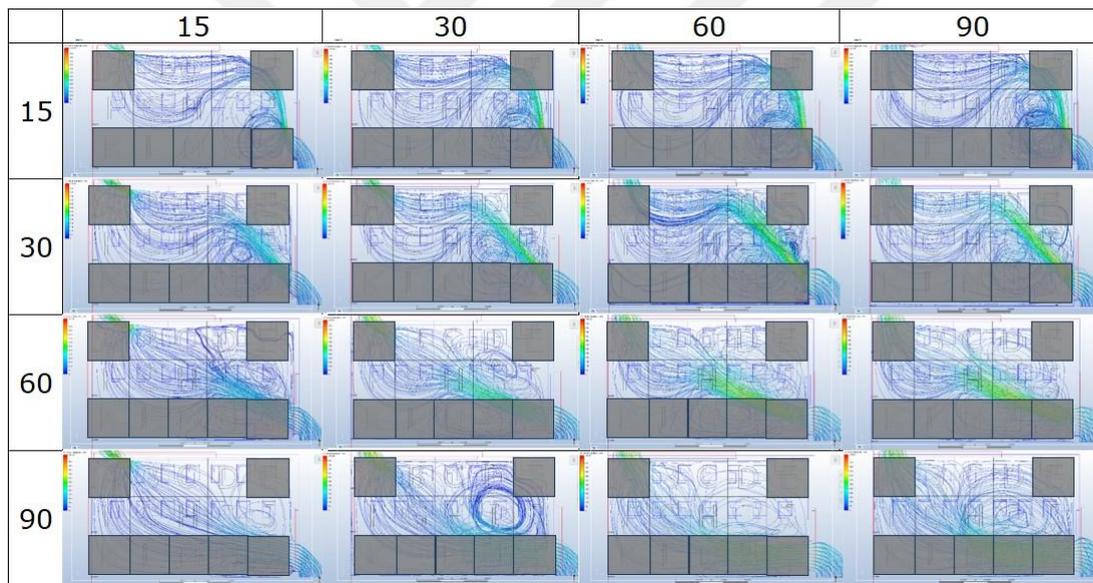
**Figure 49.** Grid Attached to Scenarios



**Figure 50.** Grid Attached to Velocity on Plane Scenarios

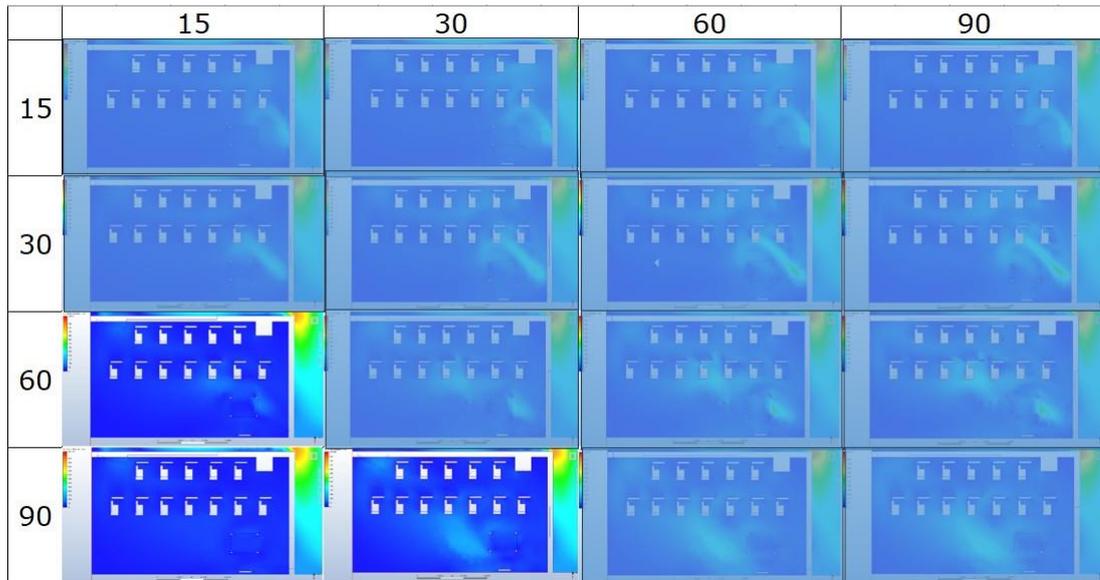


**Figure 51.** Grid Attached to 3D Air Movement 1-2 M/S



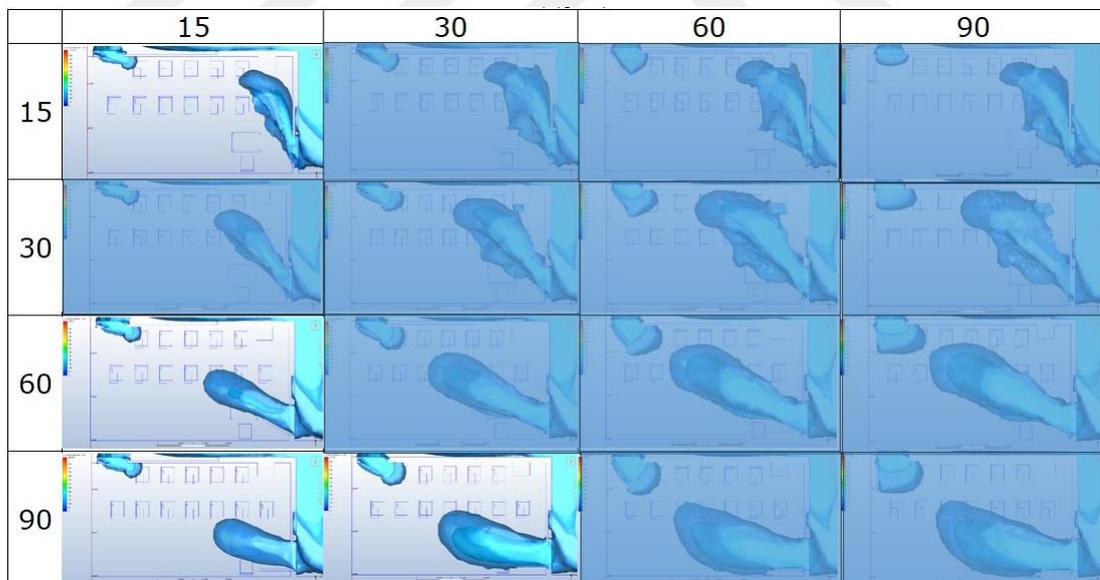
**Figure 52.** Grid Attached to Particle Velocity and Allocation.

According to the situations mentioned earlier three scenarios is referring to the best among the other scenarios. These scenarios are scenario 9(60°-15°), scenario 13(90°-15°) and scenario14(90°-30°).



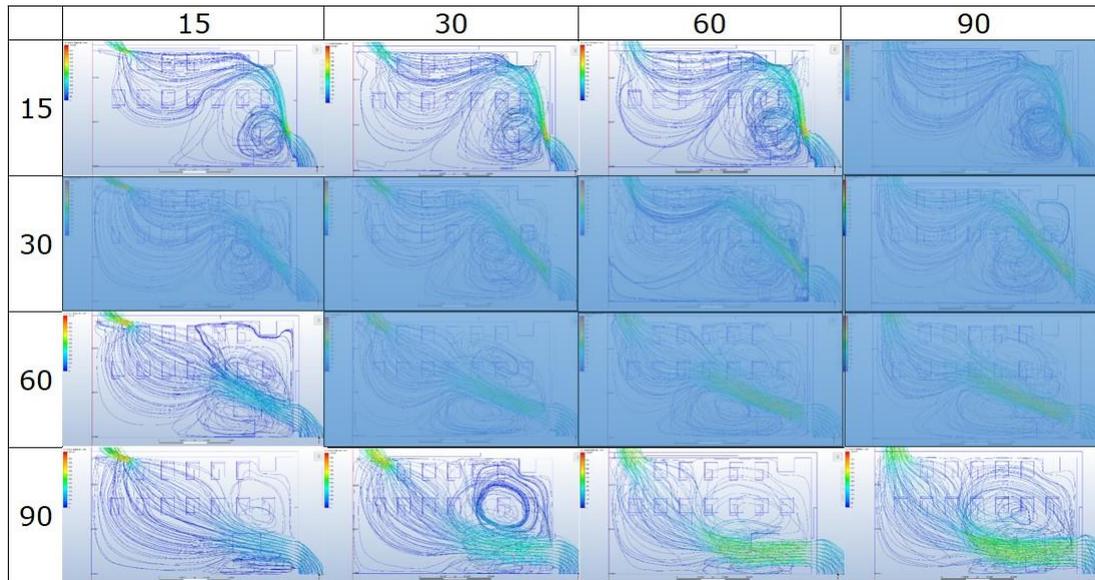
**Figure 53.** Best Scenarios for Velocity On Plane.

According to the situations mentioned earlier four scenarios is referring to the best among the other scenarios. These scenarios are scenario 1( $15^{\circ}$ - $15^{\circ}$ ), scenario 9( $60^{\circ}$ - $15^{\circ}$ ), scenario 13( $90^{\circ}$ - $15^{\circ}$ ) and scenario14( $90^{\circ}$ - $30^{\circ}$ ).



**Figure 54.** Best Scenarios For 3D Air Movement 1-2 M/S.

According to the situations mentioned earlier eight scenarios is referring to the best among the other scenarios. These scenarios are scenario 1( $15^{\circ}$ - $15^{\circ}$ ), scenario 2( $15^{\circ}$ - $30^{\circ}$ ), scenario 3( $15^{\circ}$ - $60^{\circ}$ ) scenario 9( $60^{\circ}$ - $15^{\circ}$ ), scenario 13( $90^{\circ}$ - $15^{\circ}$ ), scenario14( $90^{\circ}$ - $30^{\circ}$ ), scenario 15( $90^{\circ}$ - $60^{\circ}$ ) and scenario 16( $90^{\circ}$ - $90^{\circ}$ ).

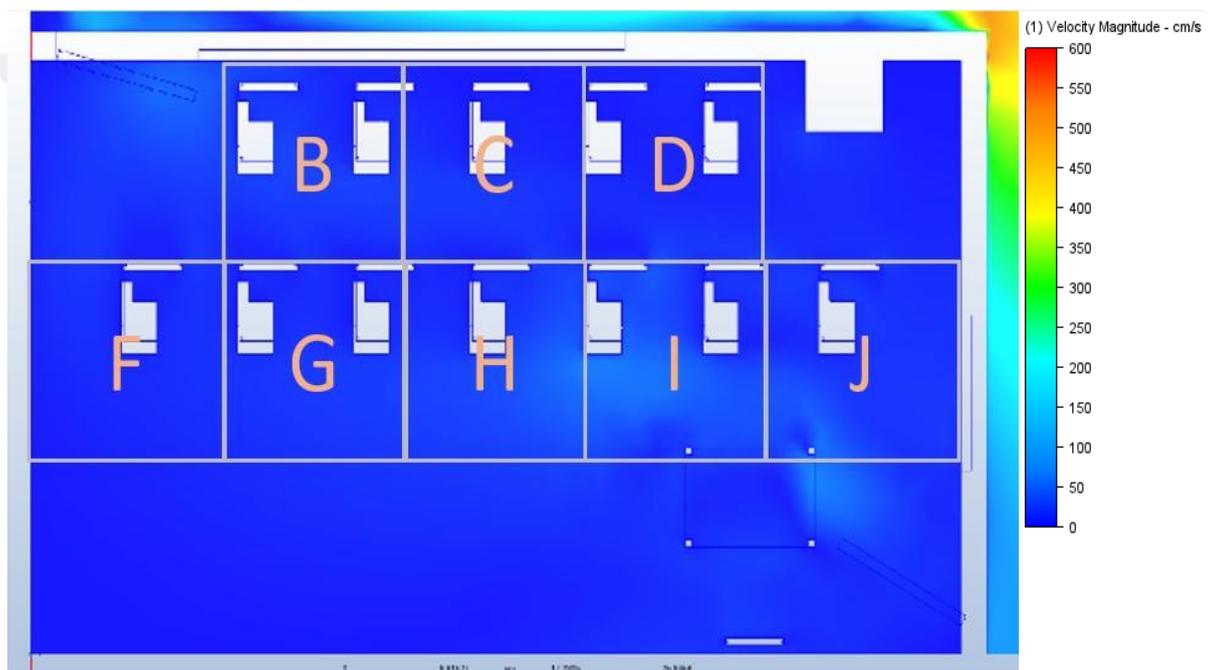


**Figure 55.** Best Scenarios for Particle Velocity and Allocation.

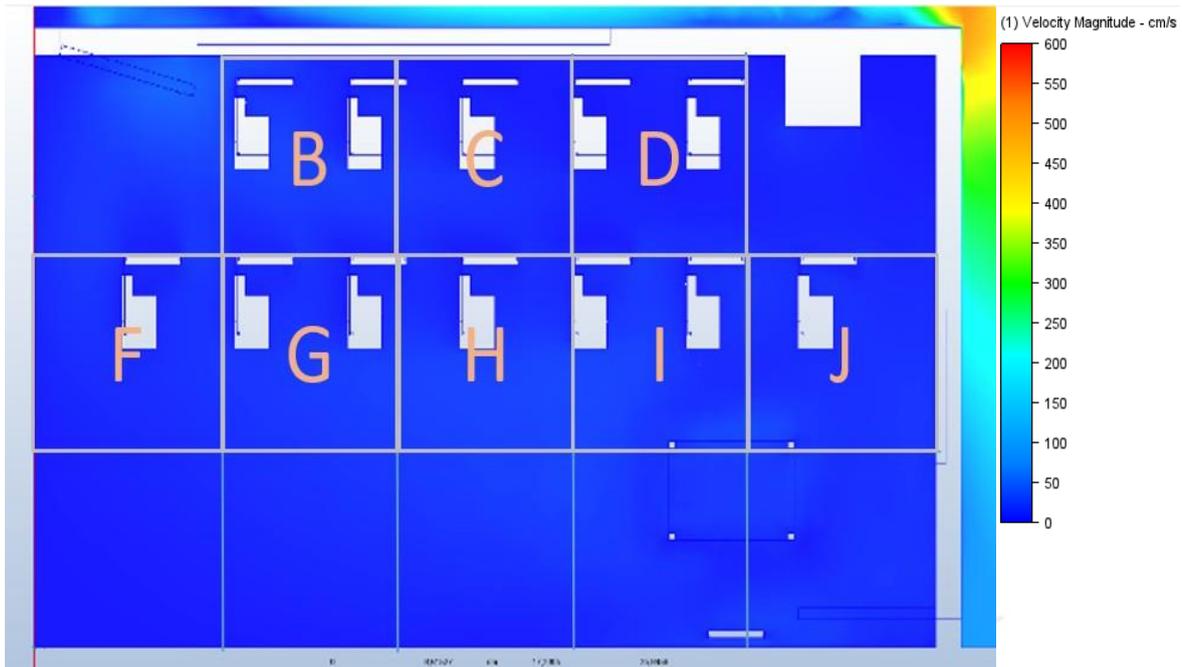
#### 4.4. Discussion

The results of this study provide valuable insights into the impact of window opening angle on natural ventilation in educational buildings. The CFD simulations showed that increasing the window opening angle can significantly increase the airflow velocity and improve the distribution of air in the classroom. This can help to reduce the concentration of indoor air pollutants and improve the overall comfort of the indoor environment. As discussion of the result, we must understand what makes the area ventilated in a better way according to comment on visualizations. Our focus is to obtain no more than 1 m/s on B, C, D, F, G, H, I and J areas identified in the grid method which are the student seating areas. One of the visualization method containa plane which indicated us the air velocity occurring on the top of the student tables which is 75cm height. This method shows us if there is any air velocity above 1m/s on top of the student tables which indicate us if is there any disturbance on students and their objects since air velocity above 1 m/s will move the papers on top of these tables. Some of the scenarios are not effective enough to ventilate the classroom. In some scenarios the movement of air was highly effective, but it was also disturbing for the users. According to these insights we used the grid system as a tool to focus student seating area which are B, C, D, F, G, H, I and J on simulations outcomes. For instance in scenario 9 the air velocity in focused area contain these air velocity values: section B 0.5-1 m/s, section C 0.5-1 m/s, section D 0.5 m/s, section F 0.5-1

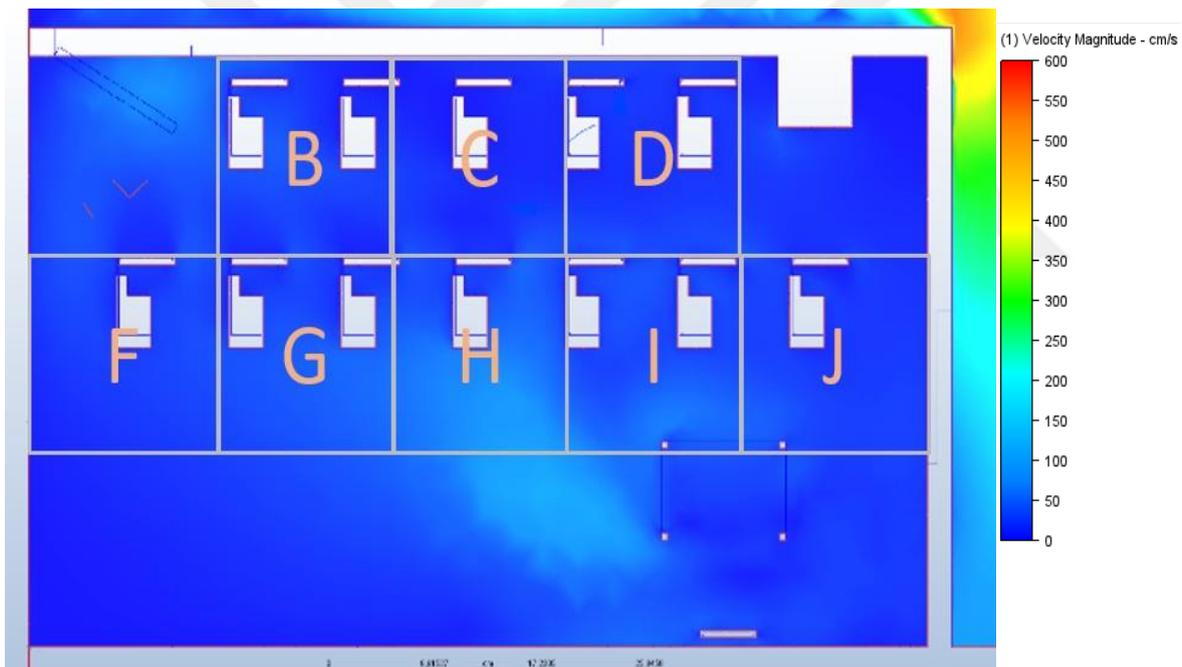
m/s, section G 0.5-1 m/s, section H 1 m/s, section I 1 m/s, section J 0.5-1 m/s. Scenario 13 the air velocity in focused area contain these air velocity values: section B 0.5-1 m/s, section C 0.5 m/s, section D 0.5 m/s, section F 0.5-1 m/s, section G 0.5-1 m/s, section H 0.5-1 m/s, section I 0.5-1 m/s, section J 0.5 m/s. Scenario 13 the air velocity in focused area contain these air velocity values: section B 0.5-1 m/s, section C 0.5 m/s, section D 0.5-1 m/s, section F 0.5-1 m/s, section G 1 m/s, section H 1 m/s, section I 1 m/s, section J 0.5-1 m/s. According to these values we can say that our best scenarios are scenario 9(60°-15°), scenario 13(90°-15°) and scenario 14(90°-30°) among the other scenarios since our desired value is no more than 1 m/s according to paper moving velocity is more than 1 m/s.



**Figure 56.** Scenario 9 (60°-15°) Grid

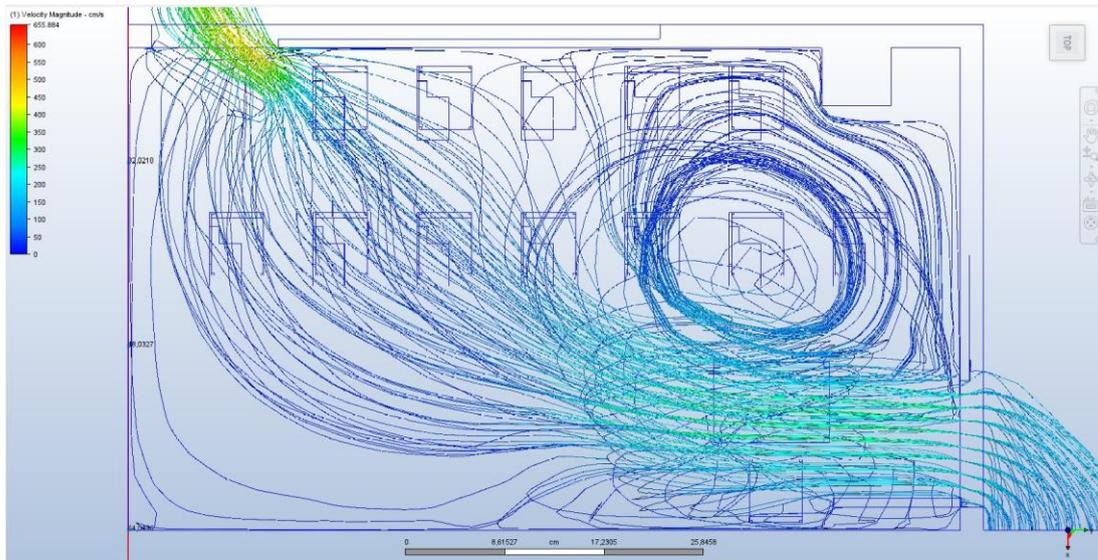


**Figure 57.** Scenario (13 90°-15°) Grid

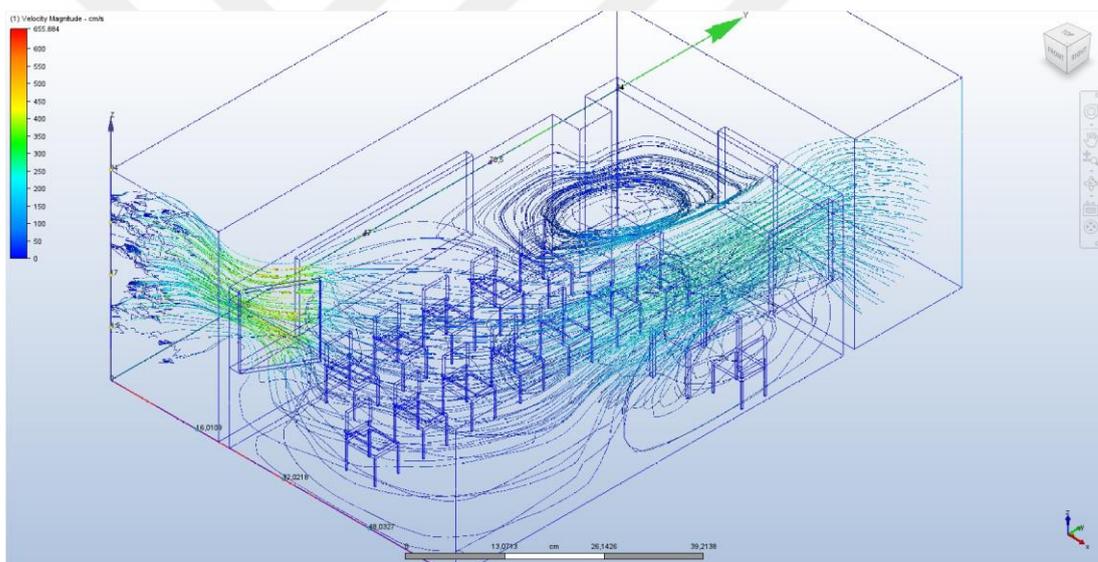


**Figure 58.** Scenario 14 (90°-30°) Grid

These 3 scenarios were the best situations in different visualization method, but in particle movement of the scenario 14 we observed a vortex that particles aren't in a movement that will be conducting air exterior of the classroom or at least we can say that according to this vortex the air particles movement will delay the effective ventilation. This situation should be considered as a scenario failure therefore the best scenarios will be scenario 9(60°-15°) and scenario 13(90°-15°).

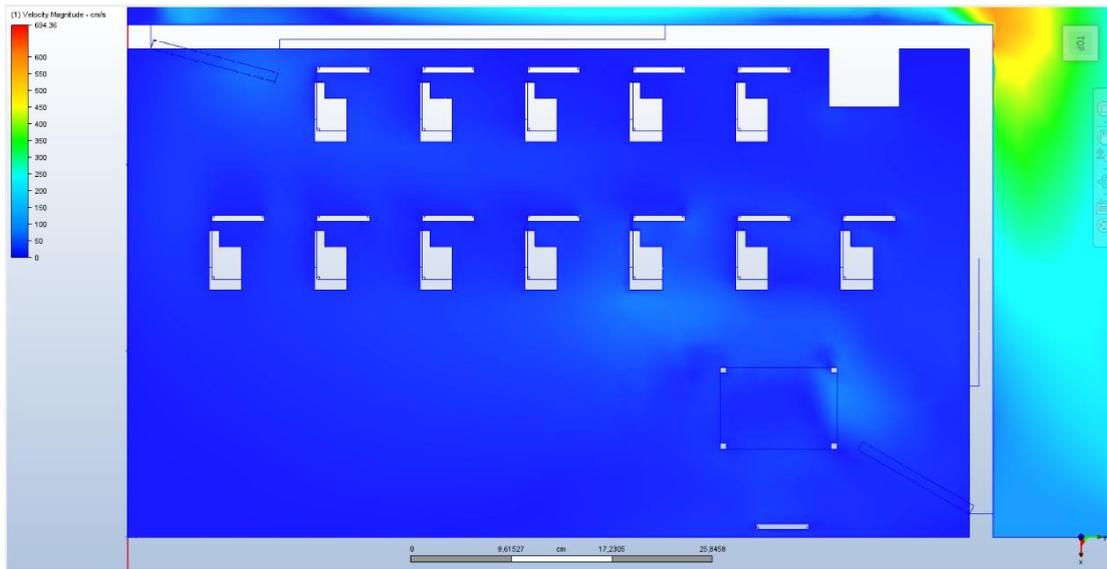


**Figure 59.** Scenario 14(90°-30°) Particle Movement Top View

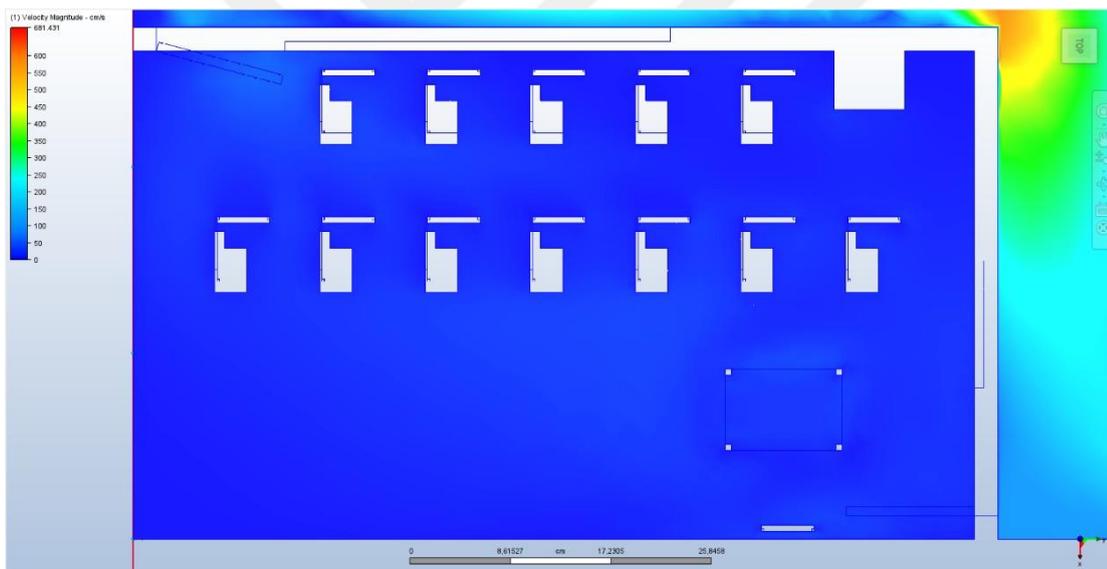


**Figure 60.** Scenario 14(90°-30°) Particle Movement Perspective View

Since the outcome of the simulations refer us to 2 best scenarios which are Scenario 9(60°-15°) and Scenario 13, we can decide which one is better than other for instance we can compare the two scenarios. The plane which indicates us the top height of student chairs tables are quite looking the same.

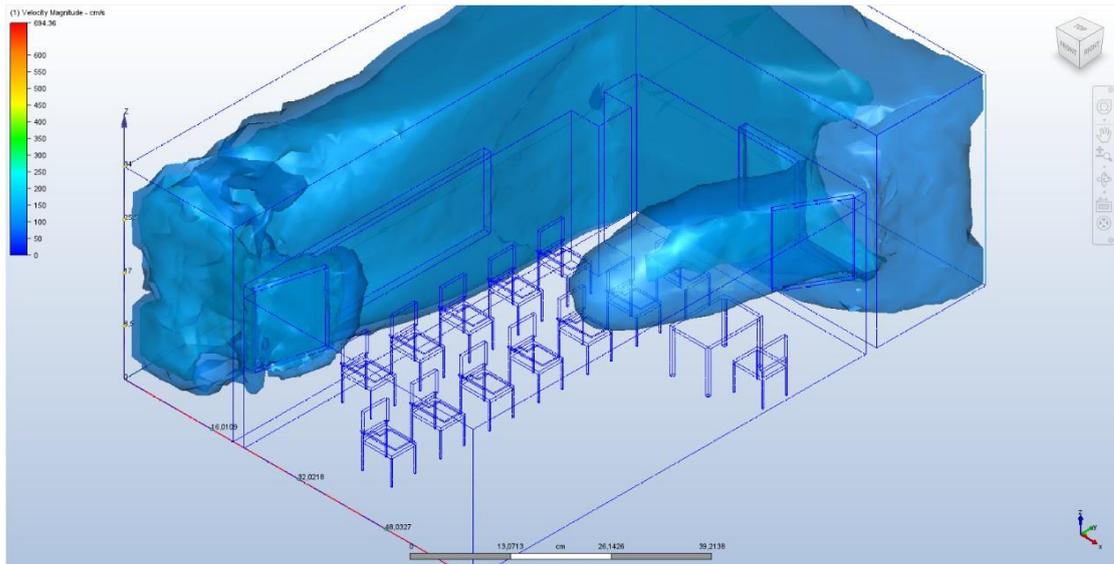


**Figure 61.** Scenario 9(60°-15°) Air Velocity On Plane

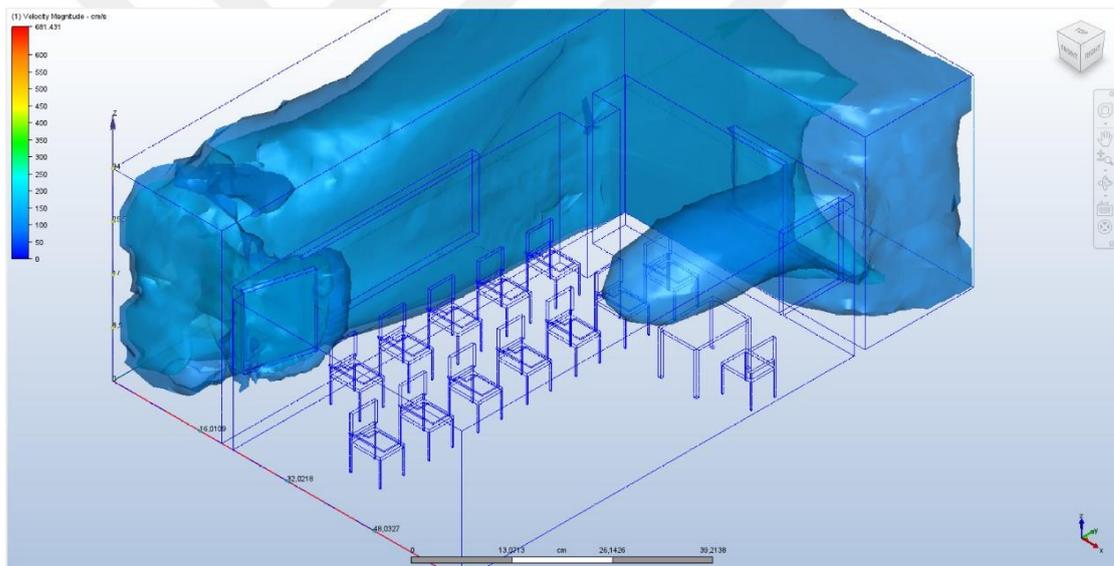


**Figure 62.** Scenario 13(90°-15°) Air Velocity on Plane

The movement of the air in the interior volume are also looking like quite the same but we can understand that Scenario 9(60°-15°) has a higher velocity compared to scenario 13(90°-15°). We can comment that there is a unwanted air velocity just in front of the student table.



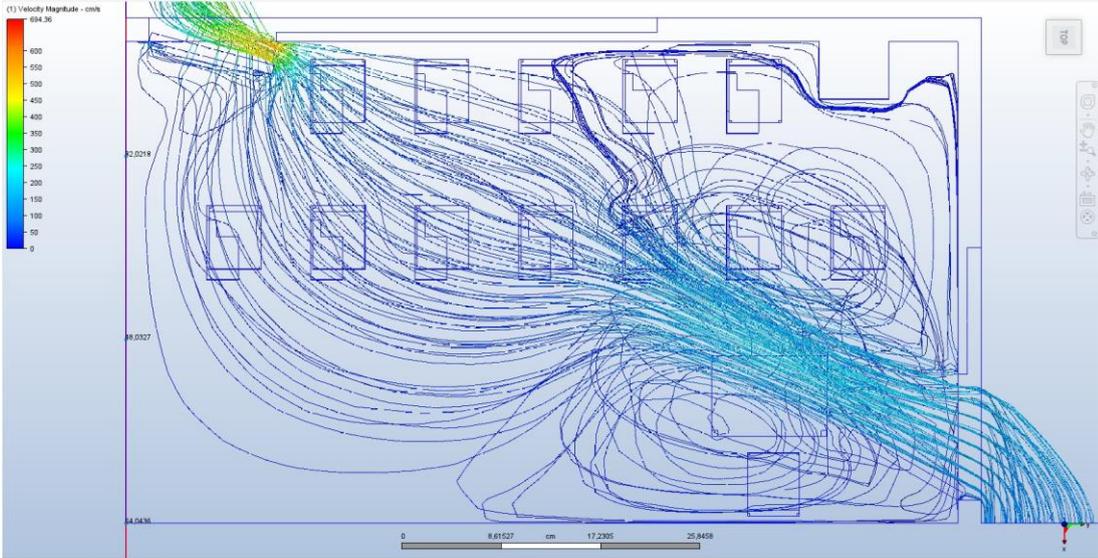
**Figure 63.** Scenario 9( $60^{\circ}$ - $15^{\circ}$ ) 3D Air Movement 1-2 M/S



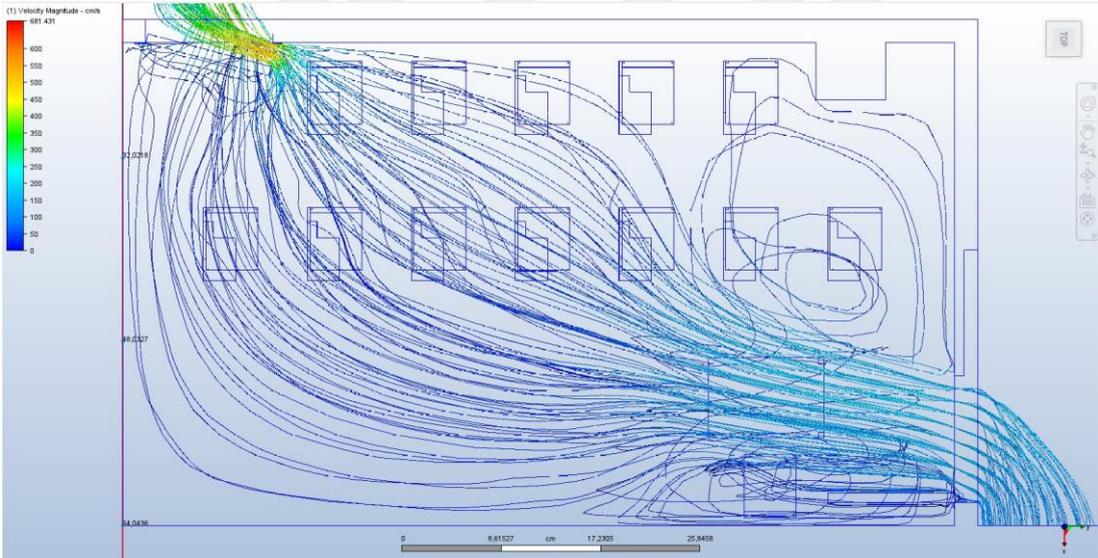
**Figure 64.** Scenario 13( $90^{\circ}$ - $15^{\circ}$ ) 3D Air Movement 1-2 M/S

In another Simulation outcome that contains the particles move indicate us that both scenarios are good in order of interior air molecule changes, but we can also comment that scenario 9( $60^{\circ}$ - $15^{\circ}$ ) has a potential to disturb student in higher air velocity that occurs outside of the classroom. The angular guidance of the window creates a focus point on students sitting area. This potential lead us to consider scenario 13( $90^{\circ}$ - $15^{\circ}$ ) is better than scenario 9( $60^{\circ}$ - $15^{\circ}$ ). It is also important to note that 15-degree outlet is a common for these two scenarios. It can be also explained with the Bernoulli effect which give us the knowledge that vacuum effect is created

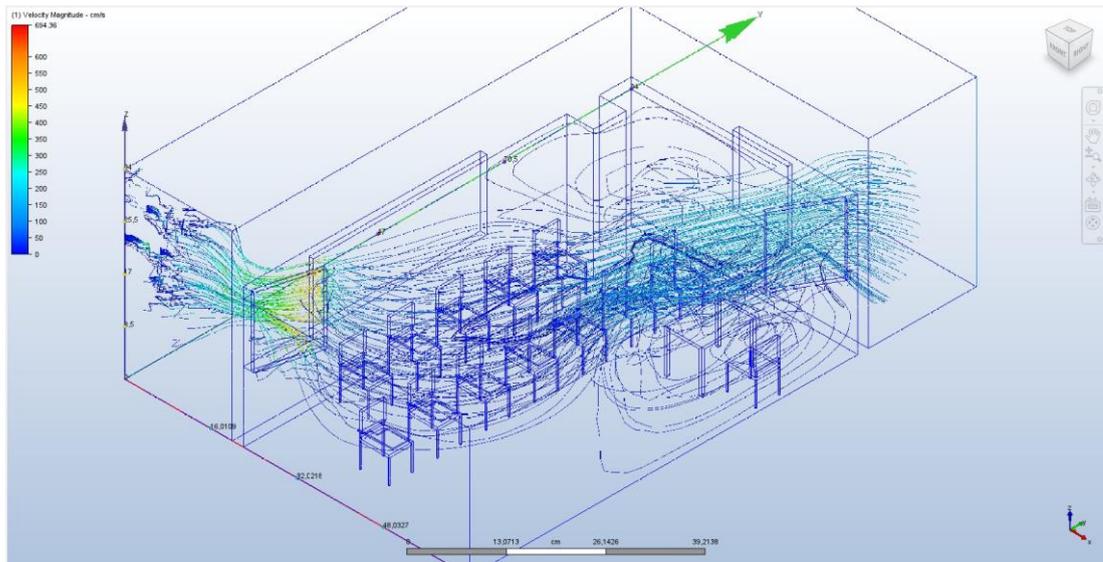
with wider inlet angle and closer outlet angle.



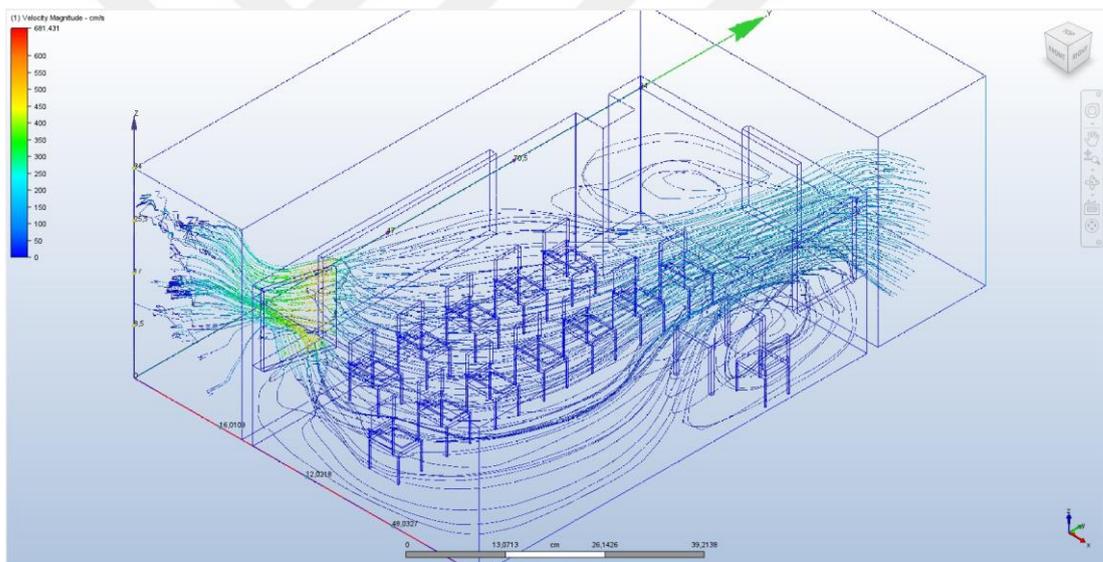
**Figure 65.** Scenario 9(60°-15°) Particle Movement Top View



**Figure 66.** Scenario 13(90°-15°) Particle Movement Top View



**Figure 67.** Scenario 9(60°-15°) Particle Movement Perspective View



**Figure 68.** Scenario 13(90°-15°) Particle Movement Perspective View

Another important finding of this study is that natural ventilation can be an effective and energy-efficient way to improve indoor air quality in educational buildings. The results of the simulations showed that increasing the window opening angle can significantly increase the airflow velocity and improve the distribution of air. This can help to reduce the concentration of indoor air pollutants and improve the overall comfort of the indoor environment. In addition, natural ventilation can help to reduce energy consumption by reducing the need for mechanical ventilation systems.

Overall, the findings of this study have important implications for the design

of educational buildings. Natural ventilation can be an effective way to improve indoor air quality and reduce energy consumption in educational buildings. However, in order to optimize the effectiveness of natural ventilation, designers must carefully consider a range of factors, including the building orientation, the location of windows, and the size and shape of the building. By carefully considering these factors, designers can create educational buildings that are comfortable, healthy, and energy efficient.

In conclusion, this study provides valuable insights into the impact of window opening angle on natural ventilation in educational buildings. Designers can use the findings of this study to optimize the design of natural ventilation systems and create educational buildings that are healthy, comfortable, and energy efficient. However, it is important to note that the results of the simulations are only valid for the specific building and conditions that were modeled. Therefore, future research should focus on studying the impact of natural ventilation in a wider range of building types and environmental conditions. In addition, future research should focus on developing new simulation tools and techniques to provide more accurate and detailed information about the impact of natural ventilation on indoor air quality and energy consumption.

Finally, it is important to note that natural ventilation is just one of many strategies that can be used to improve indoor air quality and reduce energy consumption in buildings. Other strategies, such as mechanical ventilation, air filtration, and energy-efficient lighting and heating systems, should also be considered when designing energy-efficient and healthy buildings. By carefully considering a range of strategies and technologies, designers can create buildings that are comfortable, healthy, and energy-efficient, and that meet the needs of their occupants.

## CHAPTER 5

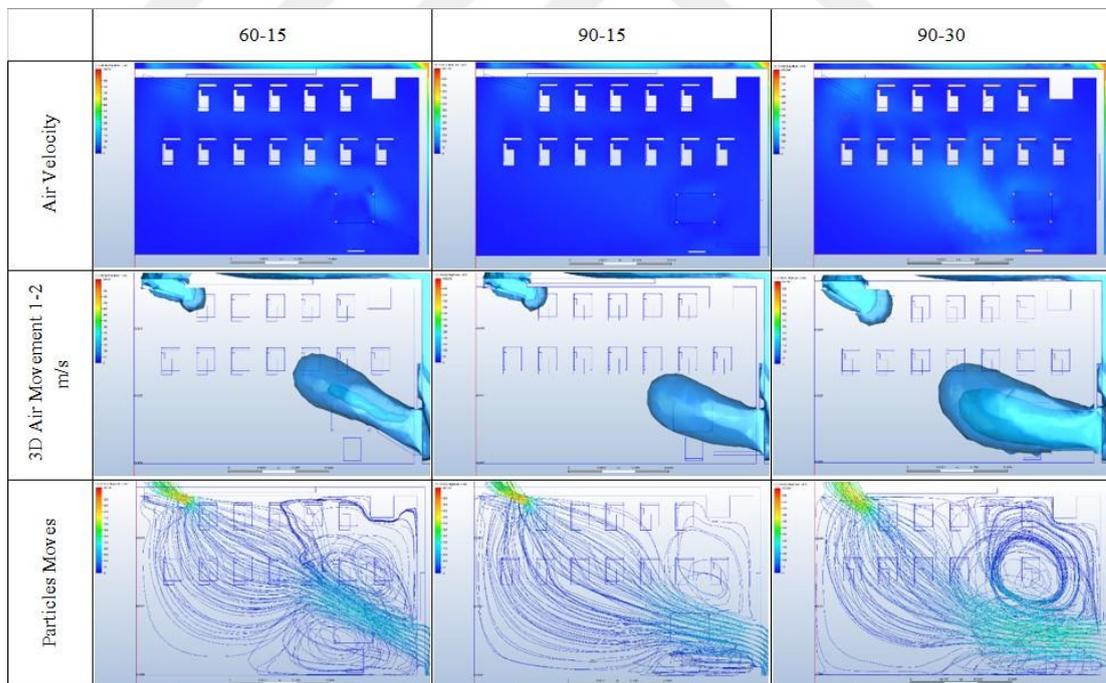
### CONCLUSION AND RECOMMENDATIONS

#### 5.1. Summary of Findings

The CFD simulations showed that the airflow velocity increased as the window opening angle increased. This is because a wider window opening angle allows more air to flow through the building. The pressure distribution in the building also changed as the window opening angle increased. This is because the inflow of fresh air from outdoors helps to cool the building and increase the pressure.

The CFD simulations provided valuable insights into the impact of window opening angle on natural ventilation in classroom. According to the outcomes 3 scenario showed us that natural ventilation was effective in certain conditions of the classroom.

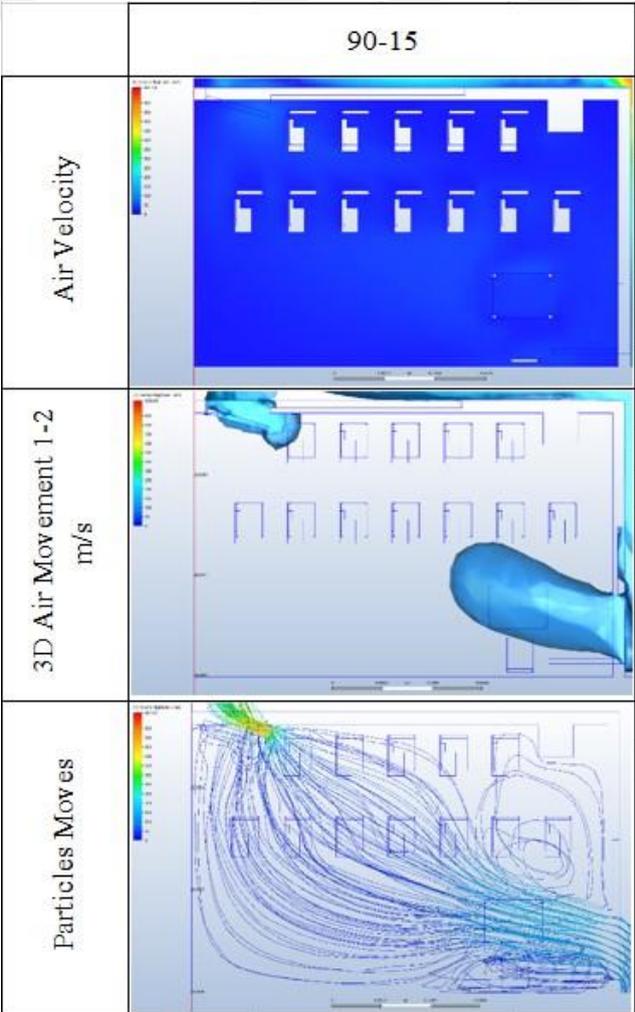
**Table 20.** Comparison Of Best Scenarios Outcomes



Our primary concern is to maintain an air velocity of no more than 1 meter per second (m/s) across student seating areas, denoted by B, C, D, F, G, H, I, and J within the grid layout. To achieve this objective, we are utilizing a visualization method employing a virtual plane positioned at a height of 75 centimeters above the student tables. This plane serves as a visual indicator of air velocity occurring

directly above the student workspace, effectively revealing any areas experiencing air flow exceeding the 1 m/s threshold.

This visualization technique allows us to proactively identify potential disruptions caused by excessive air movement. Air velocities exceeding 1 m/s can negatively impact students by disturbing their papers and other materials placed on the tables, potentially causing distraction and frustration. By monitoring the air velocity across the student seating areas, we can ensure a comfortable and productive learning environment for students. When we analyze these 3 scenarios, we understand that 1 scenario is showing better outcomes between these 3 scenarios. The results of the simulations showed that a window opening angle scenario 13(90-15) was the most effective for natural ventilation in the specific building that was modeled.



**Figure 69.** Best Scenario

However, it is important to note that the results of the simulations are only valid for the specific building and conditions that were modeled. The results may not be valid

for other buildings or conditions. For example, the results may not be valid for buildings with different shapes or sizes. Additionally, the results may not be valid for buildings in different climates. Overall, the CFD simulations provided valuable insights into the impact of window opening angle on natural ventilation in buildings. However, it is important to note that the results of the simulations are only valid for the specific building and conditions that were modeled.

## **5.2. Implications of the Study**

Computational fluid dynamics (CFD) simulations have emerged as a powerful tool in the field of architectural design, enabling researchers to understand the dynamics of natural ventilation in buildings. This study used this advanced technology to investigate the impact of window opening angles on air flow patterns within a classroom setting. By implementing a grid system, the study focused on specific areas of interest, particularly the student seating zones. This methodological approach ease to analyze of the simulated air movement within these crucial zones, revealing the role between window angle adjustments and air flow distributions. The results of this study are significant, as they demonstrate the influence of even minor adjustments to window angles on the overall air circulation patterns within a classroom. This valuable knowledge empowers architects to optimize window design, create buildings that breathe naturally, thereby reducing energy consumption and creating an environment conducive to occupant comfort and well-being.

Another important implication of this study is that the effectiveness of natural ventilation is highly dependent on the specific building and environmental conditions. The results of the simulations are only valid for the specific building and conditions that were modeled. The results may not be valid for other buildings or conditions. For example, the results may not be valid for buildings with different shapes or sizes. Additionally, the results may not be valid for buildings in different climates. Therefore, it is important for designers to carefully consider the specific conditions of each building when designing natural ventilation systems.

The findings of this study also have important implications for the design of educational buildings. Natural ventilation can be an effective way to improve indoor air quality and reduce energy consumption in educational buildings. However, in order to optimize the effectiveness of natural ventilation, designers must carefully

consider a range of factors, including the building orientation, the location of windows, and the size and shape of the building. By carefully considering these factors, designers can create educational buildings that are comfortable, healthy, and energy efficient.

Finally, this study highlights the importance of using advanced simulation tools, such as CFD, to study the impact of natural ventilation on indoor air quality and energy consumption. These tools can provide valuable insights into the complex interactions between building design, environmental conditions, and indoor air quality.

### **5.3. Recommendations for Future Research**

While this study provides valuable insights into the impact of window opening angle on natural ventilation in buildings, there are several areas where further research is needed. One important area for future research is the impact of natural ventilation on indoor air quality in different types of buildings. While this study focused on educational buildings, it would be valuable to study the impact of natural ventilation in other types of buildings, such as residential and commercial buildings.

Another important area for future research is the impact of natural ventilation on energy consumption in buildings. While natural ventilation can be an effective way to reduce energy consumption, it is important to carefully consider the trade-offs between energy consumption and indoor air quality. Future research should focus on developing strategies to optimize natural ventilation systems to achieve both energy efficiency and indoor air quality.

In addition, future research should focus on developing new simulation tools and techniques to study the impact of natural ventilation on indoor air quality and energy consumption. While CFD simulations are a valuable tool for studying natural ventilation, they have limitations and may not be suitable for all types of buildings and environmental conditions. Therefore, it is important to develop new simulation tools and techniques that can provide more accurate and detailed information about the impact of natural ventilation on indoor air quality and energy consumption.

Finally, future research should focus on developing innovative design strategies and technologies to optimize natural ventilation in buildings. While this study provides valuable insights into the impact of window opening angle on natural ventilation, there are many other factors that can affect the effectiveness of natural ventilation,

such as building orientation, window location, and building shape. Therefore, it is important to develop modern design strategies and technologies that can optimize natural ventilation in a wide range of building types and environmental conditions.





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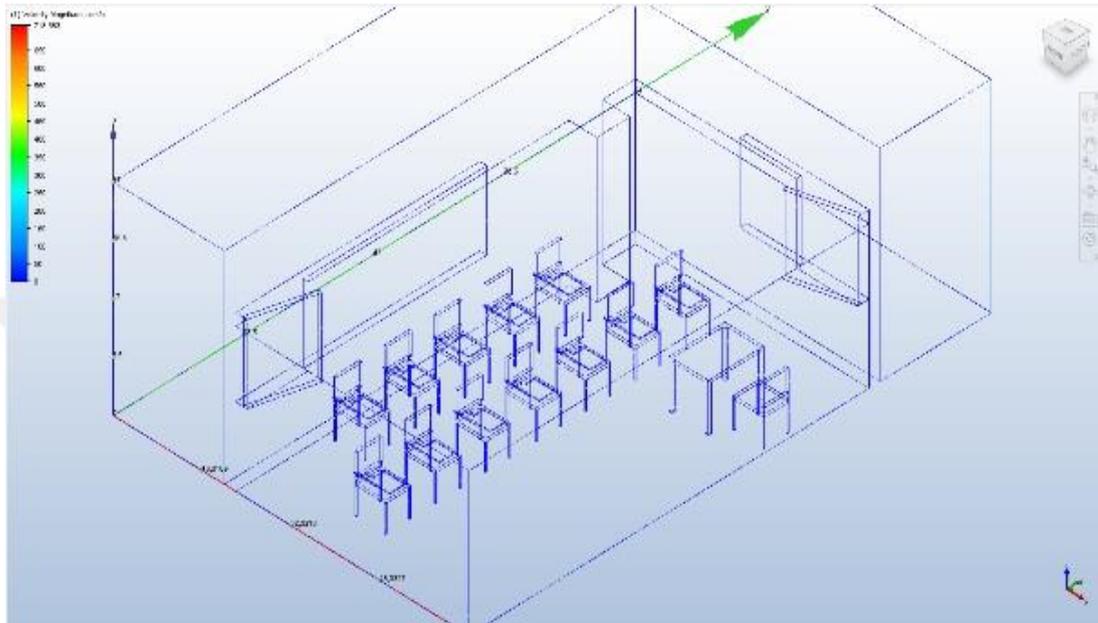
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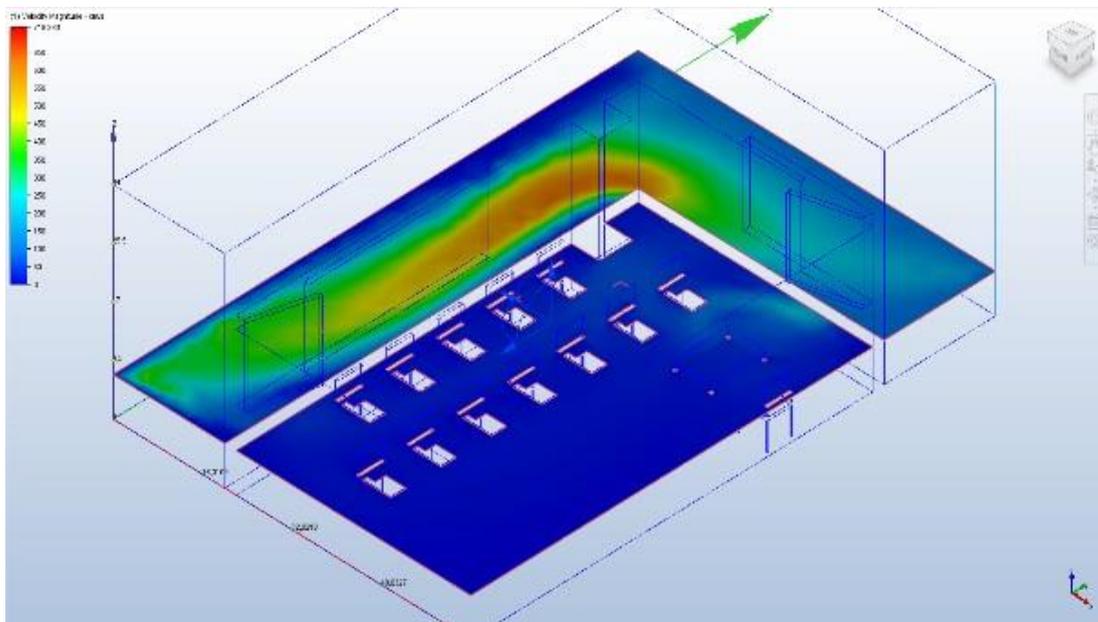


### 3. APPENDIX

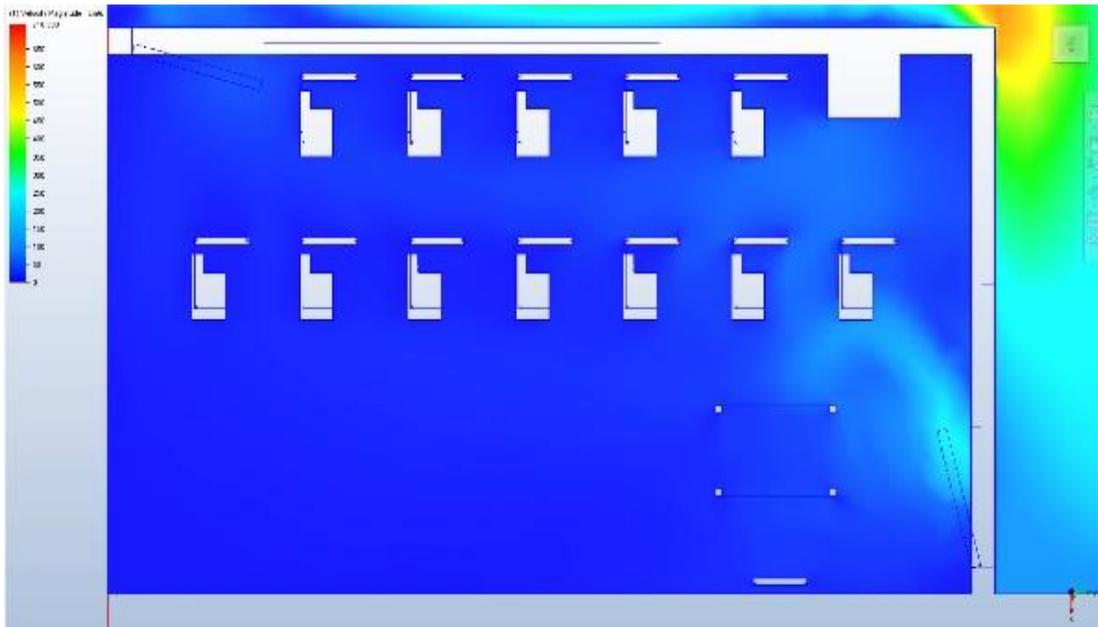
15°- 15°



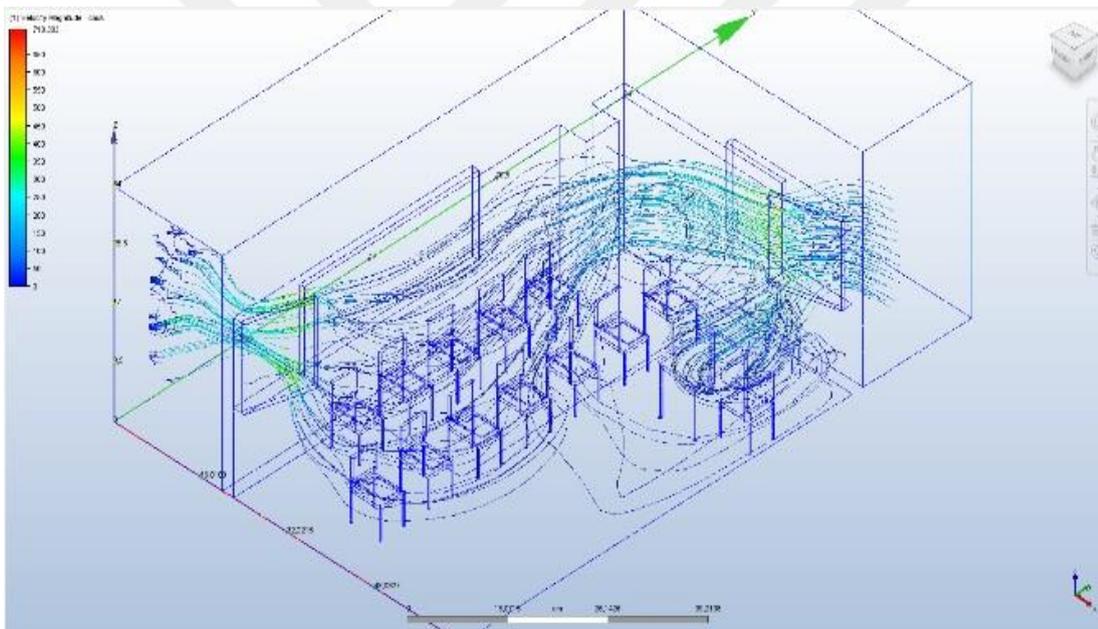
Appendix 1. 15°-15° Perspective Empty



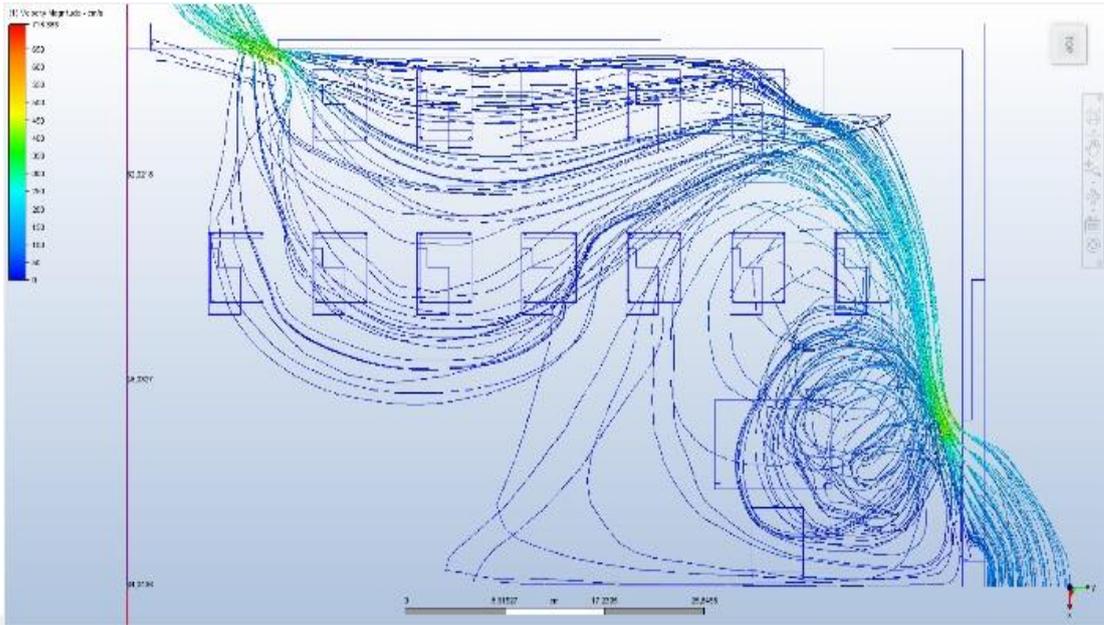
Appendix 2. 15°-15° Perspective-Velocity



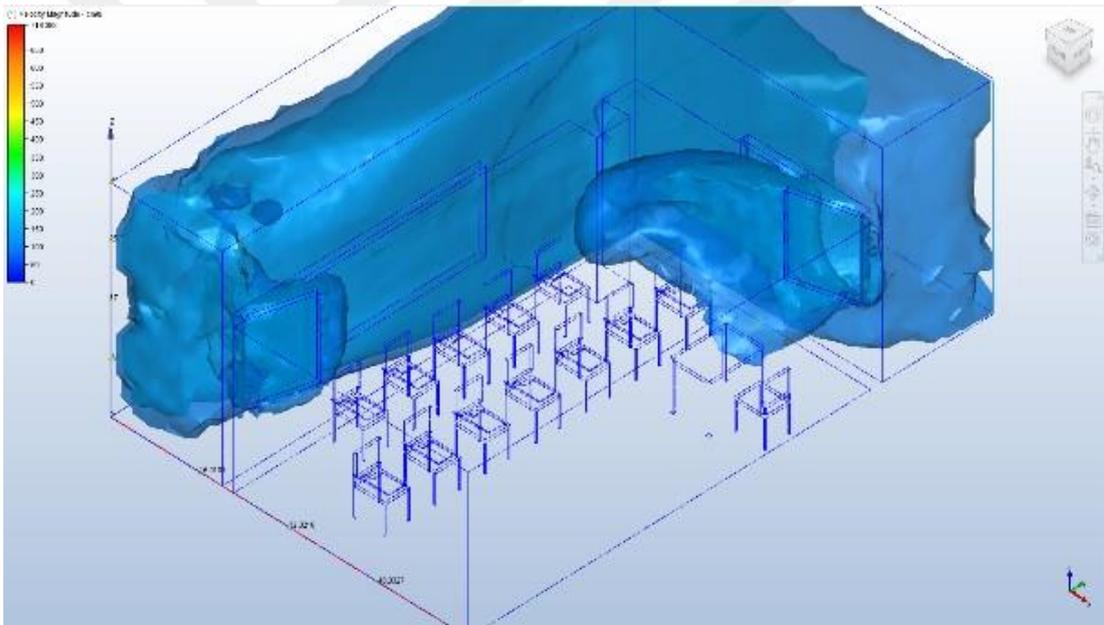
**Appendix 3.** 15°-15° Top View- Velocity



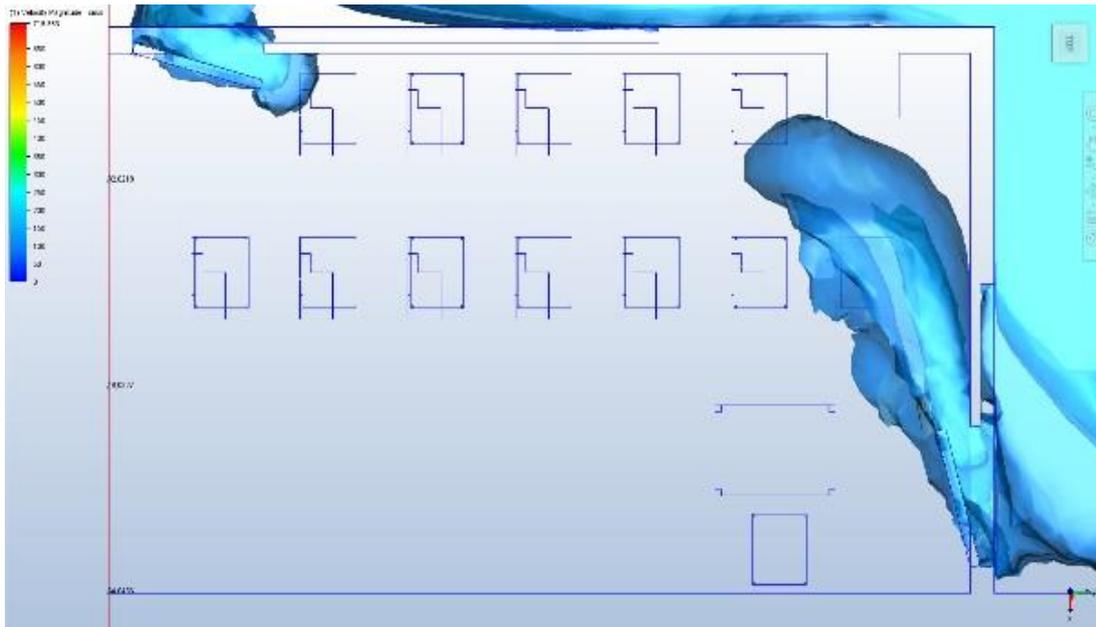
**Appendix 4.** 15°-15° Perspective- Particles



**Appendix 5. 15°-15° Top View - Particles**

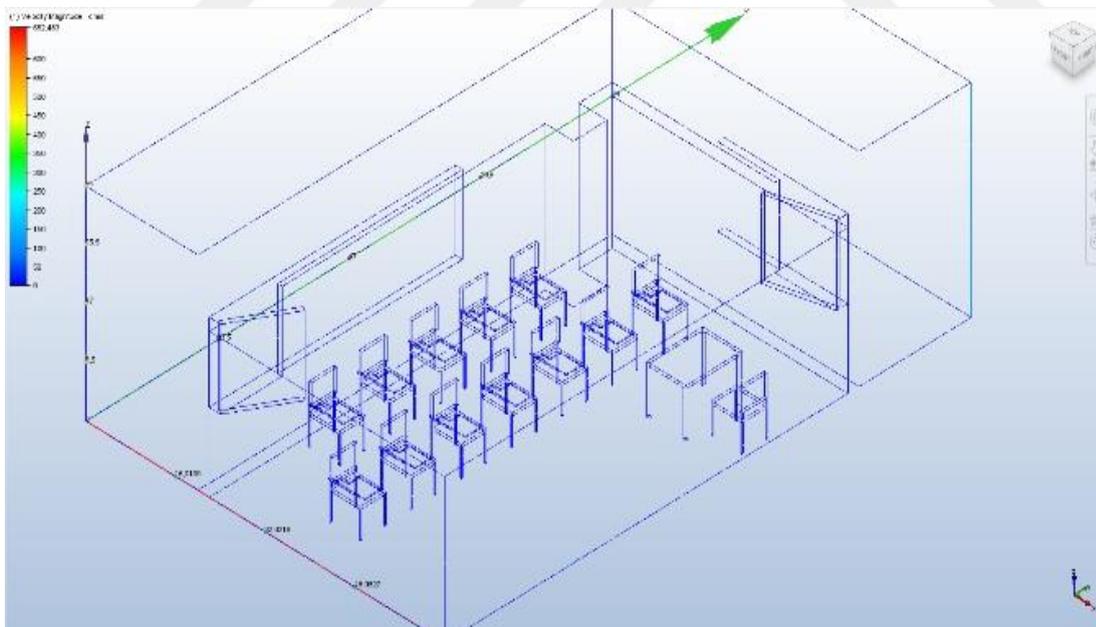


**Appendix 6. 15°-15° Perspective - 3D Air**

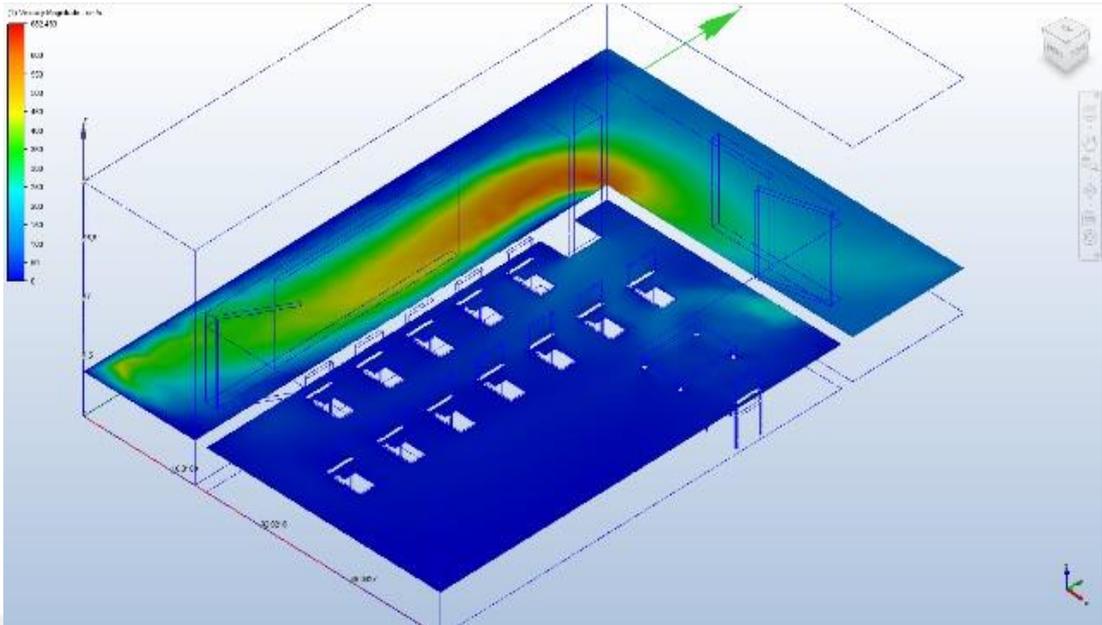


**Appendix 7. 15°-15° Top View - 3D Air**

15°- 30°



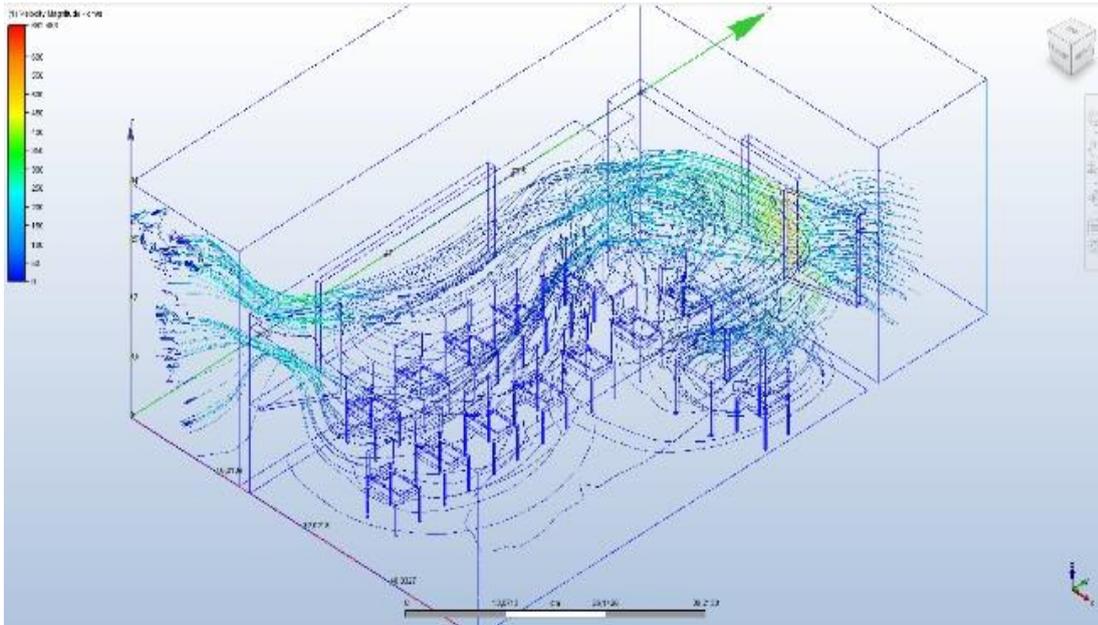
**Appendix 8. 15°-30° Perspective – Empty**



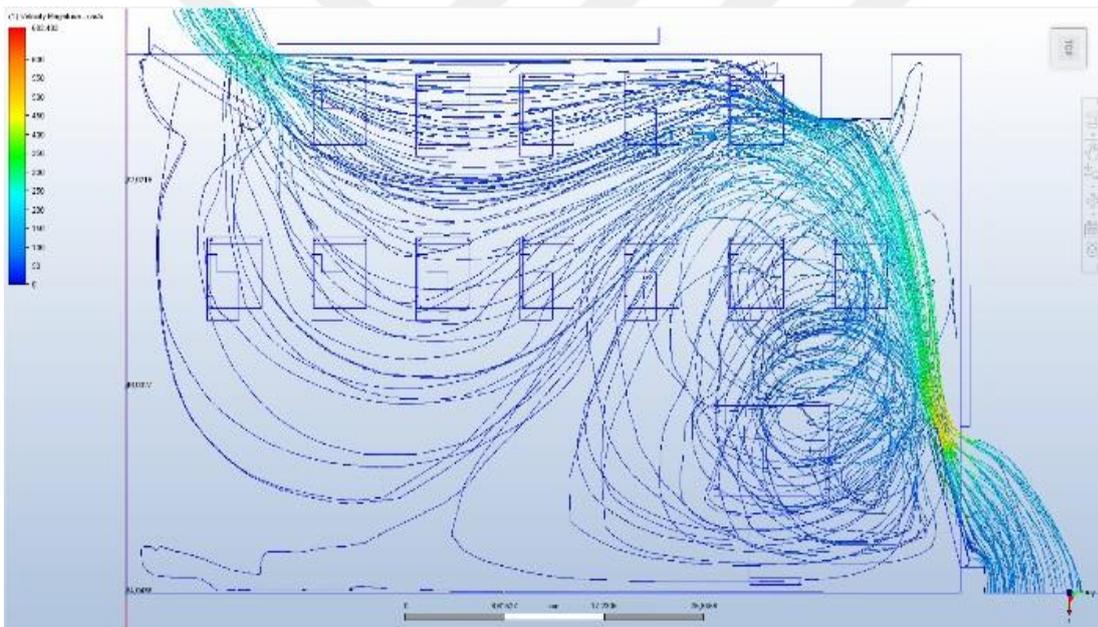
**Appendix 9. 15°-30° Perspective-Velocity**



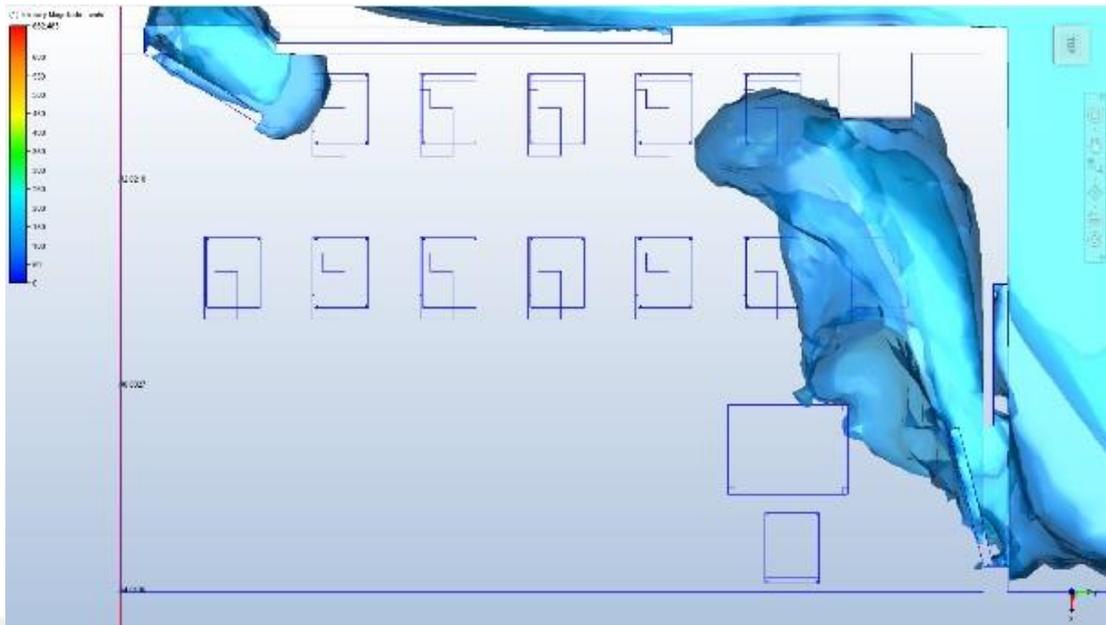
**Appendix 10. 15°-30° Top View- Velocity**



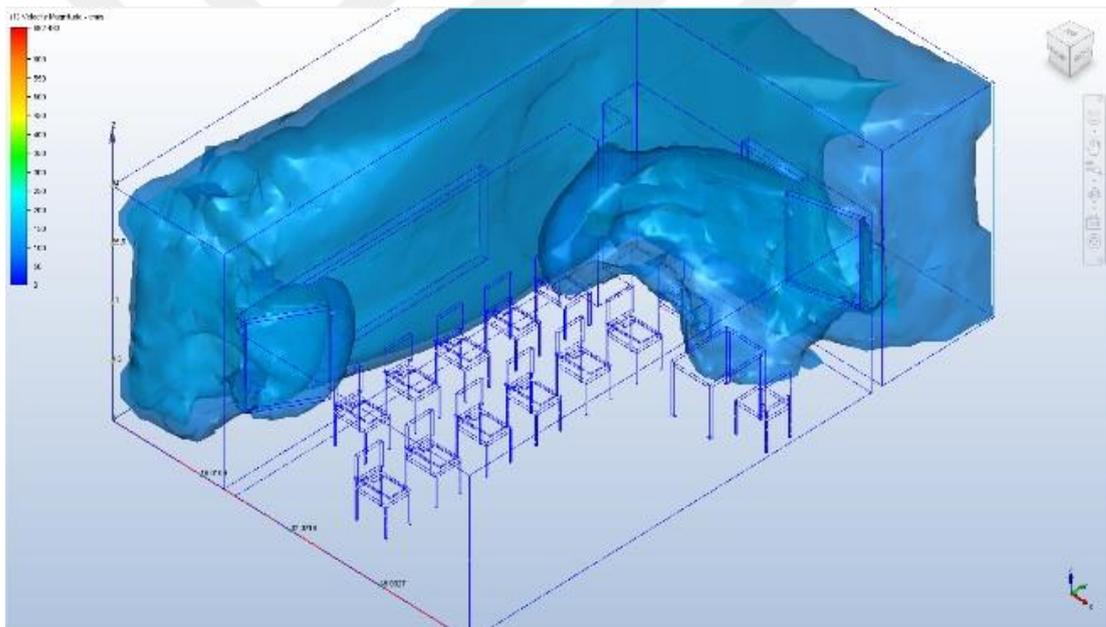
**Appendix 11. 15°-30° Perspective-Particles**



**Appendix 12. 15°-30° Top View- Particles**

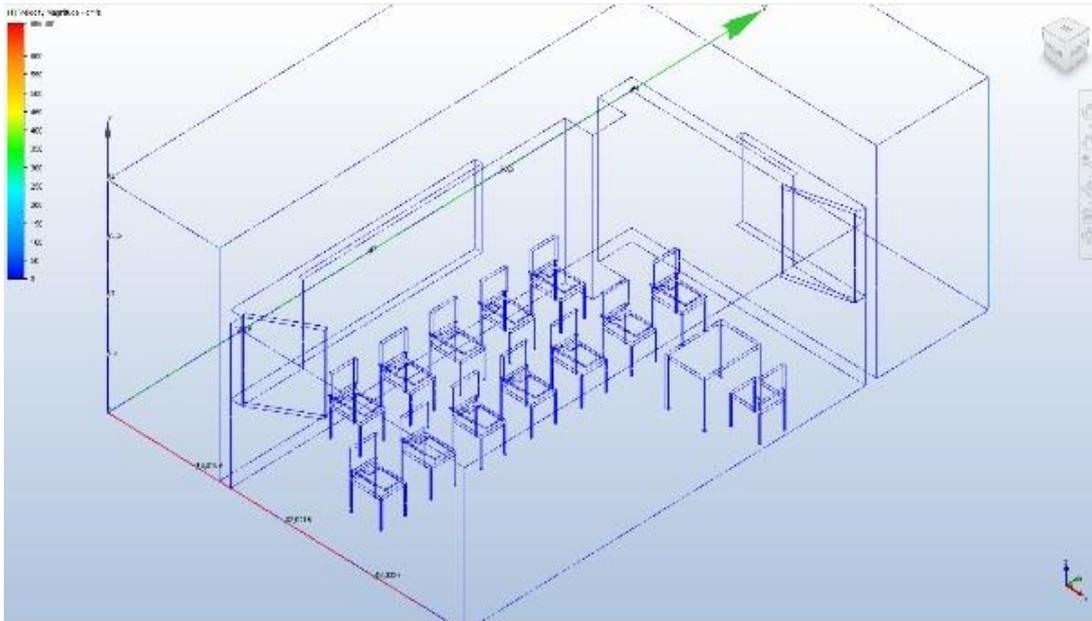


**Appendix 13.** 15°-30° Top View- 3D Air

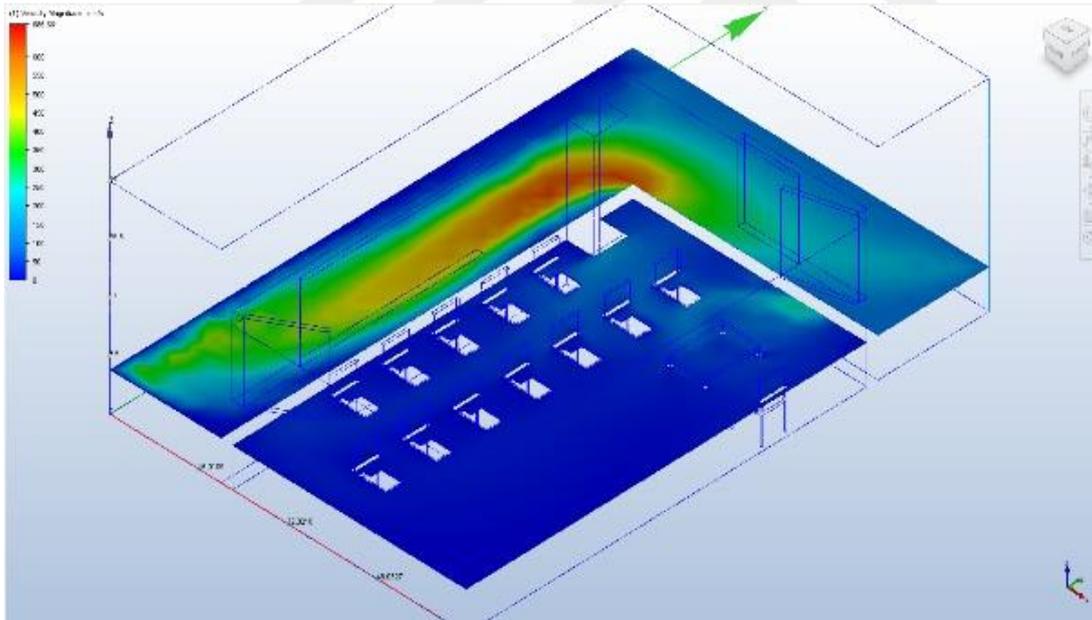


**Appendix 14.** 15°-30° Perspective- 3D Air

15°- 60°



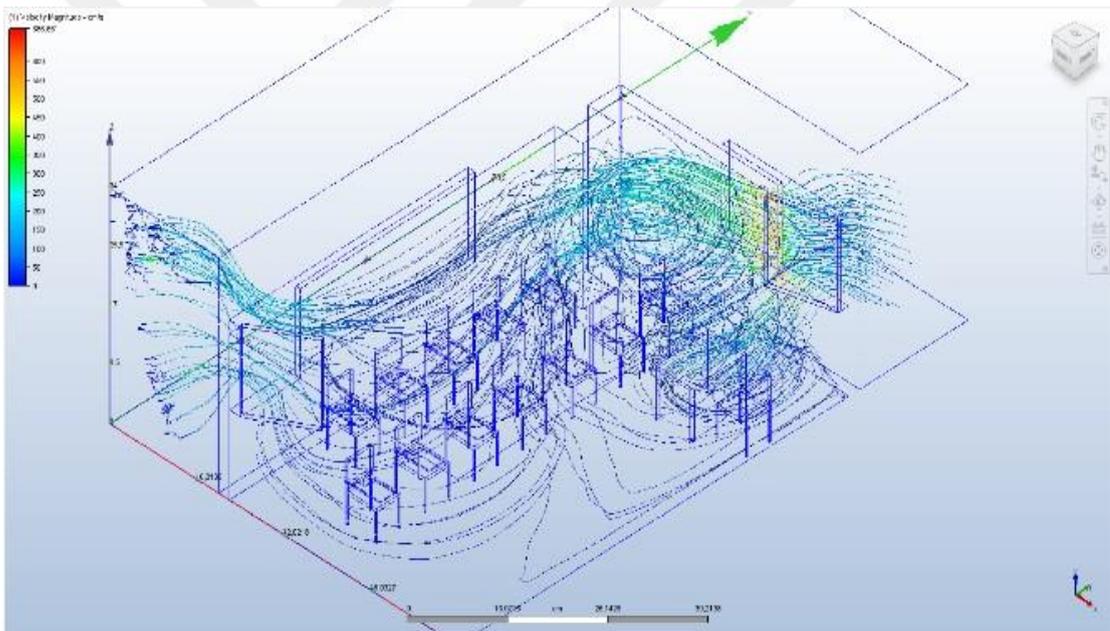
**Appendix 15. 15°-60° Perspective– Empty**



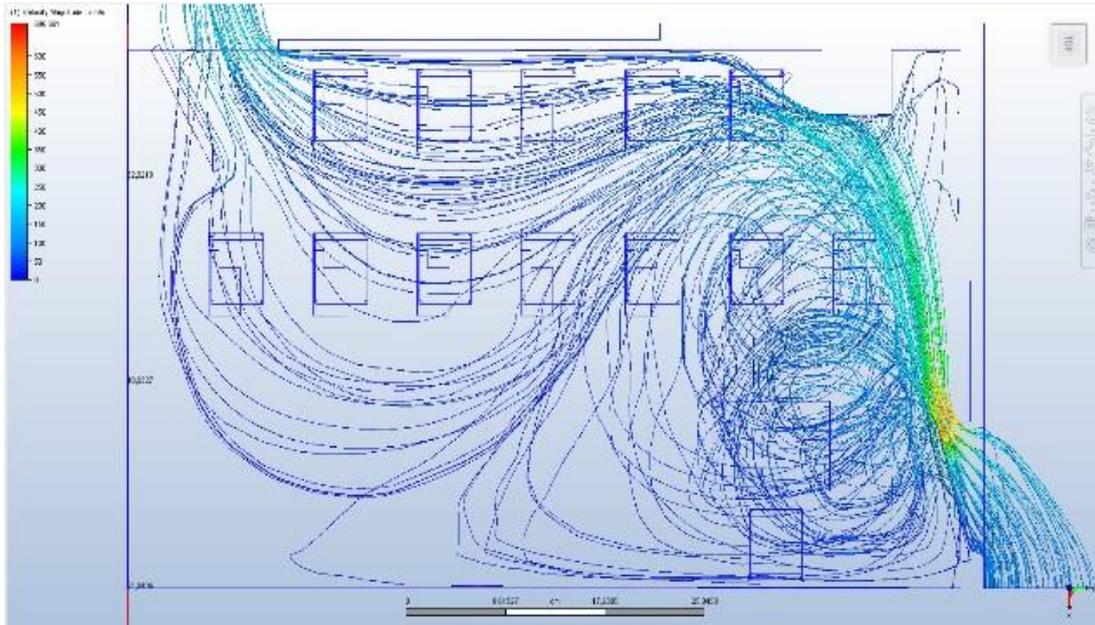
**Appendix 16. 15°-60° Perspective-Velocity**



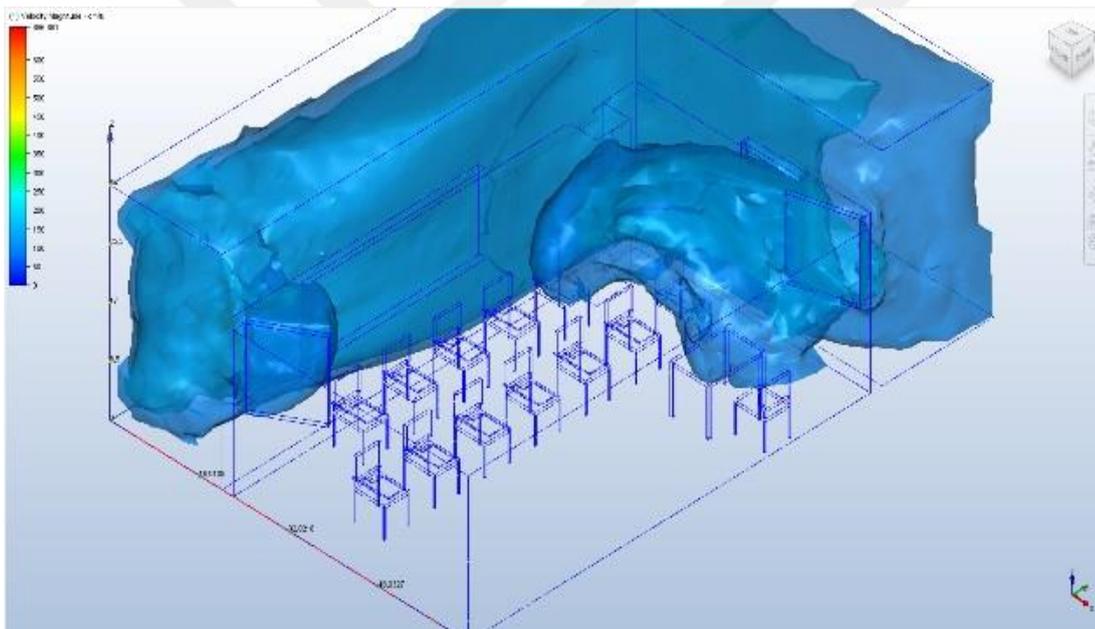
**Appendix 17. 15°-60° Top View- Velocity**



**Appendix 18. 15°-60° Perspective- Particles**



**Appendix 19. 15°-60° Top View- Particle**

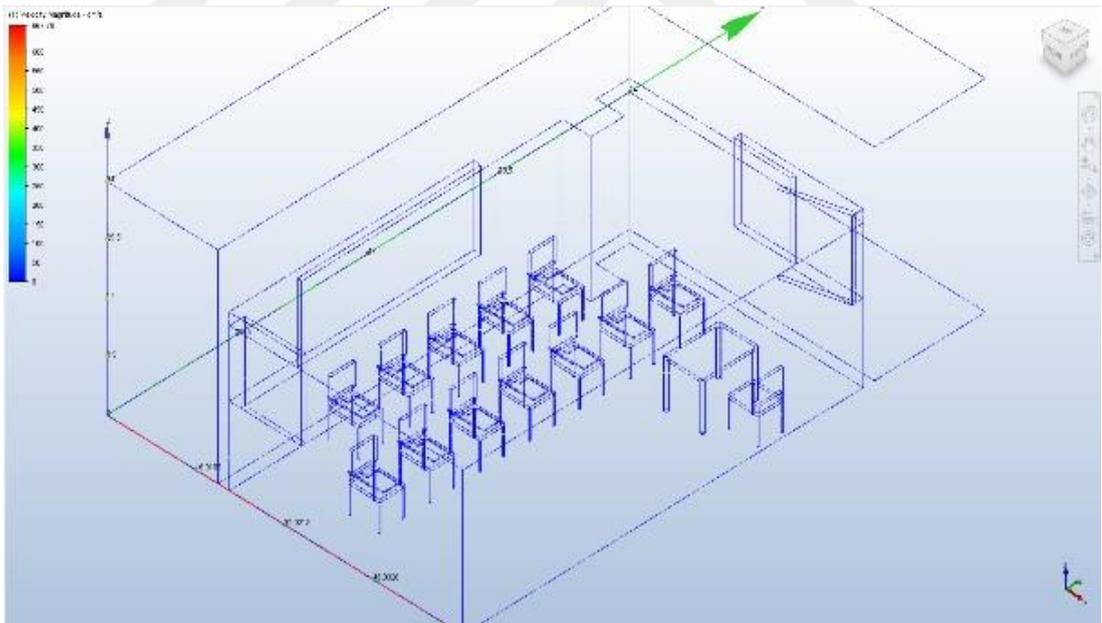


**Appendix 20. 15°-60° Perspective - 3D Air**

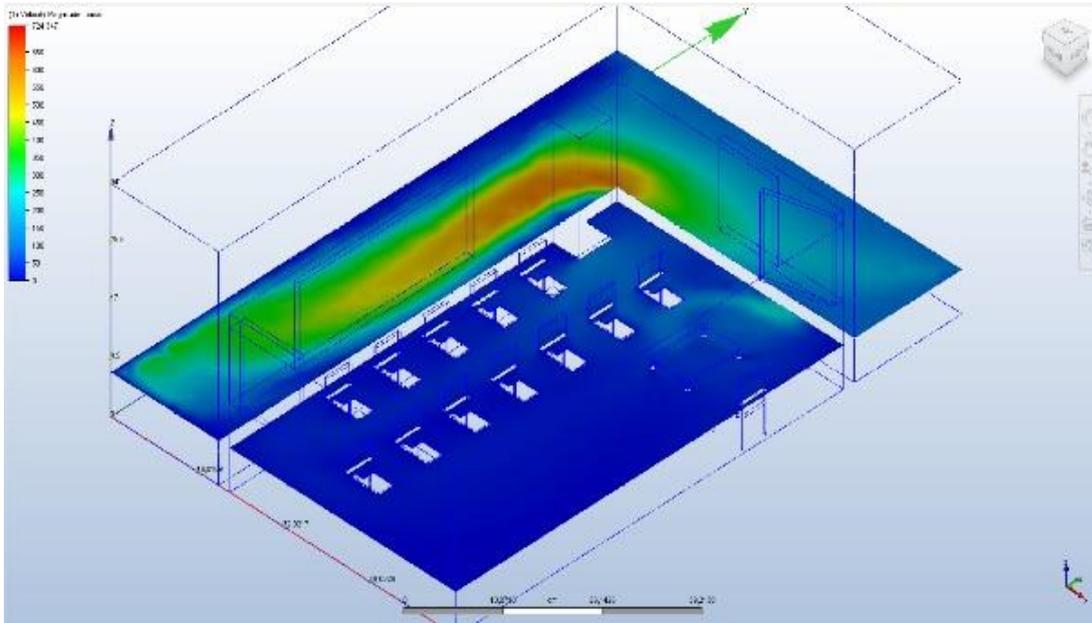


**Appendix 21.** 15°-60° Top View - 3D Air

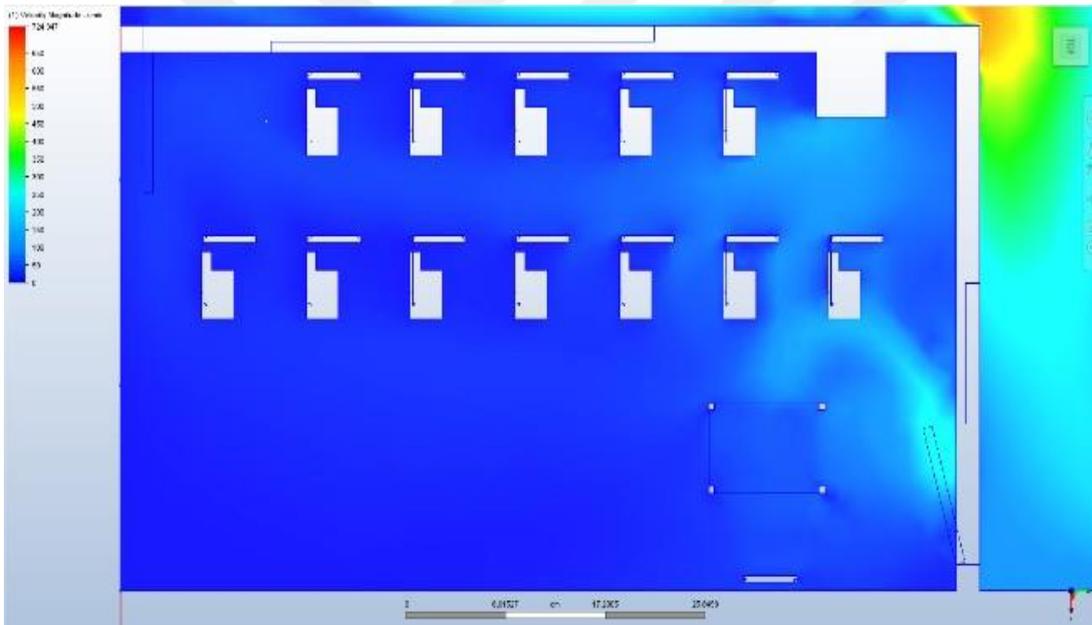
15°- 90°



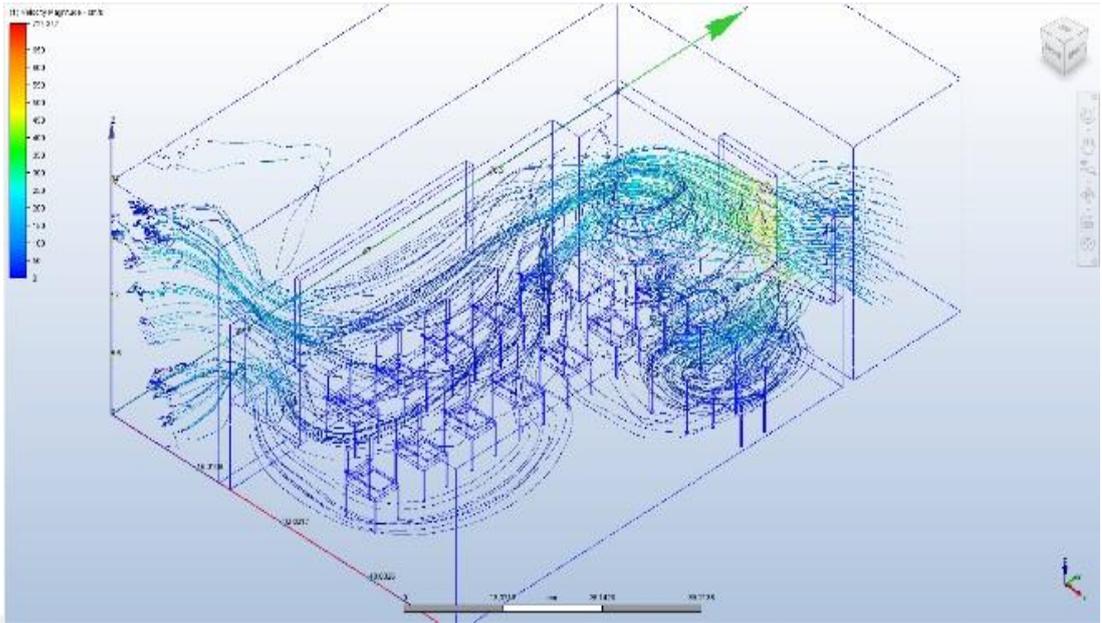
**Appendix 22.** 15°-90° Perspective – Empty

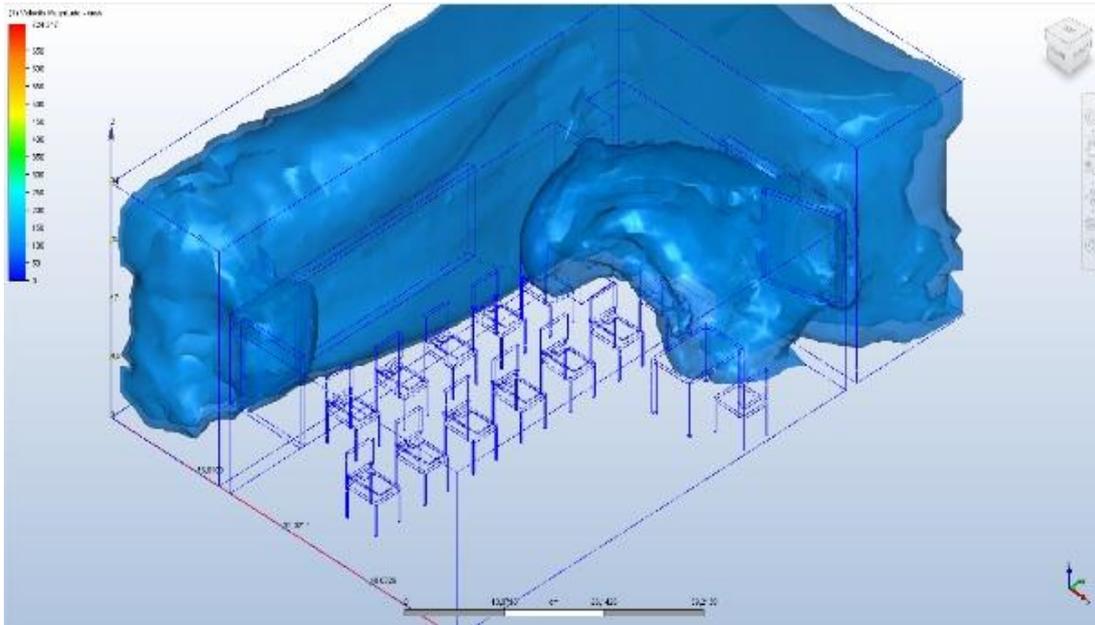


**Appendix 23.** 15°-90° Perspective -Velocity

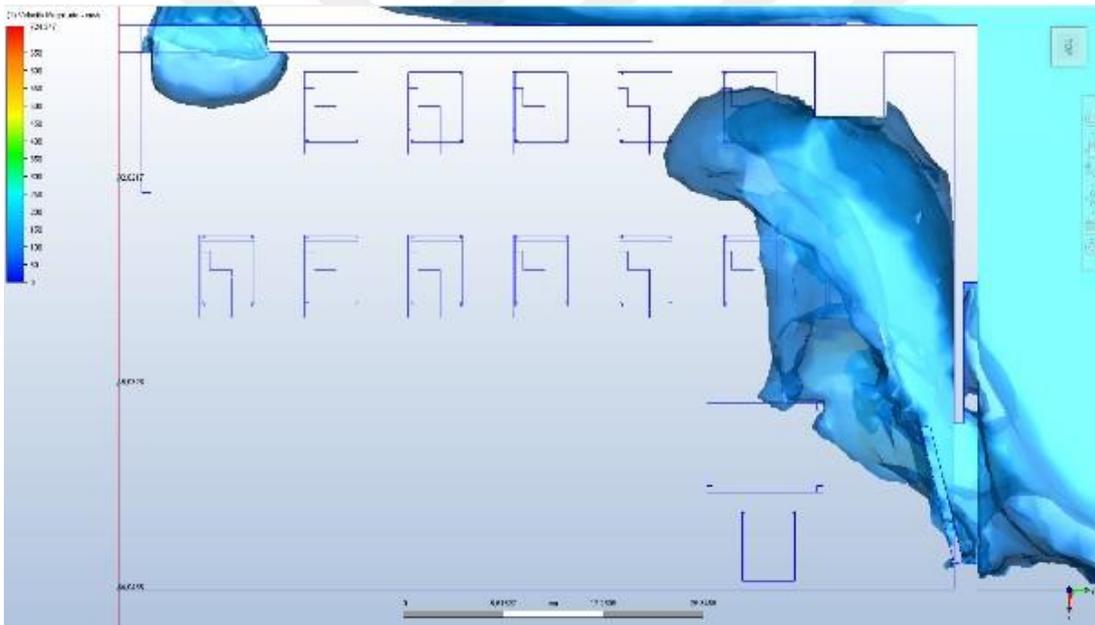


**Appendix 24.** 15°-90° Top View- Velocity



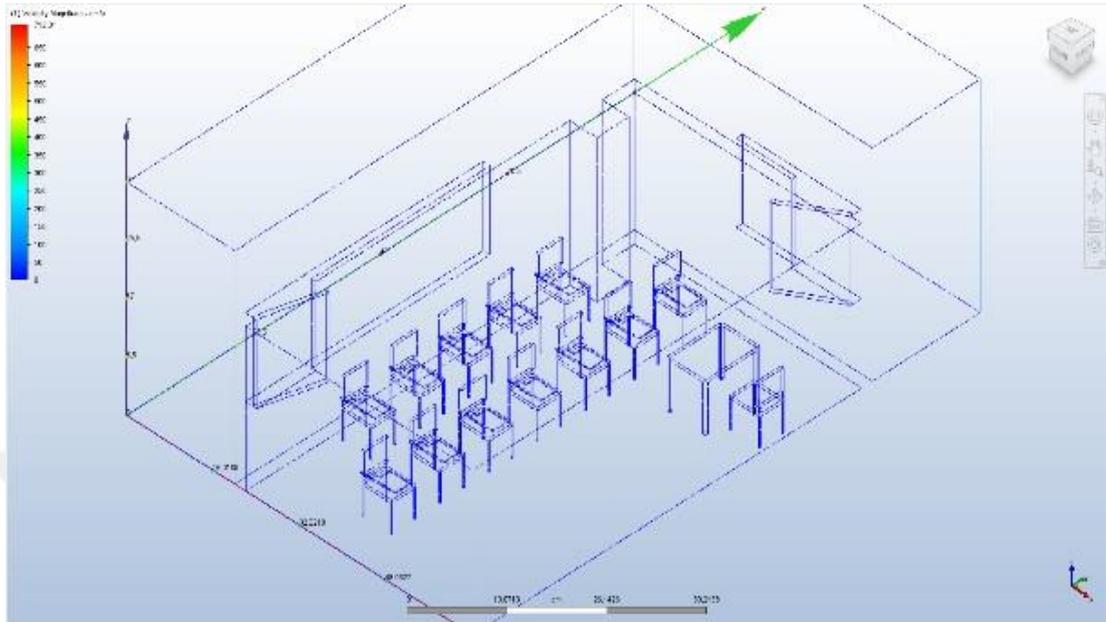


**Appendix 27. 15°-90° Perspective - 3D Air**

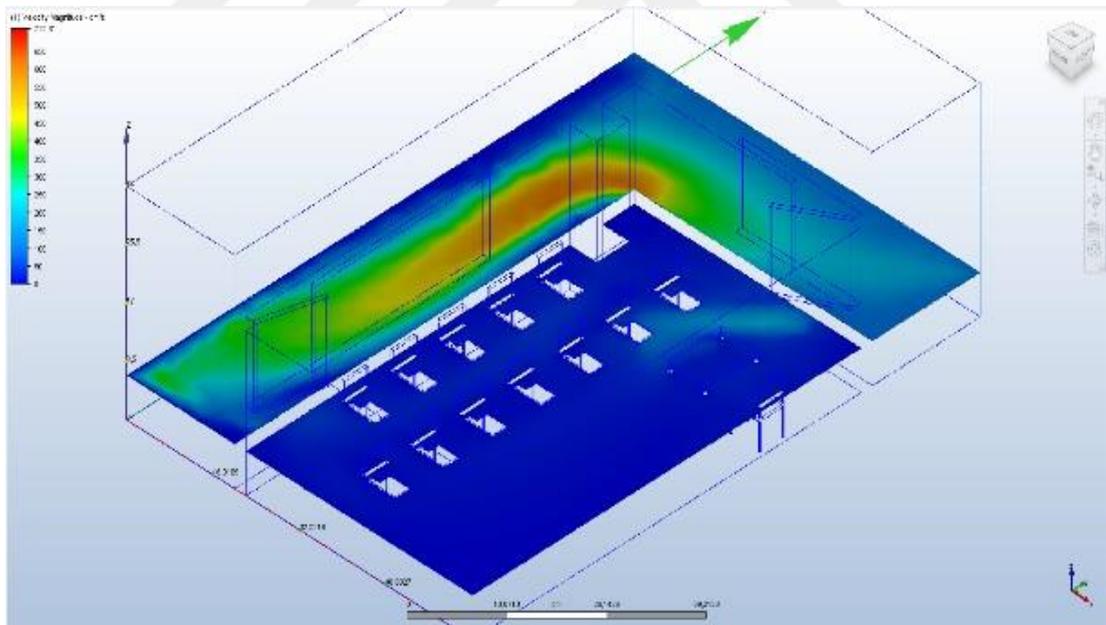


**Appendix 28. 15°-90° Top View- 3D Air**

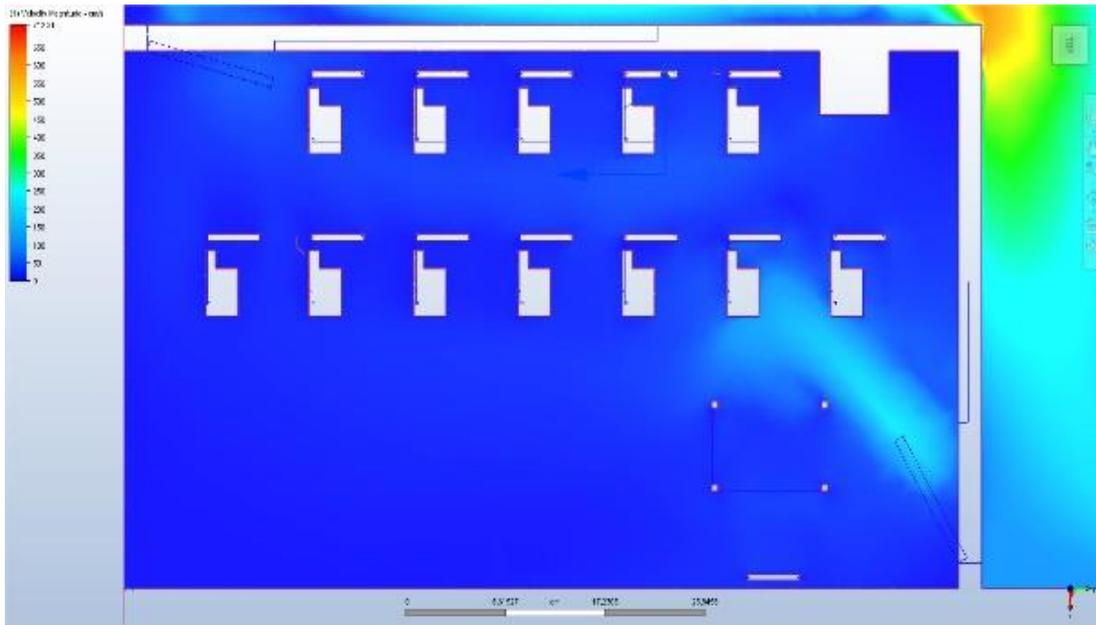
30°- 15°



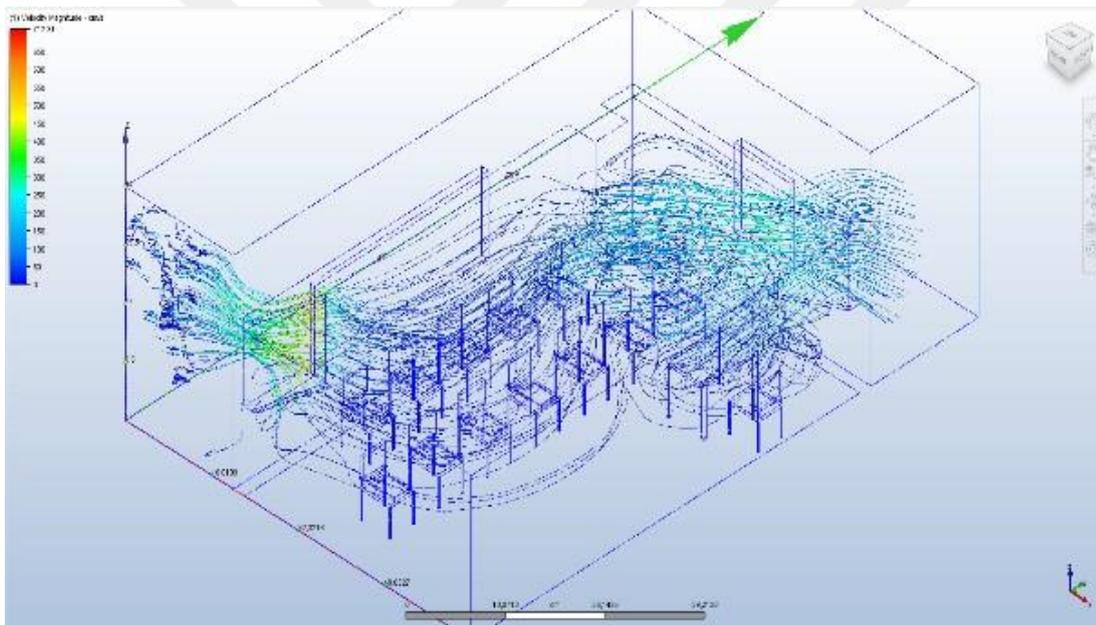
Appendix 29. 30°-15° Perspective– Empty



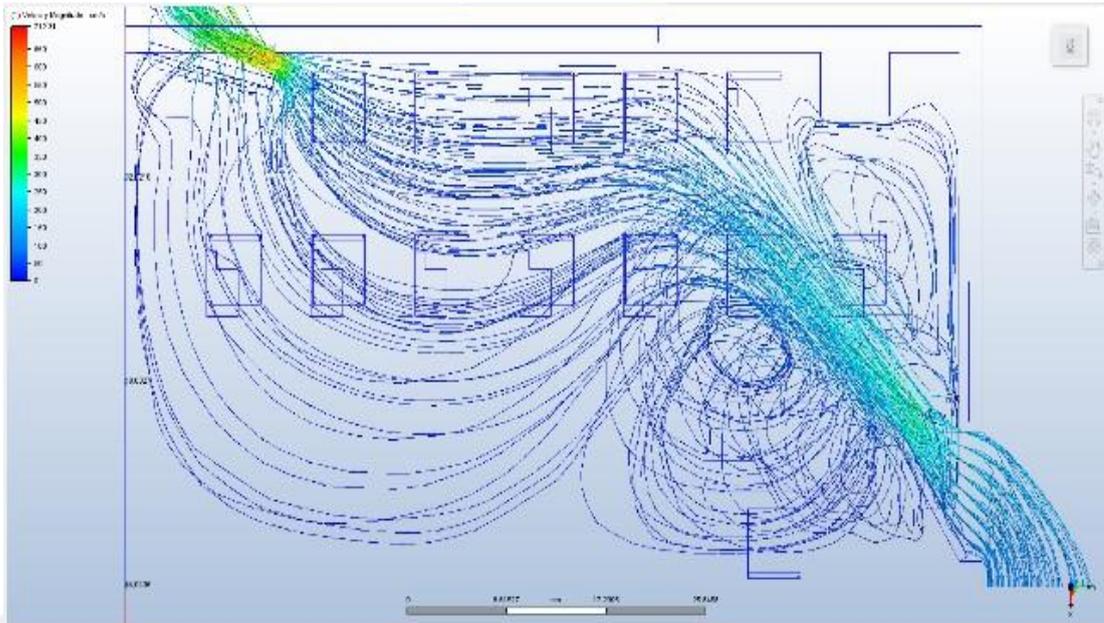
Appendix 30. 30°-15° Perspective-Velocity



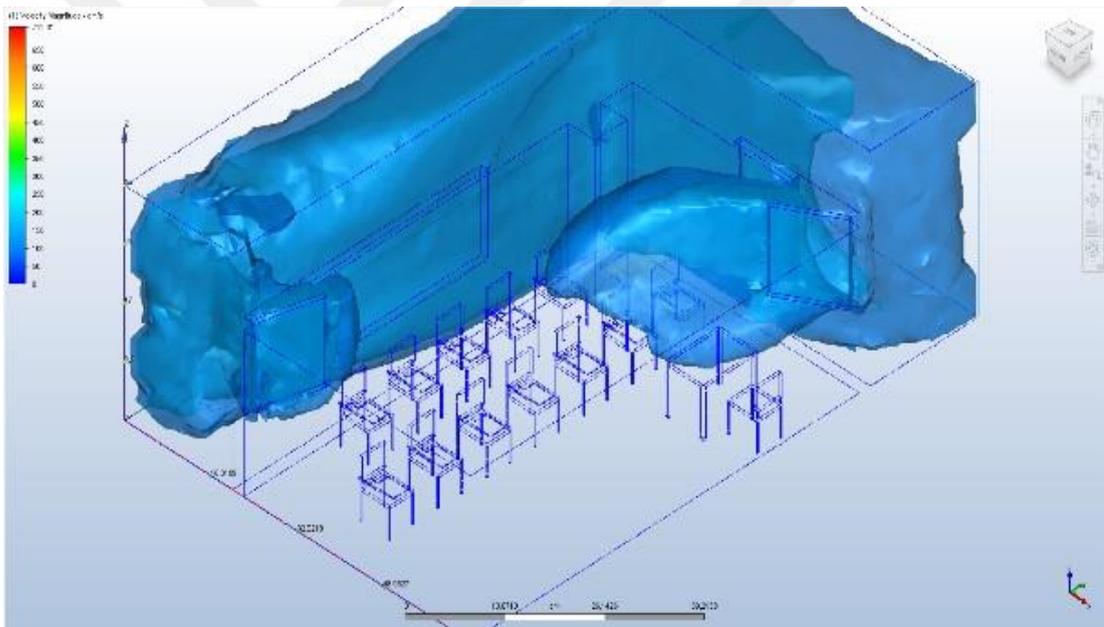
**Appendix 31. 30°-15° Top View– Velocity**



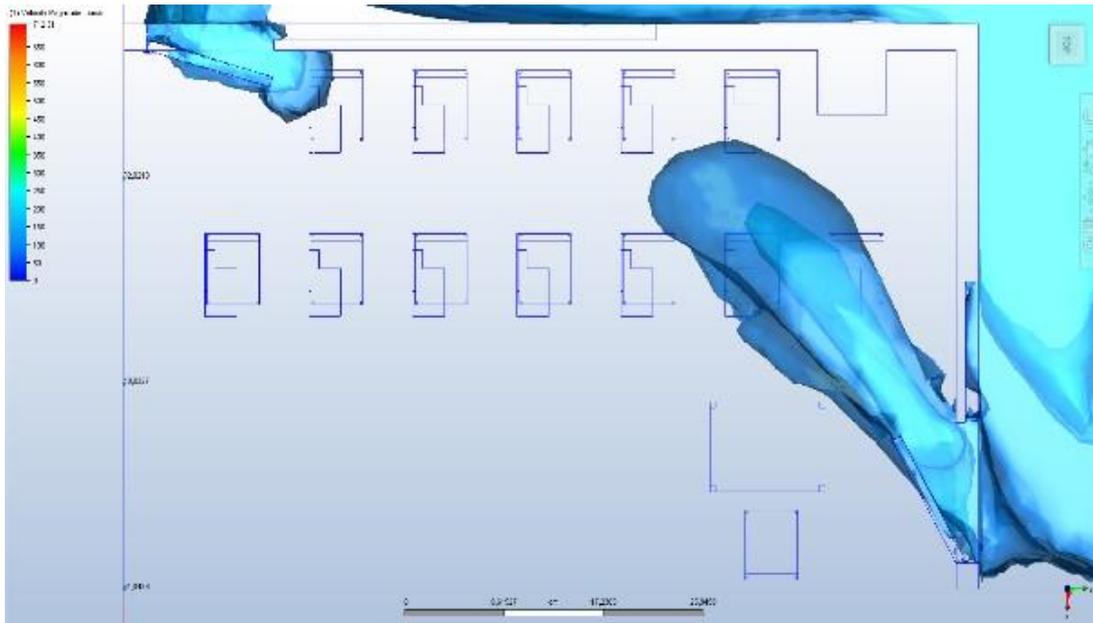
**Appendix 32. 30°-15° Perspective- Particles**



**Appendix 33.** 30°-15° Top View– Particles

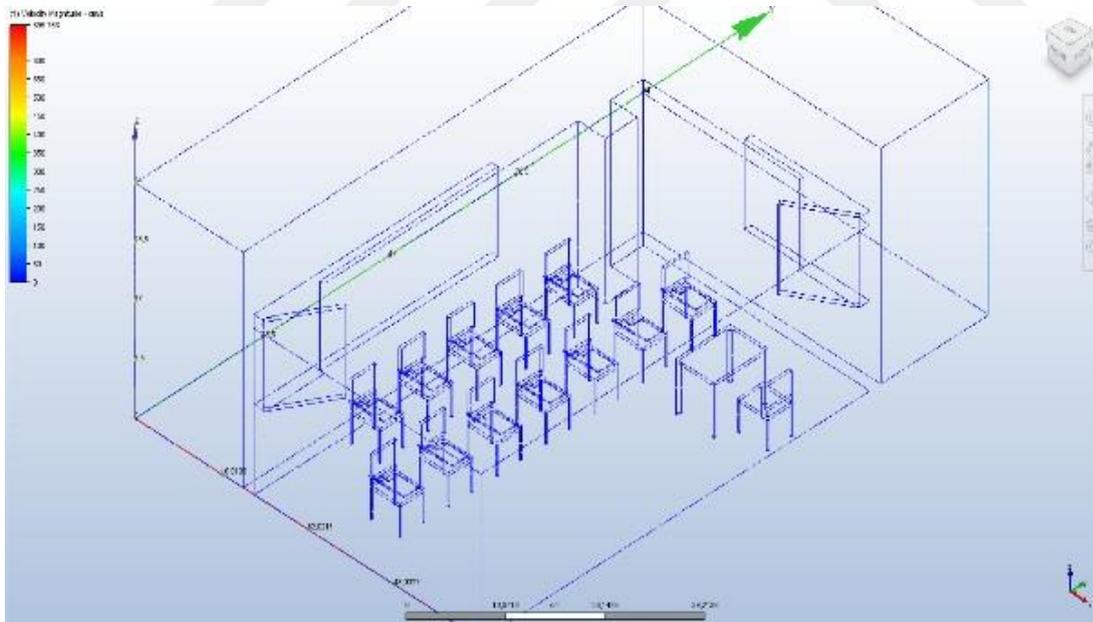


**Appendix 34.** 30°-15° Perspective - 3D Air

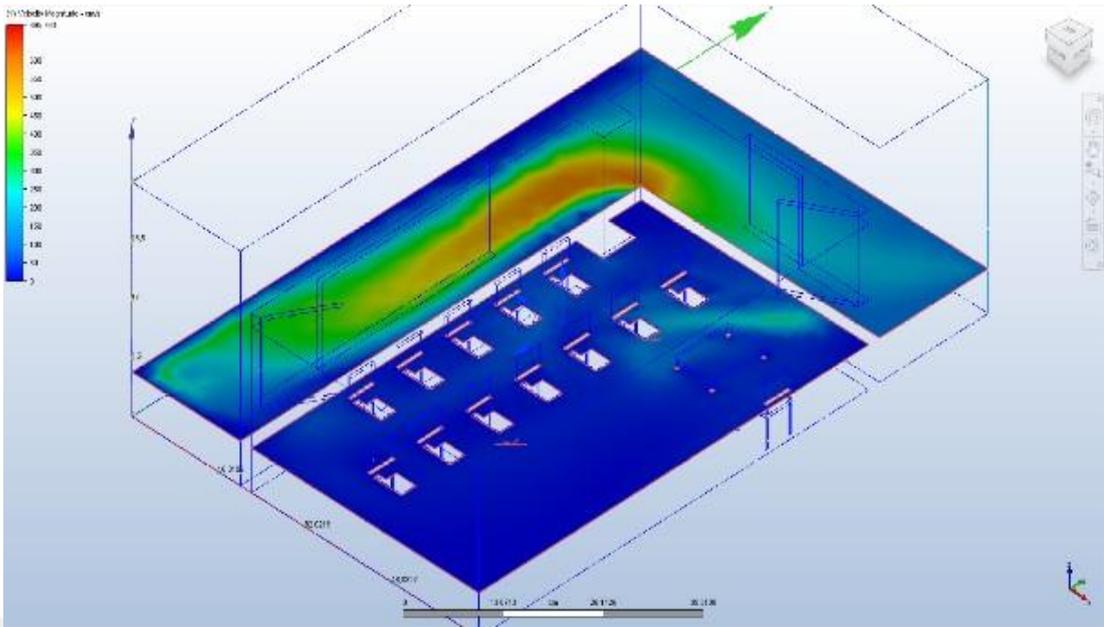


**Appendix 35. 30°-15° Top View- 3D Air**

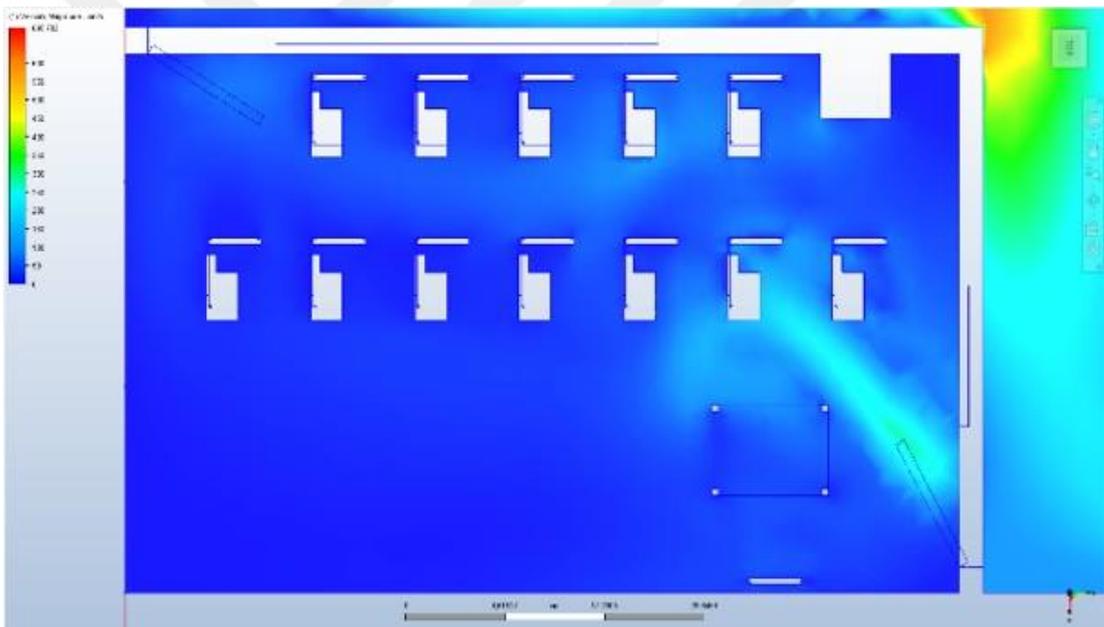
**30°- 30°**



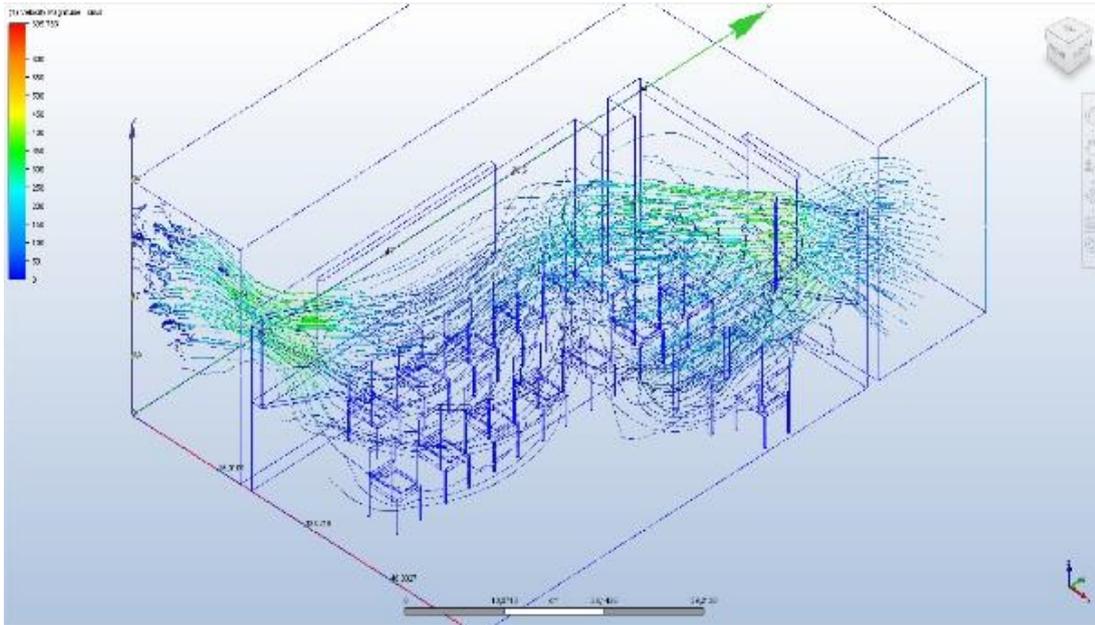
**Appendix 36. 30°-30° Perspective– Empty**



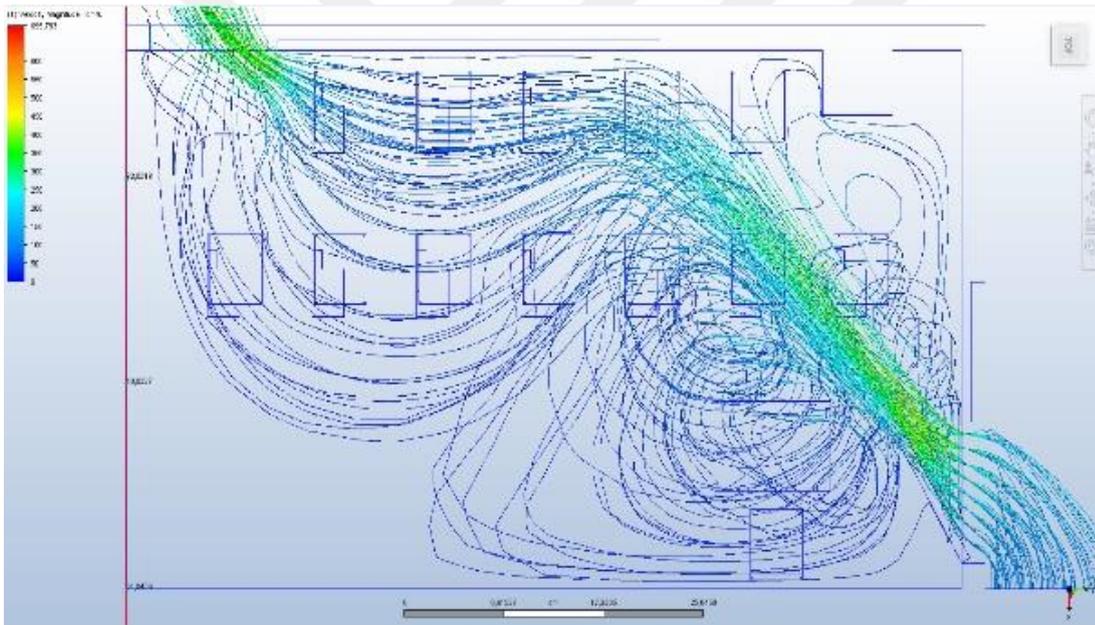
**Appendix 37. 30°-30° Perspective-Velocity**



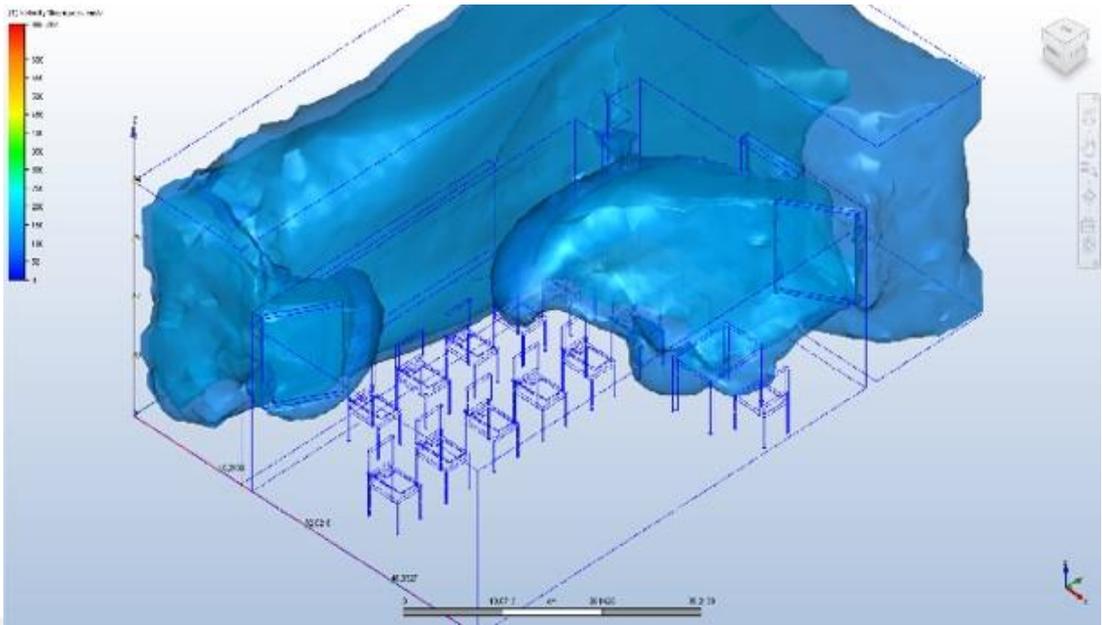
**Appendix 38. 30°-30° Top View- Velocity**



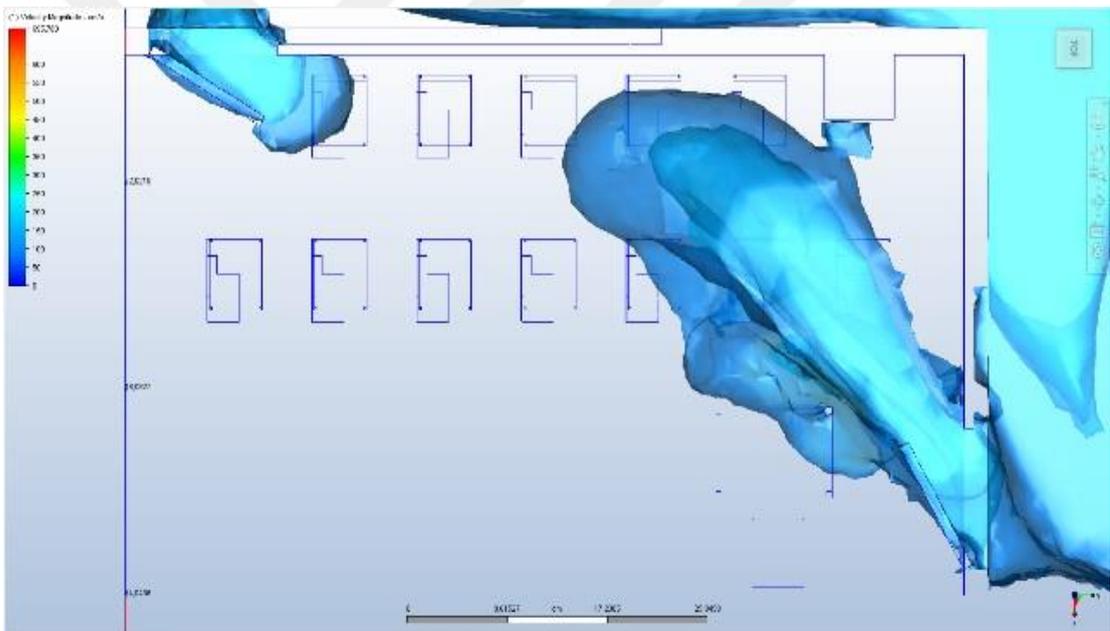
**Appendix 39.** Perspective- Particles



**Appendix 40.** 30°-30° Top View-Particles



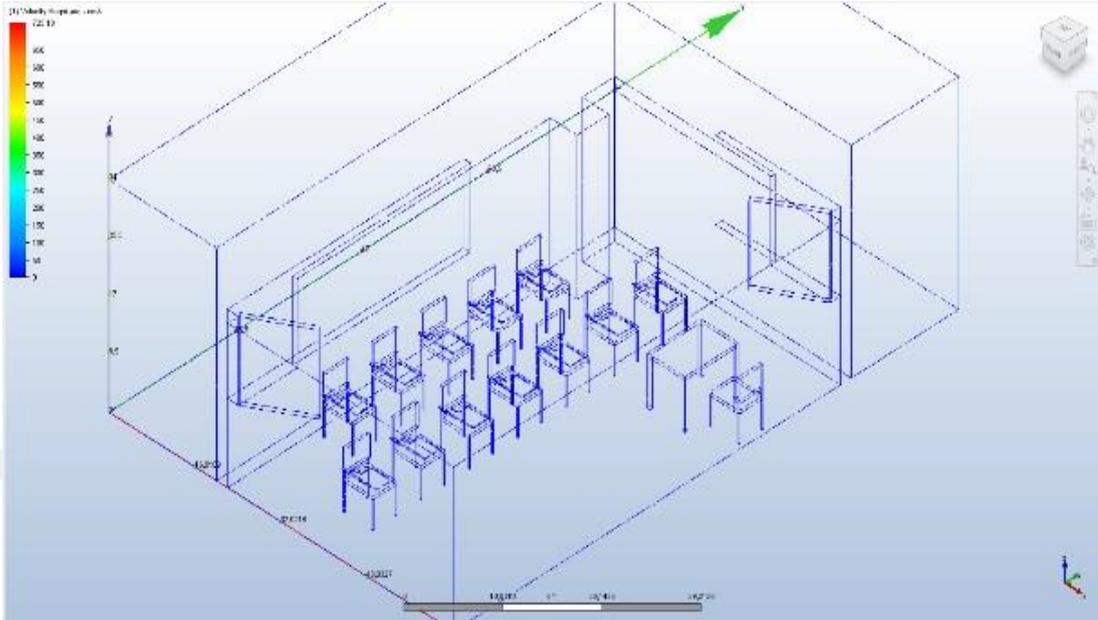
**Appendix 41. 30°-30° Perspective- 3D Air**



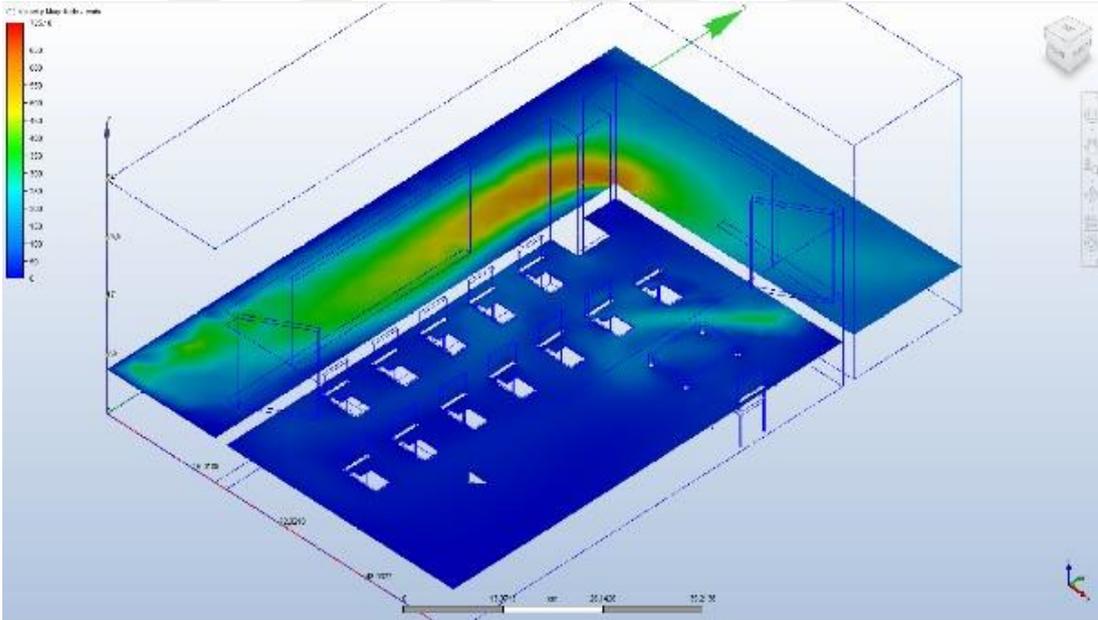
**Appendix 42. 30°-30° Top View- 3D Air**



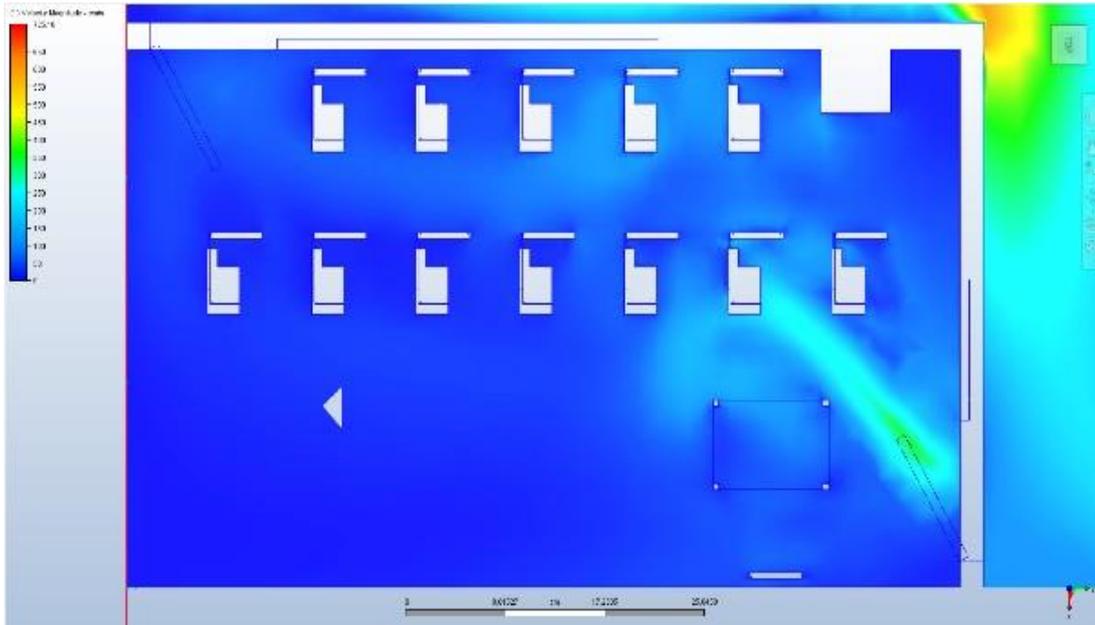
30°- 60°



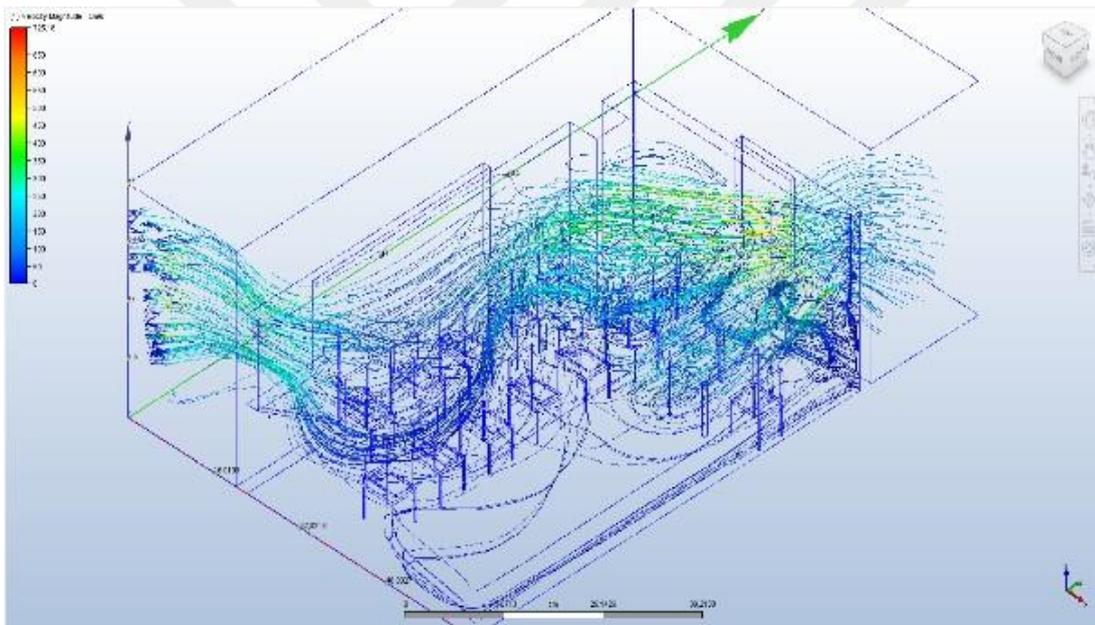
Appendix 43. 30°-60° Perspective- Empty



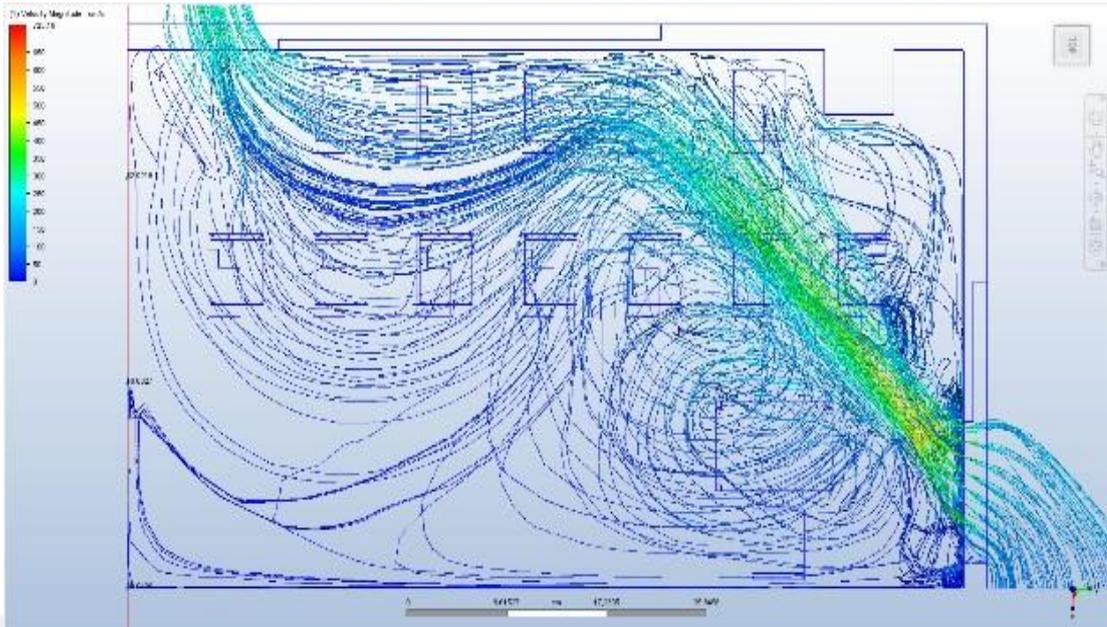
Appendix 44. 30°-60° Perspective-Velocity



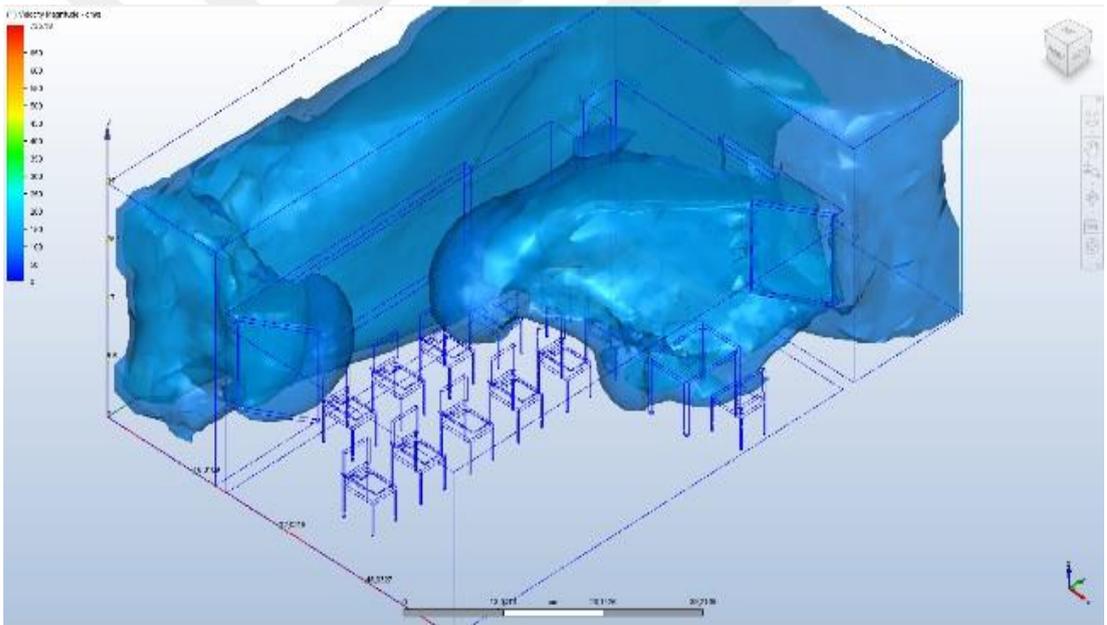
**Appendix 45. 30°-60° Top View- Velocity**



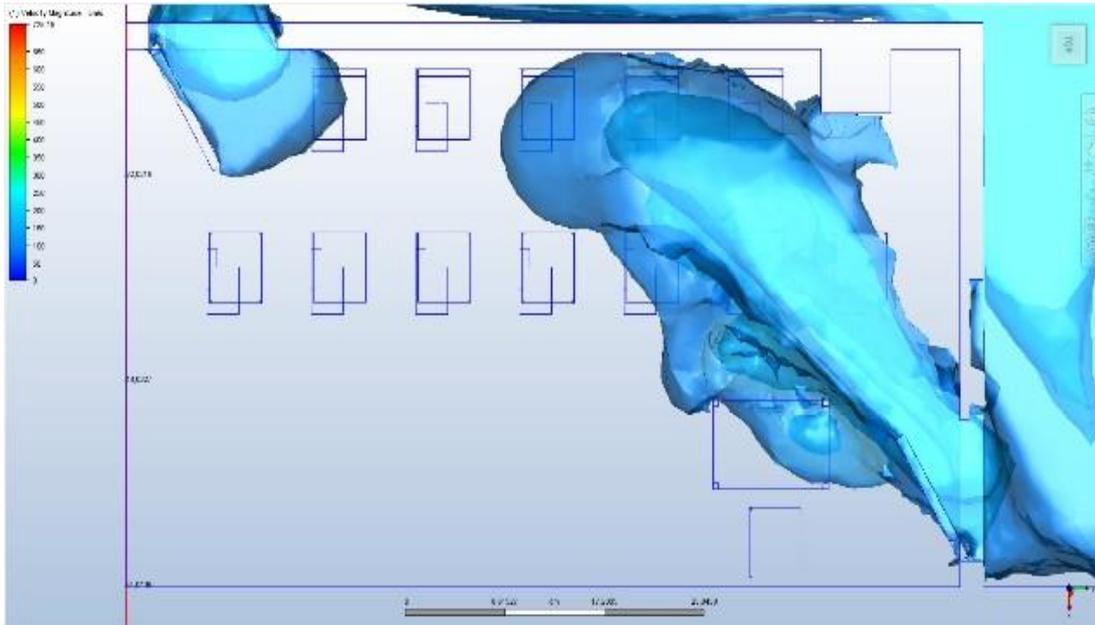
**Appendix 46. 30°-60° Perspective- Particles**



**Appendix 47.** 30°-60° Top View– Particles

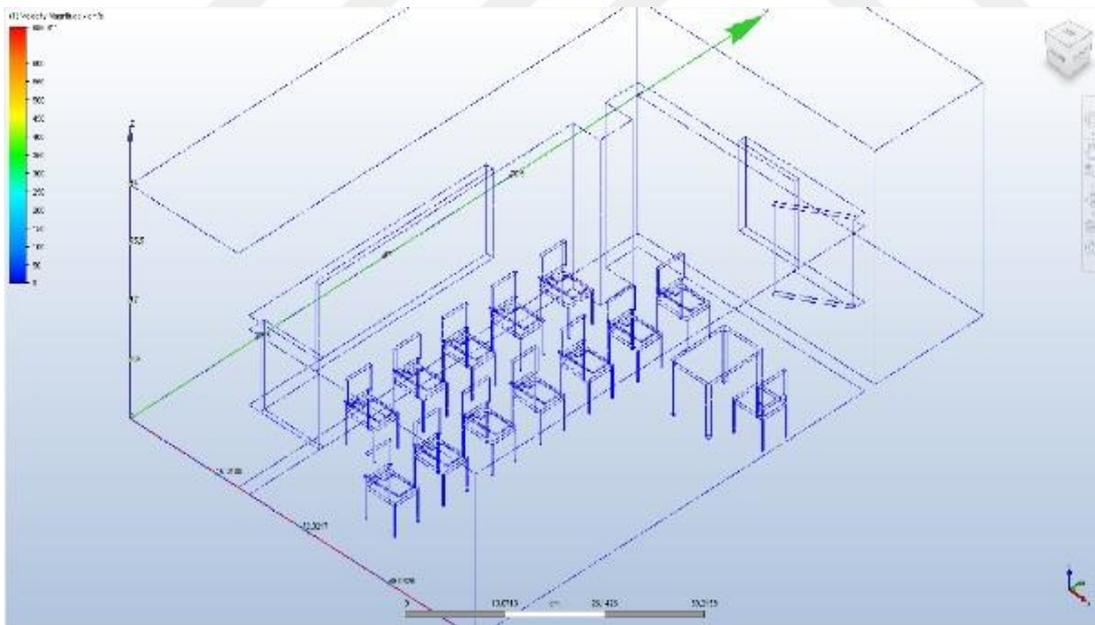


**Appendix 48.** 30°-60° Perspective- 3D Air

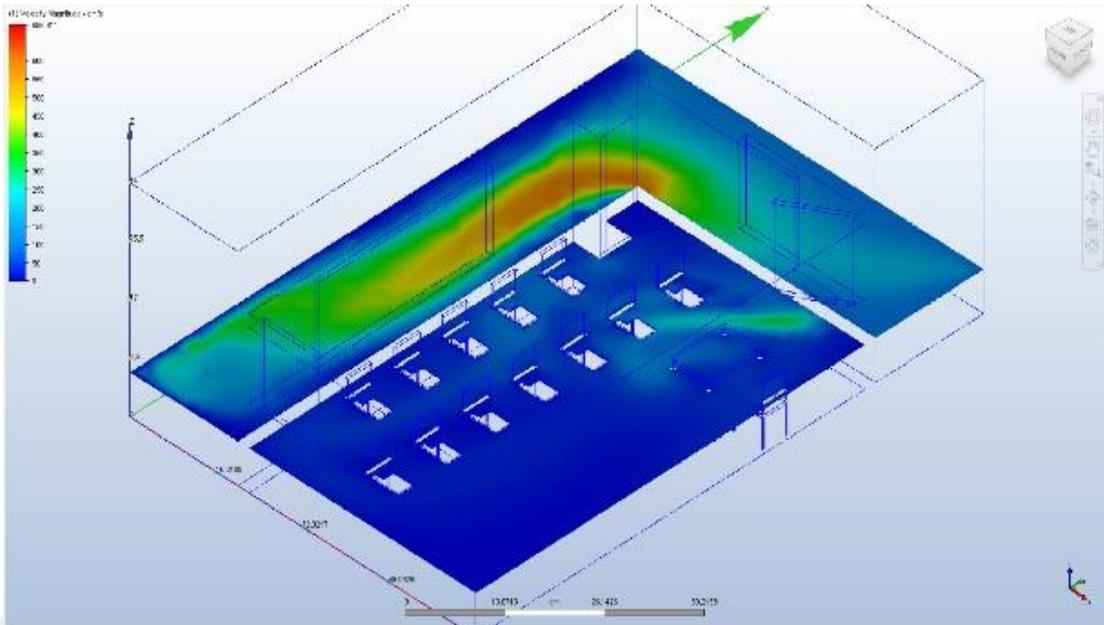


**Appendix 49. 30°-60° Top View- 3D Air**

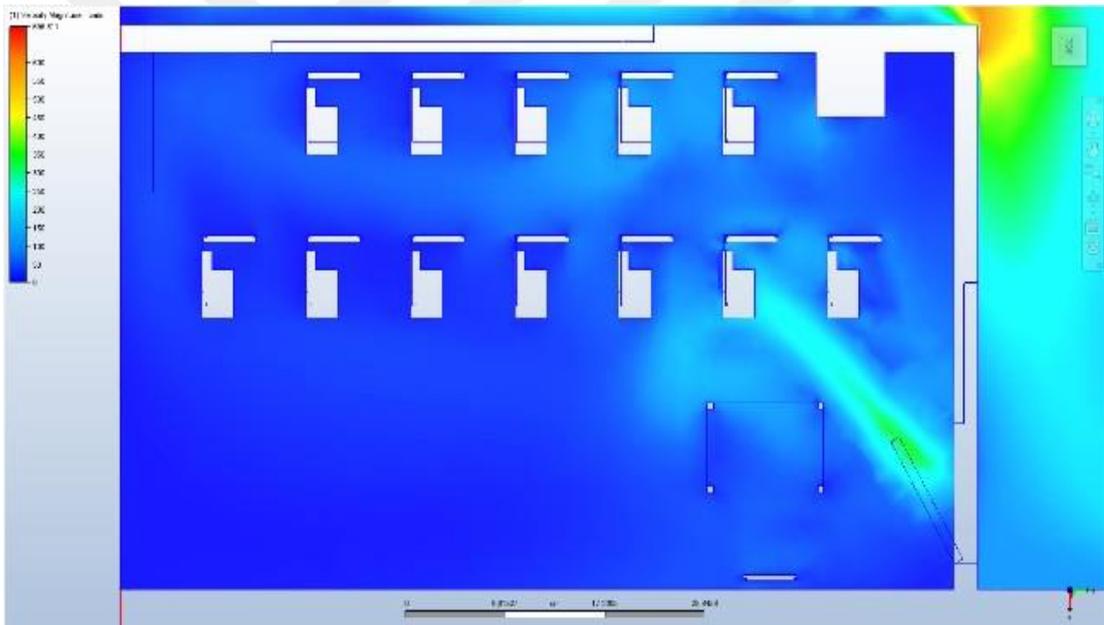
**30°- 90°**



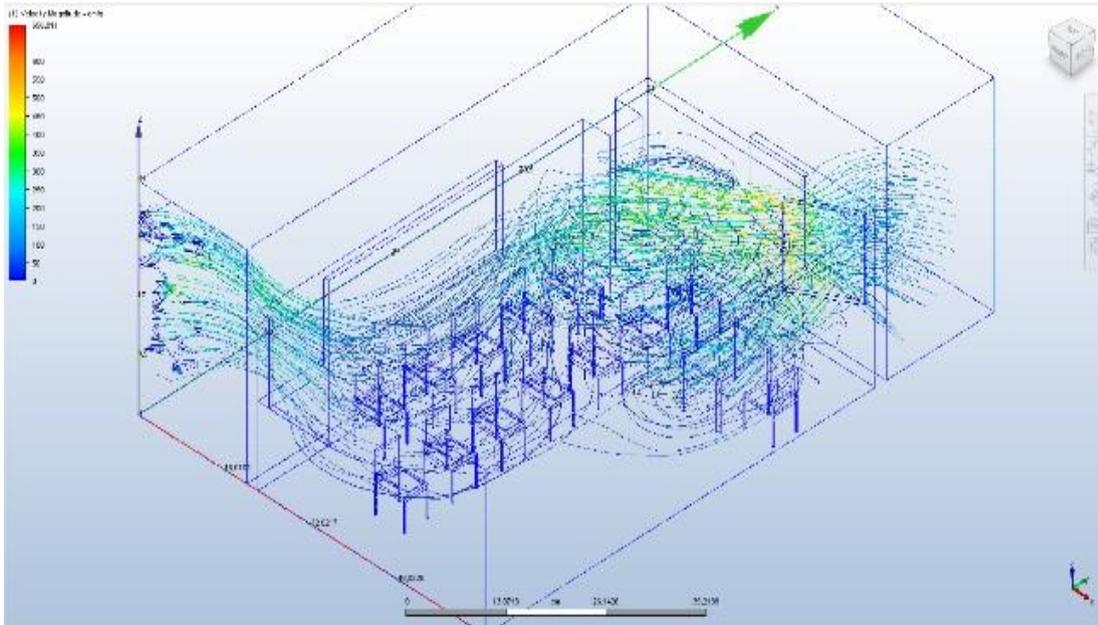
**Appendix 50. 30°-90° Perspective– Empty**



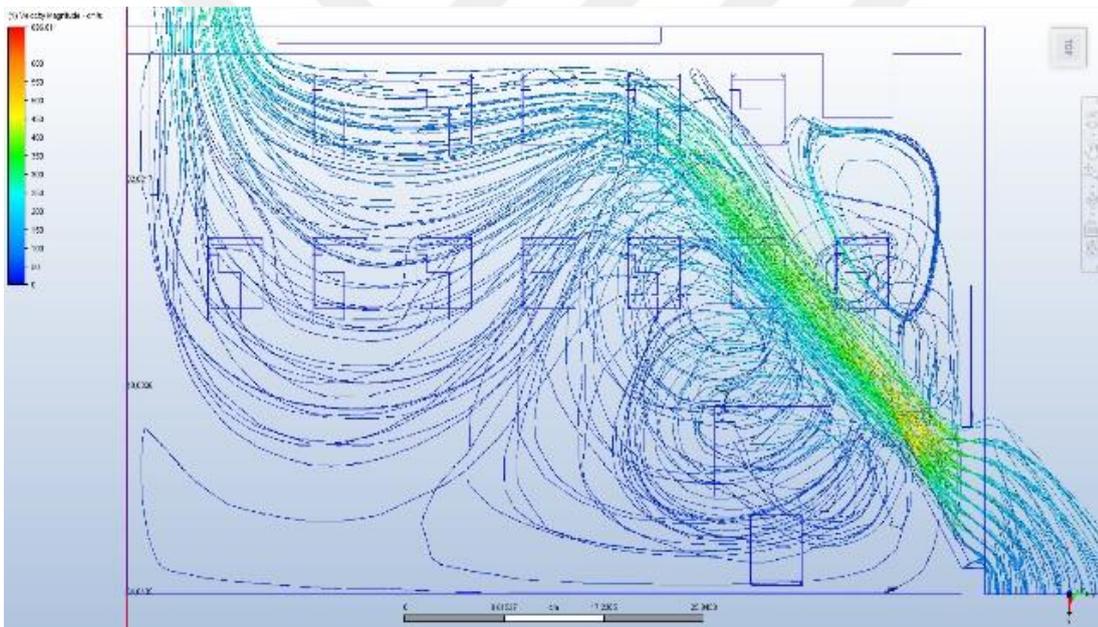
**Appendix 51.** 30°-90° Perspective-Velocity



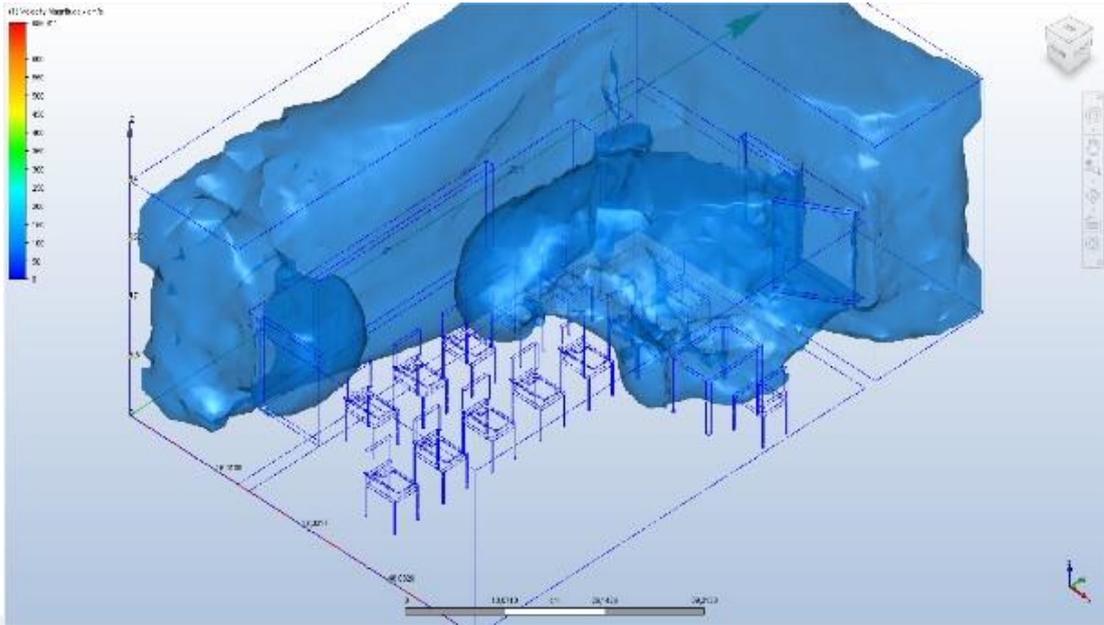
**Appendix 52.** 30°-90° Top View - Velocity



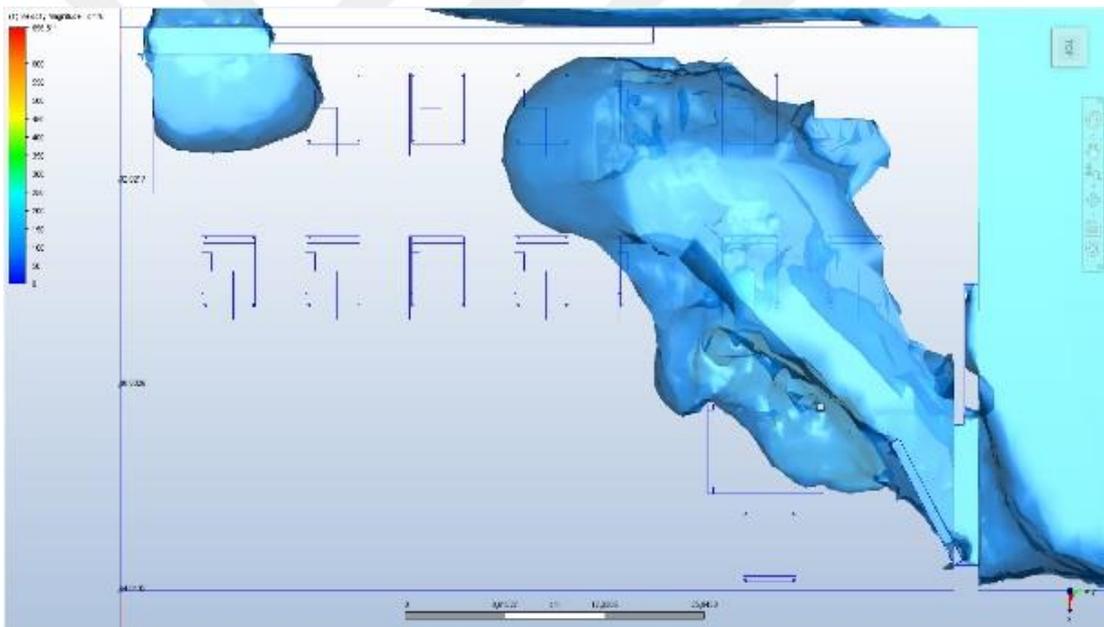
**Appendix 53. 30°-90° Perspective- Particles**



**Appendix 54. 30°-90° Top View- Particles**

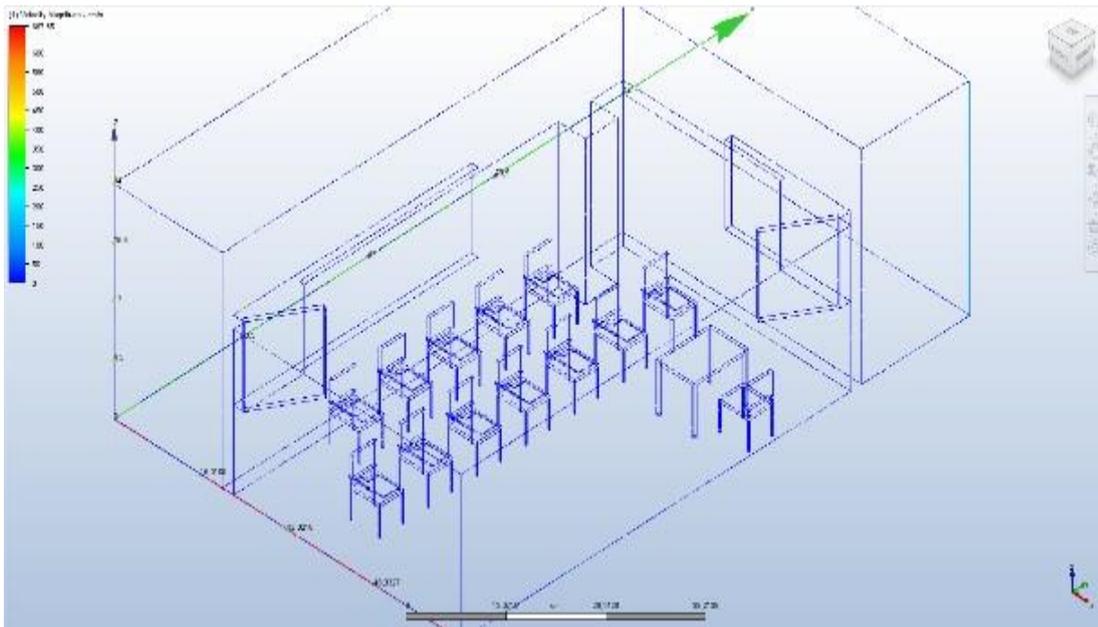


**Appendix 55. 30°-90° Perspective- 3D Air**

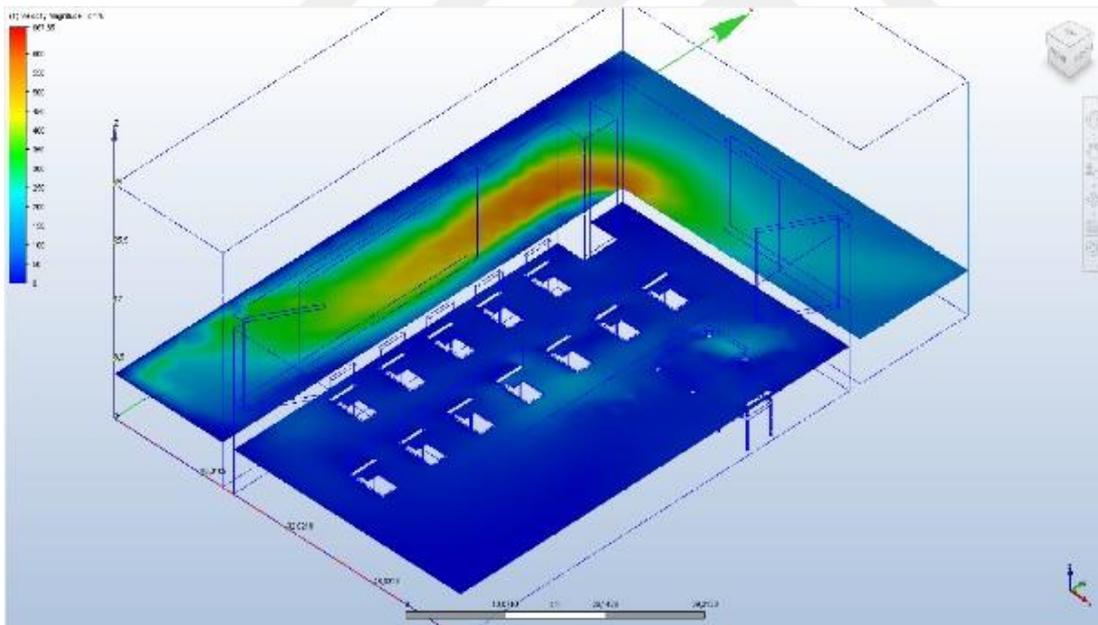


**Appendix 56. 30°-90° Top View- 3D Air**

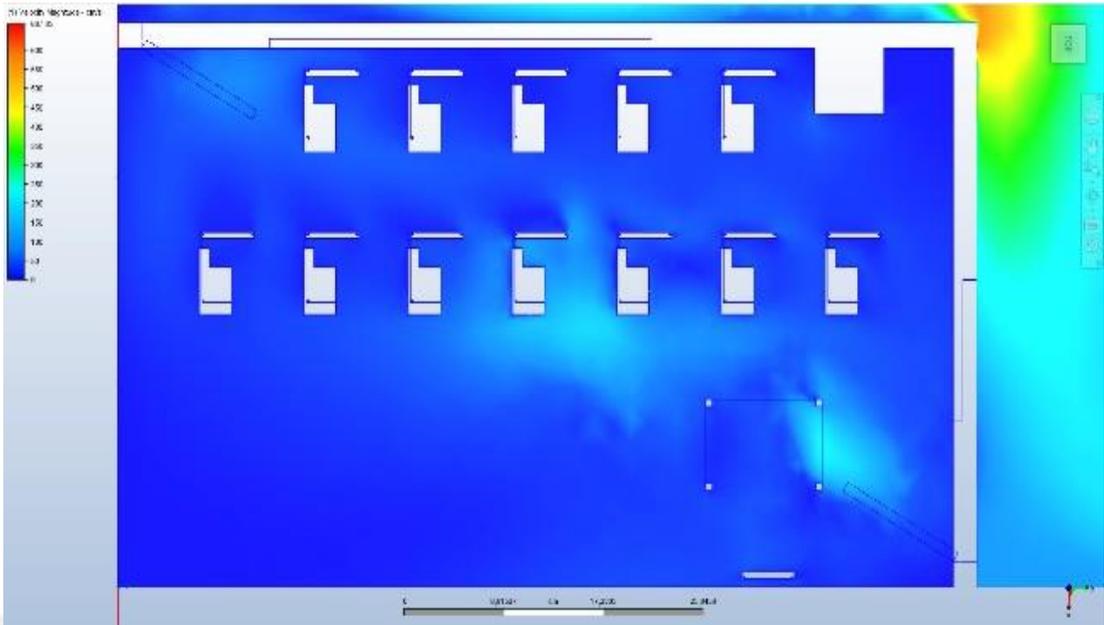
60°- 30°



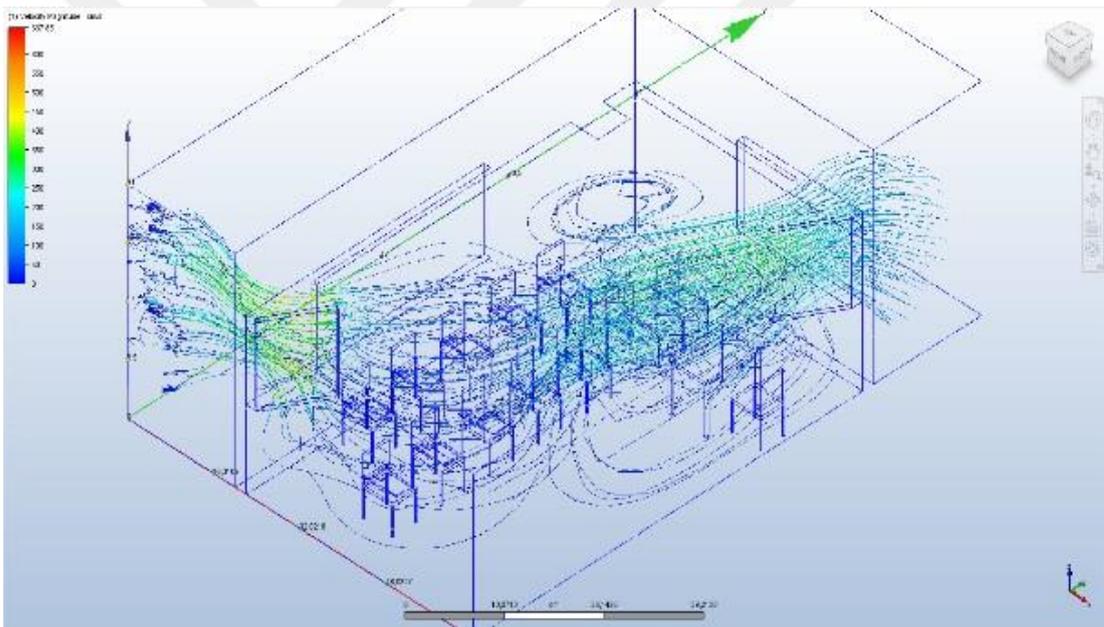
Appendix 57. 60°-30° Perspective– Empty



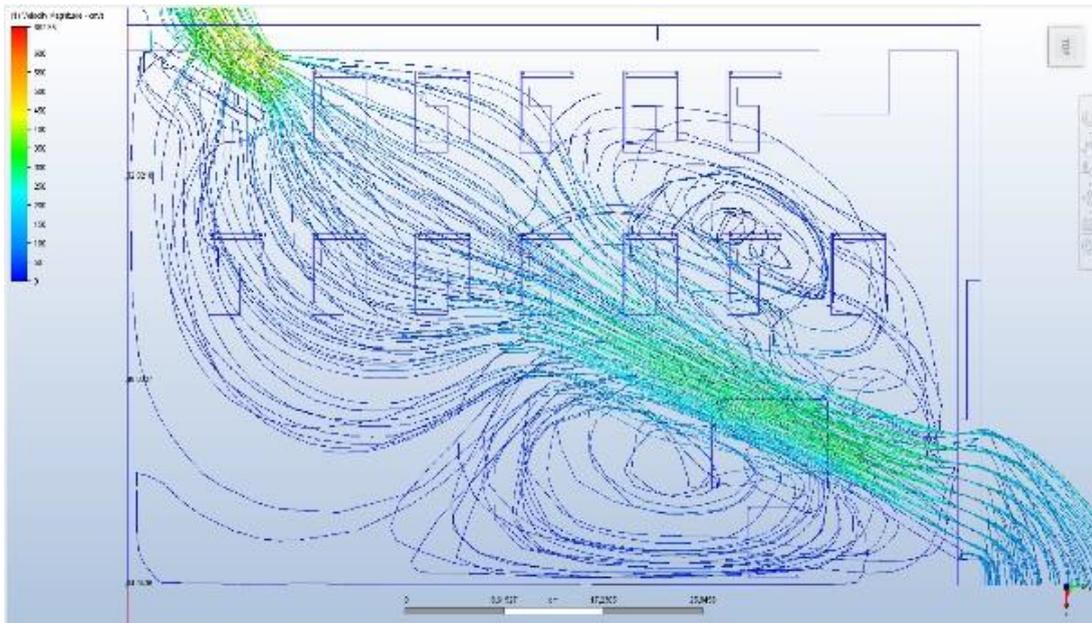
Appendix 58. 60°-30° Perspective -Velocity



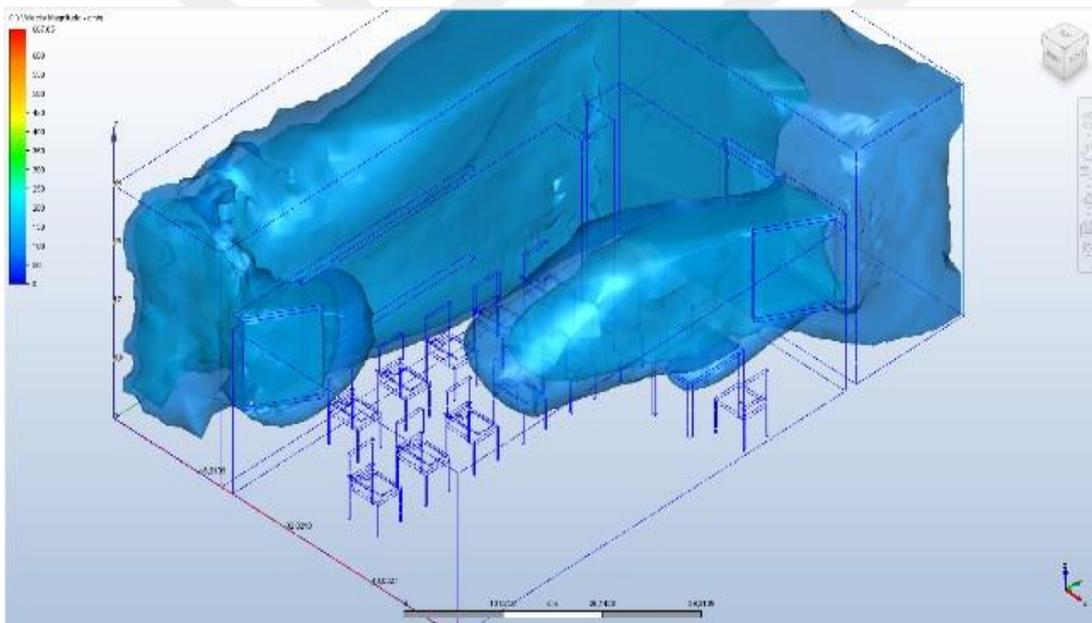
**Appendix 59.** 60°-30° Top View- Velocity



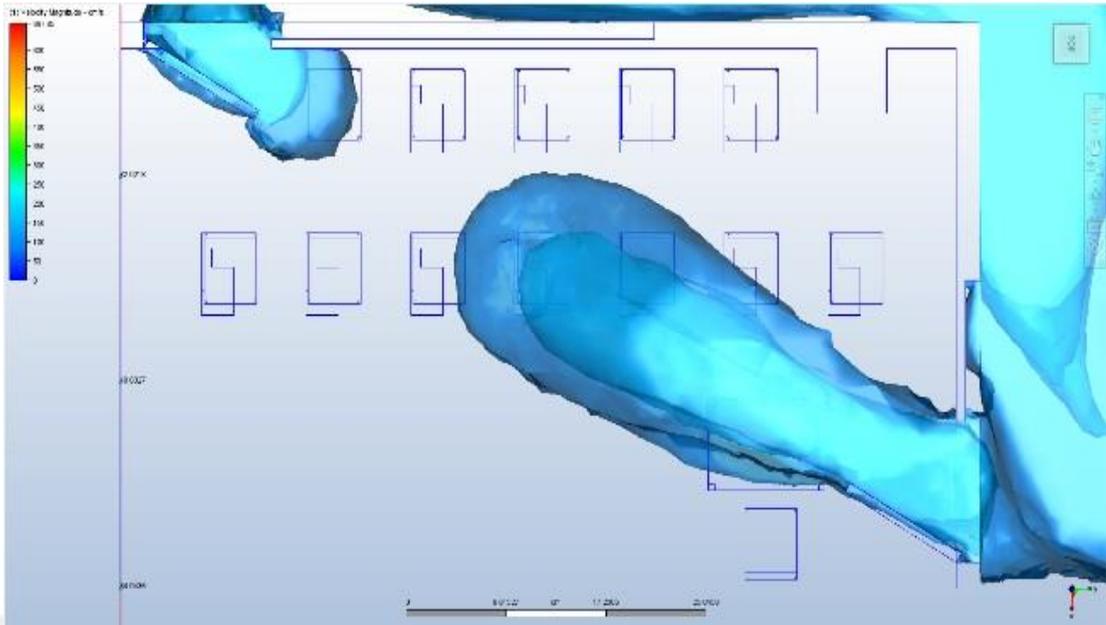
**Appendix 60.** 60°-30° Perspective- Particles



**Appendix 61. 60°-30° Top View– Particles**

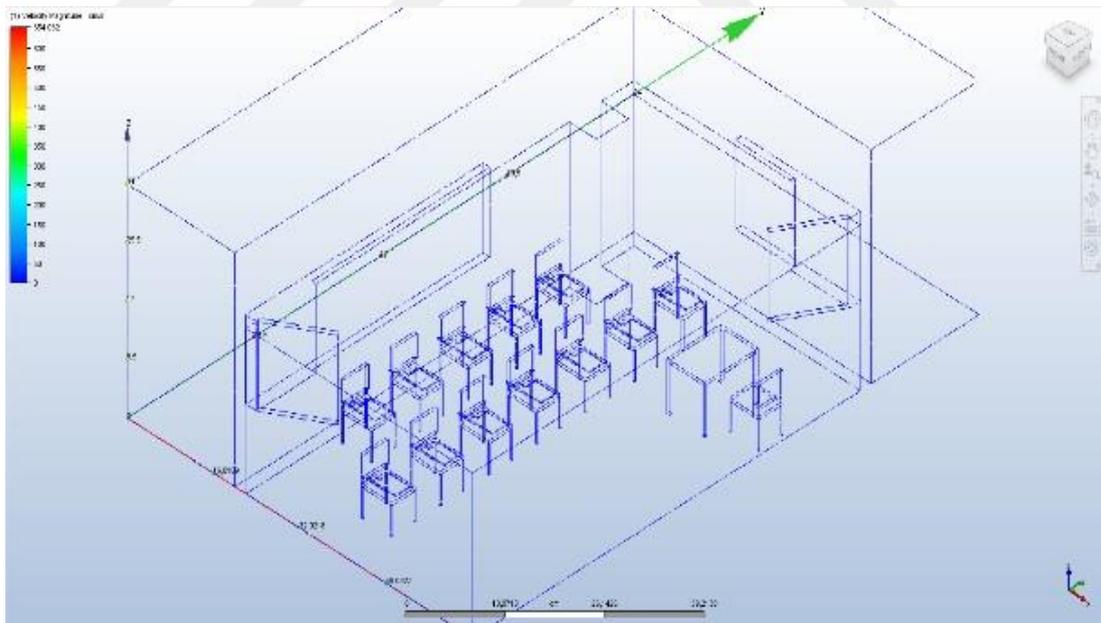


**Appendix 62. 60°-30° Perspective - 3D Air**

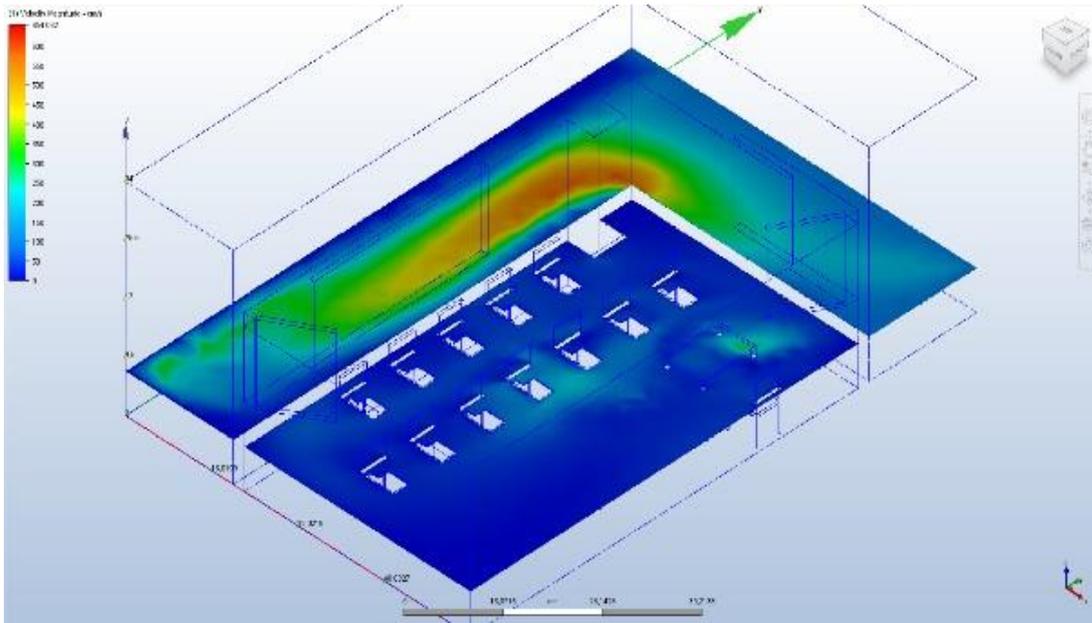


**Appendix 63.** 60°-30° Top View- 3D Air

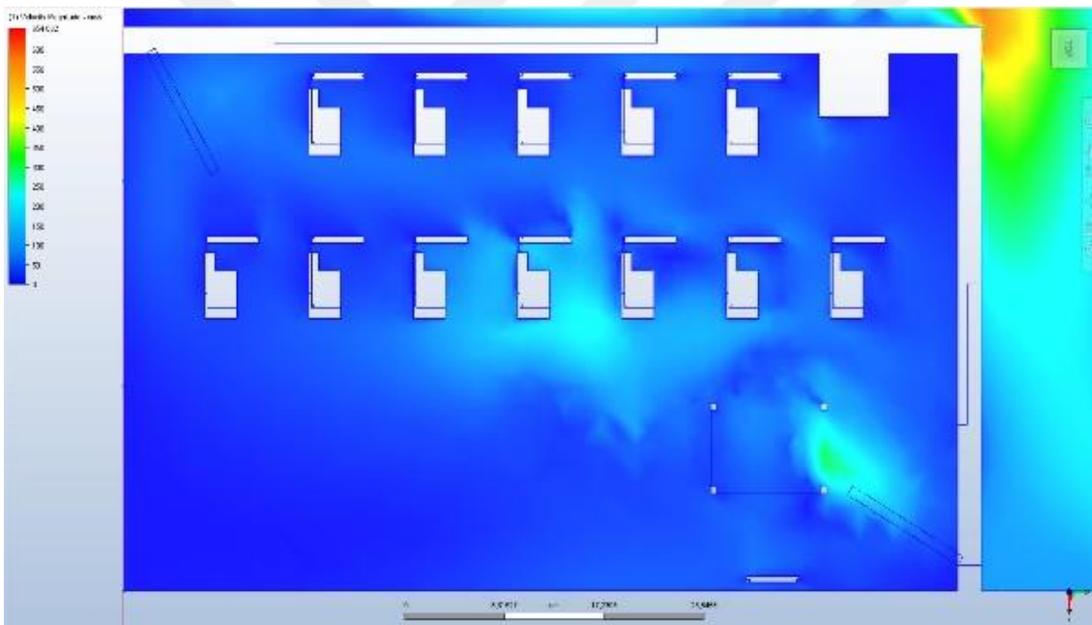
60°- 60°



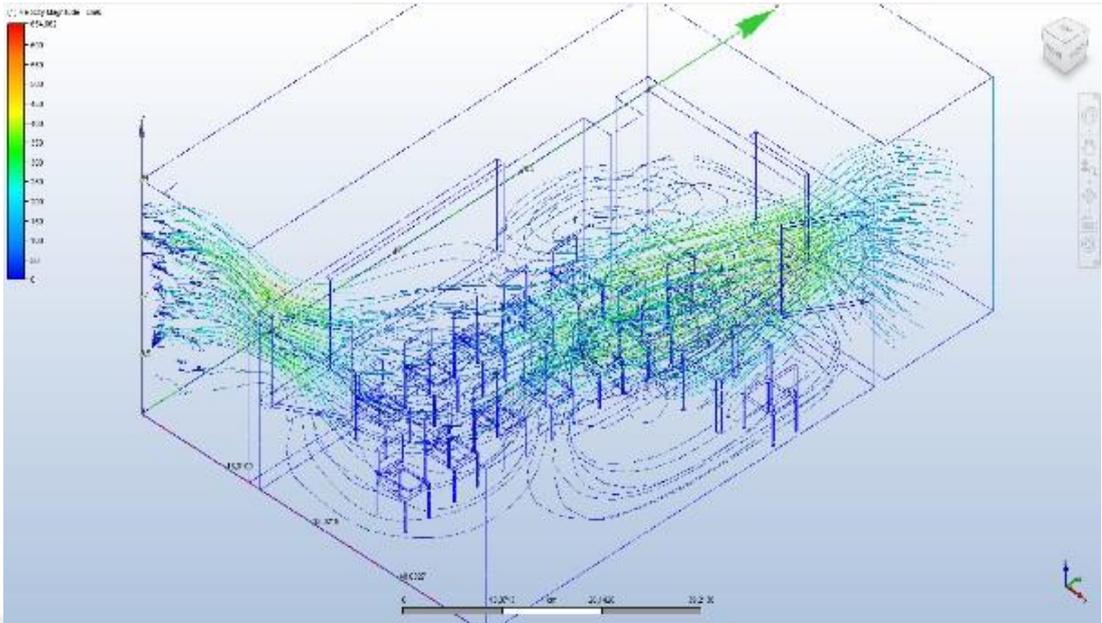
**Appendix 64.** 60°-60° Perspective– Empty



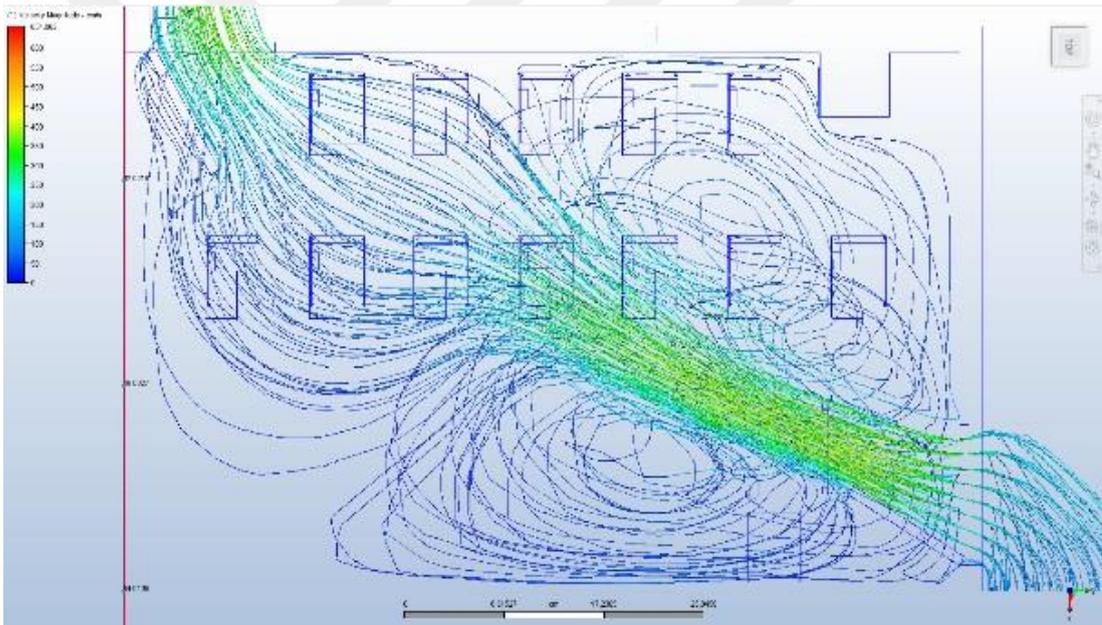
**Appendix 65. 60°-60° Perspective-Velocity**



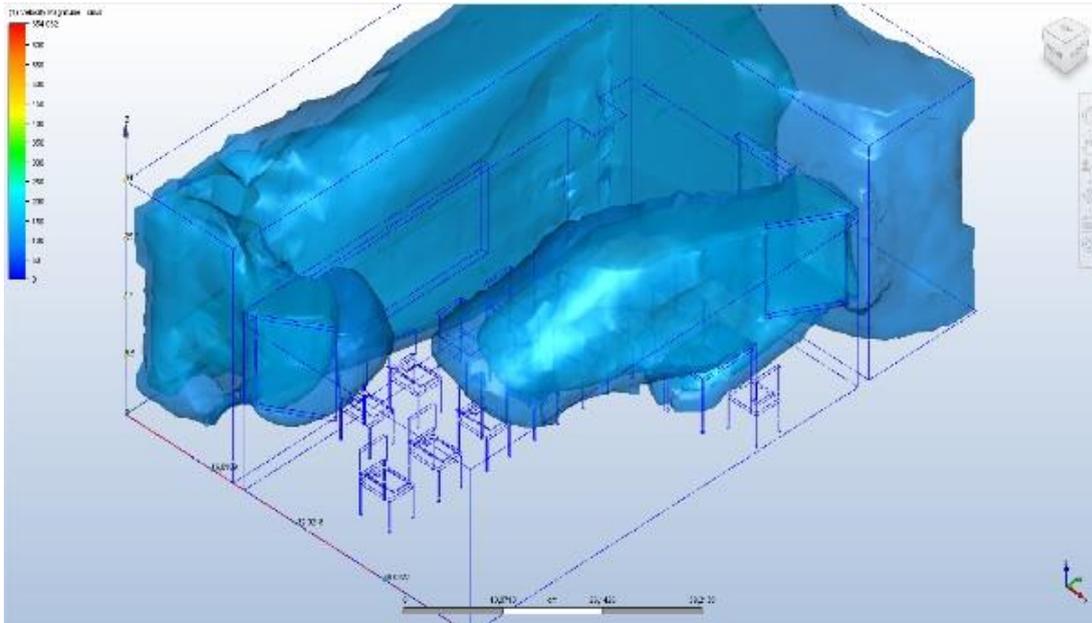
**Appendix 66. 60°-60° Top View - Velocity**



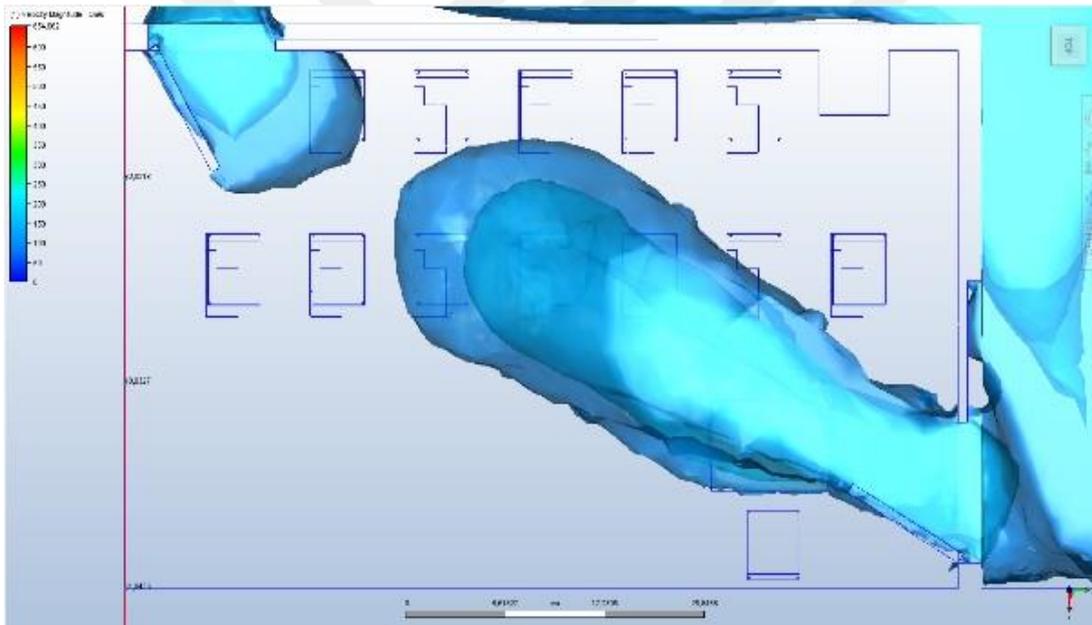
**Appendix 67. 60°-60° Perspective- Particles**



**Appendix 68. 60°-60° Top View- Particles**

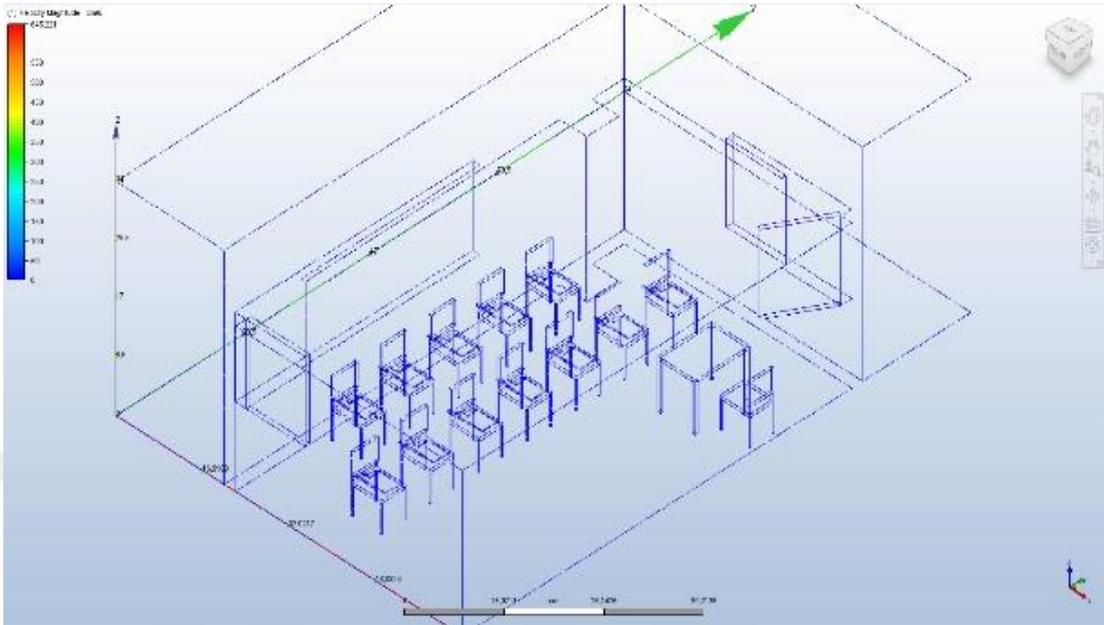


**Appendix 69.** 60°-60° Perspective - 3D Air

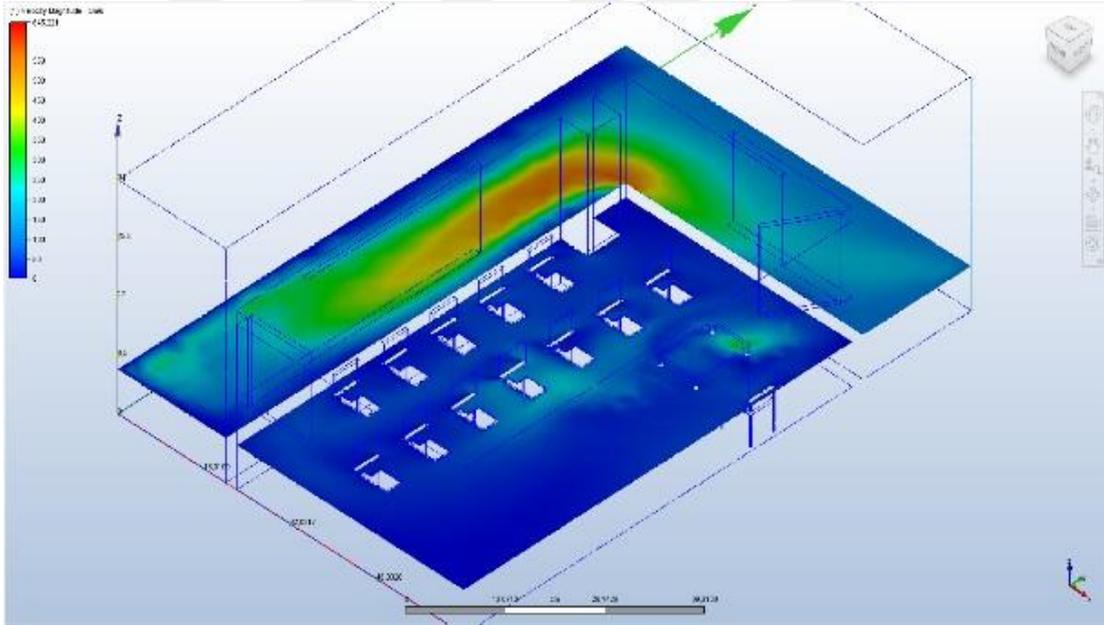


**Appendix 70.** 60°-60° Top View - 3D Air

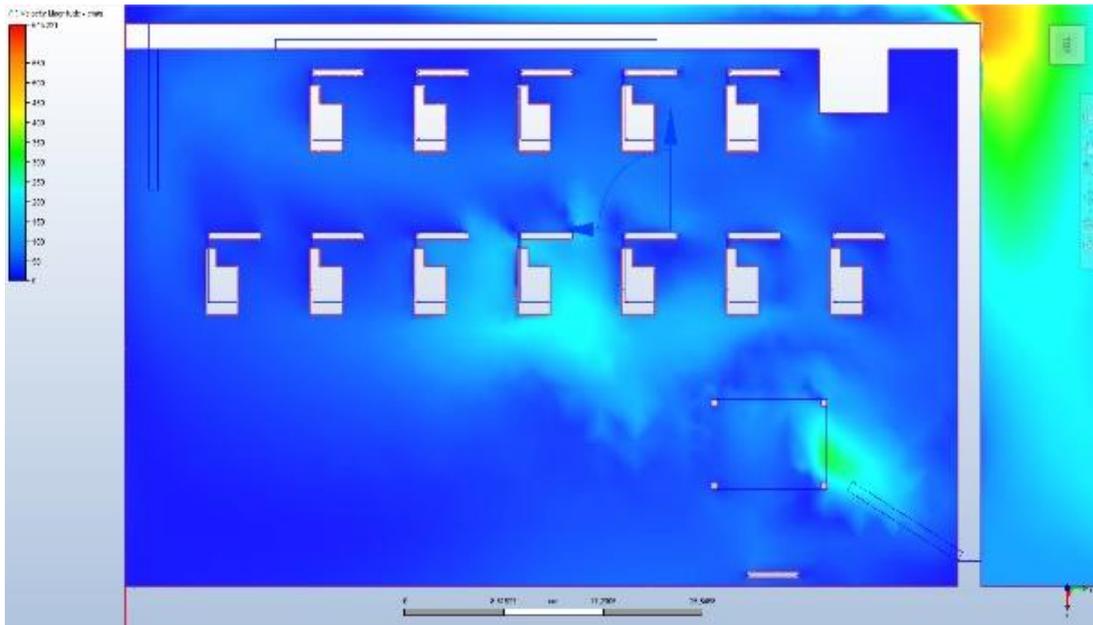
60°- 90°



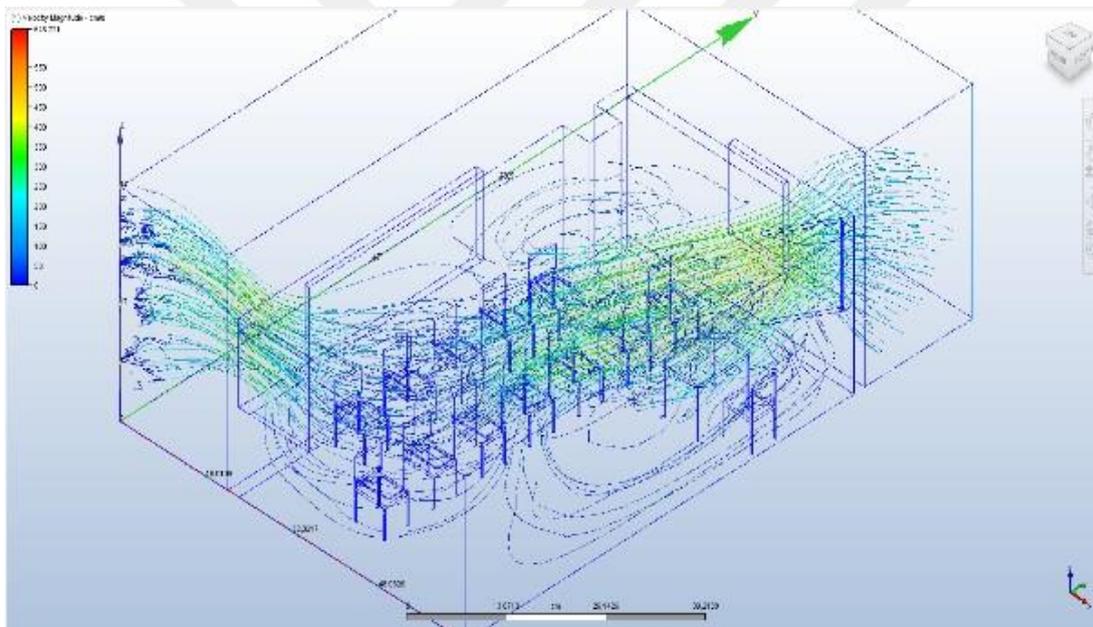
Appendix 71. 60°-90° Perspective – Empty



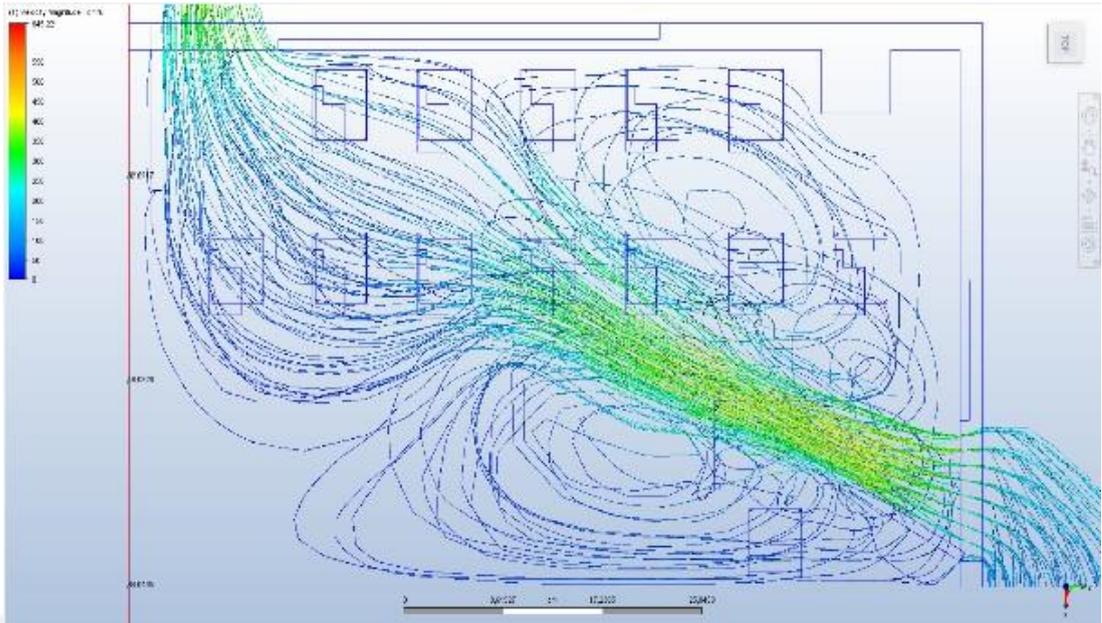
Appendix 72. 60°-90° Perspective -Velocity



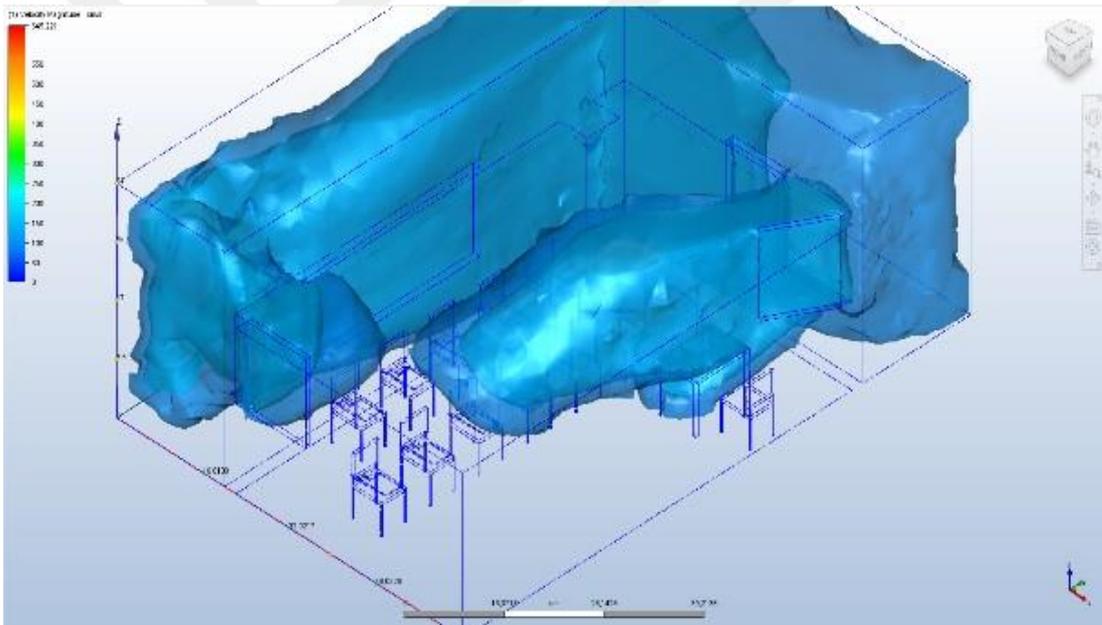
**Appendix 73. 60°-90° Top View - Velocity**



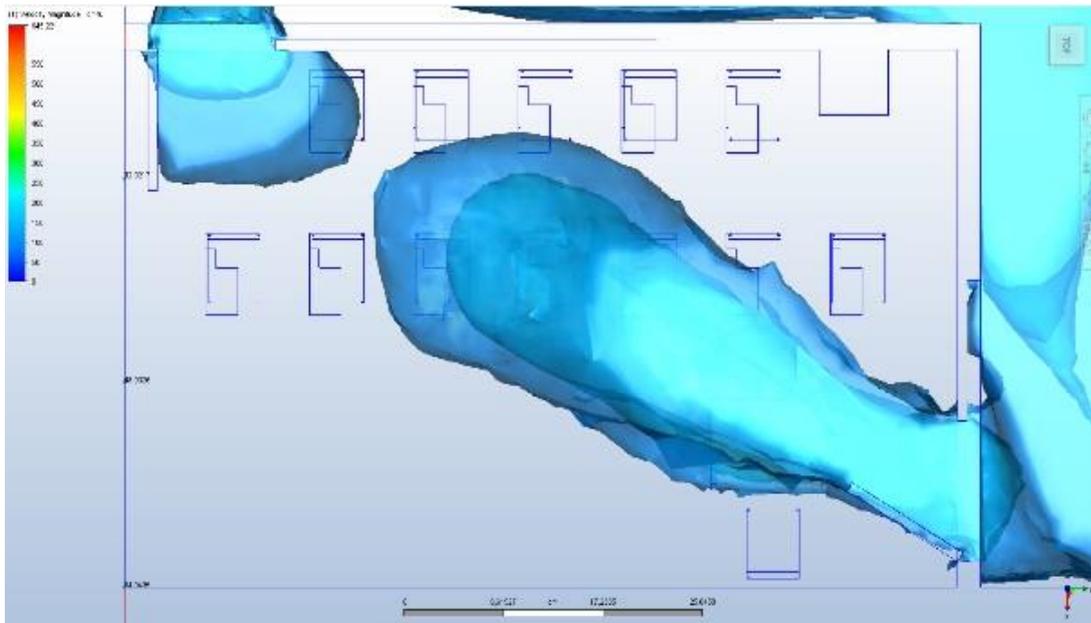
**Appendix 74. 60°-90° Perspective- Particles**



**Appendix 75.** 60°-90° Top View – Particles

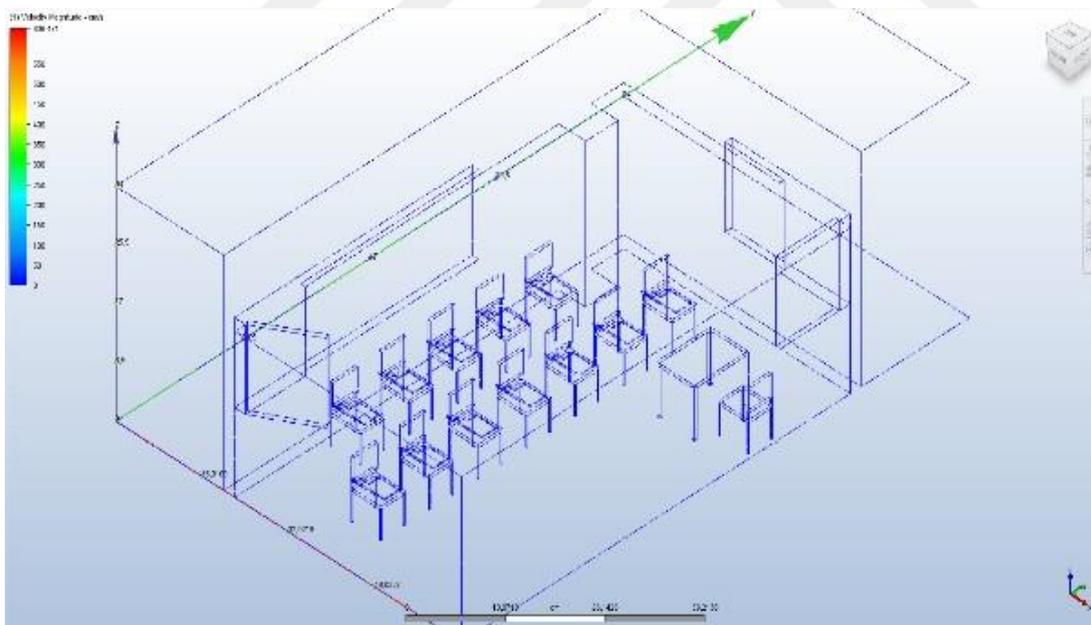


**Appendix 76.** 60°-90° Perspective - 3D Air

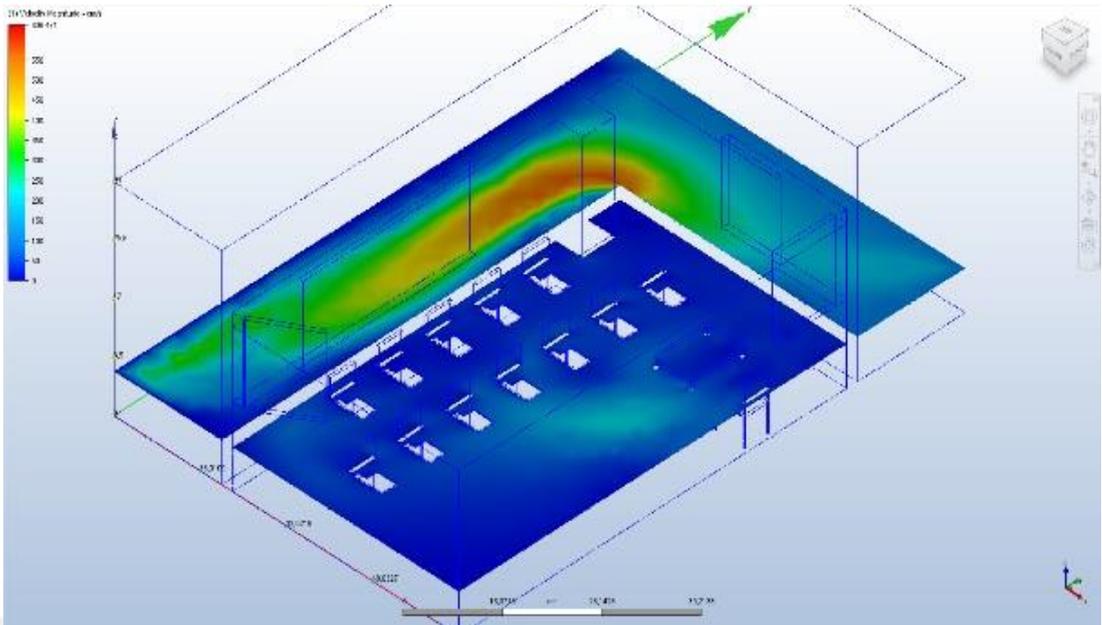


**Appendix 77. 60°-90° Top View - 3D Air**

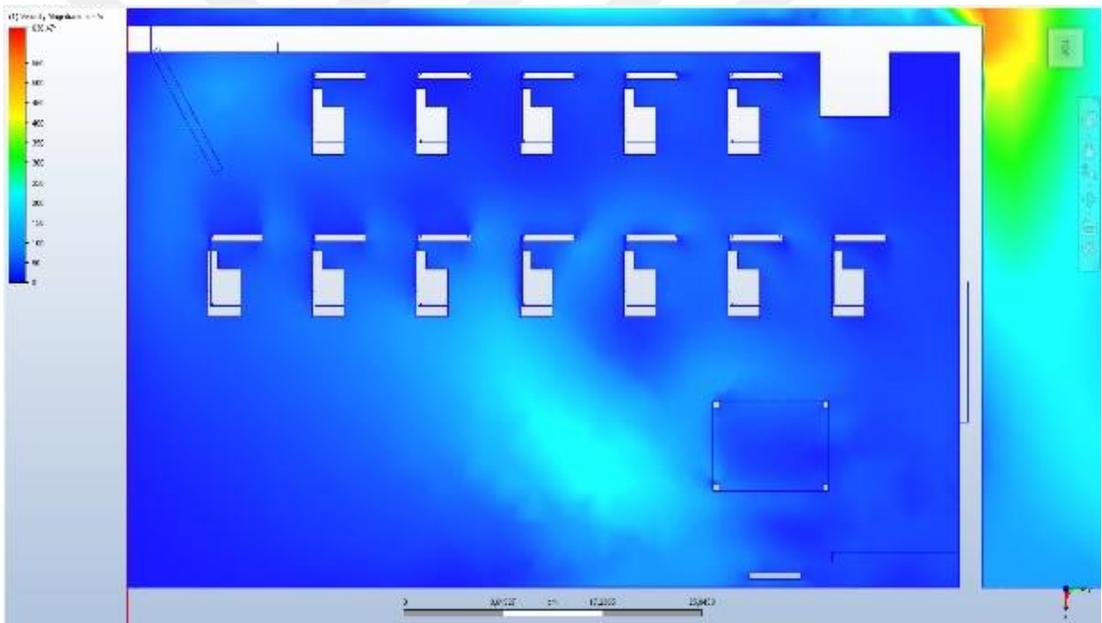
**90°- 60°**



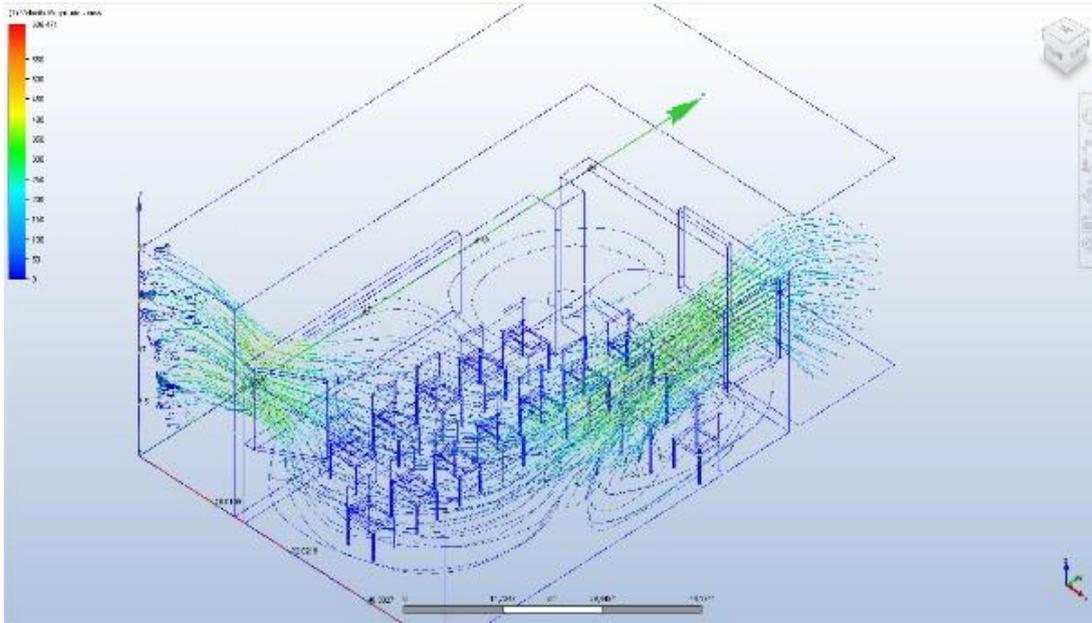
**Appendix 78. 90°-60° Perspective – Empty**



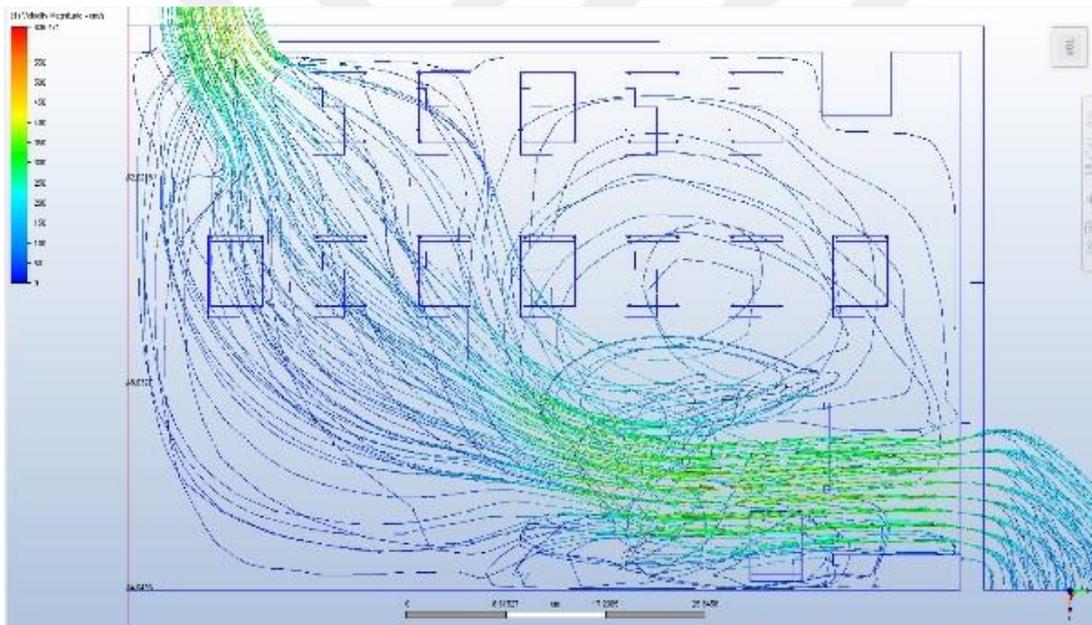
**Appendix 79. 60°-90° Perspective -Velocity**



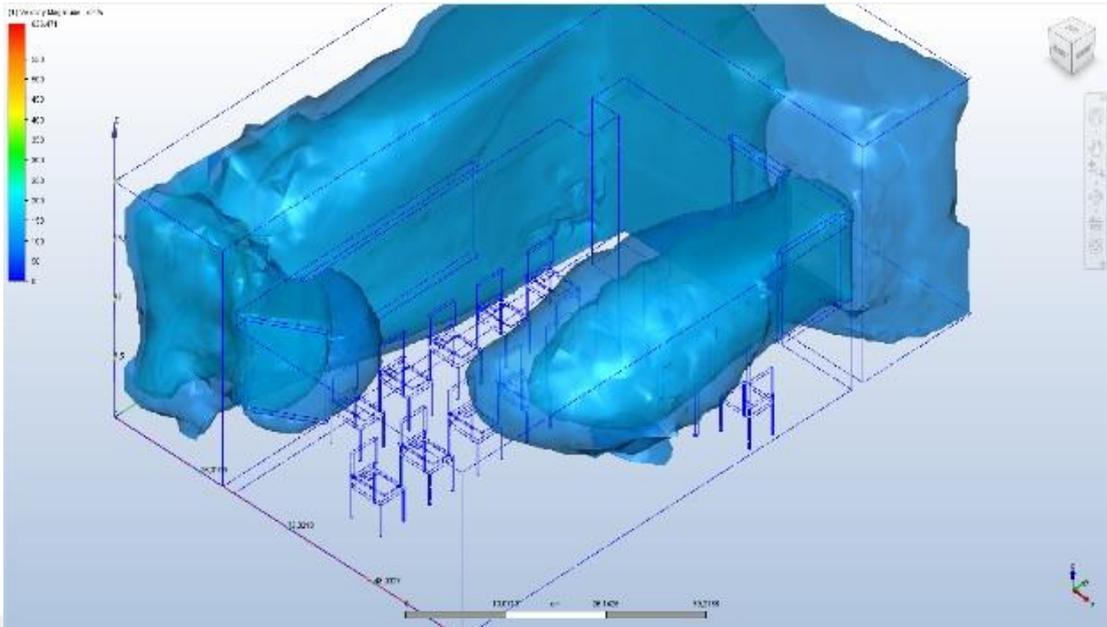
**Appendix 80. 90°-60° Top View-Velocity**



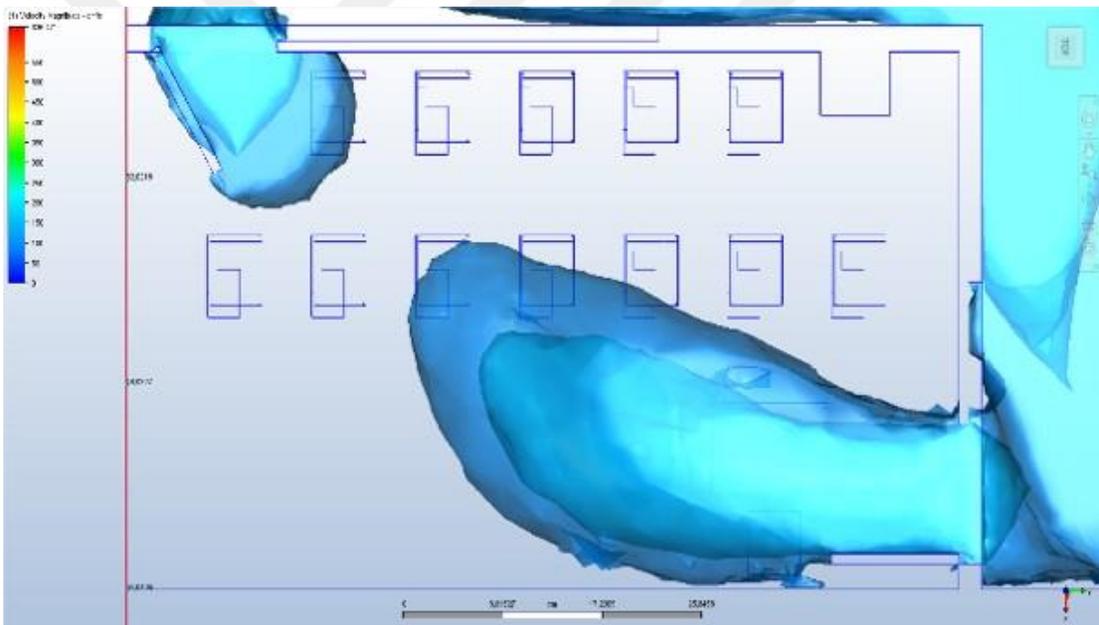
**Appendix 81.** 90°-60° Perspective-Particles



**Appendix 82.** 90°-60° Top View Particles

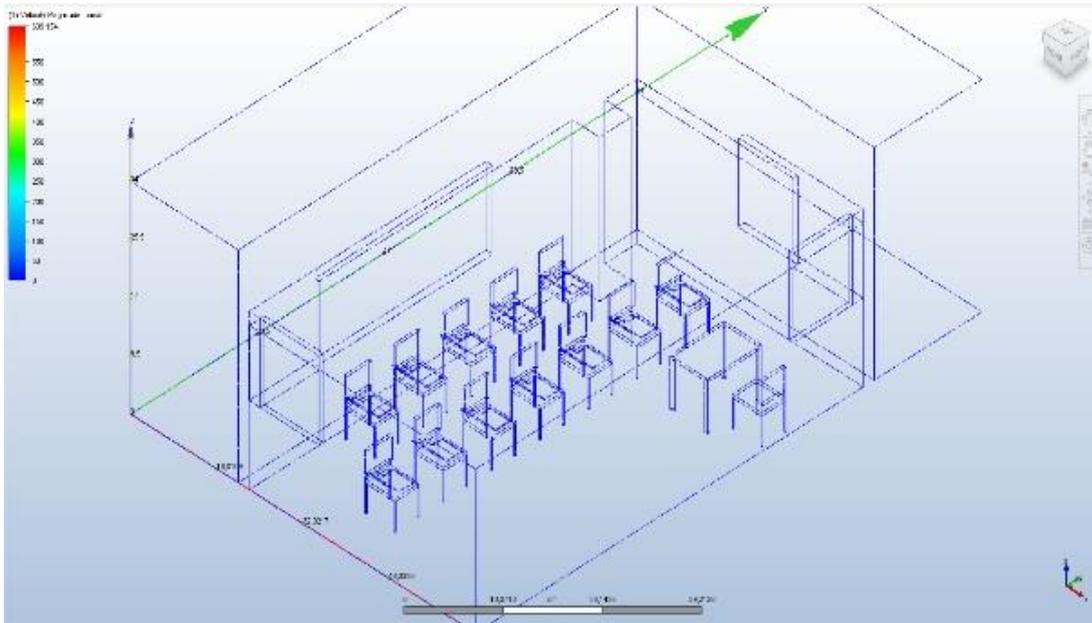


**Appendix 83.** 90°-60° Perspective- 3D Air

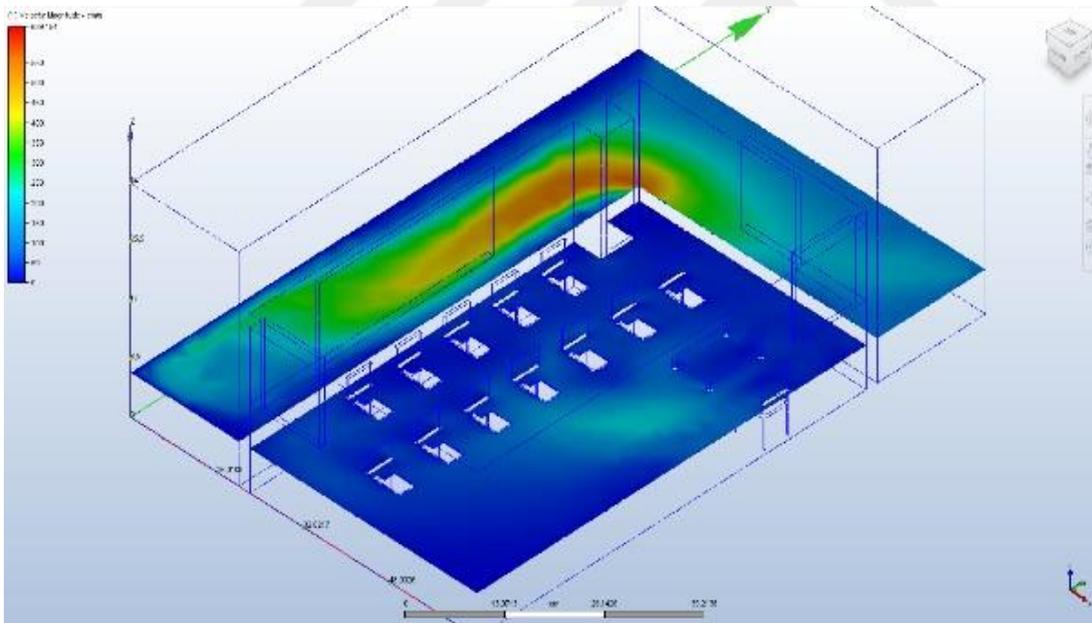


**Appendix 84.** 90°-60° Top View - 3D Air

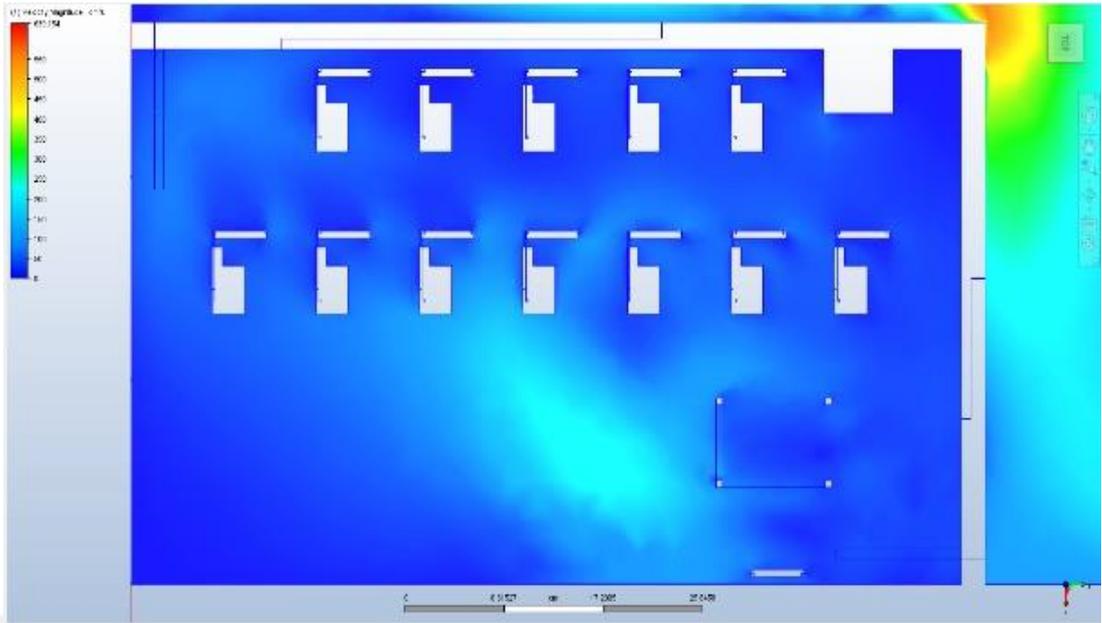
90°- 90°



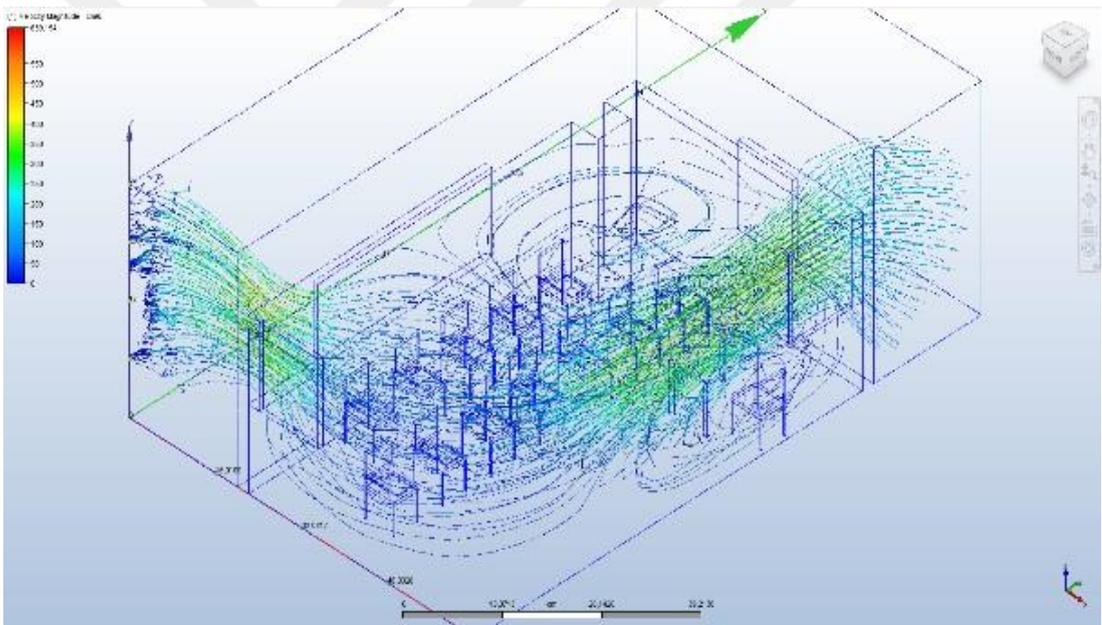
**Appendix 85.** 90°-90° Perspective – Empty



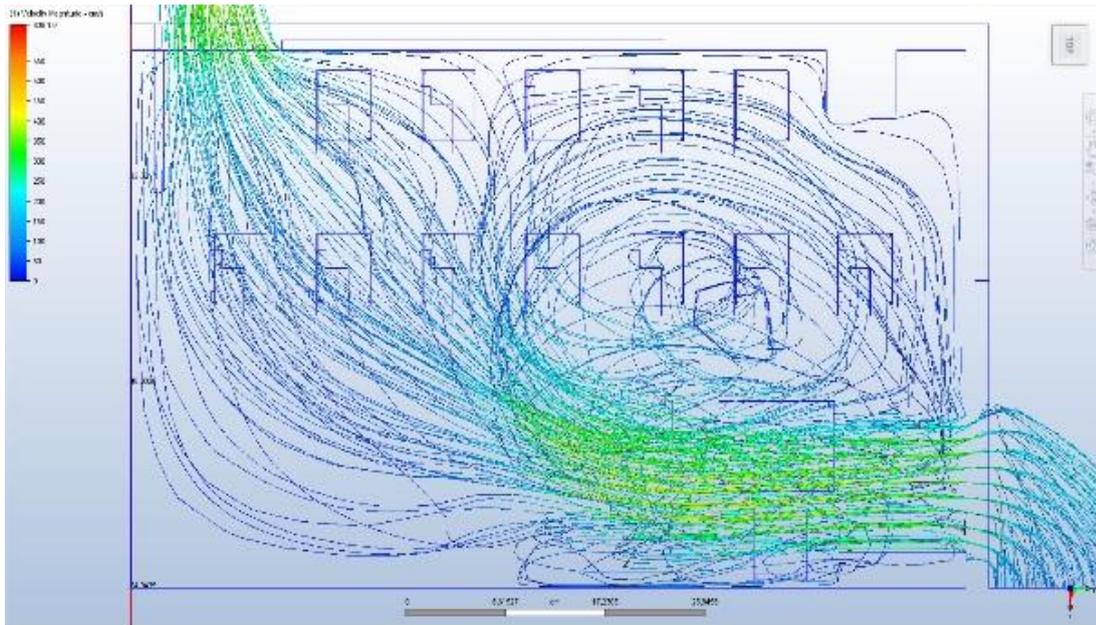
**Appendix 86.** 90°-90° Perspective -Velocity



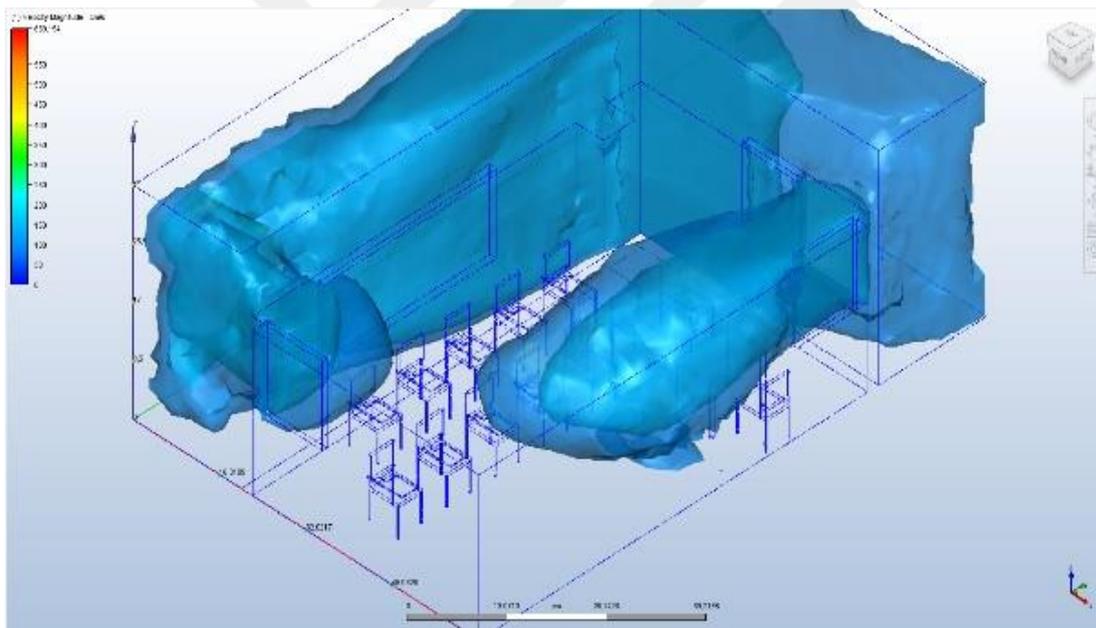
**Appendix 87.** 90°-90° Top View - Velocity



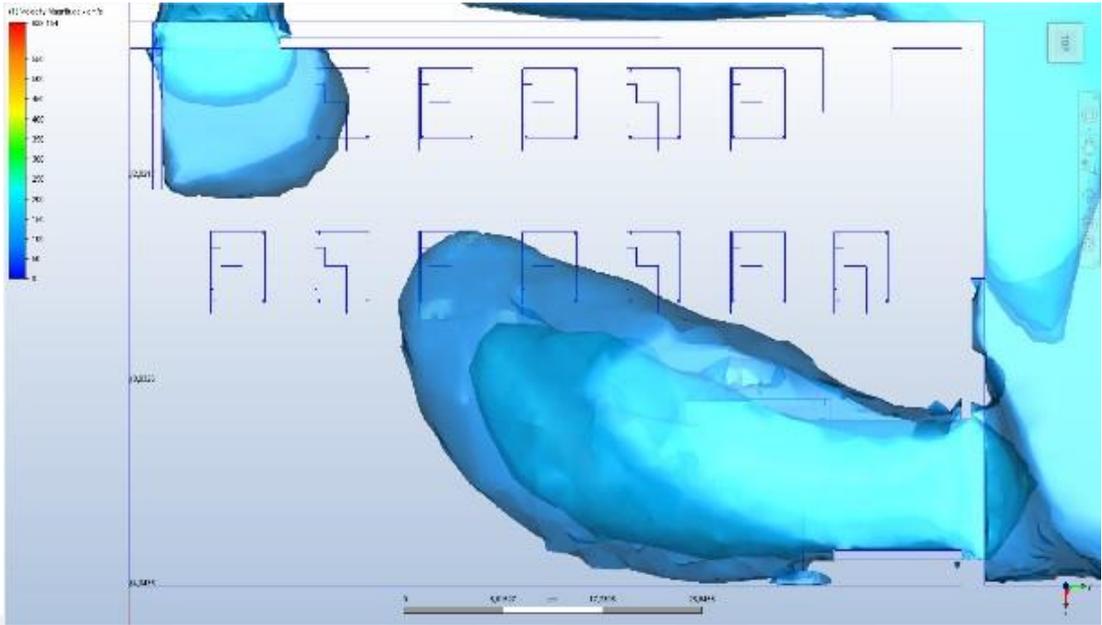
**Appendix 88.** 90°-90° Perspective Particles



**Appendix 89.** 90°-90° Top View – Particles



**Appendix 90.** 90°-90° Perspective- 3D Air



**Appendix 91. 90°-90° Top View - 3D Air**