NATURAL VENTILATION DESIGN FOR HISTORIC LIBRARIES WITH CFD (COMPUTATIONAL FLUID DYNAMICS) SIMULATION

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ABSTRACT

NATURAL VENTILATION DESIGN FOR HISTORIC LIBRARIES WITH CFD (COMPUTATIONAL FLUID DYNAMICS) SIMULATION

Libraries accumulate and protect written and printed works that make permanent knowledge and cultures have been accumulated throughout human history. Paper-based collections kept in libraries are the heritage of humanity. They are under risk of mechanical, biological and chemical degradation over the years caused by the fluctuations in temperature and relative humidity values and inability to control these values. The aim of the Thesis is to reduce degradation risks on paper-based collections in historic libraries by providing preventive conservation without damaging the structure of the building. The historic Necip Paşa Library which is home for 1147 manuscripts was chosen as a case study. In order to provide preventive conservation for manuscripts, firstly indoor microclimatic data were collected for one year and analyzed to observe the risks that may cause degradation types on manuscripts. Only chemical degradation risk was detected. Window controlled seven natural ventilation scenarios were developed to reduce the risk. Finally, ventilation scenarios were analyzed by Ansys Fluent 17.1. Computational Fluid Dynamics (CFD) modelling was used to observe the effect of natural ventilation scenarios on indoor relative humidity according to outdoor relative humidity and wind direction. Finally, k–ε turbulence model was used in CFD analysis. Results shows that during the high chemical degradation risk period (May-October), outdoor air temperature and relative humidity are suitable only 7.53% of the total time which allows appropriate natural ventilation. As a conclusion, natural ventilation is not enough to decrease chemical degradation risk totally for the Library. Therefore, additional mechanical ventilation is required.

ÖZET

TARİHİ KÜTÜPHANELER İÇİN HAD (HESAPLAMALI AKIŞKANLAR DİNAMİĞİ) SİMÜLASYONU İLE DOĞAL HAVALANDIRMA TASARIMI

Kütüphaneler, insanlık tarihi boyunca biriktirilen bilgi ve kültürlerin kalıcı olmasını sağlayan yazılı ve basılı eserleri biriktirir, korur ve geleceğe aktarılmasını sağlar. İnsanlığın mirası olan bu belgeler, yıllar içinde mekanik, biyolojik ve kimyasal bozulma riski taşımaktadır. Risklerin temel nedenleri sıcaklık ve nem değerlerinde meydana gelen dalgalanmalar ve bu değerlerin gerektiği gibi kontrol edilememesidir. Bu tezin amacı, tarihi kütüphanelerdeki kağıt bazlı eserlerin binanın yapısına zarar vermeden önleyici koruma sağlayarak bozulma riskini azaltmaktır. 1827 yılında Tire-İzmir-Türkiye'de inşa edilen ve XII. yüzyıla dayanan 1147 değerli el yazmasına ev sahipliği yapan Necip Paşa Kütüphanesi örnek çalışma olarak incelenmiştir. Binanın ana yapısında ısıtma/soğutma ve mekanik havalandırma sistemi yoktur. El yazmalarının önleyici korunmasını sağlamak için, ilk olarak iç ortam mikroklima verileri bir yıl boyunca toplanmıştır. Veriler, el yazmalarının kimyasal, biyolojik ve mekanik bozulmalarına neden olabilecek riskleri belirlemek için analiz edilmiş. Yalnızca kimyasal bozulma riski tespit edilmiştir. Kimyasal bozulma riskini azaltmak için pencere kontrollü doğal havalandırma senaryoları geliştierilmiştir. Son olarak, bina modellenmiş ve pencere kontrollü yedi doğal havalandırma senaryosu dış ortamdaki bağıl nem, sıcaklık ve rüzgâr yönüne bağlı olarak iç ortamdaki bağıl nem üzerindeki etkisini gözlemlemek için Hesaplamalı Akışkanlar Dinamiği (HAD) yönetemi kullanılarak Ansys Fluent 17.1 ile analiz edilmiştir. HAD analizinde k-ε türbülans modeli kullanılmıştır. Sonuçlar kimyasal bozulma riski olan dönem (Mayıs-Ekim) için dış hava sıcaklığı ve bağıl nem değerlerinin uygun doğal havalandırma senaryosu kullanıldığında 7.53% iyileşme meydana geldiğini gösterdi. Ayrıca sonuç göre doğal havalandırmanın tek başına kullanılmasının Necip Paşa Kütüphanesi-Tire-İzmir-Türkiye içinde bulunan kağıt bazlı koleksiyonların korunmasında yetersiz kaldığını ve ek olarak mekanik havalandırma gerektiğini ortaya koydu.

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Aa	Frequency constant	1/s
Ea	Activation energy	J/mol
$\boldsymbol{\varepsilon}$	Rate of dissipation of turbulence energy	-
k	Reaction rate constant	1/s
K	Turbulence kinetic energy	m^2/s^2
$\bar{p}$	Averaged-pressure	Pa
RH	Relative Humidity	%
R	Universal gas constant	J/mol.K
T	Temperature	^oC
$\overline{u_i}$	Averaged-v component	m/s
v_t	Turbulent viscosity ratio	m^2/s
ρ	Density	kg/m^3
v	Velocity	m/s

CHAPTER 1

INTRODUCTION

Libraries accumulate and protect written and printed works throughout human history transferring knowledge and culture to the future. Library buildings can be categorized as historic and non-historic based on the age of the building. Historic libraries contribute an essential continuum between each stage of human improvement (Bülow, 2002). Moreover, historic libraries have specific importance as they are educational and cultural centers of their periods. These buildings possess a distinct value as the cultural heritage of people. Therefore, for every physical change to be made in historic libraries, priority should be given to the conservation of architectural and cultural value of these buildings instead of providing thermal comfort conditions for visitors and employees. Movable cultural property is referred to as manuscripts, sculptures, paintings, museum collections, etc. while immovoable cultural property is referred to as architectural heritage. Historic libraries are immovable cultural properties containing movable cultural properties such as manuscripts and archives.

Historic libraries are home to manuscripts and paper-based collections which are under risk of deterioration if they kept under improper indoor climate (improper moisture, temperature, and lighting), indoor air quality (Carbon dioxide (CO_2), sülfür dioxide (SO_2), nitrogen oxide (NO_x), ozon (O_3), hidrogen sulfide (H_2S), etc.,) and microbiological conditions. Because of these conditions; chemical(shrinking, discloration), mechanical (delamination, torn) and biological (mould growth) degradation could be observed on movable cultural properties.

In historic libraries, temperature (T) and relative humidity (RH) are important parameters that need to be controlled in order to prevent the deterioration of the movable cultural properties that they contain. The fundamental reason for the mechanical degradation is the fluctuations in T and RH values while biological degradation is caused by the extreme T and RH values. The conservation conditions of historic libraries and paper-based collection have been determined with certain standards such as American Association of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) standards (ASHRAE Chapter 23, 2011), International Organization for Standardization

Table 1.1. Standard T and RH values for museums, libraries and archives (Source: ASHRAE Chapter 23, 2011).

Climate classes		Short term allowable fluctuations	Seasonal allowable fluctuations	Collection risks and benefits
AA		±5% RH, ±2°C	No change in RH, ±5°C in T	No risk of mechanical damage to most artifacts and paintings. Some metals and minerals mat degrade if 50% RH exceeds critical RH. Chemically unstable objects unusable within decades.
A	A 1	±5% RH, ±2°C	±10% RH, down 5°C	Small risk of mechanical damage to high-vulnerability artifacts; no mechanical eisk to most artifacts, paintings, photographs and books. Chemically unstable objects unusable within decades.
	A 2	±10% RH, ±2°C	No change in RH, down 5°C, up 10°C	
B		±10% RH, ±5°C	Up 10% RH, down 10% RH; Up 10K but not above 30ºC, down as low as necessary to maintain RH control	Moderate risk of mechanical damage to high-vulnerability artifacts; tiny risk to most paintings, most photographs, some artifacts, some books; no risk to many artifacts and most books. Chemically unstable objects unuable within decades, less if routinely at 30ºC, but cold winter periods double life.
C		Within 25 to 75% RH year-round T rarely over 30ºC, usually below 25ºC		High risk of mechanical damage to high-vulnerability artifacts; moderate risk to most paintings, most photographs, some artifacts, some books; tiny risk to many artifacts and most books. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods double life.
D		Reliably below 75% RH		High risk of sudden or cumulative mechanical damage to most artifacts and paintings because of low-humidity fracture; but avoids high-humidity delamination and deformations, especially in veneers, paintings, paper, and photographs. Mold growth and rapid corrosion avoided. Chemically unstable objects unusable within decades, less if routinely at 30°C, but cold winter periods double life.

(ISO 11799, 2003) and British Standards (PD 5454, 2012). In 2017, BS 16883 "Conservation of cultural heritage. Guideliness for improving the energy performance of historic buildings" was publisher but, it is not adopted to Turkey yet. Table 1.1 shows the climate classes according to ASHRAE Chapter 23.

According to Table 1.1, there is no risk of deterioration for pictures, photographs, and books in climate class A. In climate class B environments, low-risk levels on materials, medium-risk sites in climate-class C environments, and high-risk levels in climate-class D environments are observed. For paper-based collections, minimum indoor T and RH conditions must comply class A1.

States, institutions and organizations should provide the necessary support to protect cultural heritage, which is an important mission of humanity. This thesis emerged upon the request of the General Directorate of Foundations of the Republic of Turkey to evaluate and improve indoor microclimatic conditions of the Necip Paşa Library-Tire-İzmir-Turkey. In this respect, another Thesis work was conducted to provide preventive conservation measures to reduce the deterioration risks of manuscripts in the library (Coşkun, 2016). In his work, the library was monitored measuring T and RH data for one year and collected data were used to evaluate mechanical, chemical and biological degradation risks of manuscripts. The results indicated that there is no mechanical and biological risk but in a certain period, chemical degradation risk exists. One of the recommendations of the Thesis was to exhibit the effect of natural ventilation on decresing chemical degradation risk on the manuscripts and developing natural ventilation scenarios.

This Thesis study is a continuation of Coşkun (2016) and aims to develop, model and evaluate natural ventilation scenarios for the Necip Paşa Library-Tire-İzmir-Turkey.

The Thesis includes six chapters. Chapter 1 gives introduction, aim and motivation of the study. Chapter 2 presents a literature review on preventive conservation, deterioration risks on paper-based collections, natural ventilation and CFD analysis. In Chapter 3, the case building and previous studies on the building are presented. Materials and methods of the Thesis are given in Chapter 4 while results and discussion are presented in Chapter 5. Finally, Chapter 6 concludes the Thesis.

CHAPTER 2

LITERATURE REVIEW

In this section preventive conservation of historic buildings and cultural heritage, risks of deterioration on paper-based collections, CFD modelling of buildings and natural ventilation are reviewed.

2.1. Preventive Conservation

Portable cultural heritage is generally preserved in historic buildings. It is important to preserve these values that have been moved to the present. Hence, preserving the cultural values that need to be protected, such as paper-based collections, in accordance with the conditions of conservation of the indoor environment of the buildings where they are kept is the only way to protect these values. Preventive conservation approach has been developed in order to control environmental parameters (T, RH and light) and air quality (particulate pollution and substrates) which may disrupt the conservation conditions. SO_2, NO_x, O_3, H_2S, acid and alkaline are the main causes of the pollution. SO_2, NO_X and O_3 are particularly risk factors for organic materials (Baer, 1985; Brimblecombe, 1990; Pavlogeorgatos, 2003; Schieweck and Salthammer, 2011; Karaca et al, 2010). Critical air pollution levels for libraries and archives are given in standards and guidelines (Wilson, 1995; ISO 11799, 2003; Hanus and Hanusova, 2013). Degradation types of paper-based collections are shown in Figure 2.1.This approach which examines the effect of the parameters that may lead deterioration of cultural heritage, by mechanical, biological and chemical degradation analysis, allows taking the necessary measures before they become degraded by monitoring these environmental parameters (Dardes et al., 1999; Bülow, 2002; Finke, 2008; Lipovec and Balen 2008; Silva and Henriques, 2015).

Preventive conservation approach includes three steps. First step is to collect information about the cultural heritage that is planned to be protected, the historic structure in which it is located and indoor environmental conditions within this structure. In this context, indoor environmental conditions are monitored for one year period. Outdoor T and RH data of the building are also collected. In addition, information about the architectural structure of the building is also obtained. Observations made during field visits and information received from the employees are also evaluated. As a second step, the data collected in the first step are evaluated for biological, mechanical and chemical degradation risks. As the third step, based on the data analysis, retrofit and ventilation strategies are developed to decrease the degradation risks.

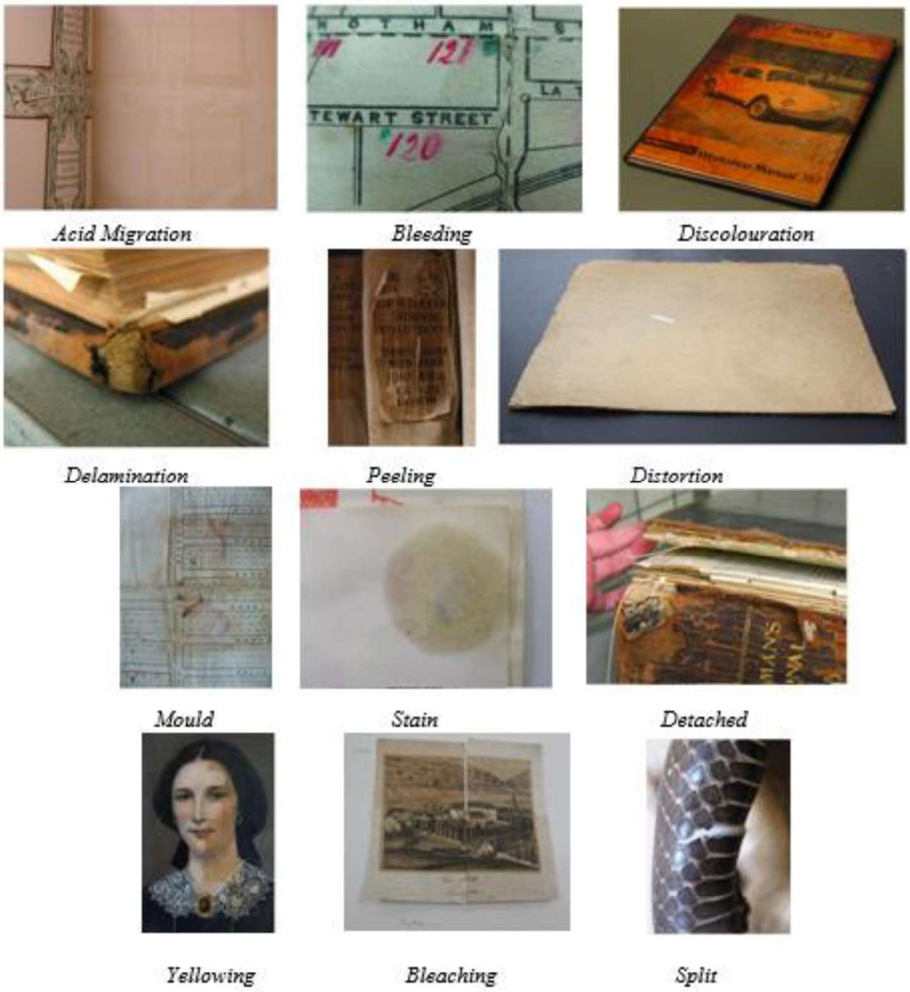


Figure 2.1. Degradation types on paper-based collections (Source: AICCM, 2019).

2.1.1. Chemical Degradation

Chemical degradation takes place as a result of chemical reactions occurring in the material in two types: hydrolysis and oxidation. Hydrolysis is defined as the reaction between material and water. The reaction occurs in the material resulting in the formation of new substances. Long cellulose chains become shorter due to acid hydrolysis and the material becomes more brittle. Oxidation is the reaction between material and oxygen.

This reaction causes physical deterioration (Coşkun, 2016).

The amount of water in the materials accelerates the chemical reaction and leads to degradation. If T and RH values are low, the rate of chemical reaction decreases (Martens, 2012). Arrhenius Equation (2.1) is used to observe the deterioration rate (k) in materials (Zou, et al., 1996).

$$k = A_a \times e^{\frac{-E_a}{R \times T}} \quad (2.1)$$

The Arrhenius equation is not sufficient for low humidity values. Hence, the lifetime multiplier (LM) equation (2.2) was demonstrated by Michalski to observe the rate of chemical deterioration according to instantaneous T and RH values (Michalski, 2003, Huijbregts et al., 2012; Martens, 2012; Silva and Henriques, 2015).

$$LM_x = \left(\frac{50\%}{RH_x}\right)^{1.3} \times e^{\frac{E_a}{R}\left(\frac{1}{T_x+273.15}+\frac{1}{293.15}\right)} \quad (2.2)$$

The value of the activation energy (Ea) in the equation varies according to type of the material. For the examined manuscripts (cellulose based) this value is 100 kJ / mol (Michalski, 2003).

Huijbregts et al. (2012) chose an unheated small church built in the 19th century as a reference building in Eindhoven, the Netherlands. The reference building was modelled and simulated for a wide range of outdoor T and RH values acros Europe. Then, annual mean LM value map is created (Figure 2.2). The Figure indicated that the climateice zore where İzmir located, is critical for LM values. Table 2.1 shows critical risk levels of LM value (Martens, 2012).

Table 2.1. Critical risk levels of LM value (Source: Martens, 2012).

	Ideal	**Good**	**Some risk**	**Potential risk**	**High risk**
LM	>2.2	1.7-2.2	1-1.7	0.75-1	<0.75

2.2.2. Mechanical Degradation

Mechanical degradation occurs due to the forces applied or short-term changes in T-RH values (Bülow, 2002; Martens, 2012). This instantaneous change affects the

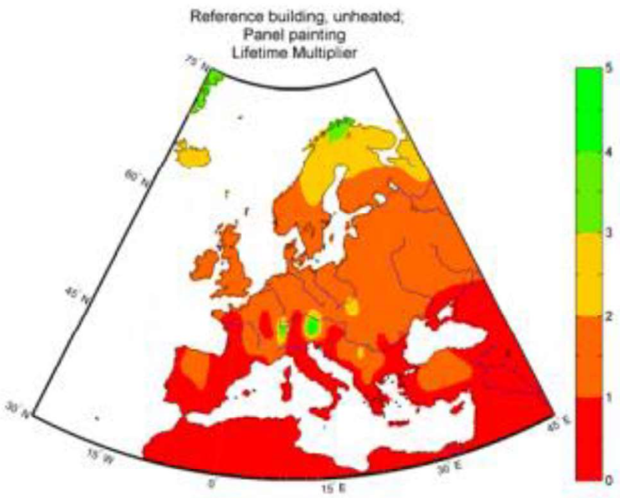


Figure 2.2. Predicted annually averaged LM values in the unheated reference building according to Huibregts Study (Source: Huijbregts et al., 2012).

moisture content in the internal structure of the material and leads to disturbances such as brittleness and swelling (Silva and Henriques, 2015). Fluctuations that are longer than the response time and shorter than the relaxation time cause the paper-based collections to absorb moisture faster. The resulting damage causes the material to reduce the critical stress value. The limit values for the ripple are set in the standards. Daily limits are ± 2°C for T, ±5% for RH for paper-based collections according to climate class A1 (ASHRAE Chapter 23, 2011; PD 5454, 2012; ISO 11799, 2003). Furthermore, when RH falls below 25%, the material becomes brittle and increases the risk of mechanical deterioration (Michalski, 1993).

2.2.3. Biological Degradation

The main causes of biological degradation are high T-RH values and substrates. As a result of degradation, mold formation is observed on the surface of the material. Warscheid and Krumbein (1994) described a growth curve of fungal microorganisms in three phases. The first two phases are defined as the growth of mycelium sections which can be called mushroom roots and formation of spores. The next phase is the spore multiplication. Preventing the formation of spores of microorganisms is important to prevent biological degradation. The duration of spores depends on T and RH values. To determine the limit values, the lowest isopleth for mold (LIM) curve is used.

Figure 2.3 shows mycelium growth and spore multiplication (Sedlbauer et al., 2001, Sedlbauer et al., 2003). The upper part of the curve shows that the medium is suitable for mold growth. This also indicates that the medium with low T and RH values is safe for mold growth. In addition, a diagram of the classification of substrates was developed in the estimation of mold formation on the surface of the material (Sedbauer et al., 2001). It is examined for three groups as optimum culture medium, biologically recycable building materials and biologically adverse recycable building materials.

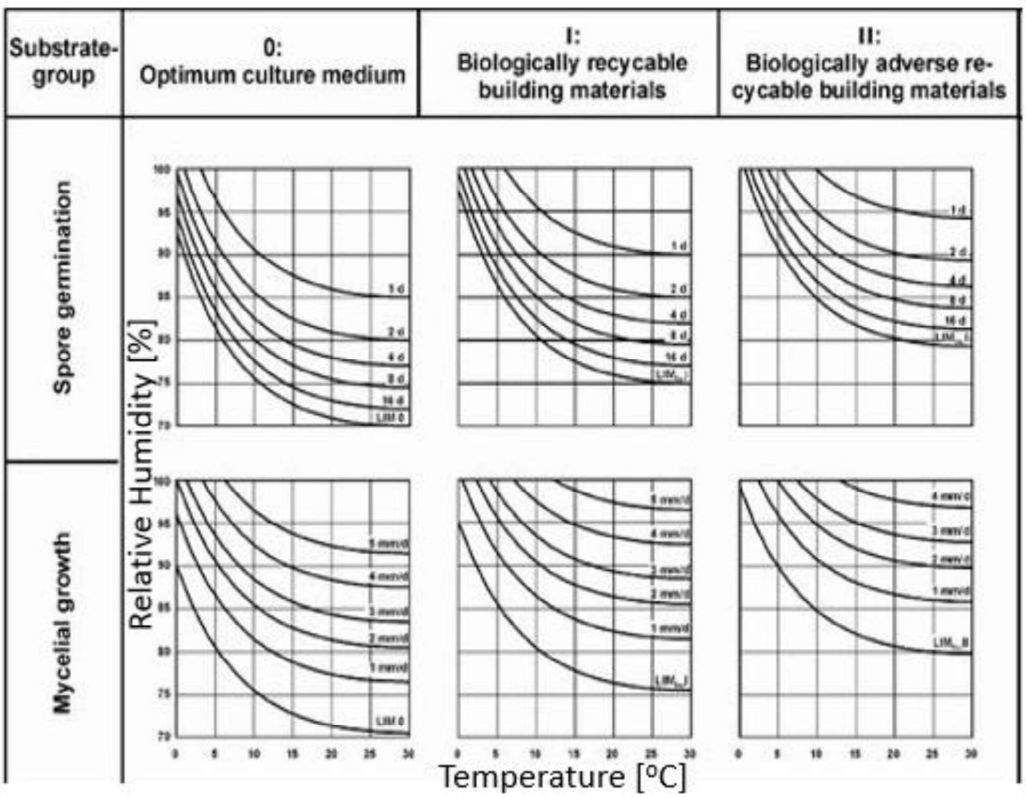


Figure 2.3. Mycelium growth and spore multiplication (Source: Sedbauer et al., 2001).

2.3. CFD Modelling

The CFD model is a form of modelling based on solving the volume to be examined by dividing it into sub-volumes. The process is called the meshing process and it can be accomplished by using several geometrical volumes like hexagonal and tetrahedral. Then, using the processor of the computer used, the mass, momentum, and energy conservation equations are solved for each volume. In addition, more detailed results are obtained compared to natural ventilation mathematical models. As an example, CFD codes are used to solve air flow rate, temperature, and airflow patterns in indoor and outdoor air volumes of buildings and many software such as Fluent, Phoenics, and Flovent have been developed by using these codes (Asfour and Gadi, 2007).

The use of CFD modelling has increased steadily over the past two decades to investigate indoor environmental conditions (T, RH, etc.) (Nielsen et al., 2007). Furthermore, articles investigating ventilation conditions by using CFD analysis have increased significantly since 2006. Low cost of CFD analysis and its ability to solve partial differential equations calculating air T, RH and velocity (v). The CFD analysis has been in use for over thirty years, but it continues to be improved for faster, more reliable and accurate results (Chen, 2008).

The CFD analysis is also used for indoor environmental conditions of historic buildings. It is a way to observe the impact of different scenarios on indoor environmental conditions. It is also essential in volumes where it is difficult to take direct measurements since it makes it possible to analyze thermo-hygrometric parameters of the entire volume (ASHRAE, 2011).

Although studies on historic buildings are increasing (Figure 2.4), the CFD analysis is not prevalent on these studies (D'Agostino and Congedo, 2014). In these studies, the effect of openings in Domus Aurea in Rome was examined by CFD analysis (Albero S. et al., 2004). In another study, it was investigated whether if it is possible to protect the Crypt of Lecce Cathedral by natural ventilation. The CFD analysis and possible solution suggestions were made and moisture analysis was performed (D'Agostino and Congedo, 2014). The CFD analysis of the Senate Room at Palazzo Madama in Turin was performed. Mechanical ventilation was tried to be optimized. Especially in the research conducted for the exhibition area, alternative scenarios that provide the best microclimate effect were evaluated (Corgnati and Perino, 2013). Balocco and Grazzini (2009) also used CFD analysis to observe the airflow to examine natural ventilation scenarios that could be used in the historic Marchese Building in Palermo. Furthermore, Papakonstantinou et al. (2000), used CFD analysis for thermal comfort and pollutant concentration analysis for the Hall of the National Archaeological Museum of Athens in their study.

72% of the work on historic buildings is for energy saving and thermal comfort. The study for building and artwork conservation is 20% (Figure 2.5). Based on the author’s knowledge, no CFD analysis has been performed on ventilation strategies to decrease degradation risks on paper-based collections in historic buildings.

The CFD analysis can be performed in two or three dimensions in indoor air examination. However, two-dimensional modelling does not provide a realistic airflow simulation, since using room ventilation problems does not take into account some of the events that determine airflow characteristics, such as air flow separation on sharp edges. Nonetheless, the solution time is undoubtedly reduced (Asfour and Gadi, 2006). Moreover, the CFD analysis can be applied with two approaches: The Large Eddy Simulation (LES) and Reynolds-Averaged Navier-Stokes Equation (RANS). LES approach provides an elegant agreement with the measured data, in terms of the mean

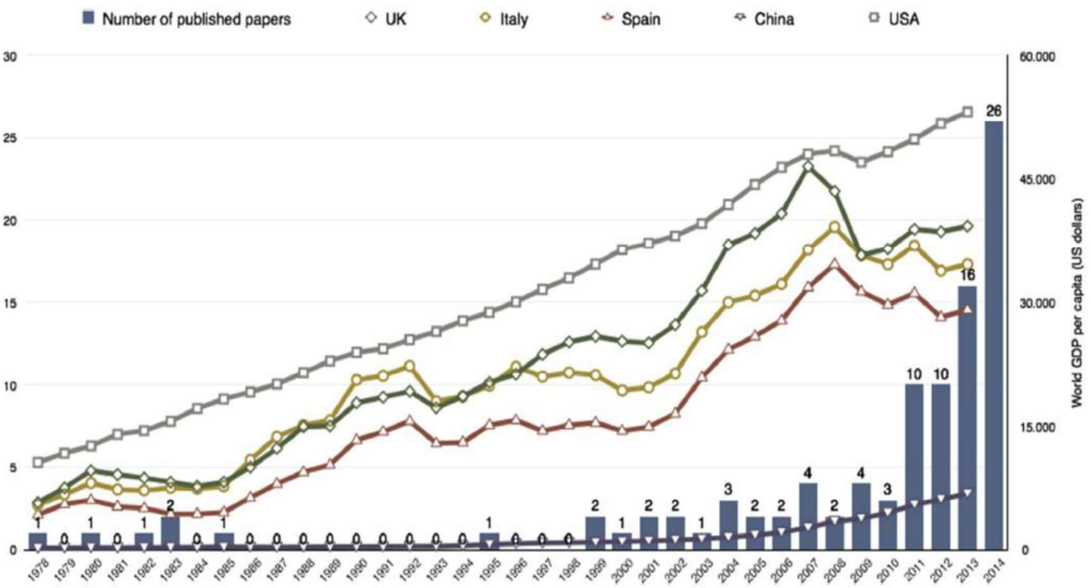


Figure 2.4. Number of publications of historic buildings on some countries (Source: Martínez-Molina et al., 2016).

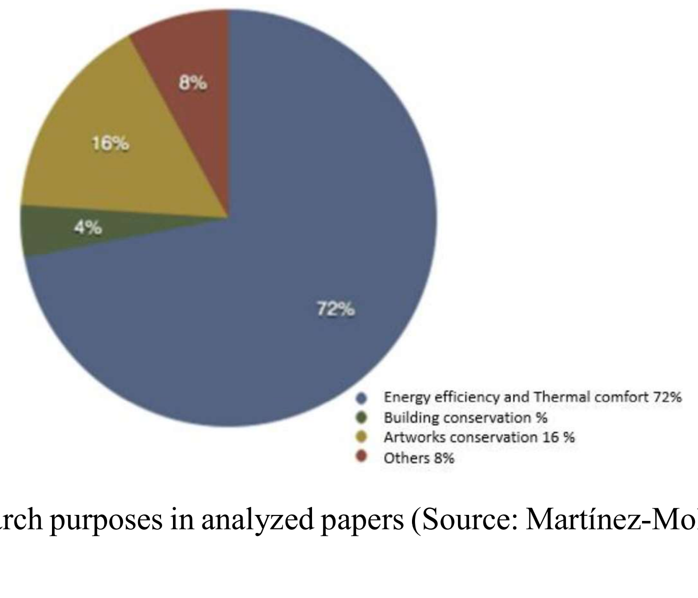


Figure 2.5. Research purposes in analyzed papers (Source: Martínez-Molina et al., 2016).

velocities, flow pattern (jet direction), and turbulent kinetic energy. Nevertheless, LES approach is more strenuous on the computer compared to RANS. When using RANS approach for the same model, it takes less than 12 hours, while LES can take up to 40 days (Hoff et al., 2017). Liu, et al., 2009, states that using LES approach limits computer memory and computing speed during the analysis for large and complex models. Therefore, they suggests that RANS approach should be used. In addition, k-ε and k-*w* turbulence models are used in CFD analysis. However, Awbi (1991) states that it would be reasonable to use the k-ε model for ventilation problems in buildings.

2.4. Natural Ventilation

Buildings are ventilated naturally or mechanically. Mechanical ventilation is simply air supply from outside to inside of the building through a fan and the discharge of air from inside to outside. The advantage of the system is the control of ventilation for the desired conditions. Natural ventilation is the movement of the air from the building openings by the pressure difference of the wind or the stack effect caused by the indoor and outdoor air temperature difference. Wind speed, direction, and air temperature parameters affect natural ventilation. Any openning that acts as the inlet and outlet for air in the building structure is also effective (BS5925, 1991.). Schulze and Eicker (2013) in their study of natural ventilation control, have two main functions of natural ventilation to ensure good indoor air quality without energy input; and improving thermal comfort by increasing daytime air v and night ventilation. The disadvantage is that it is difficult to recover heat in winter; the advantage of the summer months by increasing the rate of ventilation without cooling is stated. Results of the study show that between 13-44 kWh/m2 cooling net energy saving per year for Stuttgart, Turin and İstanbul can be achieved with well-designed natural ventilation (Schulze and Eicker, 2013).

The openings used for ventilation can be classified in many ways; however, two broad categories can be defined. These are purpose-provided (PPO) and adventurous openings. The openings that can be controlled in ventilation such as ventilation openings, windows and existing openings for ventilation purposes are PPO openings. Determination of the size and location of these openings is the main purpose of the ventilation design. Adventurous openings are cracks and unintended openings in the building. They are generally small and are difficult to define. Adventurous openings are undesirable openings for ventilation systems (Etheridge, 2012).

One of the natural ventilation methods is stack ventilation. Stack ventilation is the use of indoor and outdoor temperature differences. When the indoor temperature is higher than the outdoor temperature, it rises and exits through the openings. This is replaced by colder and dense air from below. While the effect of this method increases at low wind speed, it decreases as the temperature differences decrease in summer months (Khan et al., 2008).

Wind-driven ventilation is another natural ventilation method. Many studies have been conducted on this subject (Peren et al., 2015; Papakonstantinou et al., 2000; Shetabivash, 2015; Chu et al., 2015). Ventilation through openings using pressure differences caused by wind around the building (Chu et al., 2015). Wind-driven ventilation can be controlled through window openings. Aperture directions and location design are important for this ventilation method (Shetabivash, 2015).

Natural ventilation studies date back to the 1940s (Kotani, et al.,2009). Moreover, natural ventilation in buildings has been investigated in many areas (Santamouris et al., 1996; Allard and Santamouris, 1998; van Paassen et al., 1998). Historic buildings are also one of these topics. Fabbri and Pretelli (2014) examined indoor environmental conditions of the Malatestiana Library in Cesena, Italy, with no HVAC system. They criticized the prioritization of human-oriented thermal comfort in this library. In the determination of ventilation scenarios in historic buildings, they said that they should be designed with a focus on the conservation of buildings and artifacts, not humans. They stated that the visitor and employee oriented ventilation approach should be overturned in these buildings and focused on building and collection.

CHAPTER 3

CASE STUDY: THE NECİP PAŞA LIBRARY

The location of the library is given in Figure 3.1. It consists three zones: Manucript, Main Hall ad Entrance zones (Figure 3.2). Entarence zone is located front of the building. Main Hall zone has a dome, large stone wall (beetweeen 1.16-1.25m) and main part of the building. Inside of the Main Hall zone, there is Manuscript zone which has wooden wall. Most of valuable and ancient paper-based collections located in that zone.

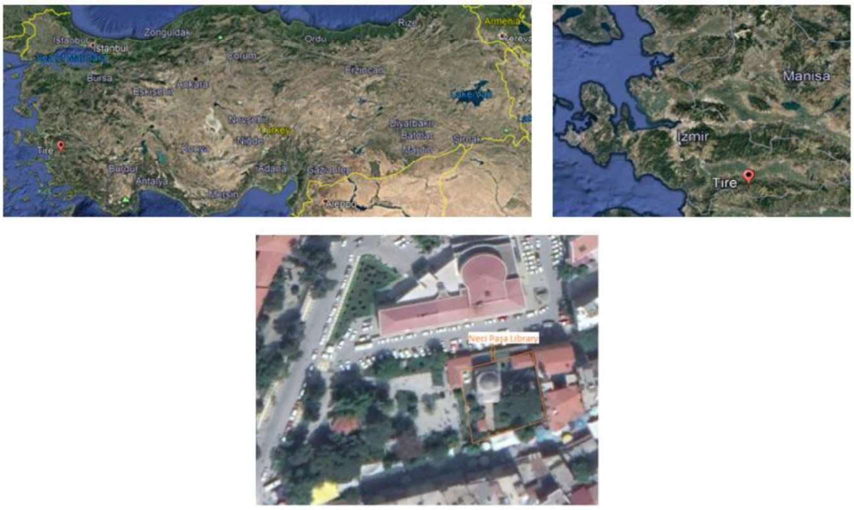


Figure 3.1. The location of the Library (Source: Google Earth Pro, 17.04.2018).

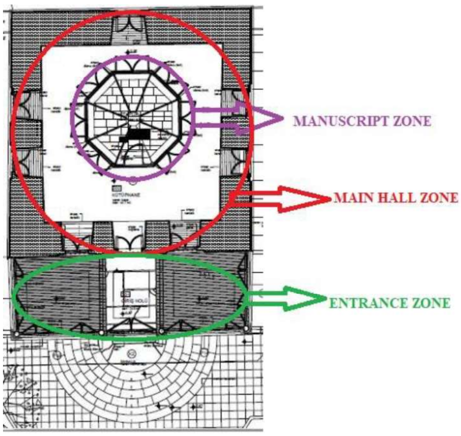


Figure 3.2. Zones in of the Library.

3.1. History of the Building

The Necip Paşa Library was built in 1827, when Tire was filled with educational institutions such as madrasahs and primary schools (Bayraktar, 2003). According to the story, Georgian Mehmed Necip Paşa accompanying Şanizade Mehmed Ataullah Efendi's (Ottoman historian and physician, He was exiled to Tire by Mahmut II. Although he was forgiven he died of a heart attack in Tire in 1826, because the message was transmitted as the execution order by mistake) journey from Istanbul to Tire, he was very pleased when he saw young people sitting under a tree reading a book in the courtyard of the İbni Melek Medresesi-Tire which was still standing at that time. The professors and the students explained that they did not have enough books. Then, Necip Paşa founded a library in 1827 with books of his personal library of Necip Paşa (Daş, 2019).

The documents found in the archives of the General Directorate of Foundations indicate that Necip Paşa founded the library while he was Minister of Baruthanos. Necip Paşa, who has several foundation studies, is a well-known statesman for the governor of Damascus and Baghdad (Bayraktar, 2003).

In the library, there are 1147 manuscripts, 1135 books printed during the Ottoman Empire and more than 9000 books written in Latin letters. Necip Paşa allocated 671 books to the library. Moreover, the library has about 13,000 books in total (Yıldırım, 2011).

The construction of the Necip Paşa Library coincided with the rapid growth of the library structures in many provinces and even in the Anatolian districts during the reign of Sultan Mahmud II. Necip Paşa Library has a main structure consisting of a single room covered with a square dome designed as a reading hall and book store. There is also an entrance section. Due to these features, the library is evaluated in the group of detached libraries. In the detached library group, Köprülü Library (1661) in İstanbul - Çemberlitaş, which was accepted as first detached library, Amcazade Hüseyin Paşa (1700) in İstanbul-Saraçhane, Ahmediye (around 1722) in İstanbul-Üsküdar, Damat İbrahim Paşa (1719-1720) in İstanbul_Şehzadebaşı, Hekimoğlu Ali Paşa (1734-35) in İstanbul-Koca Mustafa Paşa and Raşid Efendi (1797) in Kayseri are in the group of detached libraries (Bayraktar, 2003).

The Necip Paşa Library is located in a walled courtyard near a madrasa. It is designed on a high platform for prevention of moisture. The wall material is cutting stone-brick. As precaution against fire and theft, the door wings of the Mainhall where the books are located are made of iron. and the windows are protected with iron grids. Because of these features, the library carries the characteristics of traditional Turkish architecture (Bayraktar, 2003).

3.2. Previous Study in the Library

The Necip Paşa Library-Tire-İzmir-Turkey is modelled and monitored (T and RH) for one year (September 2014-2015) based on the call of the Directorate General of Foundations of Turkey before it undergoes a restoration work (10 months) and during two months period of restoration (Coşkun, 2016). Since the Library houses valuable manuscripts, it was crucial to evaluate indoor environmental conditions for degradation risks on manuscripts. Measured T and RH values are given in Figures 3.3-3.4 The restoration of the library started at the beginning of July 2015. This region is particularly indicated in the figures. While T and RH fluctuations are high due to the size of the wooden frames in the Entrance zone, the fluctuations in these values for the Main Hall and Manuscript zone are negligible as the thickness and thermal mass of Main Hall exterior walls are high (Coşkun, 2016).

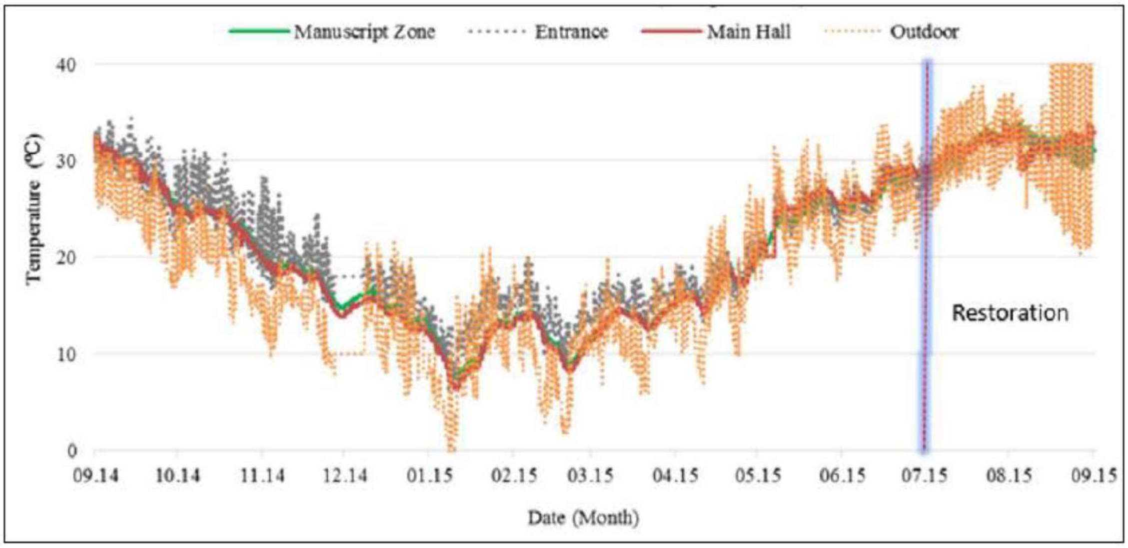


Figure 3.3. Hourly indoor and outdoor T measurements (Source: Coşkun, 2016).

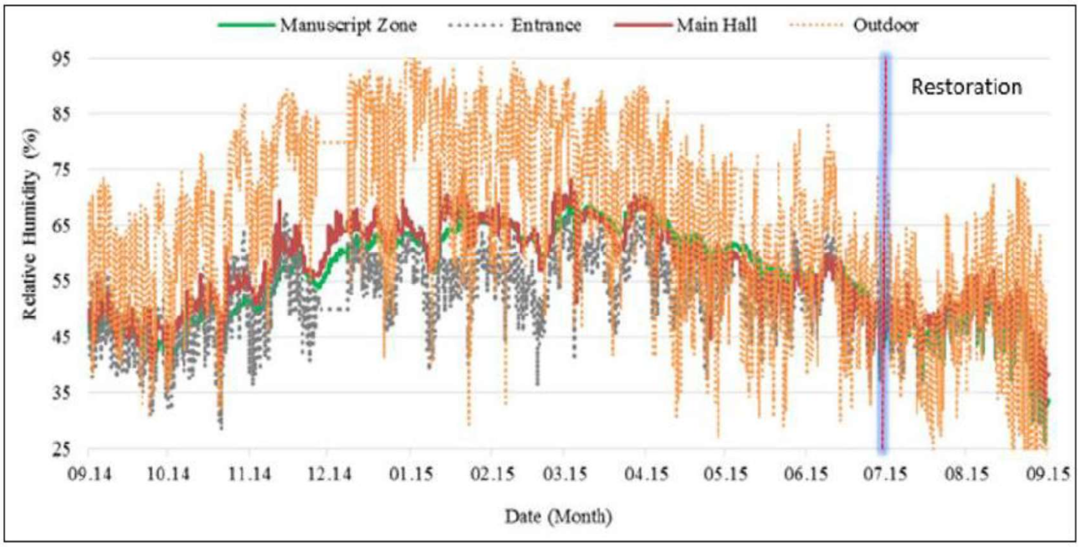


Figure 3.4. Hourly indoor and outdoor RH measurements (Source: Coşkun, 2016).

3.3. Degradation Risk Analysis

Coşkun (2016) evaluated measurements for mechanical, chemical and biological degradation risk potential in Manuscript and Main hall zones. He concluded that existing indoor environmental conditions have no mechanical and biological risk while chemical degradation risk potential exists for a certain period of the year.

Calculated LM data during measurement period are shown in Figures 3.5-3.6. While there is no risk of chemical degradation between December and April, a moderate risk level is observed in November. Between September-October and May-June, the risk of chemical degradation is high.

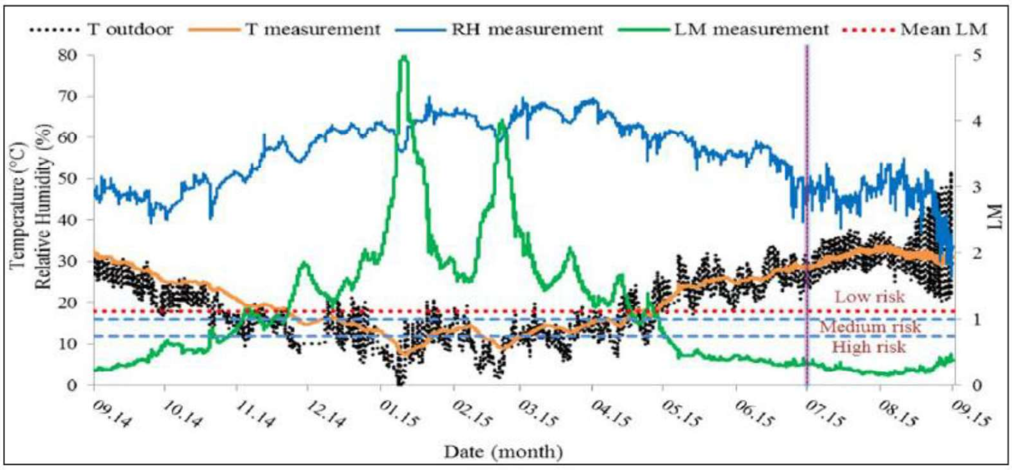


Figure 3.5. Chemical degradation risk analysis in the Manuscript zone (measurements): LM method (Source: Coşkun, 2016).

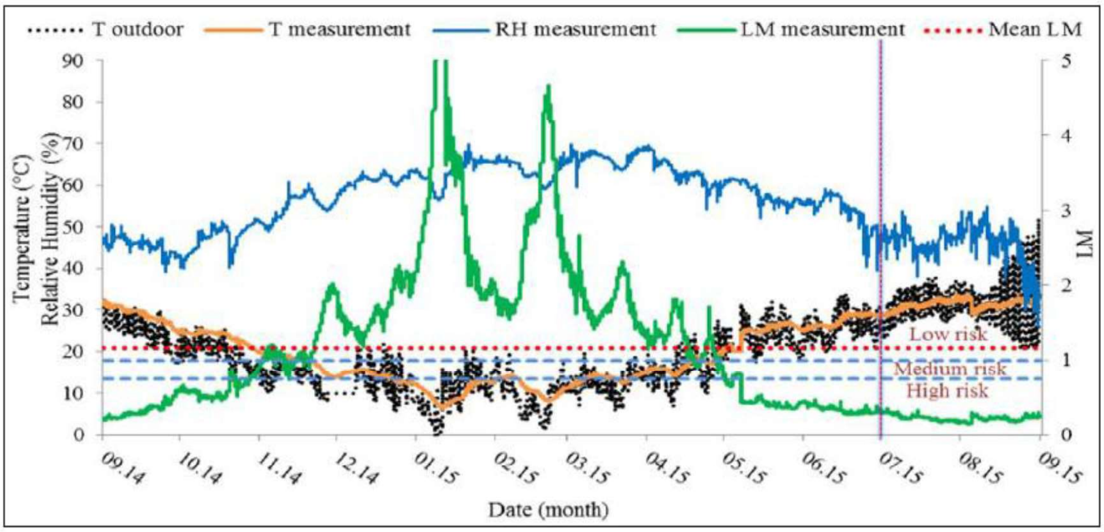


Figure 3.6. Chemical degradation risk analysis in the Main Hall zone (measurements): LM method (Source: Coşkun, 2016).

CHAPTER 4

MATERIALS AND METHODS

The flow diagram of the methodology is in Figure 4.1. First step is to take T and RH measurements which are taken from the previous study in the Library conducted by Coşkun's (2016). Second step is to develop a CFD model to observe the effects of natural ventilation on decreasing the chemical degradation risks. Then this model was validated by comparing its results with the measurements. Various natural ventilation scenarios are developed and the scenarios are analysed by the validated model. The model results were used to calculate LM values that give chemical degradation risk level. Finally, all scenarios are compared based on decreasing chemical degradation level and recommendations are given.

4.1. Model

Firstly, the library was modelled as a solid model by SolidWorks Software (Figure 4.2a) using actual dimensions taken from the architectural project of the building. However, some transitions in the solid volume were further softened to facilitate the passage of mesh volumes will be used for CFD analysis. The walls of each zone of the library were modelled separately and then assembled.

The resulting solid volume was then transferred to the SpaceClaim Direct Modeller (SCDM) module in Ansys 17.1. In this module, three different fluid volumes were created by taken reference to the solid volumes (Figure 4.2b).

The model containing the solid and fluid volume was transferred to the DesignModeller (DM) module of Ansys Software. The surface conditions were determined for the boundary conditions and CFD analysis inputs. Solid and fluid volumes were modelled as bodies under a single part to provide mesh topology and to recognize heat conduction from solid volumes to fluid volumes as well as heat convection on solid volumes during CFD analysis.

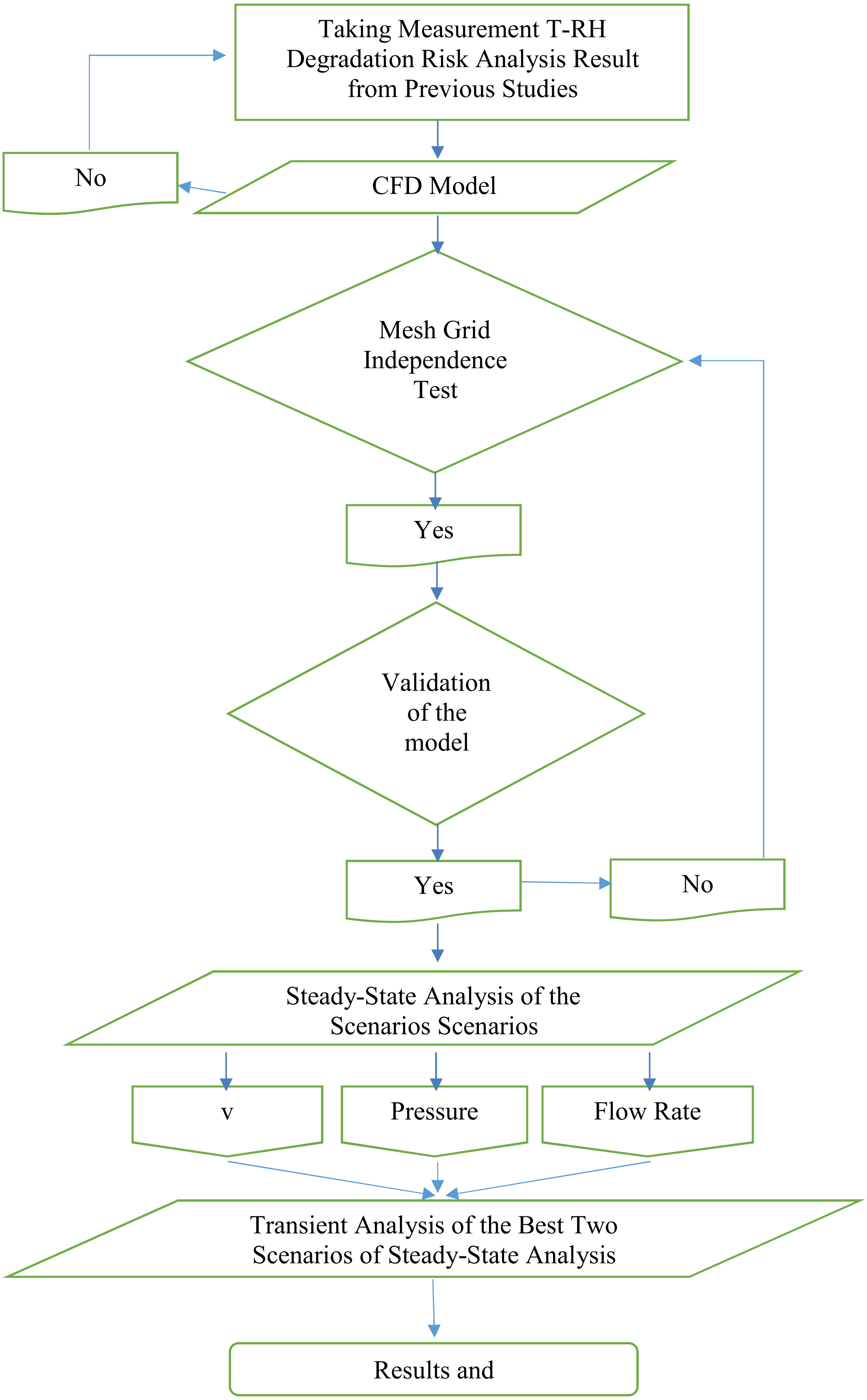


Figure 4.1. Flow diagram of the methodology

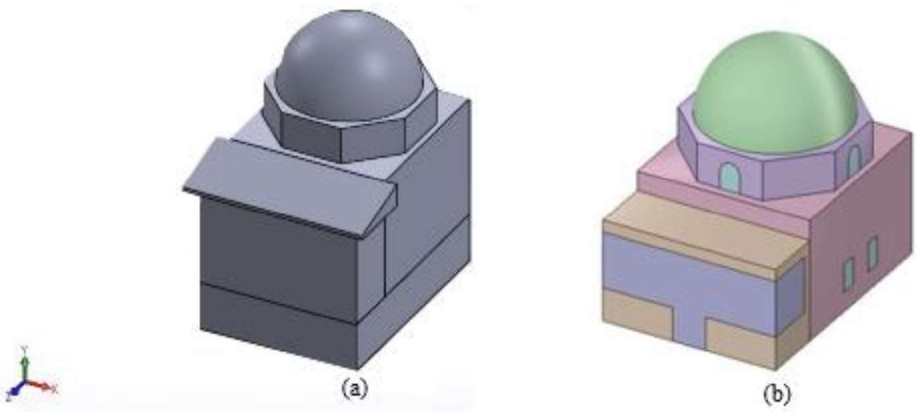
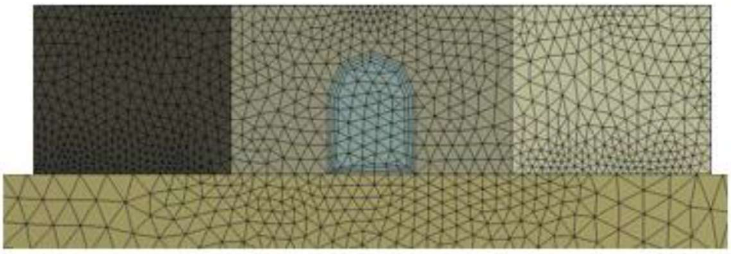


Figure 4.2. (a) SolidWorks model, (b) SCDM model.

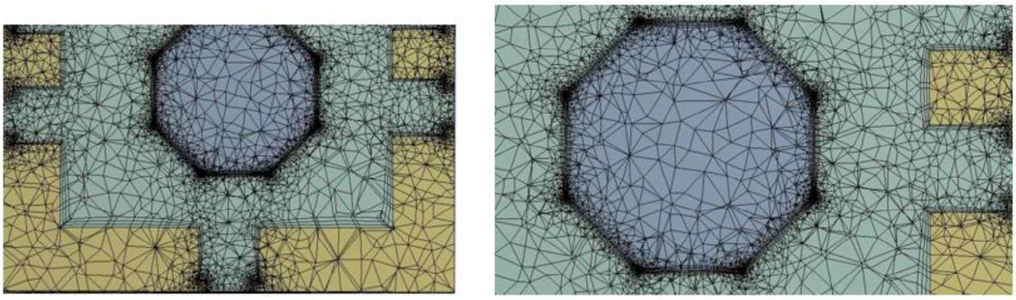
Once the model and naming were completed, the meshing process was applied. During the mesh, on the volume-to-wall boundaries, inflation was applied as much as possible (Figure 4.3); but because of some geometric constraints, it could not be applied to all boundaries. Body sizing for solid and fluid bodies was entered separately. Curvature and proximity have been chosen as a size function to ensure that the meshes are sensitive to sharp and rounded corners. High smooth translation was chosen to make the transition as smooth as possible.

4.1.1. CFD Model

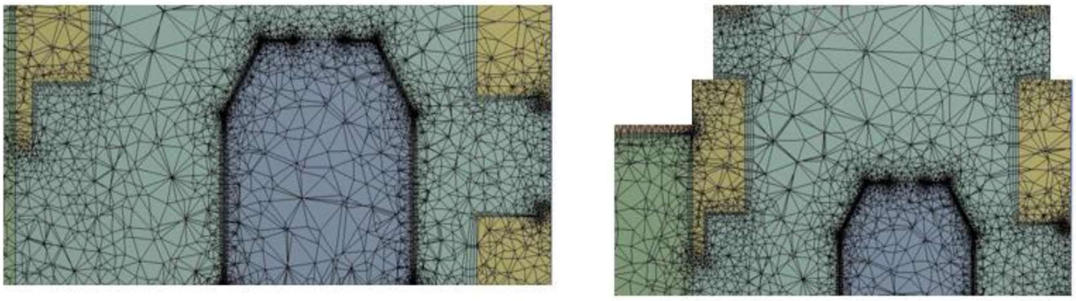
The CFD model was solved with the Fluent module in Ansys 17.1. Twenty parallel processors were run to make the solution faster. In the module with the mesh details, the gravitational acceleration was defined to take into account the buoyancy effect. For the mesh independence and validation analysis, steady-state analysis was chosen for the flow volume to initialize and transient analysis was applied. On the other hand, ventilation scenarios were analyzed by steady state analysis to compare the effect of scenarios on chemical degradation risk, regardless of time. The pressure-based analysis was performed because the pressure difference was more effective. The energy equation was also solved and k-ε model was used to observe turbulence effect. Since wall type of the building are different (Figure 4.4), they were modelled separetely. Individual material were defined for each solid volumes (Table 4.1).



(a)



(b)



(c)

Figure 4.3. Inflation (a) on windows, (b) on Main Hall zone and Manuscript zone on XZ Plane, (c) on Main Hall zone an Mauscript zone on YZ Plane.

Figure 4.4. Wall types of the library.

Table 4.1. Material properties.

	Main Hall zone	Manuscript zone	Dome	Glass	Entrance zone	Floor
ρ [kg/m^3]	2160.000	510.000	1702.390	2579.000	510.000	1711.224
Cp [J/(kg.K)]	736.448	1000.000	822.023	840.000	1000.000	873.469
k [W/(m.K]	1.031	0.300	0.825	0.960	0.300	1.299

To observe the effect of moisture transfer, the species transport equations were inluded in the numerical solutions. The flow volume was defined as water vapor and air. The change in air and water vapor densities according to the temperature change was defined as an incompressible ideal gas. The fluid, thermal conductivity and viscosity values of air and water vapor were defined as mass-weighted-mixing-law to be sensitive to mass transport. The governing equations are listed below:

$$\frac{\partial \bar{u}_i}{\partial x_i} = 0 \tag{3.1}$$

$$\frac{\partial \overline{u_i u_j}}{\partial x_i} = \frac{1}{\rho}\frac{\partial \bar{p}}{\partial x_i} + \frac{\partial}{\partial x_j}\left(v\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_i}{\partial x_i}\right)\right) \tag{3.2}$$

$$\frac{\partial k\bar{u}_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{v_t}{\sigma_k}\frac{\partial k}{\partial x_i}\right) + v\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_j}{\partial x_i} - \boldsymbol{\varepsilon} \tag{3.3}$$

$$\frac{\partial \boldsymbol{\varepsilon}\bar{u}_i}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\frac{v_t}{\sigma_{k\boldsymbol{\varepsilon}}}\frac{\partial k}{\partial x_i}\right) + C_{1\boldsymbol{\varepsilon}}\frac{\boldsymbol{\varepsilon}}{K}v\left(\frac{\partial \bar{u}_i}{\partial x_j} + \frac{\partial \bar{u}_j}{\partial x_i}\right)\frac{\partial \bar{u}_j}{\partial x_i} - C_{2\boldsymbol{\varepsilon}}\frac{\boldsymbol{\varepsilon}^2}{K} \tag{3.4}$$

$$v_t = C_\mu \frac{K^2}{\varepsilon} \tag{3.5}$$

The equations show continuity (3.1), momentum conservation (3.2), turbulent kinetic energy (3.3), energy dissipation rate (3.4), and turbulent viscosity (3.5), respectively. The turbulent viscosity is calculated in terms of k and ε. Table 4.2 shows the constants values used in the governing equations (James and Chun-Ho, 2010).

Table 4.2. Constant Values for Governing Equations

$C_{1\varepsilon}$	1.44
$C_{2\varepsilon}$	1.92
C_{μ}	0.09
σ_k	1
$\sigma_{k\varepsilon}$	1.3

Then CFD model boundary conditions were uploaded for mesh grid independency test and validation. Maximum RH difference observed time was May 7th at 15:00 and 16:00 for Manuscript zone according to the measurement. Therefore, initial and boundary conditions applied for May 7th at 15:00 (Table 4.3). One-hour transient model was used for these two steps. Since outdoor T ad RH values reported as hourly, model results also should be hourly to be able to compare with measuments.

Table 4.3. Initial and boundary conditions for mesh grid independence test and validation model May 7th at 15:00.

Initial Conditions		
	RH [%]	T[K]
Main Hall zone	53.94	298.32
Manuscript zone	60.81	297.68
Entrance zone	50.19	299.62
Boundary Conditions		
		T[K]
All outside wall surface		304.76
All outside glass surface (windows)		304.76

Moreover; T, RH results were discussed before. V is another important parameter for the Thesis. On steady-state analysis v is the on of the main parameter. Therefore; T, RH and v values investigated for mesh grid independency; therefore, one-hour transient analysis was applied for this step to observe T and RH with changing mesh size. Only the indoor environmental conditions were uploaded because the purpose was to get the initialized environment for validation and confirmation mesh independency. Although it is not exactly known that windows and doors are open or closed during the measurement it is assumed that all are closed based on the information given by the employees. The solution method was applied as Coupled Scheme. The equations order were selected as second-order-upwind. To reduce compuational cost and get more stabilised initial value, first 100 iterations were run as steady state analysis.

The results obtained from the steady-state analysis were appointed as the initial conditions of the transient-analysis. The temperature value was taken from the outdoor T measurements. The values to be recorded were T, RH, H_20 mass fraction and air v. Time step was entered as one second and one-hour analysis results were obtained.

For the scenarios, steady-state analysis was applied to reduce computational cost and investigate to eleminate scenarios according to mass transport. For two scenarios which have the highest mass transport from Manuscript zone to Main Hall zone according to steady-state analysis, 30-minute transient analysis was applied to observe LM results. Based on the mesh independence and validation model, first steady-state analysis was applied to initialize. In steady-state analysis as initilisation, windows were closed and scenarios applied in transient-analysis, because initilisation was applied to observe the air conditions before applying scenarios. Then, boundary conditions were applyied according to the scenarios.

4.2. Natural Ventilation Scenarios

Chemical degradation risk was determined between May and October when outdoor T range was between 13.1 ºC and 47.7 ºC and RH range was 31.9-87.2%. To be able to define the most infuencing parameter on LM value, Figures 4.5 is given. The Figure exhibits the change of LM with T with respect to RH values and indicates that LM change with T at constant RH is insignficant but it increases with decreasing RH values. Therefore, T effect on LM values is ignored in the Thesis.

The important parameters on determining ventilation strategies are location and number of windows, height, wind direction and speed. The library has nine windoes which are shown in Figures 4.6-4.7. Seven scenarios were developed based on the open (O)/ closed (C) situation of windows and listed in Table 4.4.

Wind direction and speed were kept constant for all scenarios to see the effect of the window opening. For the summer period, the most frequent (1001 hour, 45% of the summer period) wind direction was determined as 275° - 265° by taking the northern

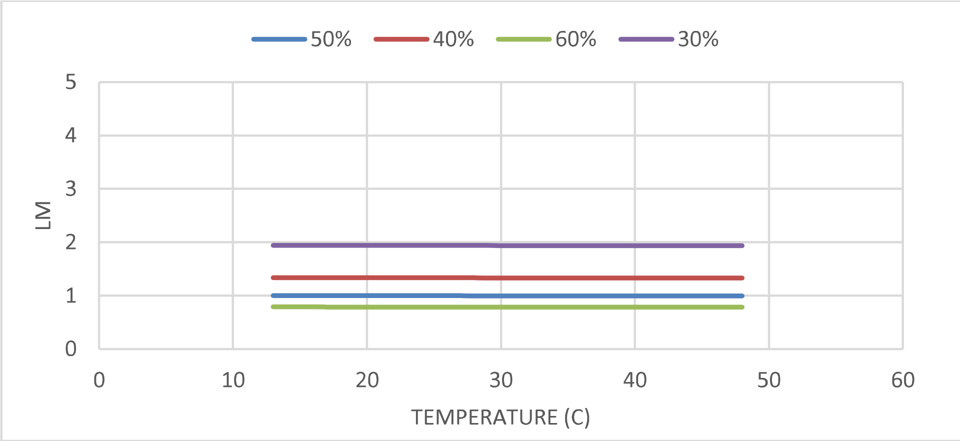


Figure 4.5. RH effect on LM Value depending on changing T.

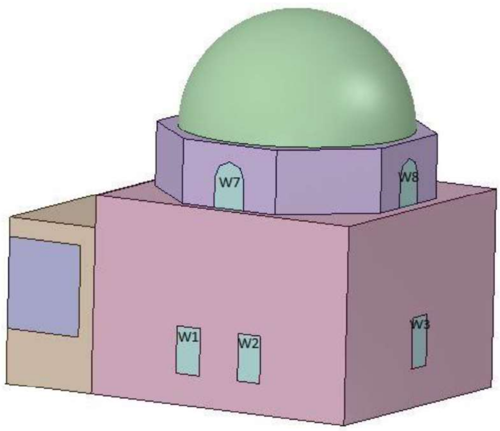


Figure 4.6. Western and southern facade windows of the Library.

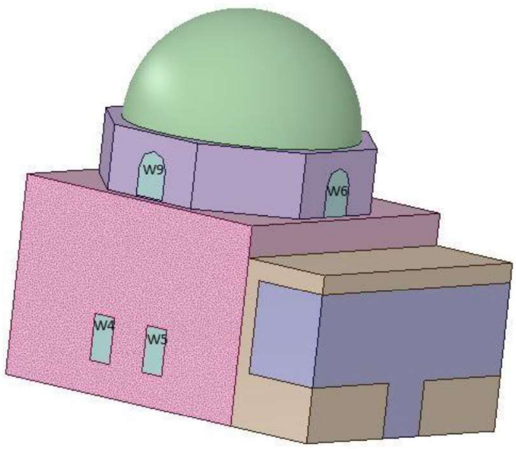


Figure 4.7. Eastern and northern facade windows of the Library.

Table 4.4. Natural ventilation scenarios of windows.

Scenario	W1	W2	W3	W4	W5	W6	W7	W8	W9
A	O	O	O	C	C	C	C	C	C
B	O	O	C	C	C	C	C	C	O
C	O	O	C	O	O	C	C	C	C
D	O	O	C	C	C	C	C	O	C
E	O	C	C	O	O	C	C	C	C
F	O	C	C	C	C	C	C	C	O
G	O	C	C	O	O	C	C	C	O

direction as 0º. For this reason, the wind direction was accepted as 270º (west to east). Summer period average wind speed (1.43m/s) is taken as v inlet boundary condition.

Since wind direction is assumed as west to east, the Main Hall zone windows (located below of the dome) on the western facade are taken as inlet because it was aimed to observe the effect of the same height windows and the higher windows on the dome.

4.2.1. Boundary Conditions

Wind speed is assigned as the inlet air v to the windows on the western facade to the normal. While outdoor air RH is assigned as 50%, in all zones, air Tand RH is defined as 25ºC and 60%, respectively. The closed windows are defined as walls and outdoor T is assigned as constant and given in Table 4.5.

Open windows other than western facade are defined as pressure outlet. Since outdoor air is not modelled, air flow through windows caused by pressure difference (resulting from the wind) is neglected (Table 4.5). The flow created by the pressure difference resluting from the air enterins (as v inlet) from western facade was examined.

4.3. Mesh Grid Independence

Mesh grid independence is important in terms of determining the optimum number of mesh in the model. Models were analyzed in different number of mesh (each with a ratio of at least 1.3). What is important during the process is to determine if the output data shows acceptable variability. Thus, the number of mesh which is selected is

Table 4.5. Initial and boundary conditions for the model.

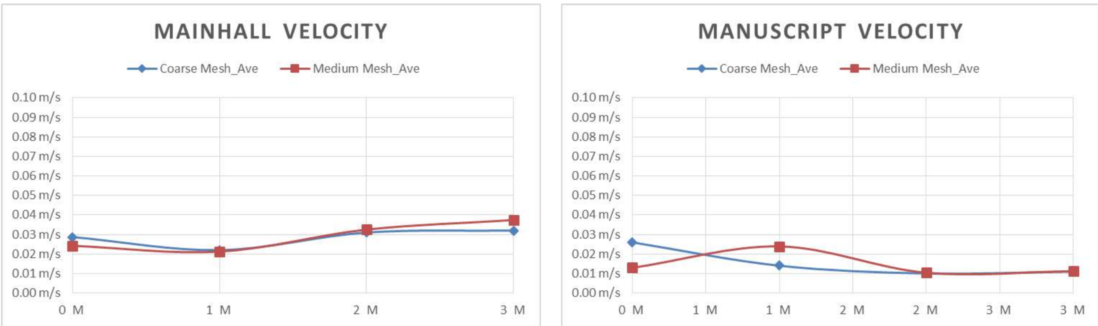
Initial Conditions			
		RH[%]	T[K]
Each zone-air		60	298.15
Each wall surface		-	298.15
Boundary Conditions			
	RH[%]	T[K]	v[m/s]
Inlet v-windows (W1-W2)	50	298.15	1.43
Windows defined pressure outlet	50	298.15	-

not a factor affecting the outputs of the model. The output data for the Thesis air T, RH and v. Therefore, while determining the number of acceptable mesh, models with two different mesh numbers are compared. Acceptable difference limit is selected as 2% for RH, 0.2 ºC for T and 0.1m/s for v. Average T, RH and v values on the surfaces of 0 m, 1m, 2m and 3m-height in the Manuscript and the Main Hall zones are compared. Since the manuscripts and other valuable books are kept in Manuscript and Main Hall zones, these are considered as the most critical zones for the scenarios. The model which has the appropriate mesh number is assigned and mesh grid independece test is applied on coarse and medium meshed models.

Coarse mesh model is analyzed with 3,218,226 elements. T and RH ranges are obtained as 297.8-304.8 K and 40.8-59.9%, respectively. The values are logical since boundary conditions of the model are maximum/minimum values are 304.8 K for max. T, 297.7 K for min. T, 59.8% for max. RH, 40,8% for min. RH general T and RH distribution can be see in Appendix A as T render view (Figure A.1), RH render view (Figure A.2)., v render view (Figure A.3), T distribution on Main Hall zone (Figure A.4), RH distribution on Main Hall zone (Figure A.5), v distribution on Main Hall zone (Figure A.6), T distribution on Manuscript zone (Figure A.7), RH distribution on Manuscript zone (Figure A.8), v distribution on Manuscript zone (Figure A.9).

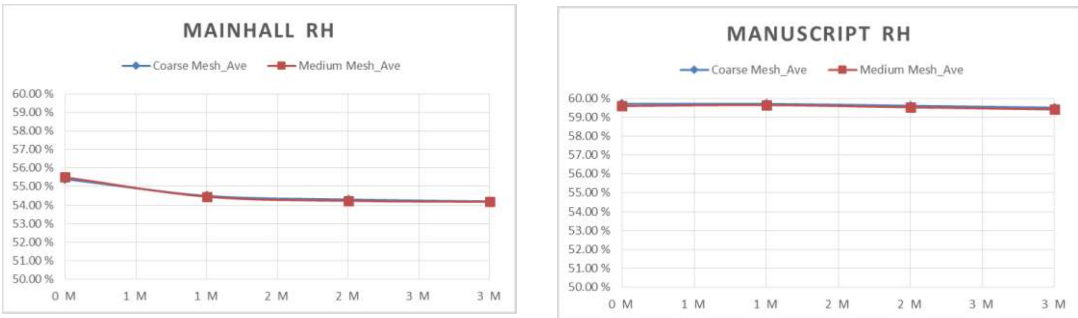
Medium mesh model is analyzed with 4,699,265 elements and gives very similar results with coarse mesh model. T and RH values change between 297.8-304.8 K and 40.8-59.8%, respectively. General T and RH distribution can be see in Appendix B as T render view (Figure B.1), RH render view (Figure B.2), v render view (Figure B.3), T distribution on Main Hall zone (Figure B.4), RH distribution on Main Hall zone (Figure B.5), v distribution on Main Hall zone (Figure B.6), T distribution on Manuscript zone (Figure B.7), RH distribution on Manuscript zone (Figure B.8), v distribution on Manuscript zone (Figure B.9).

The mean T, RH and v values in the Manuscript and Main Hall zones are compared in planes at planes at 0 m, 1m, 2m and 3m height relative to the ground (Figures 4.8-4.9-4.10). According to the results, in the Main Hall zone max. differences for v, RH and T are for Main Hall zone are 0.01m/s, 0.1% and 0.02°C and for manuscript zone are 0.01m/s, 0.11% and 0.07°C, respectively. The differences between two modelare within the limits of neglect previously determined. Consequently, it can be said that as long as the number of mesh is greater than 3,218,226, the result of the change in mesh number will change within acceptable limits. Coarse mesh model is showed in Figure 4.11.



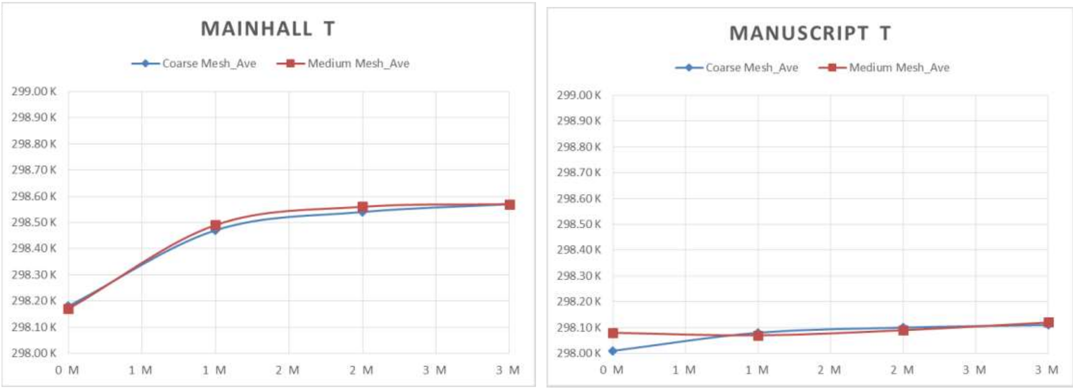
(a) (b)

Figure 4.8. Average v change with height on (a) Main Hall and(b) Manuscript zones.



(a) (b)

Figure 4.9. Average RH change with height on (a) Main Hall and (b) Manuscript zones.



(a) (b)

Figure 4.10. Average T change with height on (a) Main Hall and (b) Manuscript zones.

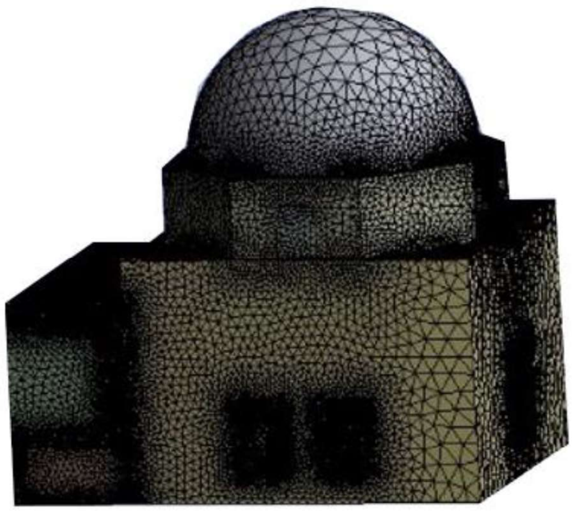


Figure 4.11. Mesh model.

4.4. Validation

The model is validated based on measured RH data since T is not significant on LM values.. Firstly, acceptable maximum difference RH is determined. The outdoor T is defined as boundary conditions on the exterior surfaces of the walls. One-hour time-dependent analysis is performed to compare RH model results. with the model for the Main Hall and Manuscript zones. Model is validated with an acceptance criteria 2% as mentioned before.

In Table 4.6, average model result and measured RH values at 1m for the Main Hall and Manuscript zones. measured values are compared with the average values of

1m in the model. The difference is 1.86% in Main Hall zone and 0.63% in Manuscript zone. Since the values are below the acceptable limit, the model is accepted as validated and scenarios are applied to the model.

Table 4.6. RH values comparison with analysis result and measured valaues.

	Relative Humidity [%]			
	Initial	Result_Ave@1m	Measured	Difference
Main Hall zone	53.94	54.45	56.31	1.86
Manuscript zone	60.81	59.64	60.27	0.63

CHAPTER 5

RESULTS AND DISCUSSION

The aim of the Thesis is to develop natural ventilation scenarios to decrease chemical degradation risk on paper-based collections in the Necip Paşa Library. Indoor and outdoor T and RH values of the Library are taken from Coşkun (2016). The CFD model of the Library is developed and validated with the measured data. Then, natural ventilation scenarios are applied to the model and the effect of each scenario is evaluated based on the decrease in degradation risks on the manuscripts.

5.1. Natural Ventilation Scenarios

The proposed natural ventilation scenarios were given in Table 4.4. Each scenario is applied to developed CFD model. While taking the results, both air changes in Manuscript zone were examined and the reasons for the results were observed. Therefore, the effect of the scenarios on the pressure difference that drives air movement has been observed in Main Hall and Manuscript zone. In order to interpret the pressure difference correctly, the planes where the pressure is examined are determined according to the midpoint of the openings given as pressure outlets in the scenarios. At the same time, the center plane is defined to observe the pressure difference for the Manuscript zone. This plane was used to observe both the change in the Manuscript zone and the change with the Main Hall Zzne. In the results taken to observe the pressure difference, the legend range is determined according to the minimum and maximum values of each scenario; because not the pressure value, but the pressure difference is important for the analysis.

Then, the v values were examined for the planes where pressure difference was examined. For v values, both magnitude and vector were examined. In the results obtained for v values, the legend interval was kept constant in all scenarios in order to ensure that the comparison was logical. Due to low-v values were observed, the legend range was set at 0-0.5m/s in the Manuscript zone, and 0-3m/s in the Main Hall zone.

Finally, in the scenarios, v magnitudes and vectors in the Main Hall zone at heights of 0.5m, 1m, 2m, 3mand 4m on XZ plane are examined (Figure 5.1). The legend range is kept constant at 0-3m/s.

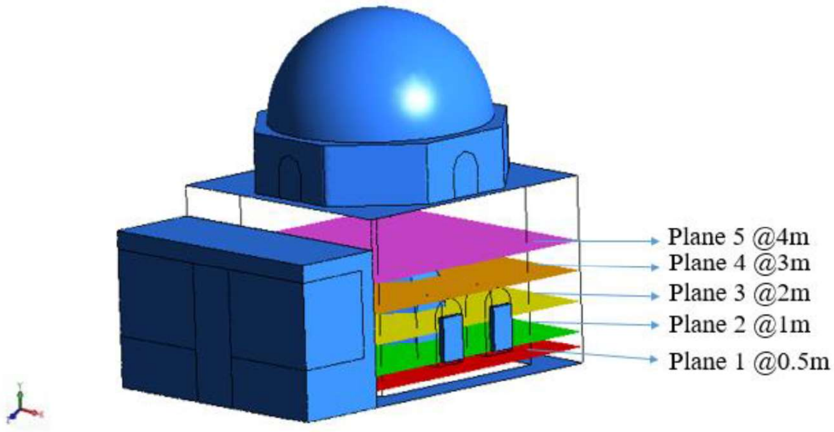
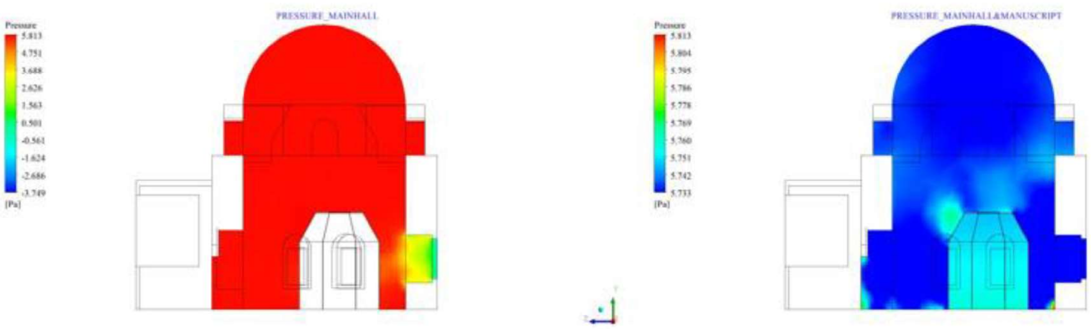


Figure 5.1. Plane locations on XZ plane

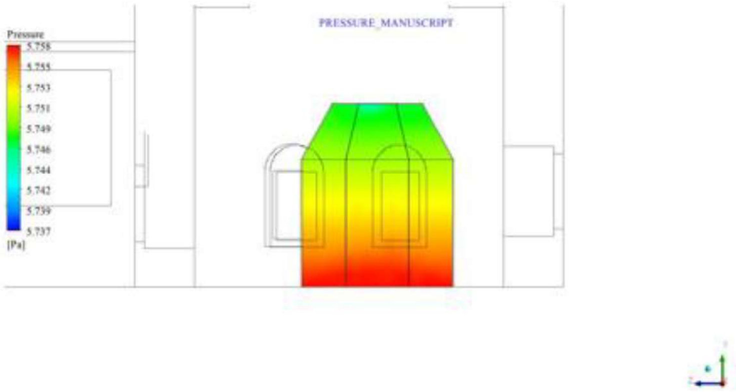
5.1.1. Scenario A

In Scenario A, air enters the building from W1 and W2 windows (western facade) and leaves from W3 window (southern facade) (Figure 4.7, Table 4.4). The aim of the scenario is to examine the natural ventilation effect of the windows on different directions and the same height. Figures 5.2 and 5.3 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.4 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

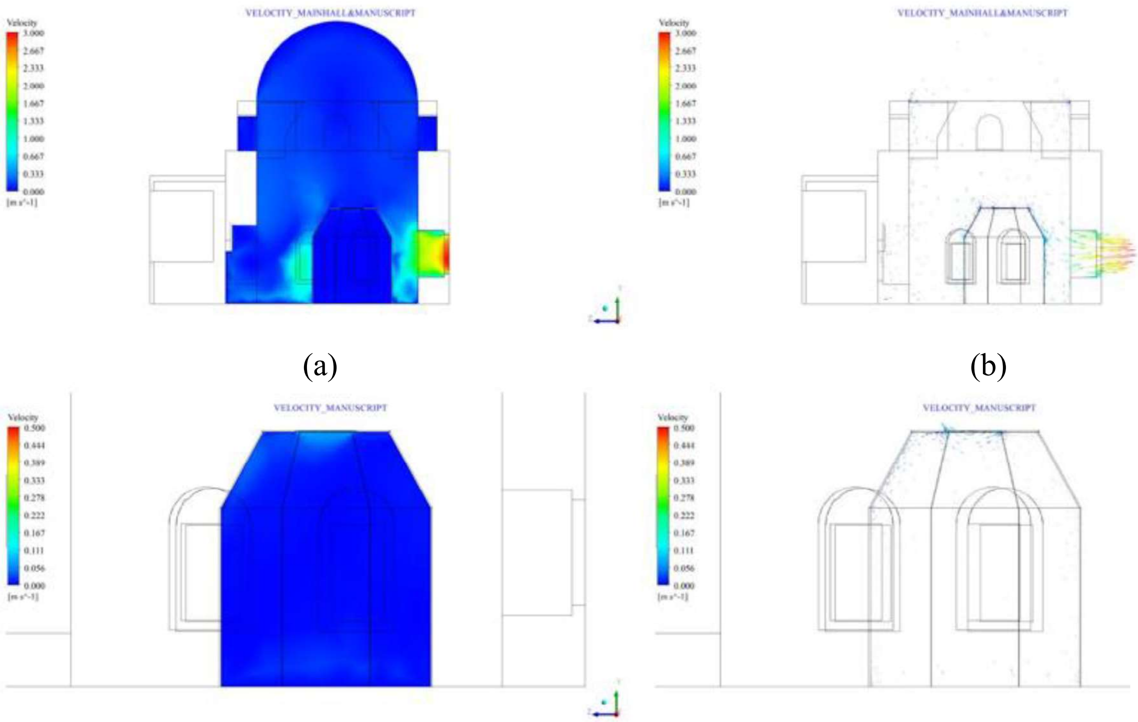


(a) (b)

Figure 5.2. Scenario A: Pressure contour on (a) Main Hall zone, (b) Main Hall and Manuscript zones together, (c) Manuscript zone on ZY Plane on the middle of the Manuscript zone (cont. on next page).



(c)
Figure 5.2. (cont.).



(a) (b)

(c) (d)

Figure 5.3. Senario A: (a) V contour and (b) v vector on Main Hall and Manuscript zones together; (c) v contour and (d) v vector on Manuscript zone on ZY Plane on middle of the Manuscript zone.

5.1.2. Scenario B

In Scenario B, air enters the building from W1 and W2 windows (western facade) and leaves from W9 (eastern facade) (Figure 4.8, Table 4.4). The aim of the scenario is

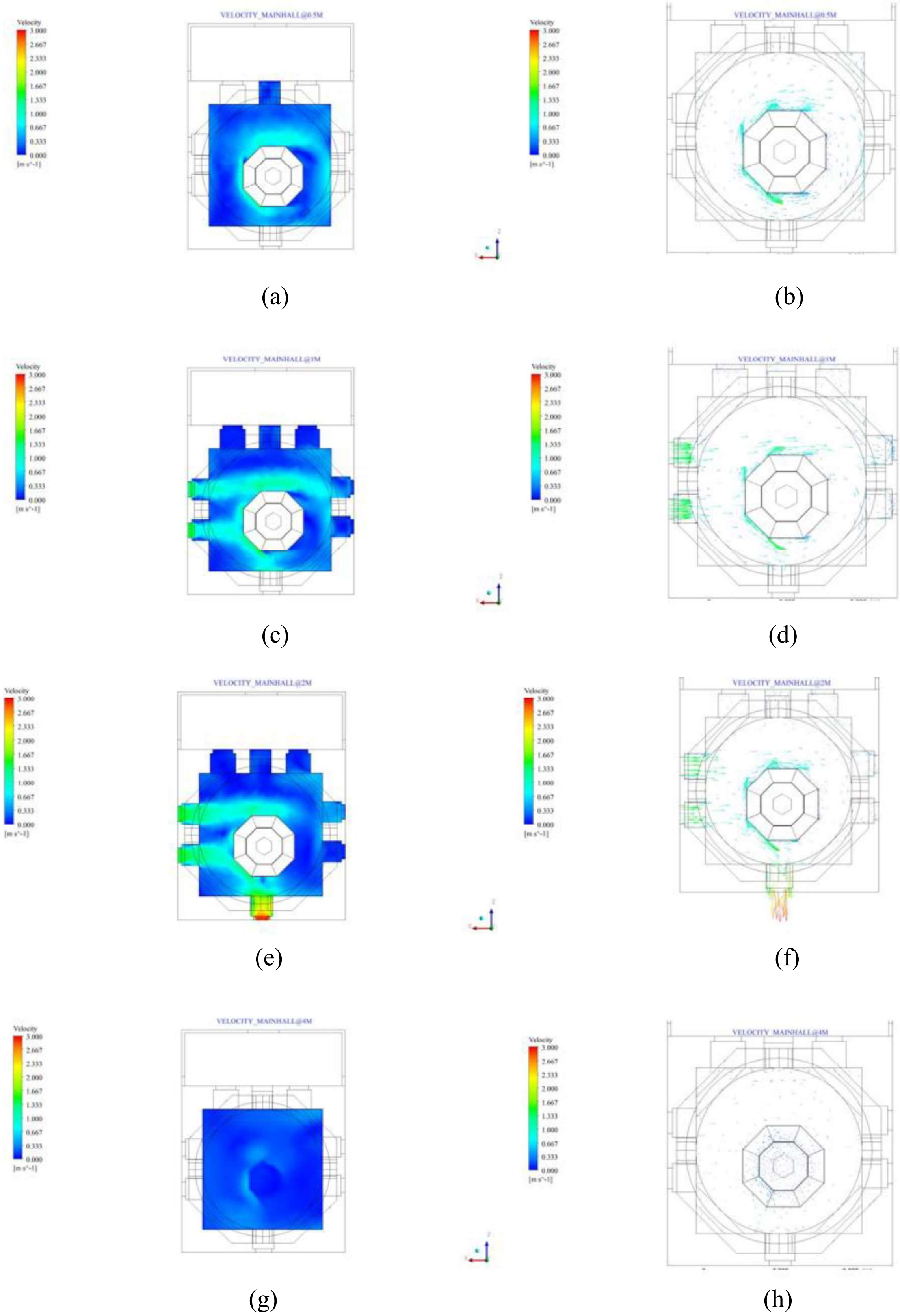
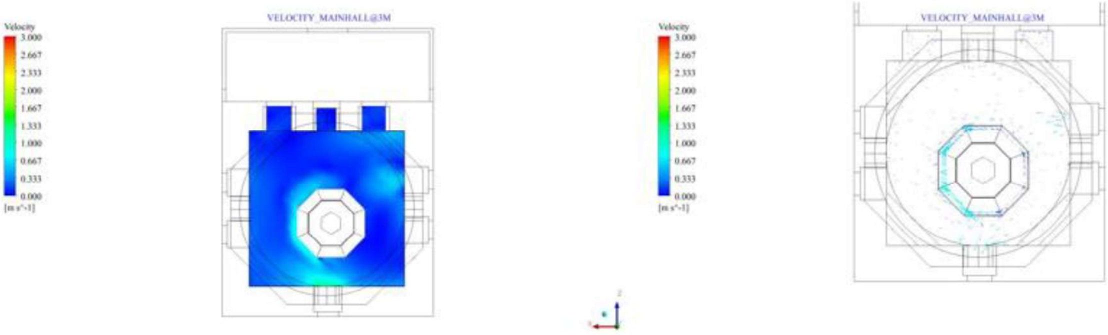


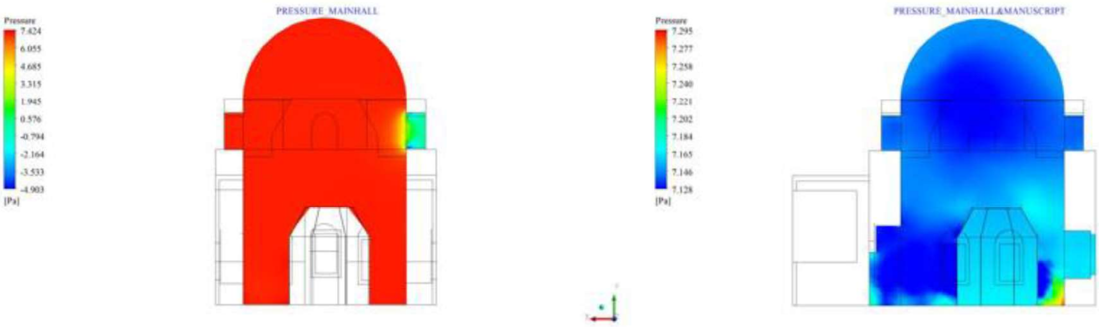
Figure 5.4. Scenario A (XZ plane): V contours on the Main Hall zone at (a) 0.5m, (c)1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont.on next page).



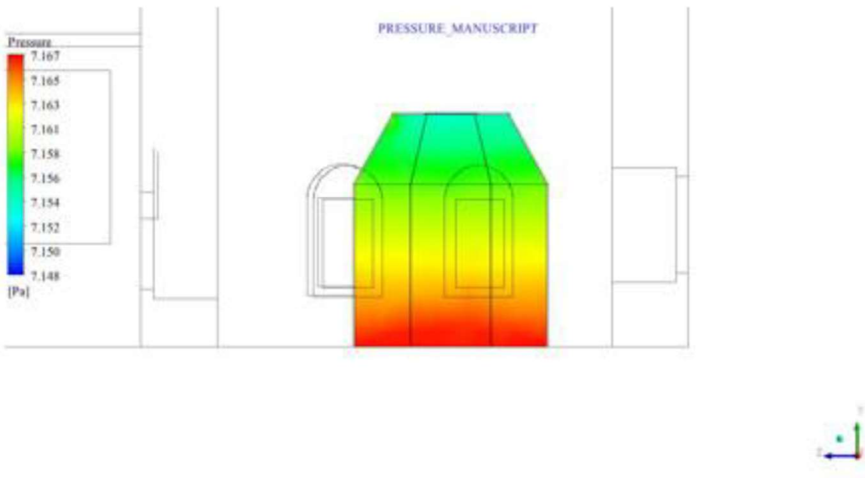
(i) (j)

Figure 5.4 (cont.).

to examine the natural ventilation effect of the windows on same direction and the different height. Figure 5.5 and 5.4 shows pressure and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.7 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

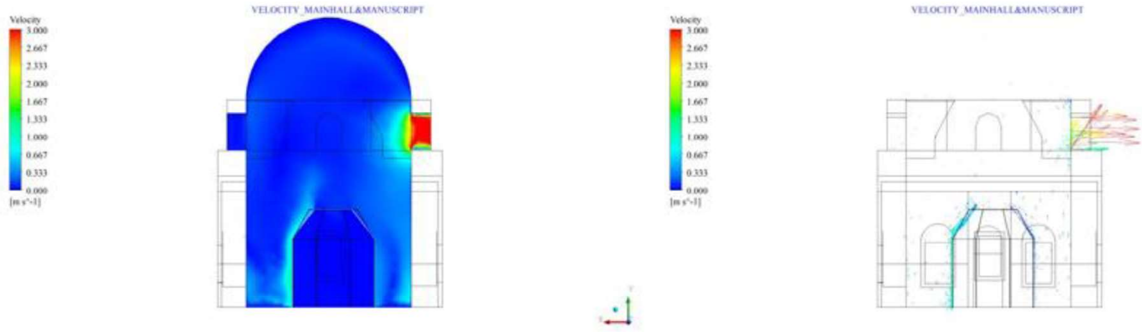


(a) (b)

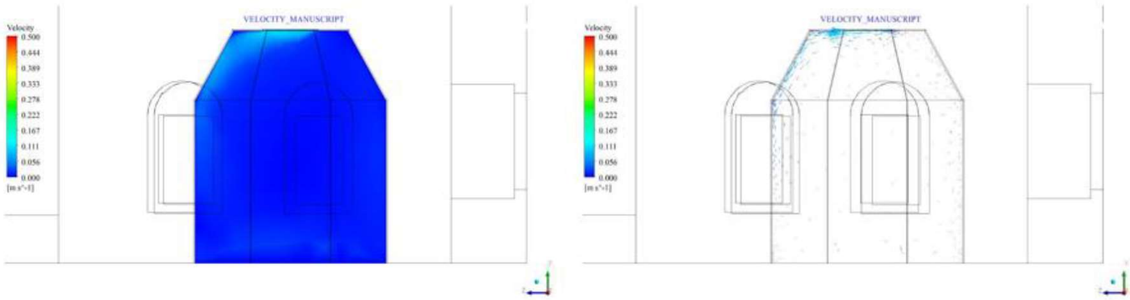


(c)

Figure 5.5. Scenario B:Pressure contour on (a) Main Hall zone on XY Plane on middle of W9, (b) Main Hall and Manuscript zones together, (c) Manuscript zone on ZY Plane on middle of the Manuscript zone.

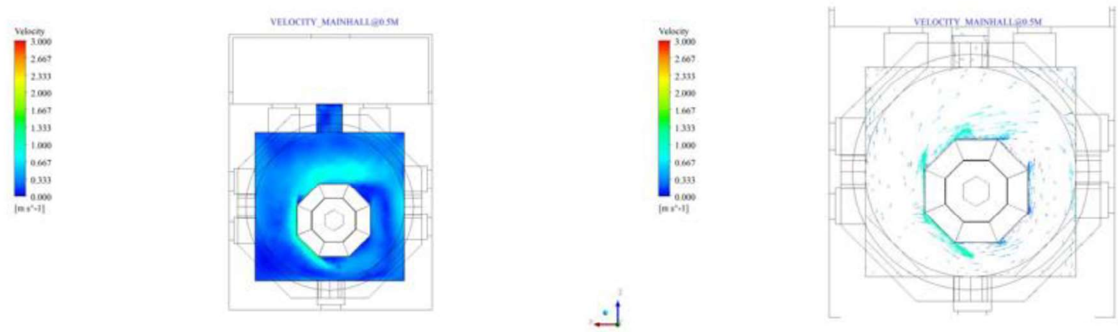


(a) (b)



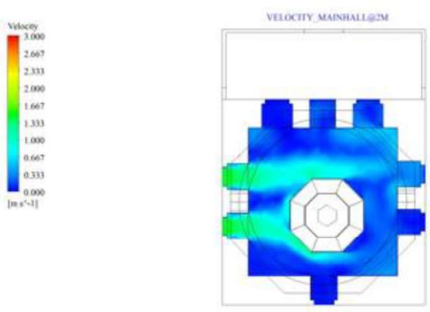
(c) (d)

Figure 5.6. Scenari B: (a) V contour and (b) v vector on Main Hall and Manuscript zones together on XY Plane on middle of W9; (c) v contour and (d) v vector on Manuscript zone on ZY Plane on middle of the Manuscript zone.

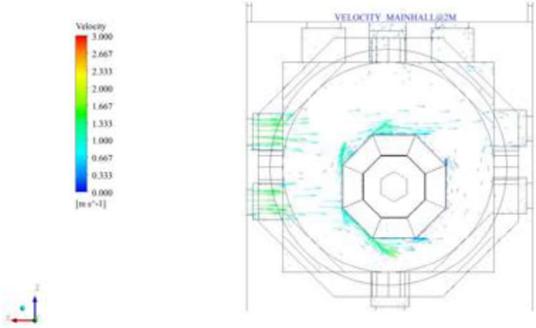


(a) (b)

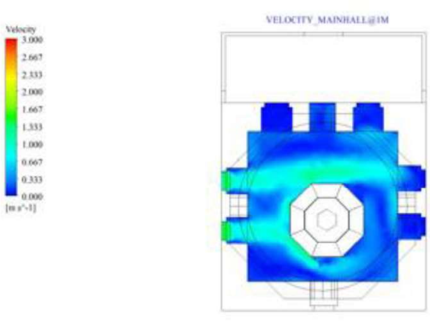
Figure 5.7. Scenario B (XZ plane): V contours on the Main Hall zone at (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont. on next page).



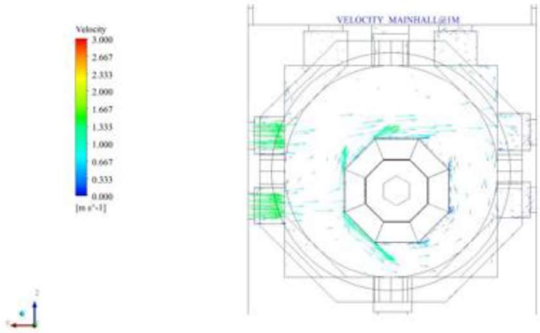
(c)



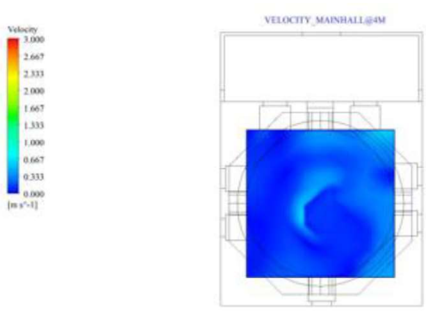
(d)



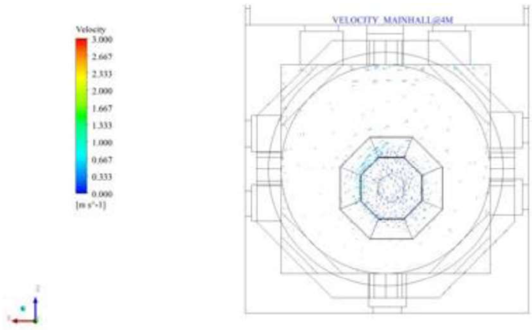
(e)



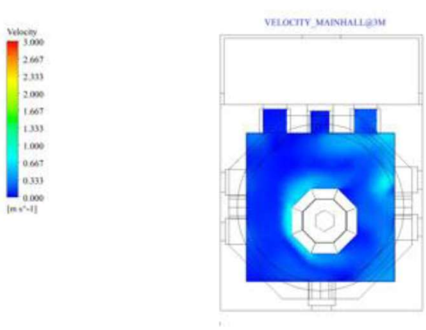
(f)



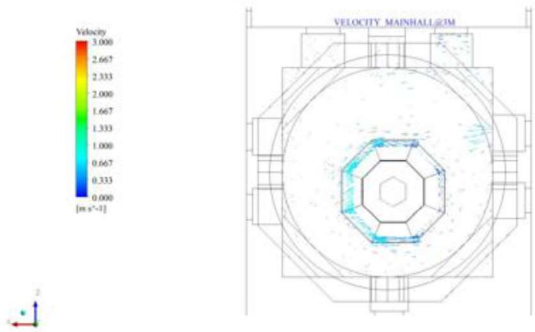
(g)



(h)



(i)

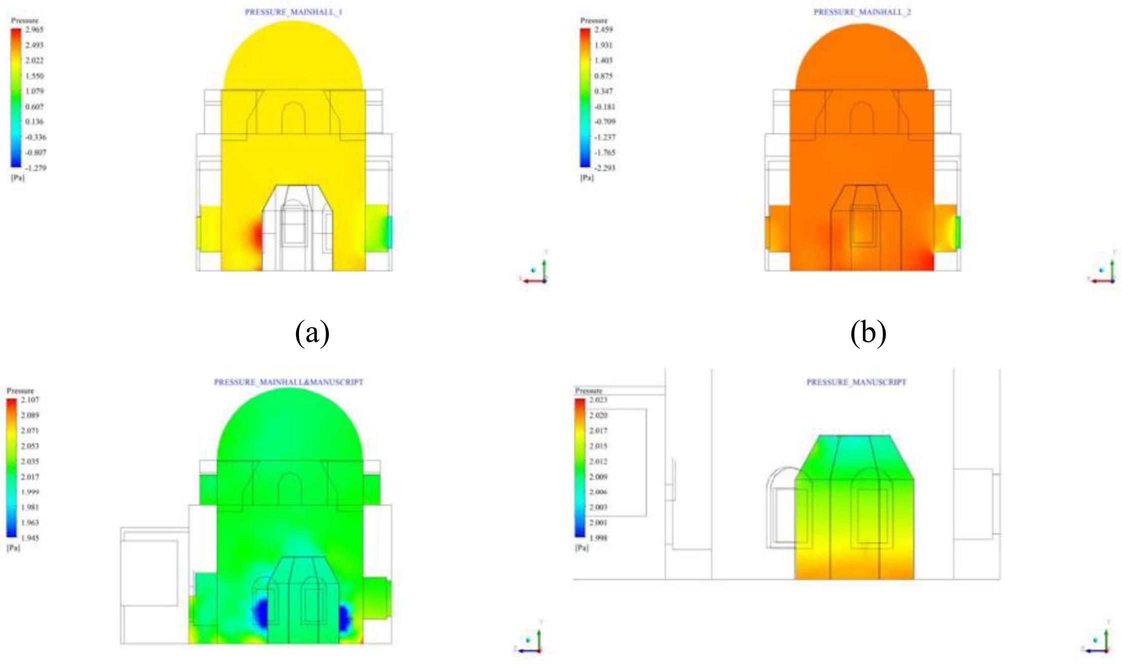


(j)

Figure 5.7 (cont.).

5.1.3. Scenario C

In Scenario C, air enters the building from W1 and W2 windows (western facade) and leaves from W4 and W5 windows (eastern facade) (Figure 4.8, Table 4.4). The aim of the scenario is to examine the natural ventilation effect of the windows on same directions and the same height. Figure 5.8 and 5.9 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.10 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.



(a) (b) (c) (d)

Figure 5.8. Scenario C: Pressure contour on (a) Main Hall zone on XY Plane on middle of W4, (b) middle of W5; Pressure contour (c) Main Hall and Manuscript zones together, (d) Manuscript zone on ZY Plane on middle of the Manuscript zone.

5.1.4. Scenario D

In Scenario D, , air enters the building from W1 and W2 windows (western facade) and leaves from W8 window (southern facade). The aim of the scenario is to examine the natural ventilation effect of the windows same direction and the different height. Figures 5.11 and 12 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.13 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

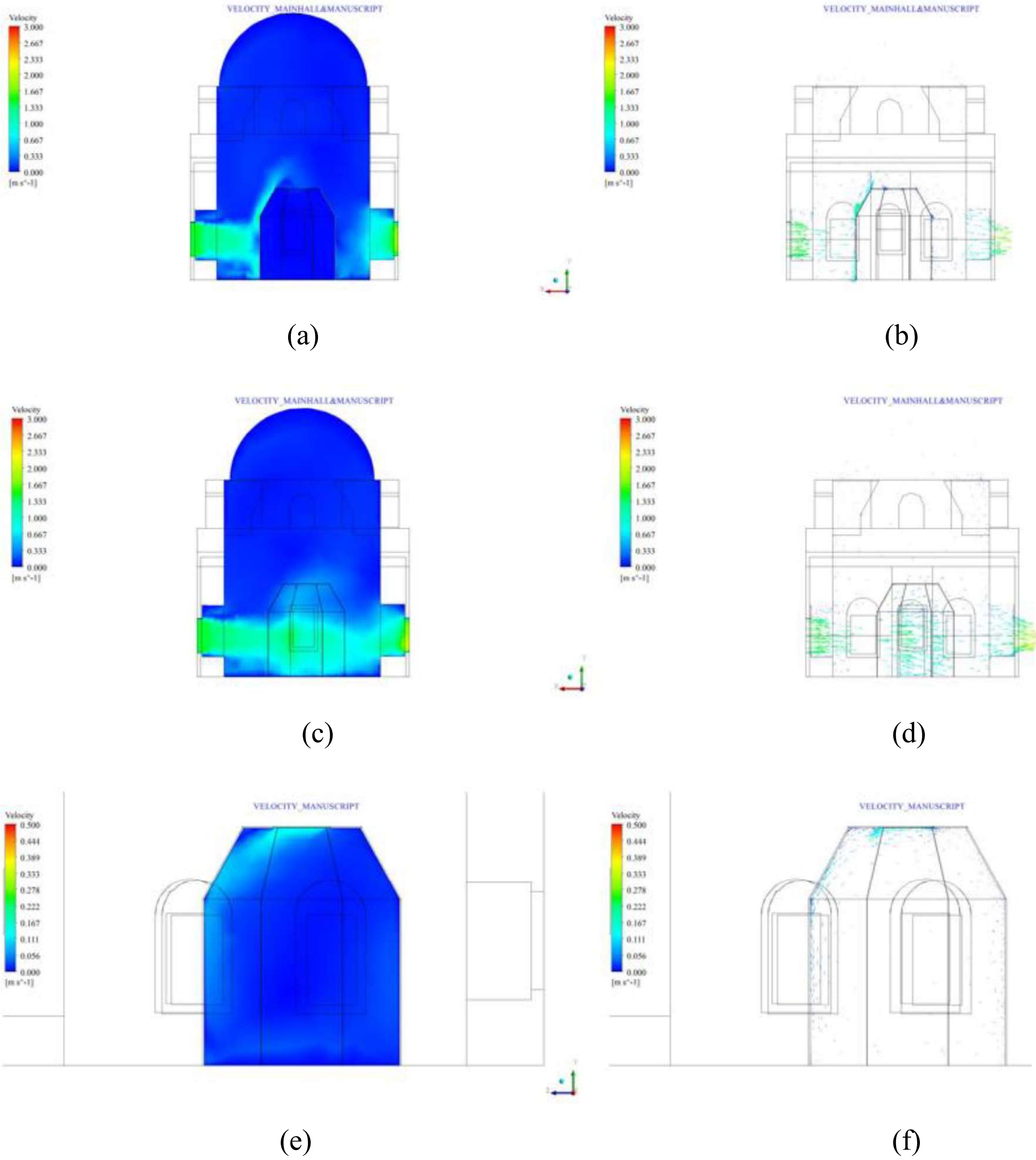


Figure 5.9. Scenario C: V contour on Main Hall and Manuscript zone on XY Plane on (a) middle of W4, (c) middle of W5, v vector on Main Hall and Manuscript zone together on XY Plane (b) middle of W4, (d) middle of W5; (e) v contour and (f) v vector on Manuscript zone on ZY Plane on middle of the Manuscript zone.

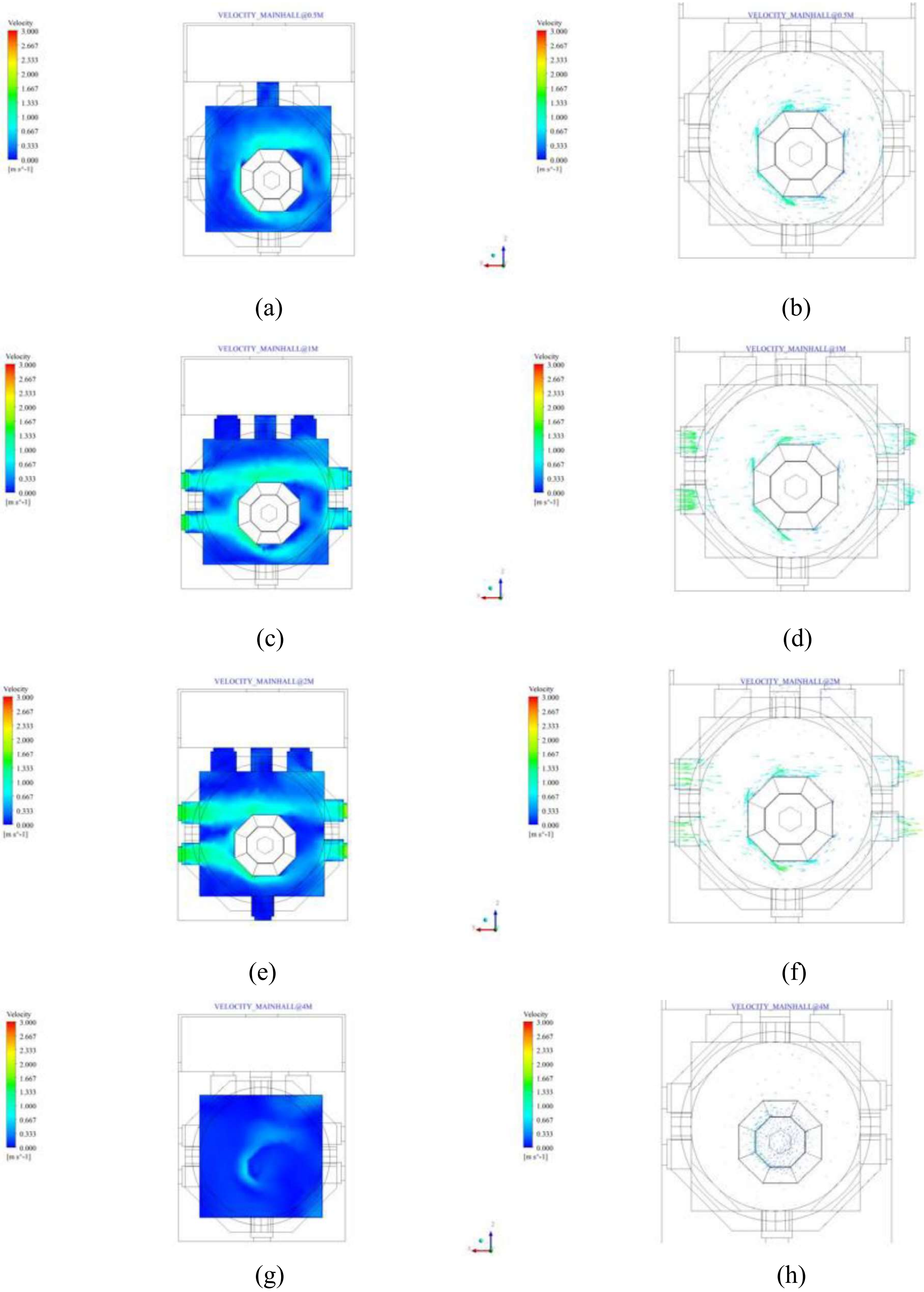
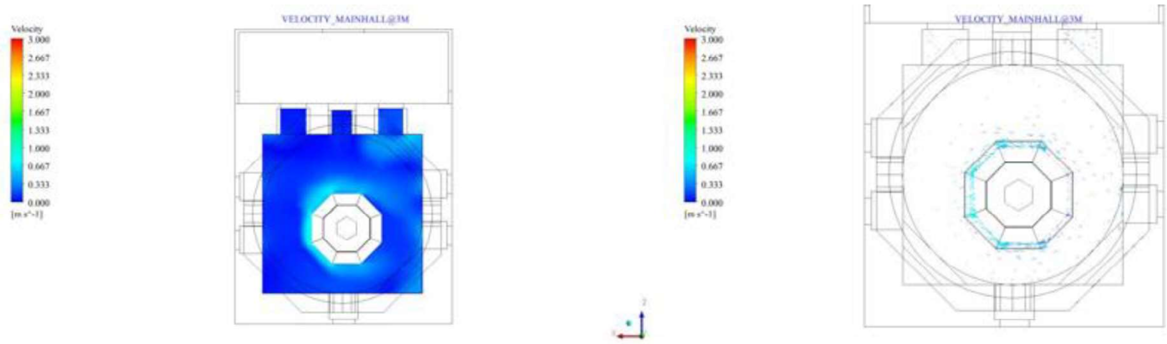
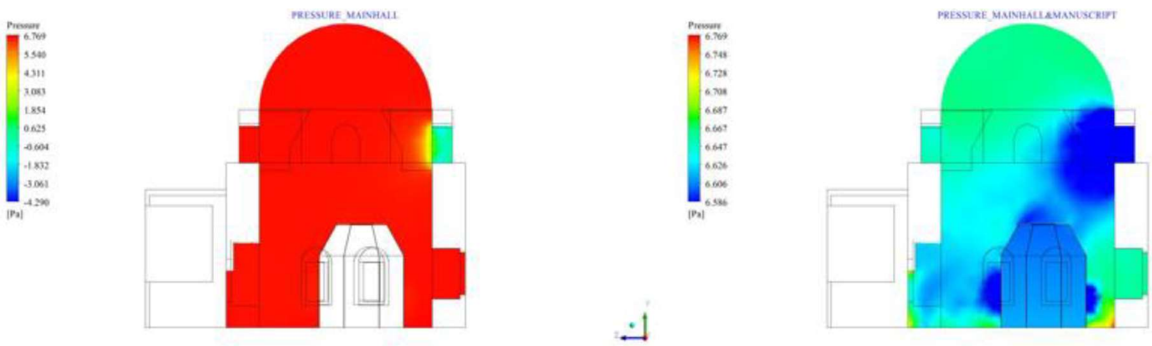


Figure 5.10. Scenario C (XZ Plane): V contours on the Main Hall zone at (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont. on next page).



(i) (j)

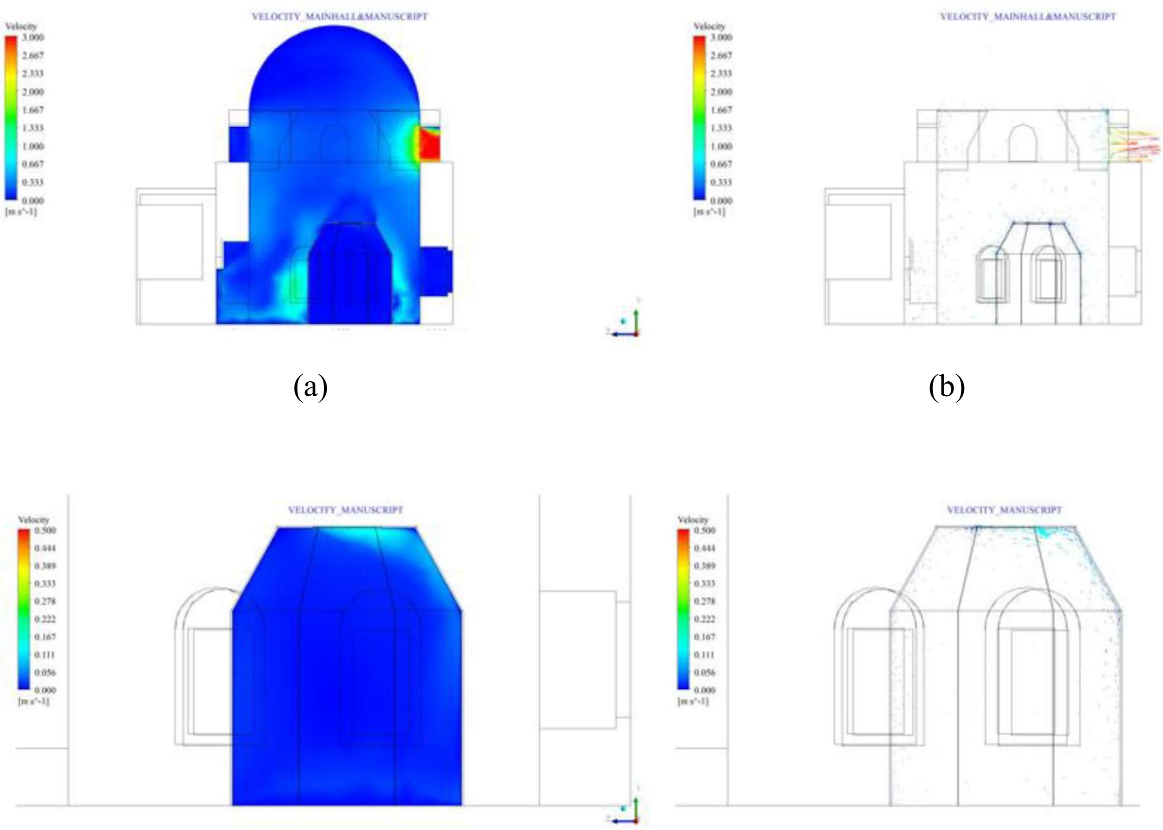
Figure 5.10 (cont.).



(a) (b)

(c)

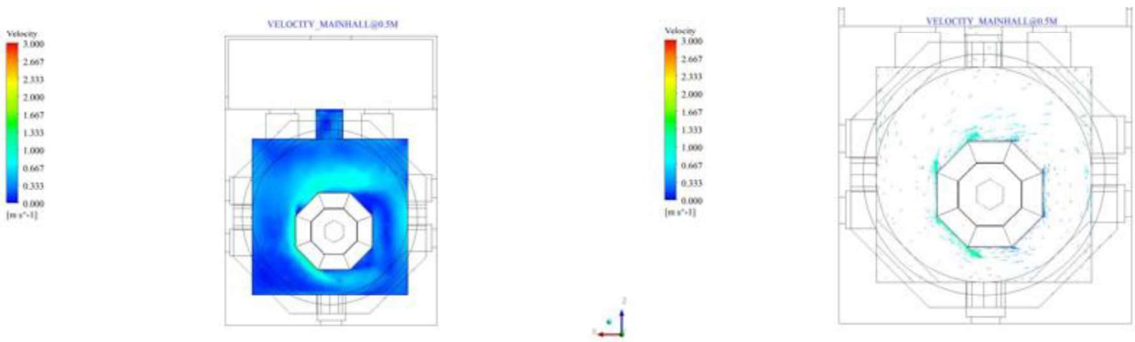
Figure 5.11. Scanario D: Pressure contour on (a) Main Hall zone, (b) Main Hall and Manuscript zones together, (c) Manuscript zone on ZY Plane on middle of the Manuscript zone.



(a) (b)

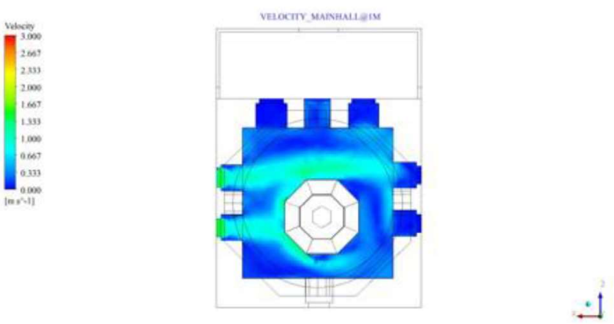
(c) (d)

Figure 5.12. Scenario D: (a) V contour and (b) v vector on Main Hall and Manuscript zones together; (c) v contour and (d) v vector on Manuscript zone on ZY Plane on middle of the Manuscript zone.

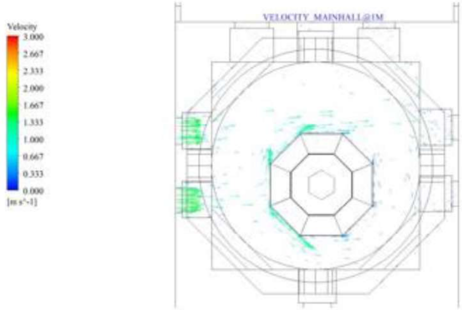


(a) (b)

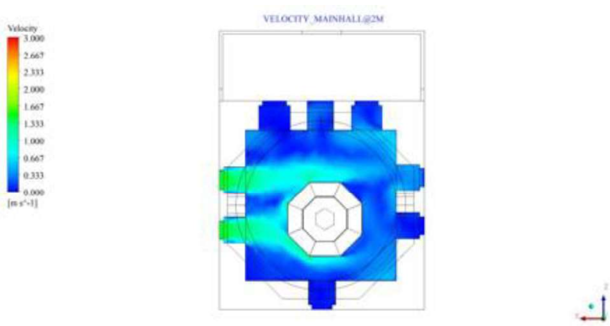
Figure 5.13. Scenario D (XZ plane): V contours on the Main Hall zoneat (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont. on next page).



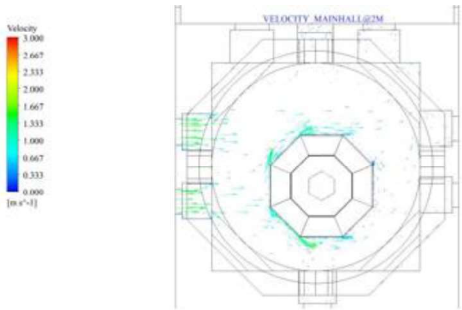
(c)



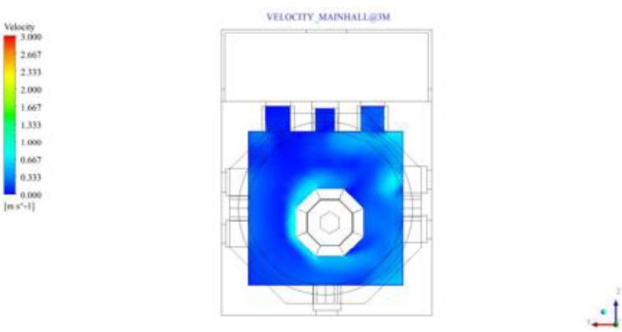
(d)



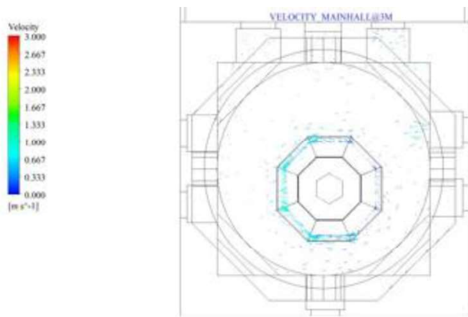
(e)



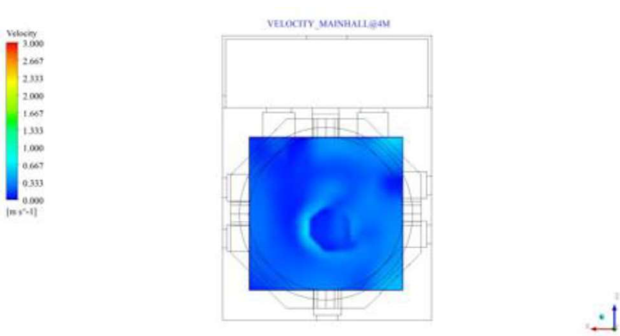
(f)



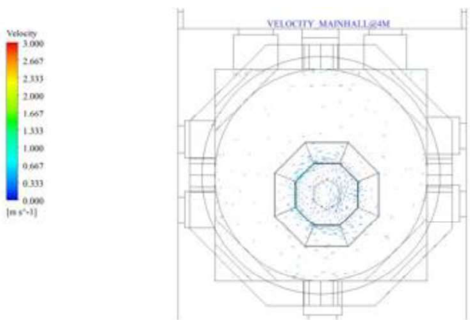
(g)



(h)



(i)



(j)

Figure 5.13. (cont.)

5.1.5. Scenario E

In Scenario E, air enters the building from W1 window (western facade) and leaves from W4 and W5 windows (eastern facade)(Figure 4.8, Table 4.4). The aim of the scenario is to examine the natural ventilation effect of the windows on different directions and the same height. Figures 5.14 and 15 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.16 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

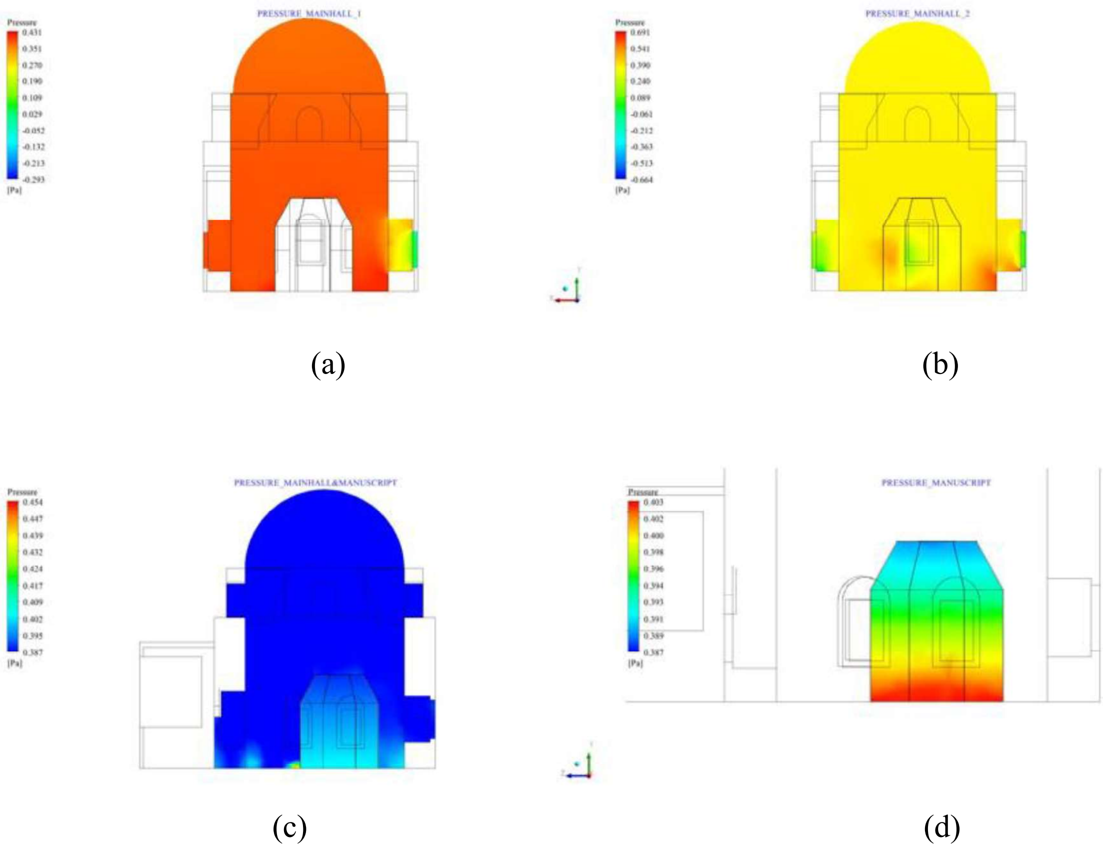


Figure 5.14. Scenario E: Pressure contour on (a) Main Hall zone on XY Plane on middle of W4, (b) middle of W5; pressure contour (c) Main Hall and Manuscript zones together, and (d) Manuscript zone on ZY Plane on middle of the Manuscript zone.

5.1.6. Sceario F

In Scenario F, air enters the building from W1 window (western facade) and leaves from W9 window W3 window (eastern facade) (Figure 4.8, Table 4.4). The aim of the scenario is to examine the natural ventilation effect of the windows on different directions and the same height. Figures 5.17 and 5.18 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.19 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

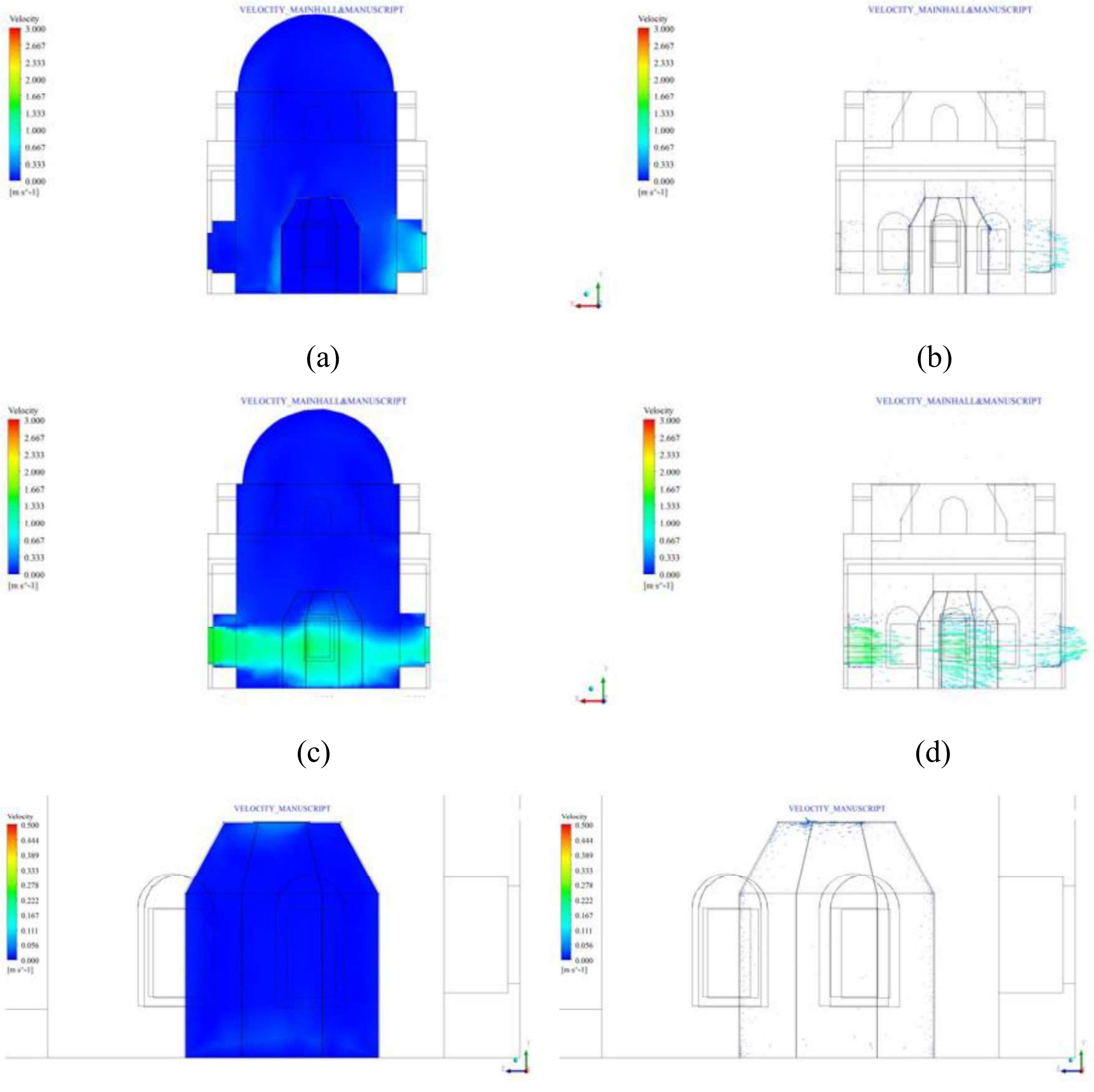


Figure 5.15. Scenario E: V contours on the Main Hall and Manuscript zones together on XY Plane (a) middle of W4, (c) middle of W5, v vectors on Main Hall and Manuscript zones together on XY Plane (b) middle of W4, (d) middle of W5; (e) v contours and (f) v vectors on Manuscript zone on ZY Plane on middle of the Manuscript zone.

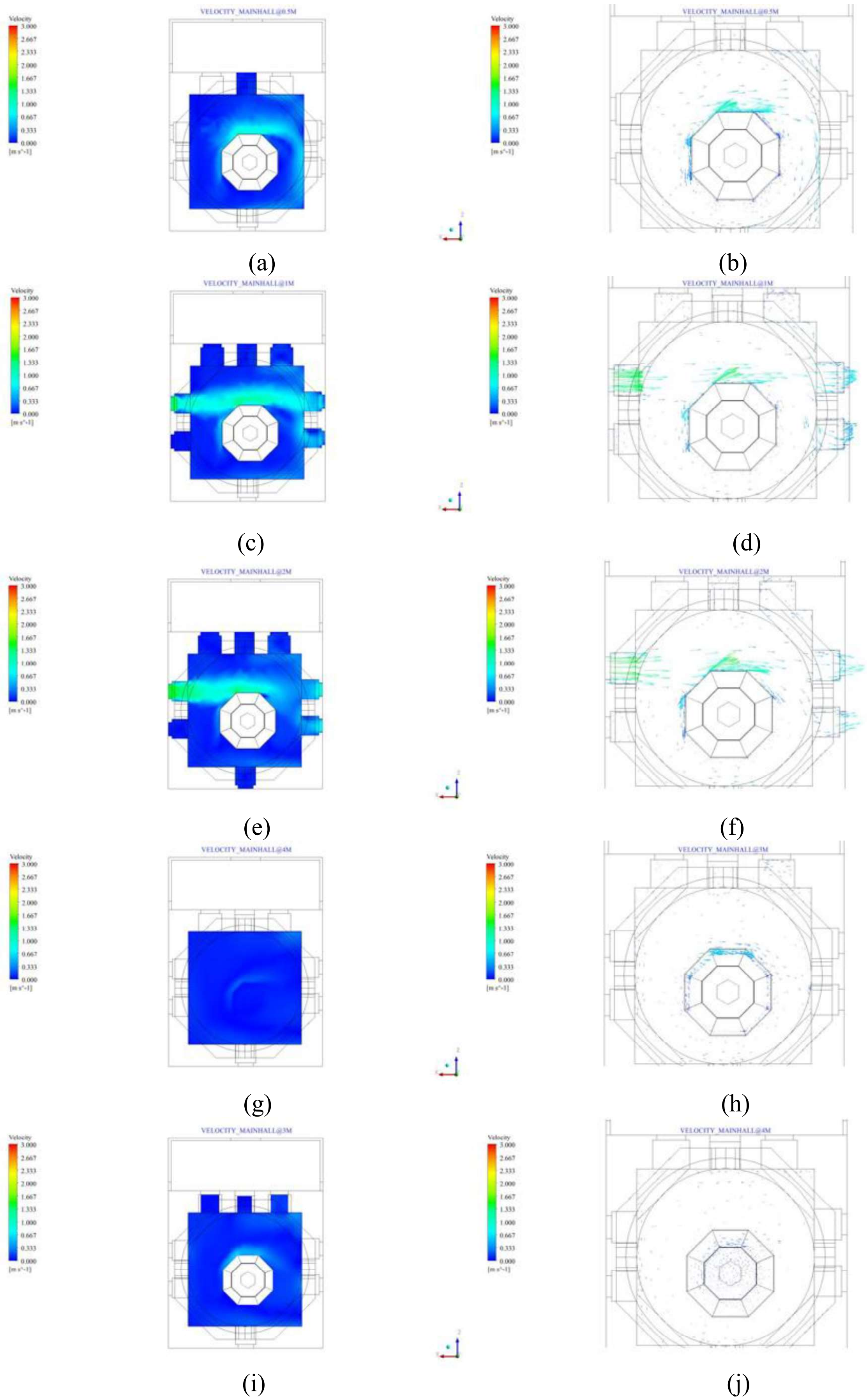


Figure 5.16. Scenario E (XZ plane):V contours on the Main Hall at (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m.

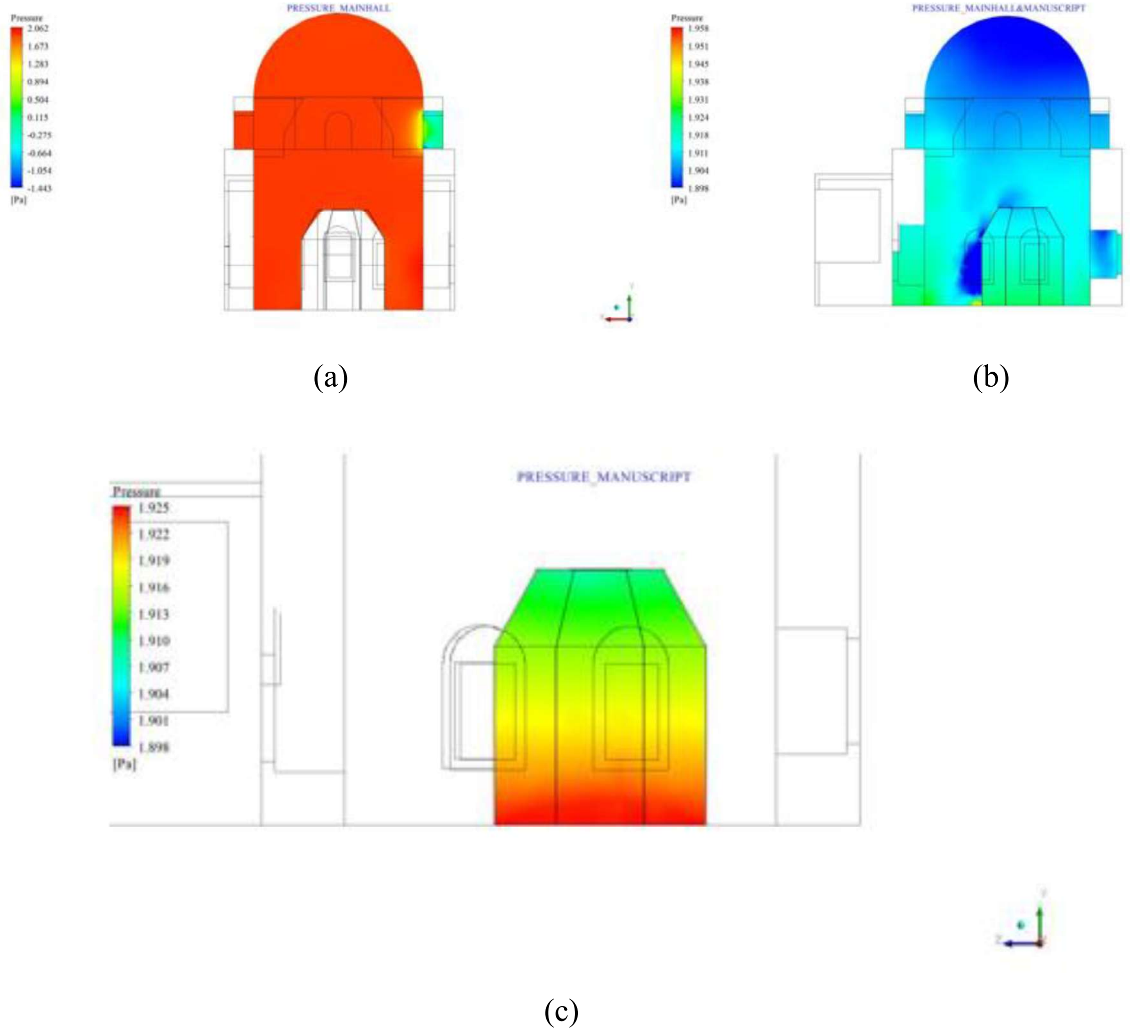


Figure 5.17. Scenario F: Pressure contour on (a) Main Hall zone on XY Plane (b) middle of W9, (b) Main Hall and Manuscript zones together, (c) Manuscript zone on ZY Plane on middle of the Manuscript zone.

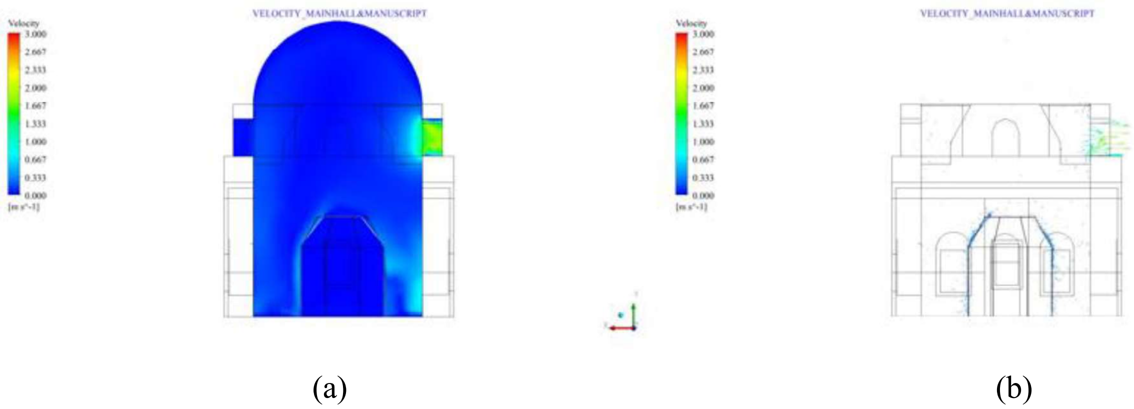
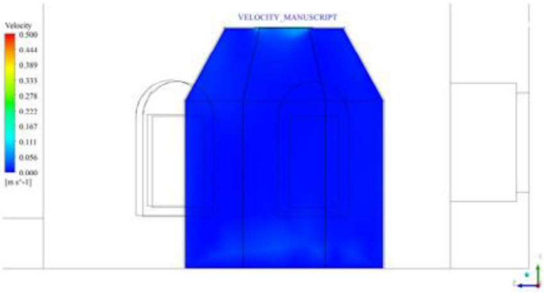
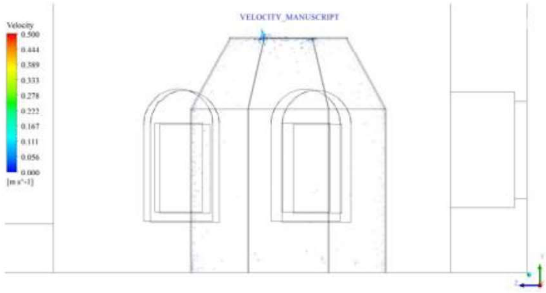


Figure 5.18. Scenario F: (a) V contour and (b) v vector on Main Hall and Manuscript zones on XY Plane on middle of W9; (c) v contour and (d) v vector on Manuscript zone on ZY Plane on middle of the Manuscript zone (cont. on next page).

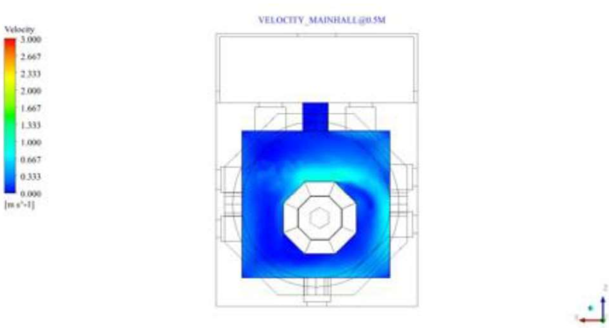


(c)

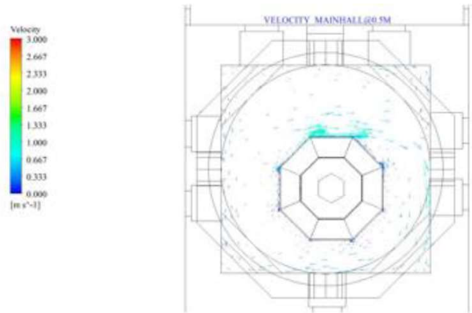


(d)

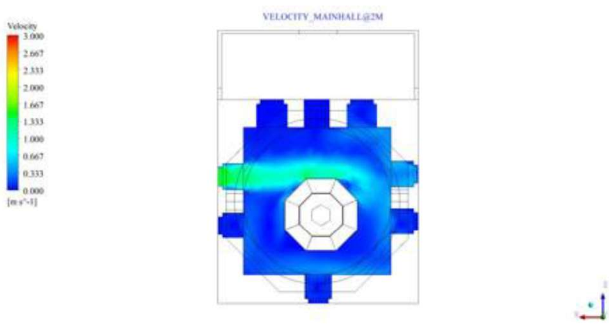
Figure 5.18 (cont.).



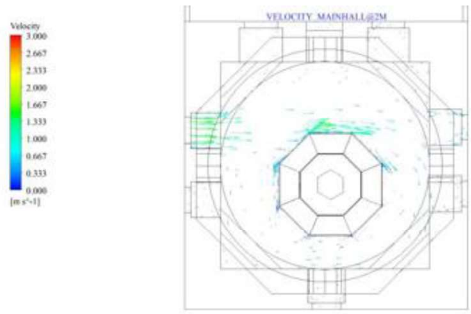
(a)



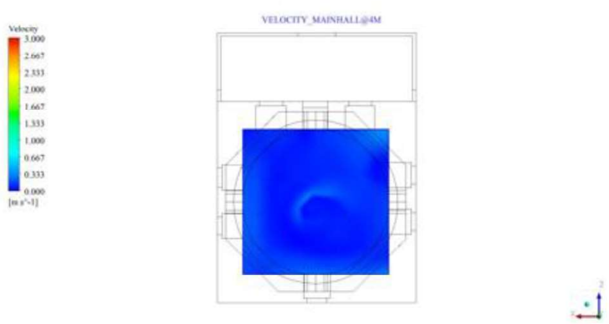
(b)



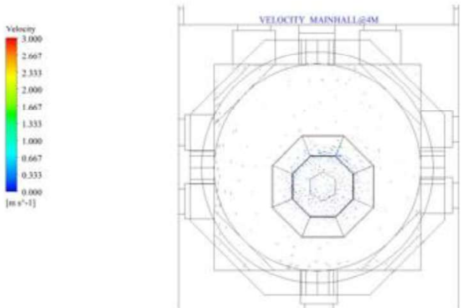
(c)



(d)

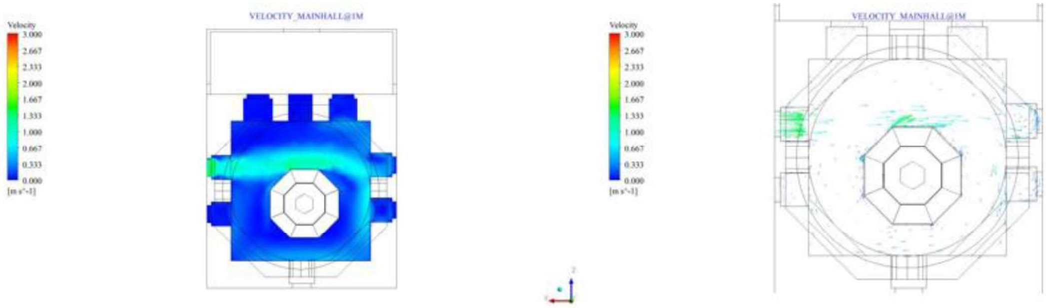


(e)

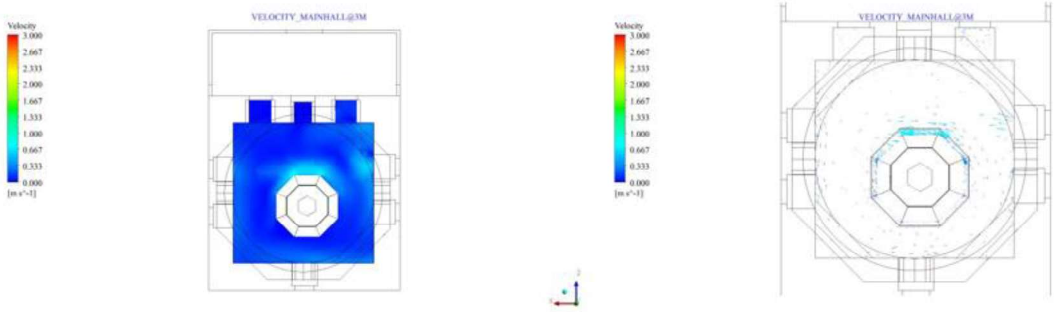


(f)

Figure 5.19. Scenario F (XZ plane): V contours on the Main Hall zone at (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont. on next page).



(g) (h)

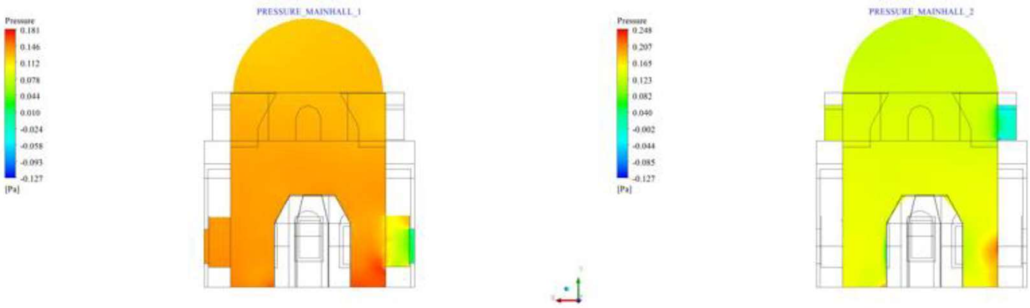


(i) (j)

Figure 5.19 (cont.).

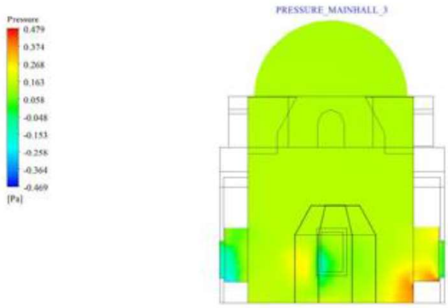
5.1.7. Scenario G

In Scenario G, air enters the building from W1 window (western facade) and leaves from W4, W5, and W9 windows (eastern facade)(Figure 4.8, Table 4.4). The aim of the scenario is to examine the natural ventilation effect of the windows on different directions and the same height. Figures 5.20 and 5.21 show pressure contours and v contours on the Main Hall and Manuscript zones at YZ plane, respectively. Figure 5.22 exhibits v magnitudes and vectors at different heights for the Main Hall zone at XZ plane.

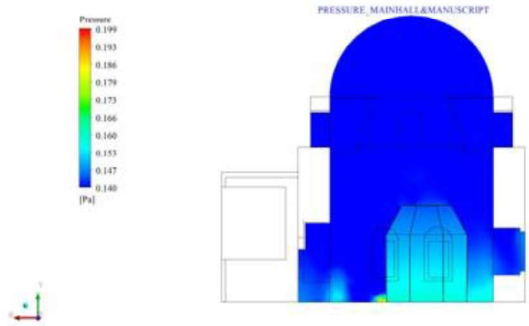


(a) (b)

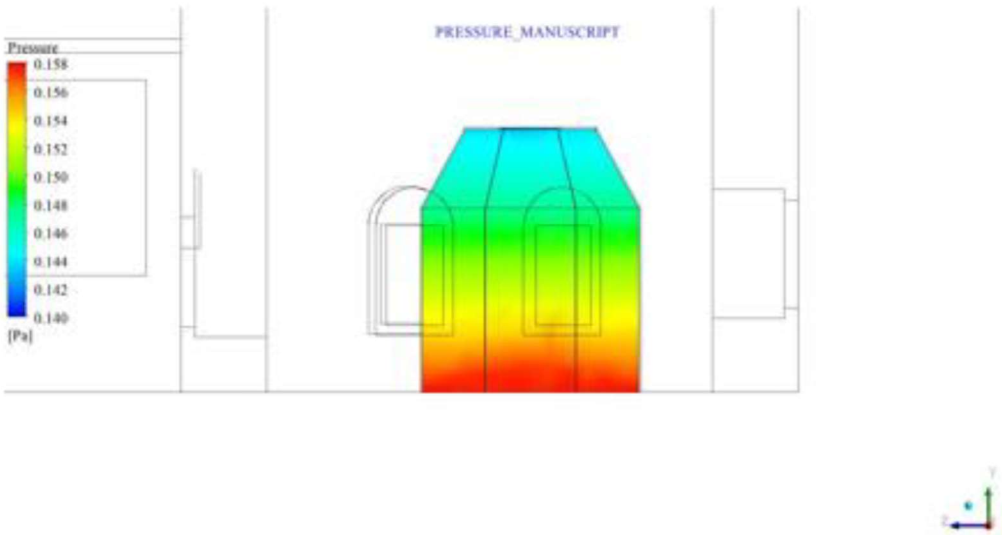
Figure 5.20. Scenario G: Pressure contour on (a) Main Hall zone on XY Plane (a) middle of W4, (b) on middle of W9, (c) on middle of W5; pressure contour (d) on Main Hall and Manuscript zones together, and (e) Manuscript zone on ZY Plane on middle of the Manuscript zone (cont. on next page).



(c)

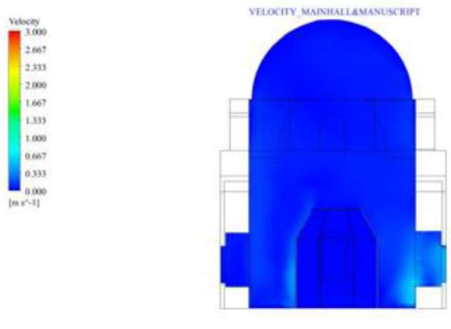


(d)

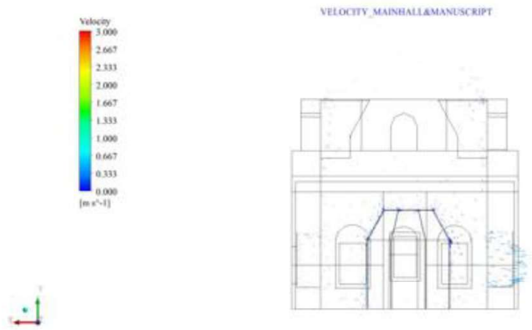


(e)

Figure 5.20 (cont.).

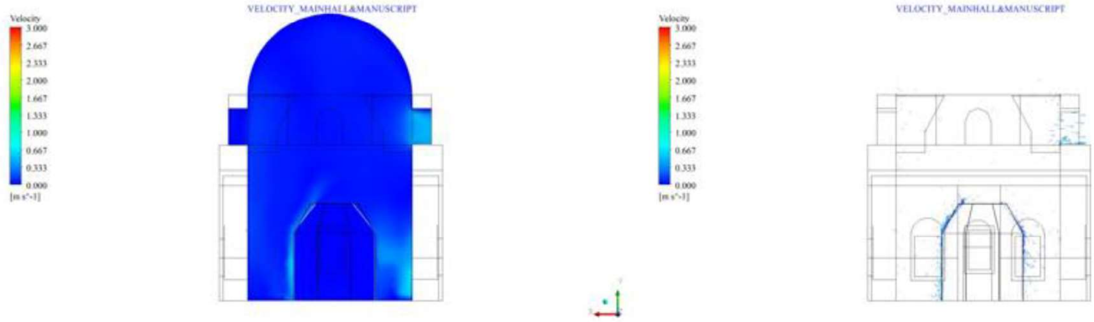


(a)

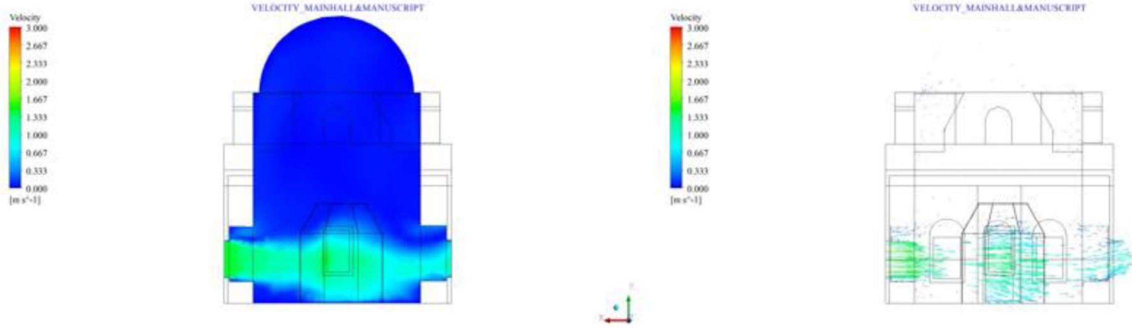


(b)

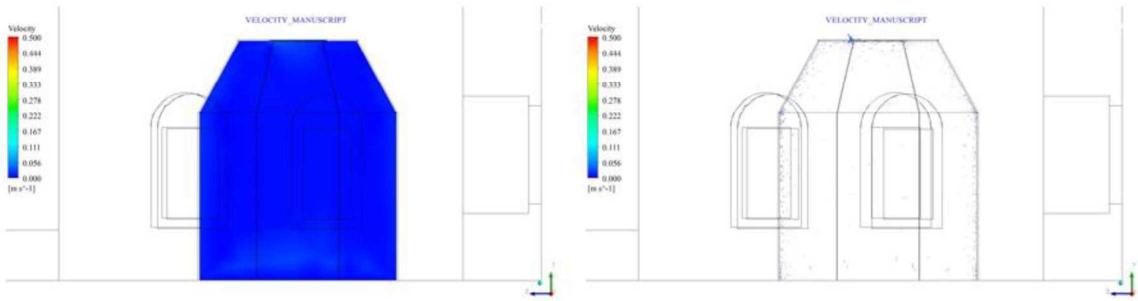
Figure 5.21. Scenario G: V contour on Main Hall and Manuscript zones on XY Plane (a) middle of W4, (c) middle of W9, (e) middle of W5, v vector on Main Hall and Manuscript zone together on XY Plane (b) on middle of W4, (d) middle of W9, (f) middle of W5; (g) v contour and (h) v vector on Manuscript one on ZY Plane on middle of the Manuscript zone (cont. on next page).



(c) (d)

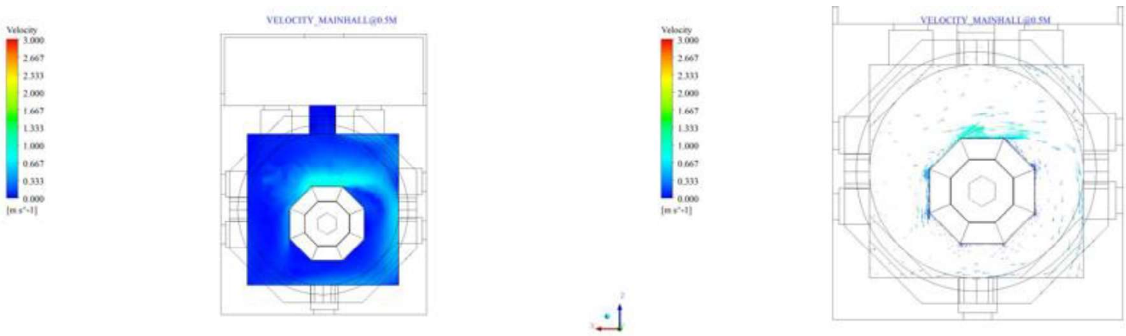


(e) (f)



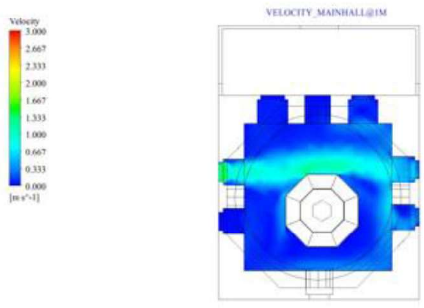
(g) (h)

Figure 5.21 (cont.).

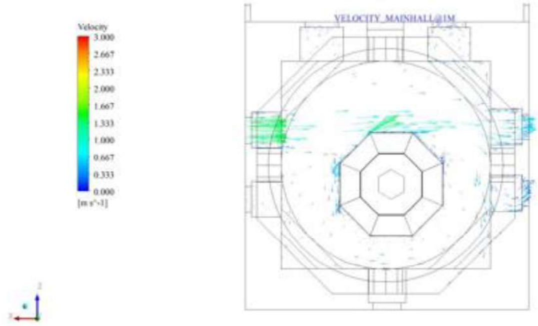


(a) (b)

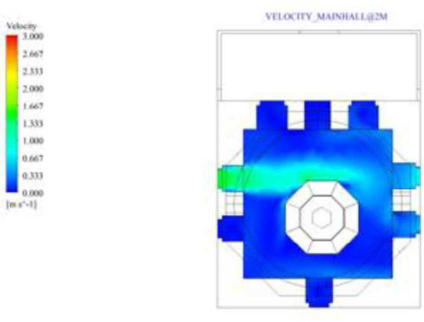
Figure 5.22. Scenario G (XZ plane): V contours on the Main Hall zone at (a) 0.5m, (c) 1m, (e) 2m, (g) 3m, (i) 4m; and v vectors on the Main Hall zone at (b) 0.5m, (d) 1m, (f) 2m, (h) 3m, (j) 4m (cont. on next page).



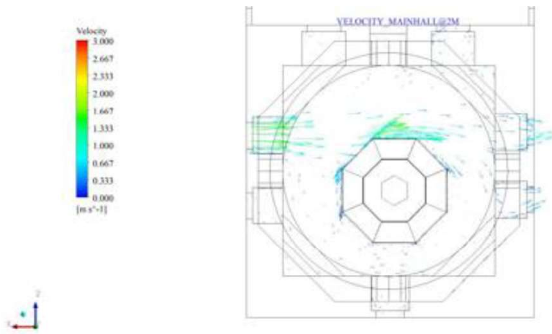
(c)



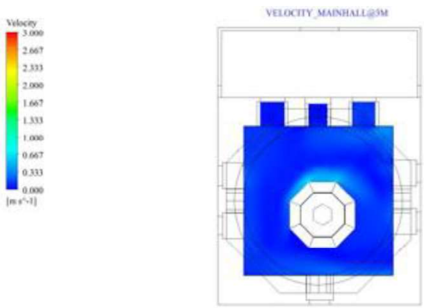
(d)



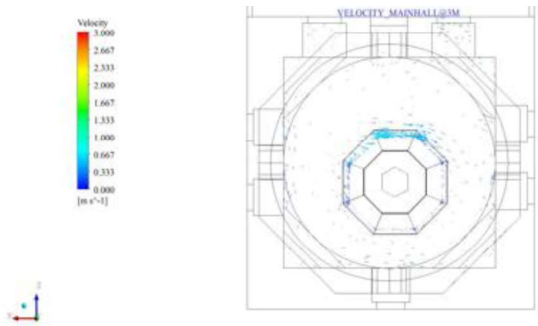
(e)



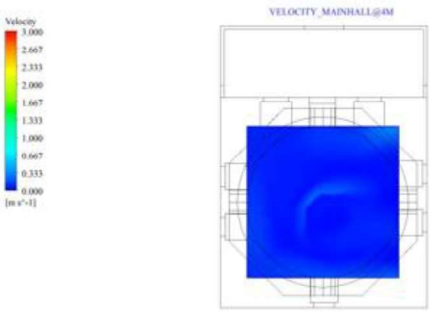
(f)



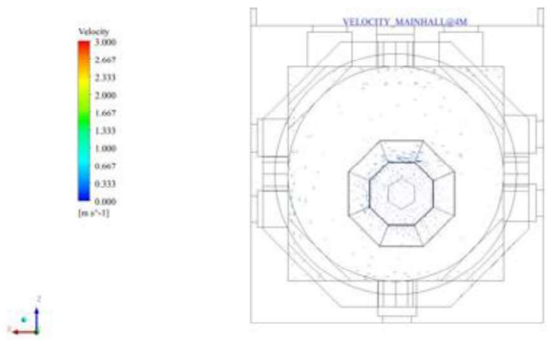
(g)



(h)



(i)



(j)

Figure 5.22 (cont.).

5.2. Discussion

The results of the analysis give the change in air v and pressure in the building according to the scenarios. This changes cause air movement in the Manuscript zone, where manuscripts are protected. The amount of air change in the Manuscript zone is taken as the main output data since the effect of natural ventilation varies depending on how much change is caused by windows on the indoor air when the outdoor conditions are better than indoor conditions. Considering that RH has a significant effect on chemical degradation, air exchange is the main parameter that changes indoor RH value.

The results of all scenarios are summarized in 4 tables. Table 5.1 shows the maximum and minimum pressure values in the Manuscript zone. Since the outside air is not modeled, the maximum and minimum pressure values have no effect on the air v, only the pressure difference exists. If the outside air was modeled, the difference according to the outside pressure would have an effect, but this change was neglected in the Thesis. When the pressure difference is examined, there is no big difference in the Manuscript zone. The maximum difference is in Scenario D with 0.0322 Pa, while the minimum difference is in Scenario E with 0.0163 Pa.

Table 5.2 givesmean velocities on the XZ plane at 0.5m, 1m, 2m, 3m, 4m and average of all planes in the Main Hall zone. When the average value of all planes is examined, the highest value is seen in Scenario D. The lowest value was observed in Scenario G. However, Scenario A, B and C values are very close to Scenario D value with a difference of 0.01m/s. V magnitude around the Manuscript zone which is located in the Main Hall zone affects the heat transfer coefficient between the two zones. As air accelerates, heat transfer rate increases. These values should be taken into consideration in further studies to reduce the risk of chemical degradation where T and RH values will be examined together.

The effect of pressure difference on the v is shown in Table 5.4. The Table gives average, maximum and minimum velocities in the y-direction on the same plane. The maximum values of the pressure difference in the y-direction and resulting pressure difference are the same in terms of size order. It can be said that the pressure difference directly drives the maximum v magnitude in this direction.

The Manuscript zone has an opening at the top for air exchange. Air flowrate values entering and leaving the zone through this aperture according to the vector v component in the y-direction for each scenario are shown in Table 5.3. Maximum air change occurs in Scenario C which has the highest average v as given in Table 5.4. Minimum air change occurs in Scenario E, the second lowest scenario in Table 5.4. When the flowrate values are compared for the same area, it makes sense to show the same variation with the average v.

5.3. Transient Analysis for Scenarios

Steady-state analysis showed that Scenario C and Scenario D are better than other scenarios according to v and pressure values as can be seen in Table 5.1, 5.2, 5.3, 5.4. Therefore, these two senarios arechosen for transient analysis and LM values are calculated to be able to evaluate the effect of the scenarios on decreasing chemical degradation risk. Minimum and maximum legend values are arranged according to maximum and minimum values on Scenario C to make comparison with the same colour scale. Legend scale is between 1.01 and 0.95 on the Main Hall zone, 0.945 and 0.91 on the Manuscript zone.

Figure 5.23 shows LM contours on the Main Hall zone. There is no big differences between two scenarios but Scenario D has higher LM values then Scenario C.

LM contours on the Manuscript zone for scenario C and D are shown in Figure 5.24. Similar to the Figure 5.23, scenario D has higher LM values then Scenario C. Differences between two scenarios can be seen more clearly in the Figure since the legend range is narrower than Figure 5.23.

Average LM values on the Manuscript and Main Hall zones are given on Table 5.5 and 5.6. The average values give similar results as Figure 5.23 and 5.24. Even there is no essential difference Scenario C and Scenario D, Scenario D gives higher LM values than Scenario C.

Table 5.1. Minimum, maximum and difference pressure on Manuscript zone on ZY Plane in the middle of the Manuscript zone.

Pressure	Scenario A [Pa]	Scenario B [Pa]	Scenario C [Pa]	Scenario D [Pa]	Scenario E [Pa]	Scenario F [Pa]	Scenario G [Pa]
Max.	5.7578	7.1670	2.0230	6.6180	0.4034	1.9201	0.1583
Min.	5.7349	7.1477	1.9969	6.5858	0.3871	1.8975	0.1400
Difference	0.0229	0.0194	0.0261	0.0322	0.0163	0.0226	0.0184

Table 5.2. Average v magnitude at 0.5m, 1m, 2m, 3m, 4m, and these 4 Plane on Main Hall zone.

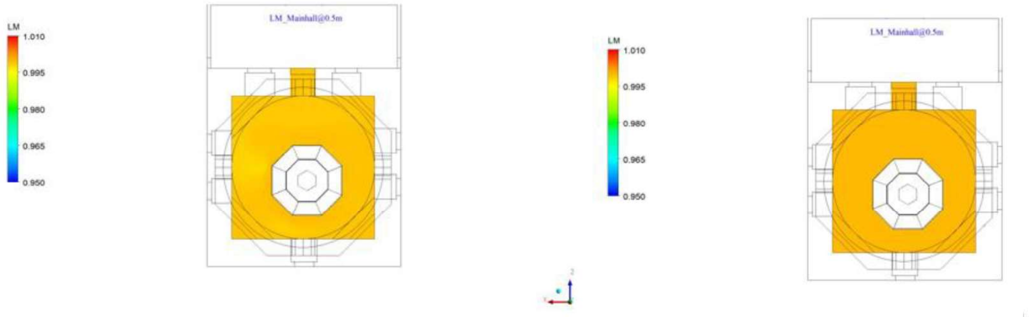
Ave. v	Scenario A [m/s]	Scenario B [m/s]	Scenario C [m/s]	Scenario D [m/s]	Scenario E [m/s]	Scenario F [m/s]	Scenario G [m/s]
0.5m	0.3346	0.3375	0.3216	0.3637	0.2009	0.2499	0.2010
1m	0.4383	0.4233	0.4778	0.4354	0.3052	0.3079	0.3042
2m	0.4907	0.3914	0.4421	0.4049	0.2883	0.2937	0.2866
3m	0.2242	0.2031	0.1721	0.2294	0.1154	0.1600	0.1188
4m	0.1623	0.1719	0.1302	0.2269	0.0786	0.1059	0.0793
Ave.	0.3300	0.3054	0.3087	0.3321	0.1977	0.2235	0.1980

Table 5.3. Flowrate inlet and outlet according to Y direction v on Manuscript zone.

Flowrate	Scenario A [m^3/h]	Scenario B [m^3/h]	Scenario C [m^3/h]	Scenario D [m^3/h]	Scenario E [m^3/h]	Scenario F [m^3/h]	Scenario G [m^3/h]
Inlet	20.4216	23.0168	51.7330	22.0210	11.8455	23.0525	13.0974
Outlet	22.2461	23.2056	52.1092	22.3904	11.8751	26.8482	12.5896

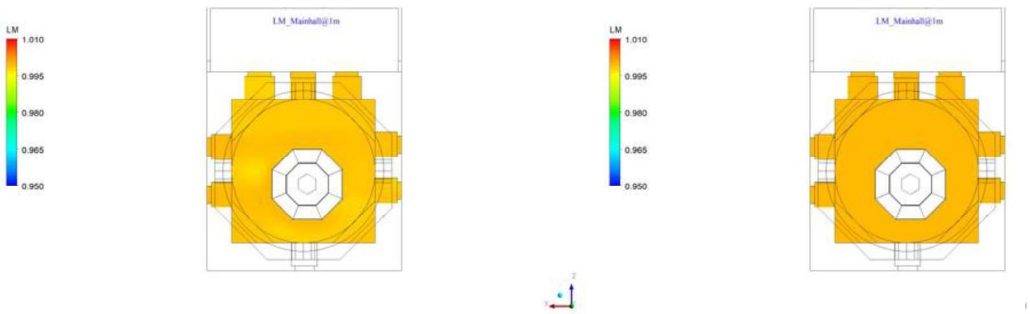
Table 5.4. Average and maximum v magnitude on Manuscript zone on ZY Plane on middle of the Manuscript zone.

V	Scenario A [m/s]	Scenario B [m/s]	Scenario C [m/s]	Scenario D [m/s]	Scenario E [m/s]	Scenario F [m/s]	Scenario G [m/s]
Ave.	0.0137	0.0227	0.0353	0.0293	0.0101	0.0119	0.0087
Maximum	0.1104	0.1303	0.1735	0.1956	0.0604	0.1193	0.0656
Maximum (Y)	0.1078	0.0831	0.1411	0.1776	0.0587	0.1001	0.0621



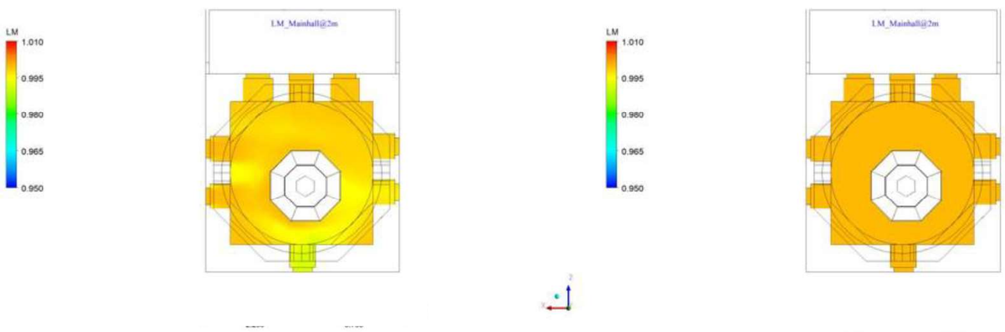
Scenario C Scenario D

(a)



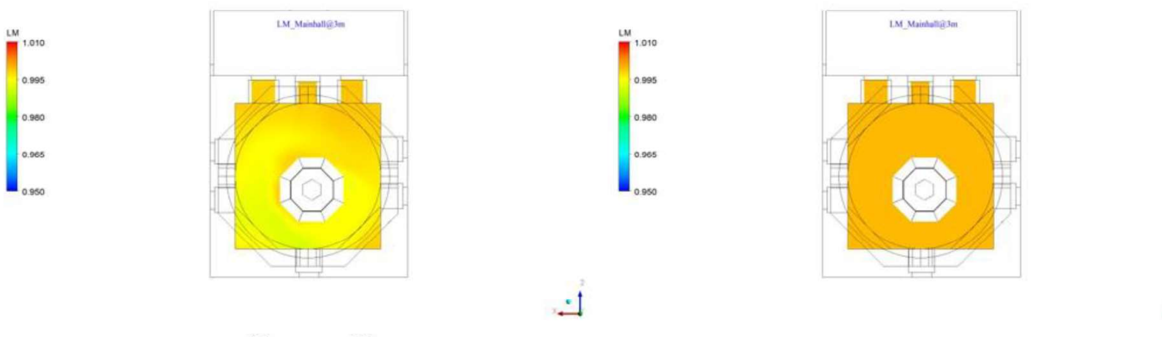
Scenario C Scenario D

(b)



Scenario C Scenario D

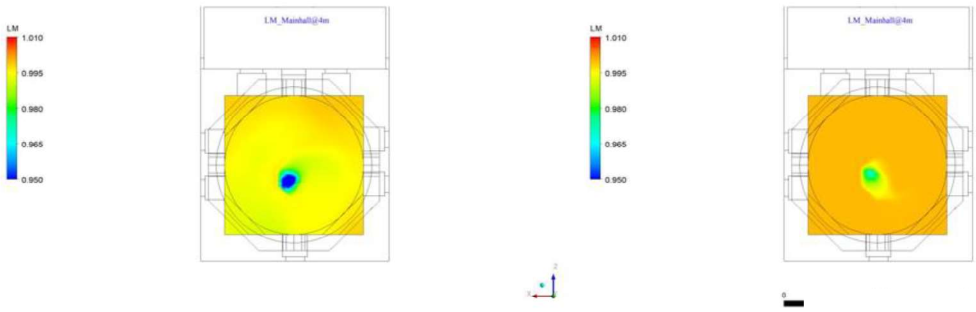
(c)



Scenario C Scenario D

(d)

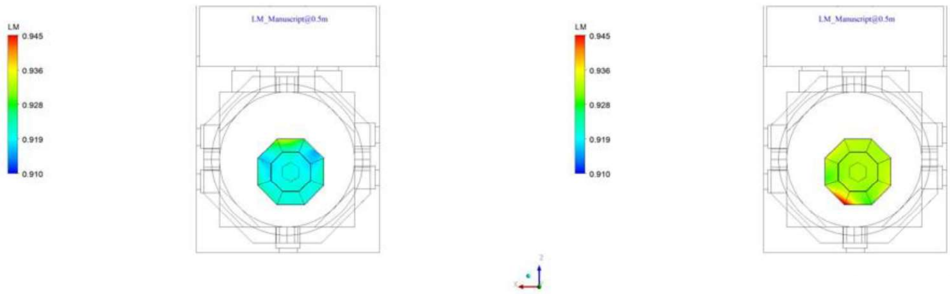
Figure 5.23. LM values contour for the Mainhall zone for Scenario C and Scenario D at (a) 0.5m, (b) 1m, (c) 2m, (d) 3m, (e) 4m on XZ plane (cont. on next page).



Scenario C　　　　Scenario D

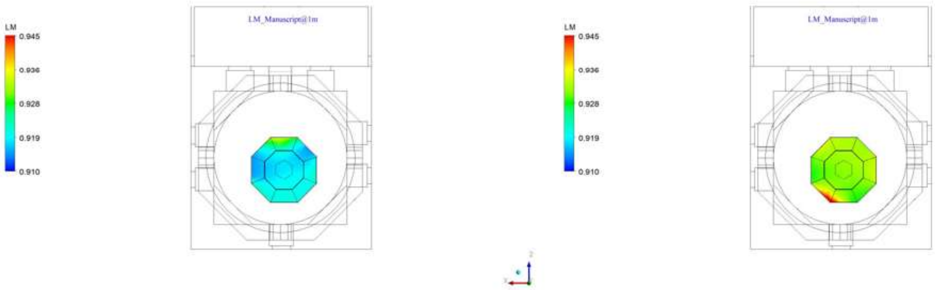
(e)

Figure 5.23 (cont.).



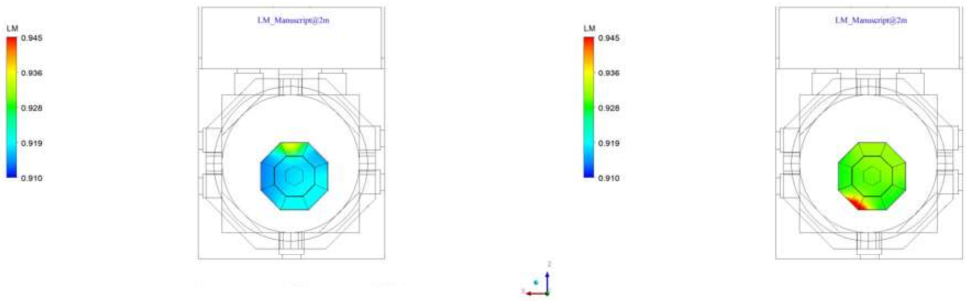
Scenario C　　　　Scenario D

(a)



Scenario C　　　　Scenario D

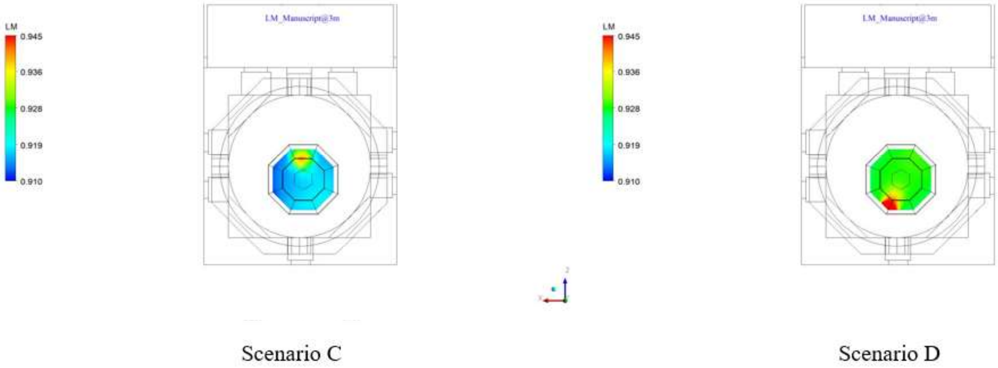
(b)



Scenario C　　　　Scenario D

(c)

Figure 5.24. LM values contour on Manuscript zone for Scenario C and Scenario D (a) on 0.5m, (b) 1m, (c) 2m, (d) 3m, (e) 4m on XZ Plane (cont. on next page).



(d)
Figure 5.24. (cont.).

Table 5.5. Average LM values for Manuscript zone on XY plane.

Height [m]				
	0.5	1	2	3
Scenario C	0.9221	0.9208	0.9189	0.9169
Scenario D	0.9338	0.9327	0.9314	0.9298

Table 5.6. Average LM values for the Main Hall zone on XY plane.

Height [m]				
	0.5	1	2	3
Scenario C	0.9996	0.9994	0.9980	0.9966
Scenario D	1.0002	1.0002	1.0002	1.0002

CHAPTER 6

CONCLUSIONS

In the Thesis, CFD model of a historic library, the Necip Paşa Library-Tire-İzmir-Turkey, is developed. Natural ventilation scenarios are proposed and applied to the model to observe the potential of the scenarios on chemical degradation risk on paper-based collections. Steady-state analysis of all scenarios gave v and pressure differences. Scenario C and D gave maximum air change and v in the Main Hall and Manuscript zone. Therefore, those two scenarios are further evaluated by transient analysis and LM values are calculated.

It can be concluded that Scenario D is the most appropriate scenario according to pressure difference, v and LM values. In the scenario, windows at different heightsand directions are left open. The Thesis is concentrated to the period of May-October that chemical degradation risk was determined. During this period, natural ventilation is conducted only when outdoor T and RH is lower that indoor T and RH. Otherwise, degradation risk increases. Between May and October, outdoor air T and RH are suitable for ventilation for 7.53% of the total time. For this short duration, Scenario D improve LM values. The results show that, even though window ventilation cannot be said to be the solution for the Necip Paşa Library, it can assist to protect the manuscripts with appropriate scenarios.

The HVAC system should be adapted to be used out of period when natural ventilation is not possible. If HVAC system is applied, maximum caution should be taken not to damage historic value of the building.

6.1. Recommendations

In the Thesis, all scenarios are evaluated based on steady-state analysis while only two scenarios are evaluated by transient analysis because of the time constraint. For more accurate results, transient analysis should be applied to all scenarios.

During measurement campaign, only T and RH data were collected. But CFD analysis also require v measurements for more accurate validation. For CFD analysis, v measurements through windows are recommended.

Outdoor air is not modelled in the Thesis because of the time constraints and the capacty of the computer used. Therefore, outdoor surface temperatures are defined as outdoor air temperatures. In addition, the air outlet openings in the scenarios have to be defined as pressure-outlets. If outdoor air is also modelled, pressure difference between the openings and the surface temperatures wouldbe assigned more accurately.

Finally, solar radiation is neglected in the Thesis. In future studies, solar radiation effect should beexamined along with T and RH values.

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APPENDIX A

COARSE MESH RESULTS

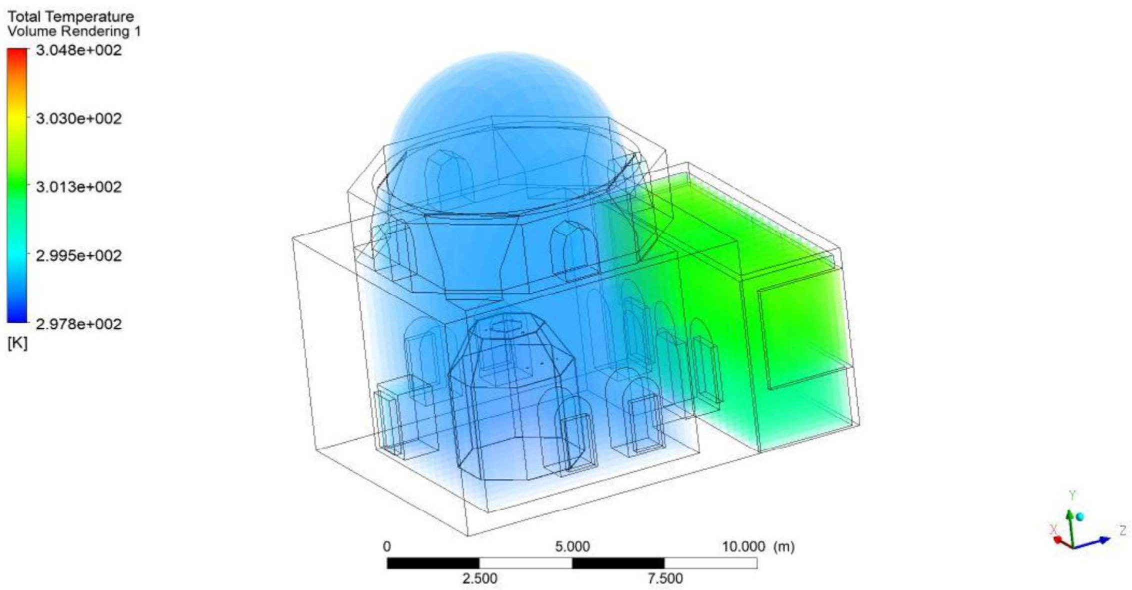


Figure A.1. Render view T result for coarse mesh.

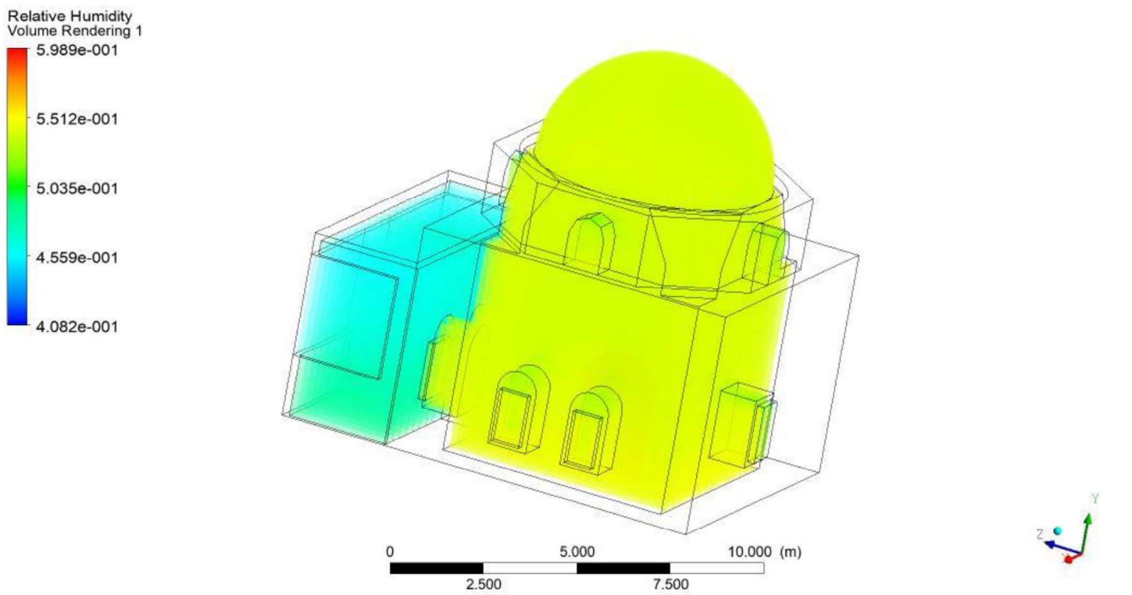


Figure A.2. Render view of RH result for coarse mesh.

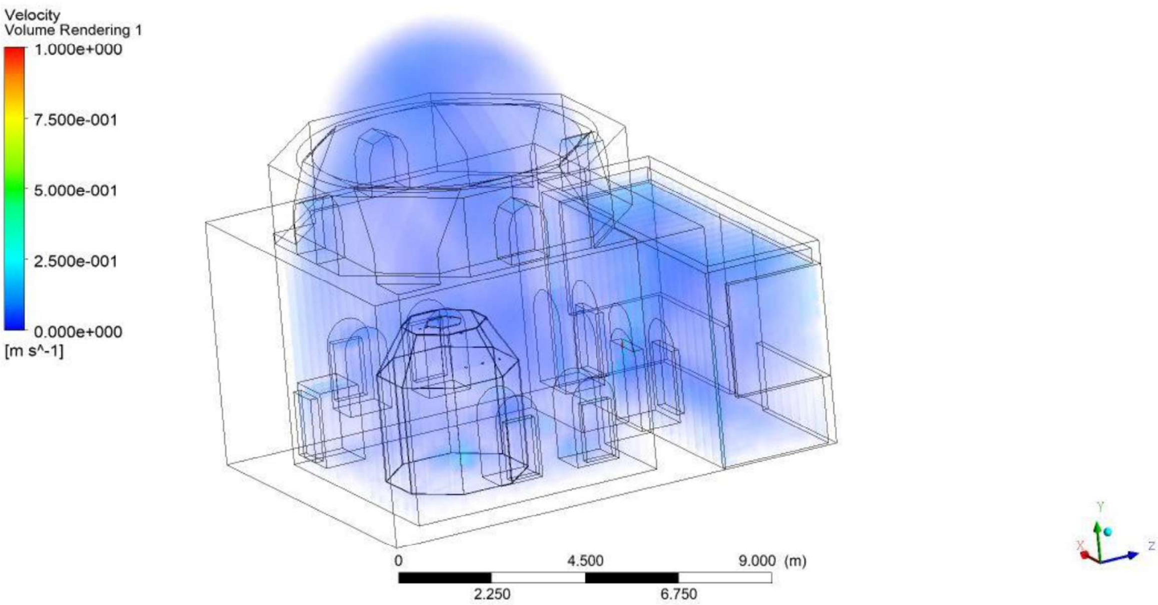
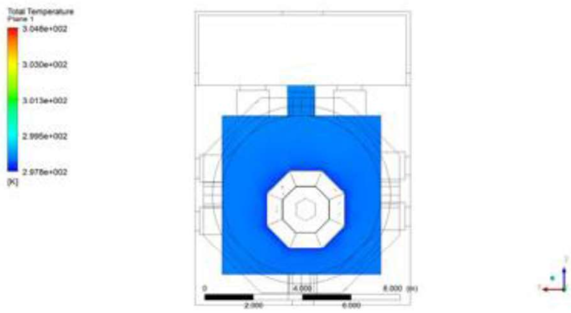
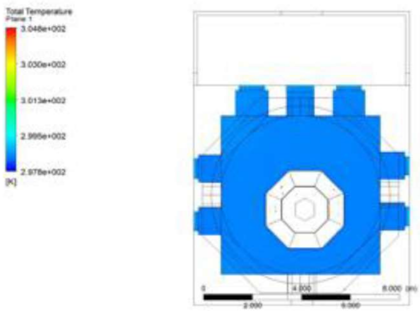


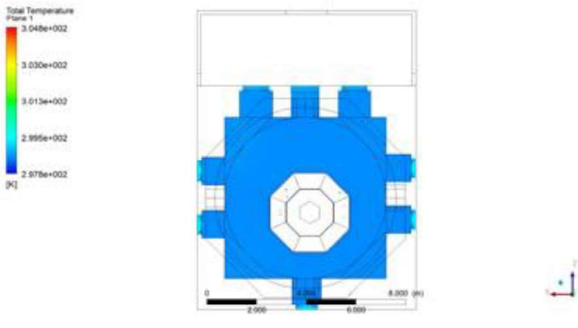
Figure A.3. Render view of v result for coarse mesh.



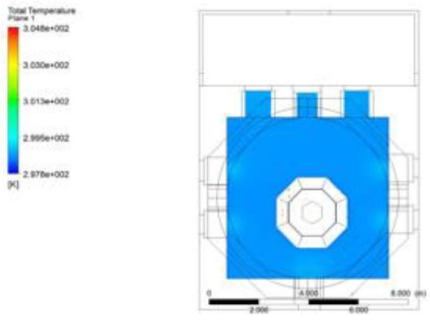
(a)



(b)

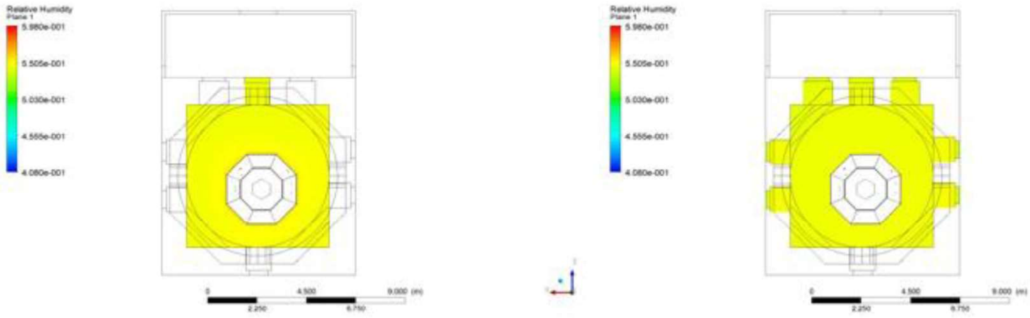


(c)

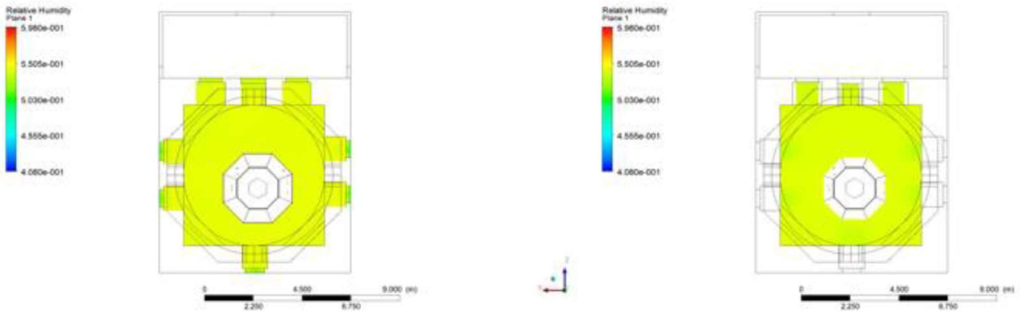


(d)

Figure A.4. T distribution on Main Hall zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3m.

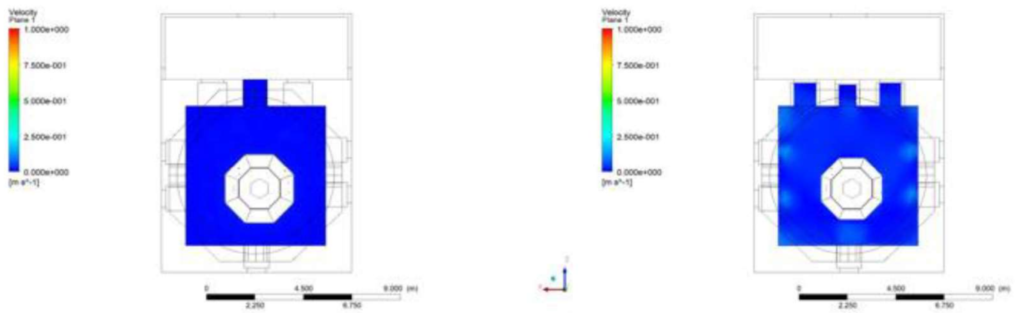


(a) (b)



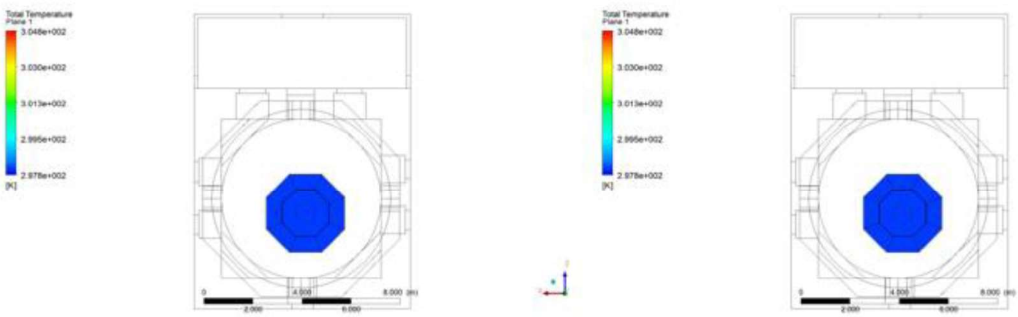
(c) (d)

Figure A.5. RH distribution on Main Hall zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3 (m).



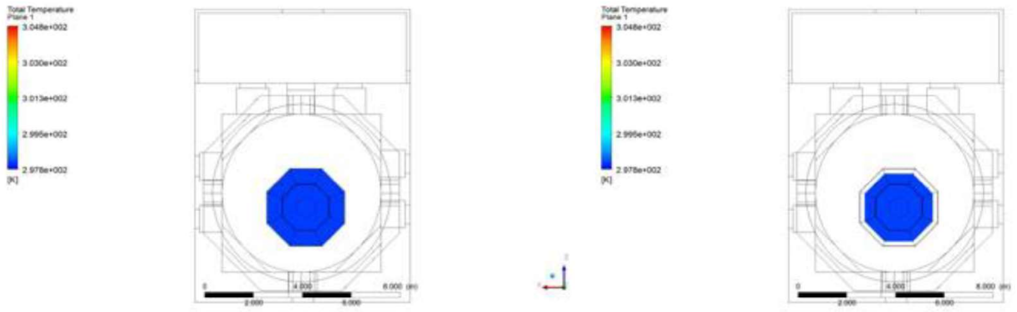
(a) (b)

Figure A.6. V distribution on Main Hall zone on (a) floor and high of (b) 3m.



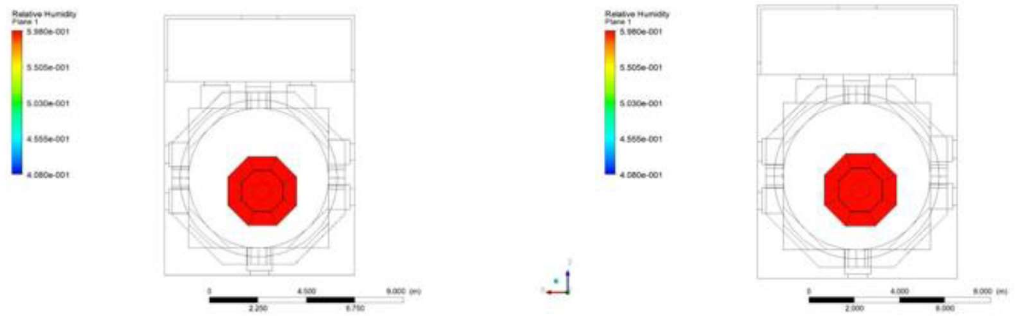
(a) (b)

Figure A.7. T distribution on Manuscript zone on (a) the floor, high of (b) 1m, (c) 2m and (d) 3m (cont. on next page).

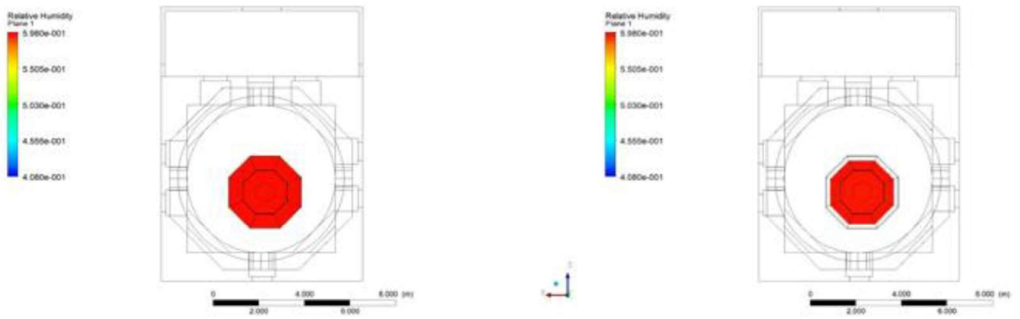


(c) (d)

Figure A.7 (cont.).

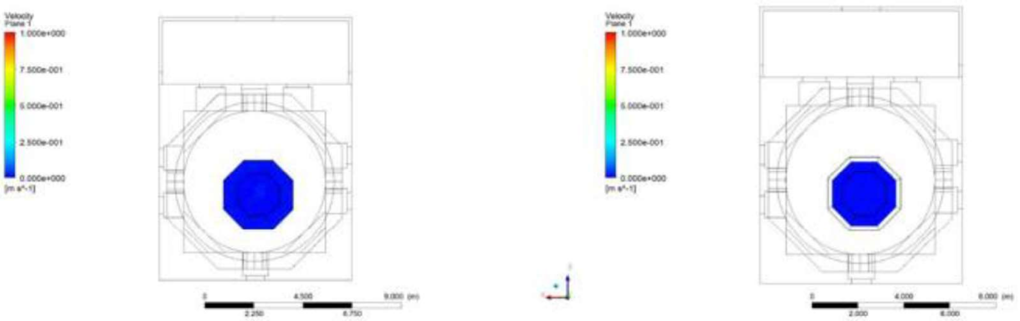


(a) (b)



(c) (d)

Figure A.8. RH distribution on Manuscript zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3 (m).



(a) (b)

Figure A.9. V distribution on Manuscript zone on (a) floor and high of (b) 3m.

APPENDIX B

MEDIUM MESH RESULTS

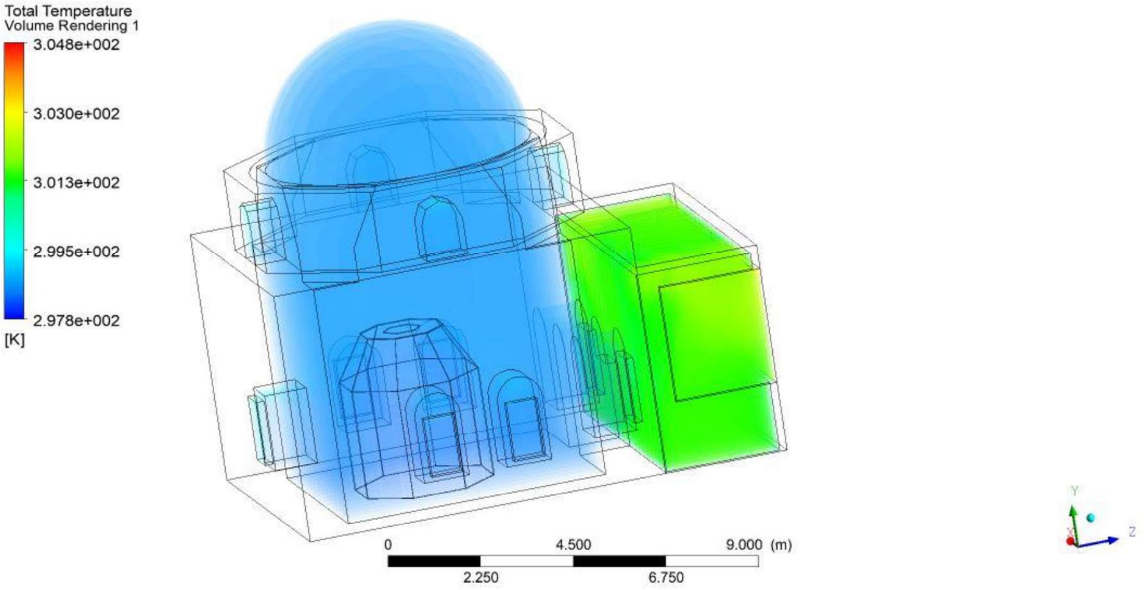


Figure B.1. Render view of T result for medium mesh.

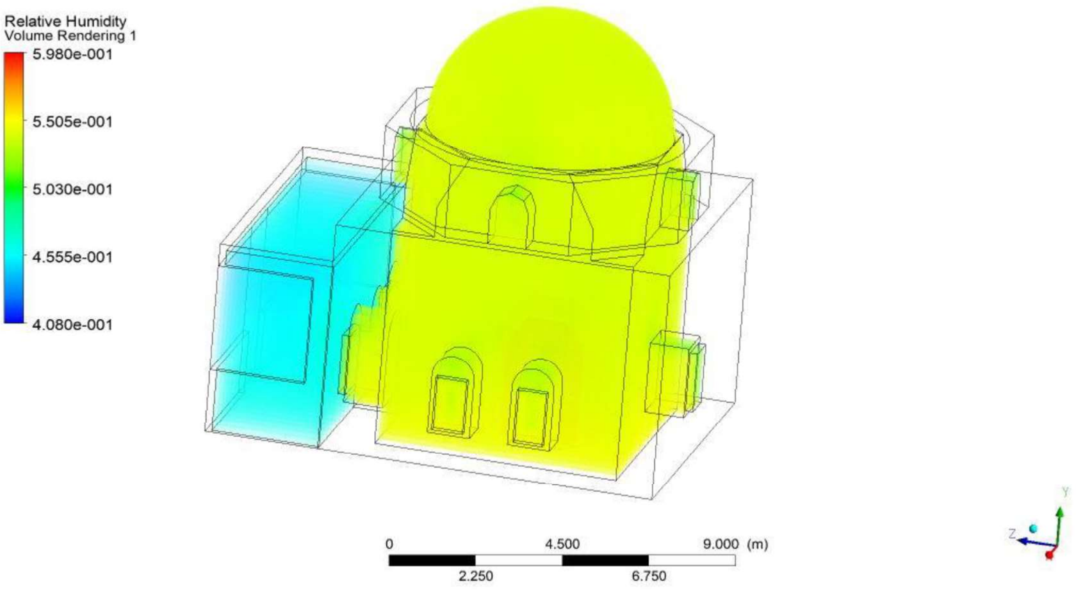


Figure B.2. Render view of RH result for medium mesh.

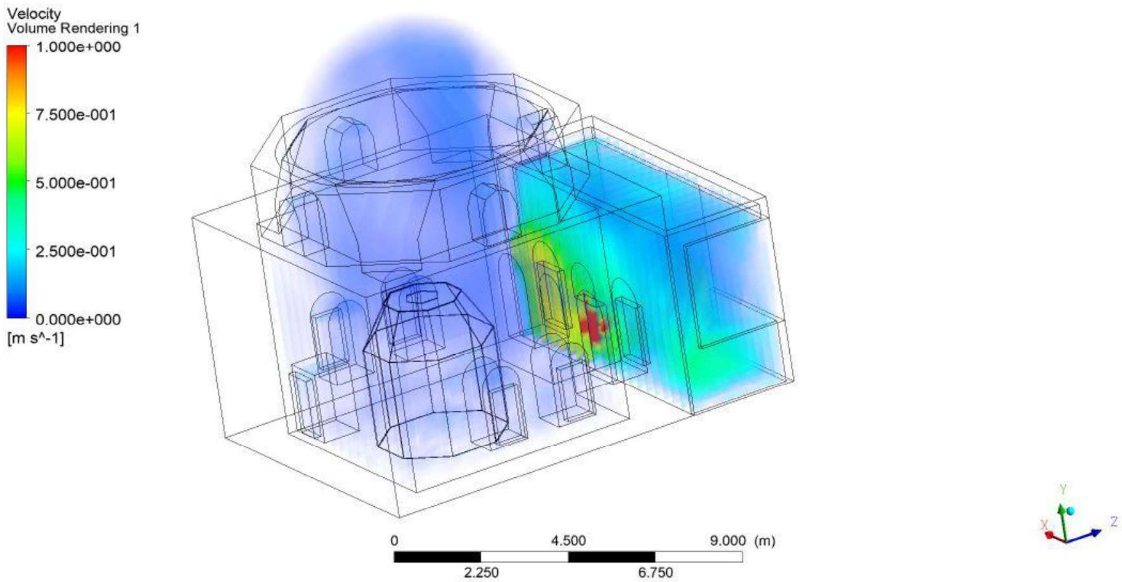
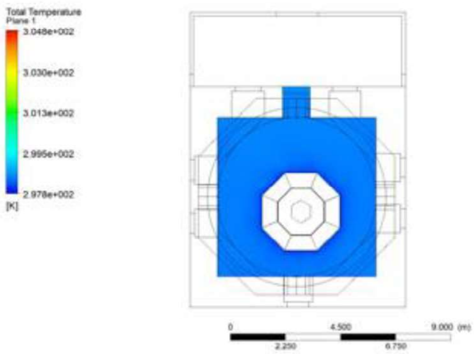
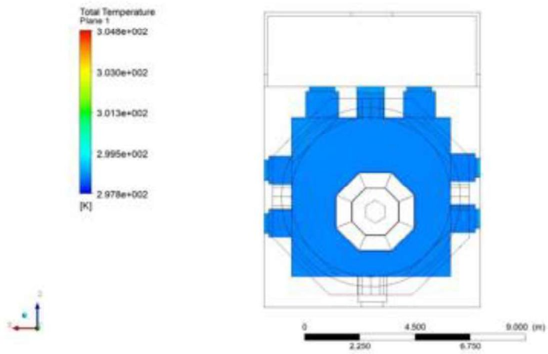


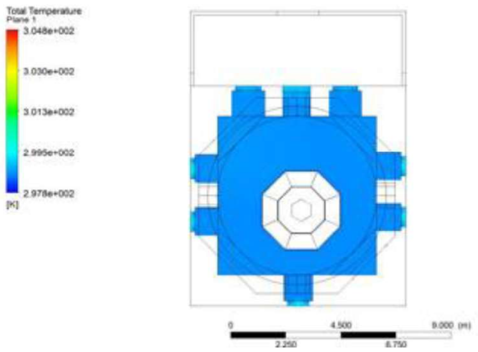
Figure B.3. Render view of v result for medium mesh.



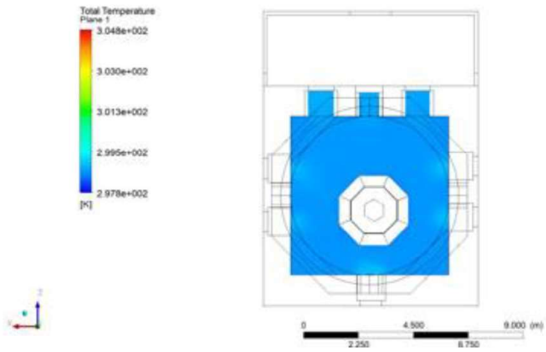
(a)



(b)

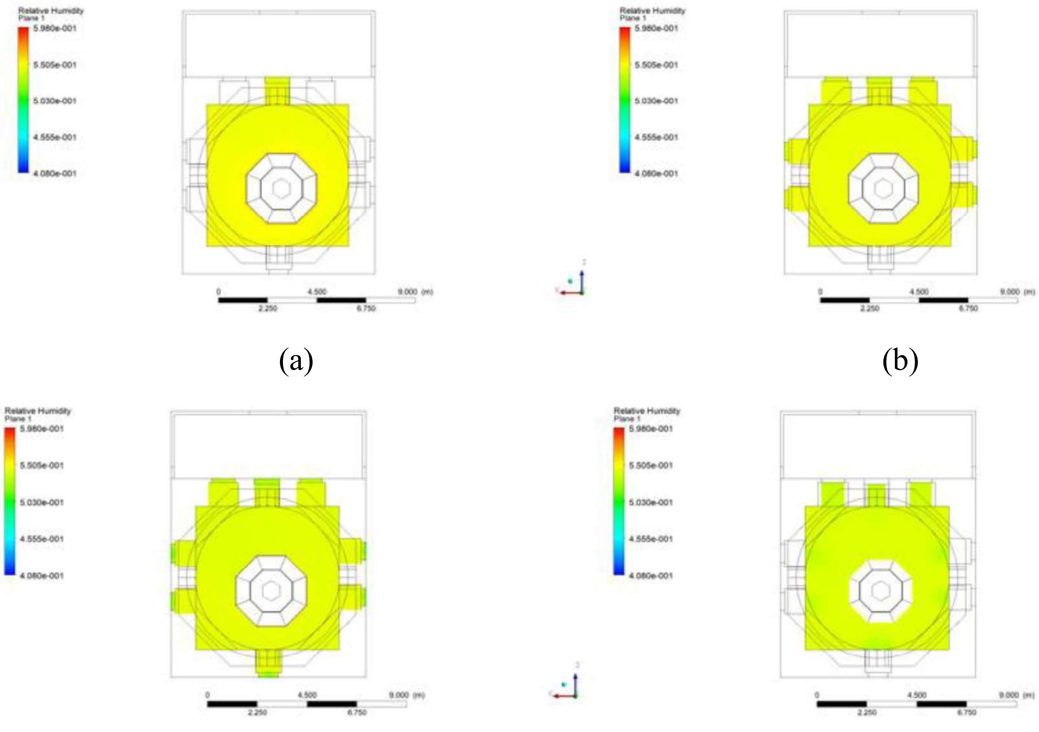


(c)



(d)

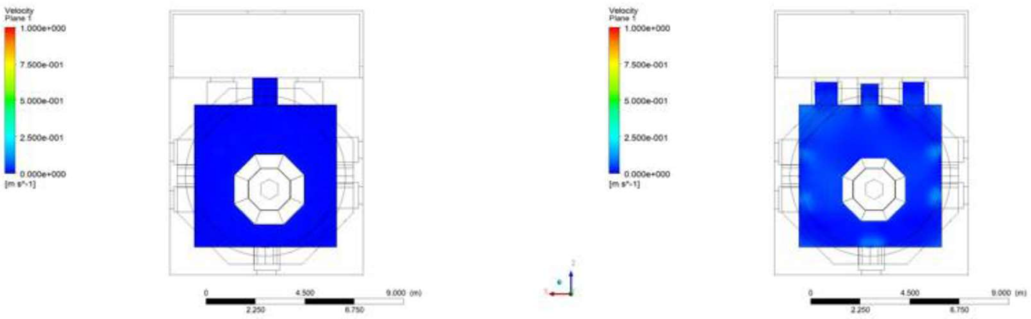
Figure B.4. T distribution on Main Hall zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3m.



(a) (b)

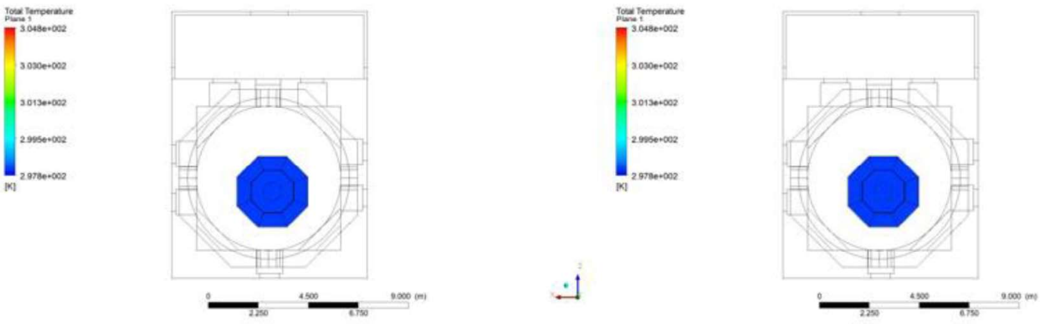
(c) (d)

Figure B.5. RH distribution on Main Hall zone on (a floor, high of (b) 1m, (c) 2m and (d) 3 (m).



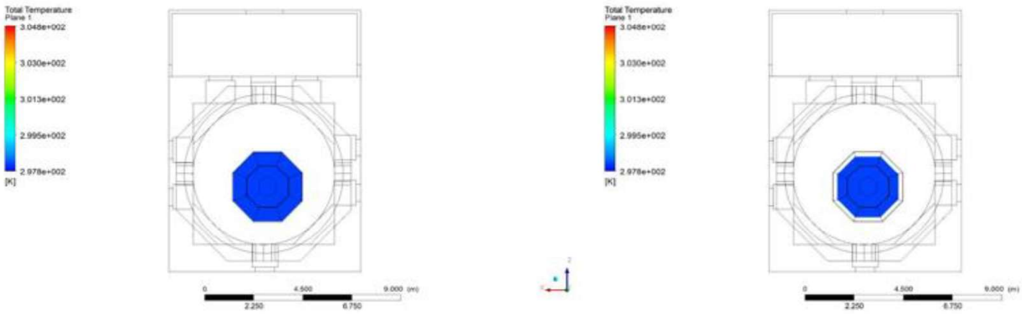
(a) (b)

Figure B.6. V distribution on Main Hall zone on (a) floor and high of (b) 3m.



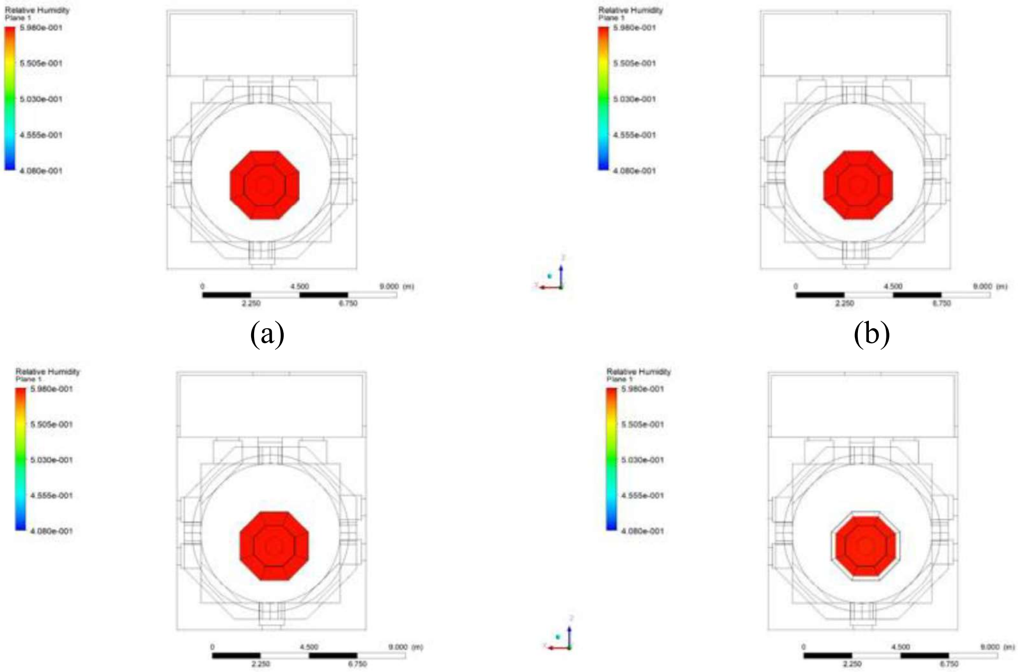
(a) (b)

Figure B.7. T distribution on Manuscript zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3m (cont. on next page).



(c) (d)

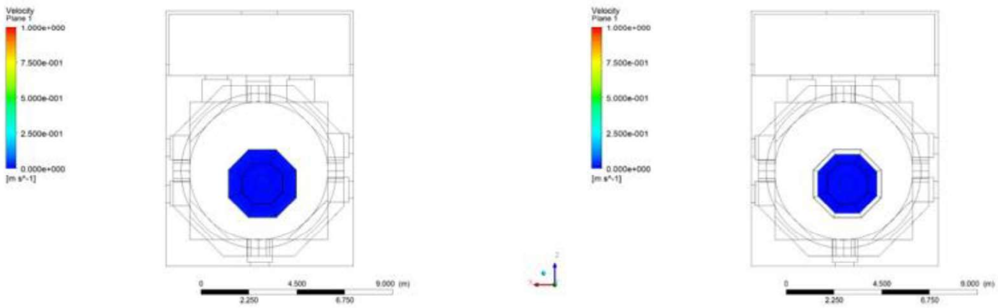
Figure B.7 (cont.).



(a) (b)

(c) (d)

Figure B.8. RH distribution on Manuscript zone on (a) floor, high of (b) 1m, (c) 2m and (d) 3 (m).



(a) (b)

Figure B.9. V distribution on Manuscript zone on (a) floor and high of (b) 3m.