MODELLING OF INDOOR CLIMATE OF HISTORIC LIBRARIES FOR PREVENTIVE CONSERVATION OF PAPER BASED COLLECTIONS

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ABSTRACT

MODELLING OF INDOOR CLIMATE OF HISTORIC LIBRARIES FOR PREVENTIVE CONSERVATION OF PAPER BASED COLLECTIONS

Libraries were seen as an education and cultural center. Cultural properties in libraries can deteriorate chemically, mechanically and biologically because of inadequate indoor climate (temperature, relative humidity and whose fluctuations) and substrates. The aim of the thesis is to improve indoor climate of the historic libraries to preserve paper based collections by preventive conservation approach. As a case study, Necip Paşa Library was selected. The Library, which houses 1147 valuable manuscripts, was built in 1827 in Tire-İzmir-Turkey and has no heating-cooling system except entrance zone. Preventive conservation approach was performed in three phases. As the first phase, the indoor microclimate of the Library was monitored for one year. Secondly, the chemical, mechanical and biological degradation risk analyses are carried out on the manuscripts based on the measurements. According to the measurements, only the chemical degradation is observed. Lastly, the library was modelled via DesignBuilder v4.2.054, and calibrated with respect to ASHRAE Guideline 14. To minimize chemical degradation risk, natural and mechanical ventilation strategies are integrated into DesignBuilder. The natural ventilation scenario did not influence on chemical degradation risk, while the latter diminishes the chemical degradation risks for some extent. The building had two main interventions: the addition of a semi-open entrance space and the closure of this space by wooden-framed windows. To evaluate the effect of these interventions, two different models are developed via DesignBuilder. The simulations of the models did not exhibit any difference on the indoor climate comparing with the existing construction. Evaluation of the scenarios and interventions result with that the mechanical ventilation system is the most effective solution for the Library.

Keywords and Phrases: Library, Tire Necip Paşa Library, Degradation Risks, Paper Based Collections, DesignBuilder, Preventive Conservation, Calibration

ÖZET

KAĞIT KÖKENLİ KOLEKSİYONLARIN ÖNLEYİCİ KORUNMASI İÇİN TARİHİ KÜTÜPHANELERİN İÇ ORTAM İKLİM KOŞULLARININ MODELLEMESİ

Kütüphaneler eğitim ve kültür merkezi olarak görülmüştür. Kütüphanelerdeki yetersiz iç ortam iklim koşulları (sıcaklık, bağıl nem ve bunlardaki dalgalanmalar) ve partiküller, el yazması eserler üzerinde kimyasal, fiziksel ve mekanik bozulmalara neden onlabilir. Bu tezin amacı, tarihi kütüphanelerdeki elyazması eserlerin korunması için iç ortam iklim koşullarının önleyici korunum yöntemi kullanılarak geliştirilmesidir. Necip Paşa kütüphanesi örnek çalışma olarak seçilmiştir. Kütüphane 1827 yılında Tire-İzmir-Türkiye'de yapılmıştır, 1147 elyazması esere ev sahipliği yapmaktadır ve revak bölümü haricinde herhangi bir ısıtma-soğutma sistemine sahip değildir. Önleyici koruma yöntemi üç safhada uygulanmıştır. İlk safhada, iç ortam iklim koşulları bir yıl boyunca izlenmiştir. İkinci olarak, ölçümlere göre el yazması eserler üzerinde kimyasal, mekanik ve biyolojik bozulma analizi yapılmıştır. Sonuçlara göre eserler üzerinde kimyasal bozulma riski gözlenmiştir. Son olarak, kütüphane DesignBuilder v4.2.054 ile modellenmiştir ve modelin kalibrasyonu ASHRAE 14 standartlarına göre yapılmıştır. Kimyasal bozulma riskini azaltmak için, doğal ve mekanik havalandırma modele adapte edilmiştir. Doğal havalandırmanın kimyasal bozulma üzerinde bir etkisi olmamıştır, diğeri kimyasal bozulma riskini belirli bir seviyede azaltmıştır. Binaya iki ana müdahele olmuştur: giriş bölümüne yarı açık revak kısmının eklenmesi ve bu kısmın ahşap çerçeveli camlarla kapatılması. Bu değişimlerin etkisini hesaplamak için DesignBuilder aracılığıyla iki model oluşturulmuştur. Modellerin simulasyon sonuçlarını şuan ki yapı ile karşılaştırıldığı zaman, iç iklim hava koşulları arasında herhangi bir farklılık gözlenmemiştir. Tüm bu senaryolar ve müdaheleler değerlendirildiği zaman, mekanik havalandırma sistemi en etkili çözüm olarak görülmektedir.

Anahtar Kelimeler ve Deyimler: Kütüphane, Tire Necip Paşa Kütüphanesi, Bozulma Riskleri, Kağıt Bazlı Eserler, DesignBuilder, Önleyici Koruma, Kalibrasyon

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A	Cross sectional area	m^2
A_a	Frequency constant	1/s
E_a	Activation energy	J/mol
k	Reaction rate constant	1/s
k_{th}	Thermal conductivity	W/m.K
M_i	Measured value	
N_i	Number of data points	
R	Universal gas constant	J/mol.K
R_{th}	Thermal Resistance	K/W
S_i	Simulated value	
T	Temperature	^{o}C
U	Overall heat transfer coefficient	$W/m^2.K$

CHAPTER 1

INTRODUCTION

1.1. Problem Statement

Buildings can be categorized according to their age (historic, non-historic) and manner of construction (museum, library, archive, dwelling, palace etc.) (Bülow, 2002). Historic buildings provide a substantial continuity between each phase of human development and need to be treated different from non-historic buildings (Bülow, 2002). Historic buildings represent the cultural heritage of societies. Therefore, during the restoration and energy efficient retrofits in historic buildings, preliminary concern must be the preservation of the cultural heritage value.

The percentage of historic buildings in the Europe, which were constructed before 1945, are represented by 23% among the total buildings (Dol and Haffner, 2010). Only, 6.1% of the total buildings are characterized as historic buildings in Turkey (TUIK, 2000).

Heritage value in historic buildings related to historical and architectural features. Beside these non-portable features, portable cultural properties such as collections, manuscripts, ceramics, make contribution to heritage value of historic buildings. The portable cultural properties in a historic building are change with respect to usage of historic buildings.

Historic libraries can be seen as an education and culture center among the historic buildings. The primary sources of the national portable heritage such as manuscripts, unique historical books, collections and archival documents are kept in the historic libraries. (Şinasi and Arslan, 2007). These cultural properties should be preserved by proper storage and exhibition conditions from any environmental risk factors are related to indoor climate (inappropriate humidity, temperature and lighting), indoor air quality (gaseous and particulate pollution like CO_2, SO_2, NO_X, O_3, H_2S etc.) and microbiology (Dahlin, 2002). Chemical, mechanical and biological degradation observe on the cultural properties because of the environmental risk factors. As a result of that, delamination, shrinking, swelling, discoloration and mould growth can be seen on the surface of the cultural properties.

Indoor climate of historic libraries needs to be controlled properly to preserve cultural properties from any degradation risk. Extreme values in temperature (T) and relative humidity (RH) will result in chemical deterioration on the cultural properties. Fluctuations in T and RH values are the main reason for mechanical degradation. Biological degradation is related to the extreme T, RH values and substrates in the environment.

Optimum indoor T and RH values for libraries, museums and archives are defined by the national and international standards. The most well-known standards are the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards (ASHRAE Chapter 21, 2003), British standards (PD 5454, 2012) and International Organization for Standardization (ISO 11799: 2003). In Turkey, there is no any standard related to the storage conditions of paper based collections to the author knowledge.

The standard T and RH values for the preservation of historic properties in museums, libraries and archives are defined in ASHRAE Chapter 21 (ASHRAE, 2003) and five different climate classes is created (Table 1.1). The climate classes are defined with respect to historic properties which are kept in museums, libraries, archives etc.

Table 1.1. Standard T and RH values for museums, libraries and archives
(Source: ASHRAE, 2003)

<table>
<tr><th colspan="2">Climate Classes</th><th>Short term allowable fluctuations</th><th>Seasonal allowable fluctuations</th></tr>
<tr><td colspan="2">AA</td><td>±5% RH, ±2°C</td><td>No change in RH, ±5°C in T</td></tr>
<tr><td rowspan="2">A</td><td>A_1</td><td>±5% RH, ±2°C</td><td>±10% RH,
down 5°C</td></tr>
<tr><td>A_2</td><td>±10% RH, ±2°C</td><td>No change in RH,
down 5°C, up 10°C</td></tr>
<tr><td colspan="2">B</td><td>±10% RH, ±5°C</td><td>Up 10% RH, down 10% RH; Up 10K but not above 30ºC, down as low as necessary to maintain RH control</td></tr>
<tr><td colspan="2">C</td><td colspan="2">Within 25 to 75% RH year-round
T rarely over 30ºC, usually below 25ºC</td></tr>
<tr><td colspan="2">D</td><td colspan="2">Reliably below 75% RH</td></tr>
</table>

There is not any degradation risks for paintings, photographs and books in climate class A, while low, medium and high risk levels are observed on the materials for climate classes B, C and D. Mechanical degradation risk on brittle materials can be introduce as low, medium and high for the climate classes A, B and C, respectively. For paper based collections, minimum required indoor climate conditions are satisfied in climate class A_1.

Historic buildings are important part of cultural heritage value and preservation of them is a duty for societies and countries. Governments and organizations give moral and material support for the restoration of the historic buildings to preserve cultural properties. The Turkish Republic of Prime Ministry Directorate General of Foundations (DG) requested to improve indoor climate of the Necip Paşa Library after restoration by proposing a HVAC system. To reply the request and preserve the manuscripts in the Library from degradation risks, preventive conservation approach is used.

1.2. Aim and Objectives

The main aim of the study is to diminish degradation risks on the paper based collections in historic libraries by using preventive conservation approach. Necip Paşa Library-Tire-Izmir-Turkey is defined as the case building. The Library was built in the beginning of the 19th century and housing 1147 manuscripts. Chemical, mechanical and biological degradation risks on the manuscripts are evaluated by measuring the indoor microclimate parameters such as temperature and relative humidity. The library is also modelled by Design Builder v4.2.054 software to determine the effects of the scenarios proposed to improve the indoor microclimate to prevent deterioration on the manuscripts. The models also used to evaluate the effect of the interventions on the building since its construction. In the Thesis, only temperature and relative humidity are take into account when assessing the degradation risks on the manuscripts. The risk factors caused by indoor air quality (gaseous and particulate pollution) and light are kept out of the scope of the thesis.

1.3. Limitations and Assumptions

During this study, there have been some limitations and assumptions arisen from several sections of the methodology of the thesis. Indoor and outdoor temperature and relative humidity values are measured by mini data logger equipment. Some of the data are missing due to the low battery devices. The missing data points are filled by using the measurements of other data loggers, and previous days’ measurements. The accuracy of the measurement devices are taken from device’s catalogue.

There are some limitations related to the dynamic simulation modelling software, DesignBuilder. The program doesn’t contain all of the construction materials. Thus the properties of materials are measured and calculated, especially the ones of the case specific.

The occupancy and operation schedule of the library is defined by the interviews with the library staff. Actually, the schedules need to be recorded day by day, but in the study, the standardized schedules of the DesignBuilder are used.

1.4. Thesis Outline

The thesis consists of six chapter. The second chapter presents the literature studies about the degradation risks on manuscripts, preventive conservation approach and calibration of building energy simulation models.

In the chapter three, the methodology of the thesis is given. Measurements, indoor microclimate requirements and the standards for the libraries, museums and archives are presented. The main reasons for chemical, mechanical and biological degradation are explained in detail. Besides, information about the simulation model and tool are given. The steps of the calibration process and simulations are introduced.

The chapter four defines the characteristic of the case building in a detail. Location, construction and schedules (occupancy, equipment, ventilation and lighting) of the case building are given in the chapter.

The results of the measurements, calibration process and degradation risk analysis are introduced in the chapter five by representing graphs. The last chapter is based on evaluation of the results.

CHAPTER 2

LITERATURE REVIEW

Preventive conservation of the paper based collections of libraries based on monitoring climate in the library and modelling of the library building are two main study areas of the thesis. Therefore, the literature review presented in this chapter is divided into three topics: review on preventive conservation of cultural properties, degradation risks on paper based collections and calibration of building energy simulation (BES) models.

2.1. Preventive Conservation

The cultural properties which kept in historic buildings, museums, archives and libraries are being affected by storage conditions. The controlling of indoor environment is the only way to keep cultural properties safely. The main risk factors on the cultural properties are temperature, relative humidity, light, gaseous, particulate pollution and substrates. In order to minimize the effect of these risk factors, an approach called as preventive conservation is improved. Preventive conservation can be defined as the observation of cultural heritage and application of measures such as monitoring to prevent mechanical, biological and chemical deterioration on cultural assets (Dardes et al., 1999; Bülow, 2002; Finke, 2008; Lipovec and Balen 2008; Naumovic, 2010; Silva and Henriques, 2015).

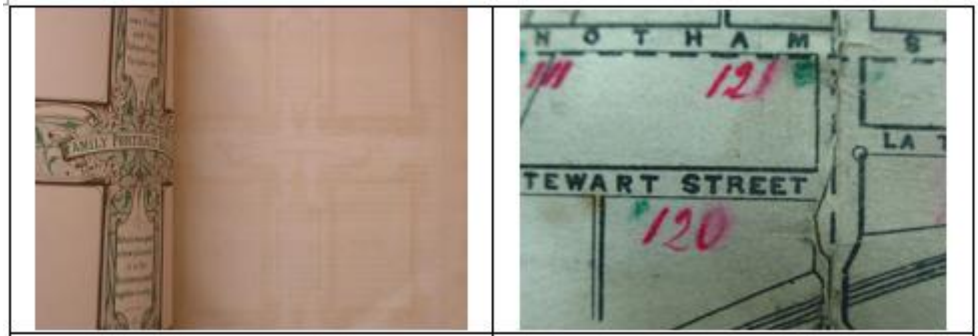
The planning for preventive conservation of a historic building and cultural properties is prepared in the three steps. The first one is the gathering information about the historic building, cultural properties and indoor environment. Initially, indoor environment is monitored throughout a year and measurements are compared with the local weather data of the building. Preliminary data about the construction of the building and storage conditions of the cultural properties are gathered. Detailed information about the building and the cultural properties are collected by on-site observations and interviews with building staff.

The assessment of gathered information and preliminary results of the measurements are made in the second step. General risk factors on the cultural properties and historic building are defined. In this last step, possible solutions to reduce general risks factors on the cultural properties and the building should be proposed (Dardes et al., 1999).

2.2. Degradation Risk Factors

The main environmental risks factors on the paper based collections in historic buildings are the indoor climate and air quality (Dahlin, 2002). Indoor climate is related to temperature, relative humidity and light. Indoor air quality can be explained by gaseous and particulate pollution. The most common pollution elements are SO_2, NO_X, O_3, H_2S, acid and alkaline particles. Organic materials are mostly affected by SO_2, NOx and O_3 (Baer, 1985; Brimblecombe, 1990). Indoor air quality is one of the major problems for preventive conservation studies in historic buildings. The effect of air pollution on the historic buildings and cultural properties are commonly studied in the literature (Pavlogeorgatos, 2003; Schieweck and Salthammer, 2011; Screpanti and De Morco, 2009; Metaxa et al., 2009; Karaca et al., 2010). Standards and guidelines for the critical pollutant levels in archives and libraries are given in the literature (Wilson, 1995; ISO 11799, 2003; Hanus and Hanusova, 2013). Detailed HVAC systems are proposed to historic buildings in order to control indoor climate and air quality (Grabon et al., 2015).

Some visual changes on the objects after deterioration are shown in Figure 2.1 (AICCM, 2016).



Localised staining

Bleeding, blurry appearance

Delamination

Detached

Discolouration

Mould

Figure 2.1. Deterioration samples on paper based collections
(Source: AICCM, 2016)

2.2.1. Chemical Degradation

Chemical reactions taking place within a material are cause of chemical degradation. Two types of reactions occured on the materials; hydrolyses and oxidation. Reaction between a substance and water is called as hydrolysis and as a result of them chemical breakdown occured in original substance and new substances are formed. Paper become less flexible and more brittle becouse of splits the long cellulose chains into shorter ones by acid hydrolysis. Reaction between a substance and oxygen is named as oxidation. As a result of that physical breakdown is occured.

The speed of chemical reaction is related to water content of materials. If the amount of water content in hygroscopic materials increase, deterioration in text and discoloration in papers are observed. Low reaction speed is observed with low T and RH values (Martens, 2012). Equation (2.1) called as Arrhenius Equation, is used to calculate deterioation rate (k) of materials (Zou et al., 1996).

$$k=A_a\times \mathrm{e}^{\frac{-\mathrm{E_a}}{\mathrm{R\times T}}} \tag{2.1}$$

Chemical degradation risk on the manuscripts arises due to extreme T and RH values. Two different techniques are used in order to calculate deterioration rate: lifetime multiplier (LM) and time weighted preservation index (TWPI) (Silva and Henriques, 2015).

The Arrhenius Equation does not response at low humidity values. Thus Equation 2.2 is developed by Michalski (2003). Chemical deterioration rate can be determined for instantaneous T and RH values by Equation 2.2 (Michalski, 2003, Huijbregts et al., 2012; Martens, 2012; Silva and Henriques, 2015; Huijbregts et al., 2015).

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

Equation 2.2 gives the instantaneous response of the manuscripts to the environmental conditions. The value of activation energy (E_a) in Equations (2.1) and (2.2) is defined with respect to type of collection. Activation energy for cellulose based collections is accepted as 100 kJ/mol (Michalski, 2003). In order to evaluate annual response, the annual averaged LM (Equation 2.3) is used (Huijbregts et al., 2012; Martens, 2012). Huijbregts et al., 2012, determine the annual averaged LM value for museum objects in a reference building. The reference building is a historic church located in Eindoven-Netherland. In order to understand the effect of climate change on the deterioration of the cultural heritage, the chemical degradation risk analysis on the reference building is carried out by using the different climate zones (Figure 2.2).

$$\overline{LM}=\sum_{x=1}^{n}\left(\frac{50\%}{RH_x}\right)^{1.3}\times e^{\frac{E_a}{R}\left(\frac{1}{T_x+273.15}-\frac{1}{293.15}\right)} \tag{2.3}$$

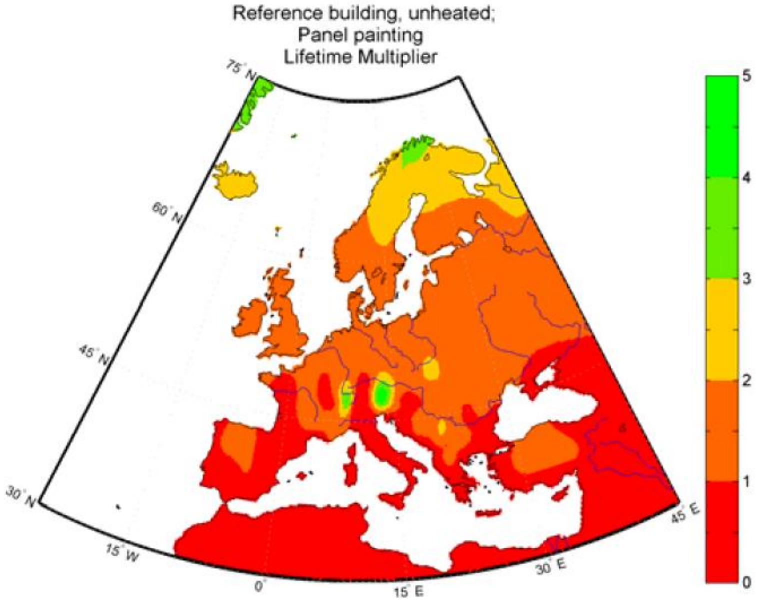


Figure 2.2. Predicted annually averaged LM in the unheated reference building for different climate zones in the Europe (Source: Huijbregts et al., 2012)

Lifetime multiplier curves for different T and RH values are calculated and shown in Figure 2.3. (Martens, 2012). Two different activation energy are used in the Figure 2.3.

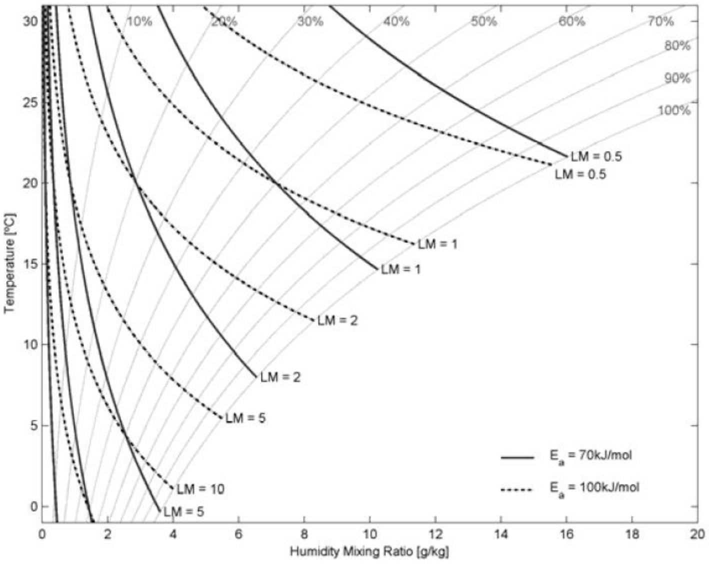


Figure 2.3. The curve of LM values in psychometric chart
(Source: Martens, 2012)

The indoor environment is called as risky and safe for collections if the LM value is lower than one and higher than one, respectively. The highest LM values are seen with the lowest T and RH values. When T and RH values increase, the reaction speed also increases. This situation results in chemical degradation.

TWPI is used to calculate the life expectancy of papers by using monitored T and RH values in a mathematical formula (Reilly et al., 1995; Krüger and Diniz, 2011; Nishimura, 2011; Silva and Henriques, 2015). The method is developed by Image Permanence Institute (IPI) and gives empirical result based on specific data for cellulose acetate. Therefore, it is not possible to obtain any results for other type of materials (Silva and Henriques, 2015).

2.2.2. Mechanical Degradation

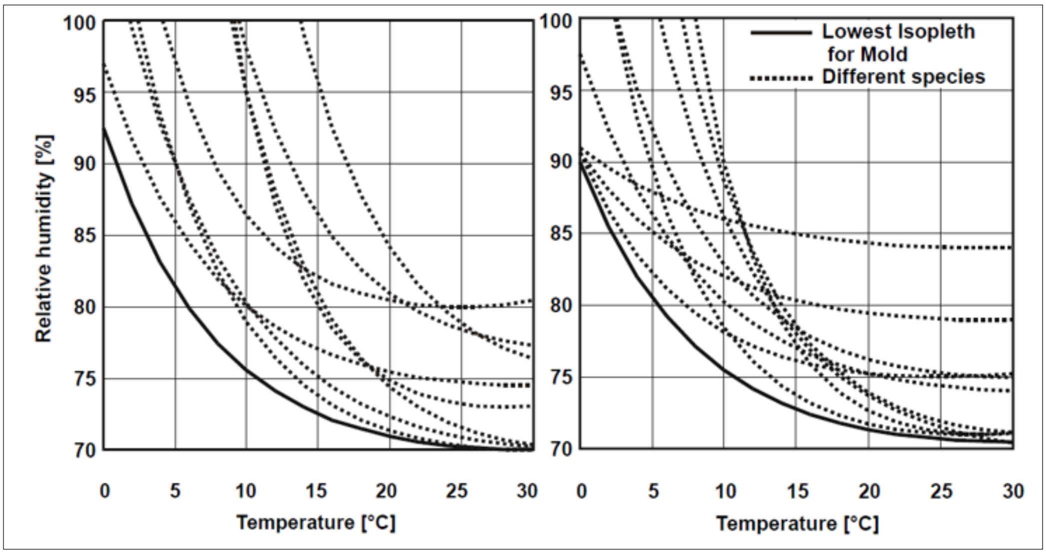
Fluctuations in T and RH are the main reason for mechanical degredation (Silva and Henrique, 2015). Dimensional alterations, shrinking and swelling on paper based collections are observed as a result of mechanical degradation. Daily allowable T and RH fluctuations for paper-based collections are ±2°C and ±5%RH, respectively. The fluctuations are standardized by ASHRAE (ASHRAE Chapter 21, 2003), PD 5454 (PD 5454, 2012) and ISO 11799 (ISO 11799: 2003). In addition, high (above 65%) and low (below 25%) RH values result in mechanical damage. At low RH values (below 25%), warping, cracking, embrittlement and delemination can be observed on paper based collections.

2.2.3. Biological Degradation

T, RH and substrates are the main reasons for biological degradation. Mould growth on surface of the materials is the indicator of biological degradation. Substrates can be defined as material type in the environment.

The researchers (Warscheid and Krumbein, 1994) define a growth curve for fungus microorganisms, and it is divided into three phases. First two phases are called as mycelium growth and spore germination. The last phase is named as sporulation. In order to avoid from biological deterioration, spore germination of the microorganisms needs to be prevented.

Isopleth systems determine the germination time and growth rate with respect to T, RH values and substrates. Lowest isopleth for mold (LIM) line is used to determine the lowest occurring limit of mould growth. LIM graphs for spore germination and mycelium growth is given in Figure 2.4 (Sedlbauer et al., 2001, Sedlbauer et al., 2003). At low T and RH values, the collections are safe in terms of the biological degradation risk.



(a) (b)

Figure 2.4. LIM line for isopleths of different species. (a) Spore germination (b) Mycelium growth (Sedlbauer et al., 2003)

In order to determine mould growth, Sedlbauer’s isopleth diagrams (Figure 2.4) are used as a reference in most of the studies such as Huijbregts et al., 2012; Martens, 2012; Silva and Henriques, 2015. The above of the LIM curve is called as risky region for mould growth.

Sedlbauer et al., 2001 study on the prediction of mould growth on the surface of and inside building components in Phd thesis. In order to predict mould growth on material surfaces an isopleth diagram is created for different substrate types with respect to T and RH values. The substrates are categorized in four groups and individual isopleth diagrams are created only first three groups 0, I and II (Figure 2.5).

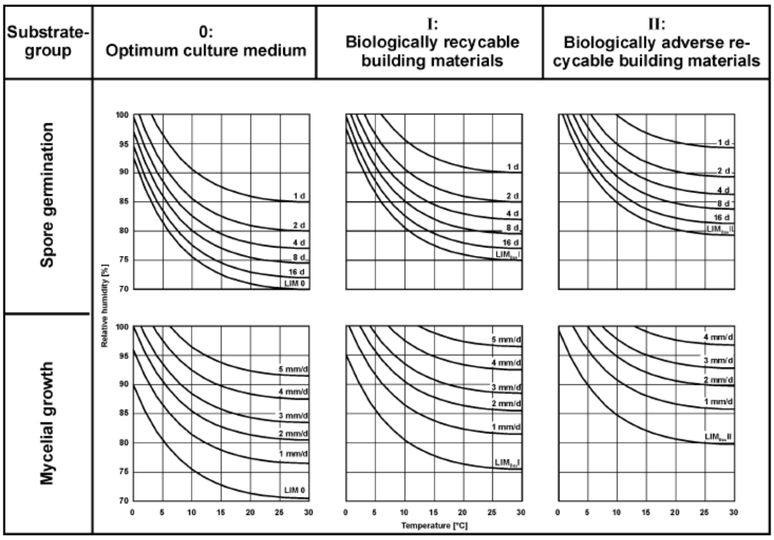


Figure 2.5. Development of the LIM line for isopleths for substrate classes 0, I and II
(Source: Sedlbauer et al., 2001)

2.3. Calibration of BES Model

In this section, the literature on calibration methods of building energy simulation models are reviewed. Calibration process is an important part of simulation of a BES model. In order to get more accurate data from the BES models, the calibration need to be carried out properly. There is not exact solution for calibration process, therefore, the researchers are developed different techniques and are followed different procedures (Kaplan et al., 1992).

Reddy, 2005 classified calibration techniques into four categories;

i. Calibration based on manual, iterative and pragmatic intervention
ii. Calibration based on a suite of informative graphical comparative displays
iii. Calibration based on special tests and analytical procedures
iv. Analytical/mathematical methods to calibrate models

i) Calibration based on manual, iterative and pragmatic intervention

The simulation parameters are changed manually in order to match with measurements in the first technique and it is called as ad-hoc technique. Base load analysis is used in the technique and the calibration process is divided into seven steps; base case modelling, base load consumption analysis, swing-season calibration, site interview and measurements, heating and cooling season calibration, validation of calibrated base model and evaluation energy conservation measures (ECMs) of simulation model (Kaplan et al., 1990; Hunn et al., 1992; Norford et al., 1994; Reddy et al. 1994; Lunneberg, 1999; Pedrini et al., 2002; Yoon et al. 2003).

The ad-hoc technique is improved and evidence-based methodology is started to use in the calibration process (Raftery et al., 2011). In evidence based methodology, data about the simulation model is ordered with respect to a hierarchy and any parameter related with simulation model cannot be change without evidence (Raftery et al., 2011; Bertagnolio et al., 2012). The hierarchy of data sources for evidence based methodology is given in Figure 2.6.

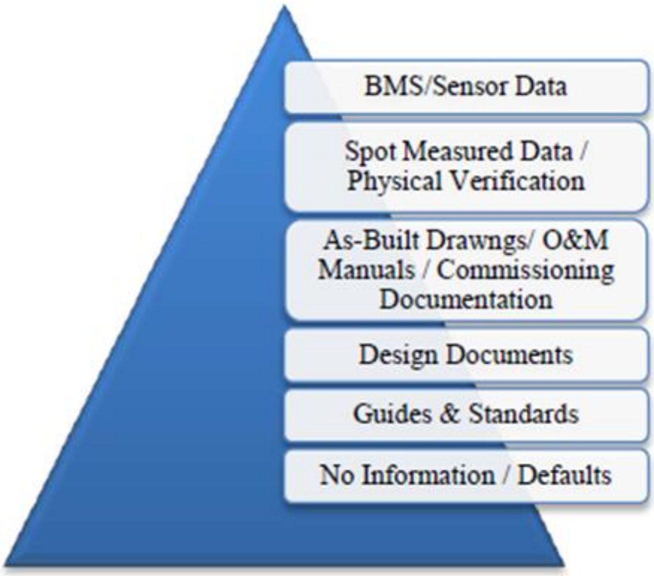


Figure 2.6. The hierarchy of data sources
(Source: Coakley et al., 2014)

ii) Calibration based on a suite of informative graphical comparative displays

In the second technique, calibration is based on graphical comparative displays. In the technique, bar-charts are used to compare data differences between the simulated and measured values. The technique is valid only monthly analysis and is insufficient for hourly analysis (Bronson et al. 1992; Haberl et al. 1993; McCray et al. 1995; Haberl and Bou-Saada, 1998).

iii) Calibration based on special tests and analytical procedures

The third calibration technique can be called as automated calibration and the signature analysis approach is used (Manke and Hittle, 1996; Reddy et al., 1999; Liu et al., 2005; Kandil and Love, 2013; Basurra et al., 2015, Li et al. 2015).

iv) Analytical/mathematical methods to calibrate models

The last technique proposed by Carroll and Hitchcock (Carroll and Hitchcock, 1993) and based on mathematical analysis. There are a small number of studies on the technique (Reddy et al., 2007; Sun and Reddy, 2006; Baltazar and Claridge, 2007; Heo et al. 2012; Coakley et al., 2012; Manfren et al, 2013).

The validation of calibrated model can be made by dimensionless error indicators. Mean bias error (MBE) and the coefficient of variation of the root mean squared error CV(RMSE) are accept as criteria for the calibration of model. The acceptance criteria for the MBE and CV(RMSE) in ASHRAE Guideline 14 are 10% and 30% for the hourly measurements, respectively (ASHRAE, 2002).

CHAPTER 3

MATERIALS AND METHODS

The degradation risks on the paper based collections in historic libraries are evaluated by observing indoor climate through measurement campaigns. Libraries are also modelled through building energy simulation (BES) software to observe the effect of retrofitting, climate change and various ventilation scenarios on the indoor climate. The models should be validated using measurement data. In the Thesis, one year measurement campaign was conducted on the case building, Necip Paşa Library, as well as the building was modelled and validated by Design Builder software. Therefore, the methodology of the Thesis can be summarized under three titles: measurements, calibration and simulations (Figure 3.1).

During the measurement campaign indoor and outdoor temperature (T) and relative humidity (RH) values in and out of the Library are measured and stored for a year. The measured data are used to evaluate indoor climate of the Library based on chemical, mechanical and biological degradation risk on the manuscripts. Then BES model of the Library is created via DesignBuilder software. Simulation weather file created by using outdoor measurements and uploaded to BES model. The model is calibrated using measurement data with respect to ASHRAE Guideline 14 (ASHRAE, 2002). Following the calibration, the model is simulated for two different ventilation scenarios (mechanical and natural ventilation) applied to the building to improve indoor environment to decrease the degradation risk on the manuscripts. Beside the existing building model, two more models are created for the changes in the architecture of the Library representing different periods: semi-open entrance and no entrance models. The latter models are simulated in the same way of existing building model and results are compared.

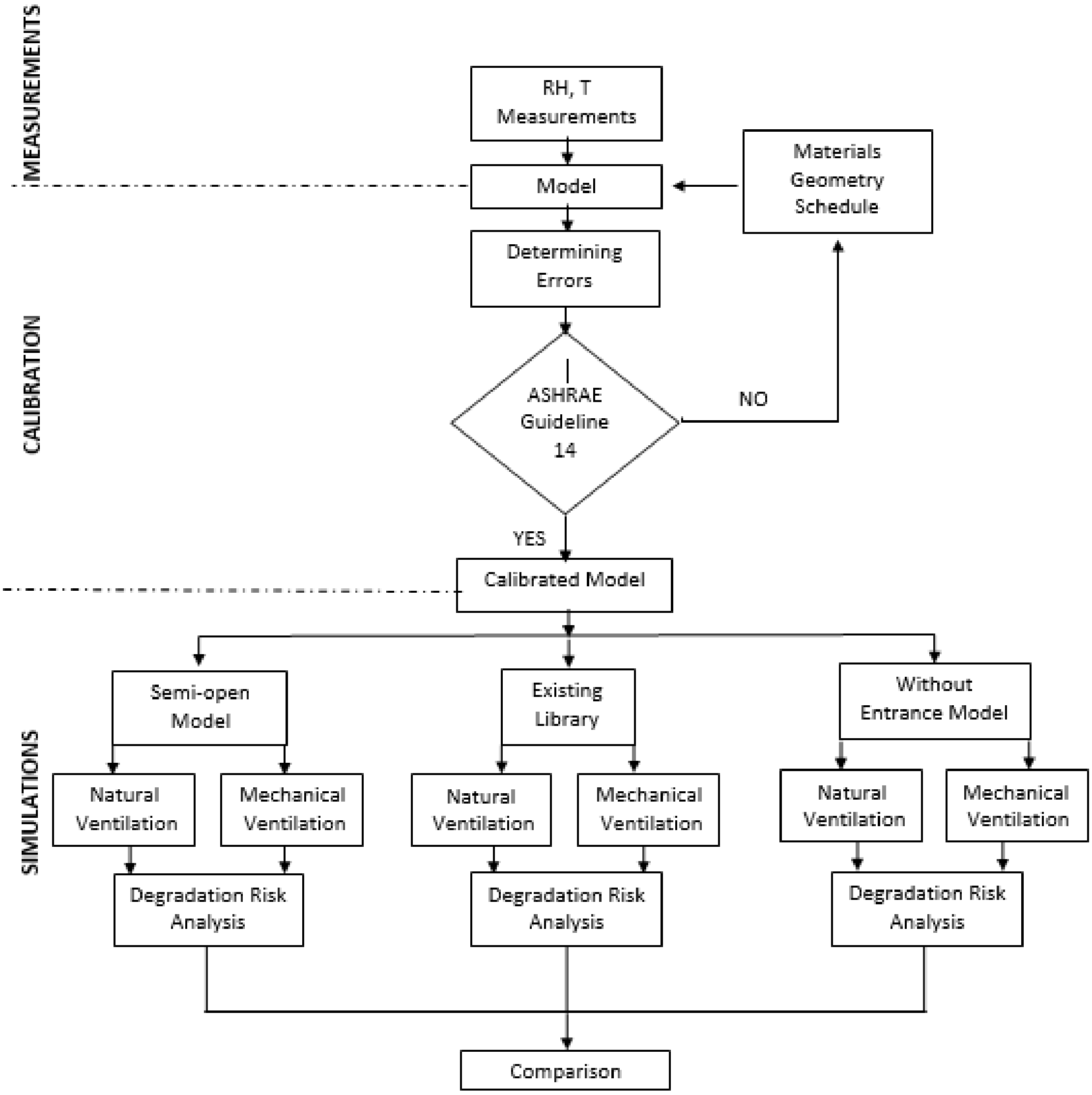


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Figure 3.1. Flow diagram of the methodology

3.1. Measurements

The T and RH data of the Library were monitored throughout a year, from the beginning of September 2014 till the end of August 2015. Five mini dataloggers were located in the main hall (#1&2), manuscript zone (#3), entrance zone (#4) and outside of the Library (#5), (Figure 3.2).

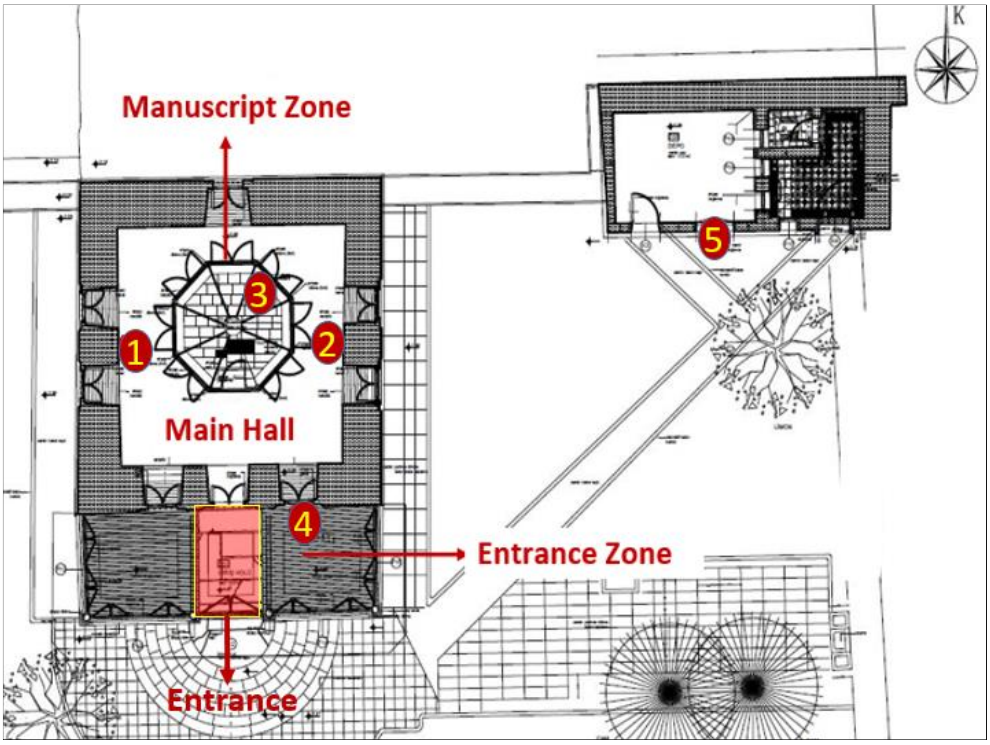


Figure 3.2. Locations of mini data loggers
(Source: Ekizoğlu, 2012)

All data loggers are located approximately 1.5 m above from the ground level. Technical specifications of mini data loggers are given in Table 3.2. Data loggers measure T and RH values with an accuracy of ±0.35°C and ±2.5%, respectively. During the monitoring campaign, some of the data were missed due to low battery of the data loggers. The missing data were calculated by using the data which are taken from other data loggers and previous days' measurements.

Table 3.1. Technical specifications of data logger

Type	HOBO U12 Temp/RH/Light/External Data logger
Measurement Range	Temperature: -20°C to 70°C Relative Humidity: 5% to 95%
Accuracy	Temperature: ±0.35°C from 0°C to 50°C Relative Humidity: ±2.5% from 10% to 90%
Battery life	1 year typical use
Memory	64K bytes

T and RH values are measured and stored every ten minutes by data loggers. The hourly average of the measurements are taken and the numbers of data points are reduced in order to compare measurements with simulation results and standards in the literature. Indoor and outdoor climate of the library is evaluated with respect to hourly data. Also, a weather file which installed to the BES model, is created by using the outdoor measurements. Two data loggers are used in the main hall and #2 in the Figure 3.2, is not evaluated in this study due to the respective numbers of missing points.

3.2. Degradation Risks on Manuscripts

Degradation risks on manuscripts are divided into three main categories: chemical, mechanical and biological risks. The main reasons for degradations are T, RH and substrates materials.

3.2.1. Chemical Degradation

Chemical degredation risk on manuscripts is evaluated by using Lifetime Multiplier (LM) method. Equation 3.1 is used to calculate LM values where; for cellulose activation energy (E_a) and universal gas constant are accepted as 100 J/mol and 8.314 J/mol.K, respectively (Silva and Henriques, 2015). Equation 3.1 gives instantaneous response of the manuscripts to the indoor environment. 1°C decrease in T or 5% decrease in RH give same result in Equation 3.1. There critical values which show the risk level of indoor environment on manuscripts are listed in Table 3.2 (Martens, 2012).

$$LM_x = \left(\frac{50\%}{RH_x}\right)^{1.3} \times e^{\frac{E_a}{R}\left(\frac{1}{T_x+273.15}-\frac{1}{293.15}\right)} \tag{3.1}$$

In order to evaluate annual response of the manuscripts, average of LM values are taken into account (Huijbregts et al., 2012).

Table 3.2. Critical LM values
(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*

3.2.2. Mechanical Degradation

Fluctuations in T and RH data are the main reason for mechanical degredation (Silva, 2015). The mechanical degradation is observed when allowable daily fluctuation values are exceeded. Daily allowable fluctuations for T and RH values are defined as 3°C and 5%, respectively (Grygierek, 2014). In ASHRAE climate class A_1 daily allowable fluctuations in T and RH values for short time period are standardized as ±2°C and ±5%RH (ASHRAE, 2003).

3.2.3. Biological Degradation

Biological degredation on manuscripts are measured by mould risk factor (MRF). The limit values for MRF are given in Table 3.3.

Table 3.3. The critical values for MRF
(Source: Silva and Henriques, 2015)

	Ideal	**Good**	**Some risk**	**Potential risk**	**High risk**
MRF	*0*	*<0.5*	*[0.5; 1]*	*1*	*>1*

In the Thesis, WUFI-Bio software is used to asses MRF (WUFI, 2011). Three substrate classes are defined in the software to evaluate critical water content and to determine spore germination (Table 3.4). Paper based collections are the members of substrate II.

Table 3.4. Substrate classes
(Source: WUFI, 2011)

Substrate Class 0	**Substrate Class I**	**Substrate Class II**
Optimal culture medium	Bio-utilizable substrates (wall paper, plaster board etc.)	Less bio-utilizable substrates with porous structure (plasters, mineral building materials, certain woods)

Critical water content can be defined as the the minimum amount of moisture content in a spore which allows germination. Shematic drawing of a spore on the wall surface are given in Figure 3.3. Water content in a spore is compared with critical water content in order to decide is there any mould growth or not on the surface of a wall.

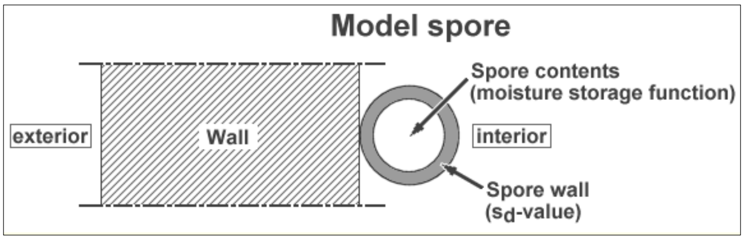


Figure 3.3. Schematic drawing of the spore
(Source: WUFI, 2011)

In the software, critical water content represent with unit of kg/m^3. The unit of water content comes from simplification. Moisture content is accepted as porosity (m^3/m^3) of a material at 100% RH in the software. The unit of water content is obtained by multiplying porosity of the material with density of water (1000 kg/m^3) (Noval et al., 2001). Critical water content in the software related to moisture content in the material. Critical water content is defined as 450 kg/m^3 for substrate class II (for mineral based building material) in order to keep objects safely (Krus et al., 2009).

Limiting isopleths diagram (LIM) in WUFI-Bio software shows the mould growth rate of substrates. The critical curves for different substrate classes are given in Figure 3.4. Germination is to be expexted on substrates for data point which is above the LIM curve.

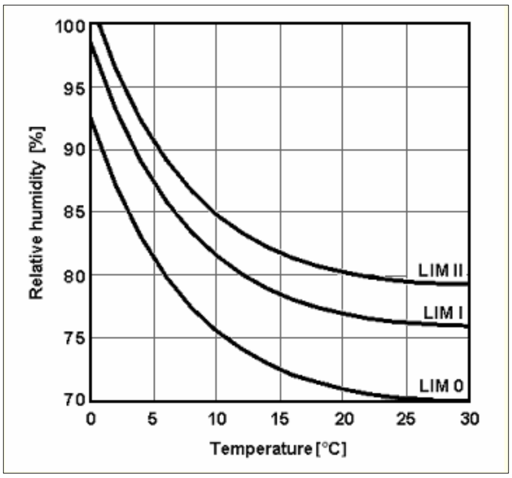


Figure 3.4. Isopleth diagram for substrate classes
(Source: WUFI, 2011)

In the software, seven different mould index value are used to determine the MRF. (Table 3.5) (WUFI, 2011). Mould index values are the indicator of mould growth level on the surface of materials.

Table 3.5. Description of mould index values
(Source: WUFI, 2011)

Index	Description
0	No growth
1	Some growth visible under microscope
2	Moderate growth visible under microscope, coverage more than 10%
3	Some growth detected visually, thin hyphae found under microscope
4	Visual coverage more than 10%
5	Coverage more than 50%
6	Tight coverage, 100%

3.3. BES Model

The BES model of the library is developed and all simulations are made by DesignBuilder dynamic simulation software (DesignBuilder, 2012).

3.3.1. The Model

The simulation model of the historical library consists of three zones: main hall, manuscript zone and entrance zone, is created with respect to geometry and construction materials of the library. Surrounding buildings and trees are drawn in order to obtain more accurate model.

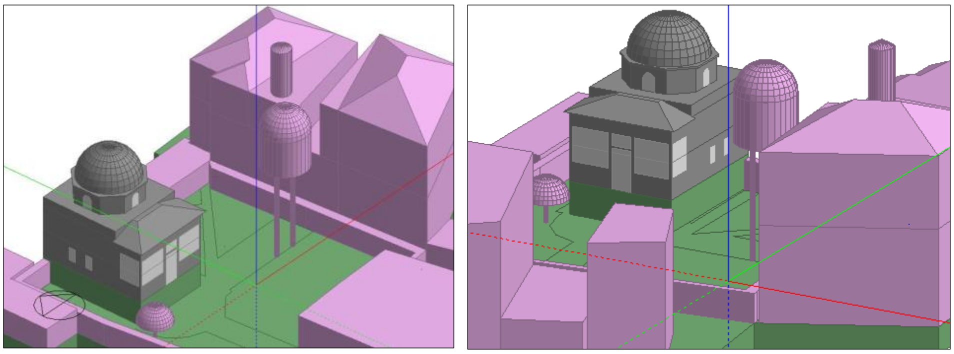


Figure 3.5. BES model of the Library

The library is drawn in building format while surrounding buildings are drawn in component format (Figure 3.5). In DesignBuilder software, component blocks functions for only shadow and wind calculations. Outer view and zone plan of the Library is shown in Figure 3.6.

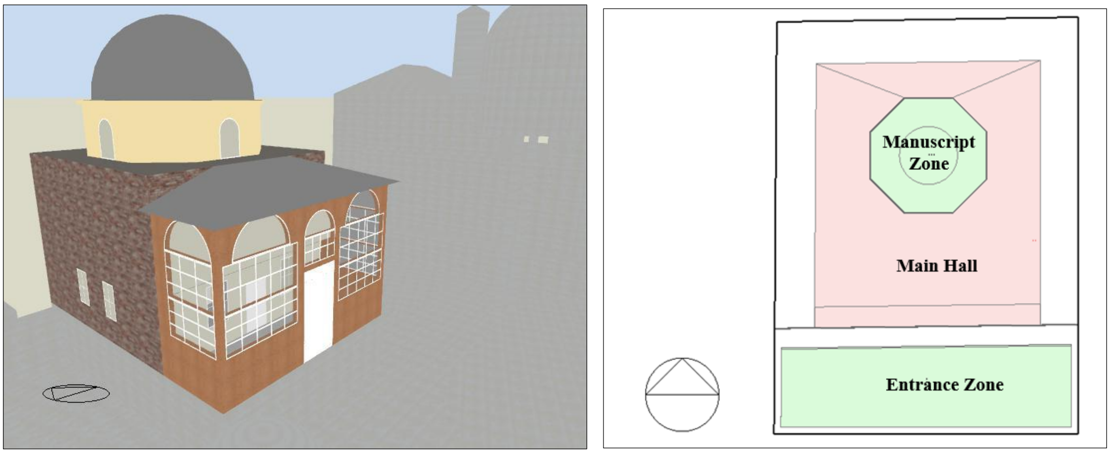


Figure 3.6. Outer view and zone plan of the Library

Inner view of the Library and the manuscript zone are shown in Figure 3.7. At the initial stage of the modelling, the Library was drawn as a simple cubic shape. Then, top of the Library was covered with dome and entrance zone was added. The wall between the entrance zone and the main hall was drawn as partition. In order to define the manuscript zone inside of the main hall, the main hall was drawn into two parts (Figure 3.8). Geometry of the model was completed by adding windows and doors.

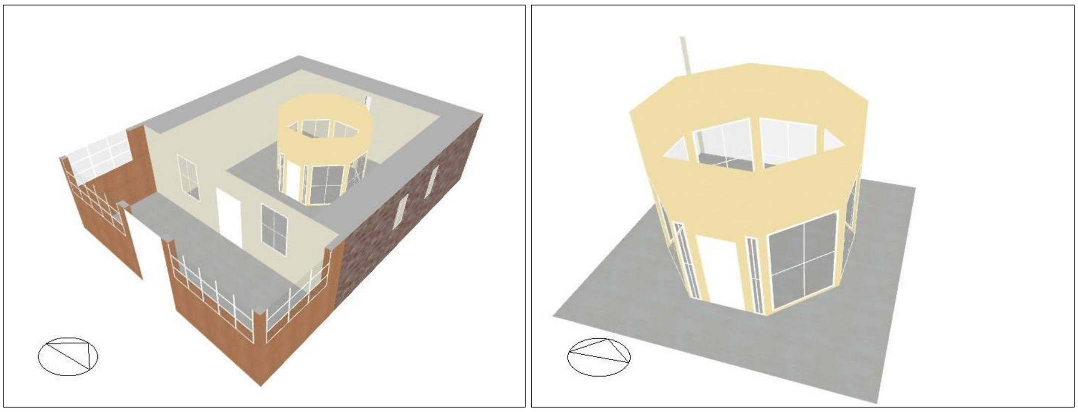
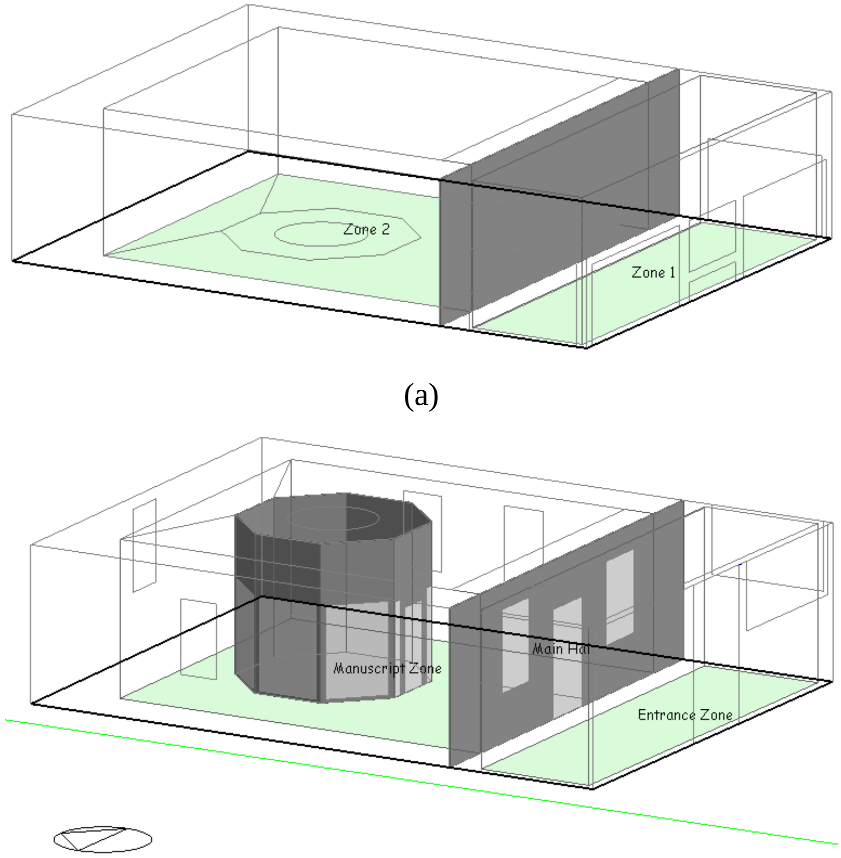


Figure 3.7. Inner view of the model



(a)

(b)

Figure 3.8. The sections of the main buildings (a) upper part and (b) lower part

All construction materials of the Library were defined in situ and integrated into the model while schedules for occupancy, equipment, lighting and HVAC system was created based on the information obtained from the manager of the Library.

Overall heat transfer coefficients (U) of the external walls were calculated by electrical analogy. In Equation 3.2, thermal resistance (R_{th}) and area (A) of the wall were used to calculate U. The wall area was obtained from architectural drawing of the Library while R_{th} was calculated by using Equation 3.3. Thickness of the wall was represented by L in Equation 3.3. Thermal conductivity (k_{th}) of the wall should be known in order to calculate R_{th}.

$$U = \frac{1}{R_{th,total} \times A} \tag{3.2}$$

$$R_{th} = \frac{\mathrm{L}}{k_{th} \times A} \tag{3.3}$$

Physical properties (density, thermal conductivity, etc.) of construction materials in historic buildings are mostly not described in the literature. Thus, different calculation and measurement methods are developed in order to calculate the physical properties. Thermal conductivity (k_{th}) of brick and stone samples, were used in the external walls of the library, was measured by QTM-500 device.

The indoor climate of unheated historic buildings is mainly affected by infiltration rate (Luciani et al., 2013). Infiltration can be defined as the movement of air through building's leakage area (Sfakianaki et al., 2008) and can be measured by blower door test which consists of a blower door machine and a fan. During the measurements pressure difference between in and out of the building and air flow rate of the fan are measured. Equation 3.4 is used to convert ACH_{50} in 50 Pa to air change per hour (ACH) in natural situation (Sherman and Dickerhoff, 1998). In Equation 3.4, the value of n is change between 10 and 30 with respect to age and type of the building (Alfano et al., 2012).

$$ACH \approx \frac{ACH_{50}}{n} \qquad (3.4)$$

3.3.2. The BES Tool

DesignBuilder dynamic simulation software, v4.2.054, is used for modelling and simulation of the Library (DesignBuilder, 2012). DesignBuilder uses EnergyPlus as simulation engine. EnergyPlus were developed in the 1980s in The USA (EnergyPlus, 2000). FORTRAN programming language using a modular approach is used to develop EnergyPlus. The solution technique of the program is based on the Predictor-Corrector Method (Rahman et al., 2008).

DesignBuilder has user-friendly interface and extensive data templates for building energy simulation inputs like lighting and HVAC systems, occupancy and equipment schedules, construction materials (Wasilowski and Reinhart, 2009), and allows to determine heating and cooling loads (Tronchin and Fabbri, 2008). The software includes thermal mass and thermal bridging. There are some limitations related with the program such as defining wall thickness between the zones, creating a zone inside of another zone. Calculation of relative humidity in the software need to be improved.

3.4. Calibration of the Model

The primary aim of the calibration is to gather more accurate results from the model by matching the behaviour of the model with the actual behavior of the building. In calibration process, actual behavior of the building represented by measured T and RH values. The model calibrated according to ASHRAE Guideline 14 (ASHRAE, 2002). Two dimensionless error indicators, are called as mean bias error (MBE) and coefficient of variation of root-mean-square error (CV (RMSE)) are used as criteria for calibration process. The mean of differences between measured and simulated values are calculated in MBE (Eq. 3.5). In this indice, negative values cancel the positive values. In CV (RMSE), method the cancellation effect is solved by taking the square of the differences between the measured and simulated values (Eq. 3.6) (Coakley, 2014).

$$MBE = \frac{\sum_{i=1}^{N_i}(M_i - S_i)}{\sum_{i=1}^{N_i} M_i} \tag{3.5}$$

$$CV(RMSE) = \frac{\left[\left[\frac{\sum_{i=1}^{N_i}[(M_i - S_i)^2]}{N_i}\right]\right]^{\frac{1}{2}}}{\frac{1}{N_i}\sum_{i=1}^{N_i} M_i} \tag{3.6}$$

The monthly and hourly upper limits for MBE and CV (RMSE) are given in Table 3.6 (Coakley, 2014). The acceptance of the model is measured by the limits defined in ASHRAE Guideline 14.

Table 3.6. Acceptance limits for calibration of BES models defined by ASHRAE Guideline 14 (Source: Coakley, 2014).

Standard / Guideline	**Monthly Criteria (%)**		**Hourly Criteria (%)**	
	MBE	**CV (RMSE)**	**MBE**	**CV (RMSE)**
ASHRAE Guideline 14	5	15	10	30

The flow diagram of the calibration process is shown in Figure 3.9. After, the simulation of the model, the results are compared with measurements, and error values are calculated. If the error values higher than ASHRAE Guideline 14 values, the model is updated and simulated again. This process continue until the error values match with the ASHRAE limitations. The simulation model is calibrated with respect to hourly T and RH values.

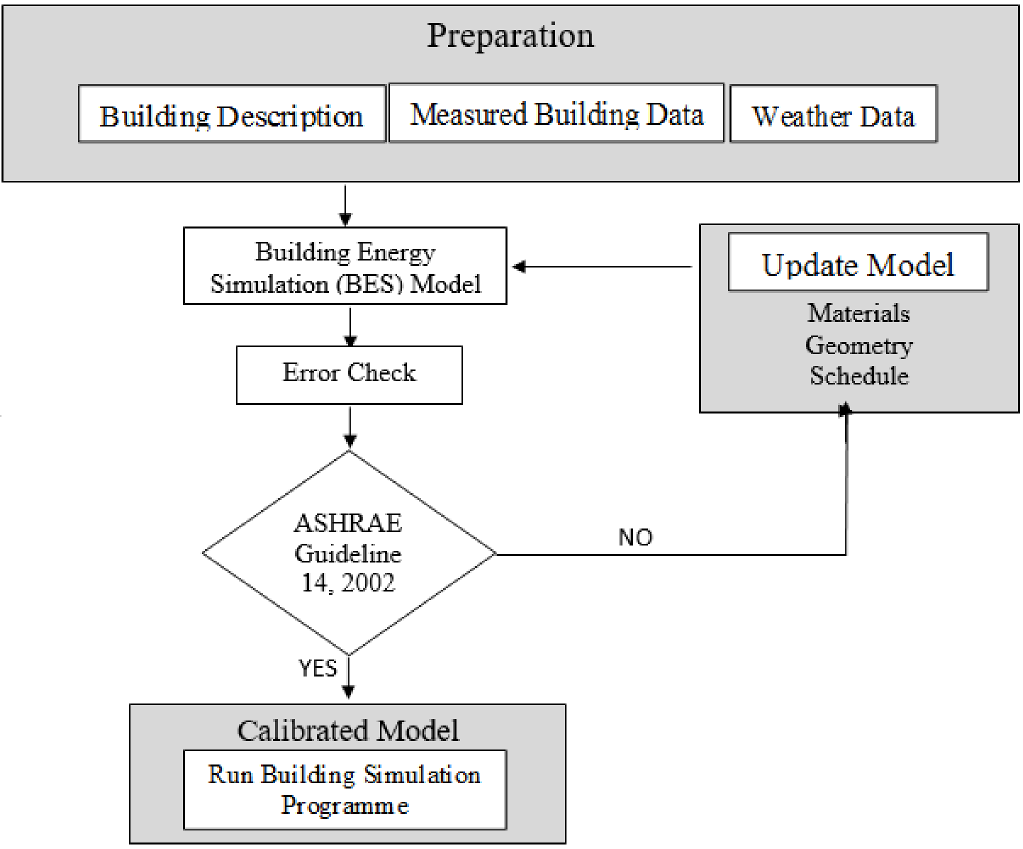


Figure 3.9. Flow diagram of the calibration process

3.5. Simulations

The main aim of simulations is to improve indoor climate of the Library by proposing different scenarios. Natural and mechanical ventilation system scenarios will be integrate to the calibrated model. The parameters, are used in the ventilation scenarios, will be defined with respect to measured T and RH values in the library.

The original construction of the Library is changed during the years. Two different models which are semi-open and without entrance model are proposed to DesignBuilder in order to calculate the effect of the models on the indoor climate of the Library. The natural and mechanical ventilation system scenarios will be integrate to the models.

CHAPTER 4

CASE STUDY

4.1. Case Study: Tire Necip Paşa Library

Directorate General of Foundations (DG) of Turkey is in charge of keeping the cultural and architectural heritage of the Country alive. One of the DG's duties is conducting restoration projects on cultural properties. Izmir branch of DG contacted our research group to carry on a project on Necip Paşa Library-Tire-İzmir-Turkey in 2014. They were planning a restoration work on the Library. The Thesis is a part of this project aiming to determine the impact of the existing indoor climate on the manuscripts and recommendations on a better preservation environment. The location of the library is given in Figure 4.1.

Figure 4.1. The location of the Library
(Source: YandexHaritalar, 2016)

The Library is surrounded by trees and on east side an office building which has an average height of 14 m and a length of 9 m is exist (Figure 4.2). Façades of the library is shown in Figure 4.3 (a), (b) and (c).

Figure 4.2. Surroundings of the Library
(Source: GoogleMaps, 2016)

(a) (b) (c)
Figure 4.3. Façades of the Library; (a) west (b) east and (c) north
(Source: Ekizoğlu, 2012)

4.1.1. History of the Building

Necip Paşa Library was built in 1827 by Mehmet Necip Paşa who was a statesmen during the reign of Sultan Mahmut II. The Libray houses 1147 manuscripts, 1135 printed book in the era of Ottoman Empire and more than 9000 books written in Latin letters. Mehmet Necip Paşa devoted 671 books to the Library and at the meantime almost 13,000 books are exist in the Library (Yıldırım, 2011). The entrance of the existing Library is depicted in Figure 4.4.

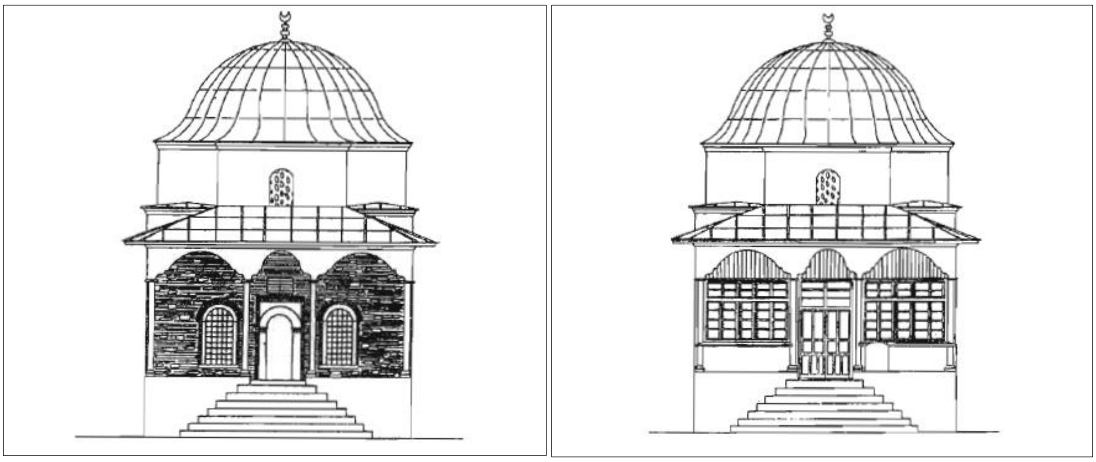
Figure 4.4. South façade of the Library
(Source: GoogleMaps, 2016)

The original construction of the library consists of a cubic shaped building covered with a dome shaped roof which is called as detached Library. First sample of detached libraries in Turkey is Köprülü Library which was constructed in 1661 in İstanbul. The libraries constructed with similar structure are Amcazade Hüseyin Paşa Library (İstanbul/1700, includes ground floor), Damat İbrahim Paşa Library (İstanbul/1719-20), Amediye Library (İstanbul/1722, includes ground floor) Hekimoğlu Ali Paşa Library (İstanbul/1734-35) and Raşid Efendi Library (Kayseri/1797).

The original construction does not contain entrance region (personal communication, Canan Malkoca). Based on the literature, first an entrance (Revak) region made of wooden frames (Figure 4.5), then an octogonal shaped cage-like structured wooden frame (at the beginning of the 20th century) was added to the Library (Figure 4.6). The last structural interventions was covering the entrance region with windows in 1930 (Fig. 4.7 (b)) (Ekizoğlu, 2013).

Figure 4.5. Necip Paşa Library with entrance region
(Source: Riefstahl, 1929)

Figure 4.6. Manuscript section
(Source: Ekizoğlu, 2012)



(a) (b)

Figure 4.7. The southern view of the Library with (a) semi-open and (b) existing entrance (Source: Bayraktar, 2003).

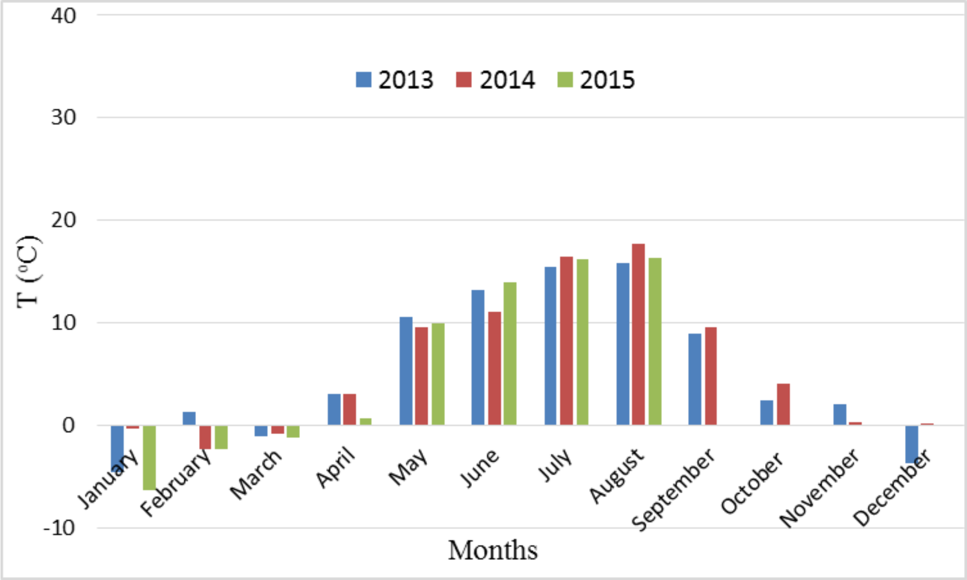
4.1.2. Local Weather data

Historic buildings generally have no heating and cooling system, therefore indoor climate is affected by the outdoor climate. The library has located in a typical Mediterranean climate called as temperate humid. The monthly average minimum temperatures are vary between 6-8°C for winter time and ≥25°C during summer time (Turhan et al., 2014). The measured average temperatures by Tire Meteorological Station for summer and winter seasons are given in Table 4.1.

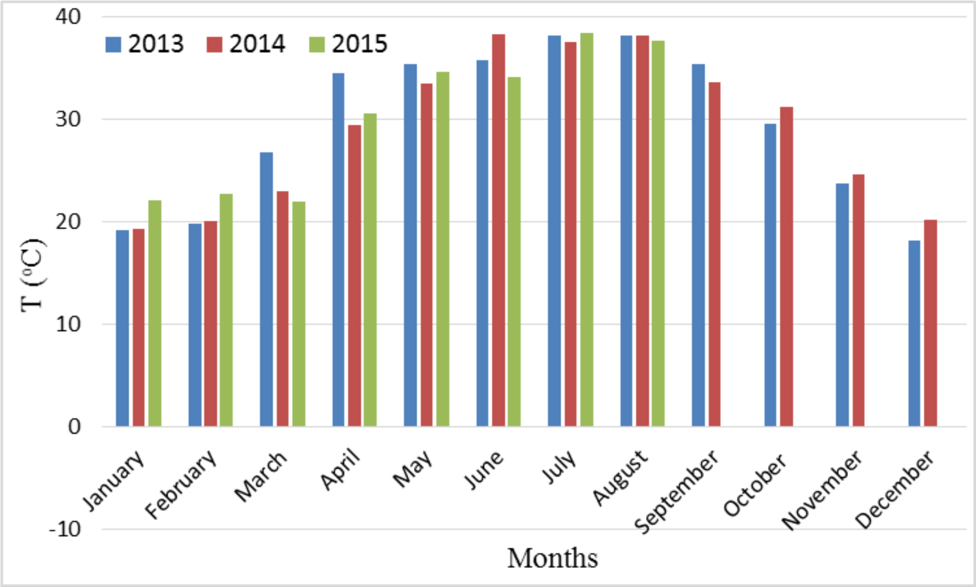
Table 4.1. Average T values for summer and winter seasons in Tire-İzmir (Source: Turkish State Meteorological Service)

	Average temperature (°C)		
	Winter (December, January, February)	**Summer (June, July, August)**	**Annual**
2013	8.9	26.2	16.98
2014	8.2	25.7	17.30
2015	8.8	25.8	17.60

Monthly minimum and maximum temperature values measured by Tire Meteorological Station between 2013 and 2015 are given in Figure 4.8. The lowest temperature values are observed in December, January, February and March (≥-10°C) while the highest temperature values are seen in July and August (≥ 35°C).



(a)



(b)

Figure 4.8. Monthly minimum (a) and maximum (b) T values for Tire between 2013-2015 (Source: Turkish State Meteorological Service)

Wind speed and directions are an important characteristic for outdoor climate. A wind vane for Tire-İzmir is created by taking data from METEONORM V.6.0 (METEONORM, 2005) (Figure 4.9).

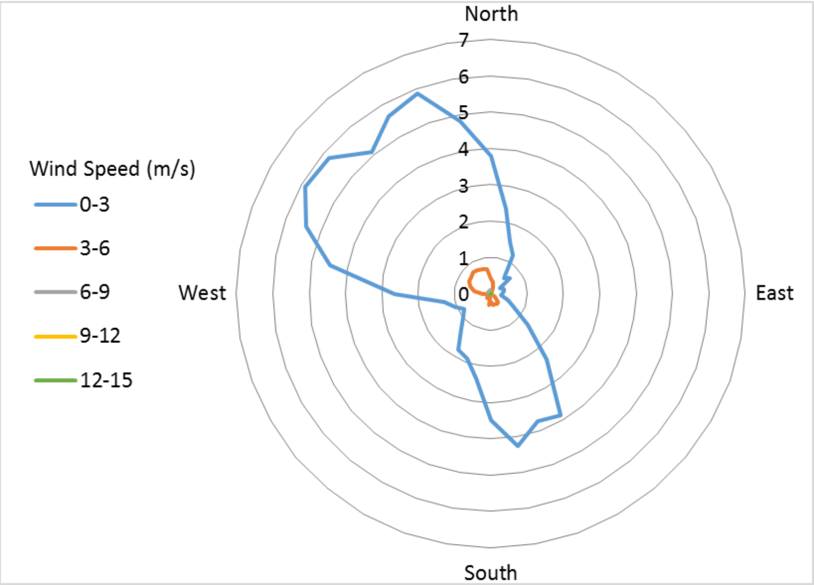
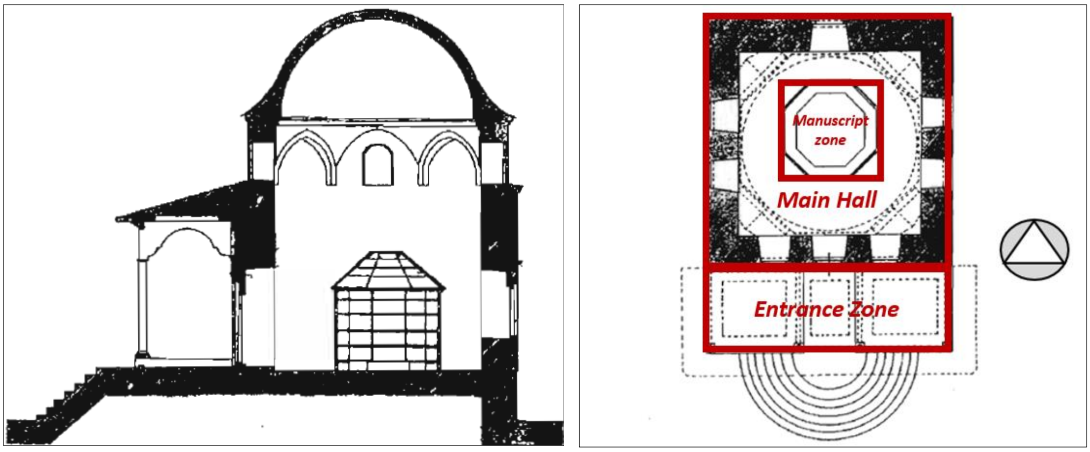


Figure 4.9. Distribution of wind speed and direction for Tire-İzmir
(Source: METEONORM, 2005)

According to Figure 4.9, predominant wind direction is north-west, wind speed is 0-3 m/s. The numbers from 1 to 7 indicate the frequency of wind speed in any direction.

4.1.3. Structure of the Library

The Library which lies on north-south direction, consists of three zones: main hall, manuscript zone and entrance zone. The zones of the library is shown in the Figure 4.10 (b).



(a) (b)

Figure 4.10. The section (a) and plan (b) of the Library
(Source: Bayraktar, 2003)

The main hall is in a rectangular shape and covered with a dome shaped roof while the manuscript zone is 3.5 m x 3.5 m in octagonal shape and located in the main hall. Entrance zone is covered by wooden frame windows and used as an office by library staff and reading hall for visitors.

4.1.3.1. Walls

The external walls of the main hall consist of plaster mortar, khorasan mortar and brick-stone. The construction materials and thicknesses of the layers are given in Table 4.2. Khorasan mortar is used as a binder between bricks and stones and also an insulation material on the wall (Topçu et al., 2015). The thickness of the external walls are different as 1.08 m for east wall, 1.16 m for west wall and 1.25 m for north and south walls.

Table 4.2. Layers of the external walls of the main hall

Construction materials	inside	Plaster mortar	khorasan mortar	brick-stone	outside
Thickness (cm)		0.5-1	2-3	105-120	

Figure 4.11. External walls of the Library

Since the outmost layer of the external wall consist of brick and stone mixture and the distribution of each component is not uniform (Figure 4.11), thermal conductivity of the mixture is measured. The brick and stone samples are collected from the Library (Fig.4.12), thermal conductivity of the samples are measured by QTM-500 device at Geothermal R&A Center of Izmir Institute of Technology. The overall heat transfer coefficient of external walls are calculated by electrical analogy (Table 4.3).

Figure 4.12. Stone and brick samples of external walls of the Library

Table 4.3. Overall heat transfer coefficient of external walls

Wall	**Thickness (m)**	**U ($W/m^2.K$)**
Main hall external wall (west façade)	1.16	0.858
Main hall external wall (east façade)	1.08	0.919
Main hall external wall (north & south façades)	1.25	0.800

4.1.3.2. Floors and Roof

The building is constructed on a soil-filled ground at 1.5 m high and accessed by stairs (Figures. 4.4, 4.5, 4.7, 4.10). Layers of ground floor for the manuscript zone and the entrance zone are almost the same with an exemption of innermost layer. Concrete, terracotta tiles and timber are used in the innermost of the ground floor for the main hall, manuscript zone and entrance zone, respectively.

Table 4.4. Layers of the ground floor of the main hall

Construction materials	inside	concrete	khorasan mortar	stone	outside
Thickness (cm)		-	10-15	3-5	

Table 4.5. Layers of the ground floor of the manuscript zone

Construction materials	inside	terracotta tile	khorasan mortar	slate	outside
Thickness (cm)		-	10-15	3-5	

Table 4.5. Layers of the ground floor of the entrance zone

Construction materials	inside	concrete	khorasan mortar	stone	outside
Thickness (cm)		-	10-15	3-5	

The layers of the dome is almost the same as external walls except a lead cover on the outer surface. Overall heat transfer coefficients for floors and dome are listed in Table 4.7.

Table 4.6. Layers of the dome

Construction materials	inside	Plaster mortar	khorasan mortar	brick	khorasan mortar	lead	outside
Thickness (cm)		0.5-1	2-3	30	2-3	0.2-0.3	

Table 4.7. Overall heat transfer coefficients of floors and dome

Section	**U ($W/m^2.K$)**
Ground Floor (Main hall)	1.379
Ground Floor (Manuscript zone)	1.241
Ground Floor (Entrance zone)	1.379
Dome	1.512

4.1.3.3. Doors and Windows

Original construction of the library consists of eleven single glazing windows with wooden frames. Seven of them are located on the external walls and they are open-able in horizontal direction. The others are situated on external walls of octagonal partition, is constructed bottom of the dome. The location of the windows in the main hall are shown with blue color in the Figure 4.13. All of the windows used on the surfaces of manuscript zone and entrance zone are single glazing windows and wooden frames. The configuration of the windows, are located in the external walls of the Library is shown in Figure 4.14.

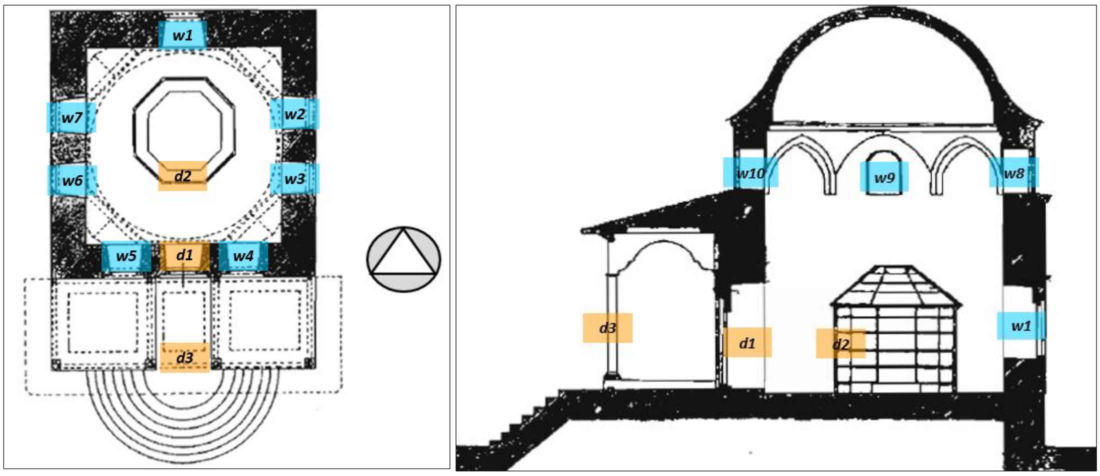


Figure 4.13. The location of windows and doors in the Library
(Source: Bayraktar, 2003)

Figure 4.14. The configuration of windows
(Source: Ekizoğlu, 2012)

Table 4.8. The components and U values of the windows

Window components	**Material**	**U ($W/m^2.K$)**
Glazing	Clear Glass (3 mm)	5.894
Frame	Wood	3.633

There exist three doors in the library and are located in the main hall, the manuscript zone and the entrance zone (Figure 4.13). A wooden door is used in the manuscript zone while a metal layer is used to cover the surface of the wooden door of the main hall (Figure 4.15). Single glazing are used on the surface of the door in the entrance zone and the manuscript zone. The door of the entrance region is wooden with single glazing windows.

Figure 4.15. The configuration of sheeting covered door
(Source: Ekizoğlu, 2012)

Table 4.9. The components and U values of the doors

Door components	**Material**	**U (W/m^2.K)**
Glazing	Glass (3 mm)	5.894
Frame	Wood	3.633
Covering	Metal	3.8

4.1.3.4. Air Tightness

The air tightness of the library was measured by blower door test and measurements were done on the door of the entrance region (Figure 4.16). All of the windows and doors except the door between the main hall and the entrance zone, are kept closed during the measurements. The airtightness of the building is calculated as 0.52 ACH based on the measurements.

Figure 4.16. Blower door test and the configuration of sheeting covered door to the entrance door

4.1.4. Schedules

In order to get more accurate results and define the characteristic of the model correctly, a proper schedule should be used in the simulation model. The schedules should be recorded daily to obtain more accurate results from the model. Since the Library had no schedule recordings, occupancy and operation schedule is estimated by interviewing the library staff and, standardized schedules are used in the developed models. The occupancy and internal gain schedules are defined in compact schedule format and uploaded to DesignBuilder. The Library is open during weekdays from 08:30 to 17:30 for summer time and from 08:00 to 17:00 for winter time.

4.1.4.1. Occupancy Schedule

The staff of the Library are two officers and one security guard. The officers use the entrance zone as an office (Figure 4.10 (b)) while the security guard stays in a security cabin which is located outside of the Library.

The entrance zone is occupied by two officer from 08:00 to 17:00 in winter time and 08:30 to 17:30 in summer time. The main hall occupied by the Library staff approximately half an hour during the weekdays to check the manuscripts and ventilate the main hall and manuscript zone.

4.1.4.2. Heating, Cooling and Ventilation Schedule

A split type air conditioner is installed in the entrance zone (Figure 4.17) for heating and cooling purposes while there is not any heating or cooling system in the main hall and the manuscript zone. Air conditioner in the entrance zone is active from 10:00 to 15:00 in summer time, from 8:30 to 17:00 in winter time.

Figure 4.17. Split air conditioner used in the entrance zone of the Library (Source: Ekizoğlu, 2012)

Ventilation schedule of the main hall is from 08:30 to 09:30 during the weekdays for summer and by one hour in a week for winter. The manuscript zone is ventilated twice a month for an hour throughout the year.

4.1.4.3. Operation Schedule of Equipment

In the main hall and the manuscript zone, there is no electrical equipment while a computer and safety camera system exist in the entrance zone. The computer is on only during office hours while the safety camera system is active at 24 hours.

4.1.4.4. Lighting

Two types of lamps are used in the Library (Figure 4.18). Three energy efficient lamps and four incandescent lamps are installed in the entrance zone and the main hall, respectively. The required light intensity for illumination of storage areas in achieves or libraries is up to 200 lux (Hanus and Hanusova, 2013).

Figure 4.16. Lamp types used in the Library

CHAPTER 5

RESULTS AND DISCUSSION

The main objective of the Thesis is to preserve paper based collections in the Necip Paşa Library. In this direction, T and RH values in and out of the library are measured from the end of August 2014 to the beginning of September 2015 by mini data loggers. Degradation risk analysis on the manuscripts are conducted by analyzing the measured T and RH values. The building energy simulation model of the library created via DesignBuilder v4.2.054. The model is calibrated according to ASHRAE Guideline 14 (ASHRAE, 2002). Following the calibration process, ventilation scenarios are proposed and applied to the model. The entrance region of the Library has faced to two interventions since its construction. In order to evaluate the effect of these interventions on the building indoor climate, two different models are created. Ventilation scenarios are proposed and applied to the new models and the degradation risks on the manuscripts are evaluated according to simulation results. Same process are repeated for the two different physical models of the library.

5.1. Measurements

T and RH data in and out of the Library was monitored every ten minutes interval from the end of August 2014 to the beginning of September 2015 via five mini data loggers. The data loggers are located in the main hall (#1 & #2), the manuscript zone (#3), the entrance zone (#4) and outside of the building (#5) (Figure 3.2).

The T and RH data collected hourly for each zone are shown for one year in Figure 5.1 and 5.2, respectively. Restoration of the Library started at the beginning of July 2015 and is represented by vertical blue line in the Figure 5.1 and 5.2. T and RH values for the manuscript zone and the main hall show almost the same trend and no fluctuations are observed because of the high thermal mass of the main hall. Since the entrance zone is covered with low thermal mass wooden framed windows, T and RH fluctuations are seen. Another reason for that, is the conditioning of the zone during working hours and the change in ventilation schedule with occupants' intervention. A detailed view on T and RH data is given hourly in Fig. 5.4 for one week data of January and June 2015.

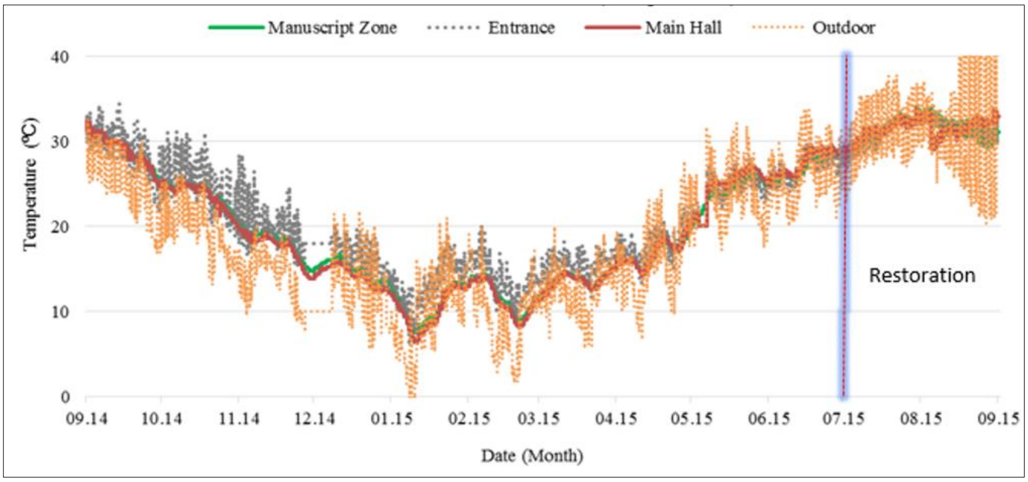


Figure 5.1. Measured hourly temperature values for each zone

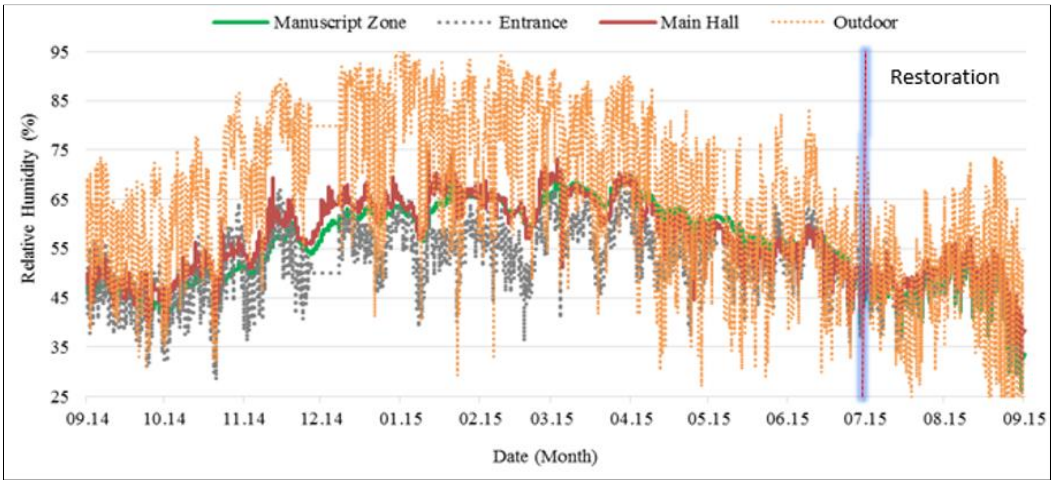
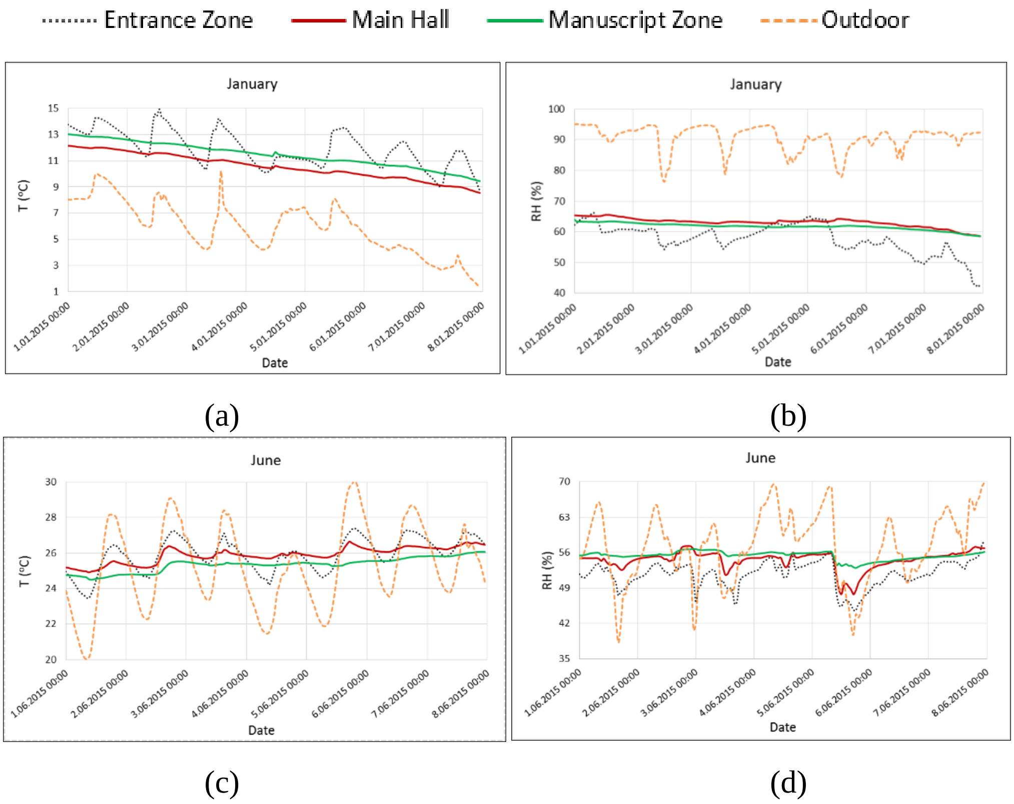


Figure 5.2. Measured hourly relative humidity values for each zone

In order to understand the effect of outdoor climate on indoor climate, measured temperature and relative humidity values are represented weekly for January and June (Figure 5.3).

It is clear from the Figure that the entrance zone is highly effected by outdoor climate. In January no fluctuations are observed in the main hall and the manuscript region while the main hall is affected by outdoor climate in June. The reason for that could be the heat gain through the windows and increase in ventilation in summer time.

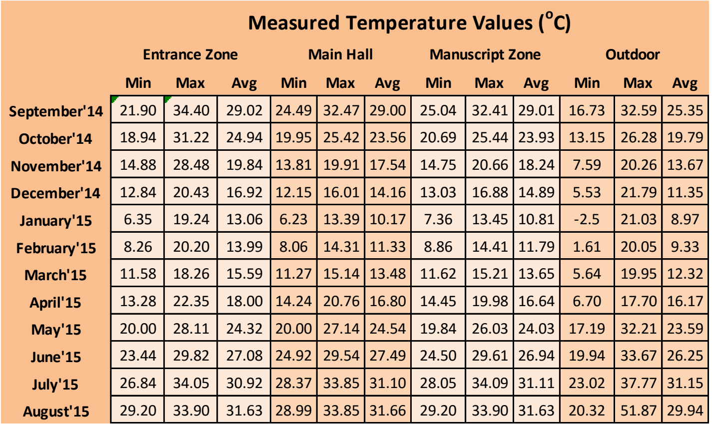


(a) (b)

(c) (d)

Figure 5.3. Measured temperature and relative humidity values in the first week of January (a, b) and June (c, d)

Monthly measured minimum, maximum and average temperature values are given in Figure 5.4. According Figure 5.4, minimum and maximum temperature values are measured as -2.5°C and 51.87°C in January and August, respectively. The restoration of the library was started at beginning of July 2015. After that date, it is possible to observe different trends in measured temperature and relative humidity values. The main reason behind the measured maximum temperature value in August is direct sunlight on the mini data logger.



Measured Temperature Values (°C)												
	Entrance Zone			Main Hall			Manuscript Zone			Outdoor		
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
September'14	21.90	34.40	29.02	24.49	32.47	29.00	25.04	32.41	29.01	16.73	32.59	25.35
October'14	18.94	31.22	24.94	19.95	25.42	23.56	20.69	25.44	23.93	13.15	26.28	19.79
November'14	14.88	28.48	19.84	13.81	19.91	17.54	14.75	20.66	18.24	7.59	20.26	13.67
December'14	12.84	20.43	16.92	12.15	16.01	14.16	13.03	16.88	14.89	5.53	21.79	11.35
January'15	6.35	19.24	13.06	6.23	13.39	10.17	7.36	13.45	10.81	-2.5	21.03	8.97
February'15	8.26	20.20	13.99	8.06	14.31	11.33	8.86	14.41	11.79	1.61	20.05	9.33
March'15	11.58	18.26	15.59	11.27	15.14	13.48	11.62	15.21	13.65	5.64	19.95	12.32
April'15	13.28	22.35	18.00	14.24	20.76	16.80	14.45	19.98	16.64	6.70	17.70	16.17
May'15	20.00	28.11	24.32	20.00	27.14	24.54	19.84	26.03	24.03	17.19	32.21	23.59
June'15	23.44	29.82	27.08	24.92	29.54	27.49	24.50	29.61	26.94	19.94	33.67	26.25
July'15	26.84	34.05	30.92	28.37	33.85	31.10	28.05	34.09	31.11	23.02	37.77	31.15
August'15	29.20	33.90	31.63	28.99	33.85	31.66	29.20	33.90	31.63	20.32	51.87	29.94

Figure 5.4. Monthly measured minimum and maximum temperature values

5.1.1. Indoor Climate Requirements

As given in Table 1.1 of Section 1.1, minimum required indoor climate conditions of paper based collections are satisfied in climate class A_1 of ASHRAE Chapter 21 (ASHRAE, 2003). Therefore, A1 is chosen as the climate class of Necippaşa Library.

Five different climate control classes for museums, libraries and archives are defined in to evaluate potential of chemical, mechanical and biological degradation risks on paper based collections. Annual averaged RH and T values for museums, art galleries, libraries and archives are defined as 50% and 15°C-25°C, respectively (ASHRAE, 2003). Allowable short term fluctuations in T and RH values for climate class A_1 are defined as ±2°C and ±5%.

5.1.2. Chemical Degredation Risk Analysis

Chemical degredation risk on manuscripts is evaluated by Lifetime Multiplier (LM) method. The LM values for the manuscript zone and the main hall are calculated hourly and the results are depicted in Figure 5.5 and 5.6.

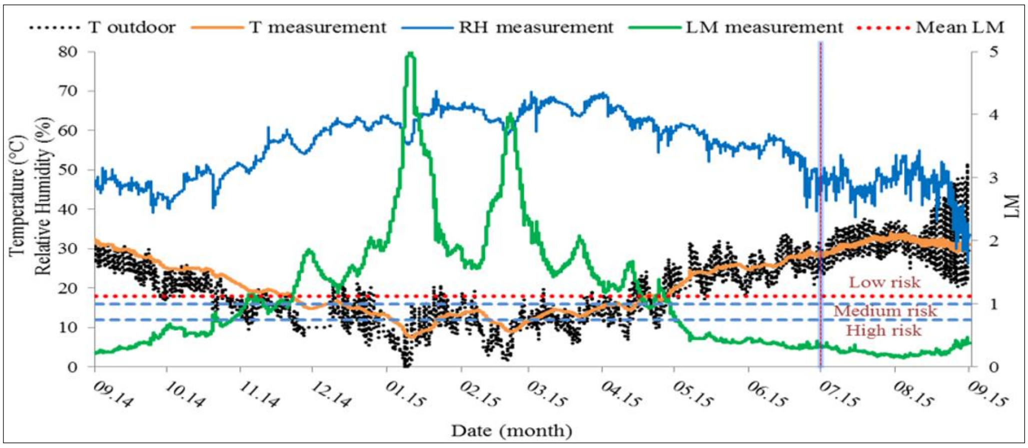


Figure 5.5. Chemical degradation risk analysis in the manuscript zone (measurements): LM method

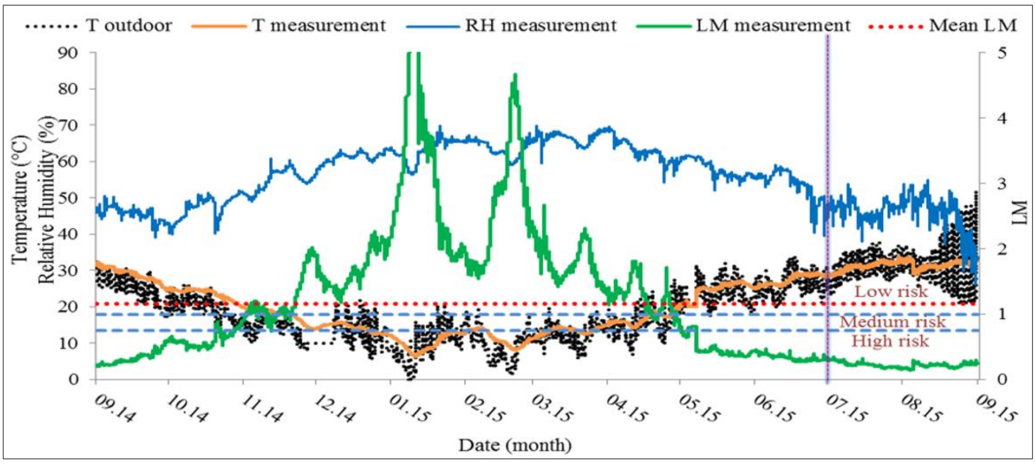
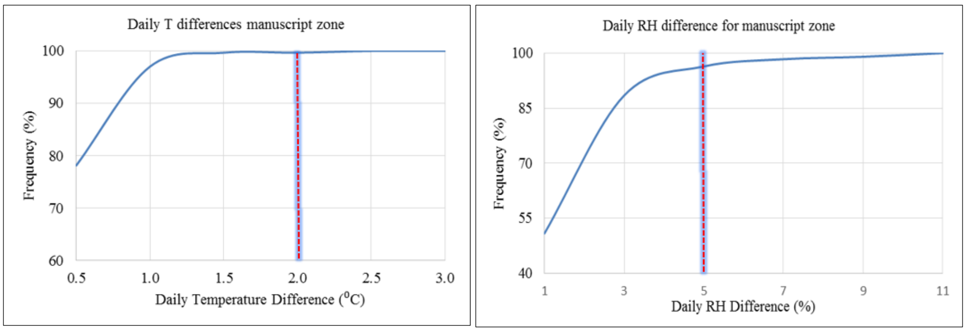


Figure 5.6. Chemical degradation risk analysis in the main hall (measurements): LM method

As can be seen from the Figure 5.5 and 5.6, there is no chemical degradation risk between December 2014 and April 2015 while medium risk level is observed in November. The manuscripts are considered as under high risk from September to October and May to June. The annually averaged LM values are shown with red dashed lines in the Figures. The mean LM values are determined as 1.119 and 1.158 for the manuscript zone and the main hall, respectively. The mean LM values are in the low risk region but very close to the medium risk region.

5.1.3. Mechanical Degredation Risk Analysis

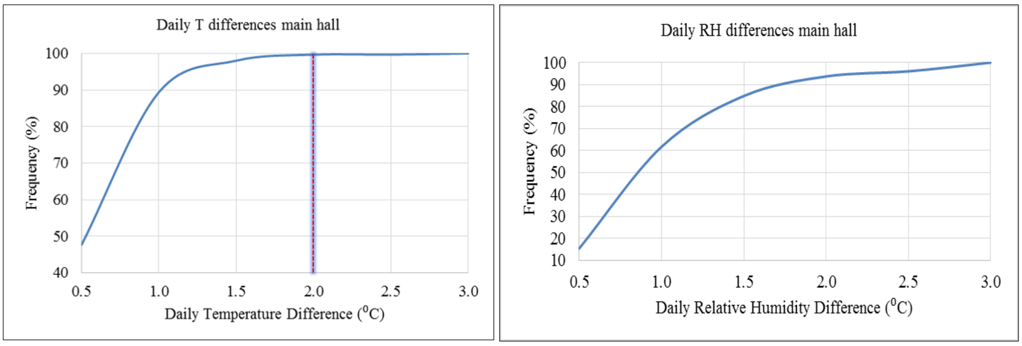
Frequency of daily T and RH fluctuations are given in Figure 5.7. The Figure indicates that there is no mechanical degradation risk in the manuscript zone. Almost 100% of the T fluctuations and 95% of the RH fluctuations are lower than allowable fluctuation values (2^{o}C and ±5% RH). Allowable fluctuations are shown with vertical blue lines.



(a) (b)

Figure 5.7. Daily (a) T and (b) RH fluctuations in the manuscript zone (measurements)

Similar to the manuscript zone, daily fluctuations in T and RH are in the acceptable limits and there are no mechanical degredation risks in the main hall (Figure 5.8).



(a) (b)

Figure 5.8. Daily (a) T and (b) RH fluctuations in the main hall (measurements)

5.1.4. Biological Degredation Risk Analysis

Mould risk factor calculations for the manuscript zone are shown in Figure 5.9 and 5.10. The red line in Figure 5.9 exhibits the critical water content for each month and the blue line shows the water content of spore in the manuscript zone. If the critical water content is exceeded, the spore can grow into new organism. According to the Figure 5.9, water content of the spore lower than critical water content, which means that there is no mould growth in the manuscript zone.

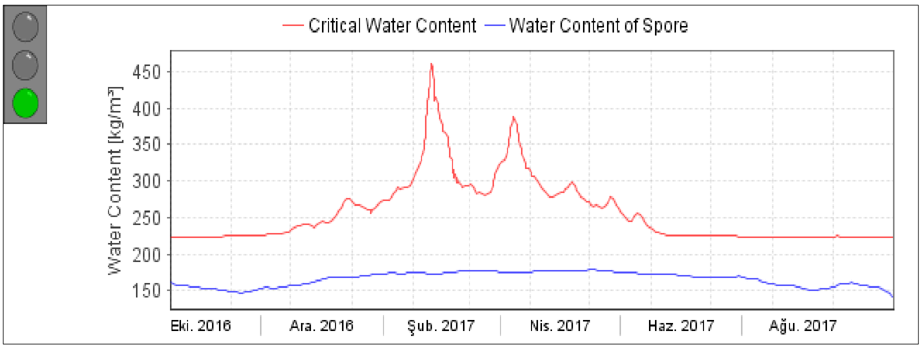


Figure 5.9. Critical water content for mould growth rate based on the measurements

Figure 5.10 shows the mould index of the spore in the manuscript zone. Since the mould index is zero, there is not mould growth in the manuscript zone.

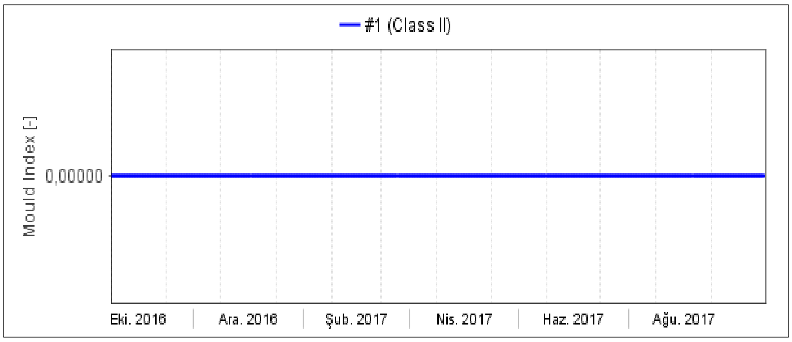


Figure 5.10. Mould index of measurements in the manuscript zone

5.2. BES Model

BES model of the Library with surrounding buildings is created by DesignBuilder v4.2.054 dynamic simulation software (Figure 5.11). The Library and surrounding buildings are drawn in building format and component format. The component blocks are taken into account only shadow and wind calculations in DesignBuilder software. CAD drawing of the Library is used to define geometry of the BES model. The height and width of the surrounding buildings are measured by laser distance meter.

5.2.1. Calibration of the Model

BES model of the Library is calibrated with respect to ASHRAE 14, 2002. Two dimentional error function which are MBE and CV(RMSE) are used for the calibration process.

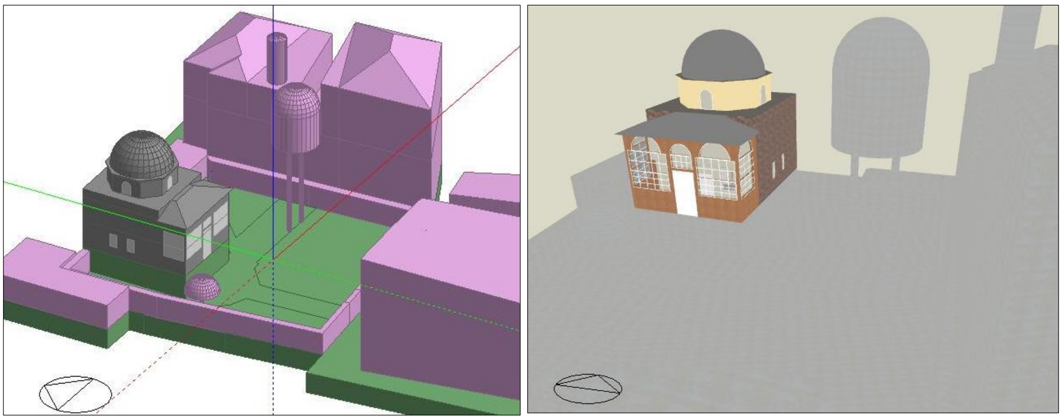


Figure 5.11. BES model of the Library

The construction materials and thickness of external walls are obtained from the restoration project and the staff of Directorate General of Foundations of T.R. Prime Ministry, İzmir Regional Directorate. Once annual T and RH meaurements are completed, the weather data for DesignBuilder software is created and uploaded to the software, then first simulation results are obtained. The error between the simulation results and the measurements are calculated and compared with the benchmarks defined by ASHRAE Guideline 14, 2002.

Prior to the validation of the model, validation of the measurement tools (mini dataloggers) are carried out with respect to their uncertainty values (±0.35°C for T and ±2.5% for RH). Then, geometry, schedules and construction matearials of the Library are updated with respect to site visits. 75 simulations are carried out in order to reach calibrated model and the updated parameters during the calibration process are listed below;

- ✓ Occupancy, equipment and lighting schedule of the Library is updated after an interview with library staff.
- ✓ Operation schedules for heating and ventilation system in the entrance space is created with respect to interview with library staff.

- ✓ The construction materials and thickness of the external walls, the dome and floors are updated following a visit to the restoration site and interview with a civil engineer.
- ✓ Restoration months (July, August 2015) do not include calibration process

Hourly measurements are used in the calibration and calculated error values for each zone are given in Table 5.1. In ASHRAE Guideline 14, the upper limits for MBE and CV(RMSE) in hourly calibration process are defined as ±10% and ±30%, respectively.

Table 5.1 Calculated error values for the BES model

	Temperature		**Relative Humidity**	
	MBE (%)	**CV (RMSE) (%)**	**MBE (%)**	**CV (RMSE) (%)**
Manuscript Zone	-1.25	7.71	5.02	17.7
Main Hall	-0.71	7.16	4.63	15.24
Entrance Zone	-6.58	12.5	14.52	22.04
ASHRAE 14 Standards, 2002	±10	30	±10	30

All calculated error values for CV(RMSE) are within the limits while MBE value for RH in the entrance zone is out of the limits. The smallest error values are calculated for the main hall.

The comparison of the measurements and simulations for the manuscript zone are given in Figure 5.12 and 5.13. Trend of T values are almost the same for measurements and simulations while fluctuations in RH values for the calibrated model is clearly seen in Figure 5.13.

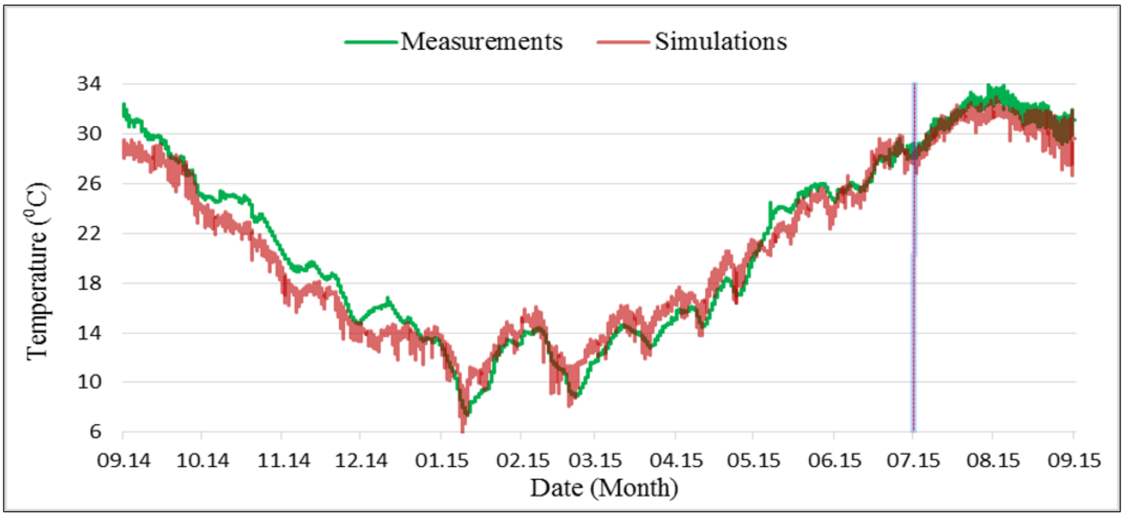


Figure 5.12. Measured and calibrated T values for the manuscript zone

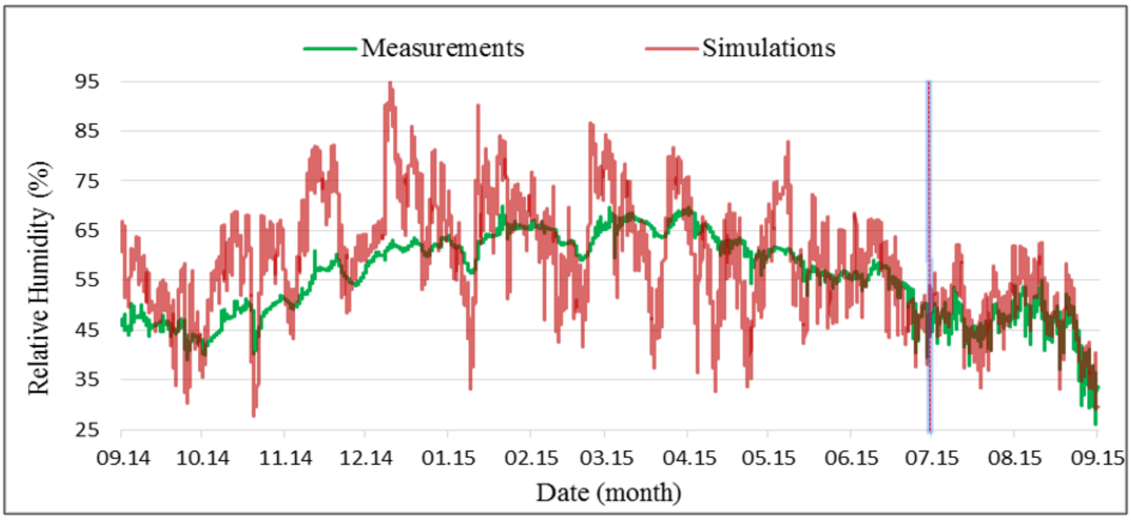


Figure 5.13. Measured and calibrated RH values for the manuscript zone

5.3. Risk Assessment of Calibrated Model

5.3.1. Chemical Degredation Risk Analysis

The LM values for the manuscript zone and the main hall are calculated and the results are illustrated in Figure 5.14 and Figure 5.15 for the calibrated model.

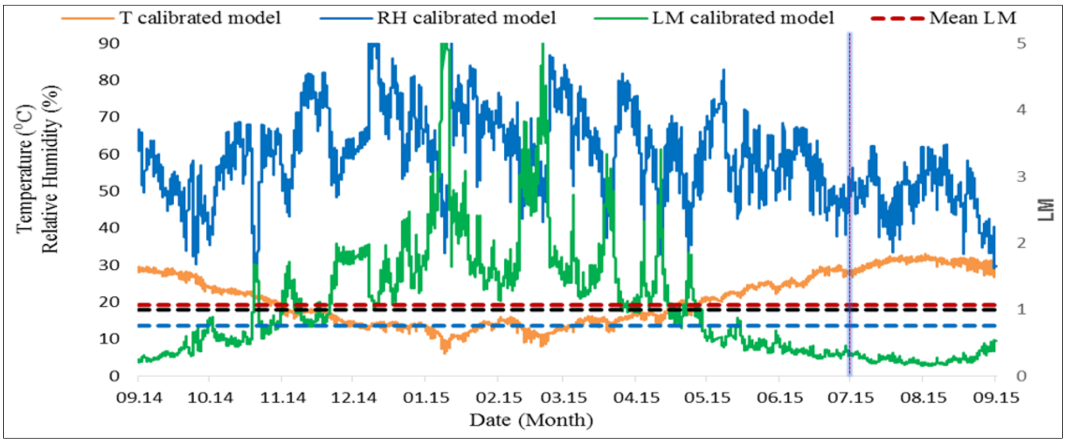


Figure 5.14. Chemical degradation risk analysis in the manuscript zone (calibrated model): LM method

As can be seen from Figure 5.14, calibrated results show the same behavior with measurements (Figure 5.5); critical months for chemical degradation and risk levels are almost the same. The mean LM value is calculated as 1.067.

Chemical degradation risk analysis for the main hall calculated and shown in Figure 5.15. The annual mean LM value is determined as 1.091. The decrease in T is generally result with the increase in LM values.

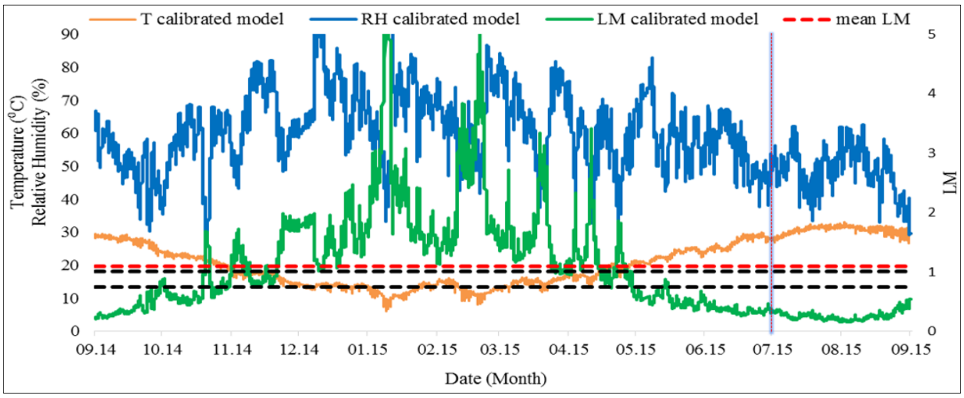
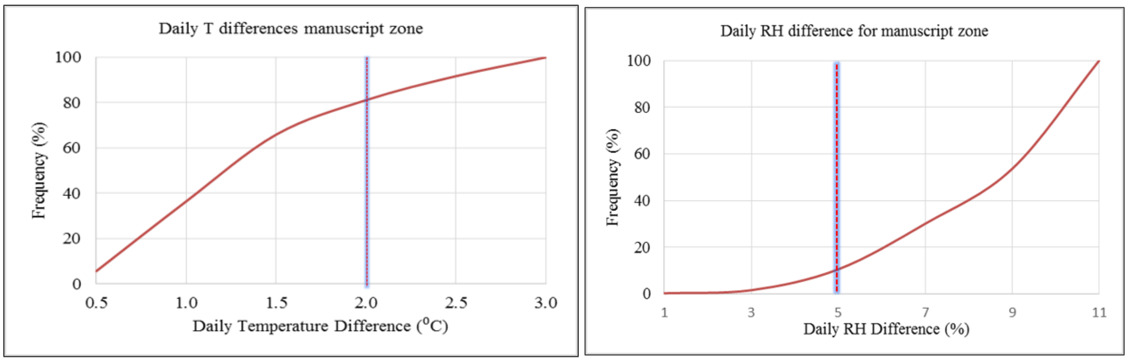


Figure 5.15. Chemical degradation risk analysis in the main hall (calibrated model): LM method

5.3.2. Mechanical Degredation Risk Analysis

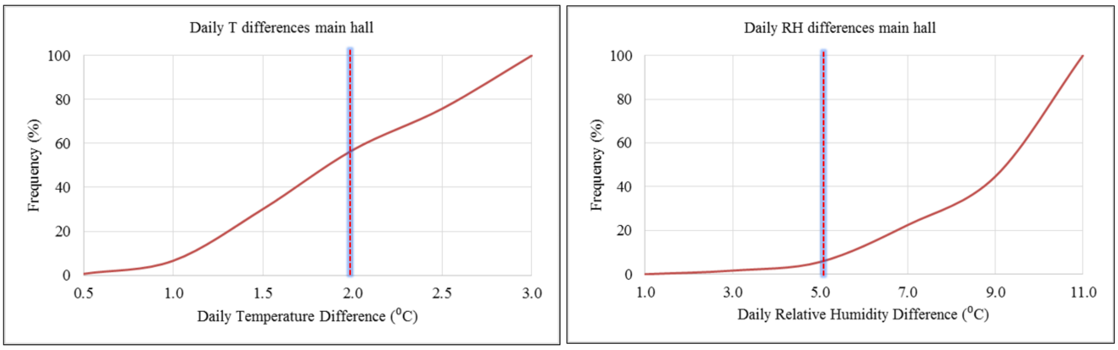
Daily T and RH fluctuations in the manuscript zone for calibrated model are given in Figure 5.16. While 80% of the temperature differences are within the limits, only 10% of the RH values are within the limits for mechanical degradation in the manuscript zone.

It can be concluded from Figure 5.16 and 5.17, the manuscripts are under mechanical degredation risk due to high RH fluctuations in the manuscript zone and the main hall.



(a) (b)

Figure 5.16 Daily T and RH fluctuations in the manuscript zone (calibrated model)



(a) (b)

Figure 5.17 Daily T and RH fluctuations in the main hall (calibrated model)

5.3.3. Biological Degradation Risk Analysis

According to Figure 5.18 and 5.19, there is no biological degredation risk on manuscripts for the calibrated model since the mould index is lower than critical mould risk factor value. The water content of spore is exceeded critical water content for some periods and it means that the spores start to germinate in that periods. The germination of spores will not cause any mould growth on the surface of manuscripts because of that mould index value is lower than critical mould index value.

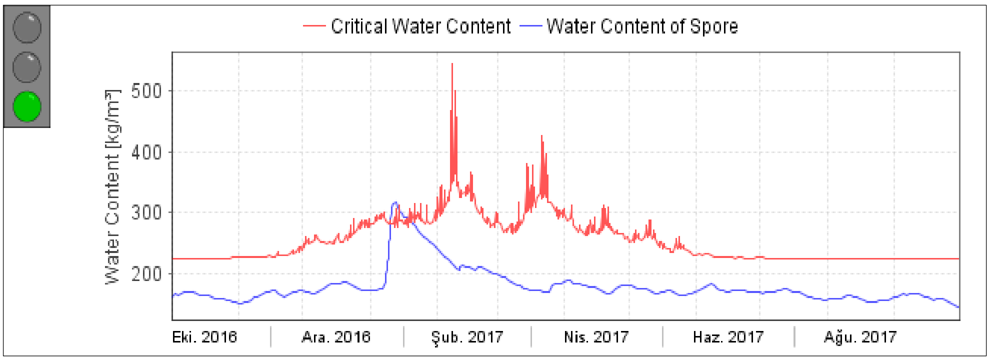


Figure 5.18. Critical water content for mould growth rate for the manuscript zone (calibrated model)

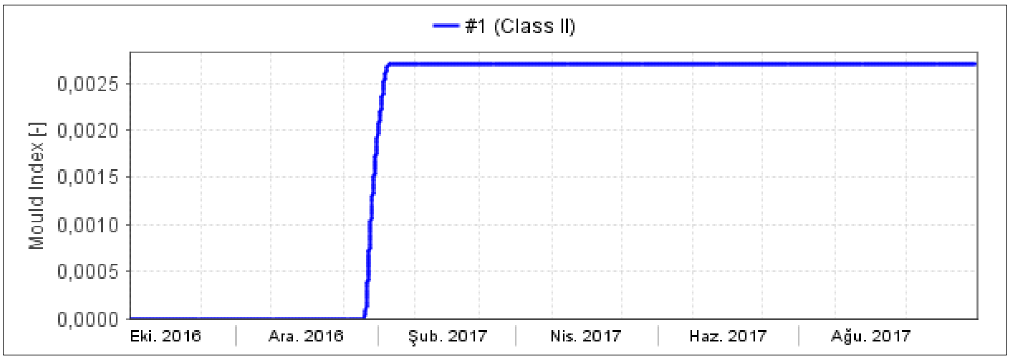


Figure 5.18. Mould index of the measured values in the manuscript zone (calibrated model)

5.4. Ventilation Scenarios

According to the evaluation of the measured T and RH, the manuscripts in the Library are under the chemical degradation risk. High temperature values in the library during summer are the main reason for chemical degradation. In order to diminish the risk, two ventilation system scenarios (natural and mechanical systems) are proposed and simulated.

Schedule of natural ventilation system scenario is mainly based on night time cooling without relative humidity control.

Mechanical ventilation system scenario includes control on both T and RH. In the second scenario, indoor climate of the library is controlled via mechanical ventilation. An air conditioner with humidifier system is uploaded to BES model of the Library.

5.4.1. Scenario 1: Natural Ventilation

According to the risk assessment based on the measurements, the manuscripts are under chemical degradation risk during hot seasons. Natural ventilation schedule defined in the simulation model, is not sufficient to prevent chemical degradation. Thus, in this scenario it is aimed to benefit from cooling side of the natural ventilation system. The windows and door of the Library is opened with respect to outdoor temperature and set value for the outdoor temperature is defined as 20°C. When the outdoor temperature is lower than 20°C, the windows of the main hall and the manuscript zone are opened together in the scenario. DesignBuilder does not allow RH control for natural ventilation system.

5.4.1.1. Chemical Degradation Risk Analysis

The effect of natural ventilation scenario on chemical degredation risk are shown in Figure 5.20 and 5.21 for the manuscript zone and the main hall, respectively. Comparing with the calibrated model, the chemical degradation risk on the manuscripts moves from high risk level to low risk level for the months of October and April while almost there isn not any improvement from May to September due to high outdoor T values.

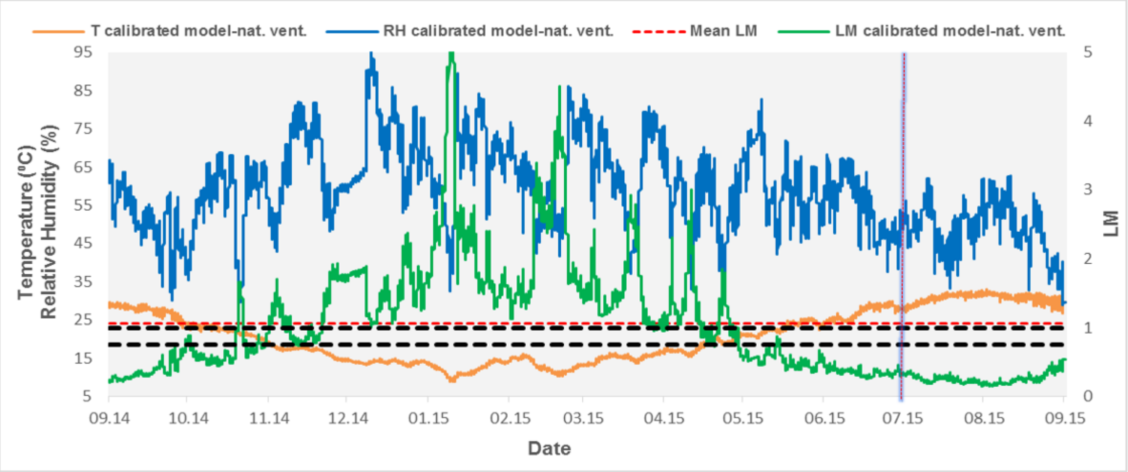


Figure 5.20. Chemical degradation risk analysis in the manuscript zone (Existing Library: Natural ventilation): LM method

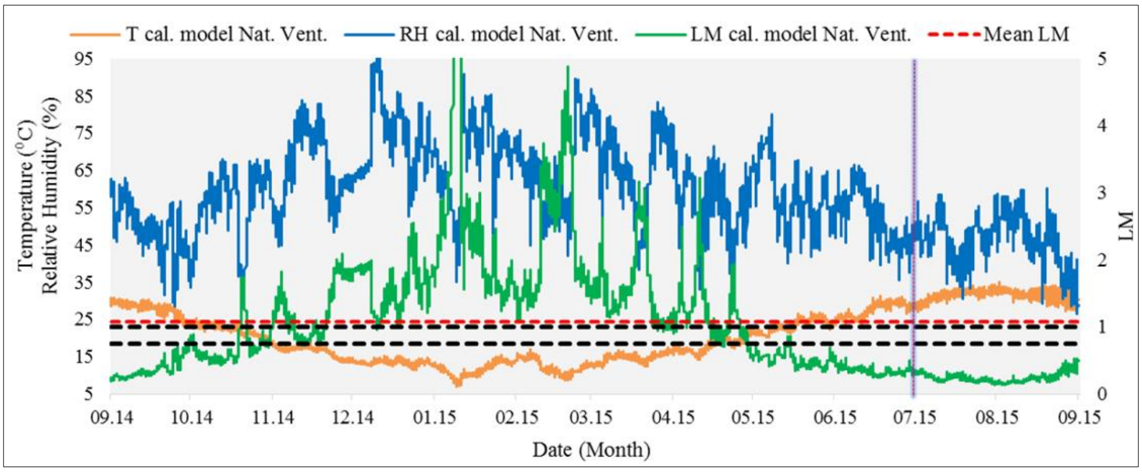
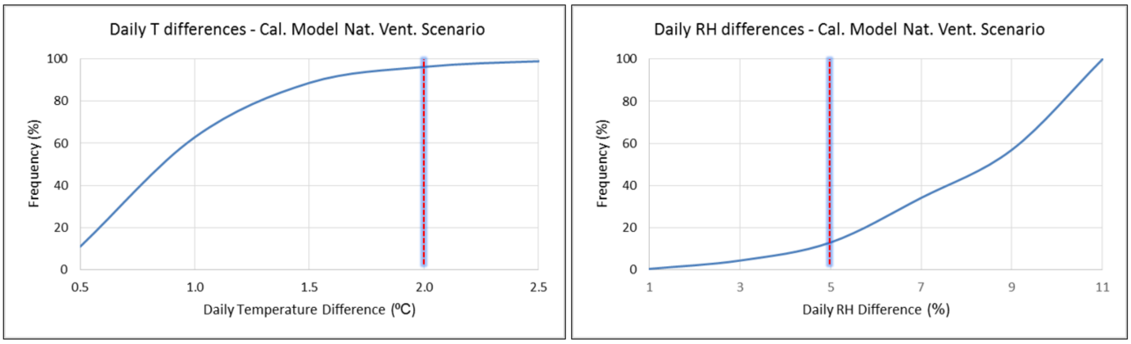


Figure 5.21. Chemical degradation risk analysis in the main hall (Existing Library: Natural ventilation): LM method

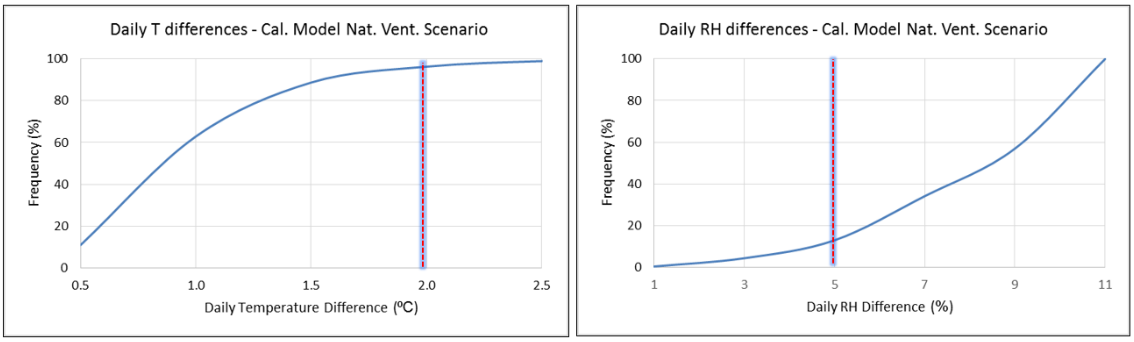
5.4.1.2. Mechanical Degradation Risk Analysis

For natural ventilation scenario, fluctuations in T and RH values for the manuscript zone and the main hall are given in Figure 5.22 and 5.23, respectively. Almost 15% of the fluctuations in RH values are lower than allowable daily fluctuation value for each zone. There is no any change in mechanical degradation risk after implementing natural ventilation system to the Library.



(a) (b)

Figure 5.22. Daily (a) T and (b) RH fluctuations in the manuscript zone (Existing Library: Natural ventilation)



(a) (b)

Figure 5.23. Daily (a) T and (b) RH fluctuations in the main hall (Existing Library: Natural ventilation)

5.4.1.3. Biological Degradation Risk Analysis

Implementation of natural ventilation system to the Library does not cause any mould growth on the surface of manuscripts (Figure 5.24). Mould index value is lower than critical value thus the manuscripts are biologically safe under natural ventilation scenario (Figure 5.25) as well.

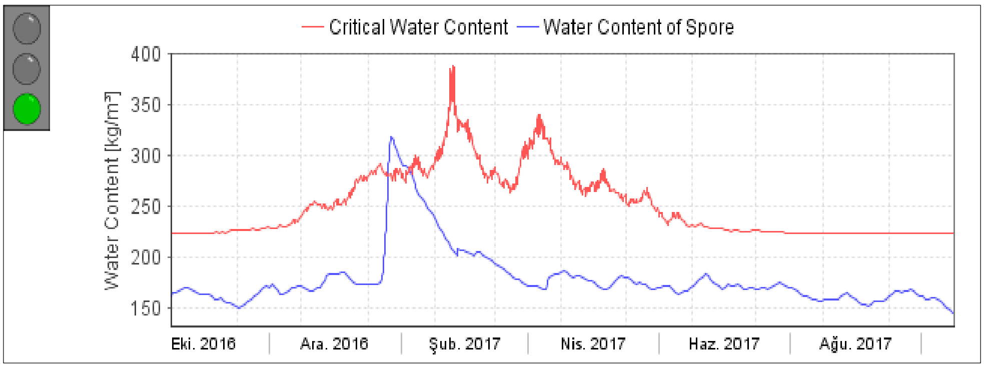


Figure 5.24. Critical water content for mould growth rate in the manuscript zone (Existing Library: Natural ventilation)

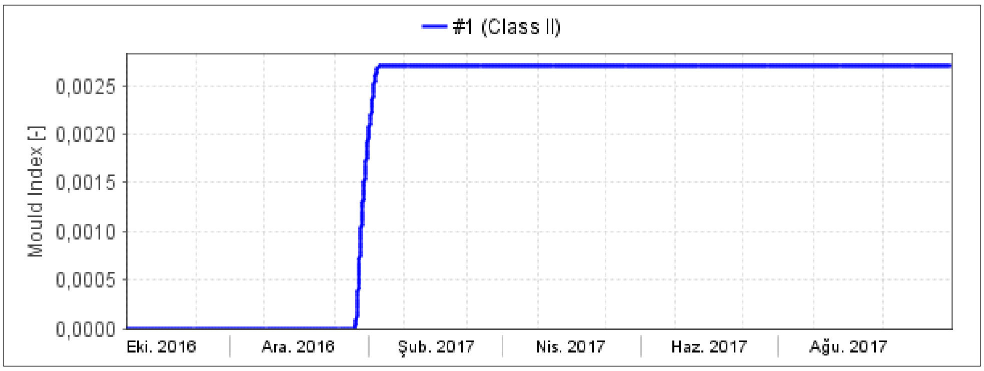


Figure 5.25. Mould index of the measured values in the manuscript zone (Existing Library: Natural ventilation)

5.4.2. Scenario 2: Mechanical Ventilation

In the scenario 2, mechanical ventilation system is integrated into the BES model. Since, chemical degredation risk is observed on the manuscripts, predominantly in hot season, a schedule for mechanical ventilation system is created to keep indoor T values lower during the hot season which is between May to September. The system becomes active when the indoor temperature is exceeded 20°C. RH control by humidistat also included to the mechanical ventilation system.

5.4.2.1. Chemical Degradation Risk Analysis

Chemical degredation risk analysis is shown in Figure 5.26 and 5.27 for the manuscript zone and the main hall with mechanical ventilation inclusion to the calibrated model. The chemical degradation risks on the manuscripts are diminished for the months of October, November, May and June. Mean LM values are 1.476 and 1.535 for the manuscript and the main hall after the mechanical ventilation scenario.

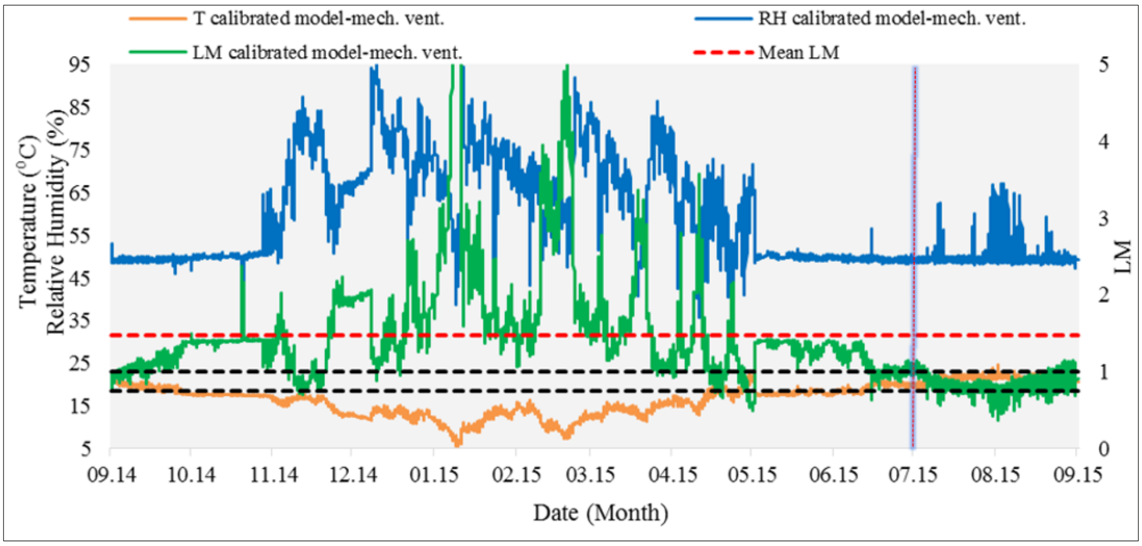


Figure 5.26. Chemical degradation risk analysis in the manuscript zone (Existing Library: Mechanical ventilation): LM method

As can be seen from Figure 5.26 and Fig 5.27, the mechanical ventilation system is active between May and November. Yet, the manuscripts are under chemical degradation risk in August and fluctuations in RH values because of restoration, are the main reason of that situation.

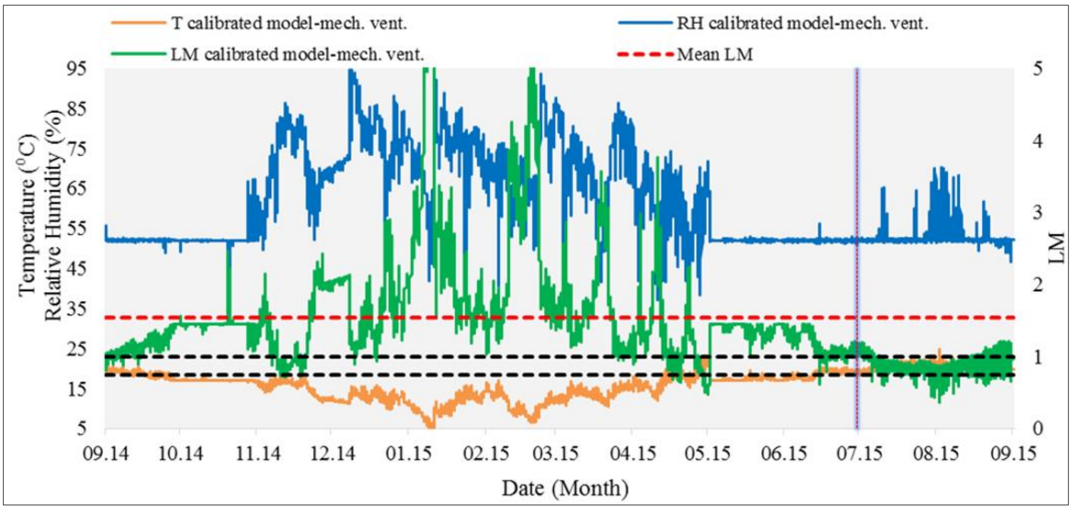
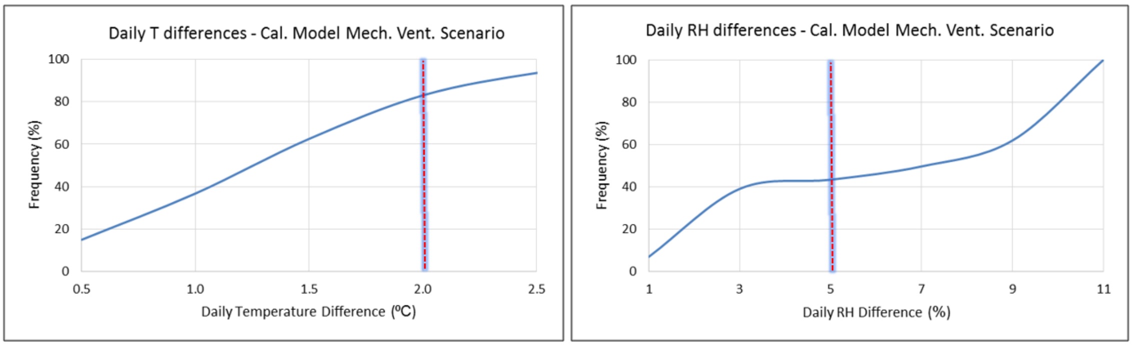


Figure 5.27. Chemical degradation risk analysis in the main hall (Existing Library: Mechanical ventilation): LM method

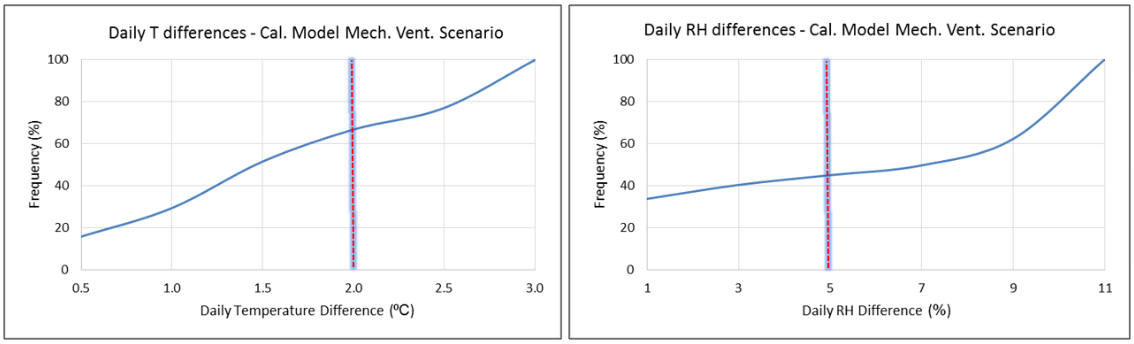
5.4.2.2. Mechanical Degradation Risk Analysis

%80 and %40 of fluctuations in T and RH values are within the limits for the manuscript zone and the main hall for mechanical ventilation scenario. As can be seen from Figure 5.28 (b) and 5.29 (b), the mechanical degradation risk on the manuscripts is reduced after implementing mechanical ventilation system.



(a) (b)

Figure 5.28. Daily (a) T and (b) RH fluctuations in the manuscript zone (Existing Library: Mechanical ventilation)



(a) (b)

Figure 5.29. Daily (a) T and (b) RH fluctuations in the main hall (Existing Library: Mechanical ventilation)

5.4.2.3. Biological Degradation Risk Analysis

Implementation of mechanical ventilation system to the Library does not cause any mould growth on the surface of manuscripts. The mould index is calculated as 0.005 (Figure 5.31) which means that the manuscripts are biologically safe for the mechanical ventilation scenario.

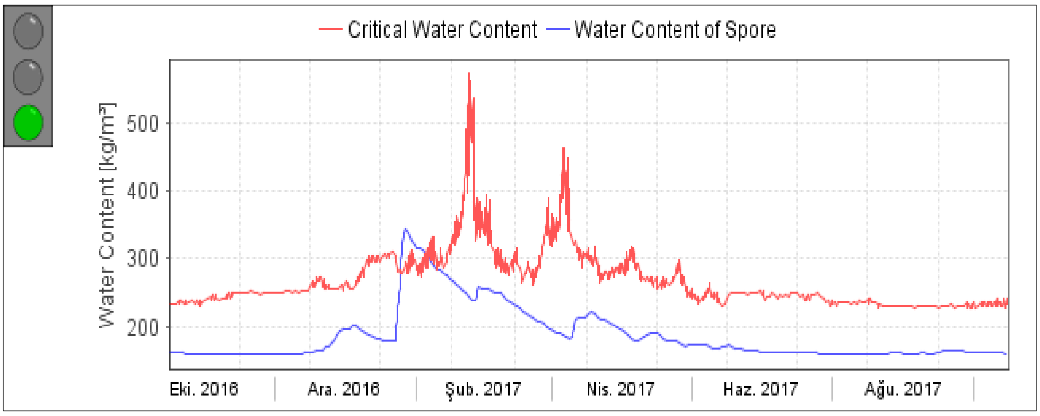


Figure 5.30. Critical water content for mould growth rate in the manuscript zone (Existing Library: Mechanical ventilation)

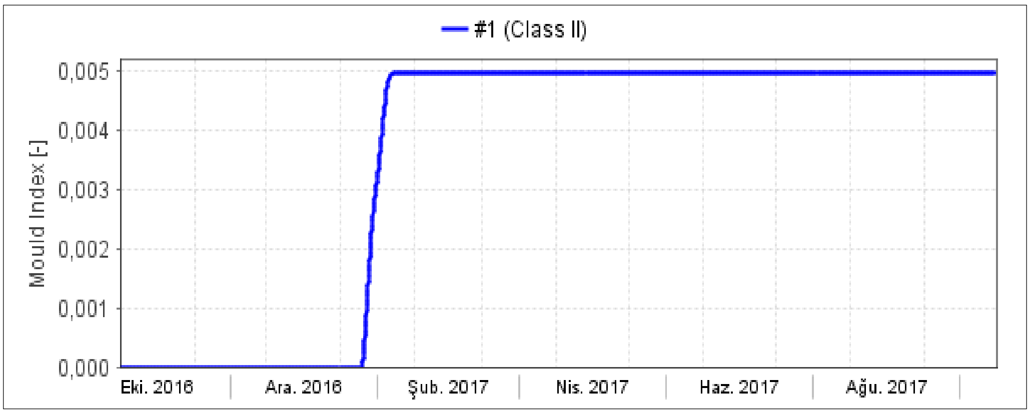
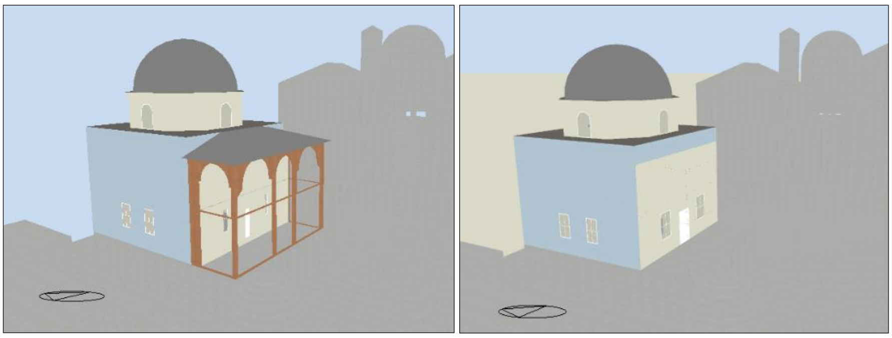


Figure 5.31. Mould index of the measured values in the manuscript zone (Existing Library: Mechanical ventilation)

5.5. Proposing New BES Models for the Library

The entrance region of the Library changed twice since its construction. To be able to see the effect of these interventions on the building indoor climate, two new models are developed. The first BES model called as semi-open model, shows the outview of the library before the entrance space is closed (Figure 5.32 (a)). In the second model, the entrance region is eliminated as aspected to be in original form. This model is named as without entrance model (Figure 5.32 (b)).



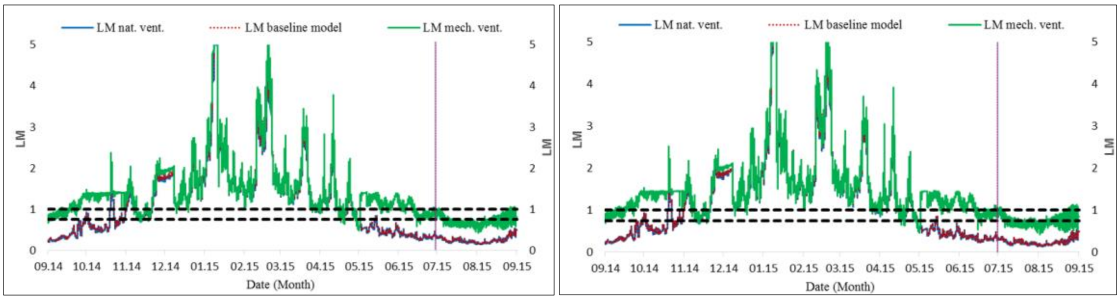
(a) (b)

Figure 5.32. (a) Semi-open and (b) without entrance model of the Library

In following part, degradation risks that can be seen on the two new models of the Library will be evaluated. Simulation of the new models are carried out by using the same procedure with the calibrated model of DesignBuilder. The results were compared with each other and the existing case.

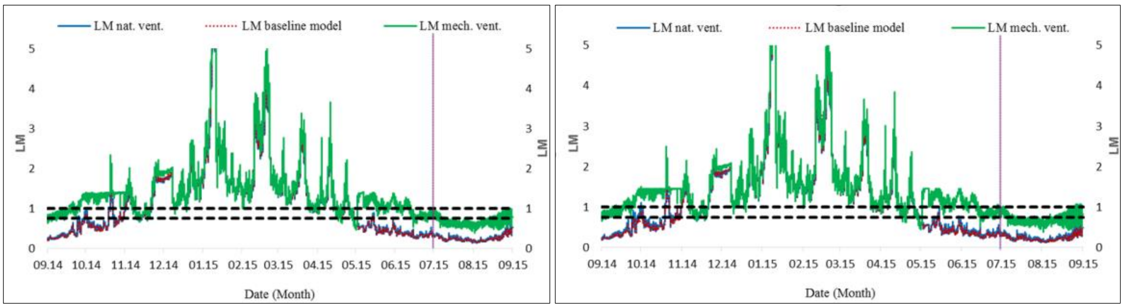
5.5.1. Chemical Degradation Risk Analysis

The critical months for the chemical degradation are the same for the semi-open and without entrance model; from May to November. Implementing natural ventilation does not make any sense on chemical degredation risk while mechanical ventilation is reduced the risk on the manuscripts for the critical months. Calculated LM values for semi-open model and without entrance model are given in Figure 5.33 and 5.34, respectively.



(a) (b)

Figure 5.33. LM values for (a) the manuscript zone and (b) the main hall for semi-open model

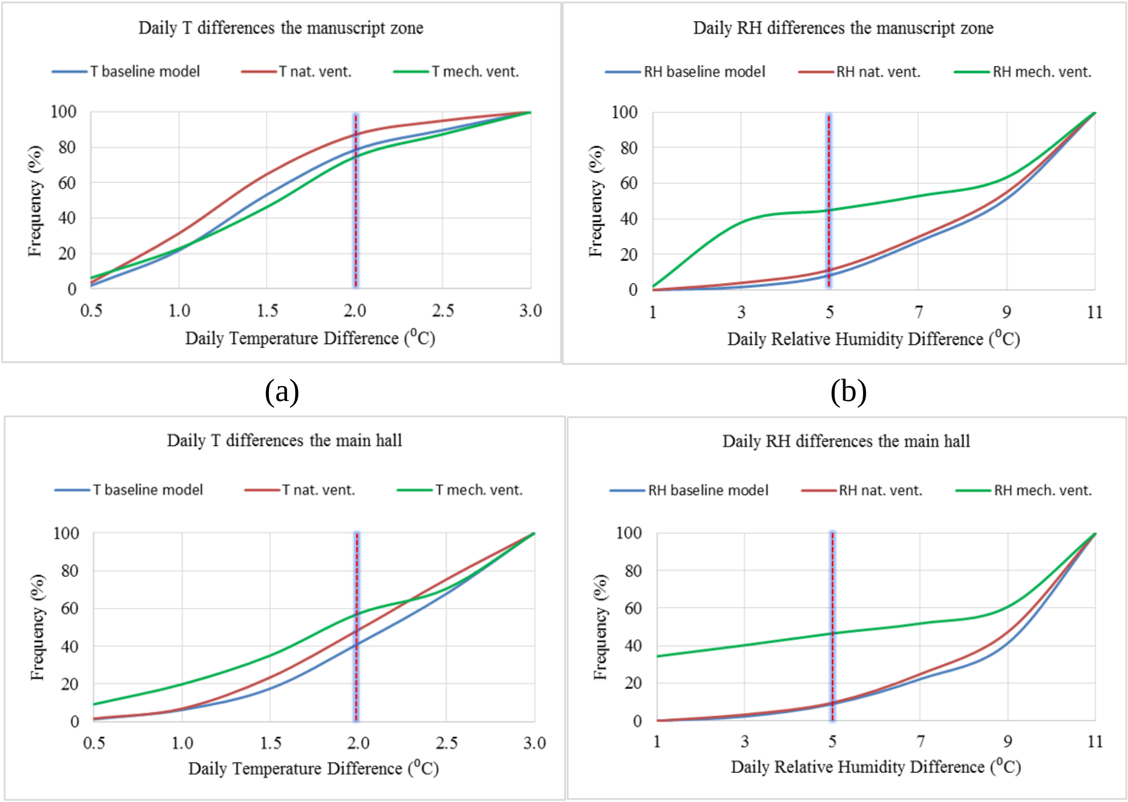


(a) (b)

Figure 5.34. LM values for (a) the manuscript zone and (b) the main hall for without entrance model

5.6. Mechanical Degradation Risk Analysis

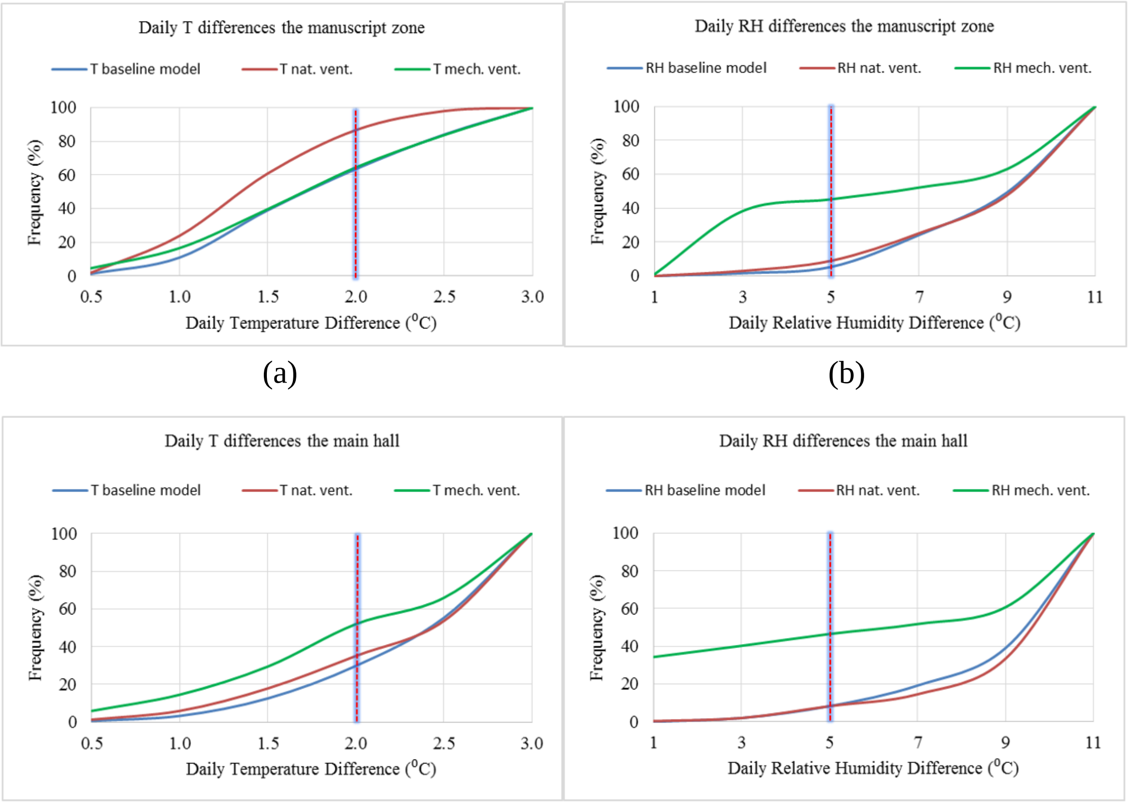
Fluctuations in T values does not cause any mechanical deterioration on manuscripts for semi-open and without entrance model while daily fluctuations in RH values indicate mechanical degredation risk. Only 10% of RH fluctuations are within the limits for both models. Mechanical degradation risk on manuscripts are reduced for both models after implementing mechanical ventilation system (Fig 5.35 & 5.36).



(a) (b)

(c) (d)

Figure 5.35. Fluctuations in (a), (c) T and (b), (d) RH values for the semi-open model



(a) (b)

(c) (d)

Figure 5.36. Fluctuations in (a), (c) T and (b), (d) RH values for the without entrance model

5.6.1. Biological Degradation Risk Anaysis

Mould index values for semi-open and without entrance model are determined and given in Figure 5.37 and Figure 5.38. Mould index value for the without entrance model is zero while for the semi-open model is 0.0001.

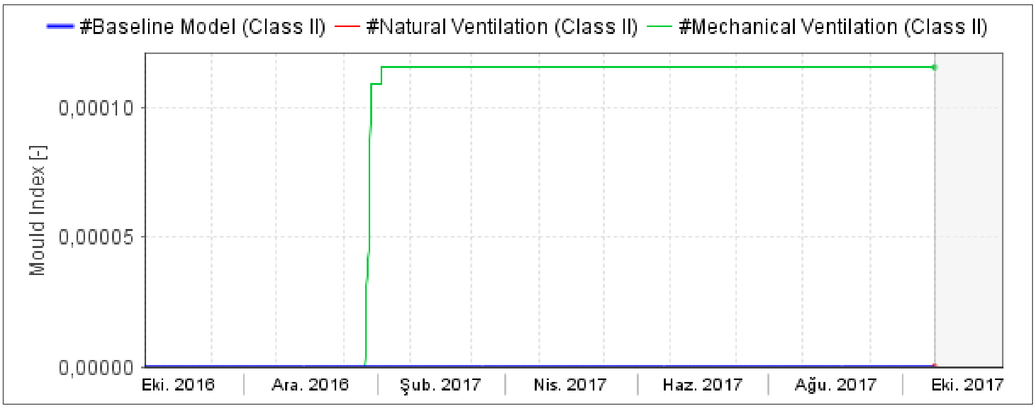


Figure 5.37. Mould index values for semi-open model

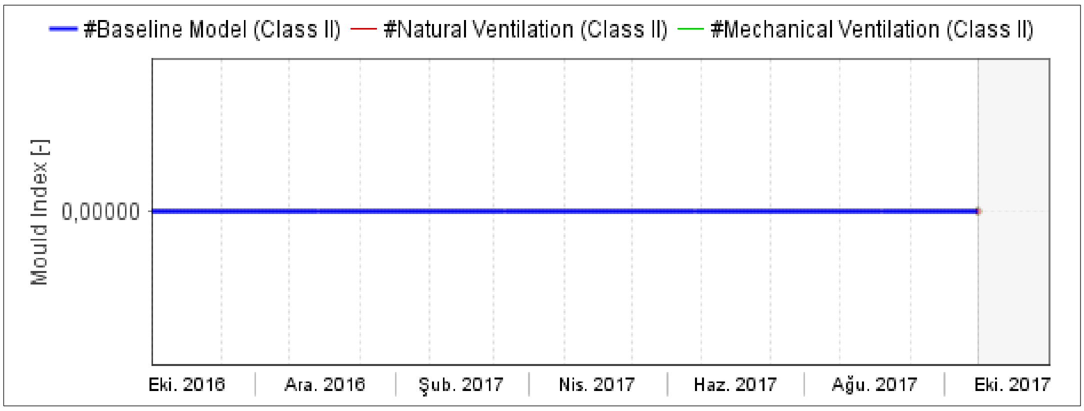


Figure 5.38. Mould index values for without entrance model

CHAPTER 6

CONCLUSIONS

Chemical, mechanical and biological degradation risks on the manuscripts in the historical library was investigated based on preventive conservation point of view in the Thesis. The Necip Paşa Library-Tire-İzmir-Turkey was monitored during one year, from the beginning of September 2014 till the end of August 2015. After evaluation of deterioration rate on the manuscripts, preventive conservation approach was proposed to the Library to diminish degradation risks.

Chemical, mechanical and biological deterioration on the manuscripts arise with respect to T, RH, fluctuations of T and RH and substrates. Based on the literature survey, chemical deterioration on the manuscripts were determined with respect to set points: 20°C for T and %50 for RH (Silva and Henriques, 2015). In addition, allowable daily fluctuations in T and RH values were accepted as ±2°C and ±5%RH in the analysis of mechanical degradation risk on the manuscripts (ASHRAE, 2003). WU-fi Bio software which was based on the principles of Sedlbauer's isopleth diagram, was used to evaluate biological deterioration (WUFI, 2011).

The Library was modelled via DesignBuilder dynamic simulation software (v4.2.054) and the model was calibrated according to ASHRAE Guidelines 14, 2002. Two dimensionless error indicators (MBE and CV(RMSE)) were used as criteria for calibration process.

Based on monitoring data, mechanical and biological degradation risk on the manuscripts were not encountered while chemical degradation risk was observed from May to November, because of high outdoor temperature values. Fig. 6.1 shows the LM values which is the indication of chemical degradation risk, for calibrated model and, natural and mechanical ventilation scenarios on the manuscript zone. Chemical degradation risk on the manuscripts are diminished for the months of May, June, September and October with mechanical ventilation scenario while no change occur with natural ventilation scenario (Fig. 6.1). Annual LM values for each scenario are given in Table 6.1. It can be concluded from the Table that life time of the manuscripts are extended approximately 50% with the application of mechanical ventilation scenario.

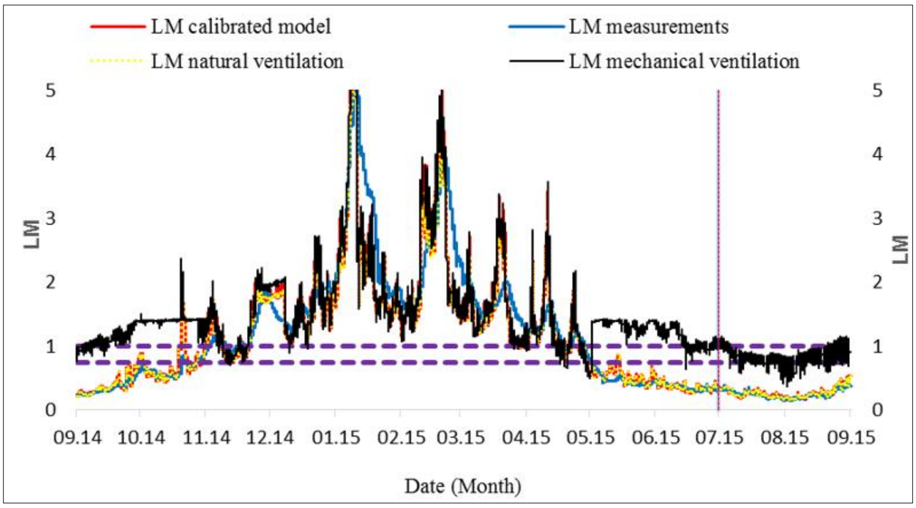


Figure 6.1. Calculated LM values for the manuscript zone (Existing Library)

Table 6.1. Mean LM values for the Existing Library

Chemical Degradation	Measurements	Calibrated Model	Calibrated Model Nat. Vent.	Calibrated Model Mech. Vent.
	Manuscript Zone (Low risk)			
Mean (LM)	1.119	1.067	1.056	1.476
	Main Hall (Low risk)			
Mean (LM)	1.158	1.091	1.054	1.535

The ventilation scenarios do not cause any biological degredation (Figure 6.2), while mechanical degradation risk arise on the manuscripts after scenarios due to increase in fluctuations of RH values (Figure 6.3 and 6.4).

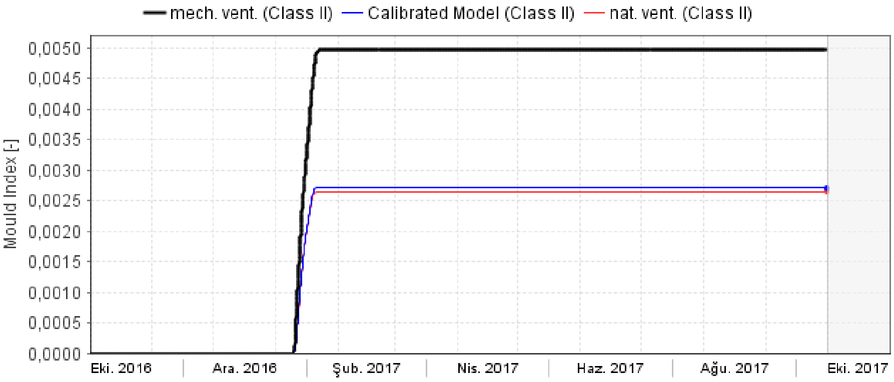
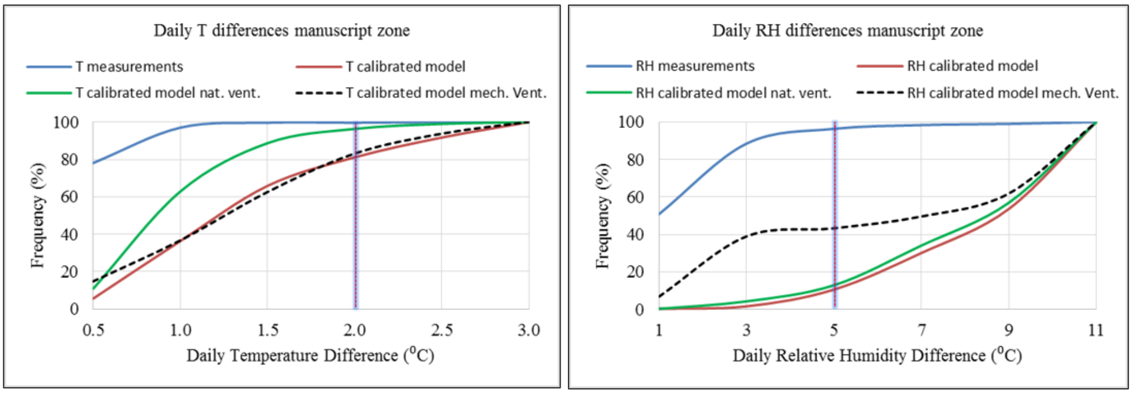
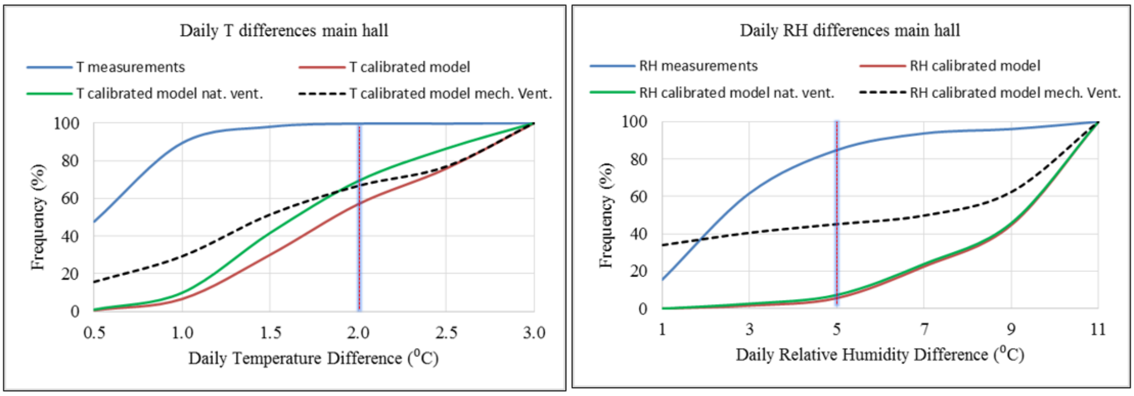


Figure 6.2. Mould index values after scenarios for the manuscript zone (Existing Library)



(a) (b)

Figure 6.3. Fluctuations in (a) T and (b) RH values in the manuscript zone after scenarios (Existing Library)



(a) (b)

Figure 6.4. Fluctuations in (a) T and (b) RH values in the main hall after scenarios (Existing Library)

In order to reduce deterioration rate on manuscripts, mechanical ventilation system is a possible solution for the Library while natural ventilation system is insufficient. The main reason for that the RH values can be controlled in the mechanical ventilation system but not be in the natural ventilation.

Two different models of the Library based on the interventions on the entrance zone are created to be able to see the impact of the entrance zone on the degradation risk of the manuscripts. In the first intervention, semi-open entrance space is added to the Library and in the second intervention, the space is closed by wooden-framed windows. Table 6.2 summarizes the chemical degradation risk analysis results of measurements, calibrated model and the new two models. Calculated LM values and annual average of them are given in Table 6.2. and Fig. 6.5. There is no difference between the results of new models and the library.

Table 6.2. Mean LM values for different models of the Library (Baseline Models)

Chemical Degradation	**Measurements**	**Calibrated Model**	**Semi-open Model**	**Without entrance Model**
	Manuscript Zone (Some risk level between 1 and 1.7)			
Mean (LM)	1.119	1.067	1.064	1.041
	Main Hall (Some risk level between 1 and 1.7)			
Mean (LM)	1.158	1.091	1.102	1.084

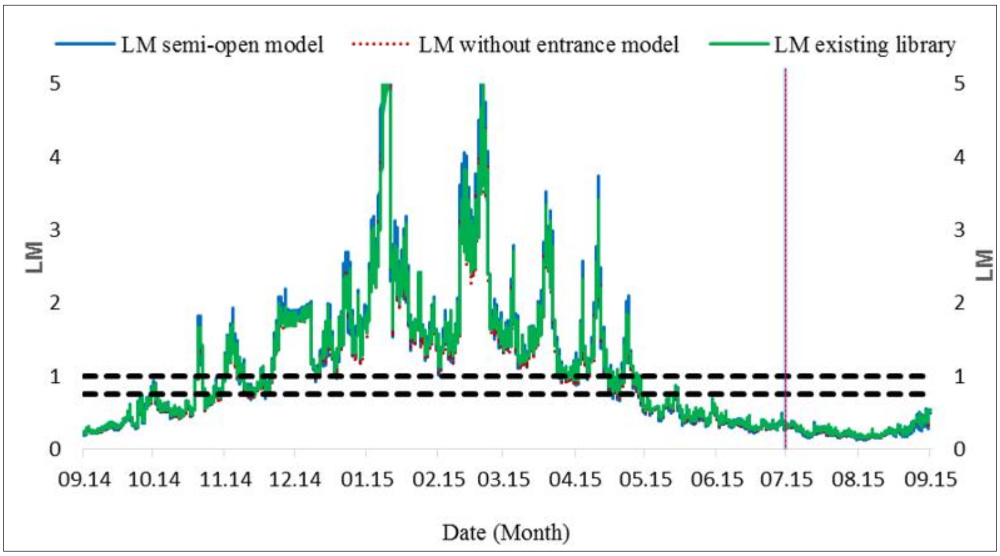
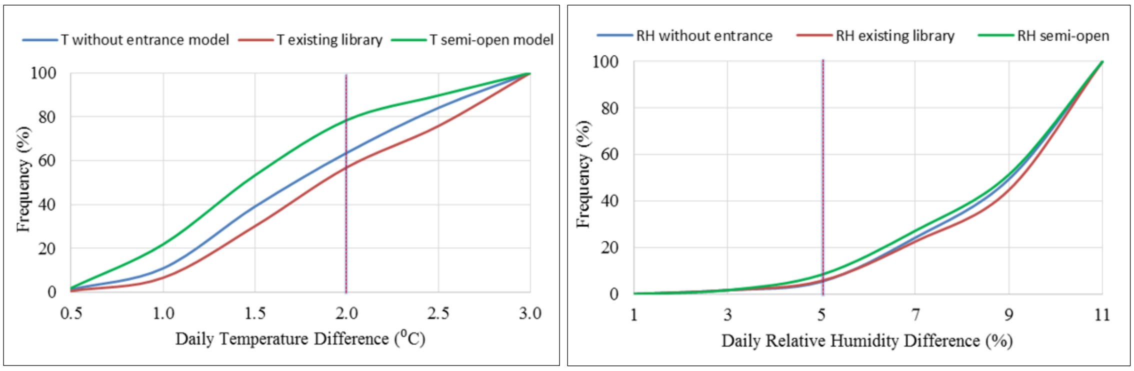


Figure 6.5. Calculated LM values for the manuscript zone (baseline models)

The frequency of daily RH fluctuations are almost same for the models and there are not much differences between them. 80% of daily fluctuations in T values are within the limit for the semi-open model while only 60% of fluctuations in T values for the calibrated and without entrance model (Figure 6.6).



(a) (b)

Figure 6.6. Daily fluctuations in (a) T and (b) RH values for the manuscript zone (baseline models)

Mould index values for the models depicted in Figure 6.7. The mould index value is zero for semi-open and without entrance model while 0.0025 for the calibrated model. There is not any biological risk on the manuscripts and they are biologically safe for each model.

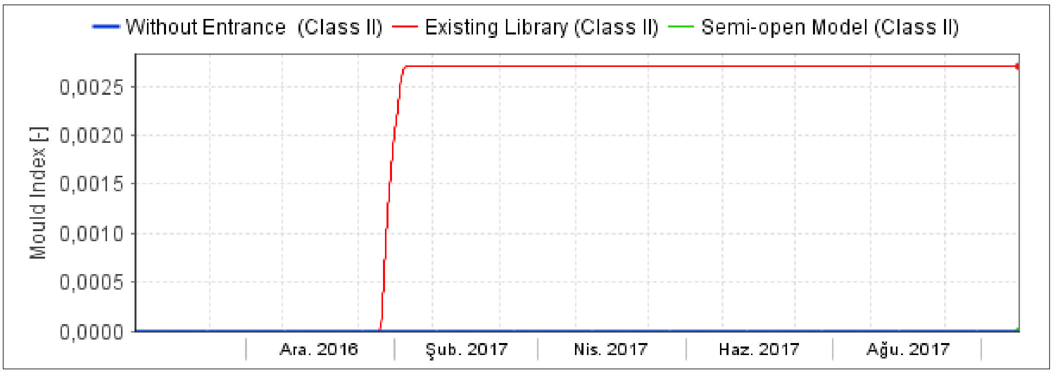
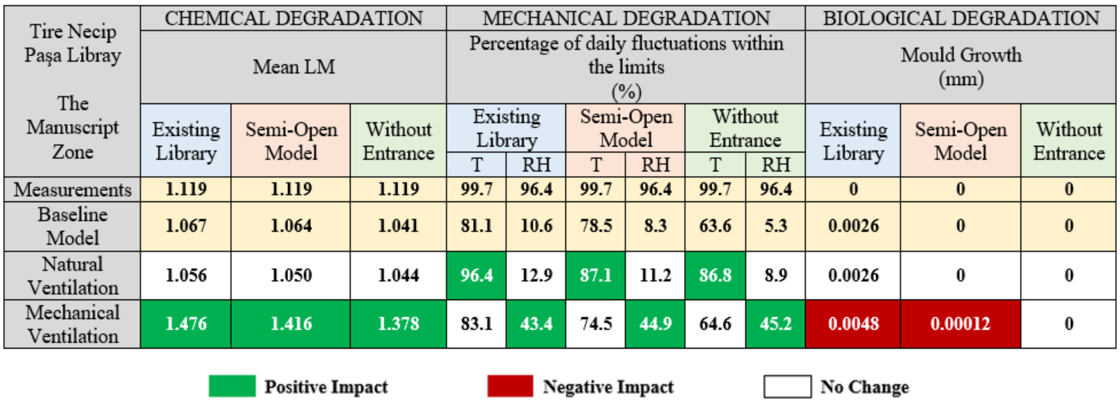


Figure 6.7. Mould Index values for baseline models for the manuscript zone

Degradation risks after scenarios are evaluated and summarized Table 6.3. Improvement on chemical degradation risk can be achieved by decrease in temperature and relative humidity values. 1^{o}C decrease in temperature or %5 decrease in relative humidity decreases the chemical degradation risk by %15. There is not improvement on chemical degradation risk with natural ventilation while fluctuations in T are decreased. On the other hand, mechanical ventilation reduce fluctuations in RH, simultaneously the chemical deterioration on the manuscripts. Mould index value increases by mechanical ventilation nevertheless it does not cause any biological risk.

When the new models are compared with each other, it can be concluded that, semi-open model is more effective for the indoor climate of the Library. Some inter are occurred in the Library during restoration. The Library has some interventions during restoration and the effect of interventions on the indoor climate can be estimated by modelling and simulation.

Table 6.3. Comparison of the Scenarios



Tire Necip Paşa Libray The Manuscript Zone	CHEMICAL DEGRADATION			MECHANICAL DEGRADATION						BIOLOGICAL DEGRADATION		
	Mean LM			Percentage of daily fluctuations within the limits (%)						Mould Growth (mm)		
	Existing Library	Semi-Open Model	Without Entrance	Existing Library		Semi-Open Model		Without Entrance		Existing Library	Semi-Open Model	Without Entrance
				T	RH	T	RH	T	RH			
Measurements	**1.119**	**1.119**	**1.119**	**99.7**	**96.4**	**99.7**	**96.4**	**99.7**	**96.4**	**0**	**0**	**0**
Baseline Model	**1.067**	**1.064**	**1.041**	**81.1**	**10.6**	**78.5**	**8.3**	**63.6**	**5.3**	**0.0026**	**0**	**0**
Natural Ventilation	**1.056**	**1.050**	**1.044**	**96.4**	**12.9**	**87.1**	**11.2**	**86.8**	**8.9**	**0.0026**	**0**	**0**
Mechanical Ventilation	**1.476**	**1.416**	**1.378**	**83.1**	**43.4**	**74.5**	**44.9**	**64.6**	**45.2**	**0.0048**	**0.00012**	**0**

🟩 **Positive Impact** 🟥 **Negative Impact** ☐ **No Change**

Historic buildings have high thermal mass and special indoor climate. The buildings form own indoor climate features throughout the years, thus any intervention to the buildings may arise unexpected results. The temperature values in the buildings can be controlled by natural ventilation while mechanical ventilation systems are become crucial in the controlling of relative humidity. For the Necip Paşa Library, integrating a mechanical ventilation system will extend the life time of the manuscripts.

6.1. Further Studies

Restoration work for the Necip Paşa Library is initiated in July 2015. Monitoring of the Library need to be continued in order to evaluate the effect of restoration on the indoor climate. A HVAC system will be integrated to the Library during the restoration. A filter system and pollutant sensor be add to the HVAC system in order to measure indoor air quality. Because of the interdisciplinary characteristics of the preservation of the historic buildings, a detailed study on the paper based collections in the Library need to be carried out by conservators for a better understanding of the current situation and future of the manuscript. There is no any standard or guideline for the indoor climate of libraries and museums in Turkey, and this can be achieved by researchers.

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