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# The effect of spatial interventions on historic buildings' indoor climate (Case Study: Tire Necip Paşa Library, Izmir-Turkey)

Turgay Coşkun[a], Özcan Gülhan[a] – Cem Doğan Şahin[b] – Zeynep Durmuş Arsan[c]* – Gülden Gökçen Akkurt[d]

[a]*Energy Engineering Programme, Izmir Institute of Technology, Izmir, Turkey*
[b]*Department of Mechanical Engineering, Izmir Institute of Technology, Izmir, Turkey*
[c]*Department of Architecture, Izmir Institute of Technology, Izmir, Turkey*
[d]*Department of Energy Systems Engineering, Izmir Institute of Technology, Izmir, Turkey*

**Abstract**

The indoor climate of historic libraries should meet rigorous requirements related to human thermal comfort and conservation of books, manuscripts and cultural proper-ties. Paper based collections in historic libraries can be deteriorated chemically, mechanically and biologically because of inadequate indoor climate conditions. In this paper, Necip Paşa Library, the historic library located in Tire-Izmir, Turkey, was selected as a case study. The chemical, mechanical and biological degradation risks on the manuscripts were evaluated based on the indoor climate parameters measured for one year period. The Library, consisting of a main hall, a manuscript zone and an entrance hall, was modelled via the dynamic simulation software, Design Builder. Calibration of the model was conducted with respect to the measured indoor temperature and relative humidity values. The portico/Revak at the south facade of Library was converted into the entrance hall by wooden framed windows in 1930. To be able to see the effect of that intervention on the indoor climate (correspondingly on degradation risk of the manuscripts), a new model, namely semi-open model, was created and simulated. A remarkable change has not been observed on chemical degradation risk when the results of semi-open and existing library models were compared, while mechanical and biological degradation risks were less in semi-open model.


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* Corresponding author. Tel.: +90 232 750 7020; fax: +90 232 750 7012.
*E-mail address:* zeynepdurmus@iyte.edu.tr

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*Keywords:* dynamic simulation model, indoor climate, historic library, spatial intervention

## 1. Introduction

Historic buildings represent the cultural heritage of societies, and provide substantial continuity between each phase of human development. Therefore, during the resto-ration and energy efficient retrofits of historic buildings, the main concern must be the preservation of cultural heritage value [3].

Historic buildings can be categorized according to their functional manner of construction (museum, library, archive, dwelling, palace, etc.). Historic libraries can be seen as educational and cultural centers where the primary sources of national heritage such as manuscripts, unique historical books, collections and archival documents are kept [3]. These cultural properties should be preserved in suitable storage and exhibition conditions far from any environmental risk factors which are related to inappropriate humidity, temperature and illuminance levels of indoor climate and microbiology [4]. The environmental risk factors can cause to chemical, mechanical and biological deteriorations. As a result, delamination, dimensional alterations, shrink-ing, swelling, discoloration and mould growth can be seen on the cultural properties.

Extreme values in temperature (T) and relative humidity (RH) are the main reason for chemical deterioration. Fluctuations in T and RH values result in mechanical deterioration on the cultural properties. Extreme T, RH values and substrates in the environment are the main risk indicators for biological deterioration.

In this paper, chemical, mechanical and biological degradation risks on the manuscripts in a historic library are evaluated by measuring the indoor climate parameter (T and RH). The Necip Paşa Library in Tire-Izmir-Turkey is selected as a case building. The Library was constructed in the beginning of the 19th century, which houses 1147 manuscripts and 1312 books printed in the era of Ottoman Empire [19]. The Library had undergone some basic interventions, one of which was the closure of portico/Revak at the south façade with wooden-framed windows in 1930. The effects of this spatial intervention on the indoor climate of the Library consequently the effect on the deterioration of the manuscripts were evaluated by modelling the Library with a Build-ing Energy Simulation Tool.

## 2. The Necip Paşa library

The Library was built in 1827 in Tire-İzmir-Turkey. The original construction of the Library consists of a cubic shaped single zone building (Main Hall) and a portico/Revak (Figure 1(a)). The Library had undergone two main spatial interventions: 1) addition of an octagonal shaped cage-like structure called Manuscript Zone, into the middle of the Main Hall in 1908, where all the manuscripts are kept in (Figure 2) the closure of the portico/Revak in 1930 to create an office space for library staff and a read-ing hall for visitors as called as Entrance Zone (Figure 1(b), Figure 2) [6].

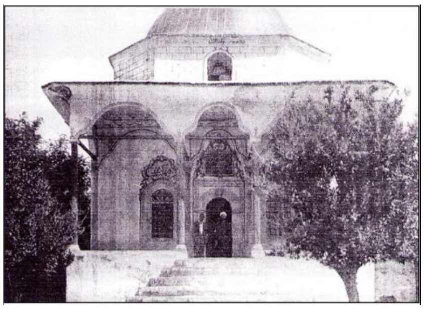
a  b 


Fig. 1. The Necip Paşa Library (a) before 1930, (b) after 1930 (Sources: [12]; [7]).

The Main Hall and the Manuscript Zone are not conditioned, while a split type air-conditioner is placed into the Entrance Hall. The Library is open during weekdays from 08:30 to 17:30 in summer, and from 08:00 to 17:00 in winter.

## 3. Methodology

Indoor and outdoor T and RH data of the Necip Paşa Library is monitored and recorded for one year. Then, the Library is modelled by a Building Energy Simulation Tool, DesignBuilder [5]. The model is calibrated by the measurements and the effect of the closure of the portico/*Revak* on the indoor climate of the Library is evaluated by simulations.

### *3.1. Measurements*

Indoor and outdoor T and RH data of the Library was recorded from September 1st, 2014 to August 31st, 2015 via five mini-dataloggers with ten minutes intervals. The location and technical specifications of the dataloggers are given in Figure 2 and Table 1, respectively.

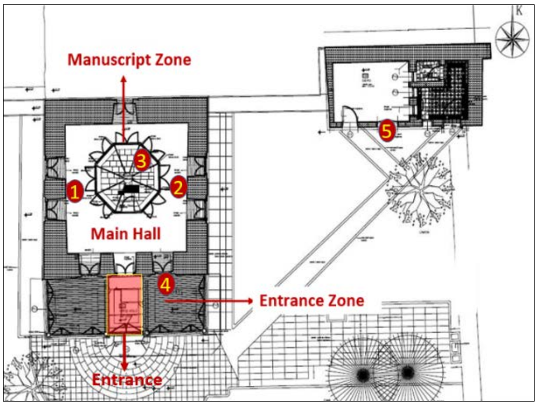



Fig. 2. Location of the dataloggers (Drawing Source: [16]).

Table 1. Technical specifications of dataloggers [9].

| Type | HOBO U12 Temperature/Relative Humidity/ 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 | One year typical use |
| Memory | 64 Kb |

### *3.2. Degradation Risk Analysis*

In ASHRAE Chapter 21 [2], five classes of control are defined with respect to the standard T and RH values for the preservation of historic properties in museums, libraries and archives. The climate classes are specified with respect to the type of historic properties. Class A1 is selected for the preservation of manuscripts, which can reasonably subjected to the permission on seasonal fluctuations [13].

*Chemical degradation*

Chemical degradation is related to amount of moisture content in hygroscopic materials. Chemical degradation risk on the manuscript can be determined by Lifetime Multiplier (LM) method which corresponds to the number of time spans an object re-mains unstable when compared to indoor climate of 20°C and 50% RH [15]. Equation (1) indicates the instantaneous response of the manuscripts to indoor climate conditions. In order to measure annual response of the objects, equivalent Lifetime Multiplier (eLM) is used (Eq.2). The eLM values lower than 0.75 and greater than 1 is an indicator of high risk and low risk levels, respectively. The eLM values in between is assumed as medium risk level [11]. Table 2 gives the risk levels for the interpretation of eLM values.

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

$$\mathrm{eLM} = \frac{1}{\frac{1}{n}\times\sum_{x=1}^{n}\left(\frac{50\%}{\mathrm{RH_x}}\right)^{1.3}\times e^{\frac{E_a}{R}\left(\frac{1}{T_x+273.15}-\frac{1}{293.15}\right)}} \quad (2)$$

$E_a$, R, $T_x$ and $RH_x$ in Equations (1) and (2) are the activation energy (100 kJ/mol for degradation of cellulose), gas constant, indoor temperature and relative humidity, respectively.

Table 2. Interpretation of the eLM values [11].

| Type | Ideal | Good | Some Risk | Potential Risk | High Risk |
|---|---|---|---|---|---|
| eLM | > 2.2 | [1.7-2.2] | [1-1.7] | [0.75-1] | <0.75 |

*Mechanical degradation*

The main reason behind the mechanical degradation is fluctuations in T and RH values. When allowable daily fluctuation values are exceeded, the mechanical degradation is observed. Daily allowable fluctuations for T and RH values are defined as ±2°C and ±5% RH in ASHRAE Climate Class A1, respectively [2]. Daily fluctuations in T and RH values are calculated by taking difference between the minimum and maximum values in a day. The manuscripts are accepted as mechanically safe, if 90% of the fluctuations are lower than allowable values [8].

*Biological degradation*

The minimum amount of moisture content in a spore which allows germination is named as the critical water content. Water content in a spore is the criteria in order to decide whether there is any mould growth, or not on the surface of a wall ([17]; [14]).

Mould risk factor (MRF) is assessed via WUFI-Bio software [17] where three substrate classes are defined to evaluate critical water content and to determine spore germination (Table 3). Paper based collections are the members of substrate class II.

Table 3. Substrate Classes [17].

| 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 based building materials) |

## *3.3. Modelling and Calibration*

The Library was modelled to be able to determine the influence of spatial intervention on the degradation risk of manuscripts. The first model, called "existing library model" represents the existing construction where the portico/Revak is converted into Entrance Zone (Figure 1a). The second model exemplifies the original construction with portico/Revak which is called as "semi-open model".

DesignBuilder v4.2.054 is used to model the Library [5]. The existing construction is first modelled and calibrated using measurement data with respect to ASHRAE Guideline 14 [1]. The calibration process is conducted with two dimensionless error indicators, i.e. mean bias error (MBE) and coefficient of variation root-mean-square error (CV(RMSE)), calculated by Equations (3) and (4), respectively [10].

$$MBE = \frac{\sum_{i=1}^{N_i}(M_i - S_i)}{\sum_{i=1}^{N_i} M_i} \quad (3)$$

$$CV(RMSE) = \frac{\left[\left[\frac{\sum_{i=1}^{N_i}\left[(M_i - S_i)^2\right]}{N_i}\right]\right]^{\frac{1}{2}}}{\frac{1}{N_i}\sum_{i=1}^{N_i} M_i} \quad (4)$$

Measured and simulated data at instance $i$ is shown by $M_i$ and $S_i$ in Equations (3) and (4), respectively. $N_i$ represents the number of data. The upper limit for CV(RMSE) and MBE values were defined in ASHRAE Guideline 14 as 30% and ±10% for hourly measurements. The upper limits are used to decide whether the model is calibrated, or not. Once the “existing library model” was calibrated, the “semi-open model” was developed and the results were compared based on the deterioration of the manuscripts.

## 4. Results

### *4.1. Measurements*

The collected hourly T and RH data is evaluated for each zone of the Library [13]. The LM values for the Manuscript Zone are calculated to determine the chemical degradation risk on the manuscripts and the results are depicted in Figure 3. The restoration study in the Library initiated nearly at the end of measurement campaign is shown with vertical blue line in the Figure 3.

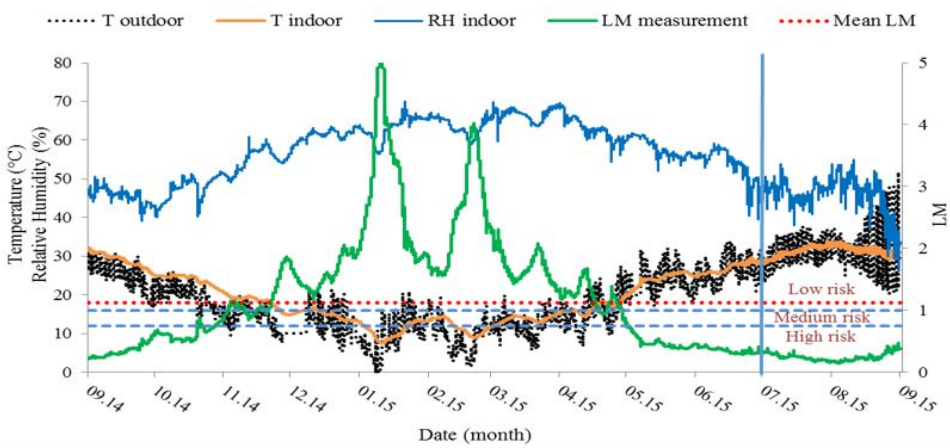



Fig. 3. Chemical degradation risk analysis in the Manuscript Zone (based on the measure-ments): LM method.

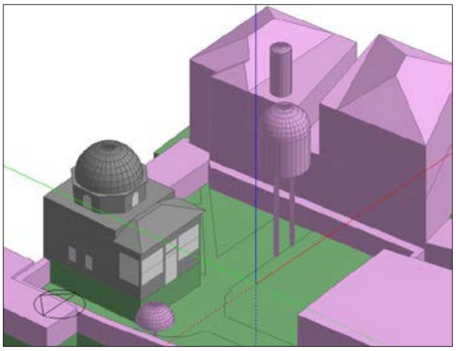
According to the Figure 3, there is no chemical degradation risk between December 2014 and April 2015, while medium risk level is observed in November 2014. On the other hand, high chemical degradation risk is observed on the manuscripts from September to October 2014 and May to September 2015. In summer time when the temperatures are high, chemical degradation risk is also high. The red dotted line in Figure 3 represents the annually averaged LM value. The mean LM value is very close to the medium risk region.

There is no mechanical and biological degradation risk for the manuscripts according to the measurements. Almost 100% of the daily T fluctuations and 96% of the daily RH fluctuations are lower than the allowable daily fluctuation values.

## 4.2. Modelling

The "existing library model" is created with respect to the geometry and the construction materials of the Library by DesignBuilder Software. Surrounding buildings and trees are included in order to obtain a more accurate model (Figure 4). The model is calibrated for hourly indoor T and RH measurements simultaneously with respect to ASHRAE Guideline 14 [1].

a



b

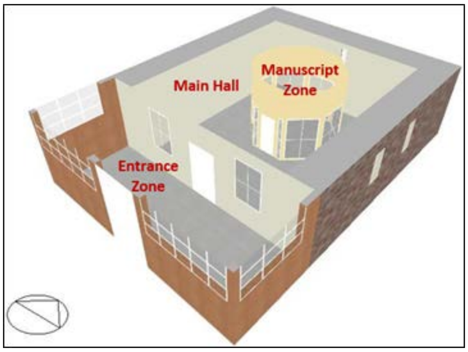



Fig. 4. (a)"Existing library model", (b) 3D zone plan.

The calibrated error ratios for the "existing library model" is -0.71% MBE and 7.16% CV(RMSE) for T, and 4.63% MBE and 15.24% CV(RMSE) for RH. Following the calibration of the "existing library model", "semi-open model" is created (Figure 5).

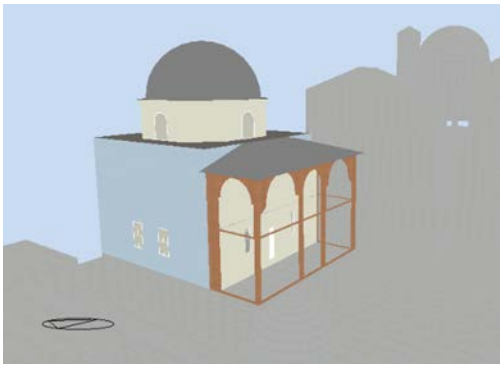


Fig. 5. "Semi-open model".

The T and RH data obtained from both models are used to determine the chemical, mechanical and biological degradation risk on the manuscripts and compared with the measurement results.

*Chemical degradation*

The LM values for “existing library model” and “semi-open model” are calculated according to simulation results given in Figure 6. The Figure indicates that LM values for two models show almost the same trend. Chemical degradation risk on the manuscripts did not diminished in the “semi-open model”.

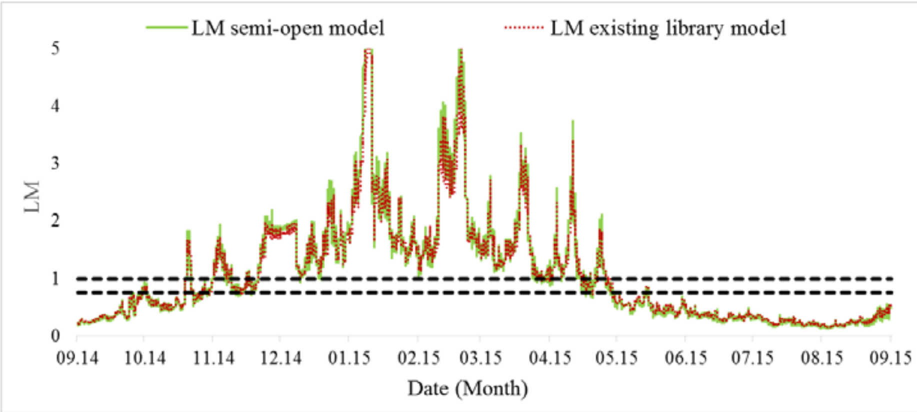



Fig. 6. Chemical degradation risk analysis for two models.

*Mechanical degradation*

Frequency of T and RH fluctuations determined as 81.1% and 10,6% for “existing building model” while 78.5% and 8.3% for “semi-open model”, respectively. Since 90% of the fluctuations should be lower than the allowable values, both models can not satisfy the requirements of ASHRAE Climate Class A1and indicates the availability of mechanical degradation risk.  The reason behind the lower frequencies for RH fluctuation may be the limitations on software’s humidity calculation methodology, and rising question on its reliability on the prediction for daily RH fluctuations.

*Biological degradation*

Mould risk factor calculations for the “existing” and “semi-open” models are shown in Figure 7. There is no mould growth risk for “semi-open model” while mould growth risk can be observed on the surface of manuscripts for the “existing library mod-el”.

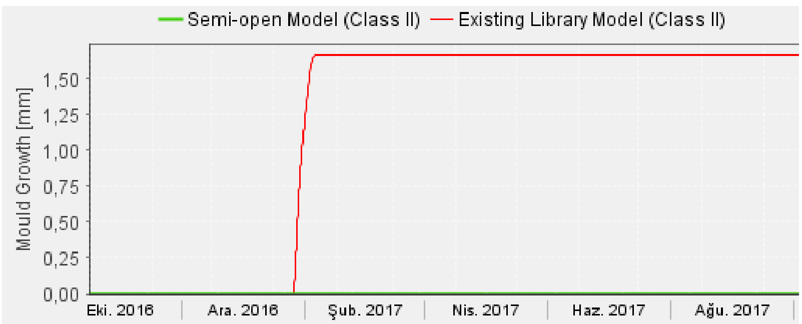



Fig. 7. Critical water content for mould growth rate based on two models.

The results are summarized in Table 4. Chemical degradation risk level is similar for both models and very close to risky region while mould growth is observed on the surface of the manuscripts in the “existing library model”. Mechanical degradation risk is slightly lower in the “existing library model” based on the simulations while there is no risk based on the measurements.

Table 4. Degradation risk on the manuscripts.

| Manuscript Zone | Chemical Degradation<br>Mean<br>LM | Mechanical Degradation<br>Fluctuations which lower than allowable values for ASHRAE Climate Class A1 (%) | | Biological Degradation<br>Mould growth<br>(mm) |
|---|---|---|---|---|
| | | T | RH | |
| Measurements | 1.119 | 99.7 | 96.4 | 0 |
| Existing library Model | 1.067 | 81.1 | 10.6 | 1.65 |
| Semi-open model | 1.064 | 78.5 | 8.3 | 0 |

## 5. Conclusions

Chemical, mechanical and biological degradation risks on the manuscripts in a historic library were investigated based on T and RH measurements and simulations. The Necip Paşa Library-Tire-İzmir-Turkey was monitored from the beginning of September 2014 till the end of August 2015. After evaluation of deterioration rate on the manuscripts with respect to the measurements, the Library was modelled via DesignBuilder Software in order to determine the influence of spatial intervention on the indoor cli-mate correspondingly the degradation risk on the manuscripts.

Based on the measured data, there were no mechanical and biological degradation risks on the manuscripts, while chemical degradation risk was observed from September to October 2014 and May to June 2015. High indoor temperature values are the main reason behind the chemical degradation.

Historic buildings form their own indoor climatic features throughout the years. Any spatial intervention disturbing long years' thermal regime may reveal unexpected results in indoor climate. Therefore, chemical, mechanical and biological degradation risk on the manuscripts for the "existing library" and "semi-open" models were com-pared in the study. According to the results, the trend of chemical and mechanical degradation risks on the manuscripts is almost the same for two models, while biological degradation risks are higher for the "existing library model". In order to improve the in-door climate, the physical structure of the Library would be returned to its original state and ventilation scenarios could be adopted.

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