Impact of climate change on indoor environment of historic libraries in Mediterranean climate zone

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Abstract: Most historic library buildings house valuable paper-based collections that are kept in unconditioned environments. This vulnerable cultural heritage is expected to be highly affected by climate change in the future. In this study, indoor microclimate of an unconditioned historic library, Necip Paşa Library (Izmir, Turkey) is analysed for existing conditions and future climate data. The measured and predicted indoor microclimate data from 'present' till 2080s are used to determine possible chemical degredation risk on library collection and human comfort. Comparison of periodic results of future climate data indicates an increase in temperature that could cause both an increase in chemical degredation risk on the library collection and a decline in thermal comfort conditions. Mitigation of climate change effects on library collection and human comfort requires taking some actions such as adding light and adaptive mechanical solutions.

Keywords: climate change; thermal comfort; degradation risk; paper-based collections; historic libraries; dynamic simulation.

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1 Introduction

Heritage value in historic buildings is related to historical and architectural features. Beside these immovable features, movable objects (artefact, manuscript, artwork, collections, paintings, sculptures, etc.) make contribution to heritage value of historic buildings. The primary sources of the national movable objects that are kept in historic libraries are paper-based collections like manuscripts, archival documents, rare and endangered books (Arslan and Ulaş, 2007).

Storage and exhibition environment of paper-based collections should be far from any inappropriate humidity (*RH*), temperature (*T*) and lighting levels, gaseous and particulate pollution like CO_2, SO_2, NO_X, O_3, H_2S etc. and microbiological conditions (Fabbri and Pretelli, 2014; Andretta et al., 2016). Assessment of indoor environment of historic libraries should primarily aim to preserve paper-based collections while accommodating at least a considerable level of thermal comfort for visitors.

Common approach for conservation of paper-based collections is to focus on risk analysis of mechanical, chemical and biological degradations (Huijbregts et al., 2015; Bülow, 2002; Krüger and Diniz, 2010; Fabbri and Pretelli, 2014). Short-term fluctuations in *T* and *RH* cause mechanical degradation which result with dimensional alterations, shrinking and swelling on paper (Silva and Henriques, 2015).

Similarly, chemical degradation risk on paper such as discoloration in paper and deterioration in text, arises due to extreme *T* and *RH* values (Zou et al*.,* 1996). Although various parameters such as time weighted preservation index (*TWPI*) (Silva and Henriques, 2015) and Arrhenius equation (Zou et al., 1996) exist in the literature for chemical degradation risk analysis, lifetime multiplier (*LM*) is mostly used for paper. Martens (2012) defines *LM* as "the *LM* corresponds to the number of timespans that an object remains unstable when compared to indoor climate of 20°C and 50% *RH*". Besides, equivalent lifetime multiplier (*eLM*) represents an equivalent value of the *LM* evaluated during the monitoring period (Martens, 2012).

Temperature, *RH* and substrates are the most influencing parameters on biological degradation. As a result of biological degradation, mould could grow on paper (Warscheid and Krumbein, 1994).

Storage and exhibition conditions of paper-based collections are defined by standards such as UNI 10829 (1999), ASHRAE (2007), EN 15757 (2010) and PAS 198 (2012). Table 1 gives *T* and *RH* values for museums, libraries and archives (ASHRAE, 2007).

Table 1 *T* and *RH* values for museums, libraries and archives

Climate classes		*Annual average*	*Short-term allowable fluctuations*	*Seasonal allowable fluctuations*
AA		50% *RH*, 15°C < *T* < 25°C	±5% *RH*, ±2K	No change in *RH*, ±5K in *T*
A	A1		±5% *RH*, ±2K	±10% *RH*, down 5K
	A2		±10% *RH*, ±2K	No change in *RH*, down 5K, up 10K
B			±10% *RH*, ±5K	Up 10% *RH*, down 10% *RH*; Up 10K but not above 30°C, down as low as necessary to maintain *RH* control
C		Within 25 to 75% *RH* year-round *T* rarely over 30°C, usually below 25°C		
D		Reliably below 75% *RH*		

Source: ASHRAE (2007)

In Table 1, climate classes are defined according to historic properties of the collections (Bülow, 2002; Şahin et al., 2017). Climate class AA permits shorter fluctuations in weekly, daily and hourly terms. Furthermore, no seasonal fluctuation of *RH* is allowed whilst *T* fluctuations should be in a range of ±5K. Climate class A refers two sub-climate classes; A1 and A2. A1 allows ±5% *RH* and ±2K while ±10% *RH* and ±5K are allowed in A2 for short-term fluctuations. Higher short-term and seasonal changes in *T* and *RH* are allowed in climate class B. Finally, classes C and D relatively avoid high and low values in *T* and *RH* compared to other classes. ASHRAE (2007) recommends climate class A1 for paper-based collections.

Apart from preserving paper-based collections in historic libraries, thermal comfort of visitors should also be taken into consideration. Thermal comfort is a subjective sensation which, in turn depends on six parameters: indoor air temperature (T_i), relative humidity (RH_i), air velocity (v_i), mean radiant temperature (MRT_i), clothing value (*clo*) and metabolic rate (*met*) (ASHRAE 55, 2004). Fanger developed two thermal comfort indices: predicted mean vote (*PMV*) and predicted percentage of dissatisfied (*PPD*), which were later standardised in ISO EN 7730 (2005) and ASHRAE 55 (Fanger, 1970). The *PMV* uses heat balance principles combining environmental and personal factors for thermal comfort and refers to a thermal scale where the value of *PMV* is zero with a tolerance of ±0.5 as 10% of the occupants feel thermally dissatisfied (*PPD*). Considering the visitors in historic libraries, thermal comfort assessment is essential since indoor environment of libraries must provide comfortable and healthy conditions (Krüger and Diniz, 2010).

Mean outdoor air temperature is projected to increase by 4–5% in Mediterranean climate zone at 2080s compared to 1961–1990 period. Since *T* is highly related to *RH* values, 5–6% decrease in *RH* is expected for the same time period (Giorgi and Lionello, 2008; Polade et al., 2017). Therefore, changes in microclimate conditions (*T* and *RH*) in Mediteranean climate zone have the potential to cause damage on paper-based collections and result in poor thermal comfort in historic libraries, especially for those without an air-conditioning system (Bülow, 2002).

Thermal comfort in historic buildings and the effect of climate change on paper-based collections for historic libraries have been investigated for different climate zones; such as cold (Bakhtiari et al., 2018), hot-dry (Ealiwa et al., 2001) and tropical climates (Kamaruzzaman et al., 2015). However, thermal comfort on historic libraries in Mediterranean climate zone and the effect of climate change on paper-based collections have not been investigated widely. According to the authors' knowledge, there is no study in the literature relating the climate change effects in historic libraries in Turkey.

The aim of this manuscript is to analyse the risk of the future climate change on paper-based collections and thermal comfort of visitors in a historic library in Mediterranean Climate Zone for the 'present', 2020s, 2050s, and 2080s. The Necip Paşa Library in Izmir, Turkey which has been housing valuable manuscripts (dating back to the 12th century) since 1827, is studied as case building. The data coded as 'present data' was collected during a one-year monitoring campaign whilst future climate data were generated based on 'morphing' approach by The Climate Change Weather File Generator (CCWorldWeatherGen) (Jentsch et al., 2008).

2 Materials and methods

The study consists of an assessment of one-year 'present' climate data recorded in the library in 2014–2015, generation of future climate data for 2020s, 2050s and 2080s, and finally comparison of the 'present' and future data based on risks for degradation of paper-based collections and thermal comfort of visitors. The flowchart of the study is given in Figure 1.

2.1 Case building

The Necip Paşa Library, which was built in 1827 in Tire-Izmir, Turkey (Figure 2). The library houses 1,147 manuscripts and 10,135 printed books (Yıldırım, 2011) which have been exhibited in unconditioned environment. The building can be divided into three zones; main hall, manuscript zone and entrance zone (Figure 3). The walls consist of rubble stone and brick while the windows are single glazed. The main hall is occupied by the visitors during weekdays between 8.30 am and 5.30 pm. Further information about the library can be found in Tire Necip Paşa Library (2018).

The Necip Paşa Library was modelled by a dynamic building energy simulation (BES) tool, DesignBuilder (DesignBuilder, 2018) in a previous study where the details of the model can be found (Coşkun et al., 2017).

Figure 1 Flow-chart of the study

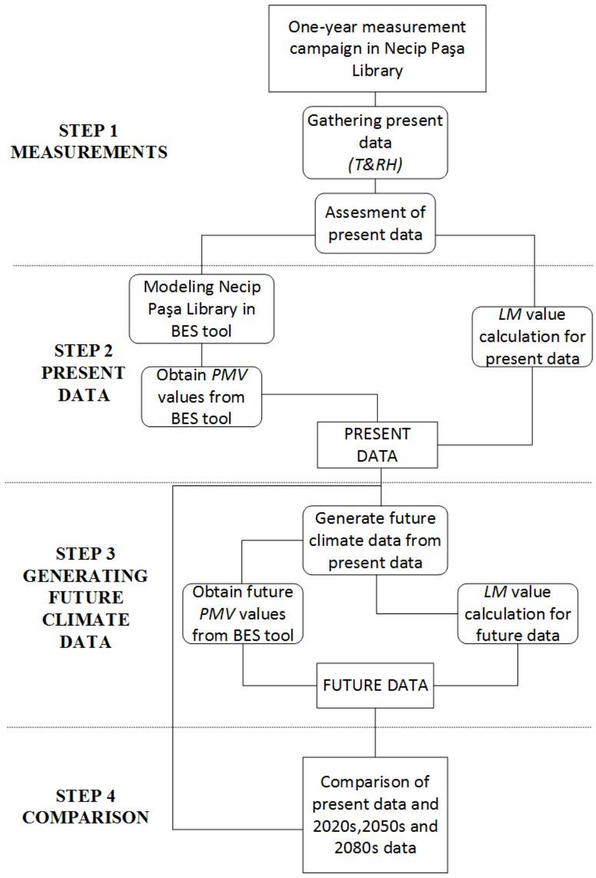
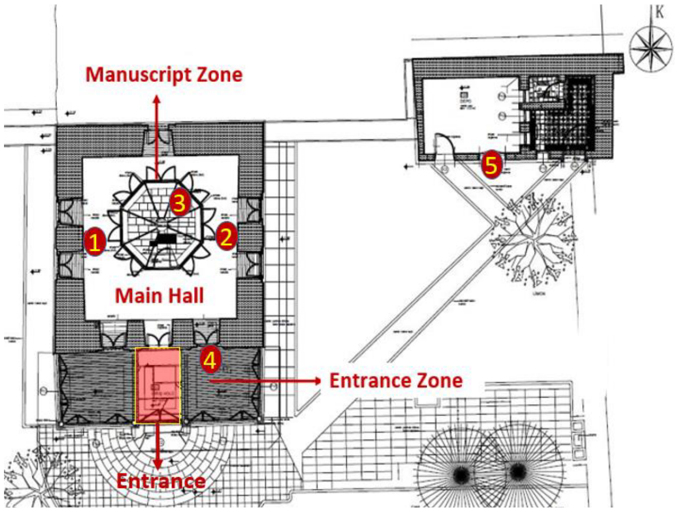


Figure 2 Entrance façade of the Necip Paşa Library (see online version for colours)

Figure 3 Schematic diagram of the library and sensor locations (see online version for colours)



Source: Şahin et al. (2017)

2.2 Measurements

The measurement campaign lasted for one year between 1 September 2014 and 31 August 2015 with 10 minute intervals. The 'present' data was obtained from five data loggers that measure indoor and outdoor *T* and *RH* values (red points on Fig 3). The distribution of the data loggers are as follows: two in the main hall (1-2), one in the manuscript zone (3), one in the entrance zone (4) and one on the external wall (5). The data logger at entrance zone was not used for this study. Technical specifications of data loggers are listed in Table 2 (Onset, 2018).

Table 2 Technical specifications of data loggers

Data loggger	HOBO U12 *T*/*RH*/light/external data logger
Measurement range	*T*: –20°C to 70°C *RH*: 5% to 95%
Accuracy	*T*: ±0.35°C from 0°C to 50°C *RH*: ±2.5% from 10% to 90%

Source: Onset (2018)

2.3 Future climate data

To evaluate impact of global warming on manuscripts and thermal comfort of visitors, the future hourly climate data is required. For this reason, 10-minute data were converted to hourly climate data. Then, future climatic data for 2020s (2020–2040), 2050s (2041–2070) and 2080s (2071–2100) were generated to investigate the effect of future climate change on manuscripts and thermal comfort of visitors in the library. In order to have a better visualisation of each data set on the figures, monthly data were created by averaging hourly data. Three different climate data were obtained by using the UK Handley Center's third generation coupled atmosphere-ocean global climate model (Jentsch et al., 2008). The model uses morphing approach which is the combination of present-day weather information data and results of climate change models by using CCWorldWeatherGen (HadCM3, 2012). These climate data, then, used in DesignBuilder as a weather data file. Finally, *PMV* and *PPD* indices of visitors were obtained according to the future climate data.

2.4 Degradation risk assessment

Indoor climate, which is highly related to *T* and *RH*, is the main environmental risk factor on the paper-based collections in historic libraries (Dahlin, 2002). High *T* and *RH* content of indoor air in historic libraries can cause corrosion on metals, oxidation, discolouring on paintings and acid hydrolysis on cellulose (Krüger and Diniz, 2010). The analysis of the 'present' data of the Necip Paşa Library indicates that mechanical and biological degradation risks are low and can be neglected (Şahin et al., 2017). Therefore, in this study, degradation risk is only evaluated in terms of chemical degradation.

Chemical degradation risk is assessed with *LM* that can be determined for instantaneous *T* and *RH* values using equation (1) (Michalski, 2003; Silva and Henriques, 2015).

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

where E_a is activation energy (100 kJ/mol) for degradation of cellulose (Silva and Henriques, 2015) while *R* is the gas constant (8.314 J/molK). The *LM* values and their risks on paper-based collections are given in Table 3. The indoor climate is called as risky and safe for collections if the *LM* value is lower than 1 and higher than 1, respectively.

Table 3 *LM* values and degree of chemical risks on paper collections

LM values	*Risk on paper-collections*
$LM < 0.75$	High risk
$0.75 < LM < 1$	Medium risk
$1 < LM$	Low risk

Source: Martens (2012)

The equivalent lifetime multiplier (*eLM*) that represents the average of reciprocal values of *LM* is used instead of taking arithmetic average by using equation (2) (Silva and Henriques, 2015). The *eLM* values and their risks on paper-based collections are given in Table 4. An *eLM* value lower than 1 means that there is chemical risk for paper-based collections.

$$eLM = \frac{1}{\frac{1}{n}\sum_1^n \left(\frac{50\%}{RH_x}\right)^{1.3} e^{\frac{E_a}{R}\left(\frac{1}{T_x+273.15}-\frac{1}{293.15}\right)}} \tag{2}$$

When *T* increases, *LM* and *eLM* values decrease. This process causes an increase in chemical reactions leading chemical degradation in manuscripts (Martens, 2012; Silva and Henriques, 2015; Şahin et al., 2017).

Table 4 Interpretation of the *eLM* values on paper collections

eLM values	*Risk on paper collections*
eLM < 0.75	High risk
0.75 < *eLM* <1	Potential risk
1 < *eLM* < 1.7	Some risk
1.7 < *eLM* < 2.2	Good
2.2 < *eLM*	Ideal

Source: Martens (2012)

2.5 Thermal comfort assessment

Thermal comfort of visitors in the library is also assessed by using 'present' and future climate data in terms of *PMV/PPD* indices which are the most common metric to estimate thermal comfort as presented in ISO EN 7730 (2005).

PMV uses six parameters for the calculation and refers to a thermal scale that runs from cold (–3) to hot (+3), originally developed by Fanger (Fanger, 1970) and later adopted as ISO EN 7730 (2005). The scale using codes given in Table 5 as –3 for cold, –2 for cool, –1 for slightly cool, zero for neutral, +1 for slightly warm, +2 for warm and +3 for hot.

The *PPD* expresses the percentage of the occupants that will be dissatisfied with the thermal environment (ASHRAE 55, 2004).

The 'present' *PMV/PPD* values were obtained using 'present' weather file of Tire-Izmir in DesignBuilder while the future *PMV/PPD* values were generated by using future climate data of the library. In addition, the metabolic rate (*met*) was selected as 1 which refers seated person while reading in ASHRAE 55 (2004). The clothing values of the visitors were chosen as 0.5 and 1 for summer (April–October) and winter (September–March) seasons, respectively.

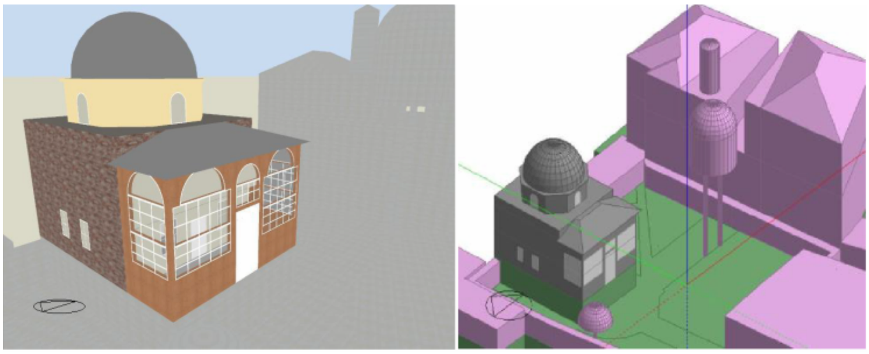
Table 5 Thermal sensation scale in ISO EN 7730 (2005)

Thermal sensation	*PMV*
Hot	+3
Warm	+2
Slightly warm	+1
Neutral	0
Slightly cool	–1
Cool	–2
Cold	–3

3 Results and discussions

Figure 4 shows BES model of the Necip Paşa Library. The model was calibrated based on ASHRAE Guideline 14 (2002) and the calibration results can be found in Coşkun et al. (2017).

Figure 4 BES model of the Necip Paşa Library (see online version for colours)



Source: Coşkun et al. (2017)

The annual average values of T_i, T_o, RH_i, RH_o, *PMV*, *PPD, LM and eLM* of 'present', 2020s, 2050s and 2080s were calculated and given in Table 6. The future data in the Table is given as differences with 'present' data. The results indicate that *T* increases, *RH* decreases by time as expected. For instance, T_i may increase by 11% and RH_i may decrease by 7.7% at 2080s compared to the 'present' climatic data.

Table 6 The annual average values of T_i, T_o, RH_i, RH_o, *PMV*, *PPD*, *LM* and *eLM* of 'present', 2020s, 2050s and 2080s

	T_i	T_o	RH_i	RH_o	*PMV*	*PPD*	*LM*	*eLM*
Unit	[°C]	[°C]	[%]	[%]	[-]	[%]	[-]	[-]
Present	21.0	19.0	56.9	66.2	1.66	59.6	1.12	0.91
2020s	+0.8	+1	–1.7	–1.8	+0.06	+3.2	–0.05	–0.05
2050s	+1.5	+1.6	–2.8	–2.9	+0.12	+6.4	–0.09	–0.08
2080s	+2.4	+2.7	–4.4	–4.8	+0.19	+9.9	–0.14	–0.13

Figure 5 shows the change in *PMV* with future climate change. In ASHRAE 55, ±0.5 of *PMV* refers as comfort zone (grey area in Figure 5). The figure refers that half of the year (summer and fall), *PMV* values are out of the comfort region and tend to increase with the time. The annual *PMV* values may increase by 0.06, 0.12 and 0.19 at 2020s, 2050s and 2080s, respectively (Table 6). The increase in *PMV* values highly depends on the increase in T_i values by future climate change (Figure 5, Table 6). PPD values may increase up to 10% in 2080s compared to present data (Table 6).

Figure 5 PMV values for 'present', 2020s, 2050s and 2080s (see online version for colours)

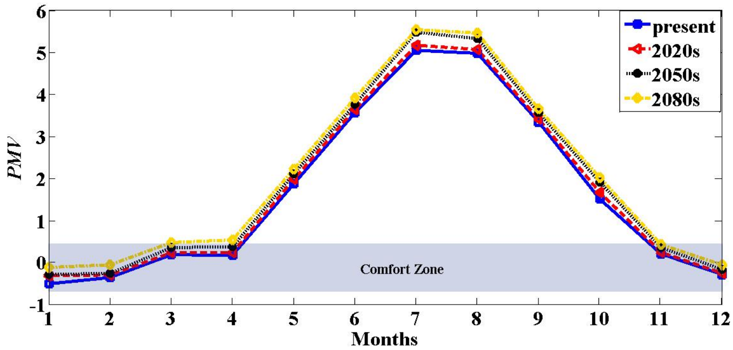


Figure 6 shows the comparison of T_o values whilst Figure 7 depicts the change of T_i values for 'present', 2020s, 2050s and 2080s. The annual average T_o value was calculated as 19°C based on 'present' data while this value may increase by +1°C, +1.6°C and +2.7°C at 2020s, 2050s and 2080s, respectively (Table 6). These results are quite inline with the projections of T_o values for Mediterranean climate zone as discussed in introduction section.

Figure 6 Comparison of T_o values for 'present', 2020s, 2050s and 2080s (see online version for colours)

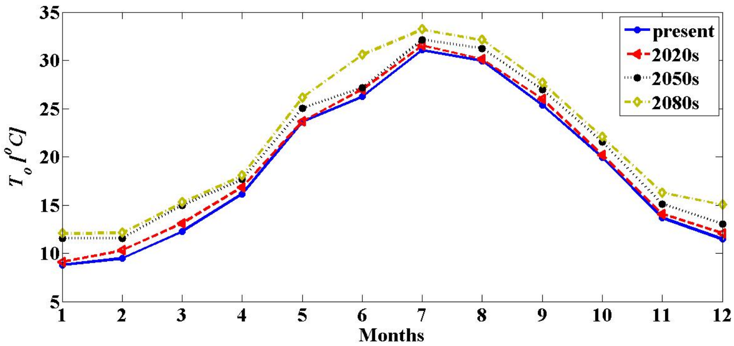
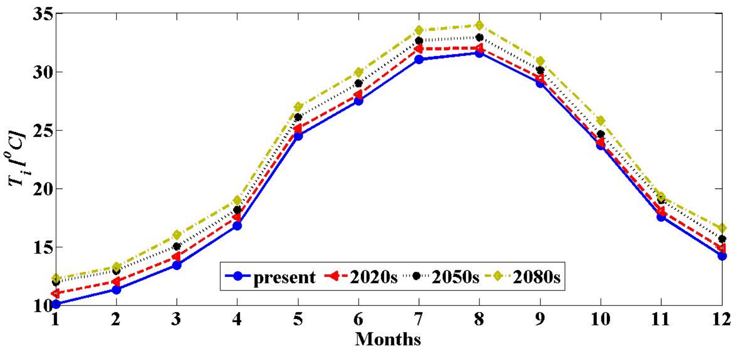


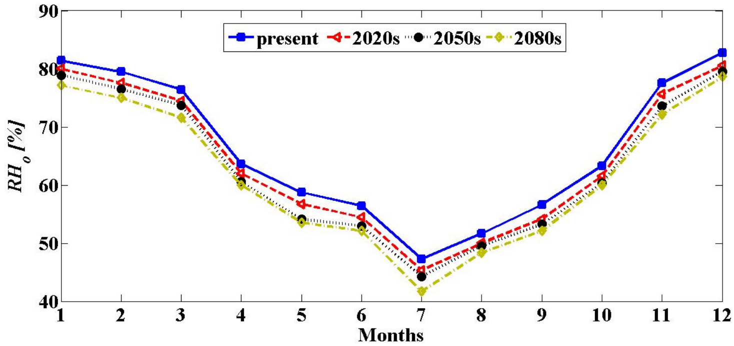
Figure 7 Comparison of T_i values for 'present', 2020s, 2050s and 2080s (see online version for colours)



The average T_i value is 21°C in the library, however, as a result of increase in T_o values, T_i values may increase by +0.8°C, +1.5°C and +2.4°C at 2020s, 2050s and 2080s, respectively (Figure 7, Table 6).

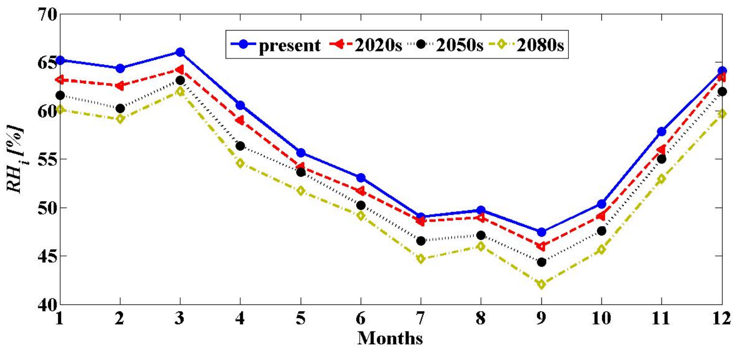
Figure 8 depicts RH_o values while RH_i values are exhibited in Figure 9. The annual average RH_o value was measured as 66.2%, however, the RH_o may decrease by –1.8%, –2.9% and –4.8% at 2020s, 2050s and 2080s, respectively.

Figure 8 Comparison of RH_o values for 'present', 2020s, 2050s and 2080s (see online version for colours)



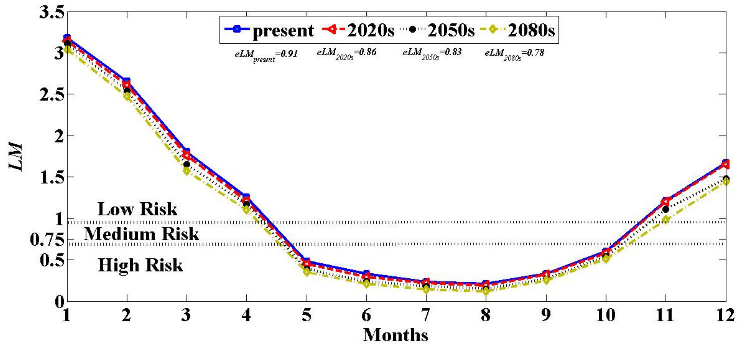
The average RH_i value in the main hall was measured as 56.9%. With an increase in T_i values in the future climate, RH_i values may decrease by -1.7%, -2.8% and 4.4% at 2020s, 2050s and 2080s, respectively.

Figure 9 Comparison of RH_i values for 'present', 2020s, 2050s and 2080s (see online version for colours)



Chemical degradation risks (*LM* and *eLM* values) are exhibited in Figure 10. According to the figure, the manuscripts are in the low and medium risk between November and April while high risk is encountered from May to October. However, future climate change will cause a decrease in *LM* values directing the values to high risk zone. For instance, 3% of the total data will be shifted from low risk to medium risk whilst 2.4% of the data will be moved from medium risk to high risk in 2080s. The results also show that *eLM* values are lower than 1 which represents a potential chemical risk on paper-based collections. *eLM* values will decrease by 5.5%, 8.8% and 14.3% for 2020s, 2050s and 2080s, respectively (Figure 7, Table 6).

Figure 10 *LM* values for 'present', 2020s, 2050s and 2080s (see online version for colours)



It is worth mentioning that the increase in T_i and correspondingly decrease in RH_i values, increases risks of chemical degradation on manuscripts. Some discussions can be stated in this part:

- Global warming will change the preservation conditions of manuscripts and thermal comfort of visitors. Some decisions concerning use/conservation balance must be taken and precautions should be developed in order to find optimal solutions.
- Historic libraries have high thermal mass and special indoor climate thus any intervention like installing HVAC system to the library may arise unexpected results. This needs a careful diagnosis and predictive studies.
- The libraries should have continuous indoor climate monitoring system in order to control *T* and *RH* values. Climate panels which record standardised continuous measurements can be a proper solution. Further details on climate panels can be found in Haugen et al. (2018).

4 Conclusions

This study investigates the effect of future climate change on paper-based collections and thermal comfort of visitors in historic buildings for 2020s, 2050s and 2080s. The Necip Paşa Library-Izmir-Turkey is monitored during one year (September 2014–2015). Thermo-hygrometric parameters of the indoor environment and *PMV/PPD* indices of visitors are assessed with the help of the standards. In addition, change in hygrothermal parameters and *PMV/PPD* indices due to global warming is investigated by generating climatic data for the time horizons of 2020s, 2050s, and 2080s.

The results evidently indicate that climate change increases chemical degradation of manuscripts while reducing human thermal comfort. The chemical degradation indicator, *LM* and *eLM* values, may decrease in the future which highlights higher risk on manuscripts in the future. The results show that there may be higher chemical risk on paper-based collections which can hamper their conservation in the future. Furthermore, the thermal comfort indicator, i.e., *PM/PPD* indices, may increase by the impact of global warming which highlights lower thermal comfort in the future.

Estimated impacts lead us to the critical decision on future use and operation of the Necip Paşa Library. Since the major function of the library is to preserve the collection, use and conservation balance should be carefully considered. It is clear that the manuscripts should be kept in certain climatic conditions. Therefore, precautions like adding light and adaptive mechanical solutions must be taken in the manuscript zone while digital library solutions may be served to users in a different space, e.g. main hall, with a higher thermal comfort solution.

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Nomenclature

CO_2 Carbon dioxide.

clo Clothing value [-].

E_a Activation energy [100 kJ/mol for degradation of cellulose].

eLM Equivalent lifetime multiplier [-].

H_2S Hydrogen sulphide.

LM Lifetime multiplier [-].

met Metabolic rate [-].

MRT Mean radiant temperature [°C].

NOx Nitrogen oxides.

O_3 Ozone.

PMV Predicted mean vote [-].

PPD Predicted percentage of dissatisfied.

R Gas constant [8.314 J/molK].

RH Relative humidity [%].

SO_2 Sulphur dioxide.

T Temperature [°C].

TWPI Time weighted preservation ındex [-].

v_i Air velocity [m^2/s].

Subscripts

i Indoor.

o Outdoor.