AN EXPERIMENTAL STUDY ON SUSTAINABILITY OF HISTORICAL WOODEN BUILDINGS EXPOSED TO OPEN SEA STREAMS

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ABSTRACT

This research deals with the impact of the microclimate on historical wooden buildings exposed to open sea streams. The Florya Ataturk Marine Mansion in Istanbul, erected on the sea, totally defenceless to weather and sea effects, has been selected as representative case study for many other buildings located in Bosphorus line. In order to address the effect of the environment on the building exposed to open sea streams microclimatic data were collected for one year. The synergistic effect of the sea-salt aerosol and microclimatic conditions were discussed for the assessment of the impact of the marine environment on the durability of the Mansion, identifying the more vulnerable parts of the building as well as the more critical periods. The results indicate that while moisture content changes from 20.9% to 36.7% and temperature changes from 14.1°C to 28.7°C, thermal conductivity coefficient changes from 0.18 $W{\cdot}m^{-1}K^{-1}$ to 0.26 $W{\cdot}m^{-1}K^{-1}$, according to the facade of the building and the season as similar to previous studies.

KEYWORDS: Wood structures, historical buildings, thermal conductivity, sustainability.

INTRODUCTION

Finely worked wood was the predominant construction material for the majority of traditional Turkish houses, including yalıs, a house constructed at immediate waterside and usually built with an architectural concept that takes into account the characteristics of the coastal location. The hundreds of waterside residences, mostly dating from the 19th century, sprinkled along the Bosphorus in Istanbul, constitute one of the city's landmarks.

It is well known that the marine microclimate is extremely dangerous for the conservation of movable and immovable heritage assets, especially which are constructed by wood material, because it intensifies natural weathering through the deposition of sea-salt particles that is controlled by various environmental parameters. Marine aerosol intensifies the natural

weathering through the deposition of sea-salt particles that may react with the surfaces and structures depending on the environmental parameters. Relative humidity variations can cause crystallization-dissolution cycles of salts which could penetrate into the material and generate decay. Buildings in marine environment are also vulnerable to biodegradation that is very effective in humid environments. As a consequence, structures and objects exposed to sea water and high moisture levels required frequent maintenance and restoration works.

Fig. 1: Florya Ataturk Marine Mansion (experimental object).

The importance of microclimatology in the preservation and restoration of cultural heritage is widely recognized (Bernardi 2008, Camuffo 2014, Thomson 1986). The study of microclimate is fundamental in the assessment of the weathering surfaces exposed to outdoor and indoor environments (Becherini et al. 2010, Becherini et al. 2013, Camuffo et al. 2004, Fojtik 2018) as the microclimatic conditions play a key role in the starting and developing not only of physical processes, but also chemical and biological ones, often acting in synergism. Moreover, in literature are reported several examples of unsuitable thermal-hygrometric conditions in historical buildings that are usually built with traditional materials, generally stone and wood, that have a bad thermal and hygrometric behaviour (Thomson 1986, Donovan 1986, Mills et al. 1987, Michalski 1990, Grinzato et al. 2002, Abuku et al. 2009, Moradias et al. 2012). In addition, the marine environment can be considered particularly critical for conservation issues, as the atmosphere is enriched with particles that are naturally generated by the action of wind on the seawater surface. Several authors have showed that marine environments that are charged with salts cause deterioration of the construction materials (Davide 2014, Meira et al. 2006, Morcillo et al. 2000, Erkal et al. 2012). Anyhow, most of the literary studies are focused on concrete structures and stone materials (Alao et al. 2014, Chabas et al. 2000), or they address only the chemical weathering due to sea-salts aerosol (Chabas et al. 2000, Zezza et al. 1995, Stefanis et al. 2005). Nevertheless, a deep and comprehensive research about microclimate and sea effects on historical structures is rather lacking in literature. The present study wants to provide an integrated approach to the problem of the impact of microclimate and sea streams on historical buildings, following the example of other studies in literature applied to other topics (Nava et al. 2010).

In this paper it is aimed at studying the impact of the microclimate on historical buildings exposed to open sea streams, through the representative case study of the Florya Ataturk Marine Mansion (Fig. 1), a historic presidential residence located offshore in the Sea of Marmara in the Florya neighbourhood of the Bakirkoy district in Istanbul. Built in 1935 by the municipality of Istanbul for Atatürk's recreational use, it is erected on steel piles driven into the seabed and linked to the mainland by a wooden pier of about 70 m in length. The building is totally defenceless to weather and sea effects, therefore periodically and costly restoration work is made. The damage patterns observed are similar to other historical buildings located nearby the Bosphorus strip mainly because of sea effect and salt deterioration.

The research is aimed at studying the impact of the marine microclimate on the Florya Ataturk Marine Mansion in Istanbul, selected as reference for the huge number of wooden buildings alongside the Bosphorus exposed to open sea streams.

The impact of the marine environment on the durability of the mansion was assessed by the analysis of the meteorological and microclimatic data in synergy with the severe sea effects. The more vulnerable parts of the building as well as the more critical periods were identified. The ambient conditions that the material is exposed to each season are different, which leads to different deformations on the material. These deformations can also affect the heat permeability of the material positively or negatively. The microclimate and sea effects were investigated for the environmental risk assessment of the Florya Ataturk Marine Mansion. The microclimate nearby the mansion was monitored continuously for one year taking also into account the local climatology. Moisture content and surface temperature of the walls were measured outside. Moisture and temperature figures were analysed on daily, weekly, monthly and yearly basis. Also, thermal conductivity coefficients were measured at certain periods during the year by placing wood materials of the same properties on the building facades where on-site measurements were made.

MATERIAL AND METHODS

In this study, the temperature and humidity values of the surface of the building were measured with hand-held measuring instruments that do not damage the building since it is a historical building. Moisture measurement (moisture meter Testo-616) and for the surface temperature measurement Testo 905-T2 was used. For heat conduction coefficient measurements; the samples are subjected to the equinox periods determined as critical periods, in June-July-August, September-October-November, December-January-February, March-April-May, the front and left side facades selected as vulnerable partitions (the front with the most sunbathing time and the left side with the least sunshine duration). Then the samples were subjected to a thermal conductivity test in the laboratory with a thermal conductivity meter (thermal conductivity meter Cole-Parmer) by comparison method according to the test standard (Fig. 2). In this measurement device using the comparison method, the heat conduction coefficient of the sample is determined using a reference body whose heat conduction coefficient is known. The temperature difference was established by placing the sample and reference body between the heat source and the heat sink. The amount of heat energy passing through the sample and reference body is the same. The heat transfer coefficient of the sample was determined by using the upper and lower thermal values of the sample and the heat conduction coefficient of the reference body.

The wooden material used in the building is scots pine. When the literature is examined, holocellulose, alpha cellulose and lignin content were found to be approximately 71-74%, 47-49% and 26-29% respectively (Tutus et al. 2010, Kılıc et al. 2010, Abuamoud et al. 2018, Zborowska et al. 2007) (Tab. 1). Standard sized samples of this pine material are produced and placed on the front and side of the building. Specimens produced according to the test device have a circular cross-section of 11.28 cm in diameter (Fig. 2).

Tab. 1: Main chemical components of scots pine (Tutus et al. 2010, Kılıc et al. 2010, Abuamoud et al. 2018, Zborowska et al. 2007).

Chemical components	Holocellulose	Alpha cellulose	Lignin
Ratio	71-74%	47-49%	26-29%

Fig. 2: A cross–section of pinewood specimen.

Fourier law was used to calculate the heat transfer coefficient by using the temperature values obtained from the comparison method. Assuming that there is no heat transfer in the radial direction from the sample and reference body, the amount of heat passing through the sample is equal to the amount of heat passing through the reference material.

RESULTS AND DISCUSSION

All the data collected during the first year with automatic and manual devices was analysed in their spatial and temporal trends in order to have a complete picture of the microclimate inside the mansion and outside on the basis of weekly, monthly and yearly periods. The monitoring of the microclimate on the Florya Ataturk Marine Mansion was performed for one year with automatic devices. The moisture content of the outer and inner walls of the building was measured manually in the different seasons. In addition, in summer and winter the thermal behaviour of inner wall surfaces differently oriented was investigated by means of thermography. The measured moisture, temperature and calculated thermal conductivity coefficient values are presented in Tabs. 2, 3 and 4, resp.

Tab. 2: Monthly moisture content (MC) values measured in site.

Year	Months	Facade	MC (%)
2018	June-July-August	Front	36.7
2018	June-July-August	Left side	32.9
2018	September-October-November	Front	27.8
2018	September-October-November	Left side	24.7
2018	December-January-February	Front	22.8
2018	December-January-February	Left side	20.9
2018	March-April-May	Front	33.1
2018	March-April-May	Left side	27.4

Tab. 3: Monthly temperature degrees measured in site.

Year	Months	Facade	Temperature (°C)
2018	June-July-August	Front	28.7
2018	June-July-August	Left side	24.1
2018	September-October-November	Front	21.9
2018	September-October-November	Left side	20.3
2018	December-January-February	Front	18.7
2018	December-January-February	Left side	14.1
2018	March-April-May	Front	22.8
2018	March-April-May	Left side	19.3

Tab. 4: Monthly calculated thermal conductivity coefficients.

Year	Months	Facade	k (W·m^{-1}K^{-1})
2018	June-July-August	Front	0.26
2018	June-July-August	Left side	0.24
2018	September-October-November	Front	0.21
2018	September-October-November	Left side	0.20
2018	December-January-February	Front	0.19
2018	December-January-February	Left side	0.18
2018	March-April-May	Front	0.24
2018	March-April-May	Left side	0.21

According to this; the difference in temperature and moisture between the front and left side facades is clearly visible. Accordingly, the heat transfer coefficient is significantly higher in the samples placed on the facade, which is heavily exposed to microclimate effects, than the samples placed on the other facade. According to this; it is important for building sustainability to concentrate the protection methods and frequency on the front facade compared to the side facade.

Graphs summarizing the variation of the thermal conductivity coefficient depending on temperature and air humidity are presented in Fig. 3 and Fig. 4.
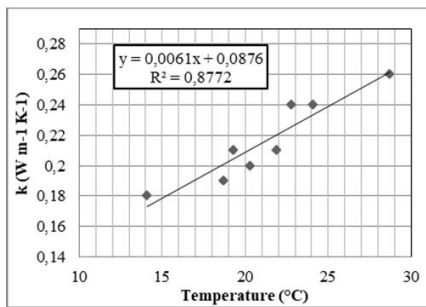

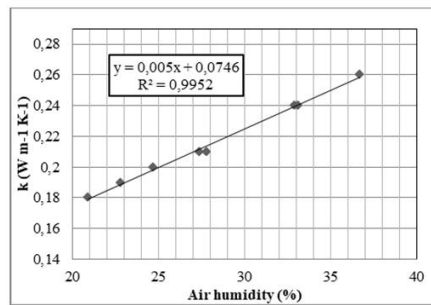*Fig. 3: Thermal conductivity coefficient according to temperature.*

Fig. 4: Thermal conductivity coefficient according to air humidity.

When we compare these values with the studies in the literature, it can be seen that similar results are obtained. In their study which analyses the variations of thermal conductivity under various temperatures, Dell'Isola et al. (2012) experimentally showed that the thermal conductivity coefficient of pinewood increased with increasing temperature and water content ratios (Fig. 5 and Fig. 6).
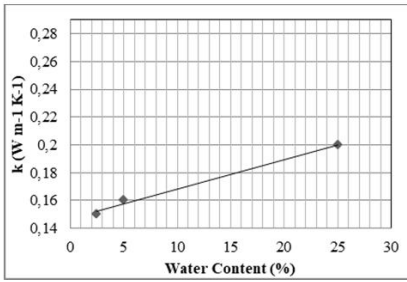
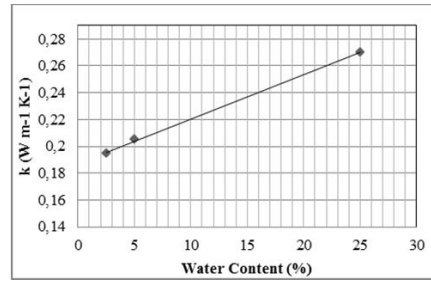Fig. 5: Thermal conductivity coefficient according to water content at 10°C. (Dell'Isola et al. (2012)).

Fig. 6: Thermal conductivity coefficient according to water content at 30°C. (Dell'Isola et al. (2012)).

Troppova et al. (2015) examined in their study the variability of the thermal conductivity coefficient of wood-based fibreboards according to the increase in temperature depending on air humidity from -10°C to 60°C. It was found that the moisture content of material increases from 0% to 14.29% and they also determined that the conductivity coefficient increased (Figs. 7 and 8).
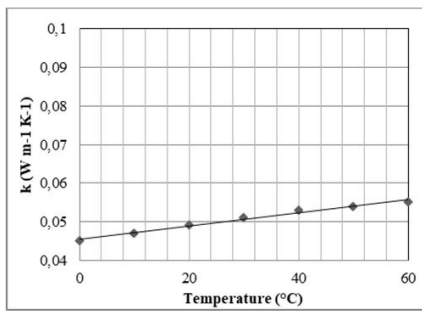

Fig. 7: Thermal conductivity coefficient according to temperature at 0% moisture content. (Troppova et al. (2015)).
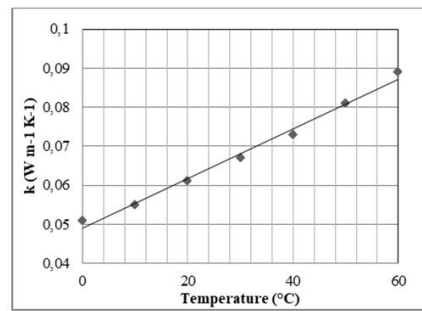
Fig. 8: Thermal conductivity coefficient according to temperature at 14.29% moisture content. (Troppova et al. (2015)).

In addition, Esen et al. (2012) stated in their study that the increase in temperature and humidity values would lead to an increase in the thermal conductivity coefficient in the wood material and they determined that the thermal conductivity coefficient of the fir wood material exposed to the sea effect increased compared to the original sample (Fig. 9). Kol (2009) in her study determined that the thermal conductivity coefficient of 5 different wood species changed with the effect of temperature and humidity and stated that the thermal conductivity of all wood species increased with the increase of temperature and humidity (Fig. 10).
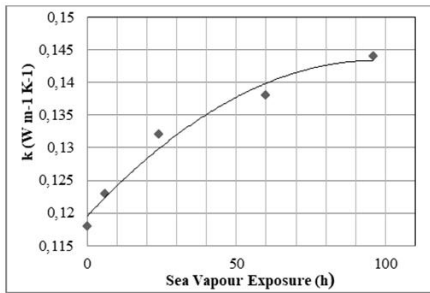
Fig. 9: Thermal conductivity coefficient according to sea vapour exposure. (Esen et al. (2012)).
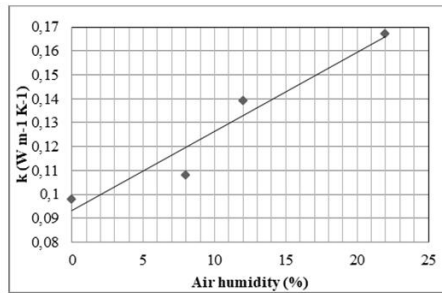
Fig. 10: Thermal conductivity coefficient according to sea vapour exposure. (Kol (2009)).

Trochonowicz et al. (2018) examined the change in air temperature and humidity and thermal conductivity coefficients of the wood based materials and he selected and showed similarly to the studies in the literature that thermal conductivity is dependent on humidity and temperature values (Fig. 11 and Fig. 12).
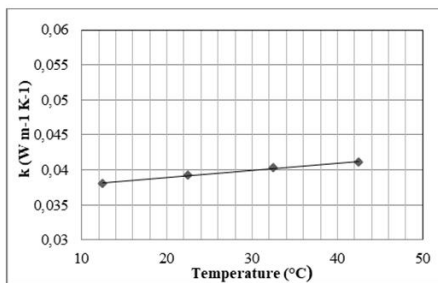

Fig. 11: Thermal conductivity coefficient according to temperature. (Trochonowicz et al. (2018)).
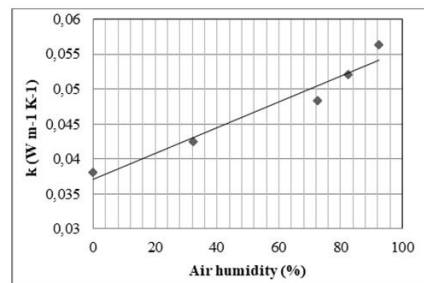
Fig. 12: Thermal conductivity coefficient according to air humidity. (Trochonowicz et al. (2018)).

Examples can be increased with this and similar studies. The common result is that the thermal conductivity coefficient of wood materials is directly related to humidity and temperature. In addition, being open to the sea effect, salinity, wind, etc. are also effective on the thermal conductivity values of wood materials.

CONCLUSIONS

Every historical building is a unique research subject with its inestimable cultural value; nevertheless the Florya Ataturk Marine Mansion can serve as a reference for the huge number of buildings alongside the Bosporus that suffers similar problems. As the mansion is opened to public as "Atatürk Museum" since 1993, the internal microclimate was also monitored and evaluated according to the recommended values for the materials preserved and human comfort requirements. The thermo-hygrometric conditions outside were measured for one year, whilst

specific campaigns were performed to investigate indoor surface temperature and wall moisture content. According to obtained results, it was well understood that thermal conductivity coefficient of the building facade material, pinewood, varies in direct proportion to outside temperature and the moisture content of the material. As a result of the measurements taken from the mansion, a linear correlation was observed between the heat transfer coefficient of the wood and the temperature. This correlation ($y = 0.0061x + 0.0876$, $R^2 = 0.8772$) is compatible with the Fourier heat equation.

Similarly, a linear relationship ($y = 0.05x + 0.0746$, $R^2 = 0.9952$) between air humidity and heat transfer coefficient was observed according to measurements. Therewithal, while the maximum "k" value ($k = 0.26$ W $m^{-1}\cdot K^{-1}$) as obtained at summer months and front facade (as having most sunbathing time), the minimum one ($k = 0.18$ W $m^{-1}\cdot K^{-1}$) was obtained at winter months and left facade as exactly opposite. The results of this research could provide useful information for the future better preservation of the building and its content, thus reducing maintenance and restoration work and improving the internal conditions in terms of conservation requirements and human comfort issues. Also, the results which are obtained in this project can contribute to elaborate the more appropriate conservation strategy for the Mansion and also for other similar buildings threatened by the risks related to the marine environment.

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