Variable Climate's Effect on Wood Material's Equilibrium Moisture Content in Turkey

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Some negative attributes of wood material have numerous practical consequences. The most important of these attributes is that wood, as a hygroscopic material, is dependent on the relative humidity of its environment. The hygroscopic nature of wood material can lead to serious problems when used in doors, windows, and interior or exterior decoration materials. The aim of this study was to evaluate the effect on wood materials equilibrium moisture due to different climates in selected provinces in Turkey. This study examined pine (*Pinus sylvestris* L.) and oak (*Quercus rubra* L.) woods, both of which are commonly used in industry. Over 12 months, the equilibrium moisture value of these wood was determined in the Bursa, Antalya, İzmir, Malatya, Trabzon, Karabük, Van, and Kars provinces of Turkey. Pine and oak samples, prepared per standards TS 2471 (1976) and TS 2472 (1976), were taken from these provinces each month, and the equilibrium moisture values were determined. It was observed that the use of Scotch pine wood samples for both indoor and outdoor use was more appropriate over the 12-month period. Malatya was the province in which the Scotch pine samples were the least affected. It was also determined that Van was the most suitable province for the interior use of oak wood material. It was not found that indoor use gave better results than outdoor use.

Keywords: Scotch pine; Oak; Wooden material; Equilibrium moisture value

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INTRODUCTION

Wood material has been used since the beginning of civilization and is the oldest building material possessing advantageous properties used by people for heat, shelter, and cooking (Özalp *et al.* 2009). It is important to know the locale where wood material is destined for use, and the climatic conditions of that area. The time of wood drying, or relative humidity can be adjusted to suit the equilibrium moisture for that climate. In many countries, the equilibrium moisture value changes in wood across various uses have been investigated (Üçüncü *et al.* 2017). The equilibrium moisture of wood materials depends on the temperature and relative humidity of the ambient air (Simpson 1998). At the same time, the wood's type (hardwood, softwood, *etc.*) and structure, specific gravity, material dimensions, cutting shapes, and drying moisture values have been found to affect the value of equilibrium moisture (Şenel 1993; Enayati and Hosseinabadi 2007).

Because of its hydroscopic and anisotropic structure, wood can give and receive moisture depending on the relative humidity and temperature of the environment. As a result of moisture exchange, dimensional expansion and contraction ratio of the wood are direction-dependent due to parallel, radial, and fiber constructions (Gündüz 2007). One of the most fundamental challenges of wood as a hydroscopic material is determining how to minimize the dimensional change that occurs as the material is dried until the equilibrium moisture content reaches the level that fits the material's usage (Kollmann and Cote 1968; FPL 2010). Introducing the wood material to the equilibrium moisture changes according to the temperature and relative humidity of the environment is important.

Unprotected wood material does not have sufficient natural resistance to different environmental factors in the field of use. It can undergo physical and chemical damage (abiotic, herbal, and animal effects) that destroy the wood (Tsoumis 1991; Eaton and Hale 1993). Engineering solutions should be presented to increase the natural resistance of wood material. In this perspective, it is necessary to determine the kind of attack mechanism against wood material for both outdoor and indoor environments (Highley *et al*. 1994; Leicester *et al*. 2003; Creemers *et al*. 2002).

Various scientific research has shown that the physical and mechanical properties of wood material change depending on the equilibrium moisture value (Devi *et al*. 2003; Cai *et al*. 2007; Rowell *et al*. 2009; Gabrielli and Kamke 2010; Sönmez *et al*. 2010; Kocaefe *et al.* 2015; Gupta *et al*. 2016). To minimize the equilibrium moisture value of wood material, various surface coverings, top surface treatments, impregnation, or heat treatment applications have been performed. It has been reported that the top surface treatment of wood material affects the value of equilibrium moisture positively (Üçüncü *et al.* 2017). In addition, in some studies, environmental or laboratory conditions were controlled and the wood moisture equilibrium in the wood material was determined in terms of wood moisture value in temperature and moisture levels (Macias Esparza *et al*. 1990). To reach the equilibrium moisture value of the wood material, the climatic conditions, such as the humidity of the environment where a tree is cut, or the temperature of the environment where a tree is located, affect many factors, such as the location of the wood species (hard or softwood) . For this reason, the equilibrium moisture value of wood material was studied in different locations and in different wood material species.

Many scientific studies have shown that the equilibrium moisture value of wood material can be achieved only in a climate cabinet or laboratory conditions. In this study, the objective was to determine the equilibrium moisture content of wood material over one year, using the samples obtained from Scotch pine and oak wood material, the types of wood most used in the furniture and most wood industrial fields.

EXPERIMENTAL

Materials

The most widely used species, both indoors and outdoors, are Scotch pine (*Pinus sylvestris* L.) and oak (*Quercus rubra* L.) wood materials. For this study, the wood materials were obtained from timber in the Karabük province (Karabuk/Turkey). The wood materials cut for test samples were carefully selected to ensure they had not acquired defects, such as decay fungus, from the forest.

Preparation of test samples

To prepare the test specimens, the annual rings of the knotless fibrous rings made of first-class wood material were positioned so that their surfaces were perpendicular to the cracks and prepared the sapwood part according to the principles of TS 53 (1981) and TS 2470 (1976).

To determine the equilibrium moisture value, pine and oak wood materials were prepared according to the TS 2471 (1976) and TS 2472 (1976) principles for both indoors and outdoors, including every wood species for one month (measuring 20 × 20 × 30 mm^3). In total, 1,920 indoor and 1,920 outdoor samples test samples were prepared.

Determination of equilibrium moisture

The wood samples were conditioned at 12% humidity in the air (20 ± 2 °C and 65% ± 5% for relative humidity) conditioning cabinet until it reached a constant weight. For the moisture value of each sample, the average humidity was chosen randomly according to the principles specified by TS 2471 (1976). For 10 samples chosen randomly, the humidity levels determined included 9.5% ± 0.5, 10.5% ± 0.5, and 12% ± 0.5.

The balance of moisture by drying methods was determined using automatic temperature controlled by a drying cabinet, and judgment by the operator. The balance should be accurate for samples with a dry weight of approximately 10 g for the samples of 0.001 g, and for 100-g samples for 0.1 g (Kantay 1986). The moisture test sample was taken from wood material. The wet weight was determined by weighing in wet form. The full drying weight was found in a special drying cabinet in 103 ± 2 °C.

Determination of density

To determine the density of test specimens, wood materials were prepared according to the principles specified in TS 2472 (1976). A total of 20 specimens were prepared for each tree sample, 20 × 20 × 30 mm^3 in size for the two species. These test samples were weighed on scales with 0.001 g accuracy (m_{12}). Thus, 12% moisture weights of the samples were obtained. Then, the samples were measured using a 0.01-precision digital caliper, and their volumes were calculated (V_{12}). The densities of the test samples obtained (δ_{12}) were determined from the following equation:

$$\delta_{12} = m_{12}/V_{12} \ (\mathrm{g/cm^3}) \tag{1}$$

Methods

These specimens prepared to determine the equilibrium moisture value were placed in Bursa, Antalya, İzmir, Malatya, Trabzon, Karabük, Van, and Kars provinces in open areas, and in closed areas that prevented exposure to sunlight or any outdoor conditions. Problems that could have arisen by making the specified numbered coding on all test samples determined to avoid mixing the samples were solved. Every month, the samples taken from the indoor and outdoor sites were brought to the laboratory in special hermetic packages. The samples were measured using scales with 0.001-g accuracy, at Karabük University Forest Industry Engineering Laboratory. Weight changes were noted to determine the value of equilibrium moisture change. The samples were dried until they reached an oven dry weight of 103 ± 2 °C to determine the moisture value in the wood material as per TS 2472 (1976). This procedure reduces the samples' moisture value to 0 at equilibrium that the sample is assumed to have attained its dry weight (Skaar 1988).

The regions and their respective cities with different climatic conditions where the experiments occurred and where the samples were observed can be seen on the map of Turkey in Fig. 1.

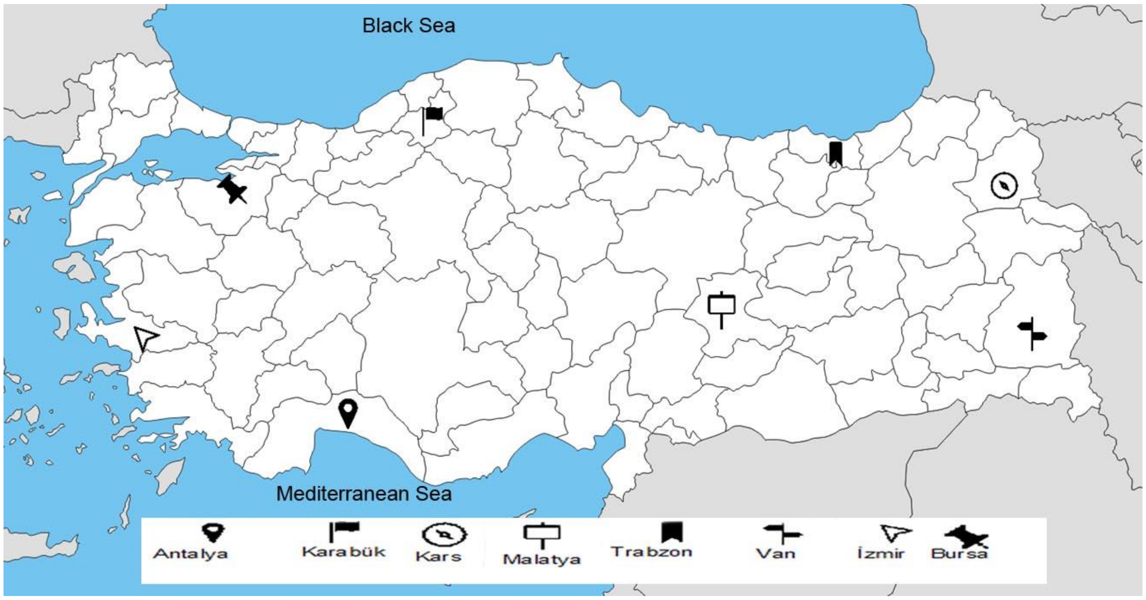

Fig. 1. The cities in the experiment's regions of application

The experiment application areas were observed starting in April 2016, in both indoor and outdoor sites in the designated locations in the provinces shown in Fig. 1. Until April 2017, the moisture samples taken from the environment or given to the environment were calculated as a percentage, measured by test samples brought to the laboratory every month. The most important factor affecting the balance of equilibrium moisture value of the wood was the relative humidity of the environment. Monthly average temperature of the provinces and humidity values for the duration of the experiments are given in Fig. 2 (TSMS 2020).

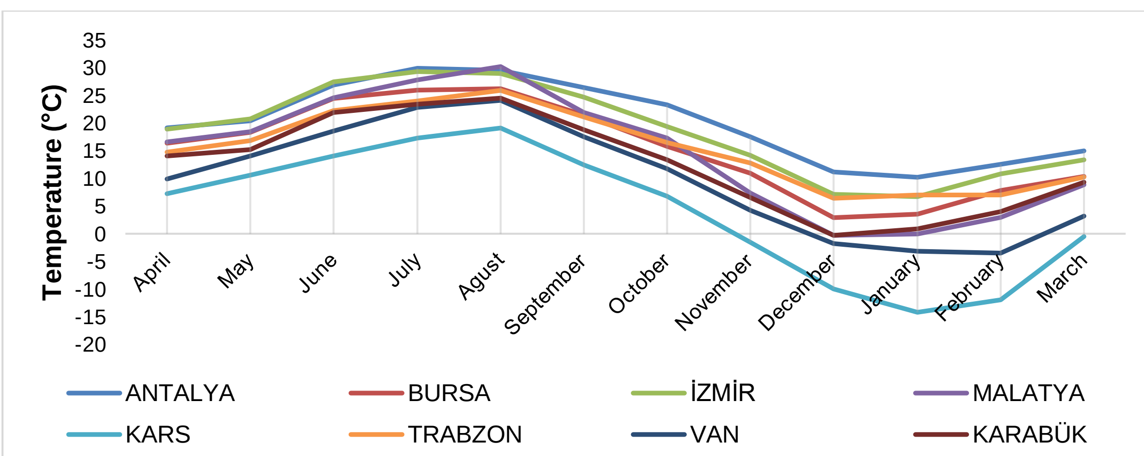

Fig. 2. 12-month average temperature values

The monthly relative humidity rate values of the provinces for the duration of the experiments are given Fig. 3 (TSMS 2020).

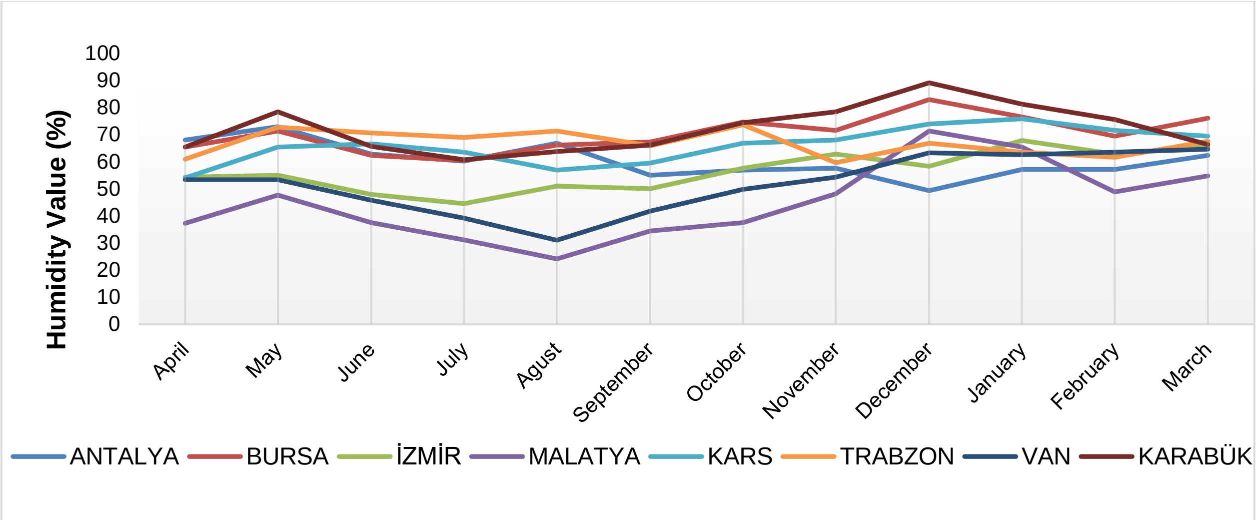

Fig. 3. 12-month average moisture values

Statistical Analyses

Data for each test were statistically analyzed by SPSS 20 version. Analysis of variance was used to test the significance between factors and levels. When the analysis of variance pointed a significant difference among the factors and levels, a comparison of the means was conducted employing a Tukey test.

RESULTS AND DISCUSSION

According to the principles specified in the standard TS 2472 (1976), density values were determined in the Scotch pine and oak wood material obtained from the test specimens in the air-dried state. The air density values of the test samples were obtained as 0.49 g cm^3 of Scotch pine and 0.56 g cm^3 of oak wood material.

Scotch pine and oak wood from the experimental samples obtained from the climatically different regions of Bursa, Antalya, İzmir, Malatya, Trabzon, Karabük, Van, and Kars provinces reached the 12% equilibrium moisture value, and they were kept at the indoor and outdoor sites for 12 months. Moisture change amounts were determined by taking samples from both types of sites every month from each province. Averages of the change in moisture in Scotch pine samples over the 12-month period are given in Table 1.

According to the average values in Table 1, the pine wood material's highest equilibrium moisture content of 23.0% was obtained in the interior of Trabzon province in December 2016. The lowest moisture value, 0.06%, was obtained in the indoor sample in August 2016, in Bursa. Similar results were achieved when compared with previous studies (Källander and Landel 2007; Mateo and Alejandra 2015).

Test specimens obtained from Scotch pine wood materials were kept in both indoor and outdoor places in eight different provinces for 12 months. The test specimens were transported regularly in laboratory conditions with special packages sealed from air humidity. Monthly equilibrium moisture values of the test samples were calculated (Figs. 4).

Table 1. Scotch Pine Wood Material at 12-Month Averages of Equilibrium Moisture Values (%)

Province		Antalya	Bursa	İzmir	Karabük	Kars	Malatya	Trabzon	Van
Month	Location	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.	Avg.
April	Interior	0.65	2.92	4.24	1.83	7.67	9.00	6.05	8.49
	Outdoor	0.41	2.32	3.02	2.02	3.75	5.73	3.77	12.20
May	Interior	18.19	-0.92	-1.24	-0.80	-4.51	-4.80	-4.85	-2.86
	Outdoor	19.19	-3.57	-1.22	0.36	0.74	-7.85	1.33	-0.46
June	Interior	1.05	4.43	7.04	2.29	0.71	5.37	10.11	8.90
	Outdoor	9.61	11.62	9.49	4.76	2.77	0.14	3.25	-15.38
July	Interior	-7.49	4.11	0.04	3.89	0.73	-1.41	4.62	-0.66
	Outdoor	-3.94	7.87	5.40	5.49	1.20	2.27	-1.00	1.08
August	Interior	-5.85	4.37	-0.45	-1.62	1.18	-1.00	4.24	3.63
	Outdoor	-1.93	0.06	-0.73	1.76	3.68	-1.85	7.92	4.84
September	Interior	-2.26	4.47	4.66	3.96	4.11	0.27	1.70	5.99
	Outdoor	-1.27	2.51	5.64	5.71	3.54	0.00	4.15	1.88
October	Interior	1.90	8.75	1.27	6.17	6.06	2.66	5.86	7.26
	Outdoor	3.96	5.42	9.00	7.56	7.75	4.88	6.14	9.48
November	Interior	3.94	3.60	3.84	4.27	6.46	5.08	6.33	11.64
	Outdoor	6.20	3.70	4.76	6.29	6.02	0.39	12.16	2.81
December	Interior	4.64	4.42	5.95	8.87	7.98	3.92	23.02	6.64
	Outdoor	2.84	14.29	6.62	5.14	5.13	3.80	11.91	18.77
January	Interior	7.81	6.94	5.17	21.22	8.15	6.05	5.66	16.42
	Outdoor	14.81	21.41	15.86	4.21	13.03	4.34	16.90	2.82
February	Interior	8.07	6.75	5.27	20.25	8.15	6.00	5.65	15.76
	Outdoor	14.71	21.24	15.92	4.12	12.94	4.34	16.90	2.82
March	Interior	2.20	4.79	4.21	1.78	7.69	9.00	6.01	8.63
	Outdoor	0.41	2.35	3.02	2.02	3.77	5.71	3.82	13.13

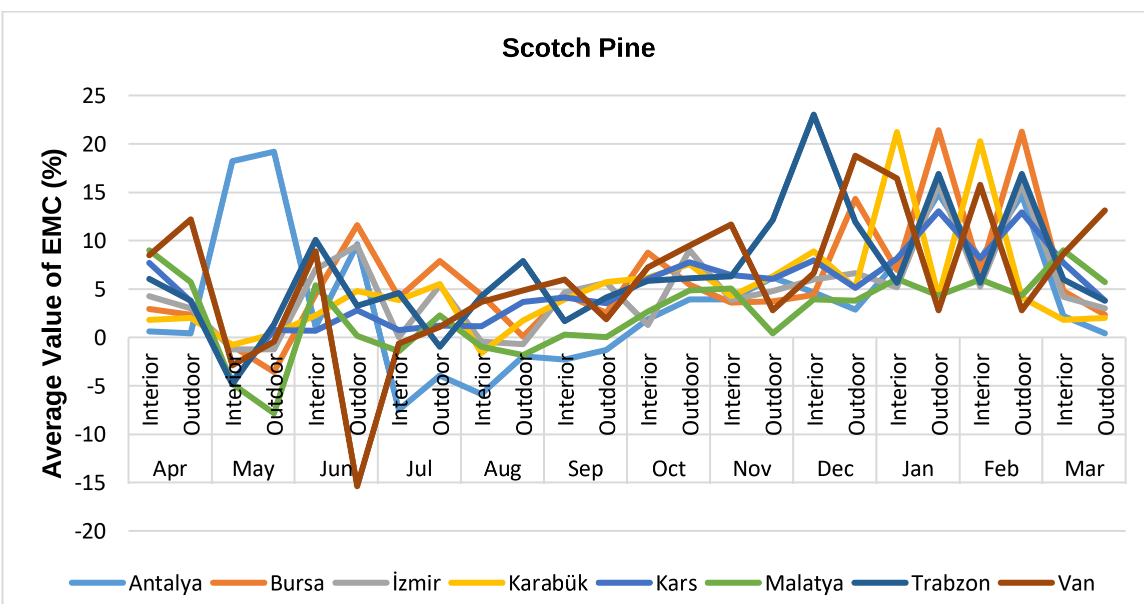

Fig. 4. The balance equilibrium moisture values of Scotch pine material (indoor and outdoor sites)

According to Fig. 4, the highest humidity value was obtained from the interior of Trabzon province; the lowest humidity value was obtained indoor Bursa.

Table 2. 12-Month Equilibrium Moisture Values of Oak Wood Material (%)

Province		Antalya	Bursa	İzmir	Karabük	Kars	Malatya	Trabzon	Van
Month	**Location**	**Avg.**	**Avg.**	**Avg.**	**Avg.**	**Avg.**	**Avg.**	**Avg.**	**Avg.**
April	Interior	0.35	1.14	2.29	2.42	7.60	5.31	-13.37	5.36
	Outdoor	0.39	1.48	2.15	2.03	5.12	2.48	-9.26	5.01
May	Interior	5.28	-0.73	0.23	-1.16	0.41	11.62	10.45	-0.28
	Outdoor	13.50	1.19	1.54	-3.15	4.71	1.19	0.54	-0.70
June	Interior	7.69	5.36	5.10	8.43	9.88	8.85	5.50	-2.96
	Outdoor	6.10	5.55	6.52	13.05	0.84	-0.23	3.13	1.32
July	Interior	-0.59	3.23	2.11	5.70	2.42	1.49	6.16	-0.32
	Outdoor	2.99	5.19	0.12	3.29	3.09	0.60	3.49	-0.83
August	Interior	0.63	0.25	-3.16	-1.77	-0.60	-1.40	2.48	2,96
	Outdoor	-0.28	-0.53	-0.49	-0.29	2.54	-1.09	3.26	3.24
September	Interior	-0.58	5.29	8.52	5.50	2.48	0.60	2.19	4.20
	Outdoor	-0.66	4.78	5.07	7.72	1.26	-2.01	4.06	3.10
October	Interior	5.94	7.83	4.47	6.06	2.90	4.44	4.28	2.03
	Outdoor	3.79	5.15	5.61	5.86	1.91	1.85	2.51	6.56
November	Interior	5.37	3.55	2.19	1.50	3.76	7.73	5.03	3.71
	Outdoor	4.56	4.60	3.12	1.62	4.28	3.48	8.42	4.92
December	Interior	5.56	5.80	6.67	3.87	3.59	2.40	6.18	5.52
	Outdoor	4.14	6.14	7.10	3.52	6.37	5.01	5.62	6.03
January	Interior	2.55	4.10	5.64	6.26	4.72	5.11	4.83	4.85
	Outdoor	4.48	5.20	6.93	6.66	7.55	5.69	5.71	5.24
February	Interior	2.55	4.19	5.70	6.14	4.78	5.20	4.89	4.79
	Outdoor	4.48	5.20	6.96	6.66	7.55	5.69	6.52	5.24
March	Interior	4.32	1.00	2.29	2.39	7.10	5.31	5.16	5.34
	Outdoor	0.56	2.67	2.13	2.03	5.09	2.48	2.48	2.88

When the data in Table 2 were examined, the average equilibrium moisture value of the oak wood test samples was the highest in May 2016, in Antalya, at 13.5%. The least change in equilibrium moisture value was obtained from the experimental groups in outdoor sites in İzmir, in July 2016, at 0.12%.

Test specimens obtained from oak wood materials were kept in both indoor and outdoor places in eight different provinces for 12. These values are given in Fig. 5. The results of the experimental study showed that the value of equilibrium moisture content in indoor and outdoor sites, in eight different provinces (Antalya, Bursa, İzmir, Karabük, Kars, Malatya, Trabzon, and Van), varied between 0.12% and 13.5%. Oak wood material exhibited values of moisture content that were less than those of Scotch pine. However, as stated in the literature, even if the high density of leafy wood materials absorbs a small amount of moisture, the coefficient of expansion is high (Örs and Keskin 2000).

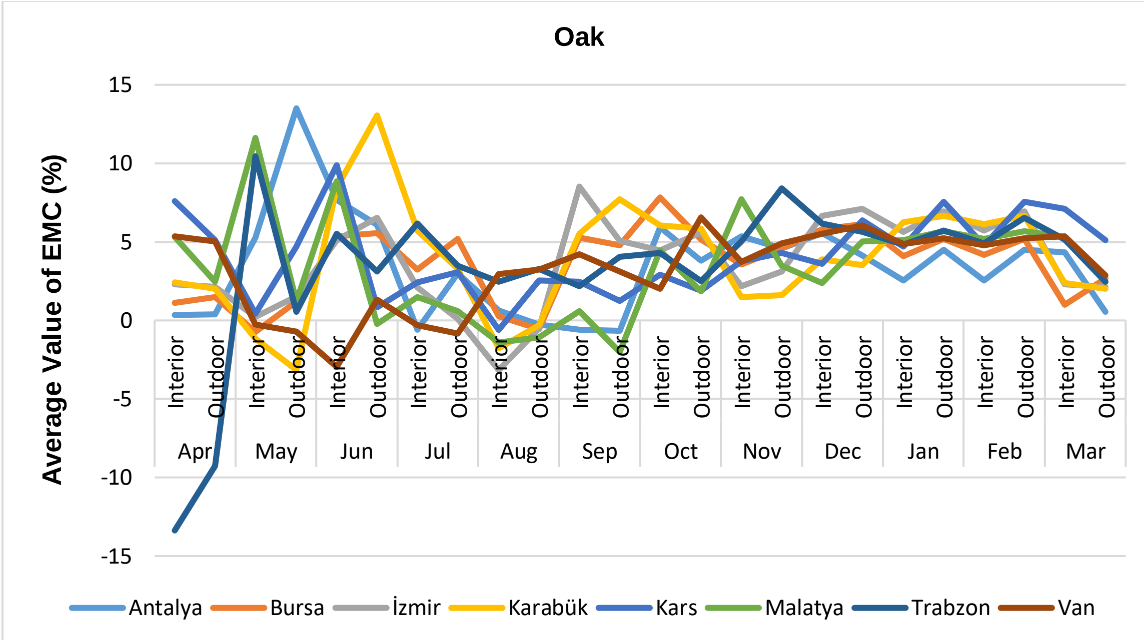

Fig. 5. The balance moisture values of oak wood tree materials (indoor and outdoor sites)

An analysis of variance was performed to determine whether the interaction between pine and oak wood material experimental groups and the time and place of each had an effect on the equilibrium moisture change of the test samples. The results of the analysis of variance are given in Table 3.

Table 3. Results of the Analysis of Variance

Source	Type III Sum of Squares	df	Mean Square	F	Sig. Level P < 0.05
Corrected Model	50444.628[a]	383	131.709	31.425	0.00
Intercept	43395.313	1	43395.313	10354	0,00
Factor A	935.349	7	133.621	31.882	0.00
Factor B	13107.846	11	1191.622	284.317	0.00
Factor C	9.048	1	9.048	2.159	0.04
Factor D	1103.956	1	1103.956	263.401	0.00
A * B	13477.023	77	175.026	41.761	0.00
A * C	1064.305	7	152.044	36.277	0.00
A * D	834.637	7	119.234	28.449	0.00
B * C	687.99	11	62.545	14.923	0.00
B * D	2515.991	11	228.726	54.573	0.00
C * D	88.078	1	88.078	21.015	0.00
A * B * C	5669.028	77	73.624	17.566	0.00
A * B * D	4589.6	77	59.605	14.222	0.00
A * C * D	727.016	7	103.859	24.781	0.00
B * C * D	86.104	11	7.828	1.868	0.04
A * B * C* D	5548.658	77	72.06	17.193	0.00
Error	8047.043	1920	4.191		
Total	101886.983	2304			
Corrected Total	58491.671	2303			

[a] $R^2 = 0.862$ (Adjusted $R^2 = 0.835$)

Factor A: province; Factor B: time; Factor C: place; Factor D: wood type

According to the analysis of variance, provincial space, and application time of the experimental groups, the applied wood type experiments were statistically significant between each other and their interactions with each other (95% significance level $P < 0.05$). To determine which applications were affected by the difference between the equilibrium moisture value of the test specimens, the Duncan test was performed. The Duncan test results of the tree species are given in Table 4.

Table 4. Provincial Duncan Test Results of Wood Species (Excluding Time and Places)

Duncan Province	Average	HG	Province	Average	HG
Malatya-Pine	2.58	A	Antalya- Pine	4.08	BCD
Van-Oak	3.22	AB	Kars- Oak	4.14	BCD
Malatya- Oak	3.41	AB	Bursa- Pine	4.87	CDE
Antalya- Oak	3.46	AB	Kars- Pine	4.95	CDE
Bursa- Oak	3.65	ABC	Karabük- Pine	5.06	DE
Trabzon- Oak	3.67	ABC	Van- Pine	5.99	EF
İzmir- Oak	3.70	ABC	Bursa- Pine	5.99	EF
Karabük- Oak	3.93	BCD	Trabzon- Pine	6.74	F

HG: Homogenous group

When the Duncan test values in Table 4 were examined, the highest humidity value was found in the Trabzon province in Scotch pine samples with 6.74%, and the lowest humidity value was found in the Malatya province in Scotch pine samples with 2.58%. The results of the Duncan test related to the relationship between the wood and the site of application are given in Table 5.

Table 5. Results of the Duncan Test Related to the Relationship Between the Wood and the Applied Province (Excluding Time and Site)

Places	Average	HG
Oak - Outdoor	3.51	A
Oak -Interior	3.78	A
Pine-Interior	4.77	B
Pine- Outdoor	5.29	B

In light of the data obtained from the Duncan test, the highest equilibrium humidity value change was obtained from the pine wood material test group with a value of 3.51% (Table 5). The tree type implementation time interactive Duncan test results are given in Table 6.

According to the data from Table 6, the samples obtained from the oak wood samples in August 2016 were the lowest balance humidity value at 0.37%. In January 2017, the highest equilibrium moisture content was achieved at 10.67% in test samples obtained from Scotch pine material. The results obtained were similar to other academic studies (Yapıcı *et al.* 2013; Yörür *et al.* 2017).

Table 6. Duncan Test Results of the Tree Type Implementation (Excluding Time and Site)

Time/Wood	**Average**	**HG**		**Average**	**HG**
August-Oak	0.37	A	October-Oak	4.55	EFGH
May-Pine	0.42	A	April-Pine	4.63	EFGH
May-Oak	0.95	A	March- Pine	4.91	FGH
August-Pine	1.14	AB	January- Oak	5.34	GH
July-Pine	1.39	AB	February- Oak	5.36	GH
July-Oak	2.36	BC	December- Oak	5.40	GH
September-Pine	2.82	CD	June-Oak	5.41	GH
September-Oak	3.17	CD	November- Pine	5.47	GH
April-Oak	3.43	CDE	October- Pine	5.88	H
March-Oak	3.58	CDEF	December- Pine	8.37	I
November-Oak	3.87	DEF	February- Pine	10.56	J
June-Pine	4.13	DEFG	January- Pine	10.67	J

HG: Homogenous group

CONCLUSIONS

1. When the first interactive results of wood species were examined, the highest equilibrium moisture content of 6.74% was obtained from Scotch pine sample groups from the Trabzon province. This high value is attributed to the structure of Scotch pine wood, which has relatively high moisture value caused by the amount of space in the cell wall. At the same time, the average monthly moisture content for a long period of the year, during the experiments were conducted, affected its high value. The lowest equilibrium moisture value was found in the Malatya province at 2.58%. When the average annual relative humidity rate value of the Malatya province was examined, Malatya had the lowest moisture. According to these results, the Malatya province is suggested as the most suitable province for the production of reinforcement elements made from Scotch pine wood material. However, it was observed that pine wood material was not suitable for outdoor use without any protection process in the Malatya province.
2. Due to the wide vessels of the oak tree and its anatomical structure, it was thought that the greater the amount of relative humidity in outdoor environments, compared with interior ones, the more the dimension stability will change, depending on the moisture value of the wood material. This aspect of wood material negatively affected the wooden materials (furniture, cabinets, door, *etc.*). It was thought that the use of oak wood could have negative consequences from exposure in an outdoor environment.
3. The lowest value of equilibrium moisture change according to the application time of the experiment was obtained in August 2016 at 0.37%. The highest value of equilibrium moisture change was obtained from Scotch pine test samples in January 2017 (10.67%). The lowest equilibrium humidity in January was due to the average temperature and the relative humidity at the lowest level in this month.
4. This study showed that reaching the equilibrium moisture value of the wood material varied depending on the temperature and humidity throughout the seasons,

geographical region, and type of the tree. In addition, even on a monthly basis, the moisture content of some wood species varied.

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