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Original Article

Determination of Moisture Index in Korea[1]

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ABSTRACT

This study aimed to obtain basic climate information for effective moisture control in wood in Korea. Two independent climate indexes, namely drying index (DI) and wetting index (WI), were determined using hourly weather data for 82 locations recorded from 2009 to 2017. These data were collected from the Korea Meteorological Administration (KMA). Hourly data had not been measured prior to 2009. DI and WI revealed that all regions were cold and wet except Baengnyeongdo, which was classified as a cold and dry region. DI and WI were normalized assuming that wetting and drying were equally important phenomena. Then, the normalized indexes were combined into moisture index (MI) to rank the moisture loading of the regions. The MIs showed that Seogwipo had the greatest moisture loading in Korea, followed by Seongsan, Namhae, and Geoje. The MIs suggested that Korea exhibited severe moisture loading. Further studies are required to investigate the relation between MI and moisture content on wood surfaces from a wood maintenance point of view.

Keywords: drying index, wetting index, moisture index

1. INTRODUCTION

One of the fundamental principles in wood science is that wood or wooden materials must be suited to their exposed climate to prevent premature failures. Such problems have been particularly reported in various regions of North America (Chouinard and Lawton, 2001; Cornic *et al*., 2002; Cornick and Dalgliesh, 2003). Thus, determining the moisture loading level in a given location is important for the prevention of deterioration and the maintenance of exposed surfaces of wooden constructions.

Currently, several climate indexes based on temperature–rainfall combinations have been developed to help designers and builders (Lstiburek, 2001; Russo, 1971). They were determined based on either wind-driven rain or the decay risk of wood used for exterior aboveground applications (Boyd, 1963; Kim *et al*., 2011; Kim and Ra, 2013, 2014; Ra, 2017; Setliff, 1986). Although these climate classifications were useful, they were not developed to evaluate potential moisture loading on the envelopes of materials, such as wood. The requirement for a more quantitative index than the available indexes resulted in the development of a moisture index (MI) (Cornick *et al*., 2002; Cornick and Dalgliesh, 2003).

MI is a function of wetting index (WI) and drying index (DI) that express the moisture entry and exit,

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respectively (Bailey, 1958; Cornick *et al*., 2002; Cornick and Dalgliesh, 2003). Since WI is defined as the wettability of wood, it can be effectively measured by determining the availability of water using rainfall and driving-rain indexes (Cornick *et al*., 2002). DI is defined as the potential evaporation for a given location. The potential evaporation is defined as the possible room in a parcel of air that is available for moisture take up. Cornick *et al*., (2002) combined WI and DI to determine the MI of cities in Canada and the United States.

The potential for moisture loading in various climates can be determined by calculating the MI using the available climate data. Because the method of calculating the MI is general, it can also be used to compare the amount of moisture loading in different regions. This study aims to determine the MIs in various regions of Korea to obtain basic climate information for effective moisture control.

2. MATERIALS and METHODS

Domestic hourly weather data recorded from 2009 to 2017 were obtained from the Korea Meteorological Administration (KMA) for 82 stations, including Seoul. Most weather data were measured every third hour prior to 2009. The hourly data of interest were temperature, precipitation, relative humidity, vapor pressure, and spot atmospheric pressure. Spot atmospheric pressure is the atmospheric pressure at the measured site, not the pressure modified to the sea level.

Herein, rainfall was used as WI. Rainfall was the preferred parameter over driving-rain indexes because it is strongly correlated and commonly available for most locations (Cornick *et al.*, 2002). And DI was calculated using equations (1), (2), and (3). It is more convenient to use long-term climate data instead of hourly data because of low amount of data. However, the use of long-term data has been reported to underestimate the DI by 21% (Cornick *et al*., 2002).

$$\triangle w(h) = w_{saturation}(hourly_{temperature}) - w_{out}(hourly_{temperature}) \quad \cdots\cdots\cdots (1)$$

$$w = 0.622 \times (v_p/(p - v_p))\, kg\, water/kg\, air \quad \cdots\cdots (2)$$

$$DI = \frac{1}{n}\sum_{i=1}^{n}\sum_{h=1}^{k}\triangle w(h) \quad \cdots\cdots\cdots\cdots\cdots (3)$$

where w is the humidity ratio (kg water/kg air), v_p is the vapour pressure (kPa), p is the total mixture pressure (kPa), *DI* is the Drying Index (kg water/kg air-year), *n* is the number of years under consideration, and *k* is the number of hours in a particular year.

DI and WI were calculated for each year for a particular location and were combined into a MI. A higher MI suggests a greater potential for moisture loading (Cornick and Dalgliesh, 2003).

Both WI and DI were normalized to have values from 0 to 1 and combined into a MI using equation (4).

$$I_{normalized} = (I - I_{\min})/(I_{\max} - I_{\min}) \quad \cdots\cdots\cdots (4)$$

For comparison, WIs and DIs of 20 cities in Canada and the United States determined by Cornick *et al*., (2002) were included in the dataset. The obtained WIs were normalized to that in Seogwipo, Korea, and DIs were normalized to that in Phoenix, Arizona, which had indexes of 2091.94 and 129.47, respectively.

Wetting and drying were assumed as equally important phenomena and were therefore given equal weight in the determination of the MI using equation (5).

$$MI = \sqrt{WI_{normalized}^2 + (1 - DI_{normalized})^2} \quad \cdots\cdots\cdots (5)$$

The determined MIs were compared and analyzed to evaluate the level of moisture loading.

3. RESULTS and DISCUSSION

Table 1 lists the average domestic weather data and the determined values of the DI, WI, and MI. Herein, WI was defined based on the total rainfall in a region and the DI was determined using the hourly weather data obtained from 82 locations from 2009 to 2017.

The average annual temperature varied from 7.39°C to 16.96°C depending on the location. Seogwipo showed the highest temperature, followed by Jeju, Gosan, and Seongsan. The location with the lowest temperature was Daegwallyeong. The average annual precipitation showed values between 739.17 and 2091.94 mm. Seogwipo and Seongsan had an annual precipitation level of >2,000 mm, and Baengnyeongdo had the lowest annual precipitation of 739.17 mm. The annual relative humidity (RH) was ~65%. The highest annual average RH was 80% in Mokpo, and the lowest was 57.94% in Gangneung. According to Russo's classification scheme (Russo, 1971), most domestic regions can be classified as mild and wet regions.

DI was calculated using the hourly climate data and ranged between 10.7 and 18.03. Seogwipo had the highest DI, followed by Gosan, Seongsan, and Mokpo. Daegwallyeong had the lowest DI. A high DI suggests that the potential drying capacity would be higher. Among the North American cities, Vancouver and Victoria, BC, Canada, have DIs similar to those in Korea. Their values are 16.10 and 17.03, respectively (Cornick *et al*., 2002; Cornick and Dalgliesh, 2004).

Fig. 1 plots DI versus WI, where each point represents the nine-year average indexes calculated from the data for 82 locations. Cornick *et al.*, (2002) divided the climate zones into four categories using DI and WI. A DI of ~20 and a WI of ~800 were used as references to distinguish between hot and cold regions as well as wet and dry regions, respectively. According to this scheme, all regions of Korea, except Baengnyeongdo, can be classified as cold and wet regions. Baengnyeongdo is the only cold and dry region. Cities occupying the lower right-hand corner of the plot have low DIs and high WIs and can be assumed to have a high potential for moisture loading. The plot also suggests that the potential moisture loading would increase with an increasing WI.

The variation in DI between the regions in Korea is not severe when compared with those in Canada and the United States. If the range of the DI is varied significantly, the ranking will be changed, making it impossible to compare the MI between regions. Therefore, the determined WIs and DIs of several cities in Canada and the United States were normalized. In this study, the WI was normalized to that in Seogwipo, Korea, whereas the DI was normalized to that in Phoenix, Arizona, because Seogwipo and Phoenix had the maximum WI of 2091.94 and the maximum DI of 129.47, respectively, in the given dataset.

In Korea, Baengnyeongdo had the lowest MI of 0.99. Other locations had MIs greater than those in Victoria, BC, Canada. Cornick and Dalgliesh (2003) used five divisions to categorize moisture loading. Their classifications ranged from zone 1 with low moisture loading to zone 5 with severe moisture loading. Victoria that has the MIs distinguishing between severe and high moisture loading zones according to Cornick *et al.*, (2002), showed the MI of 1.02. Table 2 lists the calculated MIs of the cities in Canada and the United States. According to this criterion, Korea appears to be in zone 5, a division of severe moisture loading.

The high MI of Korea is due to its higher precipitation and RH. Although Korea lies in a severe moisture loading zone, it is not in a severe decay hazard zone. According to the Scheffer index, Korea is generally classified as a middle decay hazard region (Kim and Ra, 2013, 2014). The reason for this is unclear but

Table 1. Average annual moisture indexes calculated from hourly climate data for the period of 2009–2017.

Location	Temp (℃)	Average annual Precipitation (mm)	RH (%)	Vapor pressure (hPa)	Spot atmospheric Pressure (hPa)	DI	WI	MI
Seoul	12.81	1391.42	60.03	11.20	1005.89	12.84	1391.42	1.15*1
Busan	15.10	1519.02	62.16	12.99	1007.44	14.93	1519.02	1.17
Daegu	14.59	1058.37	58.04	11.68	1009.26	13.40	1058.37	1.06
Daejeon	13.18	1253.28	68.44	12.62	1008.31	14.52	1253.28	1.01
Gwangju	14.32	1332.51	67.92	13.24	1007.97	15.24	1332.51	1.11
Ulsan	14.39	1183.67	64.76	12.89	1010.48	14.82	1183.67	1.07
Incheon	12.51	1202.26	71.74	13.08	1007.96	15.07	1202.26	1.08
Ganghwa	11.32	1229.49	69.16	11.81	1010.83	13.56	1229.49	1.10
Baengnyeongdo	11.22	739.17	70.74	11.64	998.93	13.34	739.17	0.99
Dongducheon	11.62	1382.26	64.17	11.01	1002.80	12.61	1382.26	1.14
Suwon	12.64	1345.37	69.58	12.63	1012.31	14.54	1345.37	1.12
Yangpyeong	12.01	1400.94	67.91	11.72	1010.69	13.44	1400.94	1.14
Icheon	11.66	1258.46	64.54	10.97	1007.07	12.54	1258.46	1.11
Paju	11.01	1294.66	70.54	11.79	1012.84	13.59	1294.66	1.11
Sokcho	12.64	1274.1	64.92	11.80	1013.07	13.53	1274.1	1.11
Cheorwon	10.41	1377.01	68.82	11.00	997.84	12.62	1377.01	1.14
Daegwallyeong	7.39	1239.21	72.71	9.40	925.99	10.70	1239.21	1.12
Chuncheon	11.52	1345.22	70.17	11.82	1007.13	13.57	1345.22	1.13
Bukgangneung	12.56	1214.39	61.81	10.97	1005.77	12.56	1214.39	1.10
Gangneung	13.40	1235.08	57.94	10.85	1012.22	12.42	1235.08	1.11
Donghae	13.20	1119.52	63.66	11.82	1010.44	13.55	1119.52	1.07
Wonju	12.34	1281.38	63.7	11.25	998.32	12.89	1281.38	1.11
Yeongwol	11.58	1175.56	67.96	11.28	987.68	12.92	1175.56	1.09
Inje	10.52	1194.21	66.9	10.45	992.38	11.94	1194.21	1.10
Hongcheon	11.30	1185.43	66.13	10.94	999.54	12.53	1185.43	1.09
Taebaek	9.17	1200.92	66.20	9.51	932.52	10.84	1200.92	1.11
Chungju	11.99	1137.41	65.35	11.25	1002.74	12.89	1137.41	1.08
Cheongju	13.30	1198.43	62.05	11.56	1009.48	13.26	1198.43	1.09
Chupungryung	11.81	1121.51	66.53	11.27	987.25	12.90	1121.51	1.07
Jecheon	10.33	1307.44	68.38	10.59	984.97	12.11	1307.44	1.13
Boeun	11.38	1261.62	69.92	11.44	995.72	13.10	1261.62	1.11

[*1] MIs were calculated using the DI normalized to that in Phoenix, Arizona, and the WI normalized to that in Seogwipo, Korea.

Table 1. Continued.

Location	Temp (℃)	Average annual Precipitation (mm)	RH (%)	Vapor pressure (hPa)	Spot atmospheric Pressure (hPa)	DI	WI	MI
Seosan	12.10	1238.28	76.96	13.20	1013.45	15.18	1238.28	1.09
Cheonan	12.33	1190.51	68.59	11.95	1012.03	13.73	1190.51	1.09
Boryeong	12.80	1164.21	74.19	13.38	1014.53	15.41	1164.21	1.07
Buyeo	12.57	1277.43	71.9	12.51	1015.20	14.37	1277.43	1.10
Geumsan	11.87	1229.32	69.03	11.50	996.07	13.18	1229.32	1.10
Gunsan	12.92	1190.21	78.59	14.13	1013.77	16.29	1190.21	1.07
Jeonju	13.69	1217.58	67.67	12.73	1009.76	14.63	1217.58	1.09
Buan	13.07	1153.73	71.88	12.88	1015.27	14.80	1153.73	1.07
Imsil	11.51	1333.533	70.50	11.44	987.17	13.09	1333.53	1.13
Jeongeup	13.60	1311.74	69.42	12.86	1010.85	14.78	1311.74	1.11
Namwon	12.48	1262.48	68.78	11.91	1003.19	13.66	1262.48	1.10
Jangsu	10.92	1493.52	73.07	11.41	968.36	13.06	1493.52	1.17
Gochang	13.62	1306.30	71.23	13.28	1009.58	15.28	1306.30	1.11
Sunchang	12.70	1415.10	70.14	12.20	1001.54	13.97	1415.10	1.15
Mokpo	13.84	1147.02	80.28	14.97	1011.95	17.29	1147.02	1.05
Yeosu	14.61	1457.68	63.78	12.97	1008.10	14.92	1457.68	1.15
Heuksando	13.56	1140.10	79.41	14.38	1007.17	16.56	1140.10	1.05
Wando	14.41	1542.03	71.94	14.12	1012.14	16.27	1542.03	1.17
Jindo	11.74	1451.84	77.42	12.62	960.26	14.46	1451.84	1.15
Yeonggwang	13.06	1261.48	73.63	13.30	1012.05	15.22	1261.48	1.09
Jangheung	13.73	1435.11	72.97	13.60	1010.92	15.66	1435.11	1.14
Haenam	13.60	1273.51	73.98	13.59	1014.75	15.62	1273.51	1.09
Goheung	13.88	1499.84	71.24	13.43	1009.78	15.44	1499.84	1.16
Ulleungdo	12.67	1561.83	69.83	11.99	988.69	13.73	1561.83	1.19
Uljin	12.72	1029.34	67.70	12.11	1009.56	13.88	1029.34	1.05
Andong	12.52	999.93	64.53	11.42	999.34	13.10	999.93	1.05
Sangju	12.70	1064.82	62.66	11.36	1004.71	13.03	1064.82	1.06
Pohang	14.70	1065.46	63.50	12.99	1015.51	14.93	1065.46	1.05
Bonghwa	9.91	1047.97	69.50	10.46	977.62	11.95	1047.97	1.06
Yeongju	11.73	1217.48	64.67	11.00	990.88	12.59	1217.48	1.10
Mungyeong	11.99	1224.26	60.93	10.62	995.90	12.15	1224.26	1.11
Yeongdeok	13.38	964.57	62.38	11.71	1010.69	13.42	964.57	1.04
Uiseong	11.88	888.36	67.86	11.46	1006.45	13.14	888.36	1.02
Gumi	13.42	1022.47	64.74	12.14	1010.46	13.94	1022.47	1.04
Yeongcheon	12.96	1025.90	63.61	11.44	1004.80	13.10	1025.90	1.05

Table 1. Continued.

Location	Temp (℃)	Average annual Precipitation (mm)	RH (%)	Vapor pressure (hPa)	Spot atmospheric Pressure (hPa)	DI	WI	MI
Changwon	14.69	1469.44	59.8	12.94	1011.39	14.89	1469.44	1.15
Tongyeong	14.51	1516.49	70.52	13.93	1012.07	16.03	1516.49	1.16
Jinju	13.32	1552.87	66.46	12.20	1012.57	14.00	1552.87	1.19
Kimhae	15.13	1316.2	60.98	12.89	1009.43	14.76	1316.2	1.11
Bukchangwon	14.34	1399.16	63.88	12.70	1010.06	14.43	1399.16	1.14
Yangsan	14.81	1420.33	61.00	12.50	1015.15	14.31	1420.33	1.14
Geochang	12.01	1195.1	68.62	11.72	989.11	13.45	1195.1	1.09
Hapcheon	13.33	1325.69	65.06	11.84	1012.26	13.58	1325.69	1.12
Miryang	14.02	1178.78	63.63	12.24	1014.61	14.06	1178.78	1.08
Sancheong	13.22	1530.7	63.87	11.81	999.60	13.54	1530.7	1.18
Geoje	14.72	1849.5	64.9	13.08	1010.44	15.04	1849.5	1.28
Namhae	14.54	1913.9	65.43	13.10	1010.70	15.06	1913.9	1.30
jeju	16.23	1439.68	69.08	14.63	1013.93	16.84	1439.68	1.13
Gosan	15.69	1171.52	74.29	15.24	1007.33	17.57	1171.52	1.05
Seongsan	15.64	2053.90	73.74	15.13	1013.77	17.45	2053.90	1.34
Seogwipo	16.96	2091.94	70.83	15.61	1009.66	18.03	2091.94	1.34

Table 2. Moisture indexes of 20 cities in Canada and the United States.

City	WI	DI	MI	City	WI	DI	MI
New Orleans LA	1601.4	36.44	1.07	Pittsburgh PA	931.1	30.19	0.97
St Johns NF	1193.8	10.20	1.11	Madison WI	803.9	24.67	0.96
Shearwater NS	1178.1	13.11	1.17	Ottawa ON	701.8	22.96	0.91
Vancouver BC	1058.2	16.10	1.04	Toronto ON	625.6	21.58	0.91
Atlanta GA	1306.0	39.02	0.95	San Francisco CA	506.6	25.58	0.87
Orlanda FL	1274.1	41.69	0.92	Calgary AB	293.4	26.71	0.84
Houston TX	1211.4	41.14	0.91	Fort Worth TX	857.3	53.57	0.72
Victoria BC	813.0	17.03	1.02	Colorado Springs CO	424.5	45.33	0.70
Seattle WA	927.4	24.38	0.95	Phoenix AZ	205.1	129.47	0.05
Chicago IL	914.3	29.01	0.97	Las Vegas NV	108.2	117.78	0.09

MI is based on hourly values. WI was normalized to that in Seogwipo, and DI was normalized to that in Phoenix AZ.

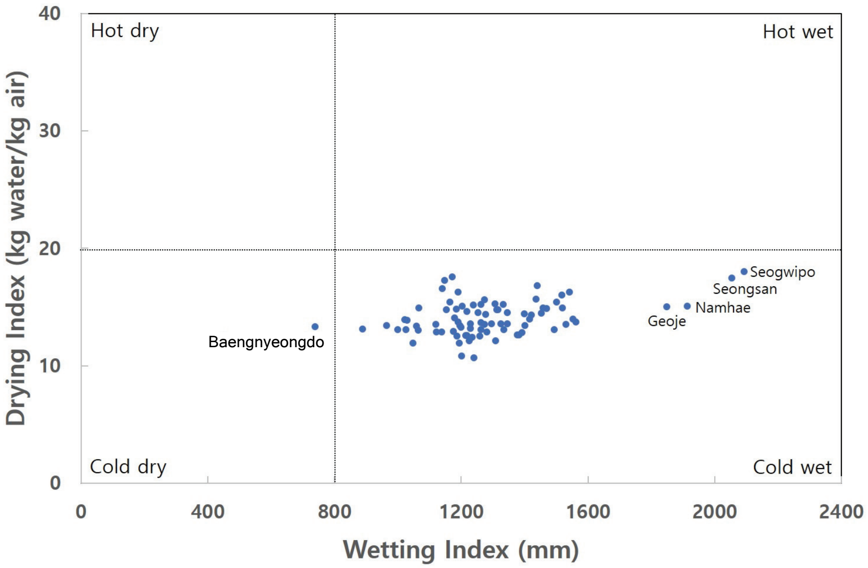

Fig. 1. Scatter plot showing the mean drying index and wetting index for 82 locations.

may be explained by the application of equal weighting for the DI and WI when combining them into a MI. Neglecting wet or dry spells may also be a reason.

A mathematical evaluation of the relation between climate and wood moisture content, particularly on wood surfaces, may facilitate better understanding of premature failures that frequently occur in wooden houses or structures from a maintenance point of view. The MI approach offers a way to group and compare countries into zones related to potential moisture problems. In addition, it has the potential to quantitatively assess the mechanisms of the effect of climate on wood moisture content. Further research to investigate the relation between the MI and the wood moisture content is required to provide a more integrated interpretation for practical purposes.

4. CONCLUSION

The following conclusions can be drawn from this study.

1. MI was determined using hourly weather data for 82 locations recorded from 2009 to 2017.
2. Seogwipo had the highest MI of 1.34, followed by Seongsan, Namhae, and Geoje. Baengnyeongdo had the lowest MI of 0.99.
3. Almost all the locations in Korea can be classified as regions of severe moisture loading.
4. Further research is required to investigate the relation between MI and moisture content on wood surfaces and to gain insights into practical applications.

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