Equilibrium Moisture Content Map for Laos

Khamtan Phonetip,[a,]* Duangphachan Souvansai,[a] and Benoit Belleville [b]

Providing the equilibrium moisture content values for territories is important for avoiding major problems due to dimensional changes in wooden products. This study evaluated the average equilibrium moisture content values for twelve months (from 1981 to 2020) for Laos and produced an equilibrium moisture content map. A model was used to generate the equilibrium moisture content values based on temperature and relative humidity data obtained from the POWER Data Access Viewer v2.0.0. for 18 provinces (148 districts) based on the geographic coordinates of each district in Laos. The lowest equilibrium moisture content (12% to 13%) values were found in Vientiane Capital City, Vientiane province, Louangprabang, Bokeo, Attapeu, Louang Namtha, Oudomxay, Houaphan, Sayaburi, Savannakhet, Salavan, and Champasak province. The rest of the districts, which had an equilibrium moisture content ranging from 13% to 16%, were mostly found on the eastern part of Laos and a small part of Northern Laos. The monthly swinging average value of the equilibrium moisture content ranged from 10% to 18% across the country. The equilibrium moisture content values for each district in Laos were also defined.

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Contact information: a: Faculty of Forest Sciences, National University of Laos, Vientiane Capital, Lao PDR; b: Faculty of Science, School of Ecosystem and Forest Sciences, The University of Melbourne, Burnley campus, 500 Yarra Boulevard, Richmond VIC 3121 Australia;
** Corresponding author: khamtanfof@gmail.com*

INTRODUCTION

The utilization of timber must consider its moisture content (MC) after the timber has been converted to wooden products; it is important to ensure the appropriate moisture content level in the utilized wood has been recommended. Thus, the desired quality of the wood product is met.

As wood absorbs or releases water vapor from the ambient air around it, not only does its MC change, but its dimensions also change. Different species will have different moisture change tolerances based on their own structural make-up (Redman *et al.* 2016). All wood must be allowed to come to a state of balance with its environment in order to prevent moisture-related damage. This state of balance is called the equilibrium moisture content (EMC) (Waterson 1997). This model was developed by Hailwood and Horrobin (1946).

The most important requirement for most wood products is that "green" or fresh cut wood must be dried before it can be used effectively. Drying makes the final dimensions more predictable and the wood easier to work with. Drying also increases the strength properties of the wood, allows it to bond more fully with adhesives, and even lowers the overall weight for shipping, storing, and handling. For any wood product or project, there is an optimal moisture balance that allows the wood to be machined well, function well, and maintain its natural beauty (Simpson 1991; Simpson 1998).

Wood, like many natural substances, is considered a hygroscopic material; it naturally absorbs and releases water vapor from and into the air around it (Phonetip *et al.* 2018a). For example, when green lumber is dried, the cellular pathways that served to transport water from the ground to the leaves of the tree remain in place, like tiny tunnels through the wood, to take in additional moisture when the air around it has high humidity or release moisture into drier air. Therefore, the amount of moisture in any particular wood stock or wood product is entirely dependent on the ambient conditions of the air around it. If the humidity is high, the wood will take in moisture; if the environment is very dry, it will release moisture. In uncontrolled environments, these changes can represent potentially damaging conditions for wood, as its natural interaction with its environment can mean rapid or extreme shifts in the moisture content of the wood.

Even in a relatively stable environment, wood is still subject to seasonal movement as humidity levels and temperatures change with the weather. For instance, EMC oscillation between January and December in Vientiane, Laos varies from 10% to 16% (Phonetip *et al.* 2018b). Controlled indoor environments with functioning heating and air conditioning can help minimize these changes, but they still can present small changes, *e.g.*, the door that sticks in winter or small gaps between the floorboards in summer. For instance, allowing the wood flooring to reach equilibrium before installation and verifying the MC of the wood with an accurate wood moisture meter is the best way to ensure the balance and harmony that EMC can bring to a beautifully satisfying and durable wood floor.

Many countries have available an EMC map based on geography and climate, so the consumers and producers understand the required level of moisture content for the specific locations. For instance, the EMC zones for Australia (Waterson 1997) and the United States of America (Simpson 1998) have been identified. The EMC data helps producers to carefully consider the level of required environment where the wood products are to be placed based on the oscillation of ambient temperature and relative humidity. The EMC data govern the final moisture content in wood products so that the wood products can minimize dimensional changes. The physical properties of wood and wood anatomical structure are main factors that affect the drying rate to get the green wood to reach the equilibrium (Redman *et al.* 2016). However, the state of removing moisture in wood have been considered in two periods, *i.e.*, when wood has higher MC than the fiber saturation point (FSP). For example, at 25%, this period the drying rate is faster than when the wood is getting lower than FSP (Phonetip *et al.* 2018a). Given the fact of the oscillation of EMC through months would help authors to continue further experiments on wood species if they are produced and placed in such conditions, then future researchers would be able to provide recommendation for a better solution to avoid dimensional changes of wood products

However, an EMC map for Laos has not yet been available. To avoid major problems due to dimensional changes in wooden products, the correct final moisture content after drying should be identified based on the particular geography and climatic conditions where the wooden products are going to be placed. This study aims to produce an EMC map for all the territories in Laos and to plot the oscillation of the average EMC that varies throughout the year, *i.e.*, from January until December.

EXPERIMENTAL

A HOBO MX Temp/RH Data Logger (MX1101, Onset Computer Corporation, Bourne, MA) recorded and transmitted the temperature and relative humidity (RH) of the indoor environments with its integrated sensors. This Bluetooth® low energy-enabled logger is designed for wireless communication with a phone, tablet, or computer using the HOBOconnect® app. The accuracy for the temperature is ± 0.21 °C from 0 °C to 50 °C and the accuracy for the RH is ± 2% when the RH from 20% to 80%; if the RH is below 20% and above 80% the accuracy is ±6% (Onset Computer Corporation 2021).

The temperature and relative humidity data were obtained from the POWER Data Access Viewer v2.0.0 (NASA 2021) for the geographical locations of interest. This data set was then validated with on-site observation using the HOBO MX Temp/RH Data Logger then plotting a linear regression model to compare the mean temperature and relative humidity from May 2021 to July 2021 at the same geography (Vientiane, Laos (18°02'29.5" N and 102°37'51.9" E). The corrections of the EMC values based on the NASA hourly temperature and relative humidity were performed by calculating the absolute difference in the values (Δ*T*) between the temperature of the measured data and temperature that obtained from NASA, as show in Eq. 1,

$$\Delta T = |T_{mi} - T_{NSi}| \tag{1}$$

where T_{mi} is the temperature at a specific time (hour) in measured on-site and T_{NSi} is the temperature measured by NASA (POWER Data Access Viewer v2.0.0). The value of the absolute difference in the values (Δ*RH*) of the relative humidity of the measured data and relative humidity that obtained from NASA, were calculated using Eq. 2,

$$\Delta RH = |RH_{mi} - RH_{NSi}| \tag{2}$$

where RH_{mi} is the relative humidity at a specific time (hour) in measured on-site and RH_{NSi} is the relative humidity measured by NASA (POWER Data Access Viewer v2.0.0).

This method was introduced by Phonetip *et al.* (2018b). This study used the temperature and relative humidity at 2 m above the ground, based on the available time extent, *i.e.*, from 1981 until 2020 (39 years).

The EMC value was calculated using Eq. 3,

$$EMC\ (\%) = \frac{1800}{W}\left[\frac{kh}{1-kh} + \frac{k_1kh+2k_1k_2k^2h^2}{1+k_1kh+k_1k_2k^2h^2}\right] \tag{3}$$

where h is the relative humidity (%/100); the constant parameters are as follows: W is the temperature dependent coefficient; and k, k_1, and k_2 are dependent on temperature (T, °C), as shown in Eqs. 4 through 7,

$$W = 349 + 1.29T + 0.0135T^2 \tag{4}$$

$$k = 0.805 + 0.000736T + 0.00000273T^2 \tag{5}$$

$$k_1 = 6.27 + 0.00938T + 0.000303T^2 \tag{6}$$

$$k_2 = 1.91 + 0.0407T + 0.000293T^2 \tag{7}$$

which was developed by (Hailwood and Horrobin 1946).

The EMC values present the range of the means using the ArcGIS modeling process to produce an EMC map for 148 districts at different geographical locations at the district centers for all 18 provinces.

The ArcMap application (Version 10.6, Esri, Redlands, CA) was used to produce a range of EMC maps. The inverse distance weighted (IDW) is held as one of the most common techniques for interpolating (Chen and Liu 2012; Yang *et al.* 2020). It is used to forecast values for any unmet location by calculating the expected position of the surrounding values. It is a deterministic process type interpolating method with a known distributed collection of samples. The values assigned to the unknown samples are determined by the weighted average of the identified points available (Lam 1983). In this study, the IDW models adopted cross-validation as an appropriate method to assess the accuracy of spatial interpolated EMC data for the center locations of 148 districts that were selected for a cross-validation process.

RESULTS AND DISCUSSION

Temperature And Relative Humidity

The temperature oscillations between the on-site measured data and the data obtained from POWER Data Access Viewer v2.0.0 are presented in Fig. 1a.

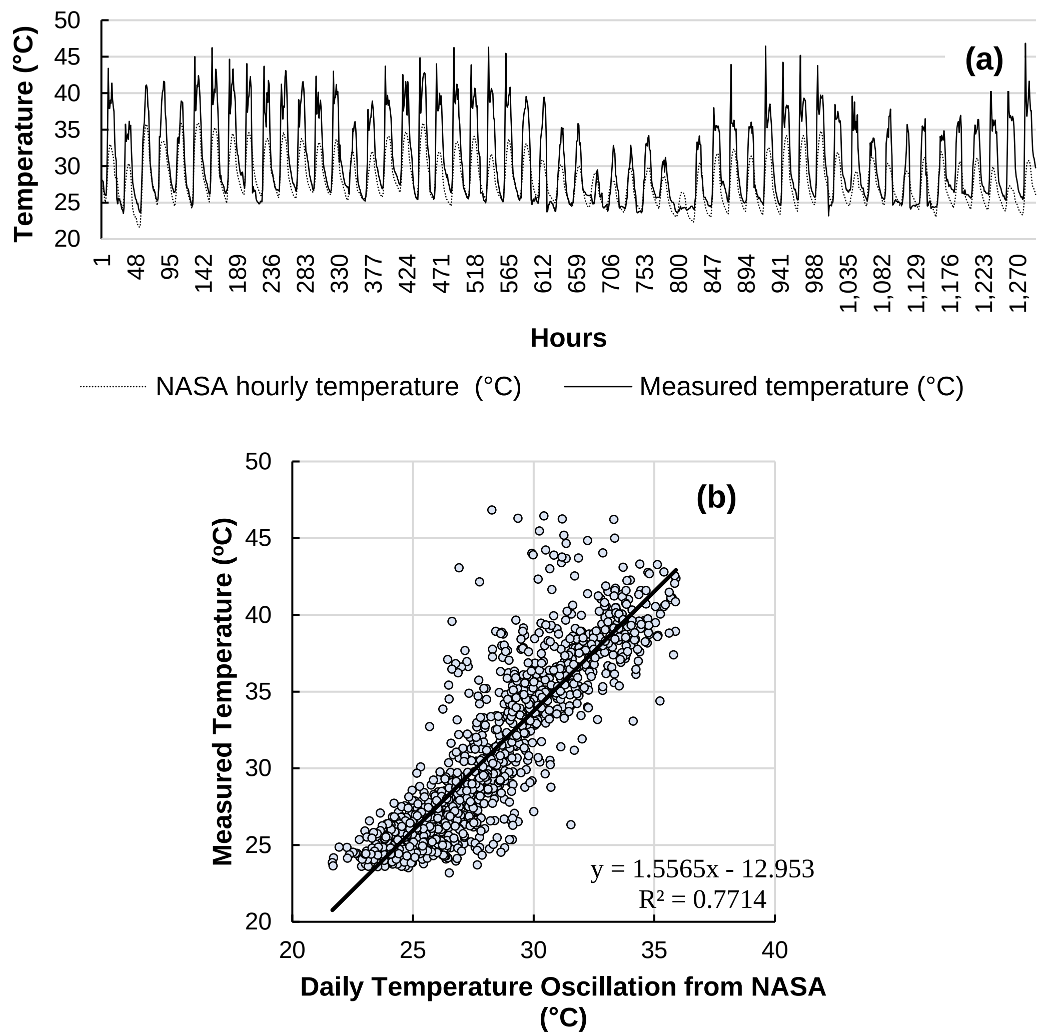

Fig. 1. Daily temperature oscillation for May, June and July in Vientiane, Laos (a) and the relationship between the measured temperature on-site and the NASA temperature data (b)

It is shown that the predicted temperature oscillation (according to POWER Data Access Viewer v2.0.0) values were lower than the values of the on-site measured data for the available data of May (21 days), June (28 days), and July (4 days) of 2021. The measured temperature and temperature predicted by POWER Data Access Viewer v2.0.0 were then plotted (as shown in Fig. 1b). A promising confidence was found, *i.e.*, $R^2 = 0.77$; this value was 0.03 higher than predicted by the POWER Data Access Viewer for solar radiation (White *et al.* 2011). However, the corrected temperature is required to be fixed *via* calculation using Eq. 1. The mean absolute value of difference was found to be 2.7 °C. This value was then added to the temperature measured by POWER Data Access Viewer v2.0.0 at the geography locations of interest.

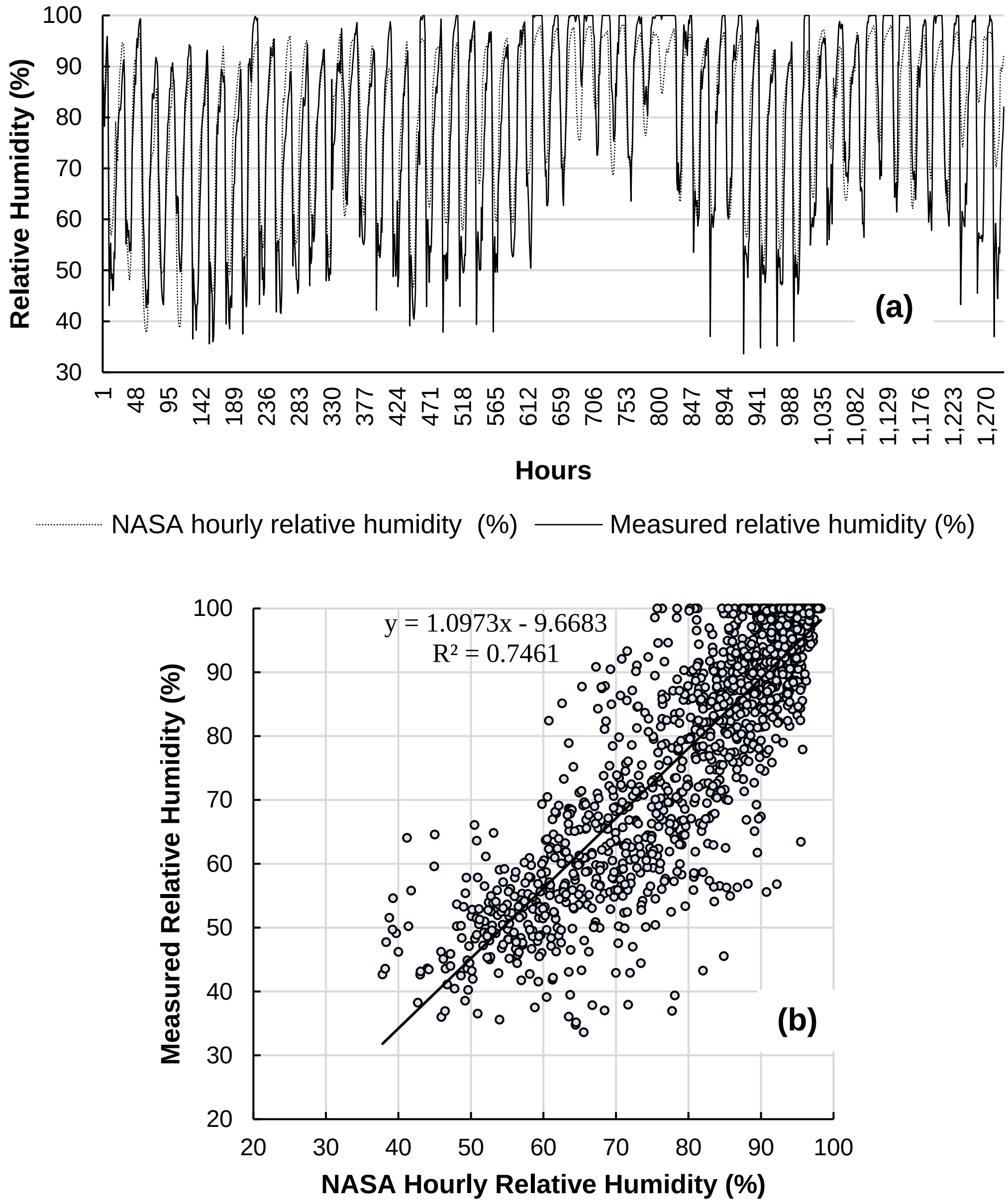

Fig. 2. Relative humidity oscillation for May, June, and July 2021 (a) and the relationship between the measured relative humidity on-site and the NASA relative humidity data (b)

The relative humidity oscillation between the on-site measured data and the data obtained from POWER Data Access Viewer v2.0.0 are presented in Fig. 2a. It is shown that the predicted relative humidity oscillation (according to POWER Data Access Viewer v2.0.0) values were lower than the values of the on-site measured data of May, June, and July of 2021. The measured relative humidity and relative humidity predicted by POWER Data Access Viewer v2.0.0 were then plotted (as shown in Fig. 2b). The promising confidence was relatively high (R^2 = 0.74). However, a corrected relative humidity is required to be fixed *via* calculation using Eq. 2. The mean absolute value of the difference was found to be 1.9%. This value was then deducted from the relative humidity measured by POWER Data Access Viewer v2.0.0 at the geography locations of interest.

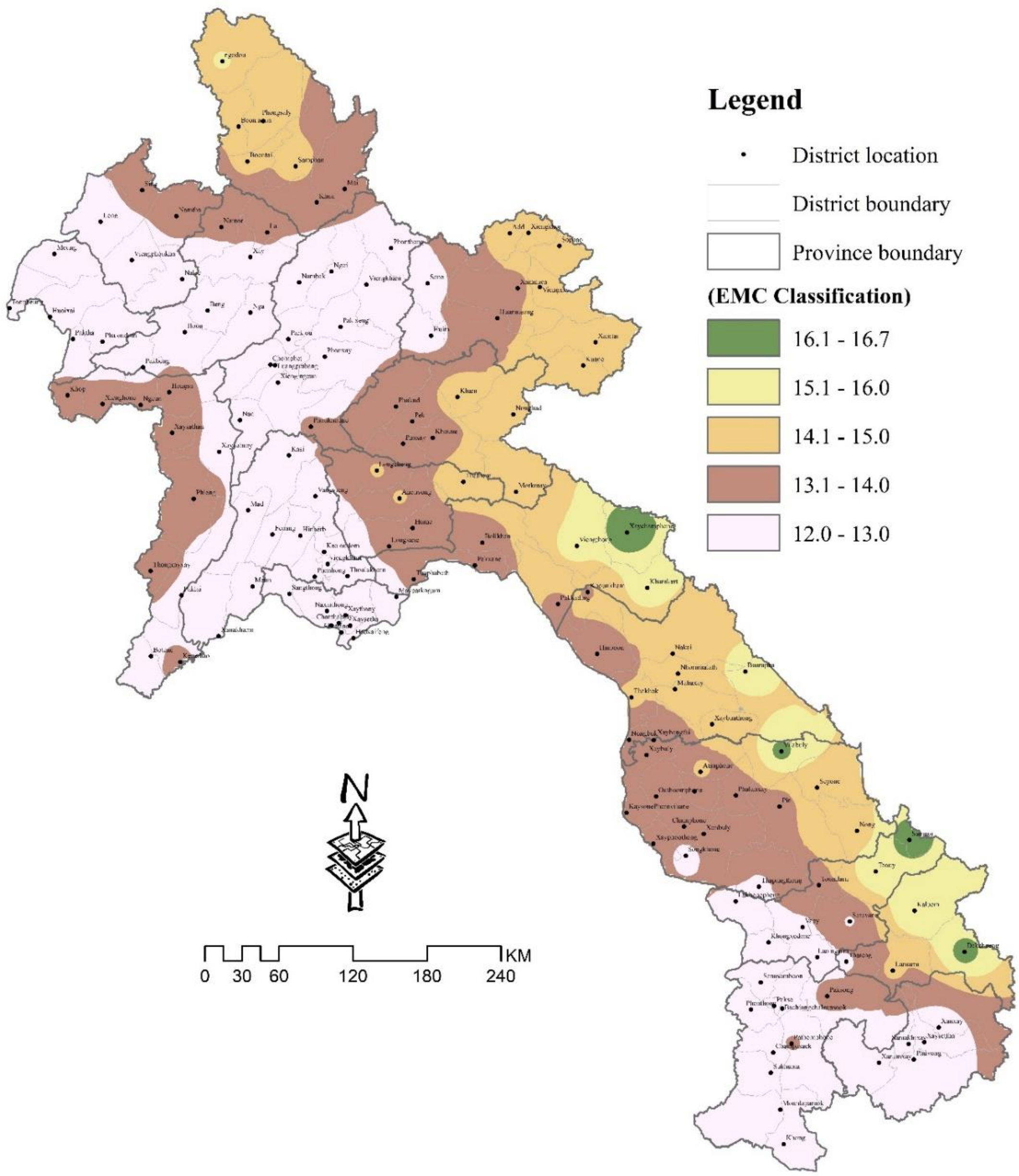

Fig. 3. The recommended average moisture contents for interior use wood products in different parts of Laos based on NASA (2021) with EMC correction

Equilibrium Moisture Content Map for Laos

After the temperature and relative humidity values were corrected for the measurement of the POWER Data Access Viewer v2.0.0, the EMC values were then calculated using Eq. 3. The results of the average EMC values for entire districts of Laos are presented in Fig. 3. The mean EMC for the entirety of Laos was 14.2% ± 2.5%. Four districts out of 148 districts had the highest EMC values, *i.e.*, 16.1% to 16.7%. These locations included the districts that lie to the East of Borikhamxay province (Saychampone district), Savannakhet province (Vilabury district), Salavan province (Samuoi district), and Xekong province (Dakchueng district).

The lowest EMC (12% to 13%) values were found in Vientiane, Vientiane province, Louangprabang Bokeo province, Attapeu province, LouangNamtha province (Long, Viengphoukha districts), Oudomxay (Hoon, Xay, Beng, Pakbeng and Nga districts), Houaphan province (Huim and Sone districts), Sayaburi province (Sayaburi, Paklai and Botene districts), Savannakhet province (Songkhone and Thapangthong district), Salavan province (Khongxedone, Vapy, Lao Ngam, Thateng and Lakhonepheng district), and Champasak province (except Paksong and Pathoumphone districts). The rest of the districts had an EMC value ranging from 13% to 16%.

Monthly Equilibrium Moisture Content in Laos

Figure 4 shows the oscillation of the average EMC values with the standard deviation from January until December. It indicated that the lowest EMC was in March (10.4% ± 1.2%), while the maximum EMC was in August (17.6% ± 0.9%). The results also clearly demonstrated the EMC values differ during the dry and wet seasons. For instance, the heavy rain starts from May until October (Phonetip 2018); this period has high humidity and low temperature in the region. The overall mean EMC for Laos is 14.2% ± 2.5%. However, producing high quality wooden products means avoiding timber defects from cracking and distortion that could be affected by different geographical locations with climates. Thus, the map of the EMC values provided in Fig. 3 is the comprehensive option for considering what moisture content level wood needs to be dried to. In addition, Table 1 can help with comprehensive information for the monthly variations in the EMC values for each district in Laos. The EMC range (10.4% to 17.6%) was 1.6% higher than the previous study, which found an EMC range of 10% to 16% for a particular location in Vientiane, Laos (Phonetip *et al*. 2018b).

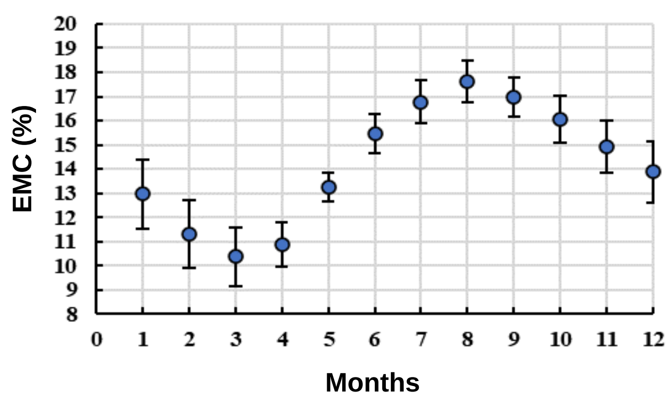

Fig 4. The average equilibrium moisture content with standard deviation from January to December in Laos

Table 1. The Equilibrium Moisture Content for Outside Conditions According to Districts in Laos

Vientiane Capital - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Chanthabuly	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
2	Sikhottabong	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
3	Xaysetha	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
4	Sisattanak	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
5	Naxaithong	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
6	Xaythany	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
7	Hadxaifong	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
8	Sangthong	11.7	9.9	8.8	9.4	12.3	14.7	15.7	16.8	16.5	15.8	14.4	13.0	13.3
9	Mayparkngum	12.2	10.5	9.4	9.6	12.4	15.4	16.6	17.5	16.7	16.0	14.8	13.4	13.7
Phongsaly Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Boon neua	14.1	11.9	10.7	11.3	13.3	15.5	17.9	18.6	17.9	16.8	15.9	14.9	14.9
2	Boontai	14.1	11.9	10.7	11.3	13.3	15.5	17.9	18.6	17.9	16.8	15.9	14.9	14.9
3	Khua	13.1	11.3	10.3	11.1	12.9	14.9	17.6	18.1	16.8	15.3	14.4	13.6	14.1
4	ngodou	15.3	12.9	11.5	11.8	13.5	16.0	18.1	18.6	18.3	17.9	17.1	16.3	15.6
5	Samphan	14.4	12.4	11.2	11.8	13.5	15.8	18.3	18.7	17.7	16.7	15.8	15.0	15.1
6	Mai	13.1	11.3	10.3	11.1	12.9	14.9	17.6	18.1	16.8	15.3	14.4	13.6	14.1
7	Phongsaly	14.1	11.9	10.7	11.3	13.3	15.5	17.9	18.6	17.9	16.8	15.9	14.9	14.9
Louangnamtha Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Namtha	13.4	11.3	10.3	11.1	13.1	14.8	16.5	16.8	16.1	15.7	15.1	14.4	14.1
2	Sing	13.4	11.3	10.3	11.1	13.1	14.8	16.5	16.8	16.1	15.7	15.1	14.4	14.1
3	Viengphoukha	12.3	10.4	9.5	10.4	12.8	14.6	16.8	17.5	16.4	14.8	13.7	12.9	13.5
4	Nalae	12.3	10.4	9.5	10.4	12.8	14.6	16.8	17.5	16.4	14.8	13.7	12.9	13.5
5	Long	12.9	10.5	9.4	10.2	12.6	14.5	16.4	16.9	16.1	15.6	14.9	14.1	13.7

Oudomxai Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Xay	12.8	10.9	10.0	11.0	13.2	14.9	17.0	17.6	16.5	15.2	14.2	13.5	13.9
2	La	13.0	11.0	9.9	10.7	12.8	14.6	17.1	17.8	16.9	15.6	14.7	13.8	14.0
3	Namor	13.0	11.0	9.9	10.7	12.8	14.6	17.1	17.8	16.9	15.6	14.7	13.8	14.0
4	Nga	12.8	10.9	10.0	11.0	13.2	14.9	17.0	17.6	16.5	15.2	14.2	13.5	13.9
5	Beng	12.8	10.9	10.0	11.0	13.2	14.9	17.0	17.6	16.5	15.2	14.2	13.5	13.9
6	Hoon	12.5	10.7	9.9	10.9	13.2	14.8	16.5	17.2	16.2	15.1	14.0	13.2	13.7
7	Pakbeng	12.5	10.7	9.9	10.9	13.2	14.8	16.5	17.2	16.2	15.1	14.0	13.2	13.7
Bokeo Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Huoixai	12.6	10.4	9.4	10.3	12.9	14.7	16.6	17.5	16.5	15.3	14.3	13.4	13.6
2	Tonpheung	12.8	10.6	9.6	10.3	12.9	14.7	16.2	16.9	16.0	15.5	14.9	14.2	13.7
3	Meung	12.6	10.4	9.4	10.3	12.9	14.7	16.6	17.5	16.5	15.3	14.3	13.4	13.6
4	Pha oudom	12.6	10.5	9.6	10.6	13.3	14.9	16.6	17.5	16.6	15.5	14.5	13.5	13.8
5	Paktha	12.6	10.5	9.6	10.6	13.3	14.9	16.6	17.5	16.6	15.5	14.5	13.5	13.8
Louangphabang Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Luangprabang	12.1	10.4	9.7	10.7	12.9	14.3	16.2	16.9	16.0	14.5	13.3	12.5	13.3
2	Xieng ngeun	12.1	10.4	9.7	10.7	12.9	14.3	16.2	16.9	16.0	14.5	13.3	12.5	13.3
3	Nan	12.7	11.0	10.3	11.2	13.5	14.8	16.2	16.9	16.0	15.0	13.9	13.0	13.7
4	Park ou	12.0	10.6	9.8	10.7	12.7	14.3	16.1	16.7	15.7	14.2	13.0	12.4	13.2
5	Nambak	12.1	10.6	9.7	10.6	12.5	14.2	16.7	17.5	16.3	14.3	13.2	12.6	13.4
6	Ngoi	12.1	10.6	9.7	10.6	12.5	14.2	16.7	17.5	16.3	14.3	13.2	12.6	13.4
7	Chomphet	12.1	10.4	9.7	10.7	12.9	14.3	16.2	16.9	16.0	14.5	13.3	12.5	13.3
8	Viengkham	12.5	11.0	10.2	11.1	13.0	14.8	16.8	17.4	16.2	14.5	13.4	12.7	13.7
9	Phonthong	12.5	11.0	10.2	11.1	13.0	14.8	16.8	17.4	16.2	14.5	13.4	12.7	13.7
10	Pak xeng	12.0	10.6	9.8	10.7	12.7	14.3	16.1	16.7	15.7	14.2	13.0	12.4	13.2
11	Phoukhoune	12.7	11.3	10.6	11.5	13.7	15.4	16.8	17.4	16.5	15.1	13.7	13.0	14.0
12	Phonxay	12.0	10.6	9.8	10.7	12.7	14.3	16.1	16.7	15.7	14.2	13.0	12.4	13.2

Houaphan Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Xiengkhor	15.5	14.1	13.0	12.7	13.5	14.6	15.5	16.0	15.9	16.2	15.7	15.1	14.8
2	Viengxay	15.4	13.9	12.8	12.5	13.5	14.5	15.3	16.2	16.1	16.5	15.8	15.2	14.8
3	Sopbao	15.4	13.9	12.8	12.5	13.5	14.5	15.3	16.2	16.1	16.5	15.8	15.2	14.8
4	Add	14.7	13.0	11.9	12.2	13.5	15.0	16.2	16.7	16.4	16.2	15.5	14.8	14.7
5	Kuane	15.3	13.8	12.7	12.5	13.7	14.8	15.6	16.9	17.0	17.1	16.1	15.3	15.1
6	Sone	12.5	11.0	10.2	11.1	13.0	14.8	16.8	17.4	16.2	14.5	13.4	12.7	13.7
7	Huim	12.5	11.2	10.4	11.1	13.1	14.8	16.3	17.0	16.0	14.7	13.5	12.8	13.6
8	Xamnuea	14.0	12.4	11.4	11.9	13.4	14.9	16.1	16.8	16.4	15.9	15.0	14.2	14.4
9	Xamtai	15.3	13.8	12.7	12.5	13.7	14.8	15.6	16.9	17.0	17.1	16.1	15.3	15.1
10	Huamueang	13.8	12.4	11.5	11.9	13.6	15.1	16.2	17.0	16.6	16.0	14.9	14.1	14.4
Xaignabouly Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Khop	12.7	10.7	9.8	10.7	13.6	15.3	16.7	17.7	17.0	16.0	14.9	13.8	14.1
2	Hongsa	13.0	11.1	10.3	11.4	13.9	15.4	16.8	17.6	16.7	15.8	14.7	13.7	14.2
3	Ngeun	13.0	11.1	10.3	11.4	13.9	15.4	16.8	17.6	16.7	15.8	14.7	13.7	14.2
4	Xienghone	12.7	10.7	9.8	10.7	13.6	15.3	16.7	17.7	17.0	16.0	14.9	13.8	14.1
5	Kenethao	12.3	10.5	9.8	10.6	13.8	15.7	16.3	17.2	17.5	16.9	15.5	13.8	14.2
6	Botene	12.6	10.6	9.8	10.6	13.5	15.2	16.0	16.9	16.8	16.3	15.1	13.8	13.9
7	Thongmyxay	13.0	11.0	10.1	11.0	13.8	15.5	16.5	17.4	16.8	16.1	15.0	14.0	14.2
8	Xaysathan	13.0	11.1	10.3	11.4	13.9	15.4	16.8	17.6	16.7	15.8	14.7	13.7	14.2
9	Xayyabury	12.7	11.0	10.3	11.2	13.5	14.8	16.2	16.9	16.0	15.0	13.9	13.0	13.7
10	Phieng	13.1	11.2	10.4	11.3	13.9	15.5	16.7	17.4	16.5	15.8	14.8	13.9	14.2
11	Paklai	12.6	10.6	9.8	10.6	13.5	15.2	16.0	16.9	16.8	16.3	15.1	13.8	13.9
Xiengkhouang Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Pek	13.2	11.9	11.1	11.7	13.9	15.6	16.7	17.4	16.7	15.7	14.3	13.5	14.3
2	Kham	14.4	13.0	12.0	12.3	14.2	15.8	16.6	17.5	17.2	16.7	15.5	14.7	15.0
3	Khoune	13.2	11.9	11.1	11.7	13.9	15.6	16.7	17.4	16.7	15.7	14.3	13.5	14.3
4	Morkmay	14.0	12.7	11.7	12.0	14.6	17.0	17.9	19.0	18.2	16.8	15.1	14.2	15.3
5	Phaxay	13.2	11.9	11.1	11.7	13.9	15.6	16.7	17.4	16.7	15.7	14.3	13.5	14.3
6	Nonghad	14.4	13.0	12.0	12.3	14.2	15.8	16.6	17.5	17.2	16.7	15.5	14.7	15.0
7	Phukud	13.2	11.9	11.1	11.7	13.9	15.6	16.7	17.4	16.7	15.7	14.3	13.5	14.3

Vientiane Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Phonhong	11.9	10.4	9.5	10.0	12.6	14.5	15.5	16.4	15.5	14.4	13.4	12.7	13.1
2	Thoulakhom	11.9	10.4	9.5	10.0	12.6	14.5	15.5	16.4	15.5	14.4	13.4	12.7	13.1
3	Feuang	12.7	11.1	10.2	10.8	13.2	14.6	15.7	16.6	16.0	15.2	14.3	13.5	13.7
4	Xanakharm	12.1	10.3	9.2	9.9	12.8	14.7	15.7	16.7	16.8	16.1	14.6	13.3	13.5
5	Mad	13.0	11.2	10.3	11.1	13.5	14.9	16.1	16.8	15.9	15.2	14.3	13.5	13.8
6	viengkham	11.9	10.4	9.5	10.0	12.6	14.5	15.5	16.4	15.5	14.4	13.4	12.7	13.1
7	Hinherb	11.9	10.4	9.5	10.0	12.6	14.5	15.5	16.4	15.5	14.4	13.4	12.7	13.1
8	Meun	12.7	11.1	10.2	10.8	13.2	14.6	15.7	16.6	16.0	15.2	14.3	13.5	13.7
9	Vangvieng	12.5	11.0	10.1	10.9	13.5	15.5	16.7	17.6	16.7	15.0	13.6	13.0	13.8
10	Keo oudom	11.9	10.4	9.5	10.0	12.6	14.5	15.5	16.4	15.5	14.4	13.4	12.7	13.1
11	Kasi	12.5	11.0	10.1	10.9	13.5	15.5	16.7	17.6	16.7	15.0	13.6	13.0	13.8
Bolikhamxai Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Pakkading	13.3	11.7	10.6	10.6	13.5	17.1	18.2	19.0	17.7	16.5	15.4	14.3	14.8
2	Xaychamphone	17.7	16.0	14.3	13.4	14.8	16.7	17.3	18.8	19.0	19.0	18.3	18.0	16.9
3	Thaphabath	13.2	11.6	10.6	10.8	13.5	15.9	16.9	17.6	16.6	15.8	14.8	13.9	14.3
4	Pakxane	13.1	11.7	10.6	10.8	13.5	16.5	17.5	18.4	17.3	15.9	14.4	13.5	14.4
5	Viengthong	14.8	13.3	12.1	12.0	14.7	17.7	18.8	19.9	18.9	17.4	15.9	15.0	15.9
6	Khamkert	15.0	13.4	12.1	11.8	14.3	17.5	18.8	19.8	18.8	17.7	16.5	15.7	15.9
7	Bolikhan	13.1	11.7	10.6	10.8	13.5	16.5	17.5	18.4	17.3	15.9	14.4	13.5	14.4
Khammouan Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Thakhek	13.3	12.0	11.0	11.0	13.5	16.9	18.2	19.1	18.0	16.9	15.4	14.3	15.0
2	Mahaxay	13.3	12.0	11.0	11.0	13.5	16.9	18.2	19.1	18.0	16.9	15.4	14.3	15.0
3	Nongbok	13.4	11.7	10.4	10.4	12.9	16.0	17.2	18.0	17.1	16.6	15.6	14.6	14.5
4	Nhommalath	13.3	12.0	11.0	11.0	13.5	16.9	18.2	19.1	18.0	16.9	15.4	14.3	15.0
5	Xebangfay	13.4	11.7	10.4	10.4	12.9	16.0	17.2	18.0	17.1	16.6	15.6	14.6	14.5
6	Xaybuathong	13.7	12.4	11.2	11.0	13.3	16.1	17.4	18.9	18.3	17.0	15.4	14.5	14.9
7	Hinboon	12.4	10.7	9.7	9.8	12.6	16.2	17.4	18.1	17.0	16.4	15.5	14.1	14.2
8	Khounkham	13.3	11.7	10.6	10.6	13.5	17.1	18.2	19.0	17.7	16.5	15.4	14.3	14.8
9	Nakai	15.5	14.1	12.7	12.3	14.3	17.0	18.0	19.3	18.6	17.6	16.5	16.1	16.0
10	Buarapha	13.3	12.0	11.0	11.0	13.5	16.9	18.2	19.1	18.0	16.9	15.4	14.3	15.0

Savannakhet Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	KaysonePhomvihane	12.5	10.9	9.8	10.0	12.8	15.9	17.2	18.0	17.1	16.4	15.4	14.0	14.2
2	Outhoomphone	12.5	10.9	9.8	10.0	12.8	15.9	17.2	18.0	17.1	16.4	15.4	14.0	14.2
3	Atsaphangthong	12.5	10.9	9.8	10.0	12.8	15.9	17.2	18.0	17.1	16.4	15.4	14.0	14.2
4	Sepone	15.0	13.4	12.1	11.6	13.4	15.4	16.2	17.6	17.7	17.5	16.7	16.1	15.2
5	Nong	15.0	13.4	12.1	11.6	13.4	15.4	16.2	17.6	17.7	17.5	16.7	16.1	15.2
6	Thapangthong	11.9	10.4	9.4	9.9	12.9	16.2	17.6	18.4	17.5	16.6	15.2	13.7	14.1
7	Songkhone	11.3	9.8	9.0	9.6	12.8	16.4	17.8	18.5	17.8	17.0	15.4	13.1	14.0
8	Champhone	12.5	10.9	9.8	10.0	12.8	15.9	17.2	18.0	17.1	16.4	15.4	14.0	14.2
9	Xonbuly	13.6	12.0	10.6	10.5	12.7	15.4	16.6	17.6	17.0	16.6	15.7	14.9	14.4
10	Xaybuly	13.4	11.7	10.4	10.4	12.9	16.0	17.2	18.0	17.1	16.6	15.6	14.6	14.5
11	Vilabuly	16.6	15.1	13.7	13.2	14.8	16.6	17.2	18.4	18.2	18.0	17.4	17.2	16.4
12	Atsaphone	13.7	12.4	11.2	11.0	13.3	16.1	17.4	18.9	18.3	17.0	15.4	14.5	14.9
13	Xayphoothong	13.6	12.0	10.6	10.5	12.7	15.4	16.6	17.6	17.0	16.6	15.7	14.9	14.4
14	Phalanxay	13.6	12.0	10.6	10.5	12.7	15.4	16.6	17.6	17.0	16.6	15.7	14.9	14.4
15	Pin	13.6	12.0	10.6	10.5	12.7	15.4	16.6	17.6	17.0	16.6	15.7	14.9	14.4
Salavan Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Saravane	11.4	10.0	9.4	10.4	13.4	16.4	17.8	18.7	17.8	16.5	14.9	13.3	14.2
2	Toomlarn	13.4	11.6	10.3	10.5	13.1	16.1	17.4	18.6	17.9	17.2	16.0	15.0	14.8
3	Lakhonepheng	11.9	10.4	9.4	9.9	12.9	16.2	17.6	18.4	17.5	16.6	15.2	13.7	14.1
4	Vapy	11.4	10.0	9.4	10.4	13.4	16.4	17.8	18.7	17.8	16.5	14.9	13.3	14.2
5	Khongxedone	10.5	9.2	8.7	9.8	13.1	16.5	18.0	18.8	18.0	16.8	14.7	12.5	13.9
6	Lao ngarm	11.4	10.0	9.4	10.4	13.4	16.4	17.8	18.7	17.8	16.5	14.9	13.3	14.2
7	Samuoi	18.1	16.4	14.7	13.8	14.6	15.5	15.4	16.3	17.6	18.9	19.1	19.1	16.6
8	Taouy	16.4	14.6	13.3	12.9	14.5	16.0	16.3	17.3	17.8	18.4	18.3	17.9	16.1
Xekong Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Lamarm	13.8	12.2	11.2	11.2	13.4	15.6	16.2	17.3	17.5	17.3	16.4	15.4	14.8
2	Thateng	11.4	10.0	9.4	10.4	13.4	16.4	17.8	18.7	17.8	16.5	14.9	13.3	14.2
3	Dakchueng	17.6	15.8	14.5	13.8	14.7	15.6	15.5	16.2	17.0	18.3	18.7	18.8	16.4
4	Kaluem	16.4	14.6	13.3	12.9	14.5	16.0	16.3	17.3	17.8	18.4	18.3	17.9	16.1

Champasak Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Pakse	10.0	8.9	8.7	9.8	13.1	16.4	17.8	18.6	17.8	16.4	14.3	11.8	13.6
2	Sanasomboon	10.5	9.2	8.7	9.8	13.1	16.5	18.0	18.8	18.0	16.8	14.7	12.5	13.9
3	Bachiangchaleunsook	10.0	8.9	8.7	9.8	13.1	16.4	17.8	18.6	17.8	16.4	14.3	11.8	13.6
4	Phonthong	10.0	8.9	8.7	9.8	13.1	16.4	17.8	18.6	17.8	16.4	14.3	11.8	13.6
5	Champasack	10.0	8.9	8.7	9.8	13.1	16.4	17.8	18.6	17.8	16.4	14.3	11.8	13.6
6	Sukhuma	10.8	9.4	9.0	10.0	13.0	15.9	17.4	18.2	17.8	16.3	14.7	12.6	13.8
7	Khong	11.5	10.1	9.5	10.2	12.9	15.5	16.9	17.6	17.4	16.0	14.7	13.1	13.8
8	Pathomphone	11.2	10.0	9.7	10.8	14.1	17.1	18.4	19.3	18.8	16.8	14.7	12.9	14.5
9	Paksong	11.2	10.0	9.7	10.8	14.1	17.1	18.4	19.3	18.8	16.8	14.7	12.9	14.5
10	Mounlapamok	10.8	9.4	9.0	10.0	13.0	15.9	17.4	18.2	17.8	16.3	14.7	12.6	13.8
Attapeu Province - EMC by District														
No.	**Name of Districts**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Samakhixay	12.5	10.9	10.0	10.2	12.3	14.2	14.7	15.9	16.4	16.2	15.0	13.8	13.5
2	Xaysettha	12.5	10.9	10.0	10.2	12.3	14.2	14.7	15.9	16.4	16.2	15.0	13.8	13.5
3	Xanxay	12.5	10.9	10.0	10.2	12.3	14.2	14.7	15.9	16.4	16.2	15.0	13.8	13.5
4	Xanamxay	12.0	10.8	10.1	10.5	12.9	15.3	16.1	17.3	17.2	15.9	14.4	13.2	13.8
5	Phuvong	12.0	10.8	10.1	10.5	12.9	15.3	16.1	17.3	17.2	15.9	14.4	13.2	13.8
Xaisomboun Province - EMC by District														
No.	**Name of District**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Mean**
1	Thathom	14.0	12.7	11.7	12.0	14.6	17.0	17.9	19.0	18.2	16.8	15.1	14.2	15.3
2	Longcheng	13.6	12.1	11.2	11.7	14.2	16.4	17.3	18.0	17.2	16.2	14.9	14.1	14.7
3	Anouvong	13.6	12.1	11.2	11.7	14.2	16.4	17.3	18.0	17.2	16.2	14.9	14.1	14.7
4	Longsane	13.2	11.6	10.6	10.8	13.5	15.9	16.9	17.6	16.6	15.8	14.8	13.9	14.3
5	Home	13.2	11.6	10.6	10.8	13.5	15.9	16.9	17.6	16.6	15.8	14.8	13.9	14.3

It is recommended that further study on the dimensional changes of different timber species should be investigated when the timber products are placed in such a wide EMC value range, *i.e.*, 10% to 18%. The results can be a good database for carpenters in production design.

CONCLUSIONS

1. The mean EMC for the entirety of Laos was 14.2% ± 2.5%. The EMC ranged from 13% to 16%. The high values mostly were associated with the eastern part of Laos. The EMC map is available in Fig. 3.
2. A monthly swinging average EMC value for the entirety of Laos ranged from 10% to 18%; each district in Laos is available in Table 1.

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