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Solar kiln Drying of Wood: The relevance of Meteorological Information in Estimating Wood Equilibrium Moisture Content (EMC)

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ABSTRACT

Timber drying makes wood fit for use and extends its service life. Solar kiln drying (SKD) of wood was introduced as alternative to air-and conventional kiln drying methods. In SKD experiments, internal condition and performance of solar kiln (SK) are dependent on ambient condition (temperature and relative humidity) of the study area. Study on meteorological information in SKD research explains timber drying mechanisms in relation to weather variabilities. An SK was set up at the Forestry Research Institute of Nigeria (FRIN). Temperature (T℃) and relative humidity (RH%) of ambient condition and internal condition of SK were measured between August and September in 2016, 2017 and 2018. Equilibrium moisture content (EMC) of the solar kiln chamber was estimated based on SK's internal T℃ and RH% using the Hailwood and Horrobin Model. Data was analysed using regression analysis at $a_{0.05}$. Ambient T℃ recorded ranged from 22.90 to 28.95; 21.20 to 26.10 and 21.43 to 26.88 while ambient RH% ranged from 75.00 to 98.33; 67.00 to 93.50 and 74.50 to 95.00 for 2016, 2017 and 2018, respectively. The SK's internal T℃ ranged from 30.10 to 41.40; 24.80 to 38.37 and 23.90 to 38.70 while RH% ranged from 39.33 to 68.67; 43.33 to 81.67 and 47.83 to 90.17 for 2016, 2017 and 2018, respectively. Coefficient of determination (R^2) between SK's internal T℃ and ambient T℃ were 0.44, 0.40 and 0.66 while R^2 between SK's internal RH% and ambient RH% were 0.04, 0.04 and 0.61 for 2016, 2017 and 2018, repectively. The R^2 between EMC and predictors (T and RH) were 0.995, 0.0.983 and 0.973 for 2016, 2017 and 2018, repectively. There was a significant difference in EMC between 2016 (8.94%), 2017 (11.04%) and 2018 (13.36%). Variation in temperature and relative humidity had effect on estimated equilibrium moisture content condition of the solar kiln.

Keyword: Solar kiln, equilibrium moisture content, meteorology, temperature, relative humidity,

Introduction

Solar kiln drying of wood is a method in which the solar energy is systematically harnessed for wood drying using a solar-based system called a solar kiln (chamber). According to reports by Keey and Perre (2014) wood seasoning through solar kiln drying method is becoming a popular process around the world- especially in locations with favourable climates because of the ‘‘free’’ nature of the energy source. Several designs of solar kilns have been introduced with various reports describing the working principles of such systems. Basically, solar kiln designs have been grouped into greenhouse type, external collector, semi-green house and mixed mode type (High**,** 2014; Pranav *et al.*, 2015). The focal point about the various designs of solar kiln systems is that they are either wholly or partly dependent on solar radiation from the sun for their operation (Hasan, 2017). The uniqueness of solar kiln drying of wood ranges from its connection with renewable, readily available energy source, to eco-friendly nature, independence on grid-connected power, no fuel combustion and lots more. It is no gainsaying that solar kiln drying of wood is a viable alternative to other conventional kiln drying methods (Keey and Perre, 2014).

However, unlike the conventional methods of drying, solar kiln drying of wood is dependent on weather. Hence, variability in atmospheric condition greatly influences the drying processes. It has been reported that irrespective of the design of solar kiln, wood species type, among other factors, drying rate and quality are influenced by fluctuating weather which results from daily atmospheric changes and seasonal variation Pranav *et al.* (2015). The resultant effect is that there has been a sort of complexity in solar kiln drying process. Consequently, for any comprehensive study on solar kiln drying of wood, it is required that meteorological information of the study area is taken into consideration. GLOBE (2005) submitted that the two climate factors that are most related to solar kiln drying of wood are temperature and relative humidity.

According to GLOBE (2005) temperature is the measure of heat in a material or medium at a particular time. Ambient temperature is not static- it fluctuates based on changes in environmental condition of a place. Temperature is one of the major driving force in the drying process. It influences the internal moisture transfer kinetics (diffusivity) which determines drying time, drying rate, and final moisture content of the samples (Wan Nadhari *et al.*, 2014). Relative Humidity on the other hand is the measure of moisture in the atmosphere at a particular temperature. It represents the ratio of water in the atmosphere (in percentage) at a point in time to the amount of water when atmosphere is fully saturated with water. According to GLOBE (2005) drying depends on the ability of air to evaporate water (drying potential). Hence, relative humidity is a key factor that determines EMC. The lower the relative humidity of the drying air, the more water of air evaporates from the product, resulting in lower final product moisture content. They are measured with the aid of meteorological instrument such as Hygrometer or dry and wet bulb thermometer).

Equilibrium moisture content is the condition at which the moisture content in wood is at equilibrium with the atmospheric moisture. At this point, wood neither takes in moisture from, nor gives off moisture to the atmosphere. Hence it is said to be stable. The EMC condition is intricately linked to environmental factors of such an area (Baronas *et al.*, 2006). Meanwhile**,** accurate EMC prediction for wood at any given relative humidities and temperatures is important in controlling the quality of wood products. The moisture content of wood during kiln-drying and manufacture should be at equilibrium to the expected EMC condition where the product will be used. The Hailwood and Horrobin equation is a formula for estimating EMC condition based sorption theory (Simpson, 1973; Majka *et al.*, 2014).

Materials and methods

Study Area

The experiments were carried out at The Forestry Research Institute of Nigeria (FRIN). The FRIN, Ibadan is located on latitude 7°23'15" to 7°24'00" N and longitude 3°51'00" to 3°52'15"E. Annual temperature of FRIN ranges from minimum of 18.07^{o}C to an average maximum of 34.4^{o}C. There are two distinct seasons. The rainy season: from April to October and the dry season accompanied by the harmattan (dry weather) in December from November to March (Ariwaodo *et al.*, 2012).

Experimental procedure

Evaluation of temperature (°C) and relative humidity (%)

A solar kiln was sited at the Forest Products Development and Utilisation. The Solar kiln's internal temperature and relative humidity were measured using sets of indoor digital thermo-hygrometers. Ambient temperature and relative humidity were measured at the Meteorological Station, Forestry Research Institute of Nigeria, FRIN (Plate 1: a and b). Measurements were taken 9 times a day, at interval of 1 hour (9:00 am, 10:00 am, 11:00 am, 12:00 pm, 1:00 pm, 2:00 pm, 3:00 pm, 4:00 pm and 5:00 pm). This represents a modified climatic data capturing system in meteorological studies (WMO, 1974, GLOBE, 2005). Daily average temperature and relative humidity were calculated from maximum and minimum values.

Plate 1: Measurement of environmental factors: inside the solar kiln chamber (a); Meteorological Station (b), FRIN.

Estimation of EMC using Hailwood and Horrobin Model

According to Simpson (1973), The Hailwood and Horrobin model is given:

$$EMC = \frac{1800}{W}\left[\frac{Kh}{1-Kh} + \frac{K_1 Kh + 2K_1 K_2 K^2 Kh}{1+K_1 Kh + K_1 K_2 + K^2 h^2}\right] \ldots\ldots\ldots\ldots 1$$

Where:

W is $349 + 1.29T + 0.0135T^2$
K is $0.805 + 0.000736T + 0.00000273T^2$
K_1 is $6.27 + 0.00938T + 0.000303\ T^2$
K_2 is $1.91 + 0.0407T + 0.000293T^2$.
T is Temperature, in degree Celsius
H is relative humidity in %/100

Results and Discussion

Table 1: Temperature and Relative Humidity for August and September in 2016, 2017 and 2018

Date	2016				2017				2018			
	Solar		ambient		Solar		ambient		Solar		Ambient	
	T	RH	T	RH	T	RH	T	RH	T	RH	T	RH
Aug., 23rd	37.53	47.33	25.70	85.33	34.33	54.33	23.88	85.50	28.8	80.30	24.10	86.00
Aug., 24th	36.33	51.67	24.45	80.00	36.10	48.00	24.63	76.50	27.67	87.33	22.95	83.50
Aug., 25th	34.63	58.33	25.20	75.00	24.80	53.00	21.20	85.50	27.12	82.50	24.08	92.00
Aug., 26th	32.13	63.00	22.90	82.33	34.33	54.33	22.05	71.00	27.65	83.83	21.43	92.00
Aug., 27th	32.67	47.33	25.30	77.33	34.33	54.33	21.20	78.00	28.77	65.00	24.67	86.00
Aug., 28th	30.27	59.33	25.30	83.67	33.70	56.67	23.75	91.00	31.38	66.50	24.92	78.00
Aug., 29th	35.73	50.33	23.60	86.00	26.50	81.67	21.75	73.00	31.43	69.33	22.33	86.00
Aug., 30th	30.10	64.67	25.55	84.33	26.40	80.67	23.75	92.00	29.65	72.17	23.58	88.00
Aug., 31st	34.40	56.33	25.20	91.00	29.43	73.33	23.88	88.00	28.28	78.67	23.55	93.50
Sept., 1st	35.33	53.67	27.60	96.67	26.40	80.67	24.25	82.50	28.28	78.67	23.55	89.00
Sept., 2nd	41.17	39.33	27.25	95.67	33.70	56.67	23.25	89.50	30.93	66.50	23.65	92.00
Sept., 3rd	40.80	39.67	27.80	95.33	33.70	56.67	24.75	87.00	30.93	66.50	23.65	83.50
Sept., 4th	41.30	40.00	27.75	96.33	26.40	80.67	24.50	76.50	29.28	80.33	24.18	79.50
Sept., 5th	32.27	61.67	23.90	95.33	31.33	63.33	24.05	90.00	29.95	77.33	24.58	78.00
Sept., 6th	32.07	68.67	24.85	97.33	32.33	63.33	24.48	79.50	28.62	80.00	23.22	81.50
Sept.,7th	39.30	44.33	28.60	94.67	28.27	73.00	24.00	74.50	23.90	90.17	22.22	87.50
Sept., 8th	36.97	51.33	27.25	98.33	31.47	64.33	22.95	80.50	28.45	78.00	24.48	87.50
Sept., 9th	40.83	40.00	28.50	91.00	31.47	64.33	24.30	80.00	23.90	90.17	22.22	84.50
Sept., 10th	40.43	42.00	24.50	97.33	32.33	63.33	24.63	93.50	28.45	78.00	24.48	79.50
Sept., 11th	37.30	49.33	25.75	89.33	33.77	59.33	22.70	79.00	33.17	64.17	24.48	85.00
Sept., 12th	33.40	58.00	26.95	96.00	37.37	45.33	24.13	77.50	38.70	54.83	25.58	74.50
Sept., 13th	36.57	52.00	25.75	95.33	29.03	71.00	22.55	79.00	31.87	66.00	25.08	86.50
Sept., 14th	34.07	61.33	24.80	90.33	36.00	50.33	25.28	84.00	35.70	47.83	25.23	76.50
Sept., 15th	37.60	55.33	25.45	96.67	34.33	56.33	25.40	80.00	35.97	59.33	25.60	95.00
Sept., 16th	36.97	54.33	27.85	88.67	29.03	71.00	25.40	71.00	35.70	47.83	25.23	86.50
Sept., 17th	41.40	41.67	28.60	78.33	36.00	50.33	25.25	81.00	35.97	59.33	25.60	82.00
Sept., 18th	41.00	41.67	28.95	85.00	35.90	45.33	24.80	83.50	27.13	75.00	22.65	90.50
Sept., 19th	40.57	39.67	28.00	83.67	32.43	63.00	24.33	67.00	34.83	50.50	25.88	88.00
Sept., 20th	35.20	51.33	26.30	89.67	38.37	43.33	26.10	81.50	37.15	53.33	26.88	81.00
Sept., 21st	37.53	45.67	27.85	96.00	32.83	61.00	24.53	80.50	34.18	59.17	25.68	84.00
Sept., 22nd	33.07	67.00	25.95	89.00	34.97	53.00	25.08	81.00	32.90	65.67	24.67	84.50
Average	**36.40**	**51.50**	**26.20**	**89.70**	**32.2**	**61.00**	**24.00**	**81.30**	**30.90**	**70.20**	**24.20**	**85.20**

Data on daily Temperature and Relative Humidity strating from 23rd August to 22nd September in 2016, 2017 and 2018 are presented in Table1. Solar kiln's internal T ranged from 30.10°C to 41.40°C; 24.80°C to 38.37°C and 23.90°C to 38.70°C while RH ranged from 39.33% to 68.67%; 43.33% to 81.67% and 47.83 to 90.17% for 2016, 2017 and 2018, respectively. Ambient T recorded ranged from 22.90°C to 28.95°C; 21.20°C to 26.10°C and 21.43°C to 26.88°C while ambient RH ranged from 75.00% to 98.33%; 67.00% to 93.50% and 74.50% to 95.00% for 2016, 2017 and 2018, respectively. Average T recorded in 2016 (36.40 and 26.20); 2017 (32.2 and 24.00) and 2018 (30.90 and 24.20) for solar kiln internal and ambient while Average RH recorded in 2016 (51.50 and 89.70); 2017 (61.00 and 81.30) and 2018 (70.20 and 85.20) for solar kiln internal and ambient. Variation in average T and RH could be attributed to differences in daily T and RH recorded during each year of experimentaion.

Table 2a: Model summary for regression analysis.

	Model	R	R Square	Adjusted R Square	Std. Error of Estimate
2016	1: Temp	0.66[a]	0.44	0.40	2.70
	2: RH	0.21[a]	0.04	-0.03	11.20
2017	1: Temp	0.40[a]	0.16	0.10	3.42
	2: RH	0.21[a]	0.04	-0.03	11.20
2018	1: Temp	0.81[a]	0.66	0.63	2.29
	2: RH	0.78[a]	0.61	0.58	7.91

Table 2b: ANOVA on regression analysis for T and RH

Year	Model		Df	Sum of Squares	Mean Square	F	Sig.
2016	1: Temperature	Regression	2	157.00	78.50	10.80	0.000*
		Residual	28	203.44	7.27		
		Total	30	360.44			
	2: Relative Humidity	Regression	2	155.62	77.81	0.62	0.55[ns]
		Residual	28	3512.24	125.44		
		Total	30	3667.86			
2017	1: Temperature	Regression	2	63.81	31.91	2.73	0.08[ns]
		Residual	28	327.40	11.69		
		Total	30	391.21			
	2: Relative Humidity	Regression	2	155.62	77.81	0.62	0.55[ns]
		Residual	28	3512.24	125.44		
		Total	30	3667.86			
2018	1: Temperature	Regression	2	279.73	139.87	26.67	0.00*
		Residual	28	146.86	5.25		
		Total	30	426.59			
	2: Relative Humidity	Regression	2	2742.67	1371.34	21.94	0.00*
		Residual	28	1750.55	62.52		
		Total	30	4493.22			

Tables 2a, 2b and 2c revealed the regression analysis between Solar kiln internal T and RH (dependent variable) and independent variables (ambient T and RH) for 2016, 2017 and 2018. Results were summarized into Equations 2 to 7. For 2016, results (model 1) implied that a unit increase in ambient T will result to about 0.040 times increase in solar T while a unit increase in ambient RH will result to 1.353 times increase in solar RH. In addition, 44% of the variation in Solar T can be predicted by ambient T and RH. However, it was observed that model was significant ($p<0.05$). This combination implied that alhough not much of the dependent variable can be explained from the independent variables, the regression model has provided a relevant information required for predictions in wood drying research. Model 2 implied that a unit increase in ambient T will result to about 0.093 times increase in solar kiln RH while a unit increase in ambient RH will result to -1.739 times increase in solar RH. In addition, 4% of the variation in Solar RH can be predicted by ambient T and RH. More so, the model was not significant ($p<0.05$). This result implied that very little of the dependent variable can be explained from the independent variables.

Table 2c: Coefficient

Year	Model		Unstandardized coeff.		Standardized coeff.	t	Sig
			B	Standard Error	Beta		
2016	1	(Constant)	-2.714	9.399		-0.289	0.775
		Amb. T	0.040	0.074	0.079	0.546	0.590
		Amb. RH	1.353	0.306	0.640	4.427	0.000
	2	(Constant)	110.234	45.657		2.414	0.023
		Amb. T	-0.093	0.318	-0.054	-0.292	0.773
		Amb. RH	-1.739	1.661	-0.194	-1.047	0.304
2017	1	(Constant)	5.133	13.940		0.368	0.715
		Amb. T	-0.016	0.097	-0.029	-0.170	0.866
		Amb. RH	1.185	0.507	0.405	2.336	0.027
	2	(Constant)	110.234	45.657		2.414	0.023
		Amb. T	-0.093	0.318	-0.054	-0.292	0.773
		Amb. RH	-1.739	1.661	-0.194	-1.047	0.304
2018	1	(Constant)	-23.532	13.157		-1.789	0.085
		Amb. T	-0.033	0.087	-0.045	-0.377	0.709
		Amb. RH	2.363	0.353	0.793	6.695	0.000
	2	(Constant)	266.212	45.423		5.861	0.000
		Amb. T	-0.113	0.301	-0.047	-0.374	0.712
		Amb. RH	-7.703	1.219	-0.797	-6.322	0.000

For 2016:

Model 1: Solar T.= -2.714+0.040AmbientT+1.353Ambient RH (R^2=0.44 or 44%, SEE=2.70, p=0.00*)…….Eqn. 2

Model 2: Solar RH.= 110.234-0.093AmbientT-1.739Ambient RH (R^2=0.04 or 4%, SEE=11.20, p=0.55^{ns})…..Eqn. 3

For 2017:

Model 1: Solar T.= 5.133-0.016AmbientT+1.185Ambient RH (R^2=0.40 or 40%, SEE=3.42, p=0.08^{ns})…….Eqn. 4

Model 2: Solar RH.= 110.234-0.093AmbientT-1.739Ambient RH (R^2=0.04 or 4%, SEE=11.20, p=0.55^{ns})….Eqn. 5

For 2018:

Model 1: Solar T.= -23.532-0.033AmbientT+2.363Ambient RH (R^2=0.66 or 66%, SEE=2.29, p=0.00*)……..Eqn. 6

Model 2: Solar RH.= 266.212-0.113AmbientT-7.703Ambient RH (R^2=0.61 or 61%, SEE=7.91, p=0.00^*)…….Eqn.7

For 2017, result (model 1) implied that a unit increase in ambient T will result to about -0.016 times increase in solar T while a unit increase in ambient RH will result to 1.185 times increase in solar T. In addition, 40% of the variation in Solar T can be predicted by ambient T and RH. More so, the model was not significant (p<0.05). Model 2 implied that a unit increase in ambient T will result to about 0.093 times increase in solar kiln RH while a unit increase in ambient RH will result to -1.739 times increase in solar RH. In addition, 4% of the variation in Solar RH can be predicted by ambient T and RH. More so, the model was not significant (p<0.05). This result implied that very little of the dependent variable can be explained from the independent variables.

For 2018, result (model 1) implied that a unit increase in ambient T will result to about -0.033 times increase in solar T while a unit increase in ambient RH will result to 2.363 times increase in solar T. In addition, 66% of the variation in Solar T can be predicted by ambient T and RH. More so, the model was significant (0.00*) at at $a_{0.05}$. Model 2 implied that a unit increase in ambient T will result to about -0.113 times increase in solar kiln RH while a unit increase in ambient RH will result to -7.703 times increase in solar RH. In addition, 61% of the variation in Solar RH can be predicted by ambient T and RH. More so, the model was significant (p<0.05). This combination (in Model 1 and Model 2) signified that the predictor variables could explain high percentage of the dependent variable. More so, the model provides highly significant information that explains relationship between ambient condition and solar kiln environment.

Table 3 revealed that EMC ranged from 6.79% to 12.40%; 7.48% to 16.52% and 8.27% to 20.26% for 2016, 2017 and 2018, respectively. Mean EMC was found to be 8.94 11.04 and 13.36 for 2016, 2017 and 2018, respectively. It was observed that mean EMC was least (8.94) in 2016 when T was highest (36.4) and RH was lowest (51.5). Whereas, mean EMC was highest (13.36) in 2018 when T was lowest (30.9) and RH was highest (70.2). This is an indication that EMC is dependent on internal condition of the solar kiln chamber. More so, seasonal variation has influence over wood drying processes in solar kiln drying environment. This corroborates Ogueke, *et al.* (2015) and Ugwu *et al.* (2015) that fluctuations in ambient condition affect outcomes of solar kiln drying processes.

Table 3: Solar kiln internal T and RH and estimated EMC Hailwood and Horrobin Model

Date	2016			2017			2018		
	Solar T	Solar RH	EMC	Solar T	RH	EMC	T	RH	EMC
Aug., 23rd	37.53	47.33	8.11	34.33	54.33	9.39	28.8	80.30	16.11
Aug., 24th	36.33	51.67	8.84	36.10	48.00	8.28	27.67	87.33	18.75
Aug., 25th	34.63	58.33	10.09	24.80	53.00	9.58	27.12	82.50	16.80
Aug., 26th	32.13	63.00	11.14	34.33	54.33	9.39	27.65	83.83	17.28
Aug., 27th	32.67	47.33	8.33	34.33	54.33	9.39	28.77	65.00	11.73
Aug., 28th	30.27	59.33	10.50	33.70	56.67	9.83	31.38	66.50	11.93
Aug., 29th	35.73	50.33	8.66	26.50	81.67	16.52	31.43	69.33	12.60

Aug., 30th	30.10	64.67	11.59	26.40	80.67	16.17	29.65	72.17	13.42
Aug., 31st	34.40	56.33	9.74	29.43	73.33	13.74	28.28	78.67	15.40
Sept., 1st	35.33	53.67	9.23	26.40	80.67	16.17	28.28	78.67	15.40
Sept., 2nd	41.17	39.33	6.79	33.70	56.67	9.83	30.93	66.50	11.96
Sept., 3rd	40.80	39.67	6.86	33.70	56.67	9.83	30.93	66.50	11.96
Sept., 4th	41.30	40.00	6.88	26.40	80.67	16.17	29.28	80.33	15.91
Sept., 5th	32.27	61.67	10.86	31.33	63.33	11.25	29.95	77.33	14.88
Sept., 6th	32.07	68.67	12.40	32.33	63.33	11.19	28.62	80.00	15.83
Sept.,7th	39.30	44.33	7.58	28.27	73.00	13.71	23.90	90.17	20.26
Sept., 8th	36.97	51.33	8.76	31.47	64.33	11.45	28.45	78.00	15.18
Sept., 9th	40.83	40.00	6.90	31.47	64.33	11.45	23.90	90.17	20.26
Sept., 10th	40.43	42.00	7.20	32.33	63.33	11.19	28.45	78.00	15.18
Sept., 11th	37.30	49.33	8.43	33.77	59.33	10.32	33.17	64.17	11.33
Sept., 12th	33.40	58.00	10.09	37.37	45.33	7.81	38.70	54.83	9.25
Sept., 13th	36.57	52.00	8.89	29.03	71.00	13.14	31.87	66.00	11.80
Sept., 14th	34.07	61.33	10.69	36.00	50.33	8.65	35.70	47.83	8.27
Sept., 15th	37.60	55.33	9.40	34.33	56.33	9.74	35.97	59.33	10.20
Sept., 16th	36.97	54.33	9.26	29.03	71.00	13.14	35.70	47.83	8.27
Sept., 17th	41.40	41.67	7.11	36.00	50.33	8.65	35.97	59.33	10.20
Sept., 18th	41.00	41.67	7.12	35.90	45.33	7.88	27.13	75.00	14.33
Sept., 19th	40.57	39.67	6.87	32.43	63.00	11.12	34.83	50.50	8.73
Sept., 20th	35.20	51.33	8.85	38.37	43.33	7.48	37.15	53.33	9.08
Sept., 21st	37.53	45.67	7.86	32.83	61.00	10.69	34.18	59.17	10.27
Sept., 22nd	33.07	67.00	11.96	34.97	53.00	9.13	32.90	65.67	11.66
Mean	**36.4**	**51.5**	**8.94**	**32.2**	**61.0**	**11.04**	**30.9**	**70.2**	**13.36**

Table 4a: Model summary for T, RH and EMC

	Model	R	R Square	Adjusted R Square	Std. Error of Estimate
2016	1: T, RH	0.997[a]	0.995	0.994	0.124
2017	2: T, RH	0.992[a]	0.983	0.982	0.351
2018	3: T, RH	0.986[a]	0.973	0.971	0.580

a. Predictors: (Constant), Temperature, Relative Humidity

Table 4b: ANOVA for T, RH and EMC

Year	Model		df	Sum of Squares	Mean Square	F	Sig.
2016	1: T, RH	Regression	2	81.185	40.593	2639.655	0.000*
		Residual	28	0.431	0.015		
		Total	30	81.616			
2017	2: T, RH	Regression	2	202.003	101.002	819.038	0.000*
		Residual	28	3.453	0.123		
		Total	30	205.456			

2018	3: T, RH	Regression	2	337.058	168.529	501.471	0.000*
		Residual	28	9.410	0.336		
		Total	30	346.468			

a. Dependent variable: moisture content

b. Predictors: (constant), temperature, relative humidity

Table 4c: Coefficient

Year	Model		Unstandardized coeff.		Standar-dized coeff.	t	Sig
			B	Standard Error	Beta		
2016	1	(Constant)	0.625	0.820		0.761	0.453
		Solar T	-0.023	0.015	-0.049	-1.569	0.128
		Solar RH	0.178	0.006	0.953	30.575	0.000
2017	2	(Constant)	-0.728	1.741		-0.418	0.679
		Solar T	-0.052	0.035	-0.071	-1.492	0.147
		Solar RH	0.220	0.011	0.930	19.493	0.000
2018	3	(Constant)	-1.632	3.783		-0.431	0.669
		Solar T	-0.083	0.073	-0.092	-1.132	0.267
		Solar RH	0.250	0.023	0.900	11.057	0.000

a. Dependent Variable: EMC

Model 1: EMC= 0.625-0.023Solar T+0.178RH (R^2=0.995or 99.5%, SEE=0.124, p=0.000*)……….Eqn. 8

Model 2: EMC= -0.728-0.052Solar T+ 0.220RH (R^2=0.983 or 98.3%, SEE=0.351, p=0.000*) …….Eqn. 9

Model 3: EMC= -1.632-0.083Solar T+ 0.250RH (R^2=0.973 or 97.3%, SEE=0.580, p=0.000*) ……Eqn. 10

Regression analysis was summarized in Tables 4a, 4b and 4c. Result (Eqn. 8) implied that a unit increase in solar T will result to about -0.023 times increase in EMC while a unit increase in solar RH will result to about 0.178 times increase in EMC. In addition, 99.5% of the variation in EMC can be predicted by solar T and RH. More so, the model was significant (0.000*) at $a_{0.05.}$ Considering the fit statistics (R^2 = 99.5%, SEE = 0.124), it can be observed that the data fitted well to the model. This is because the coefficient of determination (R^2) is high and the value of standard error of estimate is low. Furthermore, More of the dependent variable could be explained by predictor variables (T and RH).

In Eqn. 9, a unit increase in solar T will result to about -0.052 times increase in EMC while a unit increase in solar RH will result to about 0.220 times increase in EMC. In addition, 98.3% of the variation in EMC can be predicted by solar T and RH. The Model was also significant. Considering the fit statistics (R^2=98.3%, SEE=0.351), the data fitted well to the model as there was high R^2 and low SEE. Furthermore, much of the dependent variable (EMC) could be explained by predictor variables (T and RH). In Eqn. 10, a unit increase in solar T will result to about -

0.083 times increase in EMC while a unit increase in solar RH will result to about 0.250 times increase in EMC. In addition, 97.3% of the variation in EMC can be predicted by solar T and RH. The Model was also significant. Considering the fit statistics (R^2=97.3%, SEE=0.580), the data fitted well to the model as there was high R^2 and low SEE. Furthermore, much of the dependent variable (EMC) could be explained by predictor variables (T and RH).

Table 5: ANOVA for EMC between 2016 to 2018

Source of variation	df	SS	MSS	F	Sig.
Year	2	304.192	152.096	21.600	0.000*
Error	90	633.729	7.041		
Total	92	937.921			

Note: *means value is significant (p=0.05)

Table 5 revealed that there was significant difference in the EMC of solar kiln's internal condition among the years (2016, 2017 and 2018) assessed. This is an indication that significant variation in the final moisture content of timber could be observed when a species of timber is dried under varying conditions. In Table 6, the follow up test revealed that EMC values are not the same with each other. This implied that timber dried under this varying EMC condition will attain significantly different final moisture content.

Table 6: Follow-up test for ANOVA

Year	Mean EMC
2016	8.9334a
2017	11.0420b
2018	13.3618c

Values with same letters are the same

Conclusion

This research examined the relationship between ambient condition and internal condition of solar kiln as a potential to predicting final moistre content based on predicted EMC. The regression analysis revealed that there is a considerable relationship between ambient and solar kiln internal condition (T and RH). Results revealed that variation in daily T and RH resulted to significant difference in average EMC recorded in three consecutive years examined. The result indicates that meteorological information has synergy with wood drying in relation to solar kiln drying technology.

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