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Determination of utilizable wind energy for indoor ventilation in buildings across selected locations in Nigeria.

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Abstract

Presented is the analysis of hourly wind data for 15 stations across Nigeria acquired from the Nigerian Meteorological Agency mostly covering the period of five years for purposes of wind energy utilisation for indoor ventilation in buildings. Weibull's distribution function was used for modeling of wind speed frequency distribution. The Weibull parameters, power law exponent, average wind speed, most probable wind speed, the fraction of time of observation for which wind speed equals or exceeds the most probable wind speed, energy pattern factor, and wind energy densities for the whole year and also for the hot season, between May and October when ventilation is most needed was computed for the heights 2 meters and 10 meters above the ground surface. In addition, a regression of the Weibull's distribution scale factor against the mean wind speed was carried out to enable the estimation of wind data for stations not covered in this study using their respective short term measurements. Results suggest that seasonal variations have got little or no effect on wind data used and the Weibull's scale factor c relates strongly with the mean speed V_{arity}. as : $c = 0.5145+1.1376V_{arith}$ with correlation coefficient r = 0.998.

Keywords: Weibull's parameters, Power law exponent, wind parameter, utiliziable wind energy, indoor ventilation.

1.0 Introduction

Evaluation of wind data for the design of buildings and wind operated gadgets is an important step towards the realisation of thermal comfort in unconditioned buildings. For instance, evolution of cost effective wind catchers and blowers depends largely on the availability of critical parameters including the most probable wind speeds, the duration for which wind speed is equal to or exceeds the most probable wind speed and the average energy content of the prevailing wind [Ishwar and Bhargava, (1)]. Utilization of indoor thermal climate is highly essential in buildings across tropical environments. Various design principle have been treated extensively and are available in the literature. [see Ken et al (2), Erik and Henrick (3), Mohammad et al (4)]

Low-speed wind operated devices could be deployed for inducement of air motion indoors, which is fundamental to indoor ventilation. By deploying these gadgets, energy used in operating electric fans, air conditioners and other active devices used for indoor air conditioning could be saved. In the same vein, wind data is required for proper design of window openings for optimum ventilation in buildings [Ishwar and Bhargava, (1)].

Though, estimation of wind characteristics remained a challenging task, several investigators over the years have evolved various methods including the use of probabilistic models for predicting wind behavior at a location. The weibull probability distribution function, a special case of the generalised gamma distribution has distinguished itself in this regard and has found acceptability among most investigators (5,6). Earlier studies on wind characteristics carried out by some investigators in Nigeria have focused on wind power potential evaluation and generation (7, 8, 9, 10). Simiu et al [11,12] and Quine [13] extended studies on wind characteristics and went some steps further by evaluating wind risks due to the influence of strong winds. This study will seek to extend the frontier by estimating weibull's parameters for evaluation of wind data necessary for inducement of air motion in buildings and other applications.

2.0 WIND DATA:

Hourly wind record for 6-year period {mostly, 1991 –1996} for all the stations with the exception of Lokoja {1991 – 1999} was obtained from the Meteorological Agency of the Federal Ministry of Aviation and used in this study. The record

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period of data used was restricted to 6 years owing to the difficulty encountered in the acquisition and sorting of the data peculiar to studies of this nature in most developing economies. There is however a general claim that at least a 10 – year record is required for this assessment. Some investigators have however argued that data for shorter period may be adequate [Derrick (14)].

In all the stations studied the Dine's Pressure Tube Anemograph is used for measuring wind speed at the standard height of 10 meters. The instrument is able to record continuously and it's response characteristics are such that the wind speed it records is over an average of approximately three to five seconds. The method of analysis adopted by the Meteorological Agency is to tabulate the wind speed and direction on the hour. Though the method does not follow standard procedure which involves taking the arithmetic mean of the set of records over each hour, experience has shown that a given record in an hour does not differ significantly from the mean obtained over the hour except in rare cases where they have been equal to each other.

3.0 Analysis:

3.1 **Determination of weibull's parameters**.

The Weibull Distribution function is expressed mathematically as:

$$F(V) = \tfrac{K}{C}\left(\frac{V}{c}\right)^{K-1} \exp\left[-\left(\frac{V}{c}\right)^{K}\right] \qquad (1)$$

and has a cumulative distribution function of the form:

$$M(V) = 1 - \exp\left[-\left(\frac{V}{c}\right)^{K}\right] \qquad (2)$$

where V is the wind speed, k is the dimensionless shape parameter and C in kmh^{-1} is the scale parameter of the distribution.

It can be seen from equation (2) that

$$\ln\left\{\ln\left[\left(1-M(V)\right)\right]^{-1}\right\} = K\ln V - K\ln c \qquad (3)$$

Performing a regression of $\ln\left\{\ln\left[\left(1-M(V)\right)\right]^{-1}\right\}$ on $\ln V$ in equation (3), the values of k and c was obtained for all the studied sites. The raw data used for computational work were based on records of anemographs mounted at standard height of 10m for all the studied sites.

The value of Weibull's parameters at any height Z_a can be determined using the well known relations:

$$c_a = c_{10}\left(\frac{10}{z_a}\right)^{-n} \qquad (4)$$

$$k_a = k_{10}\left[1 - 0.088\ \ln\left(\frac{z_a}{10}\right)\right]^{-1} \qquad (5)$$

where C_{10} and k_{10} are the Weibull's parameters at 10m height and C_a and k_a at a base height Z_a (m). These equations were used to obtain the values at 2 meters height appropriate for the design of bungalows.

Meanwhile, the power law exponent n, is given by the expression:

$$n = \frac{\left[0.37 - 0.088\ \ln c_a\right]}{\left[1 - 0.088\ \ln\left(\frac{Z_a}{10}\right)\right]} \qquad (6)$$

4.0 Computation of Wind parameters.

Expressions for the average and most probable wind speeds, and the duration for which wind speeds equal to or exceeds the most probable value derivable from weibull distribution function are respectively given by:

$$\overline{V} = c\Gamma\left(1+\tfrac{1}{K}\right) \quad (7)$$

$$V_{mp} = c\left(\frac{k-1}{k}\right)^{\frac{1}{K}} \quad (8)$$

In addition,

$$T\left(V \geq V_{mp}\right) = \exp\left[-\frac{V_{mp}}{c}^{K}\right] \quad (9)$$

where V is the average wind speed, V_{mp} is the most probable wind speed, T is the fraction of the total period of observation during which wind speed equals or exceeds V_{mp} and Γ denoting the gamma function approximated well by the gamma expansion:

$$\Gamma(Z+1) = Z^{Z+\frac{1}{2}} e^{-Z} (2\pi)^{\frac{1}{2}} \left[1 + \tfrac{1}{12Z} + \tfrac{1}{288Z^{2}} + \ldots\right] \quad (10)$$

where, -π < arg z > π

Other expressions used for computations include:

The energy pattern factor (EPF) which is the ratio of total energy available in the wind to the energy calculated by cubing the mean wind speed given by:

$$EPF = \frac{\overline{V^{3}}}{\left(\overline{V}\right)^{3}} = \frac{\Gamma\left(1+\frac{3}{K}\right)}{\left[\Gamma\left(1+\frac{1}{k}\right)\right]^{3}} \quad (11)$$

Also, the energy density of the wind i.e. the energy contained in the air stream passing through 1m^2 area of cross section in a day given by:

$$E_{d} = 0.00031\,\overline{V}^{3} \times EPF \quad (12)$$

measured in $Kwh/m^{2}/day$.

5.0 Relationship between the weibull scale factor and the mean wind speed.

It is necessary to provide the relationship between the scale factor c of the weibull distribution and the mean wind speed V_{arith} to enable the estimation of the scale factor for stations near or around the studied sites. This will aid building designers implement the so- called measure –correlate – predict strategy that is popularly used amongst engineers and designers in computing relevant wind data for a site using shorter duration data.

Using the annual data in table 1, the regression and correlation analysis of the scale factor *c* on the mean wind speed V_{arith} was carried out and the results are presented as shown.

6.0 RESULT/DISCUSSION

The result of the analysis using equations (2) to (6) is summarized in tables 1and 2. Tables 3 to 6 shows the wind data obtained from equations 7 through 12 using the values of the weibull parameters in tables 1 and 2. Table 7 shows the comparison of the mean speed values $V_{c,k}$ obtained from the weibull parameters, and those of the arithmetic mean V_{arith} of the raw wind data. It is seen that in most of the cases, the values do not differ significantly from each other falling below 10 percent. This result justifies the appropriateness of the weibull distribution for modeling the wind data used.

It must be noted that in table 3 to 6, the values of $\mathbf{V}_{mp}$ for both the annual and the May-October period do not differ significantly for most of the stations. This suggests that seasonal variations have little or no effect on the wind data used implying that annual estimates of wind data for all the stations could be appropriate for application in the design for free airflow in buildings.

The regression and correlation analyses of the weibull scale parameter c on the mean wind speed V_{arith} showed that the scale factor **c**, is related to the mean speed as:

$$c = -0.5145 + 1.1376 \times V_{arith} \quad (13)$$

with the correlation coefficient r = 0.998.

This result shows a strong correlation of these parameters. The k values for stations within the vicinity of Ikeja, Lokoja, Warri, and Yola could be taken to be 1.48 (the mean value of the lowest and highest values for these stations) while for the rest of the stations, k values could be taken to be 3.55, following the procedure used by Derrick [14]

7.0 Conclusion:

Wind data for 15 sites have been analyzed specifically for wind energy utilization for inducing air motion for thermal comfort conditioning in buildings. In view of the simplicity of use and the enormous economic considerations in the design of wind operated air moving systems, it is desired to make direct utilization of wind energy without going into the provision of an energy storage system [Ishwar and Bhargava, (1)]. It should be noted that to compute the values of **k** and **c** at any desired height, the values of power law exponent's **n** are given in tables 1 and 2. These values in turn aid the computation for $\mathbf{V}_{mp}$, T, EPF and E_d at any desired height above the ground surface.

For wind data of other stations close to the studied areas, an approximation can be obtained from the relationship between the Wiebull **c** parameter and the mean wind speed derived and presented in this paper by the measure -–correlate – predict strategy [Derrick (14)] with short term wind measurement of the desired site.

Table 1: ***Weibull's Parameters (annual,averages)***

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	K_{10}	K_2	c_{10}	C_2	*n*
Enugu	6.47	7.55	141.50	4.04	3.54	12.49	9.85	0.15
Ikeja	6.58	3.33	39.35	1.64	1.43	7.85	5.79	0.19
Ibadan	7.43	3.70	227.23	3.21	2.81	7.69	5.66	0.19
Lokoja	7.78	6.74	151.40	1.52	1.33	4.69	3.22	0.23
Warri	5.52	5.73	6.10	1.33	1.17	3.96	2.65	0.25
Ibi	8.18	9.75	110.70	2.99	2.62	9.58	7.27	0.17
Maiduguri	11.85	13.08	353.8	3.01	2.63	10.05	7.68	0.17
Yola	9.23	12.47	186.05	1.60	1.40	3.18	2.06	0.27
Minna	9.62	6.53	258.64	2.95	2.58	13.38	10.65	0.14
Uyo	5.05	7.93	188.00	2.92	2.56	6.88	4.98	0.20
Yelwa	10.83	4.73	142.00	2.71	2.38	5.51	3.87	0.22
Oshogbo	7.80	7.03	300.00	2.71	2.37	6.94	5.03	0.20
Kano	12.05	8.53	472.14	4.77	4.18	20.70	17.52	0.10
Bauchi	10.37	9.80	666.50	2.33	2.04	5.09	3.53	0.23
Sokoto	13.02	5.25	350.75	2.34	2.05	14.13	11.34	0.14

***Table2*: Weibull's Parameters (May-Oct.)**

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	K_{10}	K_2	c_{10}	C_2	**n**
Enugu	6.47	7.55	141.50	5.07	4.44	11.22	8.72	0.16
Ikeja	6.58	3.33	39.35	1.67	1.47	7.90	5.84	0.19
Ibadan	7.43	3.70	227.23	3.39	2.97	7.96	5.89	0.19
Lokoja	7.78	6.74	151.40	1.85	1.62	4.59	3.14	0.24
Warri	5.52	5.73	6.10	1.19	1.04	3.68	2.44	0.26
Ibi	8.18	9.75	110.70	2.83	2.48	7.91	5.84	0.19
Maiduguri	11.85	13.08	353.8	3.35	2.94	10.62	8.18	0.16
Yola	9.23	12.47	186.05	1.65	1.44	3.44	2.26	0.26
Minna	9.62	6.53	258.64	2.58	2.26	11.67	9.11	0.15
Uyo	5.05	7.93	188.0	2.43	2.13	6.32	4.52	0.21
Yelwa	10.83	4.73	142.00	3.80	3.33	5.86	4.15	0.21
Oshogbo	7.80	7.03	300.00	2.79	2.44	6.95	5.04	0.20
Kano	12.05	8.53	472.14	5.33	4.67	19.68	16.55	0.11
Bauchi	10.37	9.80	666.50	3.61	3.16	5.86	4.15	0.21
Sokoto	13.02	5.25	350.75	2.89	2.53	12.15	9.54	0.15

***Table3*: Wind data at Standard Height(Annual, averages)**

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	$V_{c,k}$	V_{mp}	**T**	**EPF**	E_d
Enugu	6.47	7.55	141.50	12.00	11.64	0.47	1.21	0.556834
Ikeja	6.58	3.33	39.35	7.08	4.41	0.68	2.06	0.258466
Ibadan	7.43	3.70	227.23	7.14	6.84	0.50	1.27	0.137648
Lokoja	7.78	6.74	151.40	4.26	2.30	0.71	2.30	0.062772
Warri	5.52	5.73	6.10	3.65	1.39	0.78	2.89	0.049026
Ibi	8.18	9.75	110.70	8.82	8.36	0.51	1.30	0.273693
Maiduguri	11.85	13.08	353.8	9.26	8.78	0.51	1.30	0.315173
Yola	9.23	12.47	186.05	2.87	1.73	0.69	2.12	0.017763
Minna	9.62	6.53	258.64	12.31	11.63	0.52	1.31	0.750226
Uyo	5.05	7.93	188.00	6.32	5.96	0.52	1.31	0.102317
Yelwa	10.83	4.75	142.00	5.03	4.65	0.53	1.35	0.054538
Oshogbo	7.80	7.03	300.00	6.33	5.85	0.53	1.35	0.108874
Kano	12.05	8.53	472.14	20.50	19.70	0.45	1.19	2.483312
Bauchi	10.37	9.80	666.50	4.59	3.99	0.57	1.47	0.047392
Sokoto	13.02	5.25	350.75	12.75	11.15	0.56	1.46	1.010185

***Table4*: Wind data at 2m Height(annual, averages)**

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	$V_{c,k}$	V_{mp}	**T**	**EPF**	E_d
Enugu	6.47	7.55	141.50	9.26	8.96	0.49	1.01	0.24824
Ikeja	6.58	3.33	39.35	5.29	2.51	0.74	2.39	0.109699
Ibadan	7.43	3.70	227.23	5.18	4.84	0.52	1.13	0.048548
Lokoja	7.78	6.74	151.40	2.97	1.12	0.78	2.79	0.022715
Warri	5.52	5.73	6.10	2.52	0.50	0.87	3.78	0.018758
Ibi	8.18	9.75	110.70	6.61	6.05	0.54	1.18	0.105786
Maiduguri	11.85	13.08	353.8	6.99	6.41	0.54	1.18	0.124327
Yola	9.23	12.47	186.05	1.89	0.85	0.75	2.49	0.005212
Minna	9.62	6.53	258.64	9.68	8.81	0.54	1.19	0.334254
Uyo	5.05	7.93	188.00	4.52	4.10	0.54	1.20	0.034361
Yelwa	10.83	4.75	142.00	3.49	3.07	0.56	1.26	0.016724
Oshogbo	7.80	7.03	300.00	4.54	3.99	0.56	1.27	0.03682
Kano	12.05	8.53	472.14	16.93	16.42	0.47	0.95	1.42724
Bauchi	10.37	9.80	666.50	3.17	2.54	0.60	1.45	0.014358
Sokoto	13.02	5.25	350.75	10.18	8.19	0.60	1.44	0.471673

Table 5: Wind data at Standard Height(May-Oct.)

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	$V_{c,k}$	V_{mp}	**T**	**EPF**	E_d
Enugu	6.47	7.55	141.50	11.26	10.75	0.45	0.90	0.396985
Ikeja	6.58	3.33	39.35	2.11	4.59	0.67	1.85	0.00539
Ibadan	7.43	3.70	227.23	5.41	7.18	0.49	1.03	0.050403
Lokoja	7.78	6.74	151.40	1.45	3.02	0.63	1.62	0.001516
Warri	5.52	5.73	6.10	0.50	0.80	0.85	3.58	0.000141
Ibi	8.18	9.75	110.70	4.40	6.78	0.52	1.12	0.029694
Maiduguri	11.85	13.08	353.8	7.13	9.56	0.50	1.03	0.115999
Yola	9.23	12.47	186.05	0.89	1.95	0.67	1.89	0.00042
Minna	9.62	6.53	258.64	5.82	9.65	0.54	1.19	0.072857
Uyo	5.05	7.93	188.00	2.92	5.07	0.56	1.24	0.0096
Yelwa	10.83	4.75	142.00	4.48	5.41	0.48	0.98	0.027273
Oshogbo	7.80	7.03	300.00	3.81	5.93	0.53	1.13	0.019418
Kano	12.05	8.53	472.14	20.67	18.93	0.44	0.89	2.42465
Bauchi	10.37	9.80	666.50	4.25	5.35	0.49	1.00	0.023733
Sokoto	13.02	5.25	350.75	6.93	10.48	0.52	1.11	0.114568

Table 6: Wind data at 2m Height(May-Oct.)

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	$V_{c,k}$	V_{mp}	**T**	**EPF**	E_d
Enugu	6.47	7.55	141.50	8.51	8.23	0.46	0.98	0.18671
Ikeja	6.58	3.33	39.35	5.32	2.67	0.73	2.77	0.129042
Ibadan	7.43	3.70	227.23	5.42	5.13	0.52	1.29	0.063782
Lokoja	7.78	6.74	151.40	2.83	1.74	0.68	2.38	0.016772
Warri	5.52	5.73	6.10	2.41	0.12	0.96	5.36	0.023119
Ibi	8.18	9.75	110.70	5.29	4.74	0.55	1.50	0.068731
Maiduguri	11.85	13.08	353.8	7.52	7.10	0.52	1.30	0.171804
Yola	9.23	12.47	186.05	2.06	1.00	0.74	2.83	0.007688
Minna	9.62	6.53	258.64	8.21	7.03	0.57	1.63	0.278919
Uyo	5.05	7.93	188.00	4.06	3.35	0.59	1.73	0.035847
Yelwa	10.83	4.75	142.00	3.87	3.73	0.50	1.19	0.021424
Oshogbo	7.80	7.03	300.00	4.56	4.06	0.55	1.51	0.044453
Kano	12.05	8.53	472.14	16.32	15.71	0.46	0.94	1.271568
Bauchi	10.37	9.80	666.50	3.84	3.68	0.50	1.23	0.021735
Sokoto	13.02	5.25	350.75	8.65	7.82	0.55	1.47	0.294397

Table 7: Comparison 0f Means

STATION	***Lat.°N***	***Long.°E***	***Alt.(m)***	**Vc,k**	**Varith**	**% Dev.**
Enugu	6.47	7.55	141.50	12.0	11.0	8.6
Ikeja	6.58	3.33	39.35	7.1	7.7	8.0
Ibadan	7.43	3.70	227.23	7.1	7.3	1.6
Lokoja	7.78	6.74	151.40	4.3	4.7	9.3
Warri	5.52	5.73	6.10	3.7	4.2	12.8
Ibi	8.18	9.75	110.70	8.8	8.8	0.3
Maiduguri	11.85	13.08	353.8	9.3	9.4	1.2
Yola	9.23	12.47	186.05	2.9	3.1	6.6
Minna	9.62	6.53	258.64	12.3	12.7	2.8
Uyo	5.05	7.93	188.00	6.3	6.6	4.0
Yelwa	10.83	4.75	142.00	5.0	5.2	3.9
Oshogbo	7.80	7.03	300.00	6.3	6.3	0.5
Kano	12.05	8.53	472.14	20.5	18.7	9.8
Bauchi	10.37	9.80	666.50	4.6	4.8	4.4
Sokoto	13.02	5.25	350.75	12.8	12.6	1.6

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