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SKY LUMINOSITY FOR RIO DE JANEIRO CITY – BRAZIL

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Abstract

This paper presents sky luminosity data for Rio de Janeiro City, useful to be used in daylighting design in architecture. The data are presented as monthly graphics that correlate sunshine-hours with the frequency of occurrence during the day of a specific type of sky, that would present one of five defined characteristics (among clear and overcast sky). These results were derived from the knowledge of daily solar radiation and sunshine-hours data, for every day for a twelve year period.

1 - *Introduction*

The aim of the environment conscious design in architecture - or bioclimatic architectural design - is to create internal comfort in a building, by working with the local climate and consuming an as low as possible amount of conventional energy.

A good daylighting design allows more daylight to enter the building during the day, giving a better quality of visual comfort (natural spectrum, variability of illumination and colours throughout the day, low contrast, natural shadows and absence of glare) and contributes as one of the higher components to the saving of electrical energy.

Data are really indispensable to produce a good daylighting design. In its absence, one normally defines a standard sky luminosity, that, in principle, only helps to calculate a lower level of illumination (minimum luminosity level required by each activity). But this method can also lead to erroneous estimations and it says nothing about the higher level of illumination that could produce glare and high contrast. These problems are avoided if sky illumination data are available, either from direct measurements or from the theory based on other experimental data.

Electricity circuits network have to be designed in a very accurate way in order to complement the natural light, saving effectively large amounts of electric energy, and this can only be accomplished by the detailed knowledge of daylight.

Therefore, Section 4 presents a correlation between the sunshine-hours that may occur in a day, with predicted frequency of sky types (divided in five ranges of cloudiness), data that are used by computational programmes of building daylight simulation.

2 - Treatment of solar data

Daily solar radiation and sunshine-hours data, experimental or theoretically reconstructed, are available for a period of 12 years for the Rio de Janeiro City(1). From these data it is possible to deduce the sky luminosity for this city, following the procedure given in the literature(2,3,4).

The procedure begins with the calculation of the ratio of the measured solar radiation, global daily horizontal, to the extraterrestrial radiation, called the daily clearness index, K_T. From the knowledge of this parameter, it is possible to calculate the daily diffuse horizontal solar radiation, using the formulas of Collares-Pereira and Rabl (5),

$$H_d / H = \begin{cases} 0.99 & \text{if } K_T = H/H_O < 0.17 \\ 1.188 - 2.272\, K_T + 9.473\, K_T^2 - 21.865\, K_T^3 + 14.648\, K_T^4 & \text{if } 0.17 \le K_T < 0.75 \\ -0.54\, K_T + 0.632 & \text{if } 0.75 \le K_T < 0.8 \\ 0.2 & \text{if } K_T \ge 0.8 \end{cases}$$

and from these, the hourly data, both global and diffuse components, using the Liu and Jordan formulas (6), that is, for the diffuse component,

$$I_d = H_d \,.\, \pi \,.\, [\cos \omega - \cos \omega_S] / 24\, [\cos \omega_S - (2\pi/360)\, \omega_S \cos \omega_S]$$

and for the global component,

$$I_g = I_d \,.\, H \{[0.409 + 0.5016 \sin[(2\pi/360).(\omega_S - 60)] + \{0.6609 - 0.4767 \sin[(2\pi/360).(\omega_S - 60)]\} \,.\, \cos[(2\pi/360).\omega]\} / H_d$$

In the formulas, ω stands for the angular time

$$\omega = 15.\, t - 180^{\circ}$$

t is the time in hours, and ω_S is the sunset angular time

$$\cos \omega_S = - \mathrm{tg}\, \phi \,.\, \mathrm{tg}\, \delta$$

where ϕ is the latitude (= -22.9° for Rio de Janeiro City), and δ the declination, calculated by the formula of Cooper (7),

$$\delta = 23.45^{\circ} \sin (4.88764 + 0.01745329\, d)$$

where d is the day of the year (starting with d = 1 for the first of January).

Krenzinger et al.(8), in their studies on statistics of frequencies of sequences of days or hours with same solar radiation characteristics, demonstrated that experimental and theoretical data fit better if, instead of using directly the Liu and Jordan formulas, the theoretical data are suitably modulated by an random function as given below,

$$R = \{ 1 + 2 \,.\, [\mathrm{Random}() - 0.5]\}.\, [2.(H/H_O - 0.4)^2 - 0.25]$$

where "Random()" is a number between 0 and 1, and each time a calculation is done, a different value is given. This function breaks the symmetry of the distribution, simulating the actual variation of climate. Therefore, the new values of the hourly diffuse and global horizontal solar radiation are obtained from the Liu and Jordan formulas by multiplying by the function R.

The function R (which is called the "fish function" taking into account its graphic), modulates each hourly value independently. As a consequence the daily value could also be affected if modifications did not compensate. Therefore, the imposed constrain is that the sum of all hourly data will agree with the daily data, for the distribution to be accepted. The agreement between the experimental daily data and the sum of their distribution in hours, modulated by the "fish function", was asked to be better than 3%. While calculating the sum of the hourly values, care was taken with the first and last hours, because sometimes the formulas of Liu and Jordan give negative values for them, which the automatic calculation have to recognise and delete.

3 - The sky illumination distribution method

In this paper it is followed the method developed in Reference 2, in order to calculate the cloudiness index from the knowledge of the solar energy data. The cloudiness index is defined as the ratio between the measured atmospheric transmitance and the theoretical atmospheric transmitance for a clear day,

$$I_n = \tau_m\,(\text{measured}) / \tau_t\,(\text{theoretical for a clear day})$$

where the transmitances are defined by

$$\tau_m = I_b / I_g = 1 - I_d / I_g$$

where I_g = hourly global solar radiation,
I_b = hourly beam solar radiation,
I_d = hourly diffuse solar radiation
and, following the Hottel model (9),

$$\tau_t = a + b \,.\, \exp(-k / \cos \theta_z)$$

where θ_z is the angle between a solar ray and the vertical, given by (10)

$\cos \theta_z = \cos \phi \, . \cos \delta . \cos \omega - \sin \phi . \sin \delta$

and a and b are parameters depending of the local climate and sky. For a tropical climate (10),

a = 0.1217 ; b = 0.7417 and k (the turbidity of the local atmosphere) = 0.3950.

Therefore, the cloudiness index is

$$I_n = \tau_m / \tau_t = (1 - I_d / I_g) / [\, a + b \, . \exp(- k / \cos \theta_z)]$$

The values of the I_n are calculated every hour with the hourly data generated as explained in section 2.

As the calculation was done automatically by computer, care was taken with the extreme hours (near sunrise and sunset), the situation in which $\cos \theta_z$ could be negative. Another series of controls like these were made: as the random number is used to calculated I_d and I_g , the first could be greater than the second. Therefore, to avoid this error, it is imposed that the fraction I_d / I_g must be positive and less than or equal to one, otherwise this particular value is deleted and another random number is chosen.

After that, it is checked whether the sum of all hourly solar radiation values agrees with the daily data, both global and diffuse. For each day of every month for the twelve year period, such random numbers are chosen so that all the controls are satisfied. In this case, the distribution obtained is fixed and translated to a matrix, which puts together all the days of that month.

Five types of sky are defined for different ranges of I_n (2). Values of $I_n < 0.05$, are considered representatives of a strong cloudy sky. Values of $I_n > 0.90$, are considered representatives of a very clear sky. When I_n is within the range $0.20 < I_n < 0.70$, it is considered that there is a mean overcast sky. If $0.05 < I_n < 0.20$ the sky is considered very cloudy and when $0.70 < I_n < 0.90$ the sky is considered almost clear. These ranges are shown in Table I.

TABLE 1

Sky type	Range of cloudiness index	Sky conditions
T1	$0.00 \leq I_n < 0.05$	Strong overcast
T2	$0.05 \leq I_n < 0.20$	Cloudy
T3	$0.20 \leq I_n < 0.70$	Medium clear
T4	$0.70 \leq I_n < 0.90$	Clear
T5	$0.90 \leq I_n < 1.00$	Totally clear

This division permitted to established a correspondence between the sunshine-hours data and the number of hours corresponding to each sky type, one for each day, corresponding to a choise of the random number. For example, for August 1st, 1978, the measured value was: n/N = 0.21 and, following the calculation described above, this corresponds to three hours of T1 sky type, one hour of T2 and six hour of T3. The twelve year period permits to arrange 372 sets of six numbers, one for the value of n/N plus the corresponding five numbers for sky types (see Table 3).

4 - Results

The results were organised in matrixes like table 2 for the month of Dec. 1978

TABLE 2 - Example - Values of I_n for December 1978

				5,5	6,5	7,5	8,5	9,5	10,5	11,5	12,5	13,5	14,5	15,5	16,5	17,5	18,5
Err Id	Err Ig	Day	n/N	In	In	In	In	In	In	In	In	In	In	In	In	In	In
-0.001	-0.012	1	0.855	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.001	-0.004	2	0.728	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.001	0.000	3	0.712	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.001	0.017	4	0.794	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.002	-0.029	5	0.861	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0.006	-0.019	6	0.838	1.00	1.00	0.56	0.81	0.97	0.41	0.68	0.87	0.68	0.58	0.90	0.56	0.18	1.00
-0.021	-0.007	7	0.314	0.00	0.00	0.00	0.47	0.00	0.37	0.54	0.77	0.51	0.24	0.29	0.77	0.23	0.00
0.017	0.026	8	0.000	0.00	0.00	0.00	0.00	0.16	0.00	0.00	0.18	0.19	0.21	0.34	0.00	0.00	0.00
0.026	0.015	9	0.105	0.00	0.00	0.17	0.20	0.38	0.58	0.09	0.00	0.03	0.18	0.20	0.00	0.00	0.00
-0.014	0.004	10	0.015	0.00	0.00	0.05	0.20	0.00	0.00	0.27	0.18	0.13	0.12	0.00	0.00	0.00	0.00
0.003	0.025	11	0.538	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	1.00
0.009	-0.019	12	0.426	0.00	1.00	1.00	0.22	0.50	0.69	0.62	0.27	0.86	0.69	0.32	0.37	0.68	0.00
-0.022	-0.024	13	0.388	0.00	1.00	0.18	0.47	0.75	0.43	0.35	0.39	0.74	0.39	0.17	0.60	0.93	0.06
0.001	-0.018	14	0.604	1.00	1.00	1.00	1.00	1.00	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.013	0.027	15	0.007	0.00	0.49	0.73	0.49	0.10	0.45	0.41	0.35	0.47	0.20	0.00	0.00	0.00	0.00
0.012	-0.002	16	0.463	0.72	0.00	0.22	0.50	0.47	0.52	0.83	0.50	0.52	0.58	0.68	1.00	1.00	1.00
0.023	-0.006	17	0.246	0.00	0.00	0.00	0.24	0.02	0.86	0.00	0.51	0.00	0.23	0.19	0.49	0.00	0.00
0.000	0.004	18	0.813	1.00	1.00	1.00	0.96	1.00	0.94	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00
0.002	-0.018	19	0.828	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.90	1.00	1.00	0.95	1.00	1.00	1.00
-0.005	0.019	20	0.611	1.00	1.00	1.00	0.93	1.00	1.00	0.95	0.93	0.94	0.87	1.00	1.00	1.00	1.00
0.001	0.024	21	0.559	1.00	1.00	1.00	0.99	1.00	0.88	0.97	0.87	1.00	0.78	1.00	1.00	1.00	1.00
-0.007	0.026	22	0.462	0.00	0.57	0.90	0.98	0.88	0.69	0.72	0.90	0.38	0.69	1.00	0.63	0.16	0.82
0.021	0.024	23	0.149	0.00	0.23	0.00	0.32	0.66	0.00	0.33	0.32	0.28	0.09	0.44	0.10	0.00	0.00
-0.002	0.004	24	0.754	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.002	-0.015	25	0.866	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
-0.001	0.025	26	0.694	1.00	1.00	1.00	0.86	0.81	0.92	0.75	1.00	1.00	0.87	0.83	1.00	0.66	0.78
-0.024	-0.017	27	0.000	0.43	0.00	0.09	0.07	0.00	0.28	0.42	0.12	0.52	0.00	0.00	0.00	0.00	0.00
-0.007	0.018	28	0.022	0.00	0.43	0.31	0.04	0.00	0.23	0.17	0.30	0.21	0.44	0.34	0.32	0.00	0.00
0.005	-0.027	29	0.105	0.00	0.00	0.00	0.00	0.00	0.44	0.55	0.01	0.42	0.00	0.24	0.19	0.00	0.00
0.000	-0.008	30	0.411	1.00	0.39	0.68	0.66	0.84	0.64	0.66	0.86	0.85	0.66	0.87	0.96	1.00	0.86
0.000	-0.013	31	0.815	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

In the first two columns there are the control numbers; in the first is quoted Err I_d, that means the difference between the sum of the values of I_d produced with the at random function and the value of H_d for this day, and second column Err I_g, having the same meaning for I_g. By arranging the results in Table 2, following the definitions of type of sky (given in Table 1), the Table 3 is obtained:

TABLE 3 - Number of Hours by type of Sky - December 1978

n/N	T1	T2	T3	T4	T5
0.86	0	0	0	0	14
0.73	0	0	0	0	14
0.71	0	0	0	0	14
0.79	0	0	0	0	14
0.86	0	0	0	0	14
0.84	0	1	6	3	4
0.31	5	0	7	2	0
0.00	9	3	2	0	0
0.10	7	4	3	0	0
0.01	8	4	2	0	0
0.54	0	0	0	0	14
0.43	2	0	9	1	2
0.39	1	3	6	2	2
0.60	0	0	0	0	14
0.01	5	1	7	1	0
0.46	1	0	8	2	3
0.25	8	1	4	1	0
0.81	0	0	0	0	14
0.83	0	0	0	0	14
0.61	0	0	0	1	13
0.56	0	0	0	3	11
0.46	1	1	5	4	3
0.15	5	2	7	0	0
0.75	0	0	0	0	14
0.87	0	0	0	0	14
0.69	0	0	1	6	7
0.00	7	3	4	0	0
0.02	5	1	8	0	0
0.10	9	1	4	0	0
0.41	0	0	6	5	3
0.81	0	0	0	0	14

These six columns, together with that produced from the information of the other eleven December months (12 year period) are used to produce the results shown in Table 4. In this Table, "Events" stands for the number of days in the range n/N and n/N + 0.0499.

TABLE 4 - Cumulative Number of Hours by Sky Type for December

Events	n/N	T1	T2	T3	T4	T5
742	0.00	405	133	175	12	17
308	0.05	132	42	108	13	13
280	0.10	143	33	92	7	5
182	0.15	68	33	49	5	27
140	0.20	58	22	47	7	6
392	0.25	145	38	162	27	20
126	0.30	25	8	47	21	25
238	0.35	38	12	104	44	40
210	0.40	40	18	94	33	25
182	0.45	9	7	58	55	53
308	0.50	17	2	73	87	129
252	0.55	16	5	48	57	126
210	0.60	2	0	12	49	147
378	0.65	6	1	25	36	310
294	0.70	10	2	24	21	237
266	0.75	8	2	3	3	250
238	0.80	14	4	18	6	196
294	0.85	0	1	7	14	272
168	0.90	0	0	0	0	168
1	0.95	0	0	0	0	1
1	1.00	0	0	0	0	1
5210		1136	363	1146	497	2068

or working with the percentages,

TABLE 5 - Percentage of Type of Sky for December

n/N	T1	T2	T3	T4	T5
0.00	54.6	17.9	24	1.62	2.29
0.05	42.9	13.6	35	4.22	4
0.10	51.1	11.8	33	2.5	2
0.15	37.4	18.1	27	2.75	15
0.20	41.4	15.7	34	5	4
0.25	37	9.69	41	6.89	5
0.30	19.8	6.35	37	16.7	20
0.35	16	5.04	44	18.5	17
0.40	19	8.57	45	15.7	12
0.45	4.95	3.85	32	30.2	29
0.50	5.52	0.65	24	28.2	42
0.55	6.35	1.98	19	22.6	50
0.60	0.95	0	5.7	23.3	70
0.65	1.59	0.26	6.6	9.52	82
0.70	3.4	0.68	8.2	7.14	81
0.75	3.01	0.75	1.1	1.13	94
0.80	5.88	1.68	7.6	2.52	82
0.85	0	0.34	2.4	4.76	93
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	351	117	425	203	1004
%=	0.17	0.06	0.20	0.10	0.48

A better way to see the results is shown in Figure 1. Of course, as the numbers of events are only 5210 and the range of n/N is organised in 0.05 intervals, the lines in the graphics are cut instead of continued.

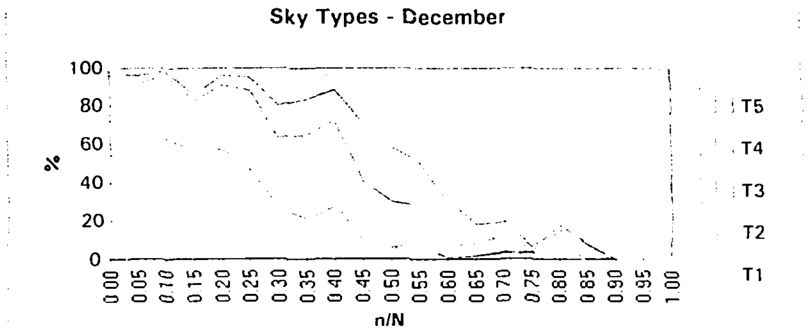

FIGURE 1

This problem could be solved acting on the numbers in order to smooth the curves, asking for a criterion of confidence. In this work, it was established that the integrals of each zone will maintain their values. Physically that means that the proportion of the sky type during the month should be maintained. The results are shown *in Table 6 and in figure 2.*

TABLE 6 - DECEMBER

n/N	T1	T2	T3	T4	T5
0.00	55	18	24	1	2
0.05	48	16	30	3	3
0.10	45	13	32	3	7
0.15	40	14	33	5	8
0.20	37	14	34	7	8
0.25	33	12	36	8	11
0.30	26	9	39	14	12
0.35	20	7	42	16	15
0.40	15	7	37	20	21
0.45	9	5	31	27	28
0.50	6	2	27	27	38
0.55	4	2	19	23	52
0.60	3	1	11	21	64
0.65	2	1	6	13	78
0.70	2	1	5	7	85
0.75	2	1	4	5	88
0.80	2	1	3	3	91
0.85	1	0	3	3	93
0.90	0	0	0	1	99
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	347	119	429	208	998
%=	0.17	0.06	0.20	0.10	0.48

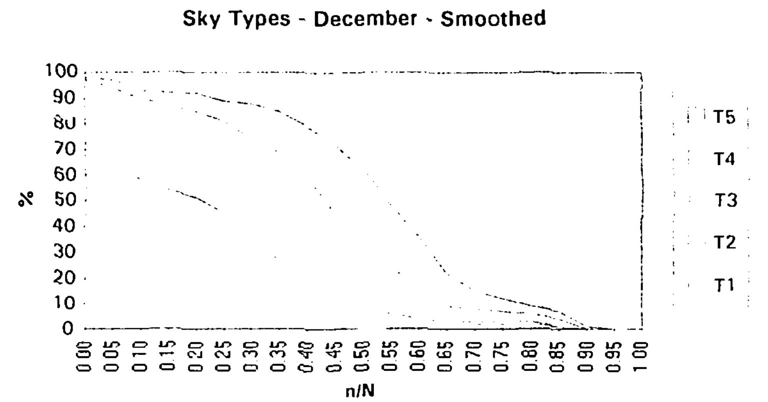

FIGURE 2 - DECEMBER

This is the main result of this paper. Figure 2 provides the daylighting designer the different types of sky for a day with established sunshine-hours, during the month of December.

In the next pages there are the other 11 tables and figures corresponding to all *months of the year.*

By using hese data in computer programmes, it will be able to predict with accuracy the luminic behaviour of every internal environment, as well as subsidise the precise calculation of the electric lighting necessary to complement the natural *one. This will provide the quality of a good lighting design able to save a lot of* conventional energy.

TABLE 7 - JANUARY

n/N	T1	T2	T3	T4	T5
0.00	63	17	20	0	0
0.05	57	14	29	0	0
0.10	48	15	35	1	1
0.15	42	12	40	4	2
0.20	35	10	45	7	3
0.25	31	7	48	9	5
0.30	25	7	47	12	9
0.35	21	5	45	16	13
0.40	14	5	44	18	19
0.45	9	3	40	22	26
0.50	5	2	31	26	36
0.55	3	1	19	28	49
0.60	1	1	10	19	69
0.65	1	1	2	7	89
0.70	0	0	1	2	97
0.75	0	0	0	1	99
0.80	0	0	0	0	100
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	355	100	456	172	1017
%=	0.17	0.05	0.22	0.08	0.48

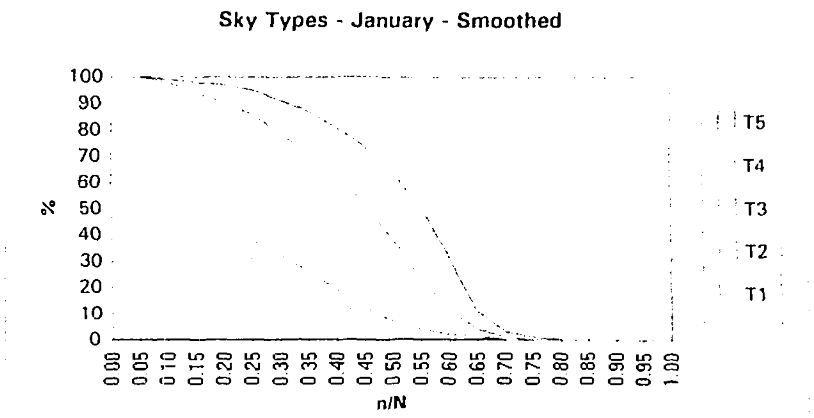

FIGURE 3 - JANUARY

TABLE 8 - FEBRUARY

n/N	T1	T2	T3	T4	T5
0.00	51	15	33	1	0
0.05	45	15	38	1	1
0.10	43	12	39	4	2
0.15	41	10	40	6	3
0.20	35	12	40	9	4
0.25	29	11	43	9	8
0.30	20	7	47	13	13
0.35	13	6	44	18	19
0.40	9	5	34	23	29
0.45	5	3	28	26	38
0.50	3	2	22	26	47
0.55	2	2	14	21	61
0.60	1	1	8	17	73
0.65	1	1	3	14	81
0.70	1	1	2	8	89
0.75	1	1	2	4	93
0.80	1	1	2	3	94
0.85	0	1	2	2	96
0.90	0	1	1	1	98
0.95	0	0	1	1	99
1.00	0	0	0	0	100
	300	105	442	207	1048
%=	0.14	0.05	0.21	0.10	0.50

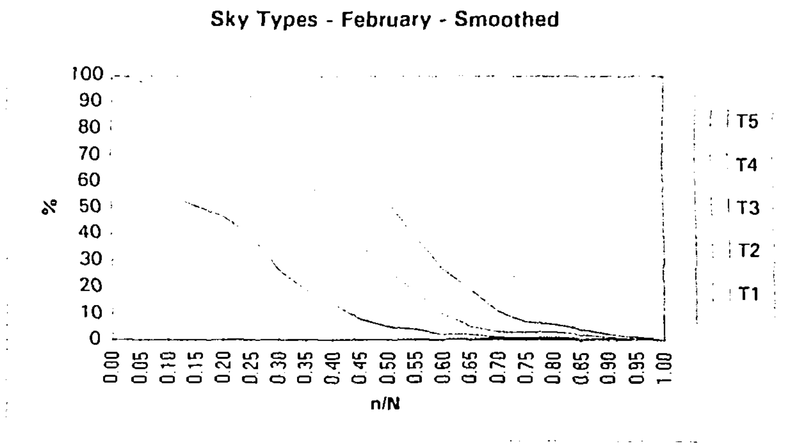

FIGURE 4 - FEBRUARY

TABLE 9 - MARCH

n/N	T1	T2	T3	T4	T5
0.00	55	17	28	0	0
0.05	50	14	36	0	0
0.10	41	15	40	3	1
0.15	34	13	43	7	3
0.20	30	11	44	11	4
0.25	26	9	45	13	7
0.30	21	7	45	18	9
0.35	14	7	45	20	14
0.40	9	4	42	22	23
0.45	5	3	33	27	32
0.50	2	1	27	28	42
0.55	1	0	19	26	54
0.60	0	0	8	20	72
0.65	0	0	1	7	91
0.70	0	0	0	2	98
0.75	0	0	0	1	99
0.80	0	0	0	0	100
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	288	101	456	206	1049
%=	0.14	0.05	0.22	0.10	0.50

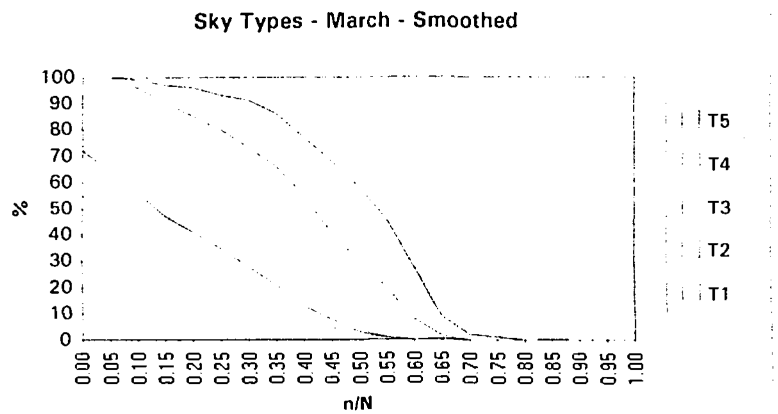

FIGURE 5 - MARCH

TABLE 10 - APRIL

n/N	T1	T2	T3	T4	T5
0.00	53	18	23	2	4
0.05	50	13	30	2	5
0.10	44	11	36	3	6
0.15	40	10	37	6	7
0.20	36	8	39	9	8
0.25	32	8	38	13	9
0.30	26	9	37	17	11
0.35	22	7	36	19	16
0.40	17	5	32	19	27
0.45	13	5	26	18	38
0.50	9	3	18	17	53
0.55	5	2	11	18	64
0.60	3	1	5	12	79
0.65	1	1	3	7	88
0.70	1	1	2	4	92
0.75	1	1	1	3	94
0.80	1	1	1	2	96
0.85	0	1	1	1	98
0.90	0	0	1	1	99
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	354	104	376	173	1094
%=	0.17	0.05	0.18	0.08	0.52

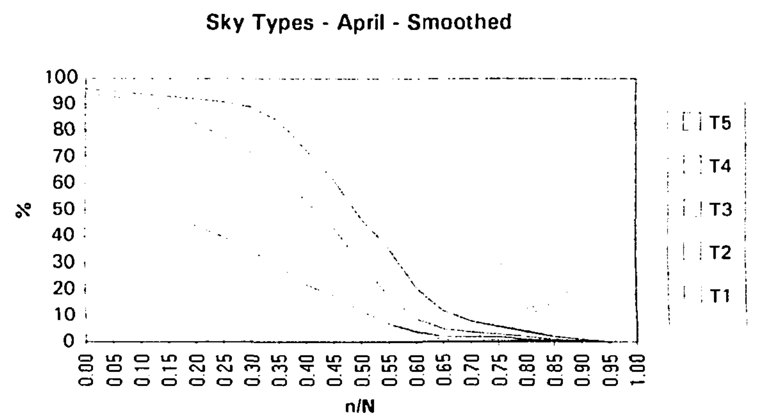

FIGURE 6 - APRIL

TABLE 11 - MAY

n/N	T1	T2	T3	T4	T5
0.00	54	16	29	1	0
0.05	51	11	35	2	1
0.10	43	11	37	5	4
0.15	35	10	38	9	8
0.20	29	10	37	13	11
0.25	25	8	36	17	14
0.30	19	5	40	18	18
0.35	13	5	39	20	23
0.40	8	4	36	24	28
0.45	5	3	28	26	38
0.50	3	1	19	22	55
0.55	1	1	10	17	71
0.60	0	0	6	11	83
0.65	0	0	3	4	93
0.70	0	0	1	1	98
0.75	0	0	0	1	99
0.80	0	0	0	1	99
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	286	85	394	192	1143
%=	0.14	0.04	0.19	0.09	0.54

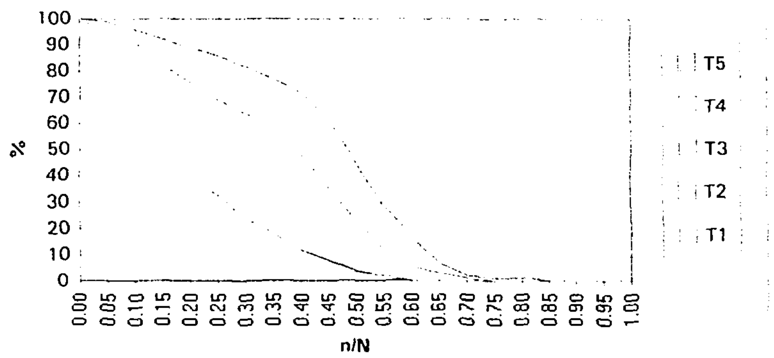

FIGURE 7 - MAY

TABLE 12 - JUNE

n/N	T1	T2	T3	T4	T5
0.00	50	15	34	1	0
0.05	48	12	37	2	1
0.10	41	11	39	5	4
0.15	31	11	41	8	9
0.20	23	11	39	11	16
0.25	18	10	38	12	22
0.30	13	8	38	13	28
0.35	8	6	35	15	36
0.40	5	4	31	17	43
0.45	3	2	23	20	52
0.50	1	2	12	21	64
0.55	0	1	6	14	79
0.60	0	0	2	9	89
0.65	0	0	1	4	95
0.70	0	0	1	1	98
0.75	0	0	1	1	98
0.80	0	0	0	1	99
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	241	93	378	155	1233
%=	0.11	0.04	0.18	0.07	0.59

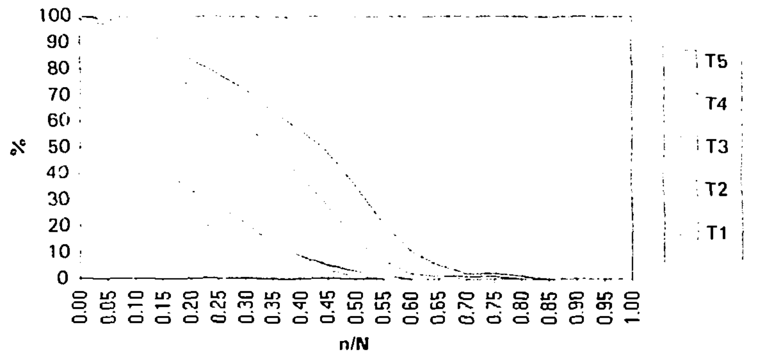

FIGURE 8 - JUNE

TABLE 13 - JULY

n/N	T1	T2	T3	T4	T5
0.00	52	17	30	1	0
0.05	44	11	40	4	1
0.10	39	7	39	7	8
0.15	32	7	37	9	15
0.20	27	5	37	10	21
0.25	21	4	35	15	25
0.30	14	5	35	18	28
0.35	10	4	34	19	33
0.40	7	3	31	21	38
0.45	3	3	24	24	46
0.50	1	2	15	23	59
0.55	0	2	8	15	75
0.60	0	0	3	12	85
0.65	0	0	1.5	5.5	93
0.70	0	0	1	3	96
0.75	0	0	0	2	98
0.80	0	0	0	0	100
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	250	70	371	189	1221
%=	0.12	0.03	0.18	0.09	0.58

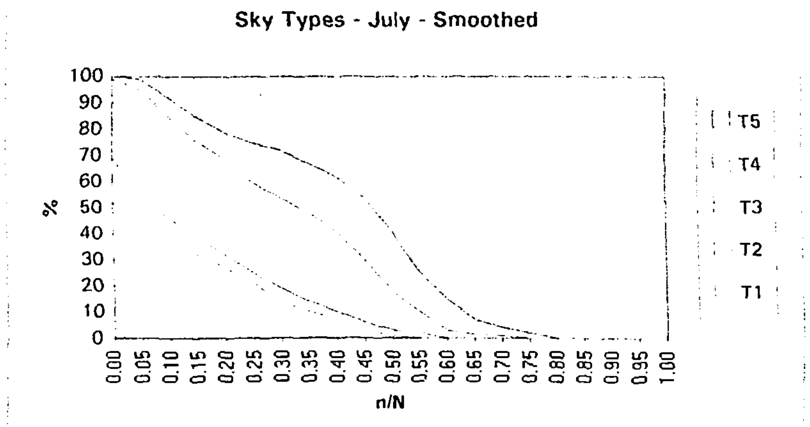

FIGURE 9 - JULY

TABLE 14 - AUGUST

n/N	T1	T2	T3	T4	T5
0.00	60	17	23	0	0
0.05	53	16	23	2	6
0.10	43	14	30	5	8
0.15	36	12	34	8	10
0.20	33	8	37	10	12
0.25	30	8	36	12	14
0.30	27	8	34	14	17
0.35	23	7	31	16	23
0.40	16	4	34	17	29
0.45	10	5	28	21	36
0.50	5	3	24	21	47
0.55	4	1	19	20	56
0.60	3	1	9	17	70
0.65	2	1	5	9	83
0.70	1	1	3	5	90
0.75	1	1	2	4	92
0.80	1	1	1	3	94
0.85	0	1	1	1	97
0.90	0	0	1	1	98
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	348	109	375	186	1082
%=	0.17	0.05	0.18	0.09	0.52

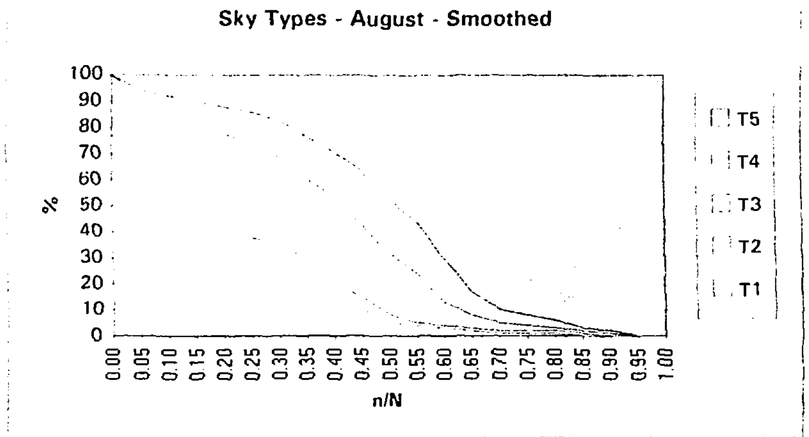

FIGURE 10 - AUGUST

TABLE 15 - SEPTEMBER

n/N	T1	T2	T3	T4	T5
0.00	59	19	21	0	0
0.05	56	17	26	1	0
0.10	50	15	31	3	1
0.15	44	12	37	5	2
0.20	38	11	40	7	4
0.25	30	11	43	10	6
0.30	23	9	44	14	10
0.35	15	7	42	19	17
0.40	10	6	37	22	25
0.45	6	4	32	23	35
0.50	3	2	23	24	48
0.55	3	1	12	19	65
0.60	1	1	6	14	78
0.65	0	0	4	10	86
0.70	0	0	2	6	92
0.75	0	0	1	3	96
0.80	0	0	0	1	99
0.85	0	0	0	0	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	339	116	401	181	1064
%=	0.16	0.06	0.19	0.09	0.51

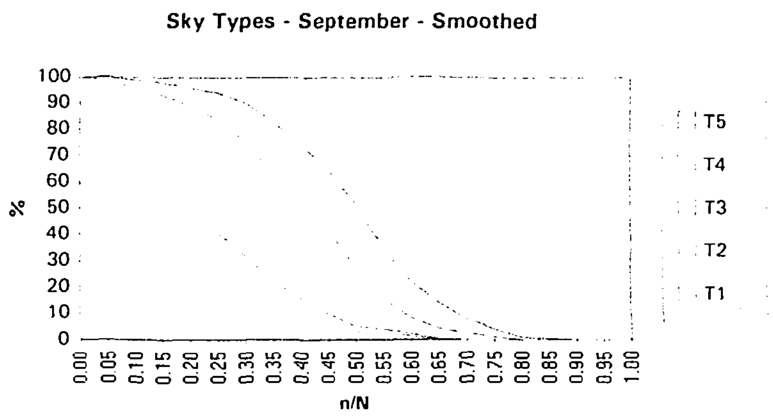

FIGURE 11 - SEPTEMBER

TABLE 16 - OCTOBER

n/N	T1	T2	T3	T4	T5
0.00	58	18	24	0	0
0.05	50	19	31	0	0
0.10	44	15	39	2	0
0.15	38	13	43	4	2
0.20	33	12	46	6	3
0.25	26	13	47	9	5
0.30	21	12	49	11	7
0.35	17	8	49	16	10
0.40	11	8	42	22	17
0.45	6	5	36	23	30
0.50	3	2	27	27	41
0.55	1	1	19	28	51
0.60	0	0	12	24	64
0.65	0	0	7	15	78
0.70	0	0	2	8	90
0.75	0	0	0	2	98
0.80	0	0	0	1	99
0.85	0	0	0	1	100
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	308	126	473	199	995
%=	0.15	0.06	0.23	0.09	0.47

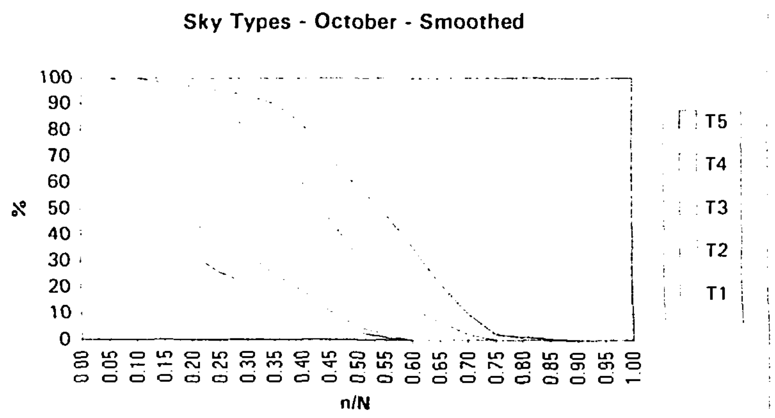

FIGURE 12 - OCTOBER

TABLE 17 - NOVEMBER

n/N	T1	T2	T3	T4	T5
0.00	62	18	20	0	0
0.05	55	16	29	0	0
0.10	49	15	34	2	0
0.15	43	12	41	3	1
0.20	36	11	45	5	3
0.25	29	9	49	8	5
0.30	23	8	49	12	8
0.35	17	7	45	19	12
0.40	12	6	39	24	19
0.45	8	4	33	27	28
0.50	4	3	27	28	38
0.55	2	1	20	25	52
0.60	1	1	12	19	67
0.65	0	1	6	11	82
0.70	0	0	3	6	91
0.75	0	0	1	3	96
0.80	0	0	1	1	98
0.85	0	0	0	1	99
0.90	0	0	0	0	100
0.95	0	0	0	0	100
1.00	0	0	0	0	100
	339	111	458	190	1002
%=	0.16	0.05	0.22	0.09	0.48

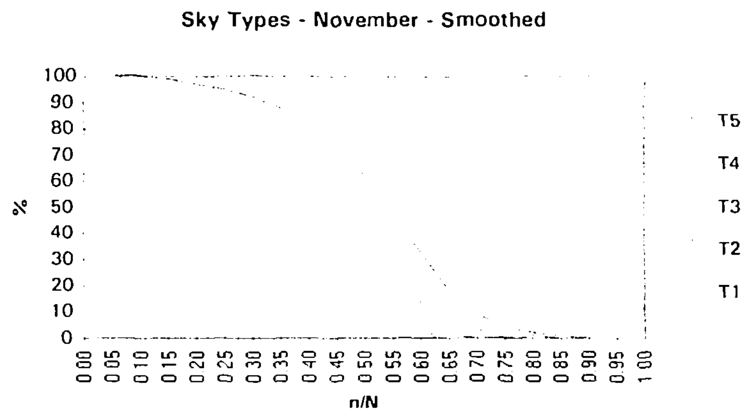

FIGURE 13 - NOVEMBER

5 - Comments about the results

Data of probability of occurrence of five sky types as functions of the sunshine-hours data are now available. They are presented as 12 tables and figures, corresponding to each month of the year. By using these data in computer programmes, it will be able to predict with accuracy the luminic behaviour of every internal environment, as well as subsidise the calculation to complement the natural with the electric lighting, in order to produce a good lighting design, with quality, able to save conventional energy.

The results shown here could be extended to all other places having sunshine-hours data. As there are many meteorological stations that measured sunshine-hours in the Rio de Janeiro State, and also in all Brazil, it constitute a good work programme for the next years in the luminic comfort area.

It should be clear that the results given here need to be validated, making use of daylight measured data. Nevertheless, until experimental data will be available, results similar to these given here would be of great will help light designers.

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