Reprint from the Journal of Optics, 1979, Vol. 8, No. 1, Pp. 9-11

An Electrical Analogue in Lighting Technology

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(Received December 23, 1978)

ABSTRACT : The predetermination of the luminous flux distribution in a room is of interest in building design. The paper describes one such study carried out by the use of an electrical analogy. A twelve surface Luminous Analogue Computer designed for the purpose has been discussed. The results are found in agreement within ±5.0 percent with those obtained from digital computer. The important feature of the network repesentation is the separation of room geometry from the boundary conditions of surface reflectance and luminous input. It is a quick and economical method for studying the effect of a single parameter on an interior visual environment.

1. INTRODUCTION

The evaluation of interior visual environment of a room, taking all inter-reflections into consideration requires a solution of the Fredholm integral equation of the form [1]

$$L(x_1,y_1)=Lo(x_1,y_1)+R(x_1,y_1)\int_S L(x,y)\times K(x,y,x_1,y_1)\,dA \quad (1)$$

Where $L(x_1,y_1)$ is the final luminous emittance at (x_1,y_1)

L_0 is the initial luminous emittance,

R is the reflection coefficient,

and K is the Kernal of the equation, is a function of the geometry of the enclosure.

By assuming uniform reflectance and luminous emittance over a finite region called "lump", the field or continuous system is replaced by discretized system. It helps in converting equation (1) to a set of finite difference equation, put in the following matrix form.

$$\begin{vmatrix} 1/R_1 - F_{1-2}\ldots\ldots - F_{1-n} \\ -F_{2-1}+1/R_2\ldots\ldots - F_{2-n} \\ \vdots \\ -F_{n-1}-F_{n-2}\ldots\ldots+1/R_n \end{vmatrix} \begin{vmatrix} L_1 \\ L_2 \\ \vdots \\ L_n \end{vmatrix} = \begin{vmatrix} L_{01}/R_1 \\ L_{02}/R_2 \\ \vdots \\ Lon/R_n \end{vmatrix} \quad (2)$$

Transfer function matrix | Response Vector | Excitation Vector

Where F_{1-n} is a dimensionless parameter, called shape factor. These can easily be determined [2].

If the lighting problem is one of analysis, the matrix (2) can easily be solved for the total luminous emittances. But in case of lighting synthesis, visual, economic and asthetic parameters are considered simultaneously. The selection of optimum combinations of the shape factor F_{n-m}, the reflectance of various interior surfaces participating in flux transfer R_n and the initial illumination distribution Lon/R_n, then becomes the main objective. The calculation process is laborious and time consuming. It is also difficult to conceive of a model whose surface reflectances and initial illumination distribution could change as easily as a variable resistance or node potential in an electrical network.

2. ANALOGUE REPRESENTATION

Since the surface elements participating in flux transfer are not in physical contact, the existing formulation of action at a distance analogy has been applied to luminous network analysis for lighting problems in buildings. It assumes,

1). All the surfaces participating in flux transfer are (a) opaque in character, (b) have diffuse reflectances, (c) do not see themselves and (d) gray and matt i.e. non-selective reflectance in wavelength.

2). The time interval between the initiation and final attainment of luminances of different surfaces is very small. Steady state condition exist almost instantaneously.

3). The enclosure contains no absorbing or scattering media

and

4). The flux incident on a surface from any other surface is uniformly distributed over the surface. As the number of surfaces composing the enlosure is increased, the flux distribution approaches the condition of uniformity at any surface.

When the energy conservation principle is applied the net flux on a surface element of an enclosure at which light flux is incident and streaming away, the first of equation (2), with slight modification could be rewritten as

$$(L_1 - L_n)/(1/\Sigma A_1 F_{1-n})$$

$$=\{(Lo_1/1-R_1)-L_1\})\frac{R_1}{A_1\,(1-R_1)} \quad (3)$$

and similarly others, depending on the surfaces participating in flux transfer. Equation (3) is a well known form of Kirchhoffs' node equation.

3. Description of the Luminous Analogue Computer

By employing the principle of the flow of current in the network as analogous to the flow of luminous flux, a Luminous Analogue Computer has been designed and fabricated. The schematic diagram of the computer is shown in Fig. 1. It is capable of taking a problem

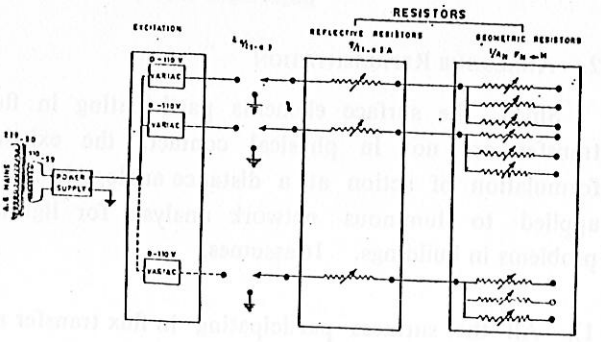

Fig. 1.

Schematic Diagram of the Luminous Analogue Computer.

involving maximum twelve surfaces. The excitations were provided by small variacs connected to a stabilized 220 Volt A.C. mains supply and the potentials at different nodes of the network were measured by a Philips VTVM, within an accuracy of 3 percent. A panel of 150, 3 watt variable wire wound resistors was set up to simulate the room geometry. The resistances were adjusted to the required value with a *GR* Impedence Bridge Type 1650 *A*, to an accuracy of 1 percent. Voltages and resistors were so chosen as to give sufficient deflections in the VTVM.

4. Usage

A typical room of floor area 6.0×4.8 m² and ceiling height 3.6 m, with centrally located window (2.4 m × 1.2 m) on longer wall, has been chosen to study the luminous flux transfer problem by electrical analogy. Each surface of the room has been divided into two halves. The excitation potentials representing the initial illumination at various surfaces of the room consists of two parts viz, (i) from the sky and (ii) from the ground., and has been employed [3] for describing an equivalent circuit or network for solving luminous flux transfer problems with any distribution of inputs or reflectances. If the initial and final luminious emittances in the numerator of each fraction (equation 3) are regarded as excitation and response potentials of the nodes of a network system, the fraction composed of geometry and reflectance terms can be simulated as resistances. The different surfaces of the enclosure were represented as nodes of a network excited by electrical potentials proportional to their corresponding luminous emittances. Each of these nodes were connected to every other node by a path that includes a resistance $1/A_n F_{n-m}$ representing the geometry and orientation of the surfaces, which for flux transfer study are not in real contact. The geometrical resistor can have a minimum value approaching 1/A for large surfaces in close proximity and a maximum value tending to infinity for small surfaces at large distances. The driving potential $Lon/(1-R_n)$ is connected to the response potential L_n by a surface reflective resistance $R_n/(1-R_n)A_n$.

This initial illumination governs the initial distribution of flux inside the enclosure and hence the excitation potentials of the nodes. Final values of the luminous emittances, corresponding to potentials that finally develop across each of the nodes, were read off on the VTVM. Hereafter, the reflected component of daylight has been obtained by method described else where [4].

Table 1 compares the inter-reflected component values obtained by analogue and digital methods at the centre of the room on working plane.

5. Discussions

The analogue and digital values agree within the limits of errors possible in the network representation, (Table 1). It is obvious that once the shape factors and the excitation potentials are known, the accuracy of the results obtained from network representation is limited to the overall inaccuracies inherent in various

TABLE 1

Comparison of the illumination at the centre of work-plane by Analogue & Digital Computer.

S.No.	Surface Reflectance			Illumination (Lux)	
	Ceiling	Walls	Floor	Analogue	Digital
1.	0.8	0.5	0.3	238.4	252.8
2.	0.5	0.8	0.3	344.0	347.2
3.	0.8	0.3	0.3	171.2	163.2
4.	0.8	0.5	0.1	237.6	252.8
5.	0.3	0.8	0.3	308.8	289.6
6.	0.5	0.5	0.3	186,4	183.2
7.	0.3	0.5	0.3	149.6	147.2
8.	0.3	0.8	0.1	236.8	228.8

experimental components. The digital computer can yield results of greater precision but the analogue has the advantage of giving quick results. It is more so when the effect of a single parameter is to be studied. The agreement shown between two sets of measurement vary within ± 5.0 percent of the digital values, except in instances where the difficultes involved in setting low values of resistances and potentials lead to further deviations.

However, as the number of resistance to be set up in an analogue increases roughly in proportion of the square of the number of surfaces, the feasibility and accuracy of the analogue is restricted with the number of surfaces participating in flux transfer. Nevertheless, it is an economical method particularly for the synthesis of lighting problems related to buildings.

Acknowledgement

The paper is published with the permission of the Director, Central Building Research Institute, Roorkee.

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