Lighting energy conservation: simple analytic methods with time-lapse photography

Rea, M. S.; Jaekel, R. R.

Publisher's version / Version de l'éditeur:

Lighting Research and Technology, 15, 2, pp. 77-82, 1983

National Research Council Canada | Conseil national de recherches Canada

LIGHTING ENERGY CONSERVATION: SIMPLE ANALYTIC METHODS WITH TIME–LAPSE PHOTOGRAPHY

by M.S. Rea and R.R. Jaekel

Reprinted from
Lighting Research & Technology
Vol. 15, No. 2, 1983
p. 77 - 82

DBR Paper No. 1128
Division of Building Research

Price $1.00 OTTAWA NRCC 22608

Canada

RÉSUMÉ

Bien que la photographie en pause permette d'obtenir des renseignements sur la consommation d'énergie pour l'éclairage, cette technique n'a pas été très développée car la quantité et les détails des résultats nécessitent une longue analyse. Deux méthodes analytiques simples sont décrites pour interpréter la photographie en pause de façon pratique: 1) une méthode pour obtenir des échantillons et réduire le nombre des données, et 2) une formule pour calculer les pertes d'énergie pour l'éclairage basées sur l'occupation des bâtiments et l'utilisation de l'éclairage. Grâce à ces deux méthodes, on peut se rendre compte du gaspillage d'énergie pour l'éclairage.

Summary Although time-lapse photography offers great potential for providing information on lighting energy conservation, it has been undeveloped because the quantity and detail of the data demand a great deal of time for analysis. Two simple analytic procedures are described to make time-lapse photography more useful: (1) a sampling procedure for data reduction, and (2) a formula for computing wasted lighting energy based upon occupancy and light usage. It is argued that poor utilisation of lighting energy can be addressed with these procedures.

Lighting energy conservation: simple analytic methods with time-lapse photography

M. S. REA and R. R. JAEKEL

1 Introduction

Lighting energy conservation work at the Division of Building Research, National Research Council Canada, is concerned with reduction of waste. In fact, conservation can be defined as continual utilisation of energy without waste. Emphasis has therefore been placed on the need to co-ordinate on-off cycles of lighting with presence-absence cycles of building occupancy[1, 2].

Time-lapse photography has already been used for assessing both lighting usage and occupancy[3-7], but in the early studies the intention was (1) to examine the reliability and acceptability of cameras, and (2) to provide raw data on use of lights in various types of buildings. Time-lapse photography is capable of providing additional information about light usage. Not only can a large number of frames be gathered easily (typically 7,200 frames per month), but each frame can also be used for careful analysis of occupancy and activity patterns. The richness of the data has, however, presented some difficulty for analysis: both quantity and detail of data have demanded a great deal of time. Consequently, it has been desirable to develop faster methods of examining time-lapse photographs without sacrificing the main advantage of the technique—the ability to examine occupancy patterns and lighting simultaneously. This paper presents simple, meaningful methods of analysing time-lapse photographs so that users will have a rapid means of attacking waste of lighting energy.

The authors are with the Energy and Services Section, Division of Building Research, National Research Council, Ottawa, Canada.

The paper was first received on 7 May 1982 and in revised version on 8 February 1983.

2 Procedure

A schematic view of a monitored, large open-plan classroom* is shown in Fig. 1. Six light circuits, each with one switch, control artificial lighting. Windows on the south, west, and east walls provide natural illumination. The classroom is divided into four activity areas.

A Sankyo ES 44XL super 8 camera with a wide-angle lens was mounted just below the ceiling in the north-west corner of the classroom to monitor artificial lighting. Although not all luminaires were within view of the camera (Figs. 1 and 2), each light circuit could be monitored. Similarly, occupancy could be evaluated relatively unambiguously in most circuit areas because activities in the classroom areas usually included several people. Nevertheless, because the camera afforded neither a complete nor an unobstructed view of all areas, some occupants were probably missed.

A custom controller powered by a 6 V lantern battery initiated single-frame exposures approximately every six mins. Real time for exposures was documented by an analogue watch suspended in front of the camera (Fig. 2). Fifty-four teaching days were monitored from 23 October 1978 to 6 March 1979.

3 Results

Lighting use between 7:00 and 21:00 h was examined for each circuit area. Every exposure obtained between integer hours was counted (i.e., all those between 07:00 and 08:00, 08:00 and 09:00, and so on), and the proportion of all frames showing light usage within a circuit area calculated. The data are shown in Figs. 3 to 8; Fig. 9 gives comparable data for all circuit areas combined.

*Robert Hopkins Elementary School, Carleton Board of Education, Ottawa, Canada.

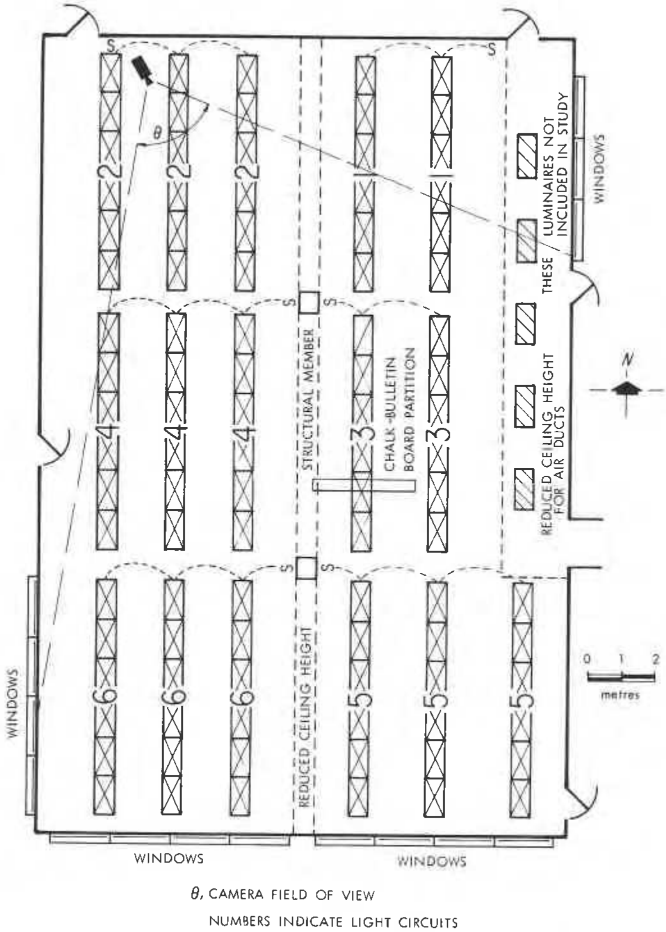

Fig. 1. Layout of open-concept classroom.

Random samples of frames within core hours (08:00 to 18:00 h) were also selected: one frame for each core hour of each teaching day. This reduced the number of frames examined during core hours by 9/10. The proportion of sampled frames showing light usage within a circuit area was calculated for every core hour. These data are also presented in Figs. 3 to 9; solid lines correspond to data from the "detailed" method and dashed lines to data from the "sampled" method. The correlations between the detailed and sampled examinations for each circuit

Fig. 2. View of classroom through the Super 8 movie camera.

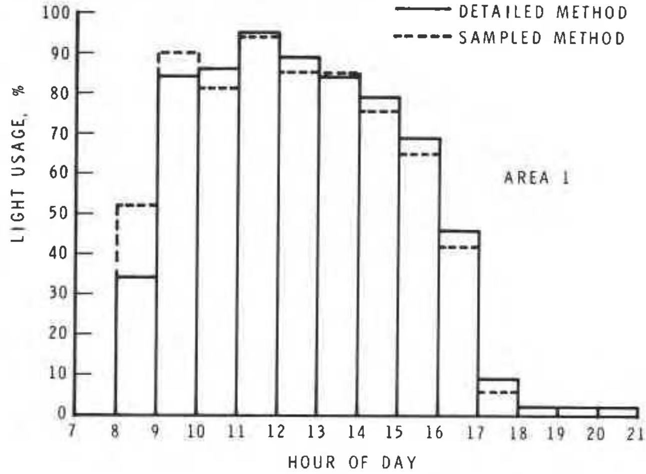

Fig. 3. Light usage profile, Area 1.

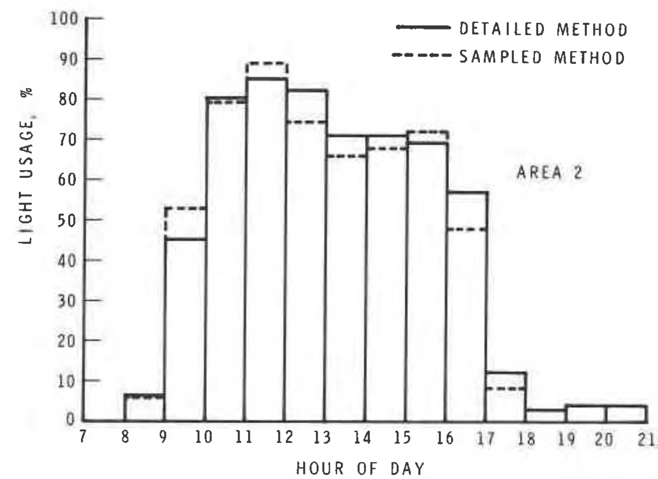

Fig. 4. Light usage profile, Area 2.

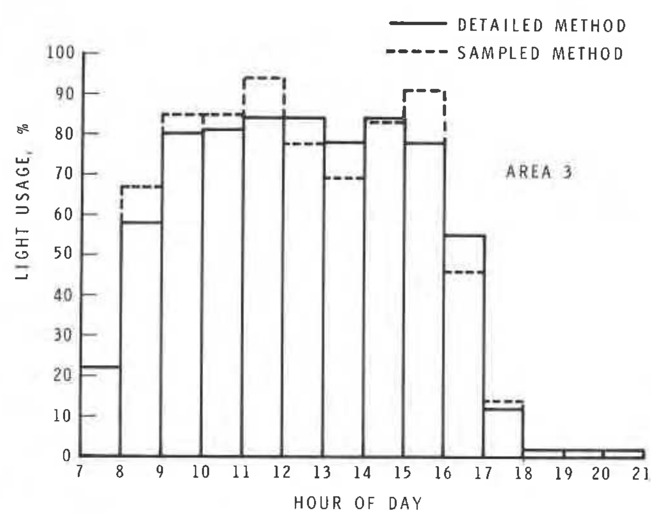

Fig. 5. Light usage profile, Area 3.

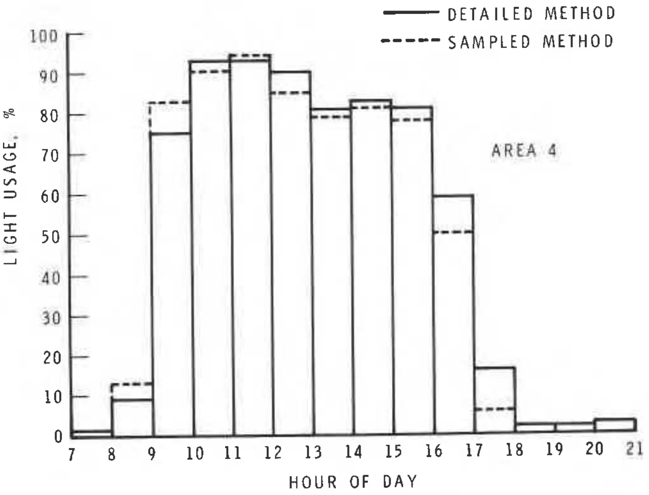

Fig. 6. Light usage profile, Area 4.

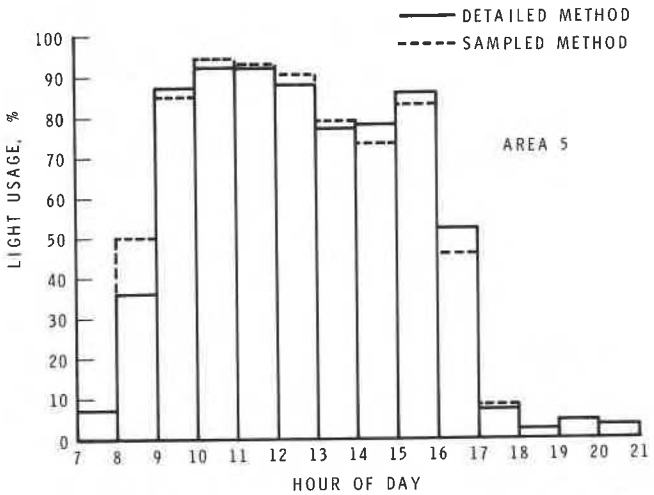

Fig. 7. Light usage profile, Area 5.

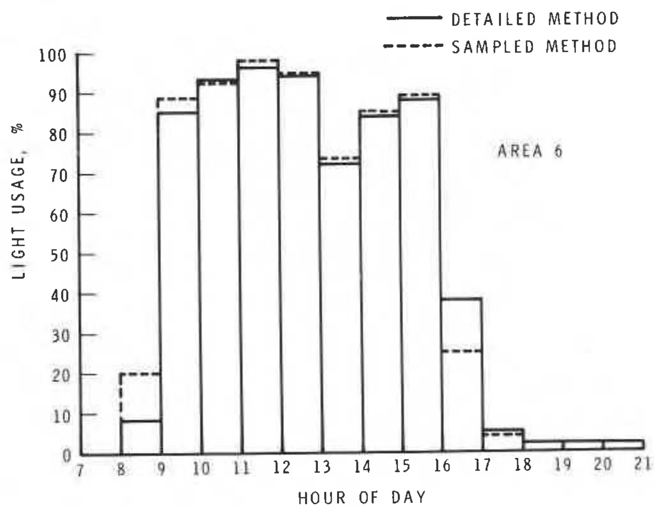

Fig. 8. Light usage profile, Area 6.

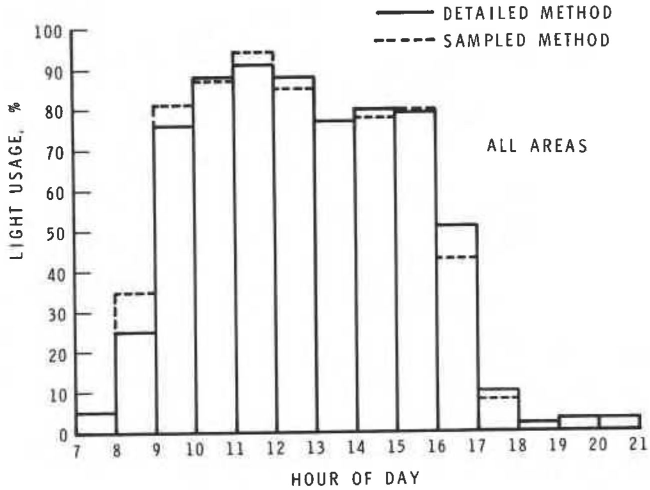

Fig. 9. Light usage profile, all areas.

area are shown in Table 1. Fig. 10 shows the correlation between the two types of examination for every combination of circuit area and core hour.

Table 1 Correlations between light usages in detailed and sampled frames

	Correlation
Area 1	0.94
Area 2	0.98
Area 3	0.96
Area 4	0.99
Area 5	0.98
Area 6	0.99

Occupancy in the randomly sampled frames was also examined. The proportion of sampled frames in which one or more persons could be seen in a circuit area was calculated for every core hour. These proportions and those for all circuit areas combined are shown in Table 2. As occupancy in circuit area 5 could not be properly monitored because of a partition, this area was eliminated from the analyses where an estimate of occupancy was required. It should be noted, too, that the camera

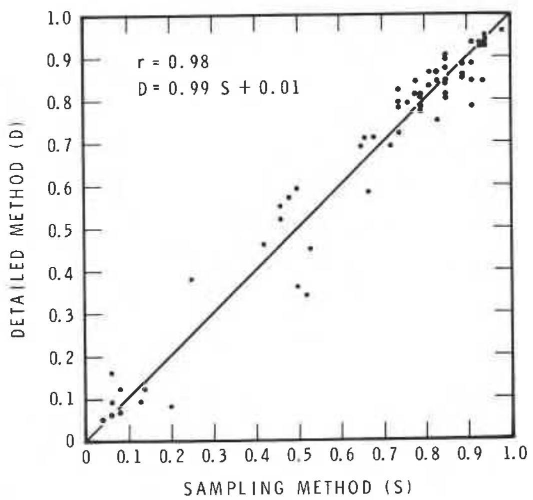

Fig. 10. Correlation of light usage between sampled data and detailed data.

Table 2 **Occupancy proportions**

	08:00 → 09:00 h	09:00 → 10:00 h	10:00 → 11:00 h	11:00 → 12:00 h	12:00 → 13:00 h	13:00 → 14:00 h	14:00 → 15:00 h	15:00 → 16:00 h	16:00 → 17:00 h	17:00 → 18:00 h	Mean	Median
Area 1	0.22	0.85	0.76	0.83	0.32	0.64	0.47	0.30	0.08	0.02	0.45	0.40
Area 2	0.00	0.60	0.42	0.31	0.24	0.25	0.42	0.11	0.04	0.00	0.24	0.24
Area 3	0.19	0.34	0.26	0.81	0.33	0.25	0.19	0.28	0.08	0.00	0.27	0.26
Area 4	0.06	0.66	0.60	0.61	0.32	0.36	0.55	0.44	0.13	0.02	0.38	0.40
Area 5	—	—	—	—	—	—	—	—	—	—	—	—
Area 6	0.09	0.70	0.47	0.85	0.24	0.38	0.70	0.37	0.06	0.00	0.39	0.38
Mean	0.11	0.63	0.50	0.68	0.29	0.38	0.47	0.30	0.08	0.01	0.35	
Median	0.09	0.66	0.47	0.81	0.32	0.36	0.47	0.30	0.08	0.00		

provided a better view of some circuit areas than of others. Occupancy may therefore be underestimated in certain circumstances.

Core hour data from the random sampling procedure were used to plot (Fig. 11) occupancy (from Table 2) versus light usage (from Figs. 3 to 8) for every combination of circuit area and core hour. An occupancy-to-light usage ratio (O/L) can give an indication of 'problem' areas and times for lighting energy conservation. If a ratio is equal to 1.0, (i.e., if it lies on line A, Fig. 11), then 'perfect' behaviour is exhibited by the occupants; every time the space is unoccupied the lights are off.* Naturally, if O/L = 0 (i.e., points lying on the abscissa) lighting energy is completely wasted.

The O/L ratios do not, however, give a complete picture of lighting energy conservation. For example, there are certain times with low occupancy to light ratios, but because they represent a small portion of the energy consumed during the day (i.e., those points near the origin) they are of little importance. Conversely, there are times with higher occupancy to light ratios when it would be more profitable to implement conservation measures because more energy is being used (i.e., those points with very high abscissa values but low or moderate ordinate values). A method for quantifying lighting energy conservation should therefore consider the absolute lighting energy consumed as well as the occupancy.

A simple measure of lighting energy waste, as qualitatively discussed by Hunt and Crisp,[8] can be determined by the difference between light usage and occupancy.

$$w = L - 0 \tag{1}$$

*Note that O/L > 1.0 in Area 2, 09:00 to 10:00. The teacher occasionally showed movies or slides to students during this time, so that there was sometimes occupancy in the area with no light usage.

where L = proportion of frames with observed light usage
0 = proportion of frames with observed occupancy
w = waste term

A table of w values for every combination of circuit area and core hour is shown in Table 3. Row means and medians indicate typical values for the circuit areas. Column means and medians indicate typical values for the core hours.

The measure, w, is probably more meaningful than 0/L for lighting energy conservation; in the former, both absolute light usage and occupancy are considered. Combinations of circuit areas and core hours with the same 0/L values do not indicate the same amount of waste. For example, points lying on line B in Fig. 11 have the same 0/L value, but points further from the origin represent larger amounts of waste simply because the absolute amount of light usage is higher. Conversely, all points lying on a particular line with slope 1.0 (e.g.,

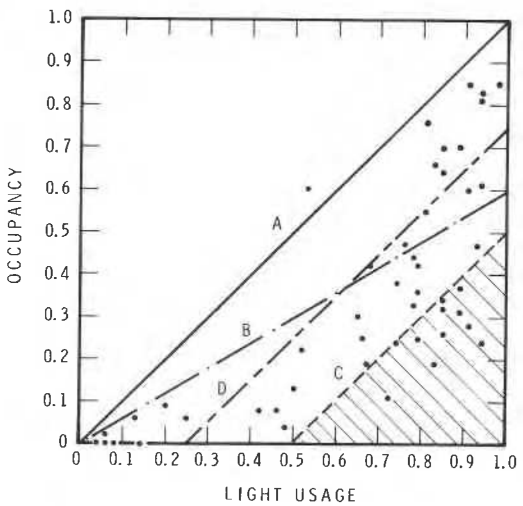

Fig. 11. Occupancy versus light usage, sampled data.

Table 3 Waste terms (w)

	08:00 → 09:00 h	09:00 → 10:00 h	10:00 → 11:00 h	11:00 → 12:00 h	12:00 → 13:00 h	13:00 → 14:00 h	14:00 → 15:00 h	15:00 → 16:00 h	16:00 → 17:00 h	17:00 → 18:00 h	Mean	Median
Area 1	0.30	0.06	0.05	0.11	0.53	0.21	0.29	0.35	0.34	0.04	0.23	0.25
Area 2	0.06	−0.07	0.37	0.58	0.50	0.41	0.26	0.61	0.44	0.08	0.32	0.39
Area 3	0.48	0.51	0.59	0.13	0.45	0.54	0.64	0.63	0.38	0.14	0.45	0.50
Area 4	0.07	0.17	0.31	0.33	0.53	0.43	0.26	0.34	0.37	0.04	0.28	0.32
Area 5	—	—	—	—	—	—	—	—	—	—	—	—
Area 6	0.11	0.19	0.46	0.13	0.70	0.36	0.15	0.52	0.19	0.04	0.29	0.19
Mean	0.20	0.17	0.36	0.26	0.54	0.39	0.32	0.49	0.34	0.07	0.31	
Median	0.11	0.17	0.37	0.13	0.53	0.41	0.26	0.52	0.37	0.04		

line C) in Fig. 11 represent equal amounts of lighting energy waste. In other words, every point on such a line represents the same amount of unused light. Lowering the absolute value of light usage by the same amount for any point on one of these lines with slope 1.0 represents equal energy savings and, because occupancy is also considered, equal lighting energy conservation.

It is also worth considering a method of gauging energy conservation efforts, again by taking into account *both* absolute light usage and occupancy. It is reasonable to assume that occupancy will be relatively constant for a given combination of circuit area and core hour. It is unlikely that the teaching activities in open-plan classrooms could be further consolidated. To eliminate wasted lighting energy (w, in equation 1), therefore, the number of light usage hours (L) will have to be reduced for a given occupancy level (0). After a completely successful energy conservation effort, the points in a plot like that of Fig. 11 will slide horizontally along the light usage abscissa until w = 0. This may well be an unrealistic goal[2], but it should be possible to select less stringent and more realistic targets so that occupants can improve lighting energy conservation.

Importantly, *quantitative* targets for lighting energy conservation can be identified by incorporating the waste term. Equation (1) can be rewritten to give a criterion such as line C in Fig. 11. The criterion line may be written:

$$0 = L - w \qquad (2)$$

where 0 = proportion of frames with observed occupancy

L = proportion of frames with observed light usage

w = waste term

= x intercept

= −(y intercept).

Any points below this criterion line (hatched area) would be candidates for lighting conservation efforts. Higher criteria (e.g., line D) can also be selected by lowering the waste term (thus increasing the y intercept). Equation (2), then, can be used to evaluate energy conservation efforts *quantitatively*. Again, the two important aspects of this measure are absolute light usage and occupancy.

4 Discussion

Random sampling of events is a traditional, practical and proven method of estimating characteristics of a large population. A great body of experimental literature rests upon the assumption that statistics based upon random sampling (e.g., mean, median, standard deviation) can be used to represent features of a larger population. This same assumption was employed to make the task of analysing the time-lapse data easier. When a check on this assumption was performed, there were high correlations between the detailed data and the sampled data (Table 1, Fig. 10). Based upon traditional statistical assumptions and direct comparisons of detailed and sampled data, subsequent analyses of the sampled data were performed.

The patterns of light usage (based on both detailed and sampled methods) shown in Figs. 3 to 9 were similar to those recorded in other buildings[3, 5-9]. Specifically, there was a rapid rise in light usage at the beginning of the working day, a fairly flat period throughout most of the core hours, and a gradual tapering off at the end of the working day. Certain hours during the working day were associated with high light usage, many exceeding the 90 per cent level. Occupancy patterns must also be considered in ascertaining whether these high usage areas and times resulted from waste or from appropriate utilisation of lighting energy for the occupant activities.

Too often energy conservation efforts are justified solely on the basis of kilowatt hours saved. This philosophy is inappropriate. Assuming that a lighting system has been designed so that occupants can see well, one wants the lights on whenever a person occupies the space*. By using only kilowatt hours saved as a criterion, one can hamper a person's ability to see by turning lights off in occupied areas or even by dimming or delamping efforts. Of course these procedures will show an immediate savings of lighting energy, but they may in the long run cost more energy in compensatory efforts to maintain productivity (e.g., by lighting overtime activities or space for additional manpower). Such productivity assessments are very difficult because of the multifaceted aspects of task performance and thus of productivity. Nonetheless, a wide variety of studies using many measures have demonstrated that people see more poorly as light levels are reduced.[10-12] Again, this large body of data is difficult to translate into profit, but because employee salaries constitute such a large proportion of building overhead it seems imprudent to run the risk of limiting peoples' ability to see.

Wasted light energy should be the prime target of energy conservation; when no one is using a space, lights should be turned off. This implies that *both kilowatt hours and occupancy* need to be considered. Time-lapse photography is capable of providing data on both light usage and occupancy; and meaningful interpretations of such data are possible with the waste term introduced in this report.

5 Conclusion

Two techniques for time lapse photography have been discussed: (1) The sampling procedure provides accurate data (based upon the high correlation between sampled and detailed techniques) at a fraction of the analysis time. (2) The waste term (w in equation (1)) can be used to evaluate and compare lighting energy conservation in various areas for different hours of the day. A change in the waste term can also be used as a measure of the success of lighting energy conservation efforts, like the introduction of more light switches or a poster campaign. It is hoped that the time-lapse photography technique and the simple analytic procedures introduced here can be used to reduce wasted lighting energy.

Acknowledgements

The authors would like to express their thanks to the teachers and administrative staff of the Robert Hopkins School and the Carleton Board of Education for their co-operation and for permission to conduct the study. The authors would also like to thank Dr. A. W. Levy, Mr. B. Guzzo and Ms. R. Adm for their contributions.

This paper is a contribution from the Division of Building Research, National Research Council of Canada, and is published with the approval of the Director of the Division.

*Assuming there is insufficient or unsuitable daylight to satisfy occupants' needs.

References

1 Levy, A. W., Lighting controls, patterns of lighting consumption, and energy conservation, IEEE Transactions on Industry Applications, Vol. IA-16, No. 3, 419-427 (1980).

2 Lowry, R. and Rea, M. S., Energy conservation through lighting controls, Ltg. Des. & Applic., 33-35 (1981).

3 Levy, A. W., Patterns of lighting use in a large open-plan office 1, Preliminary study and evaluation, National Research Council of Canada, Division of Building Research, BR Note 129 (1978).

4 Levy, A. W., Patterns of lighting use in a school classroom. National Research Council of Canada, Division of Building Research, BR Note 132 (1978).

5 Levy, A. W., Patterns of lighting use in a medium open-plan office 2, National Research Council of Canada, Division of Building Research, BR Note 139 (1979).

6 Hunt, D. R. G. and Cockram, A. H., Field studies of the use of artificial lighting in offices: 1 Basic data, Building Research Establishment, current Paper CP47/48, p. 1-23 (1978).

7 Crisp, V. H. C., The light switch in buildings, Ltg. Res. & Technol., **10**, 2, 69-82 (1978).

8 Hunt, D. R. G., and Crisp, V. H. C., Lighting controls: their current use and possible improvement, Energy Research, **2**, 343-374 (1978).

9 Hunt, D. R. G., The use of artificial lighting in relation to daylight levels and occupancy, Building and Environment, **14**, 21-33 (1979).

10 Weston, H. C., The relation between illumination and visual efficiency: the effect of brightness contrast, Industrial Health Research Board, Medical Research Council, London, England, Report No. 87, 1-35 (1945).

11 Boyce, P. R., Age, illuminance, visual performance and preference. Ltg. Res. & Technol., **5**, 3, 125-144 (1973).

12 Smith, S. W. and Rea, M. S., Proofreading under different levels of illumination, Jnl. I.E.S.(U.S.A.), 47-52 (October 1978).