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HAVING MANUAL SWITCHES

by

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Division of Building Research, National Research Council Canada

Ottawa, November 1984

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ABSTRACT

Light usage in a multi-storey office building was monitored over a one-year period using a recently developed light usage monitoring device. The effects of several factors important to light usage were analyzed. Estimates of light usage for different switching arrangements were also obtained, and comparisons were made of energy consumption and simple pay-back periods. The utility of the light monitoring device for measuring light usage was also examined.

1. INTRODUCTION

With the increase in the price of energy and with the public becoming more energy conscious, more attention has been given to finding ways to detect and prevent wasted lighting energy [1-5]. But one question being raised in the lighting community is whether energy reducing methods compromise lighting quality and quantity. There is a concern that some energy saving measures (e.g. techniques which reduce illuminance levels) might have negative effects on the visual performance or satisfaction of the building occupants [6-7].

One way to avoid this problem is to attack waste solely by turning lamps 'Off' when they are not required (i.e., when a space is vacant and the lights are not required by people working in adjacent spaces). A number of procedures can be adopted to switch lights 'Off' [8-10]. Manual switches are of particular interest because they are simple to use, are relatively inexpensive (particularly for a new building), give occupants some discretionary control over their own lighting environment, and can reduce building operating costs [11-15].

In this study, light usage was monitored for a one-year period on five floors of a multistorey office building with centrally located manual wall switches. The data were collected using prototype light usage monitoring devices, called Light Auditors, manufactured by Foundation Electronic Instruments, Inc., Ottawa. They can measure lighting consumption separately from other electrical systems [16-18]. The data were analyzed statistically to determine whether the building floors, the orientation of the four quadrants, the seasons, or the various combinations of these factors, influenced the hours of light usage. Estimations of the hours of light usage in this building were also obtained for several hypothetical arrangements incorporating manual wall switches. Estimations of lighting energy consumption and simple pay-back periods were made for these hypothetical switching arrangements, as well as for the actual monitored situation.

2. OBJECTIVES

There were three main objectives in this study:

1) to obtain data on the hours of light usage over a one-year period in a large office building with manual wall switching;

2) to test and evaluate the new Light Auditor as a data aquisition device;
3) to evaluate the impact of different switching arrangements and numbers of manual switches on lighting energy consumption and simple pay-back periods.

The first two objectives were met to our satisfaction, but the third was not. Because occupancy was not monitored, the estimates of wasted lighting energy and the potential savings from manual switches could only be approximate [2]. Nevertheless, by making some reasonable assumptions about occupancy, and with the measurements of the hours of light usage for the existing situation, some preliminary estimates could be made of the potential energy and monetary savings from different manual switching layouts.

3. BUILDING DESCRIPTION

The 21-storey Sir William Logan Building (Figure 1) owned by Public Works Canada (PWC), houses staff of the Department of Energy, Mines and Resources (EMR) in Ottawa. Five floors (3, 6, 13, 17 and 20) of this building, having convenient access, were chosen for the study. Both private and open office spaces were found on each floor.

The floor lighting layout was divided into five zones: four quadrants of equal size and the elevator lobby (Figure 2). One manual wall switch controlled the majority of lamps in a zone. The manual switches on every floor were grouped near an elevator door.

The lighting loads in the five zones were separately monitored. Together they constituted an average of 88% of the total lighting load on a floor (approximately 25 kW). Lamps on separate circuits (washrooms, enclosed storage rooms, conference rooms, security lights and some private offices) were not monitored.

Electrical lighting was supplied by 40 W, 122 cm (48 in.) fluorescent lamps in two-lamp troffers with prismatic lenses. Although the fixtures were made for two lamps, very few (1%) actually contained both lamps because of a previous delamping program carried out by PWC. Most luminaires (79%) contained only one lamp. These fixtures were wired in pairs so that two luminaires shared one ballast. A few luminaires (10%) contained one fluorescent lamp and one "non-light-producing tube". Some of the fixtures (10%) were empty. The average connected lighting load on the floors was 14 W/m^2 (1.3 W/ft^2). Glazing on the perimeter of the floors (Figures 1 and 2) had both curtains and venetian blind assemblies.

4. OPERATING HOURS

As noted in Section 2, occupancy was not monitored in this study. An interview with the maintenance manager, however, indicated that the building was usually occupied between 0630 and 2000. The building was cleaned between 1730 and 1930 and the cleaning staff were asked to turn lights 'Off' as they finished on each floor. Finally the security staff was responsible for turning lights 'Off' after nightly inspections (between 1830 and 2300 hours) and on weekends. These statements were not verified, however.

Figure 1. The Sir William Logan Building.

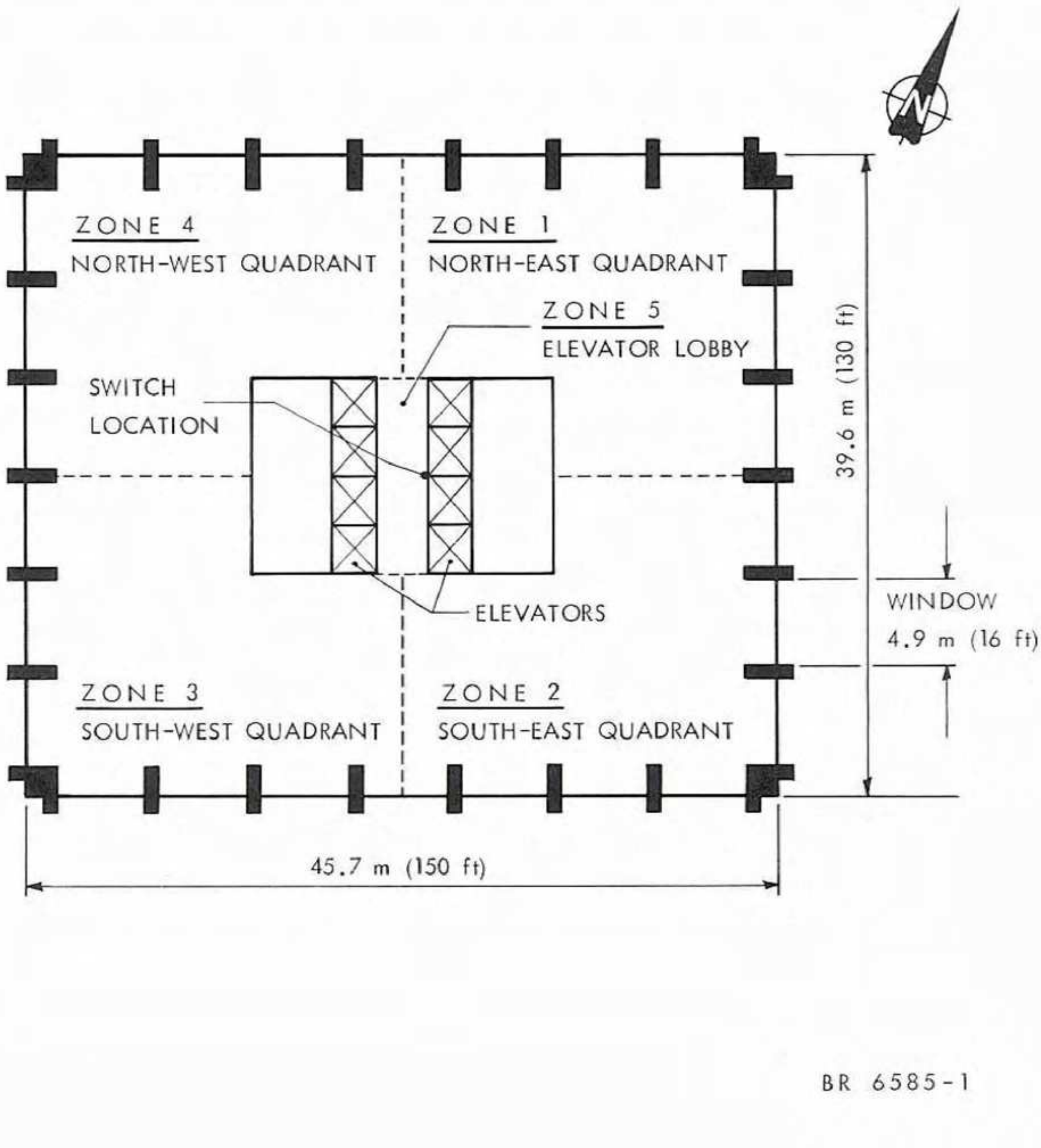

Figure 2. Floor diagram for the Sir William Logan Building, showing the monitored zones.

5. LIGHT AUDITOR

5.1 Description

The Light Auditor accumulates the number of hours (to within one tenth of an hour) that a particular lighting circuit has been 'On' by counting the number of light pulses produced by lamps operated with 60-cycle current [1]. (The Light Auditor is insensitive to daylight and to lights powered by a DC supply [17]). A nine-volt alkaline battery powers the Light Auditor for about one year. The Light Auditor must be removed from its holder before the light usage data can be read; a plug-in reader displays the accumulated hours of light usage (Figure 3). Real-time light usage data cannot be obtained with this instrument.

5.2 Installation

Twenty-five Light Auditors (one in each zone of the five monitored floors) were mounted on suitable walls using foam core, double sided tape. Before the study was started, a preliminary, four-day test of the Light Auditors was conducted. Most of the Light Auditors performed as expected, but some had minor problems. Some Light Auditors simply did not function properly and were replaced. Some Light Auditors had been placed too close to security lamps and these registered 24 hours of light usage a day; these Light Auditors were relocated. In some other cases, a single centrally located manual light switch controlled more than one contactor; thus two adjacent luminaires on one monitored switch circuit could be operating with line currents out of phase by 60 or 120 degrees. In those cases, the numbers of light pulses recorded by the Light Auditors were two or three times the single phase counts. A portable oscilloscope was used to detect these situations and the Light Auditors positioned to avoid them. Once a Light Auditor was properly positioned, its exact location was marked to ensure the same orientation for future readings of light usage.

6. MONITORING PERIODS

For the first ten weeks of the monitoring period (October 15 to December 24, 1979) weekly readings were taken. For the remainder of the year (to October 27, 1980) data were taken every second week. The data were always collected near 1000 hours on Monday mornings, except for Monday holidays, when data were collected near the same hour on the following Tuesday. There were ten classes of recording periods during this study. Appendix A describes these classes and their frequencies of occurrence during the 54 weeks of monitoring.

7. RESULTS

7.1 Refinement of the Data

To better determine when lights are used, it is desirable to know the daily hours of light usage, or at least be able to separate weekend data from weekly (five-day) data so that average daily usage can be estimated. With the Light Auditors, however, this would have required taking readings

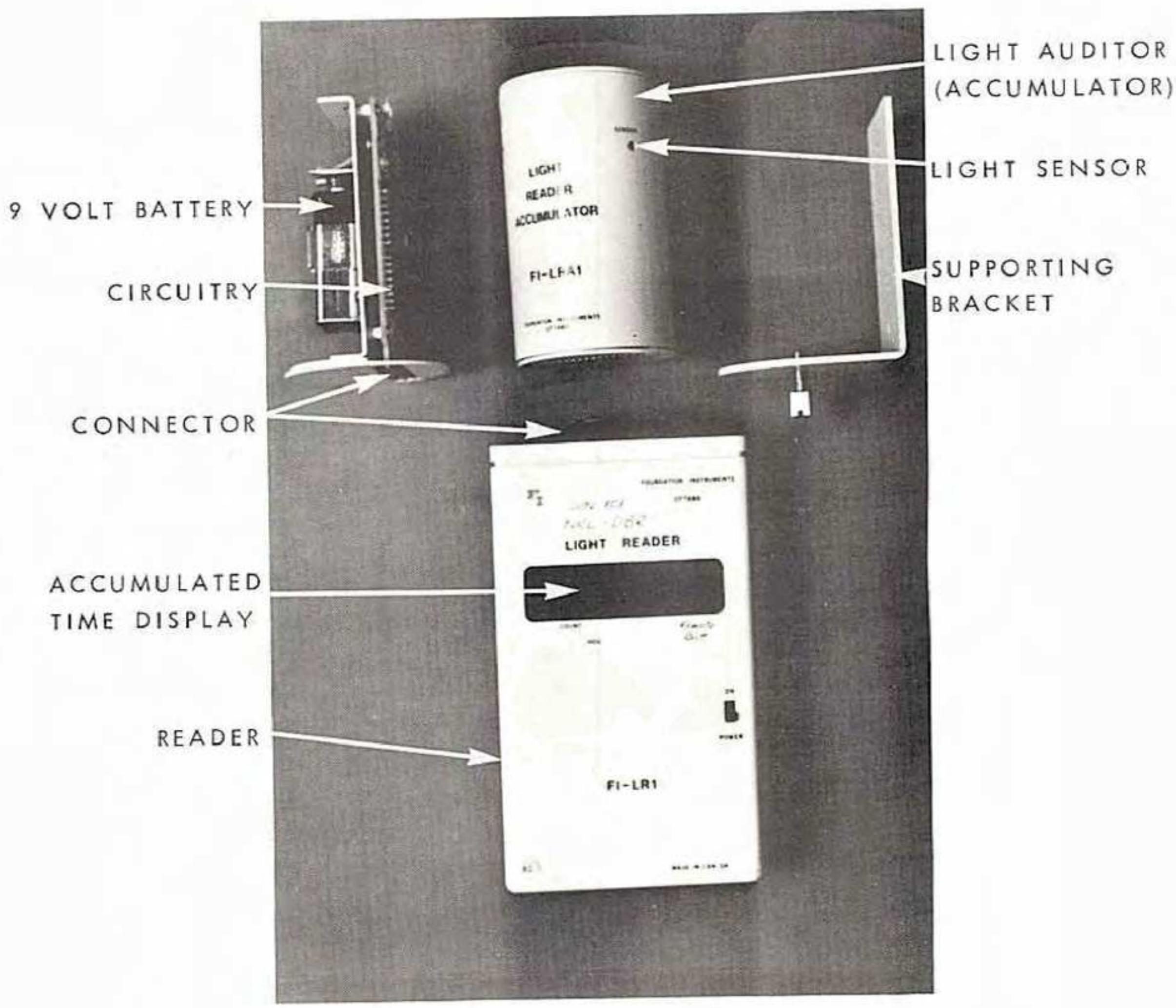

FIGURE 3

LIGHT AUDITOR, SUPPORTING BRACKET AND READER more frequently than would have been practical; most of the data were recorded every second week in this study. Because of the coarse data acquisition technique, weekend data could not be separated from five-day week data and thus the data could not be confidently transformed to give daily hours of light usage. It was only possible to transform the biweekly data to weekly hours of light usage, with weekend light usage included. In this way, the reduction in hours of light usage caused by holidays can be estimated. Appendix A documents the transformations from biweekly data to weekly data.

During the year, 15 out of the 400 possible readings were unusable. In 10 cases, data simply did not exist, primarily due to battery failure. In the other 5 cases, unusually high or low values were obtained. These dubious cases were also treated as missing. Estimates of the missing values, based upon orthodox procedures [19], were interjected into the data set before the data were transformed from biweekly to weekly readings and before the statistical analyses.

Figures 4a to 4e show the weekly hours and patterns of light usage throughout the year for each quadrant of each floor. The hours of light usage in the lobbies are not presented in these figures. Generally, however, they were similar to the average hours of light usage for the same floor.

Normal weekly hours of light usage for the quadrants ranged between 60 and 105 hours. The average weekly light usage, in hours ($\bar{h}_n$), was 75 for weeks without holidays. All eleven statutory holidays produced sharp drops in the weekly hours of light usage on every floor and in every quadrant ($\bar{h}$ = 60 hours for weeks with a holiday). Hours of light usage were as low as 35 hours during the Christmas holiday week. These data show that the switches were indeed used to turn lights 'Off' during long unoccupancy periods such as nights and holidays.

7.2 Statistical Treatment of the Data

An analysis of variance (ANOVA) and a Tukey test of pairwise comparisons were performed on the weekly data without holidays to see if there were statistical differences between floors, between quadrants, between seasons and between the various combinations of these factors.* Data for weeks with holidays were excluded from these analyses due to their fewer hours of light usage. For these statistical tests it was assumed that there was no interaction between weeks and seasons;** weeks were treated as replications within seasons. The criterion for significance in the ANOVA was $p \leq 0.01$

The ANOVA indicated a main effect for floors and seasons but not for quadrants. The average weekly hours of light usage on one or more of the

*See Appendix B for a brief description of statistical inference from the analysis of variance (ANOVA).

** The seasons were divided as follows;
Autumn (79-10-22 to 79-12-24), Winter (79-12-24 to 80-03-24),
Spring (80-03-24 to 80-06-23), Summer (80-06-23 to 80-09-22),
Autumn (80-09-22 to 80-10-20).

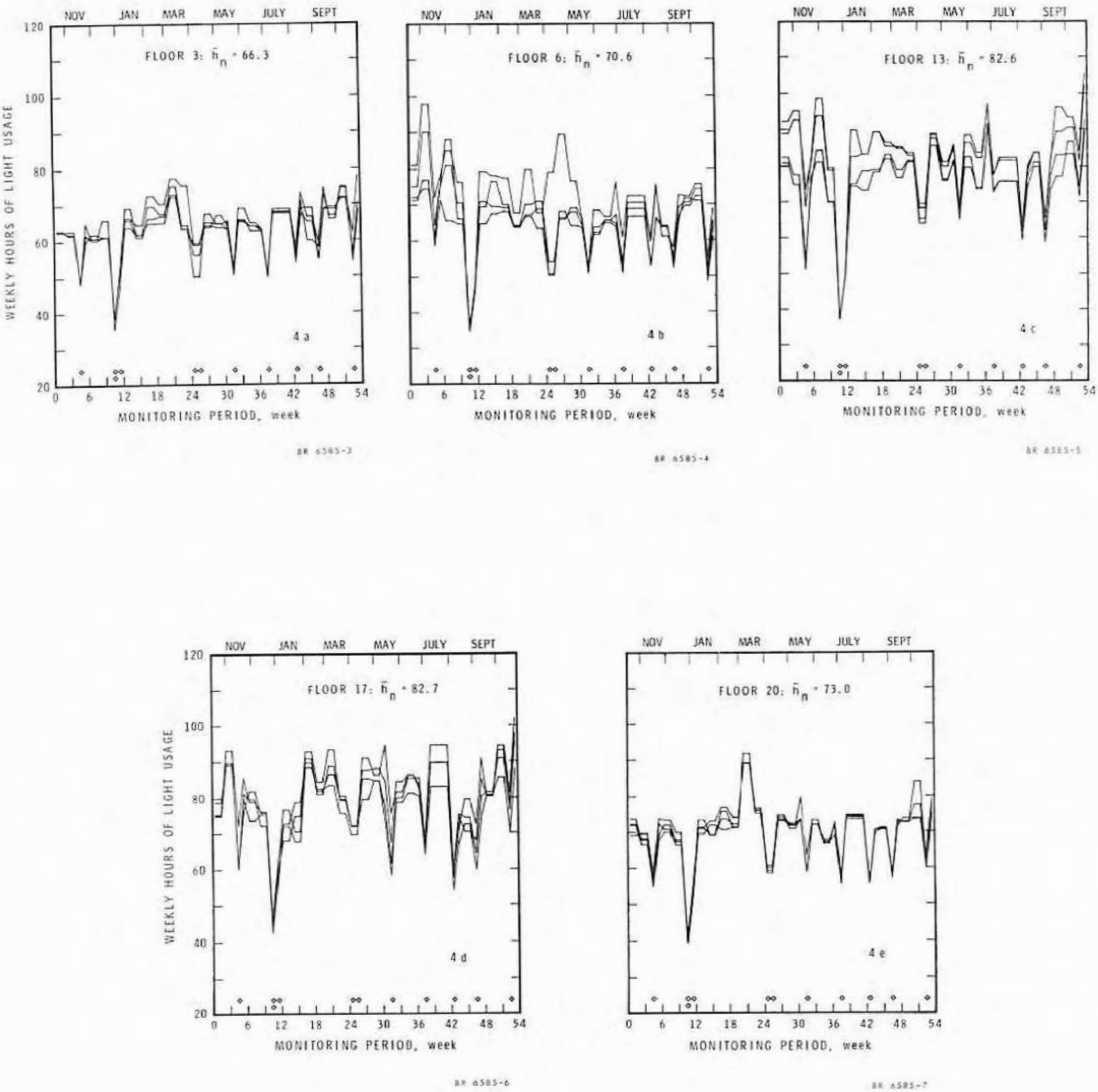

Figure 4a-e. Weekly hours and patterns of light usage throughout the 54 week monitoring period for each floor and its four quadrants. $\bar{h}_n$ is average hours of light usage per nonholiday week. Week one started October 15, 1979 and week 54 finished October 27, 1980. Diamonds indicate holidays.

five floors was statistically different from the others, and similarly light usage during one or more seasons was statistically different from the others, but the hours of light usage were not statistically different for any of the four quadrants. The Tukey test of paired comparisons was then used to see which floors and which seasons were significantly different. A confidence interval of 99% was used for all paired comparisons.

The pairwise comparisons revealed that the hours of light usage averages, for every floor, were statisticaly different except for one pair; floors 13 and 17. That is, the weekly light usage hours were statistically the same on these two floors. For seasons, the pairwise comparisons revealed that the hours of light usage in the autumn and spring were significantly different, but the hours of light usage in the autumn were not significantly different from those in summer and winter, and the hours of light usage in the spring were not significantly different from those in the summer and winter.

The ANOVA also revealed two significant two-way interactions; the variable floor interacted with the variable quadrant and with the variable season. For the significant floor-by-quadrant interaction, the Tukey test revealed that light usage values for the four quadrants were the same on floor 3, on floor 17 and on floor 20. However, on floor 6, light usage in the southeast quadrant was significantly different from the light usage values in the other three quadrants. Similarly, on floor 13, light usages in the southeast and southwest quadrants were significantly different from the hours of light usage in the northeast and northwest quadrants. For the significant floor-by-season interaction, the average hours of light usage on Floor 6 during the autumn was significantly different from the light usage average hours for any other combination of floor and season. The three-way interaction (floor-by-season-by-quadrant) was not significant.

In total, it was inferred that the variation in light usage between floors was large and due to different activities on these floors. Switching was apparently done in unison for the four quadrants on each floor, except on floors 6 and 13, where overtime activities took place in certain areas of those floors. Seasonal variations were small and seemed to be primarily due to overtime activities in the autumn on floor 6. Daylight apparently had little if any effect on hours of light usage. Of course the central switching locations were not conducive to occupant use of switches in response to daylight from the perimeter.

8. ESTIMATIONS OF ENERGY CONSUMPTION AND COST

Figure 5 was developed to display the lighting energy (power × time) consumed by the different quadrants and floors during this study. The areas of the histograms are proportional to the lighting energy consumptions in the different areas; the abscissa gives the power associated with lighting for a particular quadrant or floor, and the ordinate gives the average hours of light usage. Such a figure can also conveniently represent the effects of different switching strategies on energy consumption.

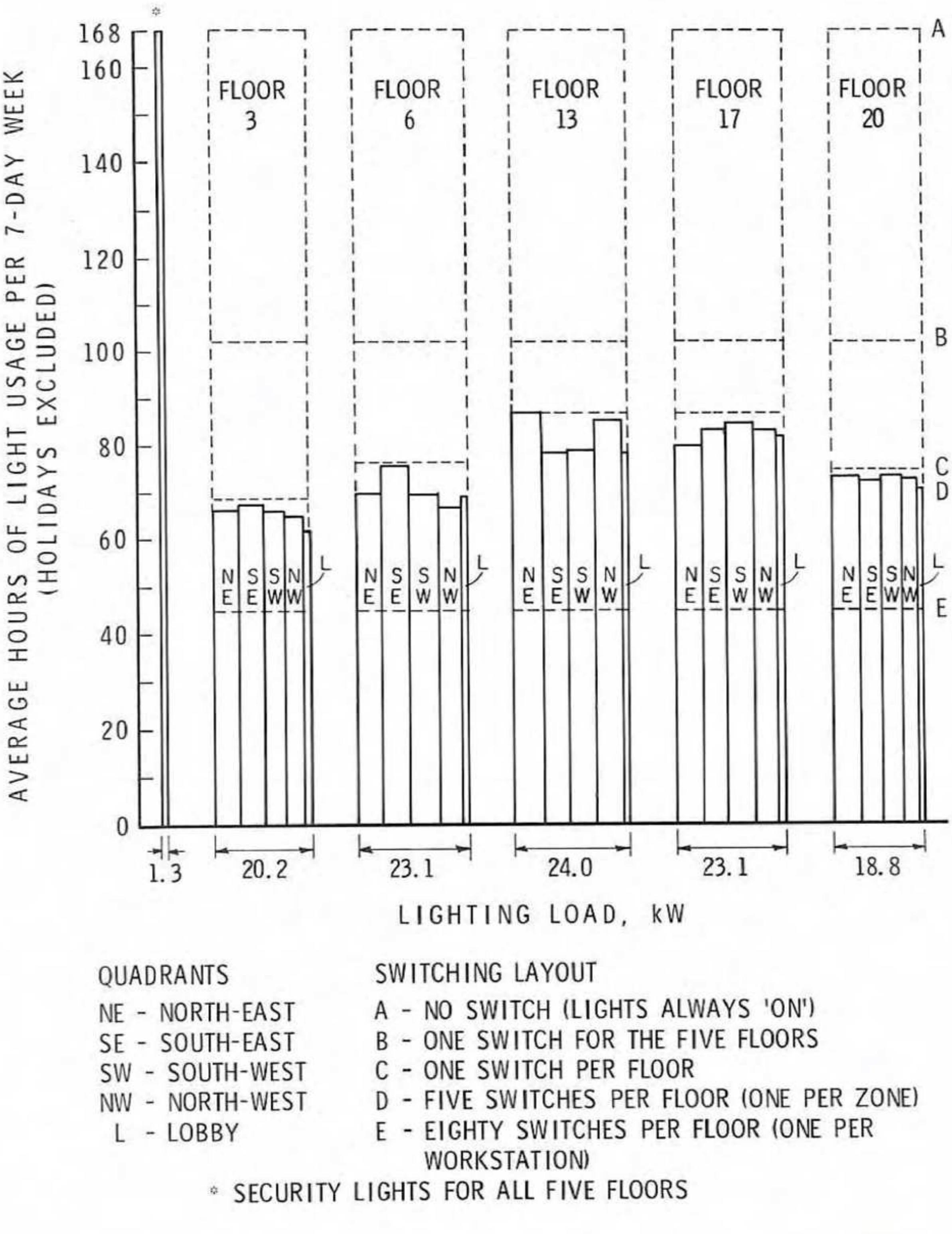

Figure 5. The effect of different switching layouts on lighting energy consumption. Energy consumption equals connected lighting load (abscissa) times hours of light usage (ordinate).

8.1 Lighting Load (Power)

The lighting loads for the various quadrants and floors in Figure 5 (abscissa values) were estimated from the fixture counts described in Section 3 and the accepted wattages for the different lamp/ballast combinations. The power used by the two fixture (two lamp)/one ballast combination was assumed to be 93 W, and the one fixture (one lamp and one "non-light-producing tube")/one ballast combination was assumed to use 30 W. Both estimates take into account line losses, voltage drops to the ballasts, and lamp wall temperature [20]. Again, the width of each histogram in this figure is proportional to the lighting load for that quadrant or floor, based on these estimates.

8.2 Hours of Light Usage (Time)

The nonholiday, weekly hours of light usage averages, as defined in Section 7.1, for each monitored quadrant, are proportional to the heights of the histograms marked with solid lines (layout D) in Figure 5.

It was also possible to represent the estimated weekly hours of light usage resulting from other switching arrangements (layouts A,B,C and E in Figure 5). For switching layout A (no switch), the lights would simply be 'On' 168 hours per week (this was the case for security lights). For layout B (one switch for the five floors), the estimated weekly hours of light usage was determined by the following two steps. First, the highest weekly hours of light usage for all twenty quadrants (five floors × four quadrants) were found for each week throughout the year. Second, the average of these maximum weekly values was determined and indicated by a dashed line (B in Figure 5). A similar technique was used to estimate the hours of light usage for layout C, one switch per floor. For this estimate, the highest weekly hours of light usage for each floor (four quadrants per floor) were found and the average of these maximum values was indicated by the dashed lines collectively marked C in Figure 5. (The dashed lines marked C are usually higher than any of the quadrant averages actually obtained and indicated with the solid lines marked D. This is because the maximum light usage values for each week throughout the year, were not always associated with the same quadrant).

This technique is satisfactory in estimating light usage if fewer switches are used, but it cannot be used to estimate hours of light usage if more switches are added to floors. The results of a PWC study conducted after the monitoring period in this study, were used to estimate the hours of light usage associated with localized switching (marked E in Figure 5). Using watt-hour meters during 'before-and-after' spot checks, PWC found a 40% reduction in energy consumption in this building after installing one local manual switch per workstation (an average of 80 switches per floor) and giving occupants instructions on the use of the light switches [13,14]. Presumably the lighting load remained the same, so this reduction in energy consumption must have been due to a 40% reduction in the hours of light usage. In the present study, the average light usage for the five monitored floors was 75 hours per week. Thus based on the PWC study, the lines marked E in Figure 5 indicate a 40% reduction in the average hours of usage for the five floors, or 45 hours of light usage per week.

8.3 Energy Consumption (Power × Time)

The areas of the histograms in Figure 5 represent the weekly energy consumption averages associated with each hypothetical switching arrangement and with the actual monitored situation. The fourth column in Table I gives an indication of the average annual lighting energy consumption for the actual and hypothetical arrangements. Naturally, the case of no switches produced the highest annual energy consumption and localized switching produced the smallest.

8.4 Cost (Simple Pay-back Period)

The cost of electrical energy to the commercial customer can be broken down into three components. The consumption rate, the daytime peak demand rate and the power factor penalty rate. Taking all of these factors together, PWC has arrived at a rate of 3.5¢/kW·h to represent the average energy cost for government buildings in Ottawa (1984 rate). Table I gives the cost of annual lighting energy consumption for the five floors using this average rate. Since 3.5¢/kW·h is fairly small compared to what is charged in other parts of the country (e.g. 9.9¢/kW·h in Charlottetown, ref. 21), an average rate of 10¢/kW·h (including power factor and daytime peak demand charges) was also used (Table I).

The monetary savings resulting from reduced consumption can be misleading without a detailed life cycle costing estimate. Such an undertaking is quite complex and a justification of more than the simplest assumptions is outside the scope of this project. Nevertheless, the relative length of simple pay-back periods for the different switching arrangements for this particular building can be readily examined, based upon the annual cost of energy in Table I.

Simple pay-back periods can be calculated from the ratio of the incremental investment costs for switches to the incremental savings from utility charges per year. PWC has estimated that the average cost of installing manual line voltage switches (as installed in this building) in the retrofit program was approximately $125 per switch (1984 prices). This estimate reflects the cost of equipment, and labor but does not include the design of the switching layout or any of the site visits before, during or after the project. Including these latter costs for professional services, an approximate average value of $150 per switch* can be assumed. Table II compares simple incremental pay-back periods for the different switching arrangements described in this section, for the two utility rates, assuming $150 per switch.** Adding switches at this fixed cost increases the simple pay-back periods. The size of the increase will depend on the effectiveness of the strategy used for reducing the lighting energy consumption (i.e. the ratio of switches installed to the reduction in light usage obtained). Pay-back periods will also increase with any increase in installation cost

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*Interestingly, this value is close to what some companies claim to charge (cost/point) for an automatic control system with local over-riding capabilities in a large building.

**The installation cost per switch will vary with the quantity of switches installed. An increase in the cost per switch would increase the incremental pay-back period for the first three arrangements and slightly reduce the incremental pay-back for the last arrangement in Table II.

Table I

Estimated impact of various switching layouts on average hours of light usage, annual lighting energy consumption and electrical lighting energy cost for five monitored floors in the Sir William Logan Building.

Switching layout	Lighting load, kW	Average annual light usage, h	Annual lighting energy usage, kW·h	Annual cost of energy[1], (3.5¢/kW·h) dollars	Annual cost of energy, (10¢/kW·h) dollars
no switch	109	8,760	955,000	33,400	95,500
1 switch / (5 floors)	109	5,090	555,000	19,400	55,500
1 switch / floor	109	3,920	428,000	15,000	42,800
1 switch[2] / zone	109	3,690	402,000	14,100	40,200
1 switch / workstation	109	2,210	241,000	8,440	24,100

[1] Annual cost of energy = (lighting load) × (average annual light usage) × (average energy cost per kilowatt hour)
[2] The monitored switching arrangement.

Table II

Simple pay-back[1] periods calculated for five floors using two utility rates, for different retrofit situations. A fixed value of $150 per switch (1984 price) was assumed.

Switching layout	Number of switches	Incremental investment cost (dollars)	Incremental savings per year 3.5¢/kW·h (dollars)	Incremental savings per year 10¢/kW·h (dollars)	Simple incremental[2] pay-back periods 3.5¢/kW·h	Simple incremental[2] pay-back periods 10¢/kW·h
No switch	0	–	–	–	–	–
1 switch / 5 floors	1	150	14,000	40,000	3.9 days	1.4 days
1 switch / floor	5	600	4,400	12,700	50 days	17 days
1 switch[3] / zone	25	3,000	900	2,600	3.3 years	1.2 years
1 switch / work-station	400	56,250	5,660	16,100	9.9 years	3.5 years

[1] Simple pay-back = $\frac{\text{investment cost}}{\text{savings per year}}$

[2] 'Incremental' represents the change compared to the previous listed condition, not to any absolute value.

[3] The monitored switching arrangement.

per switch and any decrease in connected loads (e.g. due to the installation of more energy efficient lamps). But pay-back periods will decrease as utility rates increase. Mortgage charges, inflation, reduction in heat produced by the lighting system, extended ballast and lamp life, user satisfaction (productivity) and other factors would also influence these pay-back periods in a more complete cost analysis.

9. CONCLUSIONS

The Light Auditors performed well throughout the year without any major problems. From the data collected with these devices it was determined that the average hours of light usage (75 hours per nonholiday week, including weekends) was higher than those reported in other studies on comparable buildings [14,15], but about the middle of the range in at least one other study [22]. Real time light usage and occupancy data were not available so it was not possible to determine whether the lights were always needed for that amount of time each week, however, overtime activities evidently took place. Occupancy needs to be determined and in this regard the Light Auditor, by itself, is not an ideal research tool.

The results of the statistical analyses showed that light usage in this building was affected by the floor, the season, the combination of floor and season and the combination of floor and quadrant. This complexity in light usage probably reflected different patterns of activities in the building throughout the year. Presumably, any lighting control strategy, either manual or automatic, would have to accomodate this variability in occupancy patterns. Otherwise, the building will be operated less efficiently, either in terms of energy use or in terms of occupant productivity and satisfaction. For example, a regimented lighting schedule for the whole building could result in premature light extinction at some locations where occupants are still working and unnecessary light usage at other locations where occupants have gone home.

The total energy consumption (and hours of light usage) will decrease with the number of switches installed and operated. However as more switches are added to a building, the incremental reduction in energy consumption per switch will decrease. At some point, adding more switches will not be economically feasible. Some investors claim that pay-back periods longer than two years are unattractive since better return on investment can be made elsewhere. By this criterion and the simple payback analysis in section 8.4, the installation of 25 switches (and certainly 400 switches) in this building was not economically attractive. Only if the cost of installing switches were reduced or if the price of electrical energy increased, would a major switching retrofit of this type become financially attractive.

10. ACKNOWLEDGEMENTS

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APPENDIX A

Recording Periods

There were ten different classes of recording periods in this study, depending upon the day on which the hours of light usage were recorded. Readings were taken at the start and at the end of each recording period. Underlined letters denote the occurrance of holidays. Depending on the number of working days during a recording period, an appropriate ratio (as shown in the last two columns) was used to obtain weekly hours of light usage (first week and second week) from the biweekly recording period. The dates of the lettered holidays (third column) are given in Table A2.

Table A1

Group no.	Recording periods	Holidays (see Table A2)	Frequency of recording periods in the 54 weeks	Transformation ratios	
				1st week	2nd week
1	MTWTFSSM		8	5/5	
2	MTWTFSSMT	A	1	5/5	
3	TWTFSSM		1	4/4	
4	MTWTFSSMTWTFSSM		11	5/10	5/10
5	MTWTFSSMTWTFSSMT	J,K	2	5/10	5/10
6	TWTFSSMTWTFSSM		3	4/9	5/9
7	MTWTFSSMTWTFSSM	G	1	5/9	4/9
	MTWTFSSMTWTFSSM	H	1	5/9	4/9
8	MTWTFSSMTWTFSSM	E,F	1	4/8	4/8
9	MTWTFSSMTWTFSSM	B,C,D,	1	3/7	4/7
10	M--M--M--M--MT	I	1	5/20 for all 4 weeks	

Readings were taken after a four week period for group 10. Groups 2, 5 and 10 contain a holiday, but each week within a recording period has five working days. The reduction in hours of light usage caused by the holiday in a period affected only the recording period that followed. The transformation ratios are used to break down the data into weekly values. The numerator is the number of full working days per week; the denominator is the number of full working days in the recording period. These values are only approximations. There was no method of determining the exact ratio.

Table A2

Statutory holidays during monitoring period

	Date	Weekday	Week number during the 54 week period
A	Nov 12/79	Monday	5
B	Dec 25/79	Tuesday	11
C	Dec 26/79	Wednesday	11
D	Jan 1/80	Tuesday	12
E	April 4/80	Friday	25
F	April 7/80	Monday	26
G	May 19/80	Monday	32
H	July 1/80	Tuesday	38
I	Aug 4/80	Monday	43
J	Sept 1/80	Monday	47
K	Oct 13/80	Monday	53

APPENDIX B

Analysis of Variance (ANOVA)

In the analysis of variance (ANOVA), data are structured to form a matrix. The matrix has n dimensions corresponding to the number of variables analyzed. In this experimental design, a three dimensional matrix was used corresponding to the three variables: floor, quadrant and season. The length of these dimensions depends upon the number of levels within the variables. These levels correspond to different quantitative or qualitative categories of the variables. In this design, the variable called 'floor' has five levels (3, 5, 13, 17, and 20), the variable called 'quadrant' has four levels (northeast, northwest, southeast, and southwest), and the variable called 'season' has four levels (autumn, winter, spring and summer).

These structured data are statistically analyzed in several ways by the ANOVA. One way the data are analyzed is to compare the averages for different levels within a variable. If the average for one variable level is much larger or smaller than the values in the other levels, then it is statistically different. The averages for the five floors, for example, can be compared to see if one or more floors is statistically different from the values for the other levels. Similarly, the averages for the four quadrants and for the four seasons can be compared. Such statistical comparisons of the levels within a variable are called 'main-effects'.

When statistically comparing the main-effect averages, the levels of the other variables are ignored. In other words, the averages for the different levels within some main-effects are obtained regardless of the level for any other variable. For example, the main-effect average for floor six is obtained without consideration of quadrant or season; as long as the datum was obtained on floor six, it is included in the average.

The combination of variables can be just as, or more, important than the main-effects. These 'interactions' between variables can also be statistically analyzed in the ANOVA. The averages for combinations of variable levels can be statistically compared in much the same way that levels of the main-effects are analyzed. As with the analysis for main-effects, the levels of two or more variables (e.g. floor and quadrant) are included in the average (i.e. the variable season is ignored).

If the difference between the averages for any two levels of one variable is not the same for the same levels of the other variable(s), then there is a significant interaction. So, for example, if the difference in average light usage is not the same for any two quadrants on all floors, then the ANOVA shows a significant floor-by-quadrant interaction.

When pairs of variables are statistically analyzed, as in the floor and quadrant combination, they are called two-way interactions. When three variables are analyzed, they are called three-way interactions. This categorization of interaction terms continues until all variable combinations have been statistically examined in the ANOVA. In this study there were 3 two-way and 1 three-way interaction terms.