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Publisher’s version / Version de l'éditeur:
https://doi.org/10.4224/40000549
Building Research Note, 1980-06

ISSN 0701-5232

BUILDING RESEARCH NOTE

EFFECT OF EXTENDED PERIODS OF USE ON ANNUAL

ENERGY CONSUMPTION OF OFFICE BUILDINGS

by

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Ottawa, June 1980

INTRODUCTION

Many departments within federal and provincial governments are developing energy performance standards (or energy budgets) for various types of buildings to achieve maximum practicable improvements in the efficient use of energy. A study was carried out for the Division of Building Research, National Research Council of Canada, by the associated firms of Vinto Engineering Ltd., and Yoneda and Associates Ltd. [1] to provide guidance to standards-writing bodies regarding the factors to be taken into account in setting energy budgets consumption levels. The study was also designed to illustrate how energy should be adjusted to take variations of these factors into account. The results of the study showed the relative importance of climatic conditions, hours of use of office space, and building size and shape, on the annual energy consumption of office buildings [2]. Mathematical expressions were developed to predict the annual energy consumption in terms of heating and cooling degree days, infiltration rate, envelope-to-floor ratio, hours of operation per day and days of operation per year. The study did not, however, investigate ways to adjust the energy consumption levels to compensate for various extended hours of use such as seasonal or partial overtime operations. The latter cases usually occur when small groups of building occupants work periods of overtime in large office buildings.

This study, therefore, is aimed at investigating the connection between annual energy consumption in office buildings and the number of operating hours per year, low levels of partial occupancy and the use of office space for extended hours during heating and cooling seasons. Finally, a simple method of adjusting the reference energy budgets of this class of building is suggested to compensate for various annual hours of office space operation other than that used in the reference energy budgets.

OCCUPANCY AND LIGHTS PROFILES - VINTO AND YONEDA STUDY

Operating profiles for 8, 12 and 16 hours per day were established, patterned on contemporary building operation, and 5, 6 and 7 days/week occupancy were studied [2]. Figures 1, 2 and 3 show the percentage variation profiles for people and lights for 8, 12 and 16 hours of operation per day respectively. It was assumed that cleaning and security staff represent 10 per cent of the design capacity of the building and occupy the space for four hours and that, for security reasons, 5 per cent of the full lights capacity are turned on when the building is not used.

The 8-hour profile (Figure 1) shows that the occupancy level drops from 100 per cent to 10 per cent at 4:00 p.m., while the lights load decreases by about 20 per cent every hour from 5:00 p.m. to 8:00 p.m. The 12-hour profile (Figure 2) was intended to reflect a regular 8-hour working day followed by a 4-hour overtime period [1]. The occupancy profile was similar to the 8-hour profile but at 4:00 p.m. the building remained occupied for 1 hour at 80 per cent maximum load and for 3 additional hours at 50 per cent load. It was assumed that the janitorial work was performed during the overtime period as this seemed to be common practice. The lights profile was similar to the

8-hour profile until 4:00 p.m. From 4:00 to 5:00 p.m. the lights level was maintained at 95 per cent and then reduced to 75 per cent for the remainder of the overtime and janitorial period. Fans were operated from 7:00 a.m. to 8:00 p.m; this included the morning preconditioning period.

The 16-hour profile (Figure 3) was intended to simulate the two 8-hour work shifts. Because the building was occupied until midnight, it was assumed that janitorial work did not follow immediately thereafter, but began four hours prior to morning occupancy. The lights profile assumed that the janitors turned on lights as cleaning progressed, in the same manner as they extinguished them when the cleaning was done immediately after work hours. Fan operation began at 7:00 a.m. for preconditioning and ended at midnight.

ENERGY CONSUMPTION CORRELATION

A brief description of the office building used in the Vinto and Yoneda study [1] is given in Appendix A. The Meriwether Energy Systems Analysis (ESA) program was used to calculate energy requirements when the previously described profiles of use were implemented. Table 1 gives a summary of the results, as reported in Reference 1, showing the number of days of use per year, the number of hours per day and the total energy consumption for each case.

The energy consumption data in Table 1 was used to develop a linear relationship correlating hours of operation per day and days of operation per year with the annual energy consumption. The result was expressed as:

$$E = 2.9\ D_y + 59.7\ H_d - 222 \qquad (1)$$

where

E = energy consumption $MJ/m^2 \cdot yr$.

D_y = days of operation per year $(252 \leq D_y \leq 365)$

H_d = hours of operation per day $(8 \leq H_d \leq 16)$

A comparison between the energy consumption data in Table 1 and the corresponding values predicted by Equation 1 is shown in Figure 4.

OUTLINE OF THE PRESENT STUDY

This study investigated the effects of various occupancy profiles and hours of use of office space on the annual energy consumption of office buildings. Particular emphasis has been placed on cases where the office space is used for an extended number of hours (overtime) at various levels of occupancy. The use of office space during overtime periods in summer and winter months was also studied to investigate the effects of seasonal operation on the annual energy consumption.

Table 2 gives a summary of the various occupancy profiles used in this study. The 24-hour profile represents the use of office space for 3 consecutive shifts per day, as shown in Figure 5.

Common practice in office buildings proves that only a small percentage of the total occupancy use the office space for a limited number of hours after the normal 8-hour daily operation. To simulate this situation, the 8-hour profile was changed to account for 2 overtime periods of 4 and 6 hours (Figures 6 and 7). It was assumed that the occupancy level during these overtime periods varied between 5 and 15 per cent of the design occupancy (in addition to the cleaning and security staff). The 8-hour lights profile was used without change, in the case of the 4-hour overtime, because lights level was believed to be adequate between 5:00 and 8:00 p.m. (Figure 1). In the case of the 6-hour overtime, lights profile was extended from 7:00 p.m. to 10:00 p.m. at 30 per cent of the design lights level, and then reduced to 5 per cent from 10:00 p.m. to 7:00 a.m. (Figure 7). During the 4- and 6-hour overtime operation, it was assumed that the HVAC system was in full operation to provide comfortable conditions in the office. This assumption is debatable, however, since the design of the air handling systems varies from one office building to another.

Use of an office building during extended hours in summer or winter months is illustrated by people and lights profiles as shown in Figure 8. For example, during winter overtime operation the building is used for 16 hours a day, 5 days a week, whereas the rest of the year, the 8-hour profile is applied. This can be illustrated as follows:

Months	Hours of Use
1. December, January, February and March	16 hours per day 5 days per week
2. April to November (inclusive)	8 hours per day 5 days per week

Profile 10 (summer overtime) describes the use of the office space as follows:

Months	Hours of Use
1. June, July, August and September	16 hours per day 5 days per week
2. October to May (inclusive)	8 hours per day 5 days per week

Other profiles of use listed in Table 2 are for the study of extreme cases such as occupying the office space 24 hours a day, 7 days a week (profile 2, Figure 5). On the other hand, when the building is not used all year round, profile 11 is applied assuming 2 night temperature setbacks, 15.6°C and 10°C. Finally, profiles 12 and 13 (Figures 9 and 10 respectively) are used to fill in the gaps in the matrix of profiles studied in Reference 1.

RESULTS

The Meriwether Energy Systems Analysis (ESA) program was used in this study. Equation (1) expresses the annual energy consumption in terms of the number of days per year and the number of hours per day the space is occupied, but is bounded by the following conditions:

D_y between 252 and 365,

H_d between 8 and 16.

To extend the range of application of this equation, energy analyses using profiles 2, 9, 10, 11, 12 and 13 were carried out to derive an expression for annual energy consumption in terms of the hours of use per year.

In general, the annual energy consumption per square metre of office space increased as the hours of use increased. This is illustrated in Table 3. Using that data and utilizing linear regression routines, a straight line relationship was obtained between the annual energy consumption and the hours of use of space per year (Figure 11). This relationship is expressed as:

$$E = 746 + 0.1696\ H_y \tag{2}$$

where

E = annual energy consumption $MJ/m^2 \cdot yr$.

H_y = number of hours the space is used per year h/yr

The constant 746 in Equation (2) represents the energy consumption of the building when it is not occupied. This constant agrees reasonably well with results obtained by using profile 11, i.e., 0 hour, 0 day profile where the calculated energy consumption was 756.4 $MJ/m^2 \cdot yr$, as shown in Table 3.

Since the study in Reference 1 was made using a night temperature setback of 15.6°C, it seemed reasonable to keep the night setback the same for the various profiles applied in this study. However, to show the effect of night setback on the base energy consumption of the building (0 hr/day, 0 days/yr), profile 11 was used with a night setback of 10°C instead of 15.6°C. A 4 per cent decrease in the annual energy consumption was realized by this change in the night setback (756.4 $MJ/m^2 \cdot yr$ at 15.6°C and 724.2 $MJ/m^2 \cdot yr$ at 10°C.

The difference in energy consumption caused by working the same amount of overtime at different seasons of the year (winter and summer) was determined. When the office space was used for overtime in winter, profile 9 was applied and the energy consumption was 1153.6 $MJ/m^2 \cdot yr$; during summer overtime the energy consumption was 1275.6 $MJ/m^2 \cdot yr$.

Because the total number of hours of use of the office space was the same in both cases (winter and summer seasons), the difference in the annual energy consumption was due to the effect of seasonal weather variations. A comparison between heating, cooling loads, electric and gas consumption for summer and winter overtime uses is given in Table 4. As shown there was no significant change in the annual heating load between summer and winter overtime operation. On the other hand, overtime during the summer months resulted in a 59 per cent increase in the annual cooling load and 11 per cent more energy usage than if the overtime was worked in winter.

Assume that the office space is used for the same number of hours per year as that of the combined normal and overtime periods (2760 hours per year). From Equation 2, the annual energy consumption would be 1213.9 $MJ/m^2 \cdot yr$ which is midway between the summer and winter overtime energy consumption figures. This suggests that, in similar climates, potential energy savings exist when office space is used for extended periods of time during the winter and for a shorter number of hours during summer months. Nevertheless, implementation of such a suggestion may be difficult, since controlling the timing and duration of overtime periods is not always feasible.

The level of occupancy during overtime periods is expected to contribute to increasing the annual energy consumption of office space. The magnitude of this increase is difficult to define because it depends on several factors, one of which is the design and layout of the air handling system in the building. To study the effect of partial occupancy of office space during overtime periods, profile 1 (8 hours/day, 5 days/week) was changed to accommodate the assumed variations in occupancy levels and the periods of use.

First, it was assumed that the office space is used for 4 hours overtime at 3 different levels of occupancy namely 5, 10 and 15 per cent of full occupancy (profiles 3, 4 and 5 (Figure 6)) respectively. The results (Table 5) show that changing the level of occupancy during the 4 hours overtime period from 5 to 15 per cent did not result in a significant increase in the annual energy consumption. The average energy consumption of 1157.5 $MJ/m^2 \cdot yr$, from Table 5, is about 11 per cent higher than that of profile 1 (8 hours per day, 5 days per week), see Table 3. On the other hand, when the building is used at full capacity for the same number of hours (3120 h/yr), the estimated energy consumption, using Equation (2), is 1274.8 $MJ/m^2 \cdot yr$.

Secondly, it was assumed that the office space is used for 6 hours overtime at the same three levels of occupancy, i.e., 5, 10 and 15 per cent. This is illustrated by profiles 6, 7 and 8 respectively in Figure 7. In this case, the annual energy consumption did not change significantly as a result of changing the occupancy level (see Table 6). However, the average energy consumption (1198.5 $MJ/m^2 \cdot yr$) is about 15 per cent higher than that of profile 1 (8 hours per day, 5 days per week). Also, when the building is used at full capacity for the same number of hours (3640 h/yr), then the estimated energy consumption, from Equation (2), is 1363 $MJ/m^2 \cdot yr$.

These results suggest that during overtime the low occupancy period level in the office space (up to 25 per cent) is not a significant parameter affecting energy consumption of the office building. Nevertheless, the hours of operation during which lights, heating, and cooling systems are turned on is an important factor to be considered when setting energy budgets for this type of building. Meanwhile heating, cooling, and air handling systems design and layout in a building have a direct effect on the net energy consumption especially during partial occupancy and overtime periods of space use.

When setting energy budgets for office buildings according to some basic conditions (building size and shape, climate, hours of operation, etc.) they could be adjusted to account for any number of hours of operation different from the reference number.

Assuming that the base energy budget E^* is calculated using a base hours of use per year H_y^*, then:

$$E^* = a + b\,H_y^* \tag{3}$$

The constant a in Equation (3) depends mainly on the building construction and its location, i.e., weather. For other annual operating hours of office space H_y, the base energy budget could be adjusted as follows:

$$E = a + \frac{(E^* - a)}{H_y^*}\,H_y \tag{4}$$

Although the linear relationship between annual energy consumption and hours of operation of office space was proved to be acceptable in the case studied, it is essential to examine this linearity for other geographical locations. To do so, appropriate office building models could be used to perform similar energy analysis applying various profiles of use to cover a wide range of hours of operation.

CONCLUSION

It is often assumed that the annual energy consumption in an office space is a monotonic increasing function of the number of hours per year during which the space is used. A simple linear relationship was derived to confirm this assumption by studying a large office building over a range of hours of use of between 0 and 8760 h/yr.

There are three elements that influence the net annual energy consumption: season of the year (summer or winter), number of hours of overtime and level of occupancy. This study showed that the level of occupancy during overtime periods has the least effect on the annual energy consumption, and that overtime use of office space is a significant factor to be considered when setting energy budgets for office buildings.

Finally, it is possible that reduction in the annual energy consumption of office buildings could be achieved by working for longer periods of overtime during the winter season and for fewer overtime hours during the summer season. It would be constructive to investigate the situation for other office buildings and climates since this study dealt only with one office building in one location. Also, further study is needed to investigate the interaction between the annual energy consumption of office buildings and various types of heating, cooling, and air handling systems design and layout.

REFERENCES

1. Vinto Engineering Ltd., and Yoneda and Associates Ltd., "Study of Energy Consumption of Office Buildings". Prepared for Division of Building Research, National Research Council of Canada, April 1979.

2. Bourassa, G.F., J.K. Latta, et al., "Canadian Experience Regarding the Preparation of Energy Budgets for Office Buildings". Submitted to Second International CIB Symposium on Energy Conservation in the Built Environment, Technical University of Denmark, Lyngby, 28 May - 1 June 1979.

TABLE 1

RESULTS OF MANIPULATION OF HOURS AND DAYS OF USE [1]

Days of Use per Week	Energy Consumption $MJ/m^2 \cdot yr$		
	Hours of Use per Day		
	8	12	16
7(365 days/yr)	1270	-	1840
6(304 days/yr)	1149	-	-
5(252 days/yr)	1043	1200	1436

TABLE 2

SUMMARY OF OCCUPANCY AND LIGHT PROFILES

Profile	Fig. No.	Description
1	1	8 hr/day - 5 days/week
2	5	24 hr/day
3	6	8 hr/day - 5 days/wk + 5% for 4 hr
4	6	8 hr/day - 5 days/wk + 10% for 4 hr
5	6	8 hr/day - 5 days/wk + 15% for 4 hr
6	7	8 hr/day - 5 days/wk + 5% for 6 hr
7	7	8 hr/day - 5 days/wk + 10% for 6 hr
8	7	8 hr/day - 5 days/wk + 15% for 6 hr
9	8	Winter overtime schedule
10	-	Summer overtime schedule
11	-	0 hr - 0 day
12	9	12 hr/day - 6 days/wk
13	10	16 hr/day - 6 days/wk

TABLE 3

TOTAL ENERGY CONSUMPTION FOR VARIOUS HOURS OF USE

Profile	Hours per Year	Total Energy Consumption $MJ/m^2 \cdot yr$
No. 11	0	756.4
No. 1	2016	1043.1*
8 hr/day 6 days/week	2432	1148.9*
No. 9	2760	1153.6
No. 10	2760	1275.6
8 hr/day 7 days/week	2920	1270.2*
12 hr/day 5 days/week	3024	1200.5*
No. 12	3744	1362.1
16 hr/day 5 days/week	4032	1436.1*
No. 13	4992	1658.1
16 hr/day 7 days/week	5840	1840.2*
No. 2 (6 days/week)	7488	1961.5
No. 2 (7 days/week)	8760	2199.1

* Reference 1

TABLE 4

EFFECT OF SEASONAL USE OF OFFICE SPACE ON THE ANNUAL ENERGY CONSUMPTION

	Energy Consumption $MJ/m^2 \cdot yr$	Gas Consumption M^3/yr	Electric Consumption GJ/yr	Heating Load GJ/yr	Cooling Load GJ/yr
Winter overtime (Profile 9)	1153.6	232170	5020	3850	1016
Summer overtime (Profile 10)	1275.6	267198	5140	3869	1618

TABLE 5

ENERGY CONSUMPTION FOR PARTIAL OCCUPANCY OF 4 HOURS OVERTIME

	8 hours per day, 5 days per week plus:		
	5% Occupancy	10% Occupancy	15% Occupancy
Cooling load GJ/yr	1257	1264	1269
Heating load GJ/yr	4163	4154	4144
Electric consumption GJ/yr	4471	4473	4476
Gas consumption m^3/yr	246293	247369	248416
Energy consumption $MJ/m^2 \cdot yr$	1153.6	1157.5	1161

TABLE 6

ENERGY CONSUMPTION FOR PARTIAL OCCUPANCY OF 6 HOURS OVERTIME

	8 hours per day, 5 days per week plus:		
	5% Occupancy	10% Occupancy	15% Occupancy
Cooling load GJ/yr	1318	1326	1334
Heating load GJ/yr	4200	4183	4168
Electric consumption GJ/yr	4695	4699	4702
Gas consumption m^3/yr	253003	254448	255977
Energy consumption $MJ/m^2 \cdot yr$	1193.5	1198.5	1203.6

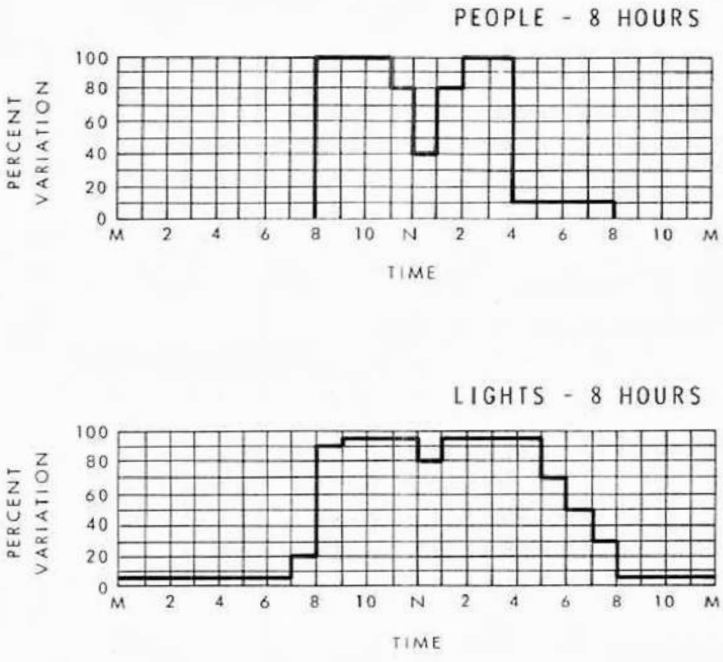


FIGURE 1

PEOPLE AND LIGHTS PROFILES

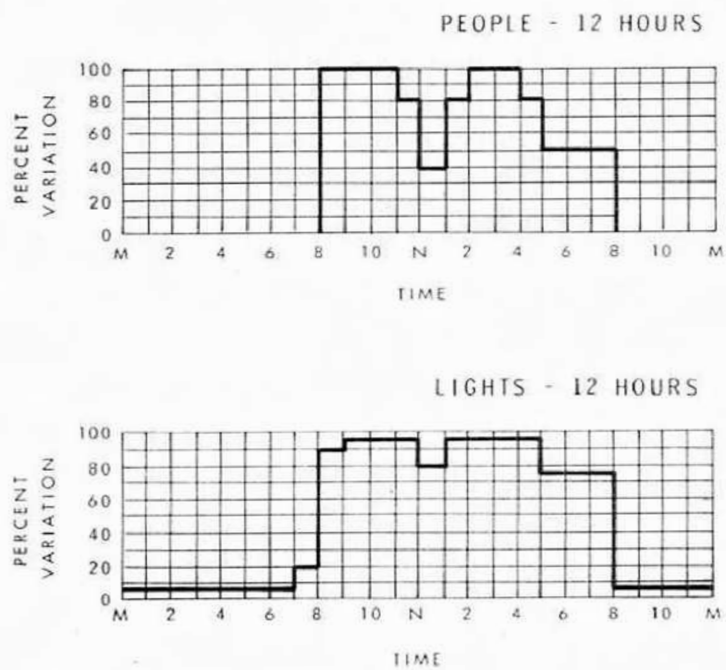


FIGURE 2

PEOPLE AND LIGHTS PROFILES

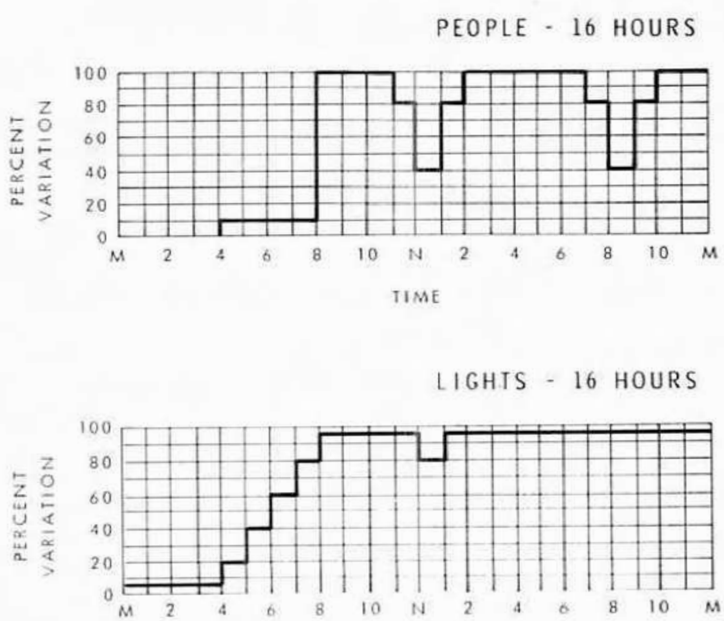


FIGURE 3

PEOPLE AND LIGHTS PROFILES

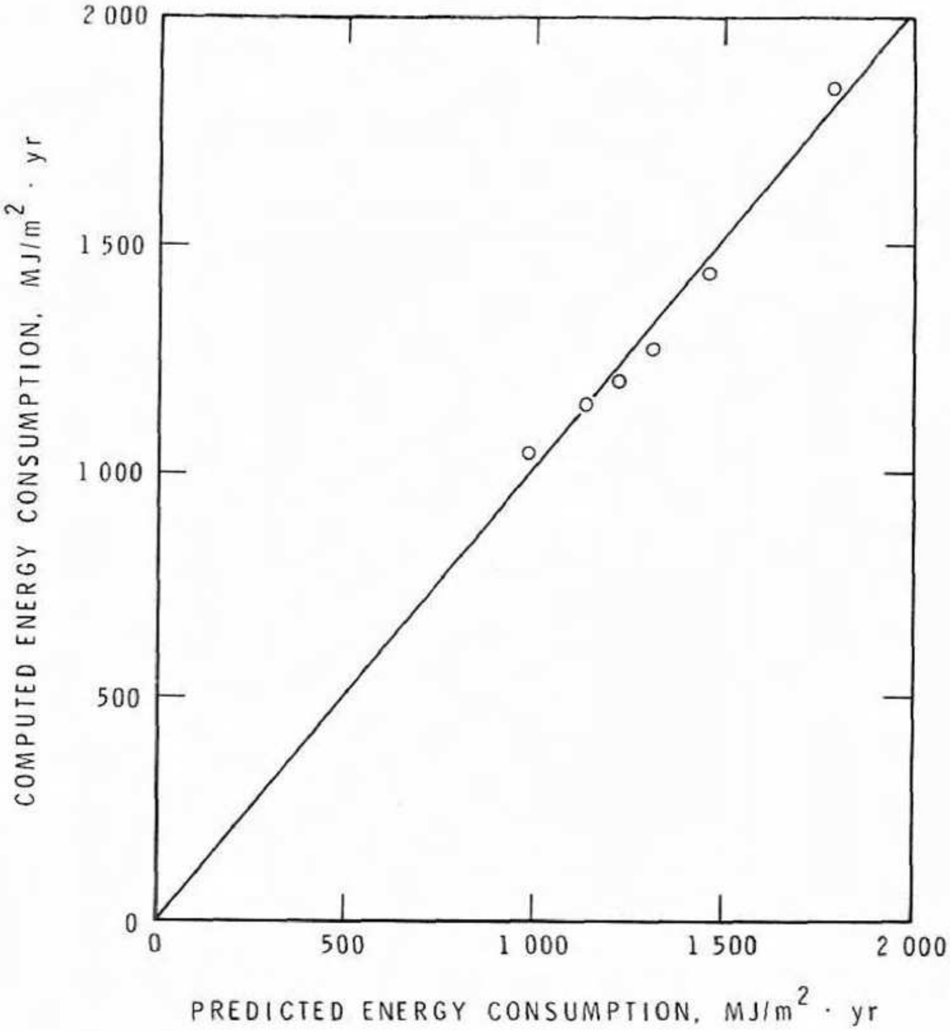
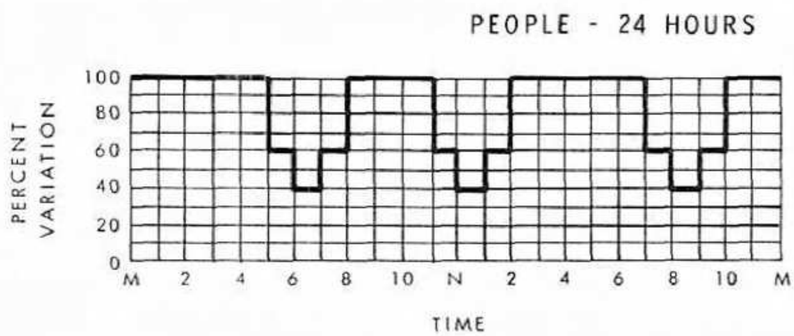


FIGURE 4

COMPARISON OF COMPUTED AND PREDICTED ENERGY CONSUMPTION (4)



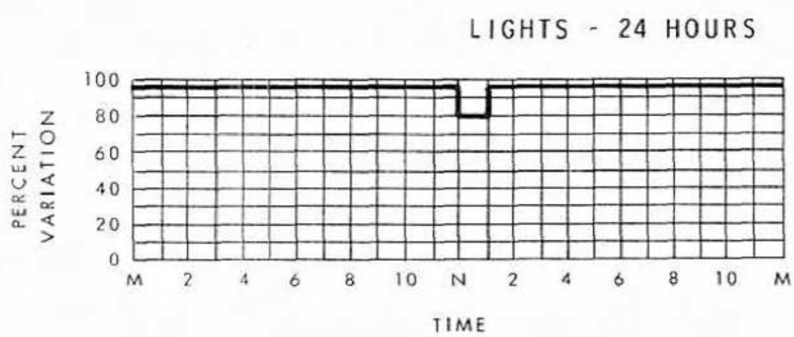


FIGURE 5

PEOPLE AND LIGHTS PROFILES

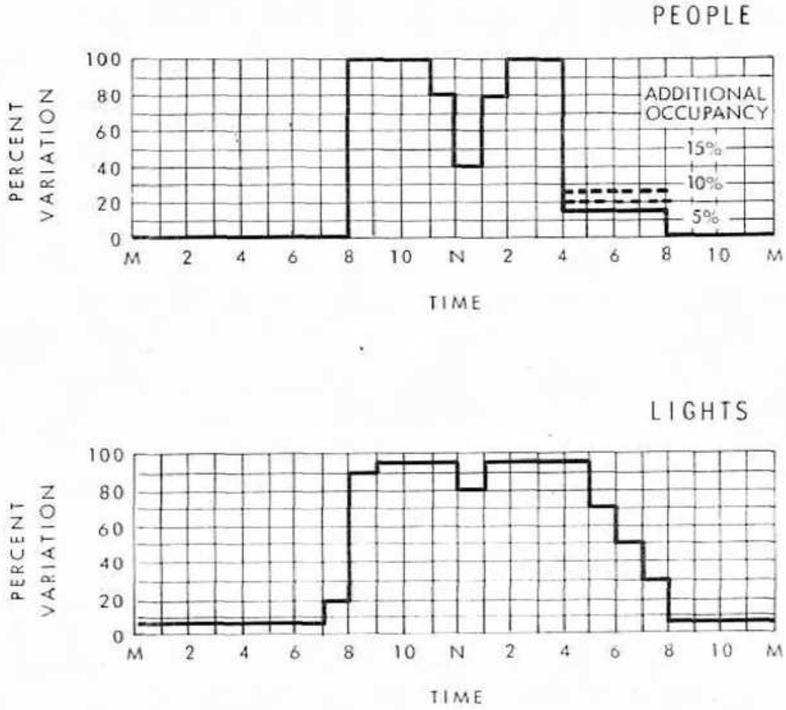


FIGURE 6

PEOPLE AND LIGHTS PROFILES FOR 4 HOURS OVERTIME (5, 10 AND 15% OCCUPANCY)

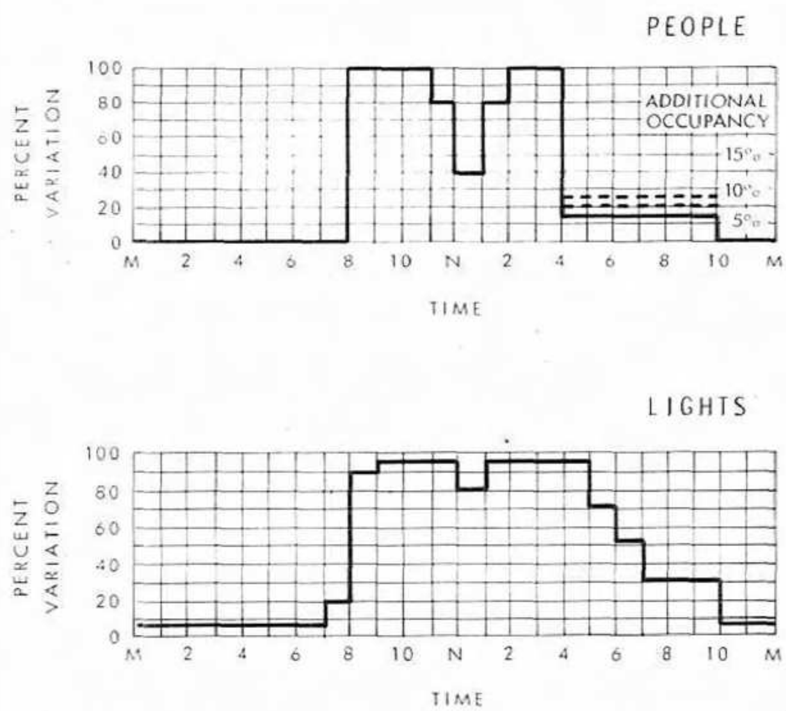


FIGURE 7

PEOPLE AND LIGHTS PROFILES FOR 6 HOURS OVERTIME (5, 10 AND 15% OCCUPANCY)

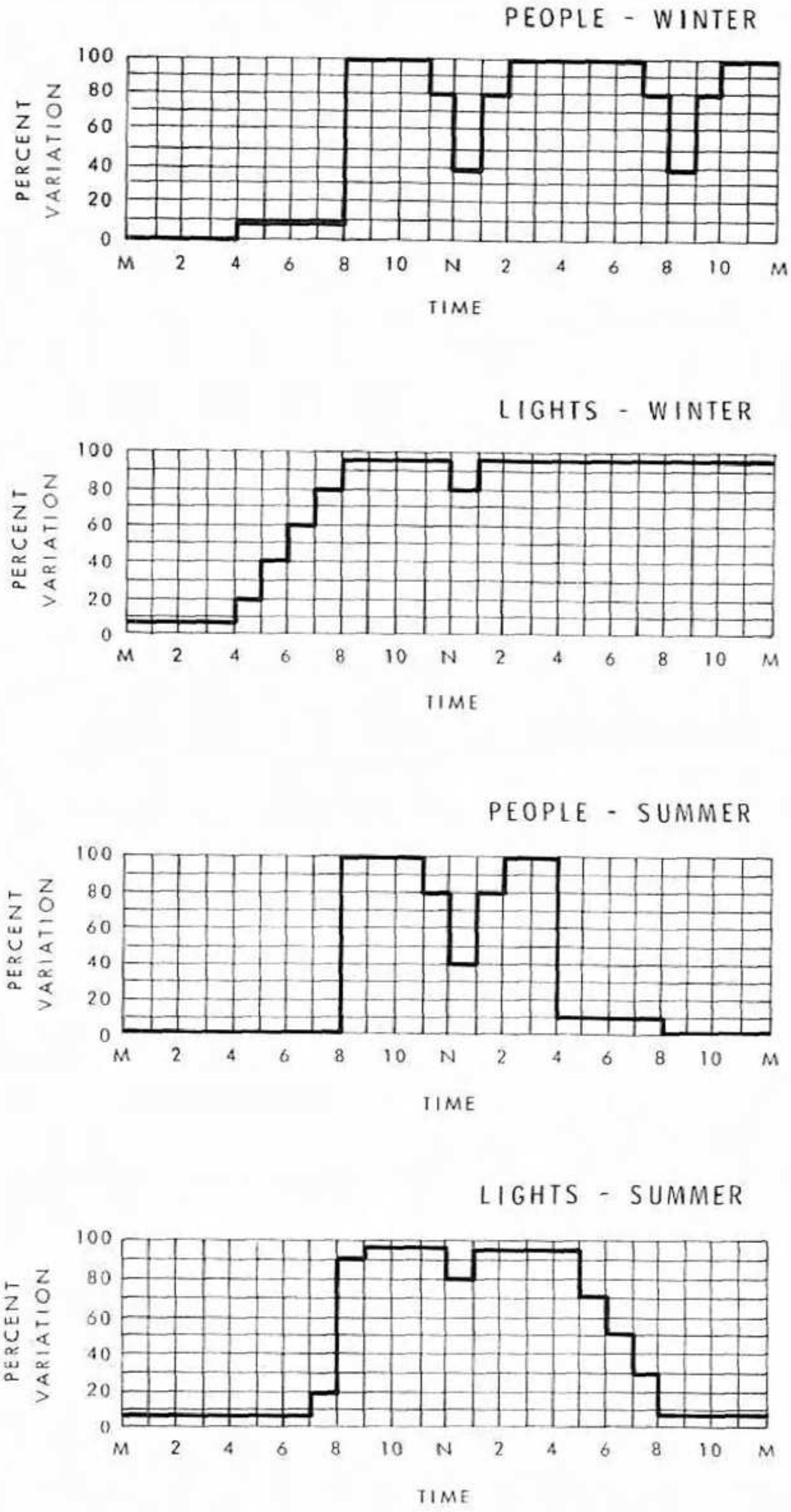


FIGURE 8

PEOPLE AND LIGHTS PROFILES FOR WINTER OVERTIME AND NORMAL SUMMER OPERATION (THESE PROFILES ARE USED FOR SUMMER OVERTIME AND NORMAL WINTER OPERATION)

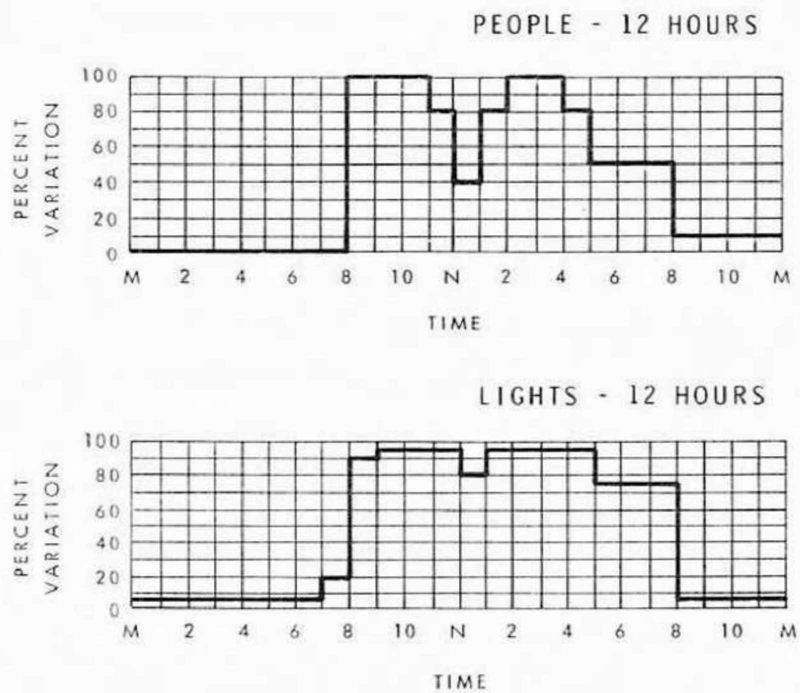


FIGURE 9
PEOPLE AND LIGHTS PROFILES

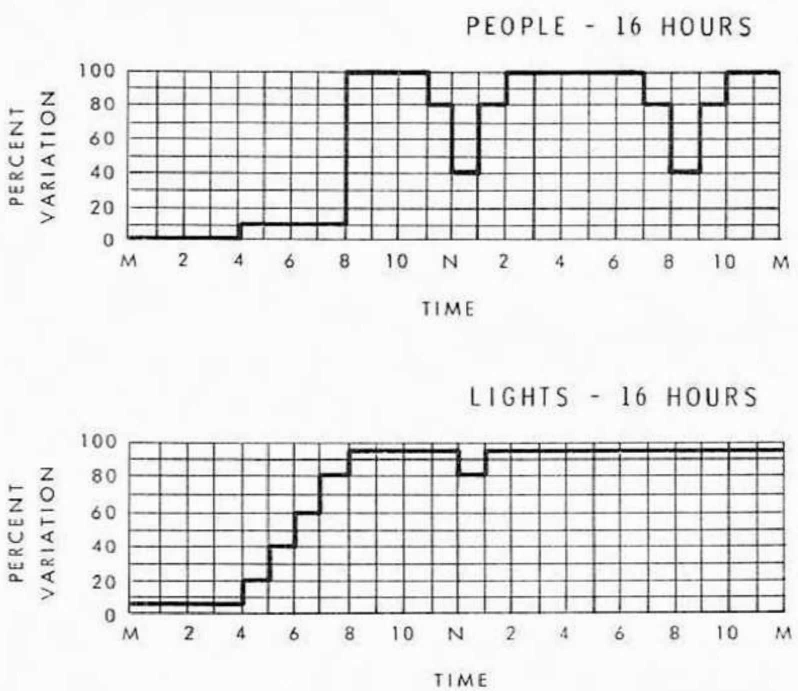


FIGURE 10
PEOPLE AND LIGHTS PROFILES

APPENDIX A

BUILDING DESCRIPTION

The office building used in this study is 12 storeys in height and has a total floor area of 12224 m^2. The building envelope is of precast cavity wall construction, with clear double glazed window units of approximately 35 per cent of exposed wall surface area. Building lighting is by fluorescent fixtures, at an installed capacity of 48.4 watts per square metre. There are two levels of parking below grade.

The mechanical system installed in the building is comprised of a medium pressure single duct variable volume system with minimum volume setting of 25 per cent of full air flow to the terminal units. Operation of the variable volume regulators is controlled by space thermostats. The system also has an economizer cycle to take advantage of outdoor air cooling. The heating plant is comprised of two gas-fired boilers, which produce hot water for both heating and cooling (by means of absorption chiller).

The 8 hours per day, 5 days per week profile (2016 hours per year) shown in Figure 1, resulted in a total energy consumption of 1043 $MJ/m^2 \cdot yr$ [1]. This result was based on the following conditions:

Location: Edmonton, Alberta	
Thermostat setting (heating):	21°C DB
	-8°C DP
Winter outdoor design conditions:	-34°C DB
	-34°C DP
Night set back temperature: (all year around)	15.6°C DB
Thermostat setting (cooling):	24.5°C DB

Shutoff and setback time schedules:

Week days: System is on only from 7:00 a.m. to 6:00 p.m.

Weekends: System is off all the time

This set of conditions is used when studying the extended periods of occupancy, but only the shutoff and setback time schedules are changed to agree with the occupancy profile.

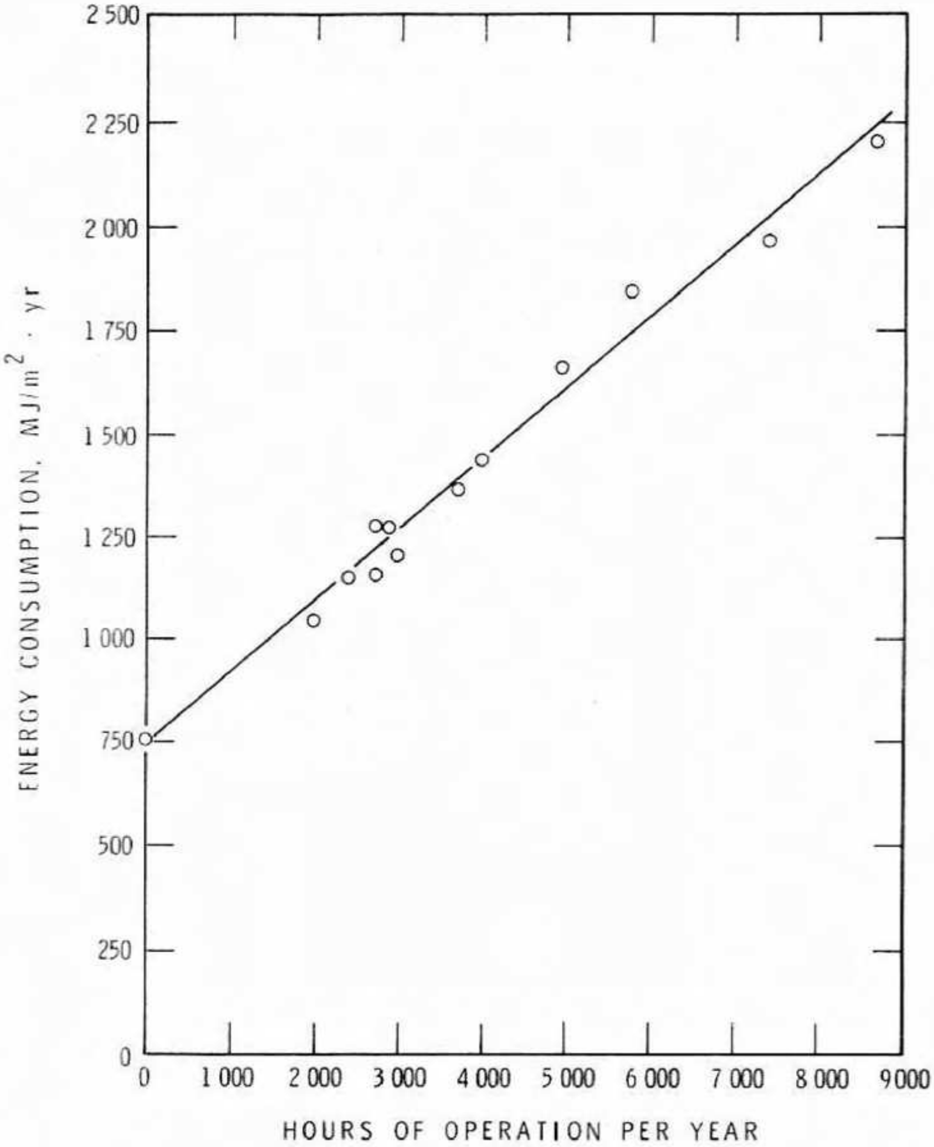


FIGURE 11

CORRELATION BETWEEN ANNUAL ENERGY CONSUMPTION AND THE NUMBER OF HOURS OF SPACE USE PER YEAR