FIELD ASSESSMENT OF DAYLIGHTING SYSTEMS

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SYNOPSIS

FIELD ASSESSMENT OF DAYLIGHTING SYSTEMS

Recently a few new Canadian buildings have been touted as "daylight buildings", designed to incorporate the best daylighting principles. From an energy efficiency point of view, the use of daylighting implies reduced electrical and cooling energy consumption by replacing some of inefficient artificial lighting with free solar lighting. Suspicion has been that energy savings are seldom realized, at least to the extent projected, and an extensive energy-use study was undertaken of two new daylit Calgary buildings. One structure was a high school and the other a university building mainly comprised of offices and classrooms. The two-storey high-school was designed with a stepped cross-section to introduce daylight at points other than the perimeter of the building. Ceilings in the university building were tilted up at the perimeter to accommodate higher windows and allow deeper daylight penetration. The windows were also equipped with a dual upper-lower blind system to allow more extensive control of daylight admission and glare.

The objectives of the study were to measure detailed energy consumption in each of the buildings, review use of daylighting and investigate opportunities for more effective exploitation of it, and use monitored data to validate daylighting simulation programs.

As suspected, daylighting was not doing much to reduce energy consumption in either building. Daylighting was used as an aesthetic quality, drawing accolades from building occupants and visitors, but not an effective energy efficiency measure. In fact, both buildings consumed more energy than other comparable buildings and as much as was typical of pre-70's levels. Surprisingly, it was learned that lighting accounted for only about ten percent of energy use (and represents the maximum that could possibly be exploited with daylighting), while energy for fans and tempering of ventilation air accounted for about fifty percent of energy used in the buildings. More efficient use of electrical lighting, increased plug loads for office equipment, and new more stringent ventilation air requirements have greatly changed the energy use patterns in these types of buildings in recent years. The net effect is usually less energy consumption but , in some instances, can lead to levels as high as in buildings constructed twenty-five years ago.

The target buildings had several factors against them in trying to exploit daylighting. Deep floor plans made it difficult to use daylight in many areas. Low fraction of lighting loads and low electricity prices in this region meant payback for elaborate dimming systems was prohibitive. In addition, better, perhaps automatic, blinds would have to be installed to reduce glare and encourage occupants to turn off lighting when not needed. On a more positive side, in some daylit spaces of the university building, electrical lighting use was as low as has been reported in demonstration energy-efficient buildings. Finally, lighting seemed to have little effect on cooling energy requirements, probably because of the extensive free-cooling available in the Calgary climate.

Both building were modelled with DOE2 and validated with monitored data. The models proved useful to confirm energy use patterns and review impact of daylighting strategies. Simulations of the buildings with weather data for other regions of Canada confirmed that the energy-use patterns for these two particular buildings were high by standards in all locations.

SOMMAIRE

ÉVALUATION DE PROJETS D'ÉCLAIRAGE NATUREL

Récemment, on a construit au Canada quelques nouveaux immeubles dits «à éclairage naturel», conçus dans le but d'intégrer au maximum la lumière du jour. Du point de vue de l'efficacité énergétique, l'utilisation de la lumière naturelle entraîne une réduction de la consommation d'électricité et d'énergie de refroidissement, attribuable au remplacement de moyens inefficaces d'éclairage artificiel par une source gratuite, l'énergie solaire. On soupçonnait que l'éclairage naturel fourni par la lumière du jour apportait rarement des économies d'énergie, du moins dans la perspective adoptée. Une étude énergétique approfondie a donc été menée sur deux nouveaux immeubles de Calgary éclairés en lumière naturelle, une école secondaire de deux étages ainsi qu'un bâtiment universitaire composé essentiellement de bureaux et de classes. L'école secondaire a été aménagée en gradins, concept qui permet de laisser entrer la lumière du jour par des parois autres que celles qui composent sa périphérie. Dans le cas du bâtiment universitaire, les plafonds inclinés de la périphérie autorisent des fenêtres de grande hauteur, ce qui en retour laisse pénétrer la lumière du jour plus loin vers l'intérieur des étages. Les fenêtres sont équipées d'un système de stores inférieurs et supérieurs grâce auxquels on peut mieux intervenir pour contrôler la lumière et l'éblouissement.

L'étude avait pour but de mesurer en détail la consommation d'énergie de chaque bâtiment, d'analyser l'utilisation de la lumière naturelle et d'explorer les possibilités d'une exploitation plus efficace de ce principe et enfin de mettre à profit les données cueillies pour valider des programmes de simulation d'éclairage en lumière naturelle.

Comme on s'en était douté, l'éclairage naturel n'apportait de réduction importante de la consommation énergétique dans aucun des bâtiments étudiés. L'utilisation de la lumière naturelle se faisait remarquer davantage par sa qualité esthétique et par l'appréciation que les occupants et les visiteurs ont manifesté; cependant, ce système n'était pas énergétiquement efficace. En réalité, les deux bâtiments affichaient une consommation d'énergie supérieure à celle de constructions comparables; leur profil de consommation était en outre davantage apparenté à la consommation type des constructions similaires antérieures aux années soixante-dix. Étonnamment, on a appris que l'éclairage comptait pour seulement dix pour cent de la consommation totale d'énergie (maximum réalisable avec l'éclairage naturel), alors que l'énergie consacrée au fonctionnement des ventilateurs et des appareils de conditionnement d'air représentait environ quinze pour cent de l'énergie totale pour ces bâtiments. Au cours des dernières années, l'utilisation plus efficace de l'éclairage électrique, les charges électriques plus élevées de matériel de bureau et des exigences

plus rigoureuses en matière de ventilation ont beaucoup contribué à modifier les profils de consommation de ces immeubles. Au total, on a obtenu une réduction de la consommation, mais dans certains cas, la consommation peut être aussi élevée que celle d'immeubles construits il y a vingt-cinq ans.

Dans les bâtiments cibles, plusieurs facteurs jouaient contre l'exploitation de la lumière naturelle. À cause des grandes surfaces, il était difficile, dans beaucoup d'espaces, d'utiliser cette source naturelle. Avec le faible pourcentage que l'éclairage occupait dans la charge totale d'énergie et les bas tarifs d'électricité pour la région, la rentabilité qu'aurait apporté l'installation de systèmes complexes de contrôle et de gradation de l'éclairage électrique n'était plus aussi intéressante. De plus, il aurait fallu installer des stores améliorés, probablement automatiques, pour réduire l'éblouissement et encourager les occupants à éteindre l'éclairage lorsqu'ils n'en ont pas besoin. L'aspect positif de la chose, c'est que dans certains espaces du bâtiment universitaire bénéficiant d'un éclairage naturel, l'utilisation de l'énergie électrique s'est avérée aussi basse que dans des bâtiments pilotes à haute efficacité énergétique. Enfin, l'éclairage semblait avoir peu d'effet sur les besoins en énergie de refroidissement, probablement à cause de la grande possibilité de refroidissement par échange avec l'extérieur que permet le climat de la région de Calgary.

Les deux bâtiments ont fait l'objet d'une modélisation sur DOE2 et leur performance a été validée au moyen des données cueillies. Les modèles se sont révélés utiles dans la confirmation des profils de consommation et pour l'étude de stratégies faisant appel à l'éclairage naturel. Des simulations de ces bâtiments avec des données climatiques applicables aux autres régions du Canada ont confirmé que la consommation de ces derniers était élevée par rapport aux normes.

EXECUTIVE SUMMARY

The objectives of this study were to:

1. quantify the energy end uses in two buildings with fenestration designed to exploit daylighting by carrying out both frequent measurement of aggregate energy use and by detailed measurement of system level energy use in selected zones,

2. Determine the energy utilization of these buildings if efforts are made to optimize the use of the electric lighting system (i.e., taking greater advantage of opportunities for more efficient operation and exploitation of daylight available in the buildings), and

3. to use the data collected through the energy use monitoring program to validate computer simulation models of the buildings and, in turn, use the validated simulation models to estimate the performance of the designs for west coast, central Canadian and maritime climate zones.

The two Calgary buildings that were addressed in this study, Lester B. Pearson High School (14, 000 m^2 gross floor area) and the Professional Faculties Building at The University of Calgary (26, 000 m^2) were occupied in 1991 and 1993 respectively, with commissioning and other work extending into late 1994 in the case of the university building. The high school is a two-storey building and the university building is a four-storey building, both with very deep floor plates.

The simulation model, after validation with measured data, was used to estimate energy use for several Canadian locations: Halifax, Montreal, Toronto, Winnipeg, Edmonton, and Vancouver. These are cities for which Typical Meteorological Year weather data are available, data files that are representative of long term conditions. The specific energy use for the school ranged between 240 and 400 kWh/m^2 and for the university building between about 500 and 700 kWh/m^2 (Vancouver versus Winnipeg in both cases). This is in the vicinity of the 470 kWh/m^2 considered to be typical for pre-1973 office buildings, but much higher than would be expected of energy-efficient commercial buildings.

Electricity use for lighting amounted to 10 percent or less of total energy use for the high school and the university building respectively, which is a much lower fraction than has been reported in the literature. This appears to be the result of a few factors. Lighting power densities have dropped in recent construction and are continuing to decline with the increasing use of T8 fluorescent lamps and electronic ballasts. Ventilation and air circulation rates have increased due to concerns about indoor air quality, which has increased electricity used in fans and cooling, as well as natural gas use for heating of outdoor air.

It was found that the specific energy use (annual energy use in kWh/m^2) for the daylit high school was near the median for other Calgary six high schools for which energy use data were obtained. However, a much higher fraction of energy use at the daylit high school was in the form of electricity. This is also consistent with much more energy being used for fans and tempering of ventilation air in the more recently constructed building.

Lighting energy use was about 30 kWh/m^2 for the school and about 24 kWh/m^2 for the Professional Faculties Building (if night-time illumination of the 24 hour circulation system is discounted in the latter case), while values of 40-50 kWh/m^2 have been identified as typical of several energy efficient buildings. This is still above the 10-20 kWh/m^2 that has been achieved in some daylit buildings. However, the two buildings that were studied have deep floor plates and much more windowless space than most of these other projects. They also have requirements that preclude the completely open plan design used in some other deep-plan daylit buildings analyzed in the literature.

In some perimeter areas of the Professional Faculty Building, lighting energy use is in the vicinity of the 5 kWh/m^2 annually that was achieved with manual switching at the BRE Low Energy Office. This performance is commonly achieved where little or no glare is experienced from direct sunlight (e.g., in east- and north-facing spaces). In these areas, daylighting features such as high-reflectance interiors, high visible transmittances, the high window heads, and the dual upper-lower shading systems appear to be successful in providing natural lighting conditions that meet the occupants requirements. Electric lighting is used much more heavily in south-facing areas, which is consistent with other research findings on the use of electric light to offset glare from windows.

Experimental evaluation of a daylight-linked dimming system in a south-facing test area of about 60 m^2 in the Professional Faculties Building indicated that payback periods of about five years could be achieved under ideal conditions for energy saving (blinds open all the way all the time) with a marginal electricity cost of $0.08 per kWh. However, with the blinds as set by the users (almost completely closed to exclude direct sunlight), the simple payback period would be about 20 years. In Alberta payback periods are considerably longer due to lower marginal electricity costs.

At the school, staff generally seem to use electric lighting in the classrooms and other spaces even when there appears to be adequate daylight. The differences in use of electric lights in spaces that appear to be adequately daylit (i.e., relatively glare-free and adequate levels of illumination) in the two buildings indicates that a better understanding of the factors that affect switching is still needed, as this has not been extensively addressed in the literature.

Comparative tests at the school classrooms that were set up for assessment of lighting effects on cooling requirements did not show any effects of lighting on cooling.

In summary, more extensive exploitation of daylighting requires 1) the development of an alternative to current window shades or blinds that can both reduce glare and improve the distribution of daylight in perimeter spaces and 2) the development of more cost-effective lighting control strategies.

It is recommended that:

1. field trials be conducted of electric lighting control based on a "manual on-automatic (occupancy-based) off" strategy to determine the performance and cost-effectiveness of such an approach,

2. research be conducted on electric lighting control through dimming based on a more comprehensive strategy to provide combined peak shaving, daylighting-linked dimming. and light system "tuning,"

3. studies be conducted to devise shading or blind systems that admit daylight through the upper portion of windows while preventing direct sunlight from entering the upper and lower portions of windows (it would be useful to test such systems in combination with the control strategies described in 1) and 2) above), and

4. studies be conducted to determine the feasibility and cost-effectiveness of open-loop control in lobby, circulation, and similar areas.

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