PERFORMANCE OF ELECTRO-CHROMIC WINDOWS IN COMMERCIAL BUILDINGS

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EXECUTIVE SUMMARY

This report summarizes the expected performance and economics of electro-chromic (EC) windows in commercial buildings. Electro-chromic devices are typically five-layer coatings applied to glass. The visible and solar transmittance of the electro-chromic layer can be altered by the insertion of electrical ions. Lowering the window transmittance can reduce cooling loads and lighting discomfort (i.e., glare). Lighting energy can also be reduced by combining EC windows with an electric light-dimming system.

The expected performance of EC windows was examined using the SUPERLITE computer program to predict daylighting levels and the ENERPASS program to predict heating, cooling and lighting energy use. The simulations were performed on a typical mid-size office building located in Toronto, Winnipeg and Los Angeles.

Electro-chromic windows by themselves save very little energy in commercial buildings. The combination of EC windows controlled on light level and an electric light-dimming system offers the best combination of energy savings, peak cooling load reduction and lighting comfort. In fact, with this system, a significant capital cost savings is achieved by reducing the size of air conditioning system and eliminating the need for window shading devices. Energy savings and cooling load reductions are greatest in locations with long cooling seasons. The simple payback (incorporating capital cost savings) for the combination of EC windows and electric light-dimming system is between 4 and 10 years in Canada and as low as 1.8 years in the southern U.S.

Electro-chromic coatings are worthy of continued development. EC windows and associated controls, however, need to be developed in tandem with the equipment and controls used for electric light-dimming systems.

RÉSUMÉ

Le présent rapport résume la performance et les facteurs économiques prévus relativement à l'utilisation de fenêtres électrochromes (EC) dans des immeubles commerciaux. Les dispositifs électrochromes sont généralement des revêtements en cinq couches appliqués au verre. La transmittance visible et solaire de la couche électrochrome peut être modifiée par l'addition d'ions électriques. La réduction de la transmittance des fenêtres peut diminuer les charges de refroidissement et l'inconfort d'éclairage (c.-à-d. l'éblouissement). On peut aussi réduire l'énergie d'éclairage en combinant des fenêtres EC et un dispositif de gradation d'éclairage électrique.

La performance prévue de fenêtres EC a été étudiée à l'aide du programme informatique SUPERLITE, qui permet de prévoir les niveaux d'éclairage naturel, et du programme ENERPASS, qui permet de prévoir la consommation d'énergie pour le chauffage, la climatisation et l'éclairage. Les simulations ont été effectuées sur des immeubles à bureaux de taille moyenne types situés à Toronto, Winnipeg et Los Angeles.

Les fenêtres électrochromes elles-mêmes ne permettent qu'une très faible économie d'énergie dans les immeubles commerciaux. La combinaison de fenêtres EC à régulation du niveau de lumière avec un dispositif de gradation d'éclairage électrique constitue la meilleure combinaison pour les économies d'énergie, la réduction de la charge de refroidissement de crête et le confort d'éclairage. En fait, cette combinaison permet des économies importantes sur le plan des coûts d'investissement en réduisant la taille des installations de conditionnement d'air et en éliminant la nécessité de dispositifs pare-soleil pour les fenêtres. Les économies d'énergie et les réductions de la charge de refroidissement sont les plus importantes dans les régions où les saisons de climatisation sont longues. La période de récupération simple (incluant les économies de coûts d'investissement) pour la combinaison de fenêtres EC avec un dispositif de gradation d'éclairage électrique est comprise entre 4 et 10 ans au Canada et n'est que de 1,8 an dans le sud des États-Unis.

La poursuite des travaux de mise au point des revêtements électrochromes est justifiée. Cependant, les fenêtres EC et les commandes associées doivent être mises au point conjointement avec le matériel et les commandes utilisés pour les dispositifs de gradation d'éclairage électriques.

1. INTRODUCTION

1.1 Background

One of the most promising new passive solar technologies, especially in commercial buildings, is the use of electro-chromic coatings in windows. Electro-chromics allow the transmission of a glazing system to be continuously varied in response to an applied voltage. By incorporating a "smart" control strategy, it has been suggested that these windows can be used to reduce lighting and cooling energy consumption to a minimum (see Figure 1.1) [Selkowitz and Lampert, 1989].

Electro-chromic (EC) windows have many other benefits. Electric light-dimming systems and electro-chromic windows can be combined to minimize energy consumption while overcoming problems of glare and variable interior light levels associated with existing systems. EC windows allow the building designer to increase the window area without fear of overheating and glare. Perhaps most importantly, EC windows in conjunction with dimmable lighting systems can significantly reduce peak cooling loads. This reduction saves on air-conditioning plant capacity and air distribution duct size, thereby displacing some of the extra capital cost of EC windows.

The purpose of this report is to determine the expected the thermal performance and cost benefit of EC windows for a variety of climates. The analysis was performed using two computer programs: ENERPASS for building energy analysis and SUPERLITE for lighting analysis.

1.2 Theory of Electro-Chromic Coatings

There are two types of optical switching films that can control the amount of light transmitted through windows: dispersed liquid crystal devices (LCD) and electro-chromic devices. In LCD's, liquid crystal droplets are dispersed in a polymeric medium which is laminated between two transparent conductor layers. These devices operate only in on-off mode usually switching from highly transparent to diffuse. The lack of modulation and the diffuse transmission means that these devices are likely limited to control of glare when visual clarity is not important (e.g., skylights). (Photochromic and thermochromic coatings are also unlikely to provide the full dynamic range of optical and thermal properties required for windows.)

The transmissivity of electro-chromic windows, on the other hand, can be continuously varied from as high as 80% to as low as 10%. An electro-chromic device usually consists of four or five

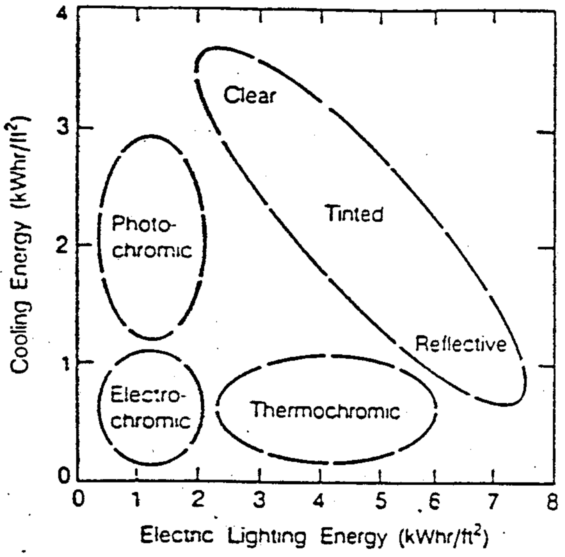


FIGURE 1.1

XBL 853-9920

Projected cooling energy and electric lighting requirements for conventional glazing and three types of optical switching materials

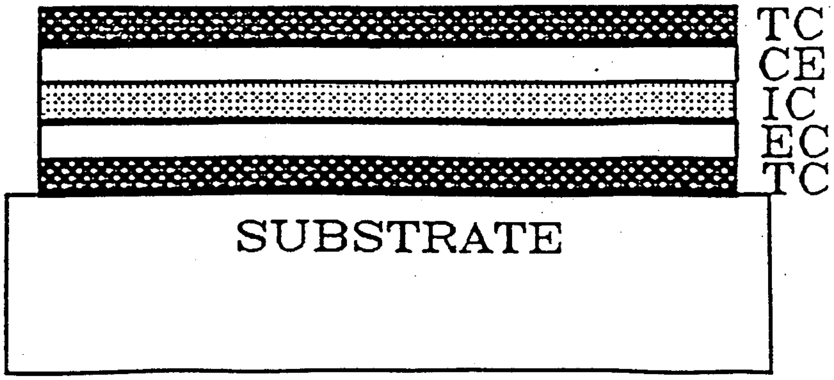


FIGURE 1.2

One example of a solid-state electrochromic device: TC - transparent conductor; CE - counter electrode; IC - ion conductor; and EC - electrochromic layers, only one of which switches (see Figure 1.2). An ion conductor layer separates the electro-chromic layer from the counter-electrode. The top and bottom layers are transparent electronic conductors. A low voltage is applied across the transparent conductors, moving ions from the counter-electrode to the electro-chromic layer and causing a change in the transmittance. Normally, the EC device is coloured in the natural state and becomes clearer as ions are transferred. By controlling the number of ions transferred, the transmission can be continuously varied. When the power is turned off, the EC layer will maintain its transmission. Thus, EC coatings consume very little power. Reversing the voltage returns the coating to its original state.

2. DEVELOPMENT STATUS OF ELECTRO-CHROMIC WINDOWS

2.1 International Activities

There is considerable international activity in developing electro-chromic or switchable glazing systems. The first commercial application of these system is for the transportation industry. Donnelly Corporation in the U.S. has developed a rear-view mirror that can be dimmed to avoid the glare from headlights. Toyota, Nikon, Schott Glass (Germany) and Nissan are also developing EC coatings for mirrors. Most of these products use tungsten oxide. PPG has announced a tungsten oxide electro-chromic coating for aircraft windows.

Eyeglasses and sunglasses will also be an early application for electro-chromic coatings. Nikon has already produced switchable sunglasses controlled by a small battery in the frame. The security aspects of EC windows are also of interest to many organizations. Electro-chromic windows can be linked to security systems. Any glass breakage would cause a short circuit and could signal an alarm. EC coatings block radio waves which may be advantageous for use in high-security buildings.

Developing EC coatings suitable for buildings is more difficult than for automotive or sunglass applications. EC coatings for windows must last much longer (greater than 20 years), be ultra-violet (U-V) light resistant and low cost. Taliq Corporation of the U.S. have developed and market a switchable window for interior applications. The window can be switched from clear to white. The product degrades when exposed to ultra-violet radiation and, as such, is limited to interior walls (as a privacy screen). Samples of the Taliq window have been tested as a part of an International Energy Agency research task. The total solar transmission was found to decrease only slightly (approximately 6%) when switched from the clear state to the white state. The product switches from being a specular transmitter to a diffuse transmitter.

Asahi Glass of Japan is probably furthest along in producing a commercial product. They have installed two hundred 40 X 40 cm prototype electro-chromic windows in the Seto Bridge Museum and 50 units in the Daiwa House in Mita-City, Japan. Asahi has been able to produce stable EC coatings that can switch from 70 - 75% transmission to 10%. (These figures do not include any transmission reduction for the glass.) The maximum size of this product is currently limited to 30 cm X 30 cm.

Several other organizations are working on switchable glazings for building exteriors, notably Lawrence Berkeley Laboratory, Oxford Polytechnic, EIC Labs (Boston), NREL (formerly SERI) and St.

Gobain Glass of France.

2.2 Canadian Activities

Several Canadian researchers have an active electro-chromic research program, including Prof. Stevens at the University of Guelph, Prof. Vo-Van Truong at the University of Moncton, and Dr. Dao at INRS - Energie in Varennes.

The University of Moncton is developing an all-solid-state EC coating. The system is a five-layer system (as described in Section 1.2) with tungsten oxide as the electro-chromic layer and lithium ions used for insertion/extraction. They have been able to produce a stable coating that can switch from 65% to 13% in the visible spectrum.

The University of Guelph is part of an international consortium that is also developing a tungsten oxide EC coating. The consortium consists of the Physics Department at the University of Guelph studying the electrolyte, Hart Chemical of Guelph producing the electrolyte, Chalmers University of Technology in Sweden studying the tungsten oxide coating and CoAT of Sweden producing the coating. The Guelph work has centred on developing a polymer electrolyte made from PMMA and polypropylene. The initial results show that their EC system can switch from 66% to 30% in the visible spectrum.

2.3 Previous EC Window Assessment Studies

Perhaps the most detailed examination of the performance of EC windows has been carried out by Lawrence Berkeley Laboratory [Selkowitz and Lampert, 1989]. They used the DOE 2.1 program to analyse the performance of electro-chromic windows and electric light-dimming systems in a southern U.S. climate. They found that, for buildings with an electric light-dimming system, the minimum energy consumption occurred with windows with an effective aperture of 0.15 (defined as the glass area times the glass visible light transmission divided by the total wall area). For buildings that used both an electric light-dimming system and EC windows, there was a slight energy benefit to larger values of the effective aperture. They also found that peak cooling load could be reduced by up to 36%.

Besant and Johnson [1992] have studied the performance of electric light-dimming systems in commercial buildings but did not investigate electro-chromic windows. They found the same trends for Canadian locations as LBL found for the southern U.S.

3. EXPECTED PERFORMANCE OF BUILDINGS WITH EC WINDOWS

3.1 Methodology

The most cost-effective method for analyzing EC window performance is by computer simulation. This requires a program that can perform a detailed analysis of building heating, cooling and lighting energy, and includes or can be easily modified to include a model for EC windows. ENERPASS Version 3.1 [Enermodal, 1991] calculates building heating, cooling, and lighting energy use on an hourly basis using measured weather data. The accuracy of ENERPASS has been confirmed in a recent International Energy Agency study [Edjems, 1992]. ENERPASS 3.1 has two major limitations for this study. First, it does not have a model for variable transmission windows. Second, ENERPASS uses a simple daylighting model. The daylighting coefficient of utilization (i.e., ratio of daylight level at the working surface divided by the daylight level at the window) is assumed constant regardless of cloud cover or sun angle. A model for EC windows was added as a part of this study and is discussed further in Section 3.2.

The SUPERLITE program [Lawrence Berkeley Laboratory, 1985] was used to overcome the shortcomings of the ENERPASS daylighting model. SUPERLITE uses information on room shape, window location and properties and weather conditions to calculate the daylight illuminance on any interior surface. By combining the daylighting predictions from SUPERLITE with the energy predictions of ENERPASS, the energy impact of EC windows could be studied.

The potential for EC windows is greatest in commercial buildings because of their high cooling and lighting energy requirements. A typical mid-size office building was chosen for the analysis. A parametric study on window size was not performed because previous work by LBL has shown the optimum window size is close to standard practice of 25% of the wall in windows. This corresponds to an "effective aperture" of 16% (glass area times visible light transmission divided by wall area. A detailed description of the building and the corresponding program input data are presented in Section 3.3.

Seven cases were examined as follows:

1) Base Case - clear windows
2) Base Case - tinted windows
3) EC windows - switch on building temperature
4) EC windows - switch on light level

5) electric light-dimming system
6) electric light-dimming system with 3
7) electric light-dimming system with 4

Three factors were used to compare the seven cases: energy use, peak cooling demand and lighting discomfort. Comparisons of heating, cooling and lighting energy savings provide a measure of the savings in operating costs between the buildings. Peak cooling savings can be converted into capital cost savings for the cooling system. If the interior light level is significantly in excess of the desired illumination, the occupant will experience lighting discomfort (i.e., glare) and will be forced to either move or close drapes. The percentage of time that this condition occurs is a measure of the inconvenience to the occupant. The amount of lighting discomfort will vary according to the orientation of the windows. In this report, the level of lighting discomfort will be based on the average for the four orientations.

3.2 Computer Program Modifications

The computer program modifications can be divided into two categories: those necessary to link SUPERLITE and ENERPASS and those necessary to model EC windows. It was decided that the best way to link the two programs was to create an intermediate file. The analysis would be a two-step procedure. First, SUPERLITE would be run to determine the daylight intensity at the work plane. These results would be saved to an intermediate file. Second, ENERPASS would read these daylight levels and determine the impact on the building's heating, cooling and lighting systems.

SUPERLITE evaluates the set of complex equations to calculate the light intensity at any point in a room accounting for the position of the sun, degree of overcastness, position of the windows and walls and reflecting properties of interior surfaces. Because of the many equations that need to be solved, the execution time of the program is quite long: over 3 minutes per weather condition to be analyzed (on a 386 PC). An annual simulation would require 400 hours of computer time if a full year of hourly weather data were to be analysed. As a result it was necessary to develop a procedure to reduce the number of weather conditions analyzed.

The program can be run in several modes depending on the type of weather data available. The program was run in Case 2 which requires geographical information (e.g., latitude) and atmospheric data (monthly average atmospheric moisture and turbidity). Atmospheric data values were supplied for several U.S. cities; for Canadian cities the closest U.S. city data was used (Canadian atmospheric data was not available in the required format).

SUPERLITE was used to perform hourly daylighting analysis for thirteen days: total clear day for each of the monthly Klein days and one totally overcast day (daylight levels on heavily overcast days are independent of sun position). The analysis is performed for each building zone to account for the different window sizes and orientations. The appropriate daylighting information for each zone is stored in a datafile.

SUPERLITE computes the daylight level for the desired interior surface and the daylighting coefficient of utilization (DLCU). The DLCU is the ratio of daylighting on the horizontal interior surface to the daylighting on a horizontal exterior surface. The DLCU definition was modified to be the ratio of the daylighting level on the horizontal interior surface to the daylight level on an exterior vertical surface to be more consistent with the ENERPASS program. The DLCUs for each hour of the year were then computed by interpolating between the totally clear and total overcast values according to the clearness index for that hour. The totally clear day was assumed to have at clearness index of 0.7 and the overcast day a clearness index of 0.3.

The SUPERLITE analysis was performed assuming the windows had 100% visible light transmission. The reduction in daylighting due to window properties was then handled within ENERPASS. This meant that SUPERLITE did not have to be re-run for changes in window transmission properties.

Each hour ENERPASS would compute the daylighting level according to the formula:

$$I_{day} = 115 * DLCU * T_{win} * H_T$$

where I_{day} is the daylight illumination at the work surface in lux
115 is a constant to convert watts/m^2 to lux
T_{win} is the window daylight transmission
DLCU is the daylight coefficient of utilization for that hour

$$DLCU = DLCU_{cl} - (DLCU_{cl} - DLCU_{oc})*(Kt - Kt_{oc})/(Kt_{cl}-Kt_{oc})$$

where $DLCU_{cl,oc}$ are the clear day and overcast day daylight coefficients of utilization as computed by SUPERLITE and stored in the datafile

Kt is the clearness index for that hour
Kt_{oc} is overcast clearness index = 0.3
Kt_{cl} is clear day clearness index = 0.7
H_T is the solar radiation on the vertical surface containing the window

The electric light illumination is then computed as follows:

$$I_{elec} = ELCU * E_{el} * P_{el}$$

where I_{elec} is electric light illumination at the work surface in lux
ELCU is electric light coefficient of utilization (a constant)
E_{el} is electric light lighting efficiency in lumens/watt
P_{el} is the lighting power density in $Watts/m_2$

The last three quantities are entered by the user. The electric light coefficient of utilization and efficiency can be determined from standard lighting handbooks. The total illumination level is the sum of the daylight and electrical light illumination.

ENERPASS was modified to adjust the illumination level according to the light-dimming and EC control systems installed. The program analyses the electric lighting system first. If an electric light-dimming system is installed, the lighting power is reduced until the desired illumination is achieved.

In the model for electro-chromic windows, the solar and daylight transmission levels are assumed to vary continuously between user-defined minimum and maximum values. The two transmissions are assumed to be dependent on one another (that is, for example, if the daylight transmission dims to the minimum value the solar transmission dims to the minimum value). Two models for switching the EC windows were added: switching on temperature and switching on light level. For the temperature control, if the room temperature goes above the cooling setpoint, the windows switch from maximum transmission to minimum transmission.

In the EC model for lighting dimming, the EC window light transmission will decrease until the desired interior light level is achieved. Lowering the daylight transmission will also lower the solar heat gain through the windows.

Finally, the ENERPASS program then calculates the heating and cooling energy required to maintain comfort conditions.

3.3 Base Case Building

The potential for EC windows was assessed for a typical mid-sized office building. The building (see Figure 3.1) is three stories high and has a total floor area of 7200 square metres. The building was assumed to be heated and cooled by six packaged roof-top units, serving the north, south, east and west perimeter zones, interior office areas and common areas. The roof-top unit fans were assumed to run continuously during office hours. Thus, use of EC windows or light-dimming systems does not affect fan energy use.

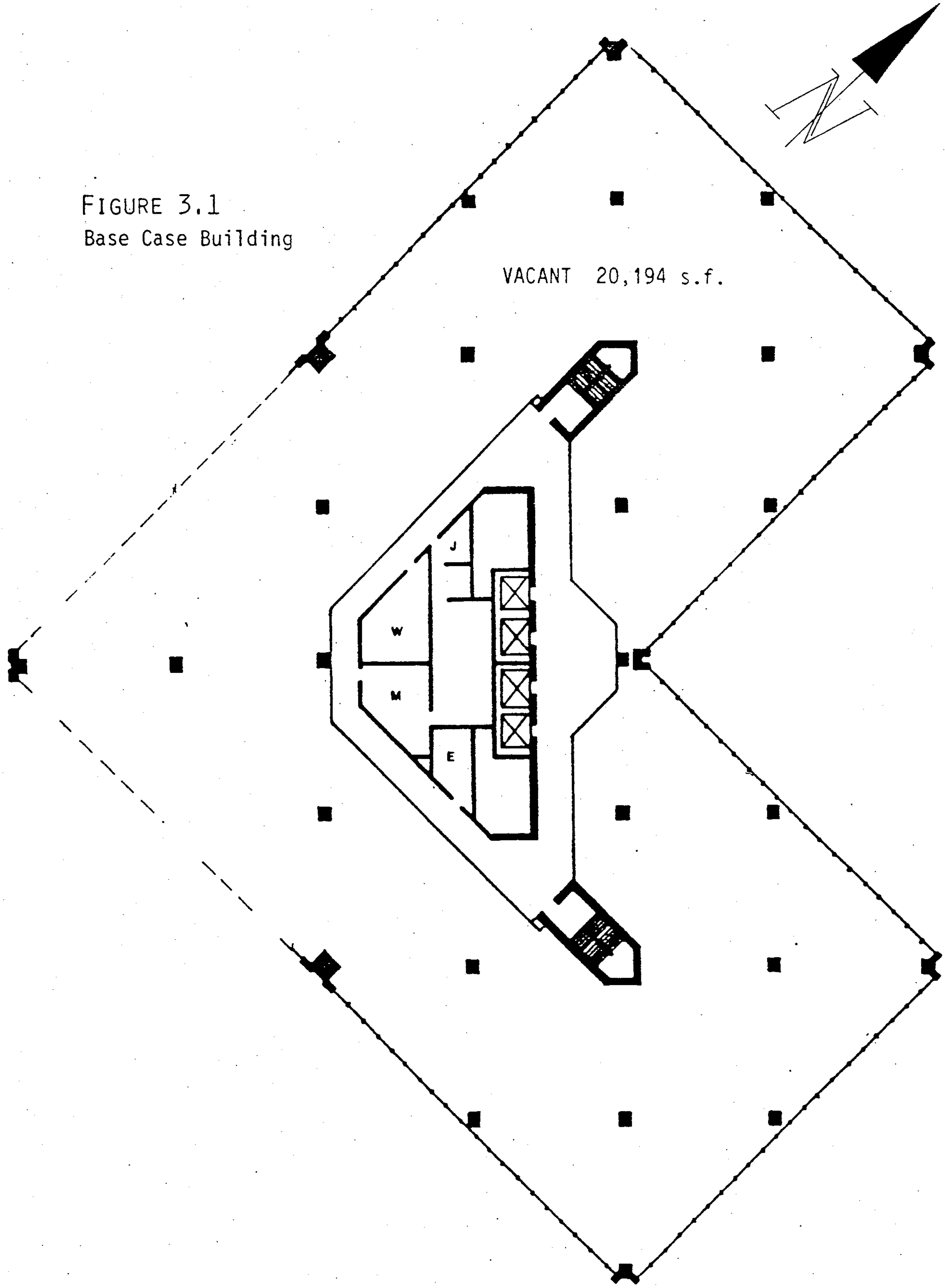
The building was assumed to be occupied for twelve hours a day, five days a week. The long operating hours allow for flexible work hours, typical of most offices and time for cleaning staff. The heating and cooling thermostat setpoints were 21°C and 24°C. Night and weekend setback of temperatures was not used to avoid any problems in determining the time and magnitude of peak heating and cooling demands.

Most of the remaining building parameters were taken from a study by Engineering Interface [1986] as typical of small to mid-sized office buildings. The building details are:

Wall Thermal Resistance (RSI)	1.4
Roof Thermal Resistance (RSI)	1.4
Window U-value ($W/m^2 {}^\circ C$)	3.0
Window to Wall Area Ratio (%)	25
Glass to Wall Area Ratio (%)	22
Installed Lighting Capacity (W/m^2)	24

The lighting system was designed to provide 800 lux of illumination in the office areas; lower lighting levels were used in common areas and washrooms. The coefficient of utilization of the electric lighting system was assumed to be 0.4 (i.e., ratio of light level on the desk to that at the lighting fixture). The light intensity and electricity use were assumed to be able to decrease linearly to zero when a light-dimming system was used. The lighting control sensors were assumed to be located on a horizontal surface 0.8 metres from the floor, 5.0 metres from the windows, with one sensor for each of the four faces of the building.

FIGURE 3.1
Base Case Building



Electro-chromic windows were assumed to have a shading coefficient of 0.8 and daylight transmission of 0.71 in the clear or bleached state, dropping to 0.1 in the coloured state. These values are the same as was used by LBL in their study of EC windows as representative of the best available in the near term [Reilly, Arasteh and Selkowitz, 1991]. Two base-case buildings were analyzed, with the only difference being the type of window used. The first case used clear double-glazed windows with the same shading coefficient and daylight transmission as the EC window in the clear state so that any changes would be due to window switching and not to a different clear state. The second base-case building used tinted double-glazed windows with the same properties as the EC windows in the coloured state.

As discussed in Section 3.1, two control strategies were used to operate the electro-chromic windows. For the temperature-controlled system, the EC window switches from the clear state to the coloured state whenever the building air temperature is at or above the cooling setpoint. For the light-level control system, the EC windows vary between the maximum and minimum daylight transmission values to achieve the desired interior light level.

3.4 Simulation Results

Simulations were performed for three locations: Toronto, Winnipeg, and Los Angeles. Performance in Toronto is representative of much of the commercial building stock in Canada. The other two cities represent the extremes in climate observed in North America. Winnipeg is the coldest large city in North America. The heating load is very high and the cooling season is very short. Los Angeles, on the other hand, has almost no heating season and cooling is required almost every day.

3.4.1 Performance in Toronto

The SUPERLITE program was run to determine the daylighting coefficient of utilization (DLCU) for each orientation for each month. (DLCU is defined as the ratio of daylighting on the horizontal interior surface to the daylighting on a vertical surface at the window.) Figures 3.2 through 3.5 show the seasonal trend in DLCU for the four building faces for the base-case office building in Toronto. The figures show that, on heavily overcast days, the DLCU is constant at approximately 9%. On clear days, the DLCU varies considerably depending on whether the work plane receives direct solar radiation. For example, for the south facade, the DLCU is 12 to 17% in June when the sun is high in the sky, whereas it rises to 30% in December when the sun penetrates deep into the building (to where the light sensor is). The DLCU ranges from a low of 6%, when the surface receives only diffuse solar

FIGURE 3.2

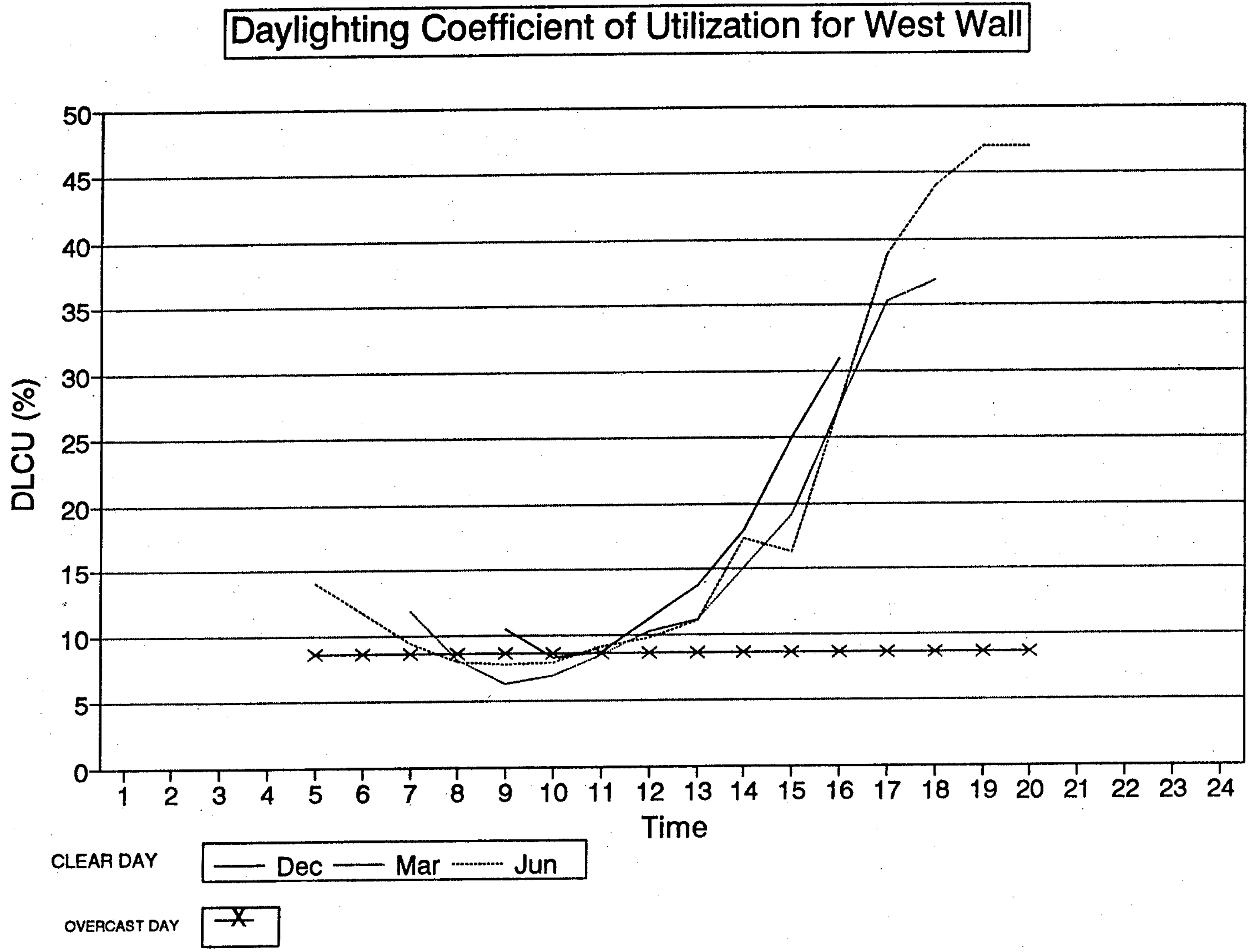

Daylighting Coefficient of Utilization for West Wall
DLCU (%)
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Time
CLEAR DAY
Dec
Mar
Jun
OVERCAST DAY

FIGURE 3.3

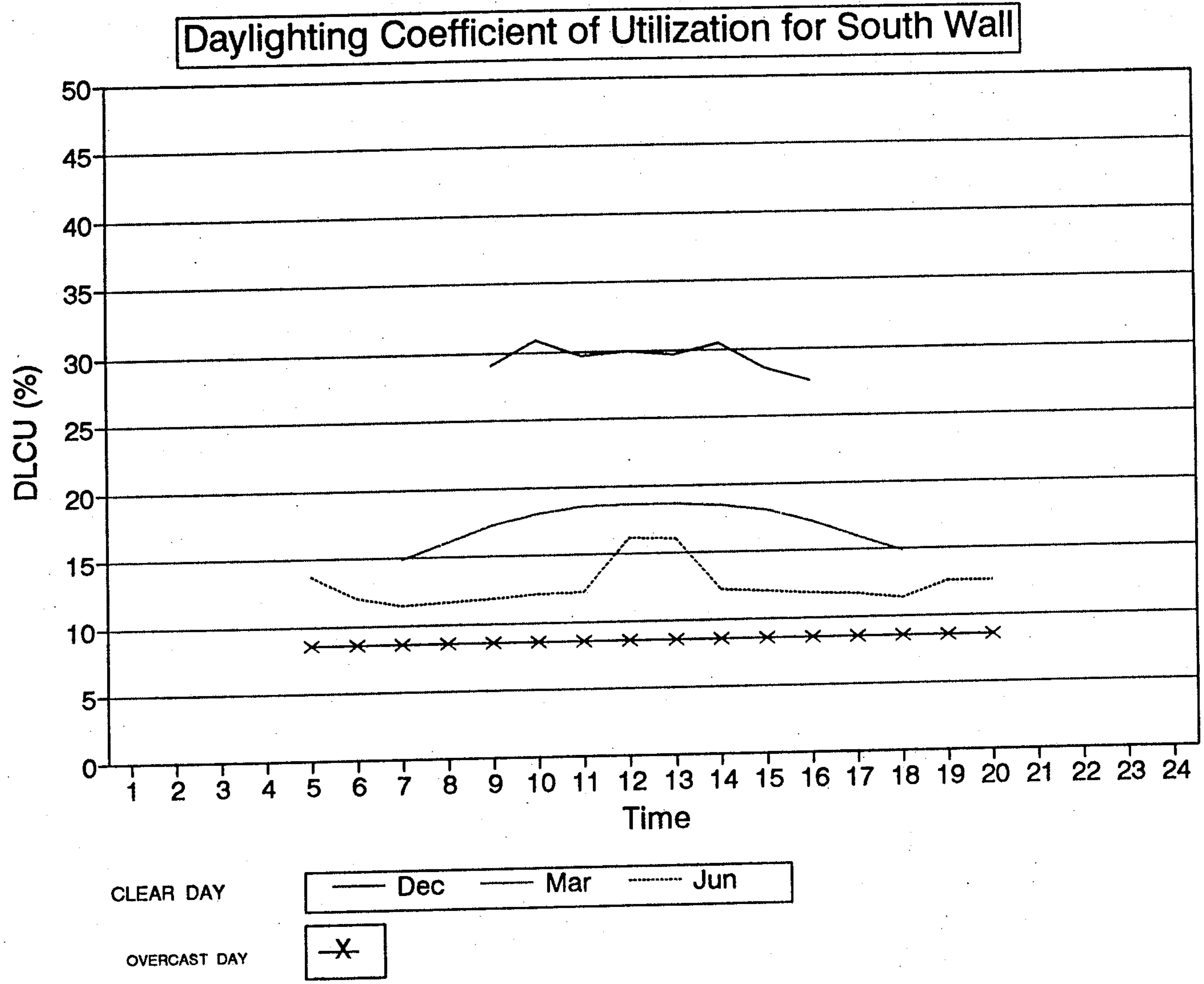
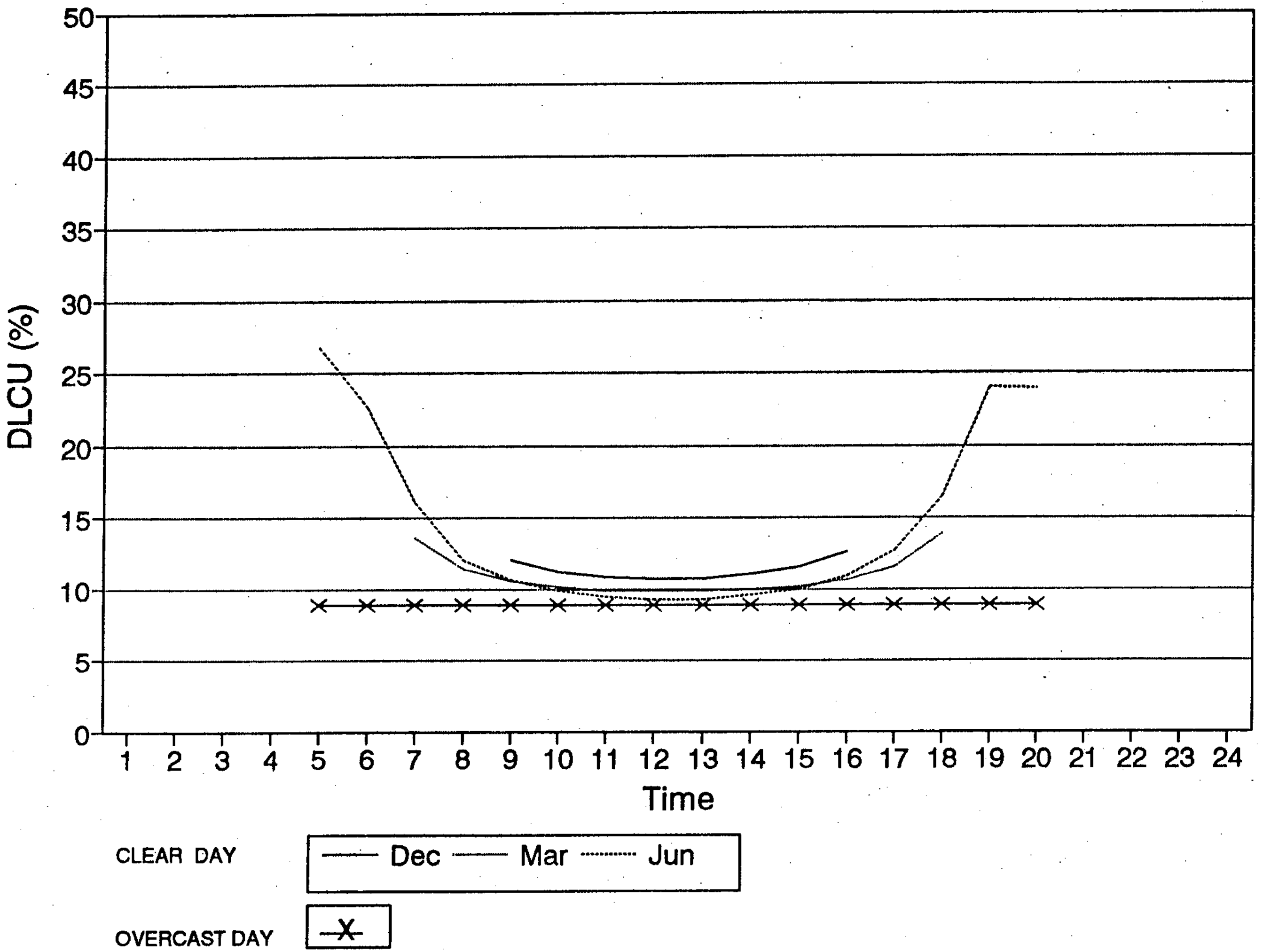
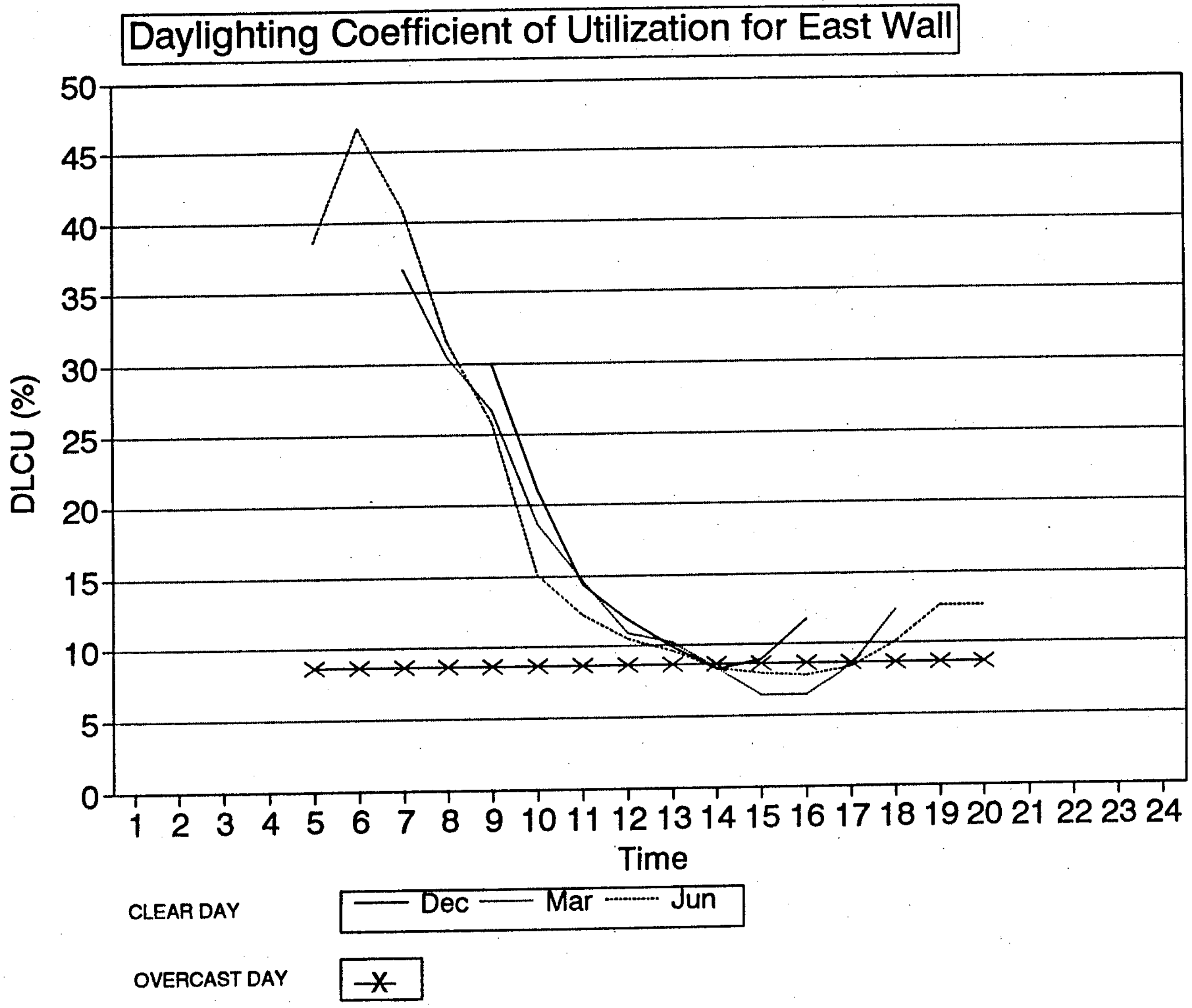

Daylighting Coefficient of Utilization for South Wall
DLCU (%)
50
45
40
35
30
25
20
15
10
5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Time
CLEAR DAY
Dec
Mar
Jun
OVERCAST DAY

FIGURE 3.4



Daylighting Coefficient of Utilization for North Wall

FIGURE 3.5


Daylighting Coefficient of Utilization for East Wall
DLCU (%)
50
45
40
35
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Time
CLEAR DAY
Dec
Mar
Jun
OVERCAST DAY

radiation, to a high of 50% when the surface receives direct solar radiation. The actual range in illumination (i.e., the product of the DLCU and incident solar radiation) will, of course, be much greater than this because the solar radiation values will be much higher when the surface is receiving direct solar radiation than when receiving diffuse solar radiation.

Figure 3.6 summarizes the performance of the seven case-study buildings described in Section 3.2 for Toronto climatic data. The results are presented in total kilowatt-hours for the building assuming the building is heated by electric resistance heat. The major factor effecting energy consumption is the use of electric light-dimming systems (the three bars on the right-hand side of the figure). The use of electro-chromic windows alone save very little energy, and as such their only advantage is in glare control. Therefore, systems with electro-chromic windows and no dimming controls will not be discussed further.

Figures 3.7 and 3.8 present the energy cost savings relative to the two base-case buildings on a per-square-metre-of-glass-area basis. Figure 3.7 is based on using electricity for heating at $0.075/kWhr. Figure 3.8 assumes electricity is used for lighting and cooling and natural gas is used for space heating at $0.17/m^3 with a seasonal combustion efficiency of 70%. In all cases, buildings with EC windows (and a light-dimming system) did not save as much energy as an electric light-dimming system alone. The difference between EC windows controlled by light level and light-dimming system alone is small for gas-heated buildings. Thus, the benefit of EC windows is not in saving energy alone.

Figure 3.9 and 3.10 show the peak cooling demand reduction and level of lighting discomfort. The results show that electro-chromic windows controlled on light level or temperature (with a light-dimming system) offer larger peak cooling savings and better light comfort compared to an electric light-dimming system alone. In fact, controlling light level be a light dimming system and EC windows totally eliminates any possibility of excessive over-lighting. Thus there would be no need for window shading devices for a building with this system.

It is concluded that EC windows controlled on light level in combination with an electric light dimming system offers the best combination of energy savings, peak cooling reduction and lighting comfort. According to Figures 3.7 to 3.10, this system can deliver energy savings of between $13/m^2 and $22/m^2 of glass, totally eliminate lighting discomfort and provide peak cooling demand savings of between 6 and 117 Watts/m^2.

FIGURE 3.6

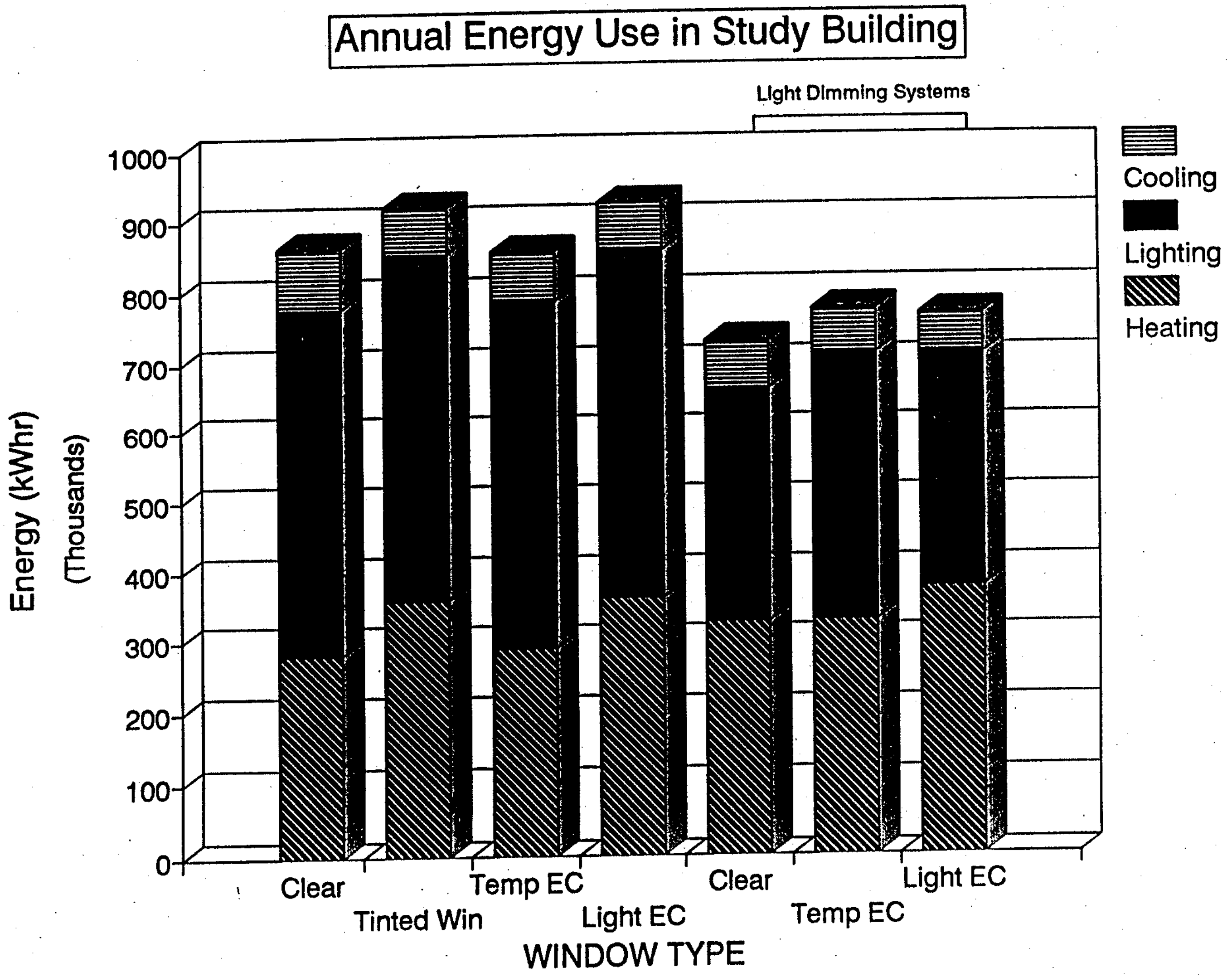

Annual Energy Use in Study Building
Light Dimming Systems
Energy (kWhr)
(Thousands)
1000
900
800
700
600
500
400
300
200
100
0
Clear
Tinted Win
Temp EC
Light EC
Clear
Temp EC
Light EC
WINDOW TYPE
Cooling
Lighting
Heating

FIGURE 3.7

Annual Savings in Electrically-Heated Study Building

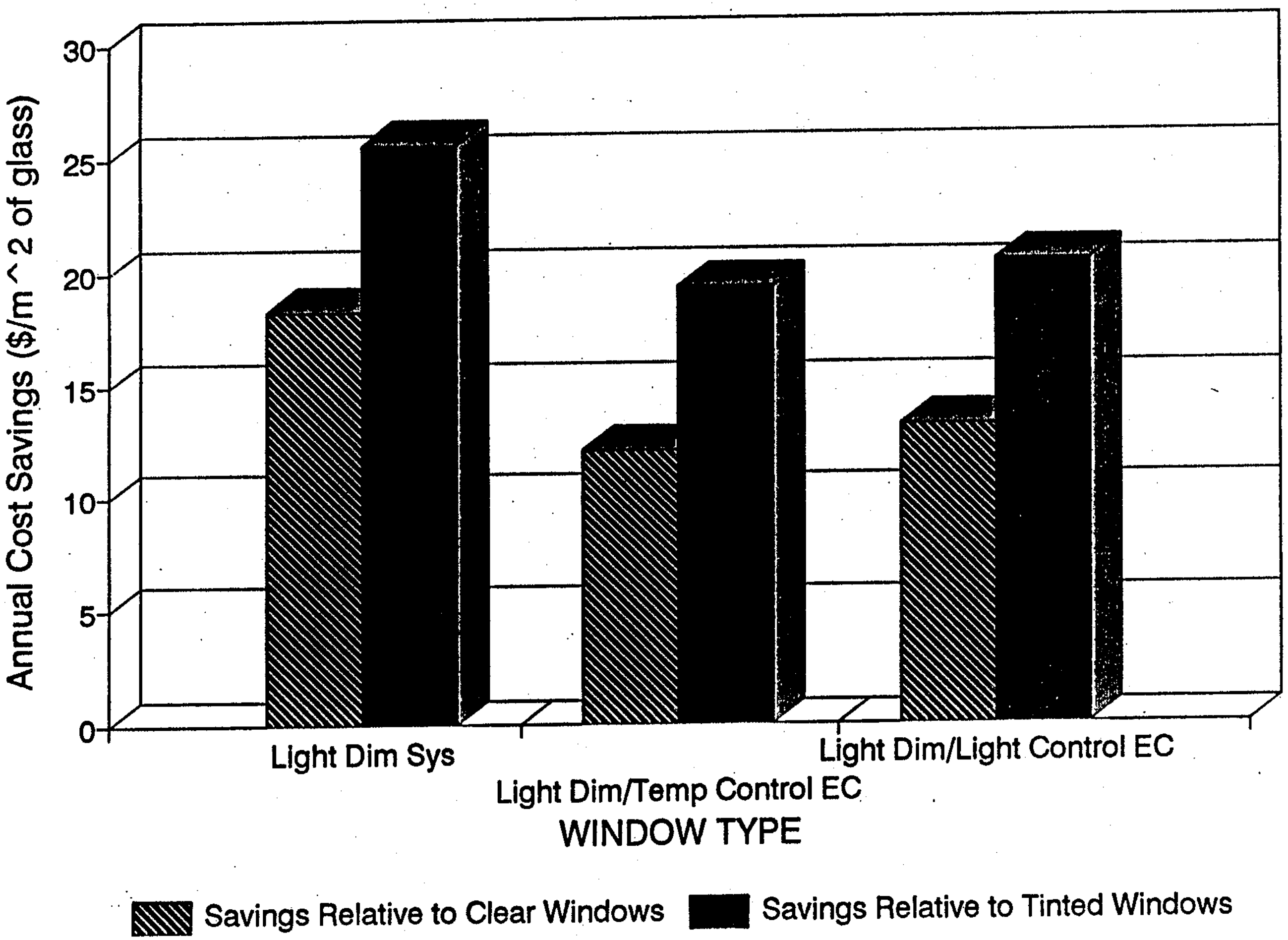


FIGURE 3.8

Annual Savings in Gas-Heated Study Building

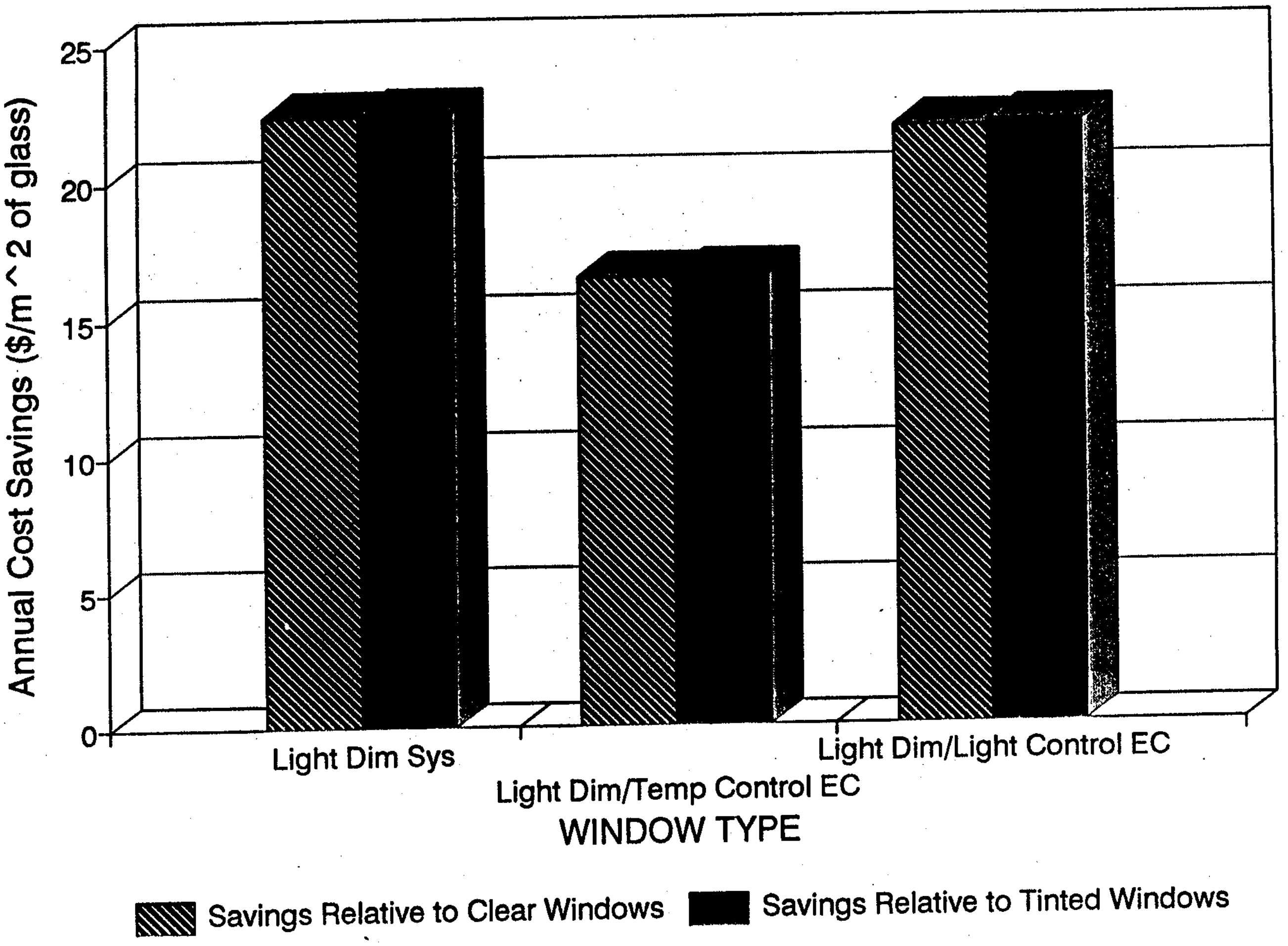


FIGURE 3.9

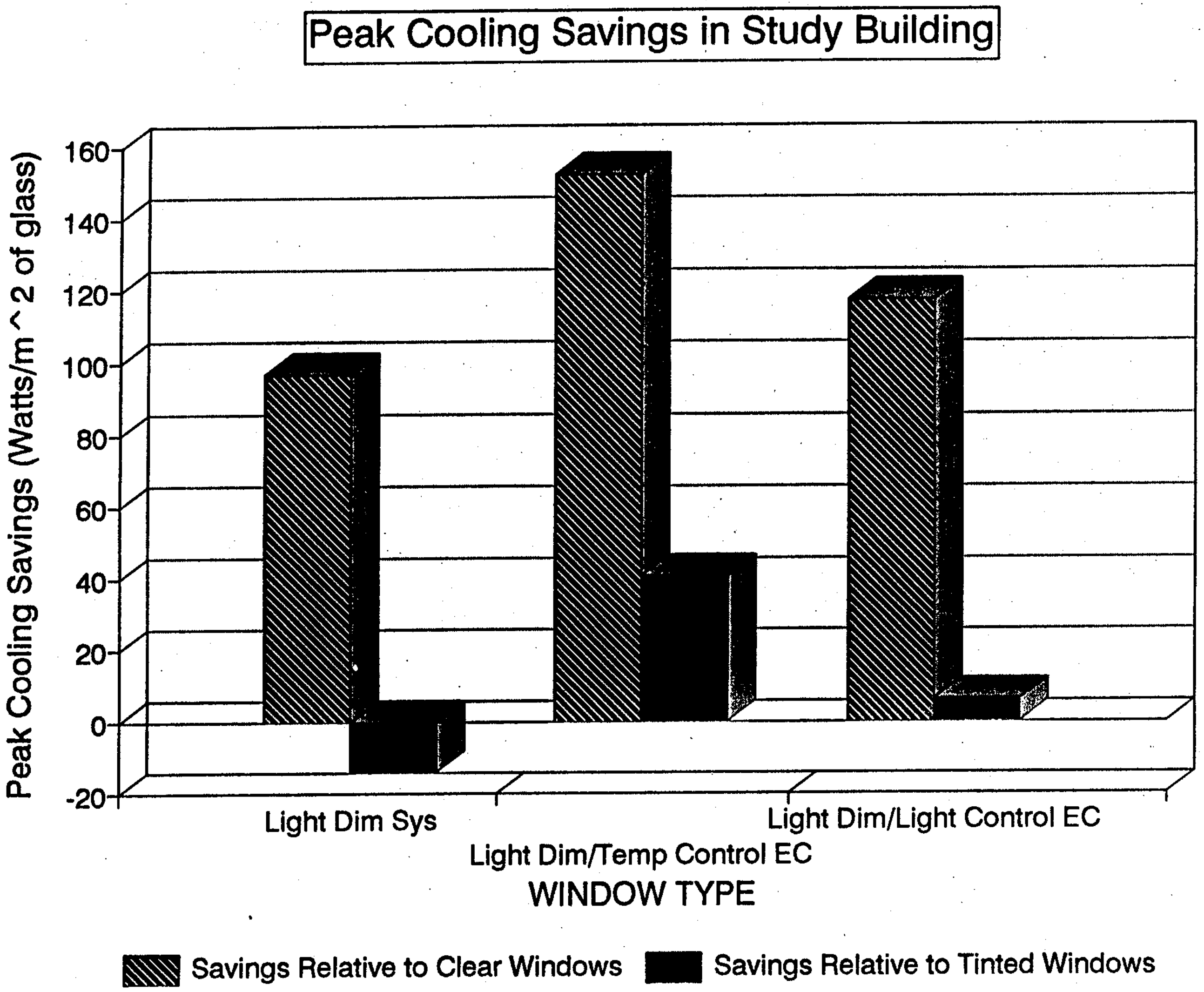
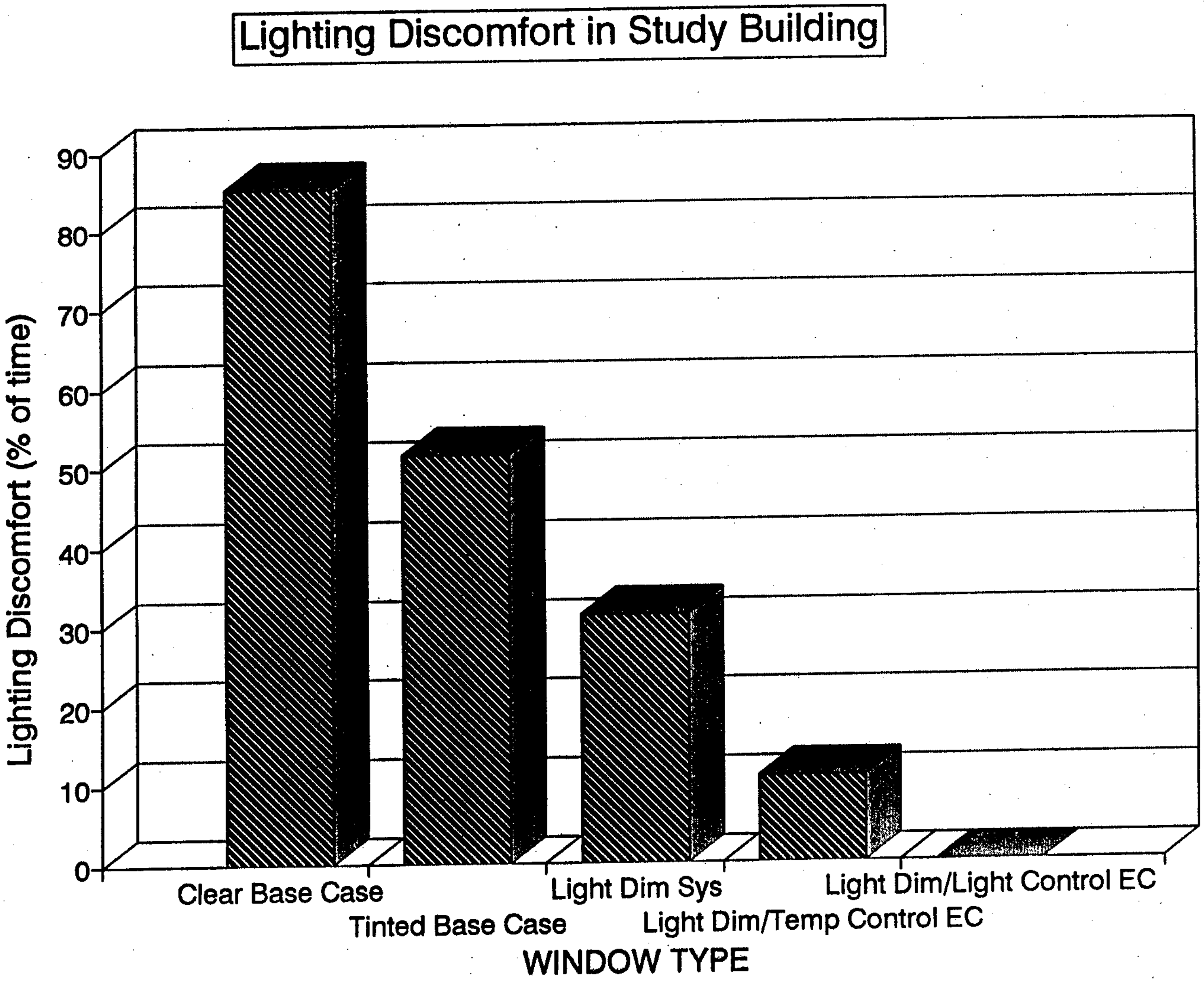

Peak Cooling Savings in Study Building
Peak Cooling Savings (Watts/m ^ 2 of glass)
160
140
120
100
80
60
40
20
0
-20
Light Dim Sys
Light Dim/Temp Control EC
Light Dim/Light Control EC
WINDOW TYPE
Savings Relative to Clear Windows
Savings Relative to Tinted Windows

FIGURE 3.10


Lighting Discomfort in Study Building
Lighting Discomfort (% of time)
90
80
70
60
50
40
30
20
10
0
Clear Base Case
Tinted Base Case
Light Dim Sys
Light Dim/Temp Control EC
Light Dim/Light Control EC
WINDOW TYPE

3.4.2 Performance in Other Locations

The seven cases described in Section 3.1 were studied for buildings located in Los Angeles and Winnipeg. The results follow the same trend as seen in the Toronto results. Again, the combined electric-light-dimming system and light-controlled EC windows offers the best combination of energy savings and lighting comfort. Only this system will be discussed further; the performance of the other systems is included in Appendix A.

Figures 3.11 and 3.12 compare the annual cost savings for the two base-case buildings assuming electric and natural gas space heating, respectively. The results show significantly greater savings in Los Angeles with slightly lower savings in Winnipeg. In general, savings are greatest for locations with high cooling loads and for buildings that use low-cost energy (i.e., natural gas) for space heating.

Figure 3.13 compares the peak cooling savings relative to the two base-case buildings. The peak cooling savings are significantly higher in Los Angeles and lower in Winnipeg. In fact, use of EC windows in Winnipeg results in an increase in peak cooling load relative to the building with tinted windows.

FIGURE 3.11

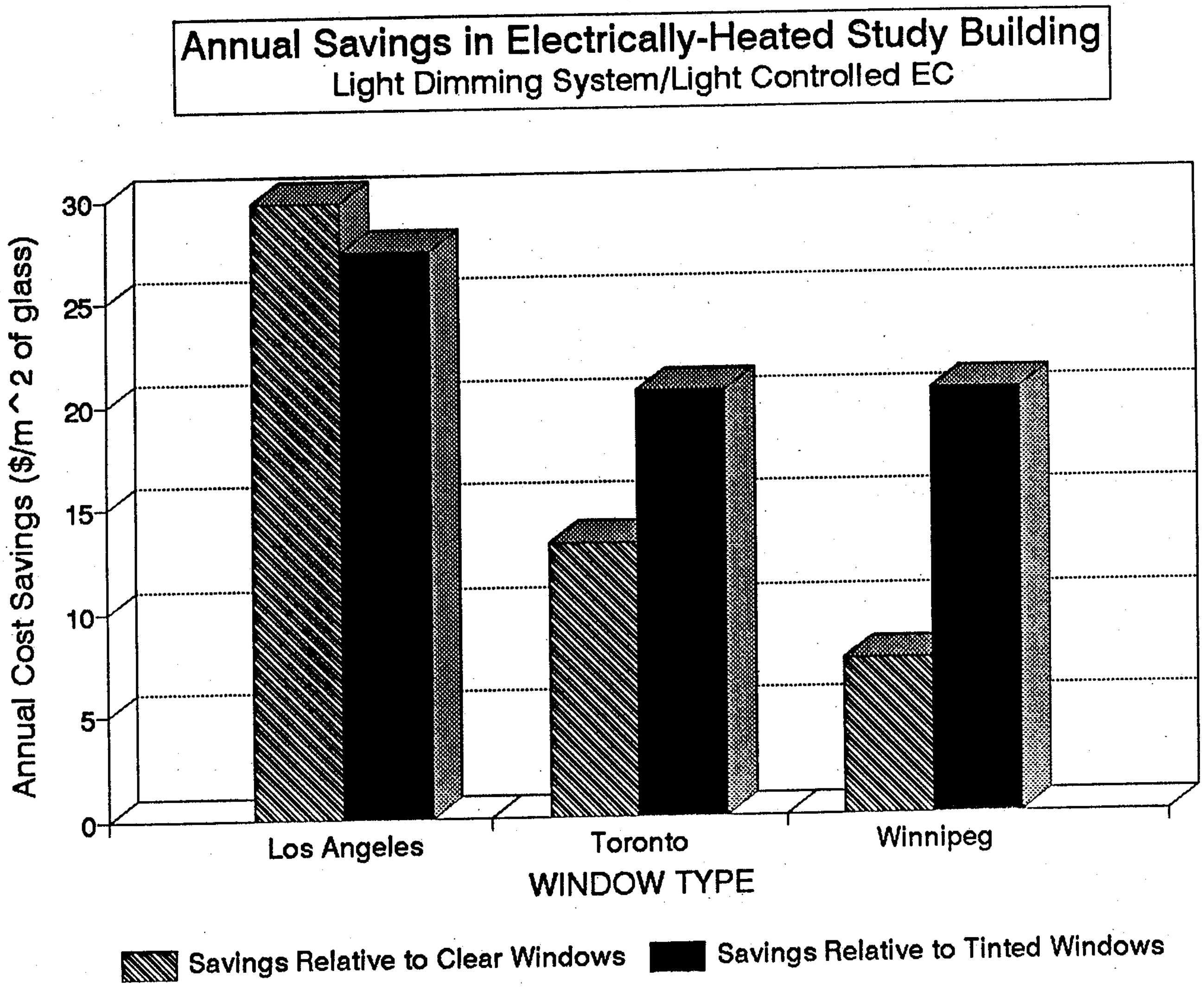

Annual Savings in Electrically-Heated Study Building
Light Dimming System/Light Controlled EC
Annual Cost Savings ($/m ^ 2 of glass)
30
25
20
15
10
5
0
Los Angeles
Toronto
Winnipeg
WINDOW TYPE
▨ Savings Relative to Clear Windows
■ Savings Relative to Tinted Windows

FIGURE 3.12

Annual Savings in Gas-Heated Study Building
Light Dimming System/Light Controlled EC

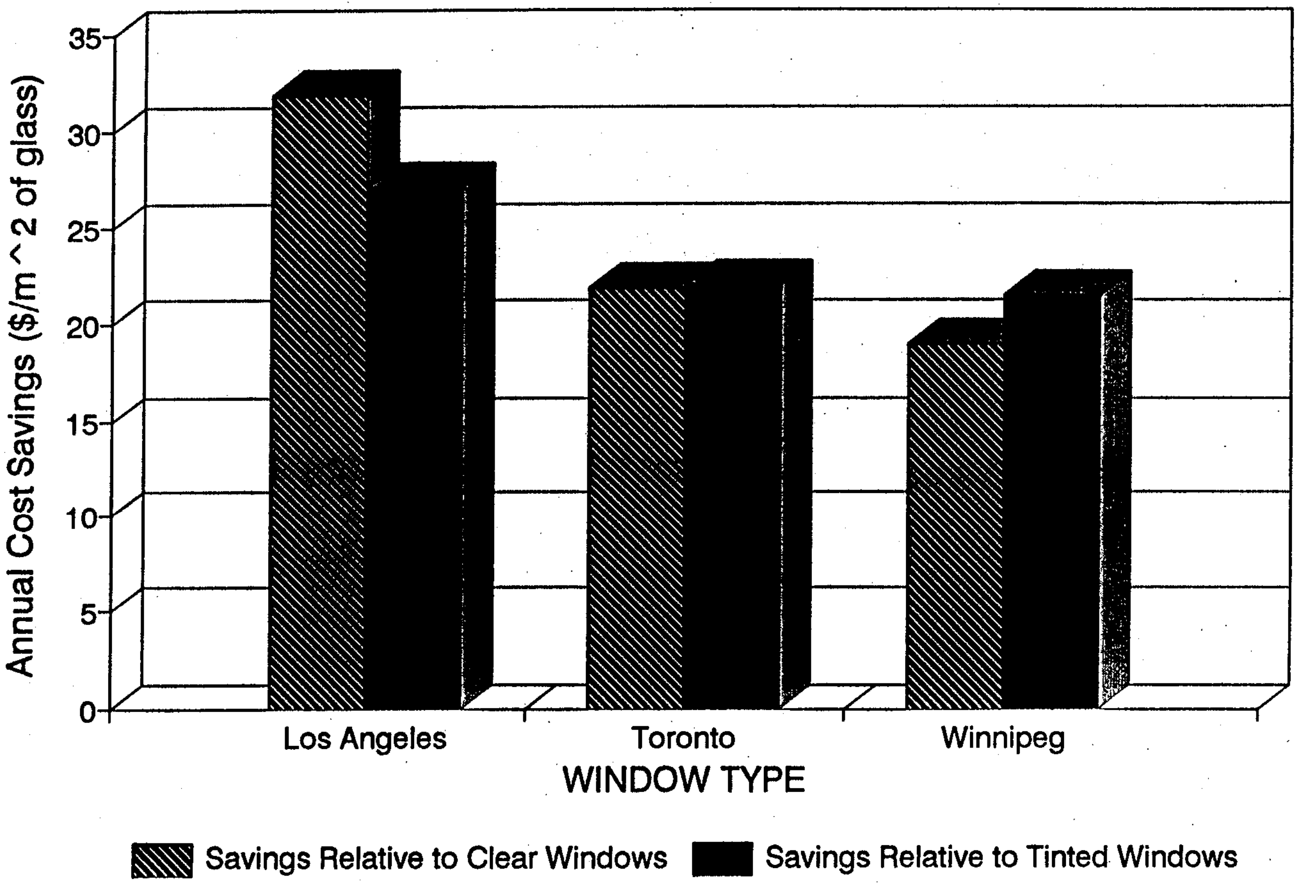
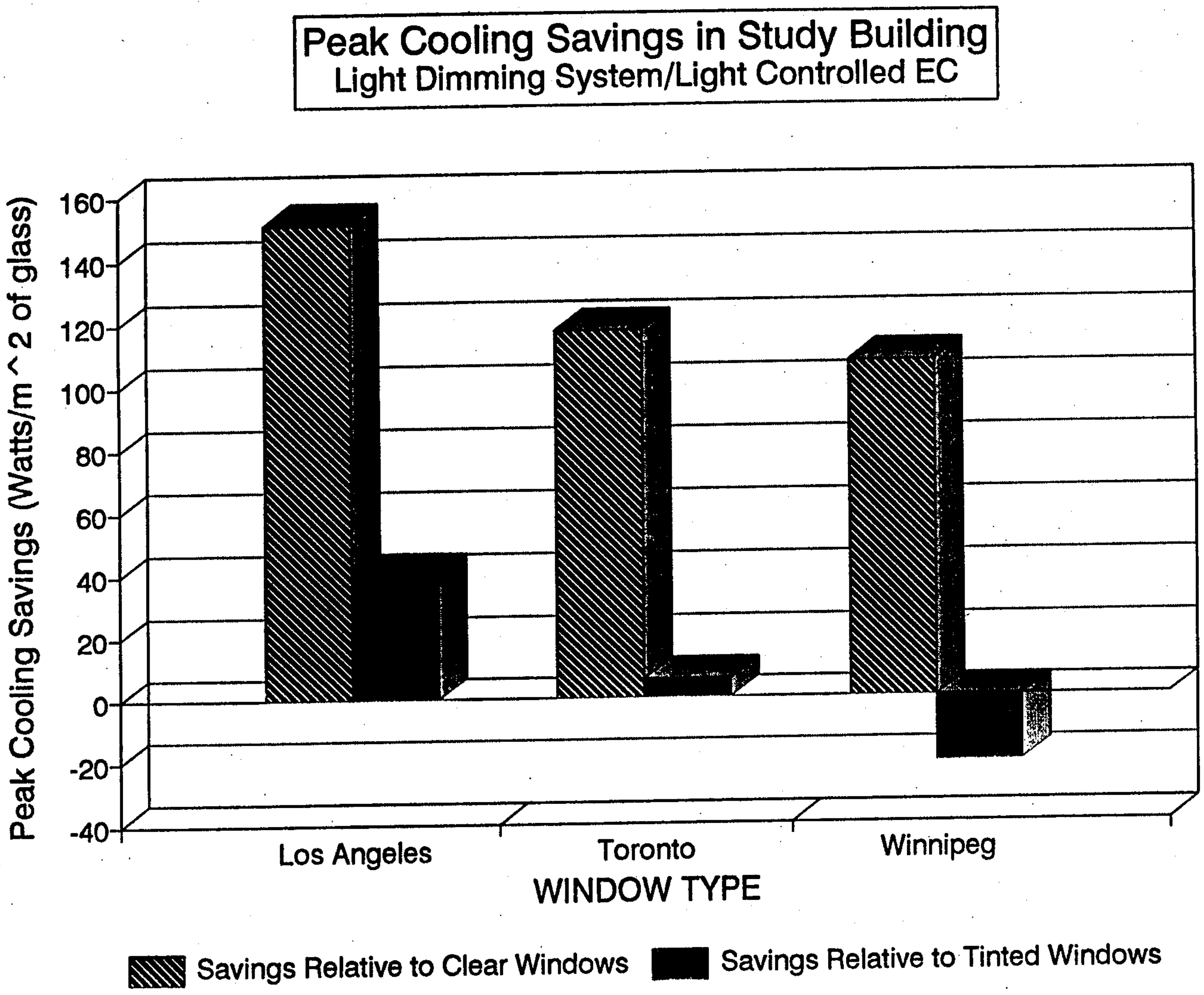


FIGURE 3.13


Peak Cooling Savings in Study Building
Light Dimming System/Light Controlled EC
Peak Cooling Savings (Watts/m ^ 2 of glass)
160
140
120
100
80
60
40
20
0
-20
-40
Los Angeles
Toronto
Winnipeg
WINDOW TYPE
Savings Relative to Clear Windows
Savings Relative to Tinted Windows

4. COST ASSESSMENT

It is difficult to estimate with any confidence the cost of electro-chromic windows when they become commercially available. Nevertheless, the technology to produce these coatings is similar to conventional processes for applying low-emissivity coatings to glass and as such the costs would be expected to be similar. A value of US\$50/m^2 (C\$60/m^2) is a reasonable estimate. Additional costs would be required for the control system.

The incremental cost of electric light-dimming systems (over conventional lighting controls) has been determined to be between \$15. and \$32. per square metre of affected (i.e., perimeter) floor area [Scanada, 1990; Besant, 1992]. These prices reflect the fact that dimming systems are not commonly installed. Lower costs are possible if this technology becomes widespread. For the case-study building, this represents a cost of between \$85 and \$175 per square metre of glass area. Much of the wiring, sensors and controls needed to control the electric-light-dimming system can also be used to control the electro-chromic windows. If a \$15/m^2 of glass area allowance is made for the extra cost for EC window control, the total cost for the electro-chromic windows and light-dimming system is expected to be between \$150 and \$240 per square metre of glass area. An average value of \$195/m^2 will be used.

Using EC windows and lighting control systems reduces some of the other capital costs for buildings: specifically, air-conditioning system size and the need for drapes or blinds. The installed cost for commercial building air-conditioning systems is typically \$350 to \$700/kW of cooling capacity. For the base-case building with tinted windows in Toronto, the 6 Watts/m^2 of glass peak cooling load savings translates into a \$3/m^2 capital cost savings (using the average value). For the building with clear windows, the 117 Watts/m^2 represents a \$61/m^2 capital cost savings. Commercial window blinds cost approximately \$60/m^2 installed.

Table 4.1 summarizes the cost performance of the EC windows and electric light-dimming system relative to the two base-case buildings for the three locations studied. The same energy costs were used for all three cities so that any differences are due to local performance. The simple payback for the systems based strictly on energy savings is over ten years for Canadian locations. If, however, the capital cost savings are included the payback ranges from 1.8 to 10.7 years depending on location and type of heating fuel. The economics look best in locations where the ratio of cooling costs to heating costs is high: that is, buildings located in regions with high cooling loads and using (low-cost) natural gas for space heating.

Table 1: Cost and Performance of EC Windows

(all values are per square metre of glass area and include an electric light dimming system)

	LOS ANGELES		TORONTO		WINNIPEG	
	Relative to Clear Windows	Relative to Tinted Windows	Relative to Clear Windows	Relative to Tinted Windows	Relative to Clear Windows	Relative to Tinted Windows
Annual Energy Savings (kWhr/m^2)	397	365	176	273	99	273
Peak Cooling Savings (Watts/m^2)	151	40	117	6	107	-21
Annual Cost Savings - elec. heating ($/m^2)	29.75	27.35	13.22	20.48	7.39	20.46
Annual Cost Savings - gas heating ($/m^2)	31.83	27.07	21.88	22.02	18.99	21.49
Capital Cost ($/m^2)	195	195	195	195	195	195
Capital Cost Savings ($/m^2)	139	81	121	63	116	49
Simple Payback - elec. heating	1.9	4.2	5.6	6.4	10.7	7.1
Simple Payback - gas heating	1.8	4.2	3.4	6.0	4.2	6.8

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions are made based on this study:

- The combination of electro-chromic windows that switch on light intensity and electric light-dimming systems offer the best performance in terms of energy savings, peak cooling demand reduction and glare control.

- EC windows that do not incorporate electric light-dimming systems or the switch on temperature appear to have a very modest energy benefit.

- Accounting for capital cost savings in the cooling system and window blinds, the simple payback for the EC windows and electric light-dimming systems ranges from 1.8 to 10.7 years (assuming EC coatings can retail for \$60/m^2). The economics look best in buildings with high cooling loads and using (low-cost) natural gas for space heating.

5.2 Recommendations

As a result of this study, the following recommendations are made:

- electro-chromic windows should only be installed in conjunction with an electric light-dimming system,

- give the potential energy savings and improvement in lighting comfort, electro-chromic windows should continue to be developed, and

- electro-chromic windows and associated controls should be developed in tandem with the equipment and controls required for electric light-dimming systems.

6. REFERENCES

Besant, R.W. and C.A. Johnson. 1992. "Assessment of Daylighting Potential for Commercial Office Buildings In Canada". Prepared for Department of Mechanical Engineering, University of Saskatchewan, Saskatoon, Saskatchewan. Contract No. 23216-9-9013/01-SS.

Eijdems, H. and Poel, A. 1992. "Simulation Support Group Working Document: Base Case Calculations - Compilations of Results", Report prepared for the International Energy Agency Task XIII by the National Institute for Social Housing in the Netherlands

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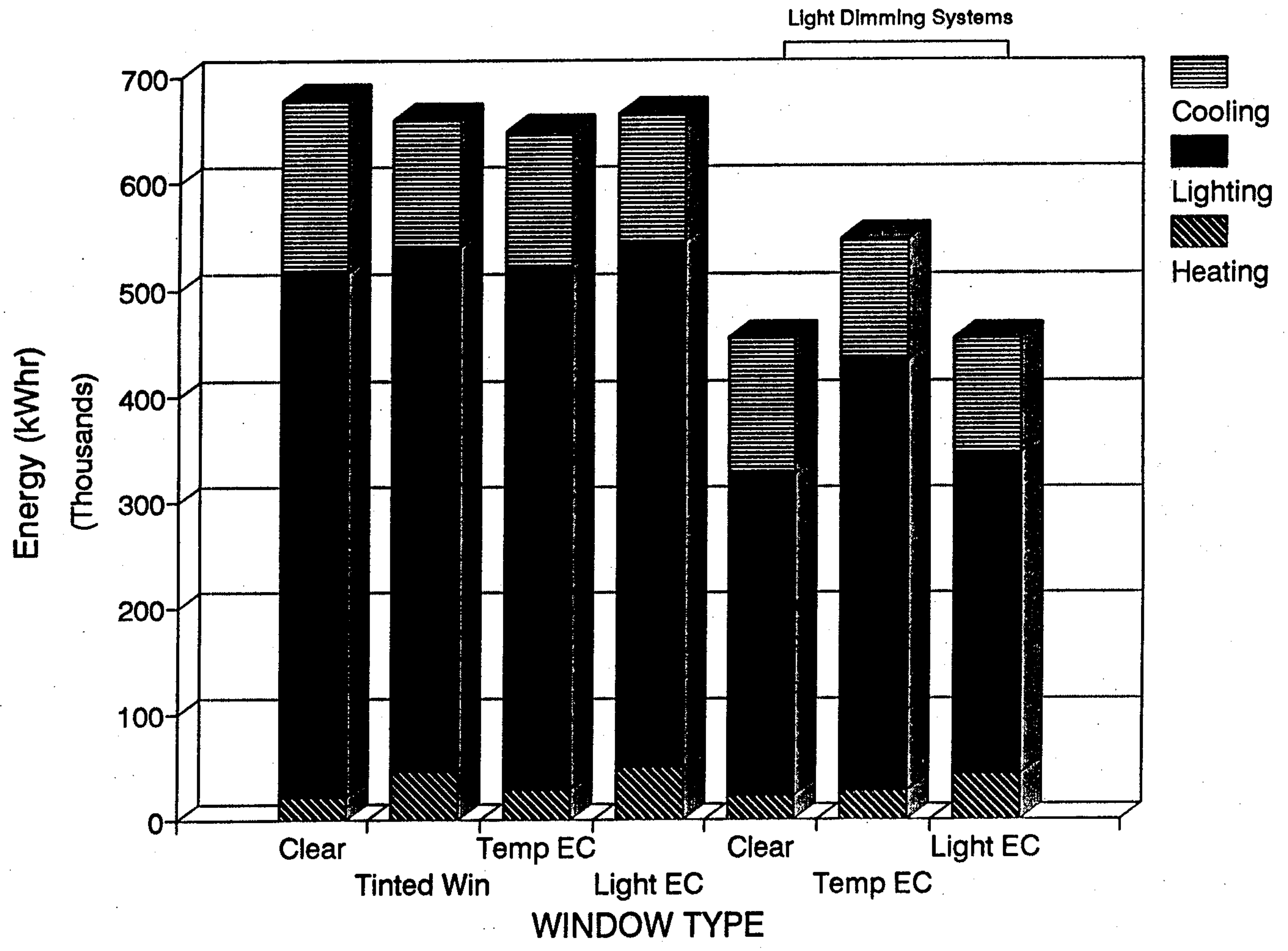
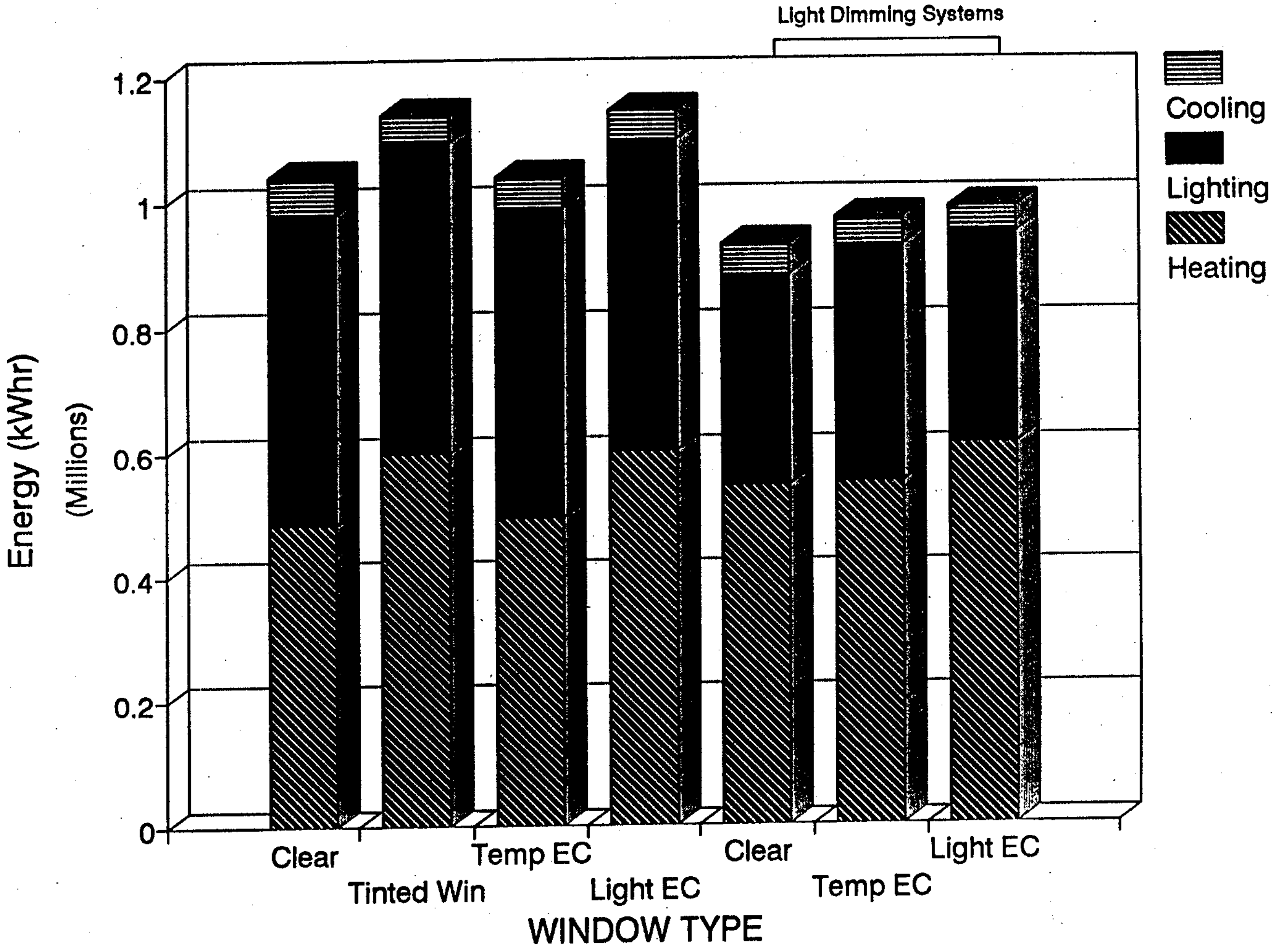
Selkowitz, S.E. and C.M. Lampert. 1989. "Application of Large-Area Chromogenics to Architectural Glazings". Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098.

APPENDIX A:

SIMULATION RESULTS FOR LOS ANGELES AND WINNIPEG

Annual Energy Use in Study Building (Los Angeles)





Annual Energy Savings in Study Building (Winnipeg)

APPENDIX B:

BUILDING SIMULATION INPUT DATA

```
                           ***************************
                           * ENERPASS 3.1 Input Data *
                           ***************************

SAMPLE HOUSE
File Name........: TOR1    .V30
System Type......: Multiple Forced Air
Options..........: Economizer/Free Cooling

                                 Environment Data
                                 ----------------

Soil Type............................................: wet clay

Orientation of the Building is   0.0  Degrees from South (Positive West)
Slope of Skylight Glazing from Horizontal (DG)..........:   0.0

Infiltration : (air changes)
Zone           1        2        3        4        5        6
Nominal      0.10     0.10     0.10     0.10     0.00     0.00
Maximum      3.00     3.00     3.00     3.00     0.00     0.00
```

```
                Building Description Data - Zone #1 - NORTH WEST
                -------------------------------------------------

------------ WALL ------------      ------- WINDOW -------     ----- DOOR -----
ink to   area     const      dir       area   frame  glazing     area      RSI
zone     (m^2)    code                 (m^2)  code   code        (m^2)  (m^2*C/W)
  3      622.3    -1         W         155.8   7      -1          4.0      0.50
  2       77.0     1         N           0.0   7      -1          0.0      0.00
  4       77.0     1         S           0.0   7      -1          0.0      0.00
  5      510.0     1         E           0.0   1       1          0.0      3.78

                    --------- ABOVE-GRADE FLOOR -----------
                    link to  area     const   avg. height to
                     zone     (m^2)   code      ceiling  (m)
                       1      257.0    8          2.5
                       1      257.0    8          2.5

                    -- CEILING --      ------ SKYLIGHT ------
                    area    const      area    frame  glazing
                     (m^2)  code        (m^2)  code   code
                     257.0   -1          0.0    1       1

    ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
     area     const    avg.    insul      insul     unins      const  height to
      (m^2)   code   dpth (m) dpth (m)    (m^2)     (m^2)      code   ceil  (m)
       0.0     1        0.0      0.0       0.0      257.0       1       2.5
```

```
                          List of Codes Used in Zone #1
                          -----------------------------

Wall.......: -1: Office Wall                                   1.41
Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum          RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U   2.30
Frame......:  7: Aluminum/TB frame- 10% of window area U   5.70
Glazing....: -1: custom glazing                                2.78
Glazing....:  1: Standard single-glazed clear window     U 6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil         RSI 0.62
Ceiling....: -1: Small Office Building Ceiling                 8.00
Below Grade:  1: 100mm concrete/uninsulated                RSI 0.42
```

```
                Building Description Data - Zone #2 - SOUTH WEST
                ------------------------------------------------

------------ WALL ------------     ------- WINDOW -------   ----- DOOR -----
link to  area    const     dir      area   frame  glazing    area       RSI
 zone    (m^2)   code               (m^2)  code   code       (m^2)   (m^2*C/W)
   0      622.3   -1        S        155.8  7       -1         4.0       0.50
   3       77.0    1        E          0.0  7       -1         0.0       0.01
   5      510.0    1        N          0.0  2       -1         0.0       0.01

                    --------- ABOVE-GRADE FLOOR -----------
                    link to  area    const   avg. height to
                     zone     (m^2)  code     ceiling  (m)
                       2      257.0    8          2.5
                       2      257.0    8          2.5

                    -- CEILING --     ------ SKYLIGHT ------
                    area    const     area    frame  glazing
                     (m^2)  code       (m^2)  code   code
                     257.0   -1          0.0    1      1

     ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
      area    const   avg.   insul     insul     unins     const  height to
       (m^2)  code  dpth (m) dpth (m)   (m^2)     (m^2)    code   ceil   (m)
         0.0    1       0.0     0.0       0.0     257.0      1       2.5




                         List of Codes Used in Zone #2
                         -----------------------------

Wall.......: -1: Office Wall                              1.41
Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum     RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U  2.30
Frame......:  2: Wood or PVC frame- 20% of window area U  2.30
Frame......:  7: Aluminum/TB frame- 10% of window area U  5.70
Glazing....: -1: custom glazing                           2.78
Glazing....:  1: Standard single-glazed clear window    U 6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil    RSI 0.62
Ceiling....: -1: Small Office Building Ceiling            8.00
Below Grade:  1: 100mm concrete/uninsulated           RSI 0.42
```

```
              Building Description Data - Zone #3 - SOUTH EAST
              ------------------------------------------------

----------- WALL ------------        ------- WINDOW -------     ----- DOOR -----
ink to  area    const      dir        area   frame  glazing     area      RSI
zone    (m^2)   code                 (m^2)   code   code        (m^2)  (m^2*C/W)
  3     622.3   -1          E         38.9    7      -1          0.0     0.00
  4     140.0    1          N          0.0    7      -1          0.0     0.00
  5     510.0    1          W          0.0    1       1          0.0     0.00

                  --------- ABOVE-GRADE FLOOR -----------
                  link to  area     const   avg. height to
                   zone    (m^2)   code     ceiling  (m)
                     2     257.0    8          2.5
                     2     257.0    8          2.5

                  -- CEILING --       ------ SKYLIGHT ------
                  area     const      area     frame  glazing
                   (m^2)   code        (m^2)   code   code
                  257.0     1           0.0     1      1

    ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
     area    const   avg.    insul     insul      unins      const  height to
     (m^2)   code   dpth (m) dpth (m)  (m^2)      (m^2)      code   ceil  (m)
      0.0     1       0.0      0.0      0.0       257.0       1        2.5




                       List of Codes Used in Zone #3
                       -----------------------------

Wall.......: -1: Office Wall                                   1.41
Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum          RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U   2.30
Frame......:  7: Aluminum/TB frame- 10% of window area U   5.70
Glazing....: -1: custom glazing                                2.78
Glazing....:  1: Standard single-glazed clear window     U 6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil       RSI 0.62
Ceiling....:  1: Gypsum/ wood frame & RSI3.5/shingles RSI 3.58
Below Grade:  1: 100mm concrete/uninsulated                RSI 0.42
```

```
                Building Description Data - Zone #4 - NORTH EAST
                ------------------------------------------------

------------- WALL -------------      ------- WINDOW -------    ----- DOOR -----
link to  area     const       dir       area   frame  glazing     area       RSI
 zone    (m^2)    code                 (m^2)   code   code       (m^2)   (m^2*C/W)
   0      622.3    -1          N         77.8    7      -1          4.0       0.50
   5      510.0     1          S          0.0    7      -1          0.0       0.00
   6       55.0     1          W          0.0    1       1          0.0       0.00

                      --------- ABOVE-GRADE FLOOR -----------
                      link to  area     const   avg. height to
                       zone     (m^2)   code     ceiling  (m)
                         4      257.0    8           2.5
                         4      257.0    8           2.5

                      -- CEILING --      ------ SKYLIGHT ------
                      area    const      area    frame  glazing
                       (m^2)  code        (m^2)  code   code
                       257.0   1           0.0    1      1

       ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
        area    const   avg.    insul     insul      unins     const  height to
         (m^2)  code  dpth (m) dpth (m)   (m^2)      (m^2)     code   ceil  (m)
           0.0    1       0.0     0.0       0.0      257.0       1       2.5
```

```
                          List of Codes Used in Zone #4
                          -----------------------------

Wall.......: -1: Office Wall                                  1.41
Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum        RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U  2.30
Frame......:  7: Aluminum/TB frame- 10% of window area U  5.70
Glazing....: -1: custom glazing                               2.78
Glazing....:  1: Standard single-glazed clear window     U  6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil       RSI 0.62
Ceiling....:  1: Gypsum/ wood frame & RSI3.5/shingles RSI 3.58
Below Grade:  1: 100mm concrete/uninsulated              RSI 0.42
```

```
                    Building Description Data - Zone #5 - CENTER
                    --------------------------------------------

------------ WALL ------------      ------- WINDOW -------     ----- DOOR -----
link to  area     const     dir      area   frame  glazing    area       RSI
 zone   (m^2)    code                (m^2)  code   code       (m^2)   (m^2*C/W)
  6     1260.0    1          W         0.0   1       1         0.0       3.78

                  --------- ABOVE-GRADE FLOOR -----------
                  link to  area     const   avg. height to
                   zone    (m^2)    code     ceiling  (m)
                     5     972.0     8          2.5
                     5     972.0     8          2.5

                  -- CEILING --       ------ SKYLIGHT ------
                  area     const      area    frame  glazing
                   (m^2)   code        (m^2)  code   code
                   972.0     1          0.0     1      1

    ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
     area    const   avg.     insul     insul      unins     const   height to
     (m^2)   code  dpth (m) dpth (m)    (m^2)      (m^2)     code    ceil  (m)
      0.0     1       0.0      0.0        0.0      972.0       1       2.5




                        List of Codes Used in Zone #5
                        -----------------------------

Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum      RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U  2.30
Glazing....:  1: Standard single-glazed clear window    U 6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil     RSI 0.62
Ceiling....:  1: Gypsum/ wood frame & RSI3.5/shingles RSI 3.58
Below Grade:  1: 100mm concrete/uninsulated            RSI 0.42
```

```
              Building Description Data - Zone #6 - INTERIOR AREA
              ---------------------------------------------------

------------ WALL ------------     ------- WINDOW -------   ----- DOOR -----
link to  area    const     dir      area   frame  glazing    area      RSI
 zone    (m^2)   code               (m^2)  code   code       (m^2)   (m^2*C/W)
   0        0.0    1        S          0.0   1       1         0.0       3.78

                    --------- ABOVE-GRADE FLOOR -----------
                    link to  area    const   avg. height to
                     zone     (m^2)  code     ceiling  (m)
                       6      400.0    8          2.5
                       6      400.0    8          2.5

                    -- CEILING --     ------ SKYLIGHT ------
                    area    const     area    frame  glazing
                     (m^2)  code       (m^2)  code   code
                     400.0    1          0.0    1      1

     ------ BELOW-GRADE WALLS ------  -- BELOW-GRADE/SLAB-ON-GRADE FLOOR --
      area    const   avg.   insul     insul     unins     const  height to
       (m^2)  code  dpth (m) dpth (m)   (m^2)     (m^2)    code   ceil  (m)
         0.0    1       0.0     0.0       0.0     400.0      1       2.5




                         List of Codes Used in Zone #6
                         -----------------------------

Wall.......:  1: Gypsum/ 2x4 cavity no ins/gypsum     RSI 0.45
Frame......:  1: Wood or PVC frame- 10% of window area U  2.30
Glazing....:  1: Standard single-glazed clear window    U 6.30
Floor......:  8: Wood floor/wood frame/gypsum ceil    RSI 0.62
Ceiling....:  1: Gypsum/ wood frame & RSI3.5/shingles RSI 3.58
Below Grade:  1: 100mm concrete/uninsulated           RSI 0.42
```

```
                          HVAC and Equipment Data
                          -----------------------

                      HVAC System: Multiple Forced Air

    A: HEATING SYSTEM
    Zone                1       2       3       4       5       6
    Source    (1-2):  1       1       1       1       1       1
    Unit ID#  (1-5):  1       1       1       1       1       1
    Possible SOURCE values...(1-Furnace, 2-Heat Pump)

    A: COOLING SYSTEM
    Zone                1       2       3       4       5       6
    Source    (0-2):  1       1       1       1       1       1
    Unit Id#  (1-5):  4       4       4       4       4       4
    Possible SOURCE values...(0-none, 1-Air Conditioner, 2-Heat Pump)
```

```
--------------------------------------------------------------------------------
     FURNACE UNIT #1 -- TYPICAL OFFICE BUILDING FURNACE

     Fuel (0-Elec,1-Nat gas,2-#2 oil,3-#6 oil,4-Prop,5-Dist steam):     0
     Maximum Rated kW Heat Input..................................:   900.0

     Furnace Performance
     % of Full Load:     25.0     35.0     45.0     75.0    100.0
     Efficiency (%):    100.0    100.0    100.0    100.0    100.0
--------------------------------------------------------------------------------
     AIR CONDITIONING UNIT #4 -- LENNOX GCS11-3003 2 COMPRESSORS)

     Cooling Performance [kW] vs. Indoor Wet Bulb Temp. (fixed outdoor)
     Entering WBT......:   17.20    18.30    19.40    20.55    21.70
     Total Cooling.....:  173.60   178.60   183.60   189.30   195.00
     Sens Cooling......:  138.88   126.36   113.84   101.76    89.70
     Compress Power(kW):   52.36    53.32    54.30    55.40    56.48

     Design Ambient Temperature (C)...................:    29.00
     Condenser Fan Power (kW).........................:     2.20
```

```
                   HVAC System Air Handling Data
                   -----------------------------

                HVAC System: Multiple Forced Air

AIR FLOW (l/s)
Zone               1       2       3       4       5       6       7    Total
Infil            265     169      27     169       0       0    ....      630
Exfil              5       9      67       9     790      40    ....      920
Supply           700     700     700     700    2650    1090    ....     6540
Recirc           160     160     160     160     610     250    ....     1500
Outdoor          540     540     540     540    2040     840    ....     5040

Exhaust          800     700     500     700    1250     800    ....     4750
Trans              0       0       0       0       0       0    ....
from zone          0       0       0       0       0       0       .
Trans              0       0       0       0       0       0    ....
from zone          0       0       0       0       0       0       .

Trans out          0       0       0       0       0       0    ....

 SCHEDULES (code)
 Zone              1       2       3       4       5       6       7    Total
 Supply            2       2       2       2       2       2
 OutDoor           2       2       2       2       2       2
 Exhaust           2       2       2       2       2       2
 Trans 1           2       2       2       2       2       2
 Trans 2           2       2       2       2       2       2

 FAN POWER (W)
 Zone              1       2       3       4       5       6       7    Total
 Supply           0.0     0.0     0.0     0.0     0.0  8000.0
 Recirc           0.0     0.0     0.0     0.0     0.0  4000.0
 Exhaust          0.0     0.0     0.0     0.0     0.0  4000.0
```

```
                                Operating Schedules
                                --------------------

  Schedule        Title        Operating  Schedule           Hourly Values
   Number                        Days     Ratio

     1   internal heat gai         5         1.00         0   0   0   0   0   0
                                                          0 100 100 100 100 100
                                                        100 100 100 100 100 100
                                                        100   0   0   0   0   0

     2   supply air                7         1.00       100 100 100 100 100 100
                                                        100 100 100 100 100 100
                                                        100 100 100 100 100 100
                                                        100 100 100 100 100 100

     3   dhw profile               7         1.00         0   0   0   0   0   0
                                                          4  11   2  20   2   5
                                                          2   0   0   4  11  20
                                                         11   4   2   0   0   0
```

```
                                 Operating Data
                                 --------------

         ZONE #1 -- NORTH WEST

         Maximum Occupancy..................................:     40
         Activity level (1-9)...............................:      2
         Occupancy schedule (code 1-9)......................:      1
         Maximum Hourly Process Load :  heat (W)............:   3000
                                     :  moisture (kg/hr)....:      0
         Process schedule (code 1-9)........................:      1

         Thermostat Heating Setpoint (C)....................:     21.0
         Degrees of Heating Setback  (C)....................:      4.0
         Thermostat Heating Schedule (code 1-9).............:      1
         Thermostat Cooling Setpoint (C)....................:     24.0
         Degrees of Cooling Setup    (C)....................:      0.0
         Thermostat Cooling Schedule (code 1-9) ............:      1
-----------------------------------------------------------------------------
         ZONE #2 -- SOUTH WEST

         Maximum Occupancy..................................:     40
         Activity level (1-9)...............................:      2
         Occupancy schedule (code 1-9)......................:      1
         Maximum Hourly Process Load :  heat (W)............:   3000
                                     :  moisture (kg/hr)....:      0
         Process schedule (code 1-9)........................:      1

         Thermostat Heating Setpoint (C)....................:     21.0
         Degrees of Heating Setback  (C)....................:      4.0
         Thermostat Heating Schedule (code 1-9).............:      1
         Thermostat Cooling Setpoint (C)....................:     24.0
         Degrees of Cooling Setup    (C)....................:      0.0
         Thermostat Cooling Schedule (code 1-9) ............:      1
-----------------------------------------------------------------------------
         ZONE #3 -- SOUTH EAST

         Maximum Occupancy..................................:     40
         Activity level (1-9)...............................:      2
         Occupancy schedule (code 1-9)......................:      1
         Maximum Hourly Process Load :  heat (W)............:   3000
                                     :  moisture (kg/hr)....:      0
         Process schedule (code 1-9)........................:      1

         Thermostat Heating Setpoint (C)....................:     21.0
         Degrees of Heating Setback  (C)....................:      4.0
         Thermostat Heating Schedule (code 1-9).............:      1
         Thermostat Cooling Setpoint (C)....................:     24.0
         Degrees of Cooling Setup    (C)....................:      0.0
         Thermostat Cooling Schedule (code 1-9) ............:      1
```

```
                              Operating Data
                              --------------

      ZONE #4 -- NORTH EAST

      Maximum Occupancy...................................:      40
      Activity level (1-9)................................:       2
      Occupancy schedule (code 1-9).......................:       1
      Maximum Hourly Process Load :  heat (W)...........:    3000
                                  :  moisture (kg/hr)...:       0
      Process schedule (code 1-9).........................:       1

      Thermostat Heating Setpoint (C).....................:      21.0
      Degrees of Heating Setback  (C).....................:       4.0
      Thermostat Heating Schedule (code 1-9)..............:       1
      Thermostat Cooling Setpoint (C).....................:      24.0
      Degrees of Cooling Setup    (C).....................:       0.0
      Thermostat Cooling Schedule (code 1-9) .............:       1
-----------------------------------------------------------------------------
      ZONE #5 -- CENTER

      Maximum Occupancy...................................:     145
      Activity level (1-9)................................:       2
      Occupancy schedule (code 1-9).......................:       1
      Maximum Hourly Process Load :  heat (W)...........:   11400
                                  :  moisture (kg/hr)...:       0
      Process schedule (code 1-9).........................:       1

      Thermostat Heating Setpoint (C).....................:      21.0
      Degrees of Heating Setback  (C).....................:       4.0
      Thermostat Heating Schedule (code 1-9)..............:       1
      Thermostat Cooling Setpoint (C).....................:      24.0
      Degrees of Cooling Setup    (C).....................:       0.0
      Thermostat Cooling Schedule (code 1-9) .............:       1
-----------------------------------------------------------------------------
      ZONE #6 -- INTERIOR AREA

      Maximum Occupancy...................................:       3
      Activity level (1-9)................................:       3
      Occupancy schedule (code 1-9).......................:       1
      Maximum Hourly Process Load :  heat (W)...........:   29000
                                  :  moisture (kg/hr)...:       0
      Process schedule (code 1-9).........................:       2

      Thermostat Heating Setpoint (C).....................:      21.0
      Degrees of Heating Setback  (C).....................:       4.0
      Thermostat Heating Schedule (code 1-9)..............:       1
      Thermostat Cooling Setpoint (C).....................:      24.0
      Degrees of Cooling Setup    (C).....................:       0.0
      Thermostat Cooling Schedule (code 1-9) .............:       1
```

```
                            Water Heating Data
                            ------------------

          Daily Hot Water Load (l/day).......................:  250.00
          Hourly Hot Water Demand Schedule (code 1-9)........:    3
          Auxiliary Heat Source..............................: IMMERSION HEATER
          Desired Hot Water Temperature (C)..................:   55.0
          Volume of Auxiliary Tank (l).......................:  272.00
          Height of Auxiliary Tank  (m)......................:    1.2
          RSI value of Auxiliary Tank (m^2*C/W)..............:    1.8
          Zone Location of Tank .............................:    6
          Immersion Heater Capacity (kW).....................:    1.00

------------------------------------------------------------------------------

                              Economic Data
                              -------------

          Off-Peak Electricity schedule (code 1-9).............:     1
          Ratio of Off-Peak to Peak Cost.......................:     1.0

          Electric Peak Rate Structure :  First     250 kWhr at      7.77
                                          Next    12250 kWhr at      5.72
                                          Next    99999 kWhr at      4.11
                                          Remaining     kWhr at      4.11
                                          Minimum charge ($/mo):     4.85
                                          Demand Rate ($/kW)...:     4.00
                                          Demand Threshold (kW):    50
```

```
                          Lighting and Electrical Data
                          ----------------------------

  Zone              1       2       3       4       5       6
  Indoor Receptacles
  Load   (W/m^2)    0.0     0.0     0.0     0.0     0.0     0.0
  Schedule (1-9)    1       1       1       1       1       1

  Lighting Control: Off

  Indoor Lighting
  Load   (W/m^2)   23.7    23.7    23.7    23.7    23.7     9.5
  Schedule (1-9)    1       1       1       1       1       1

  Outdoor Receptacle Load (W)..........................:     0.0
  Receptacle Schedule (code 1-9).......................:     1
  Outdoor Lighting Load (W)............................:   400.0
  Lighting Schedule (code 1-9 or 0 for photocell).....:     0
```