Title

EFFECTS OF LOW-EMISSIVITY GLAZINGS ON ENERGY USE PATTERNS IN NONRESIDENTIAL DAYLIGHTED BUILDINGS

Authors

Sweitzer, G.
Arasteh, D.
Selkowitz, S.

Publication Date

1986-12-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

APPLIED SCIENCE DIVISION

Presented at the ASHRAE Winter Meeting, Symposium on Fenestration Performance, New York, NY, January 18–21, 1987, and to be published in the Proceedings

Effects of Low-Emissivity Glazings on Energy Use Patterns in Nonresidential Daylighted Buildings

G. Sweitzer, D. Arasteh, and S. Selkowitz

December 1986

APPLIED SCIENCE DIVISION

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

DISCLAIMER

LBL-21577
BS-240

Presented at the ASHRAE Winter Meeting in New York City, NY, January 18-21, 1987, and published in *Low-E Coatings: ASHRAE Symposium on Fenestration Performance*, 1987 (*ASHRAE Transactions*, Vol. 93, Part 1).

Effects of Low-Emissivity Glazings on Energy Use Patterns in Nonresidential Daylighted Buildings

G. Sweitzer, D. Arasteh, and S. Selkowitz

Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

December 1986

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

EFFECTS OF LOW-EMISSIVITY GLAZINGS ON ENERGY USE PATTERNS IN NONRESIDENTIAL DAYLIGHTED BUILDINGS

G. Sweitzer D. Arasteh S. Selkowitz

Windows and Daylighting Group
Applied Science Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

ABSTRACT

Fenestration is the most significant envelope design determinant of energy use in nonresidential buildings. This paper presents our assessment of energy use effects of low-emissivity (low-E) versus conventional glazings for a range of window-to-wall ratios in a daylighted office building, in representative hot and cold climates. Low-E glazings transmit "cooler" daylight than their conventional counterparts because, for a given visible transmittance, they reflect a much larger fraction of incident solar infrared radiation. We thus use the ratio of visible transmittance to shading coefficient, which we define as K_e, to compare the effect of representative glazing characteristics on component and total-building energy use, peak electrical demand, and required cooling equipment sizes.

We conclude that insulated glazings with low-E coatings can provide lighting and cooling energy savings in both hot and cold climates. The most dramatic lighting, cooling, and total electricity energy savings are achieved for increases of K_e within the range of 0.5 to 1.0; higher K_es provide diminishing savings. The increased R-value of low-E insulated glass units provides significant benefits in cold climates and is not a liability in hot climates.

Low-E glazings also help increase the mean radiant temperature of interior environments in winter and reduce it in summer, and provide greater architectural design freedom without adverse energy consequences. Further, the higher first costs of these glazings may be more than offset by savings from smaller cooling equipment, energy and peak-demand cost savings, long-term financial gains from better rentals, and increased productivity due to improved occupant comfort.

INTRODUCTION

Fenestration is the most significant envelope design factor affecting energy use in nonresidential buildings. In order to counter the negative energy impacts of cooling loads from large areas of glazing, architects and engineers have typically used conventional tinted and/or reflective glazings and/or smaller window areas in order to comply with energy codes. Energy use for these cases increases monotonically with interior floor-to-ceiling window-to-wall (WWR) ratio and with the glazing's shading coefficient (SC) due to increased solar gain (and associated cooling loads) (Johnson et al. 1984).

More recently, the energy benefits of daylighted perimeter zones have been explored. A significant fraction of electric lighting (and some cooling energy) in these areas can be saved by dimming or switching electric lights in response to available daylight. This strategy, if properly implemented, can reduce total electricity consumption for a typical office building perimeter zone to less than that for one with no windows (Figure 1) (Johnson et al. 1984). For such a daylighted zone, lighting energy requirements at first decrease rapidly with increasing WWR. However, once daylight has satisfied the interior design illuminance requirements for most of the occupied period, little additional lighting energy savings can be captured. At this point, additional glazing only adds thermal loads to the space with minimal further lighting energy savings so that total electricity use rises as shown in Figure 1 (Johnson 1983, 1984, 1986). The degree to which daylighting can reduce lighting loads depends primarily on WWR and visible transmittance (T_v).

The thermal impact of fenestration in daylighted buildings can, thus, vary significantly with glazing type. Different tinted or coated glazings will have different SCs for the same T_v, or alternatively, different T_vs for the same SC. In this paper, we examine component and total building energy use, peak electrical demand, and required cooling equipment sizes for a range of glazing characteristics in daylighted building modules. We compare conventional clear, tinted, and reflective glazings versus low-E glazings. Low-E glazings, originally developed to improve the insulating capabilities of residential glazings by reflecting long wave infrared radiation, also often have high solar-infrared reflectances. With moderately high visible transmittances (0.60 - 0.80 on clear glass), low-E glazings are ideal for any daylighted or nondaylighted building where high visible transmittance and reduced solar heat gains are desired. The selective transmittance effect of a low-E coating is shown in Figure 3, which presents the spectral transmittance of representative low-E and conventional glazings.

METHODOLOGY

The procedure used in this study is based on our previous analyses of energy use in nonresidential buildings (Johnson et al. 1983, 1984, 1985; Arasteh et al. 1985, Selkowitz et al. 1983). Using DOE-2.1C (Curtis et al. 1984) as the energy-analysis tool, we examined lighting, cooling, heating, fan, and total energy consumption in addition to peak demand and chiller size for a prototypical office building design for two climatic extremes: Madison, WI (cold) and Lake Charles, LA (hot).

The building prototype, illustrated in Figure 2, is representative of current design and use practices; it is described in detail in the above-referenced reports. It includes a 100-ft-square (30.5-m) core surrounded by four identical perimeter zones. Each perimeter zone faces a cardinal direction and is composed of ten 10-ft-wide (3-m) by 15-ft-deep (4.6-m) by 8.5-ft-high (2.6-m) closed offices. Shades, drapes, or blinds (which reduce visible transmittance by 65% and solar heat gain by 40%) are automatically deployed inside the glazing whenever the directly transmitted solar radiation exceeds 20 Btu/hr-ft^2 (63 W/m^2). This response simulates the use of shading to control thermal comfort and glare, not to conserve energy.

We examined the luminous and thermal transmittances of glazings using two approaches: (1) defining energy performance in terms of two dimensionless parameters that cover the full range of glazing options currently available and (2) characterizing performance of windows with specific glazings and WWRs. Analysis results using these two options are detailed below:

(1) Previous studies (Johnson 1984, 1985) have defined a glazing aperture parameter (the effective aperture, A_e) and a glazing luminous efficacy constant (K_e). The effective aperture is defined as the product of the WWR and the T_v. Effects of mullions and other opaque elements can be accounted for with the WWR term while a dirt depreciation factor can be incorporated into the T_v. This lumped parameter is particularly useful when analyzing daylighted conditions because various combinations of WWR and T_v that yield the same A_e will generally have the same influence on component and total building energy performance (Johnson et al. 1983, 1984). K_e is the ratio of the T_v to the solar thermal gains (SC) associated with a given fenestration system.

(2) Nine glazings are described in Table 1. These are representative of generic rather than specific products. The energy implications of each glazing are presented in the context of three building envelop configurations, each characterized by a different WWR (Figure 3) and representative of the current stock of U.S. office buildings. The largest WWR (0.75) represents the large glazed areas typical of many office buildings designed from the 1950s through recent years. The 0.50 WWR represents a horizontal-band window that was commonly used in the years following the oil crisis. The smallest WWR (0.25) is typical of both U.S. buildings before the 1940s and some building designs of the 1980s.

Figure 4 shows visible transmittance plotted against shading coefficient for the nine generic glazings listed in Table 1. (SC and T_v were obtained from a survey of manufacturers' literature.) Note that the slopes for these families of glazings correspond to the index K_e. (Reference lines are drawn for $K_e = 0.5$, 1.0, 1.5, and 2.0.) Figure 2 shows that reflective insulated glass (IG) units generally have the lowest K_e, followed by bronze-tinted IG units, clear IG units, and green-tinted IG units. A low-E coating added to the #2 surface (numbered surfaces starting from the outside), or a low-E film suspended in the airspace of IG units improves the K_e significantly. The maximum theoretical K_e is 2.8; this corresponds to T_v = 1.0 and $T_s = 0.36$, no absorptance.

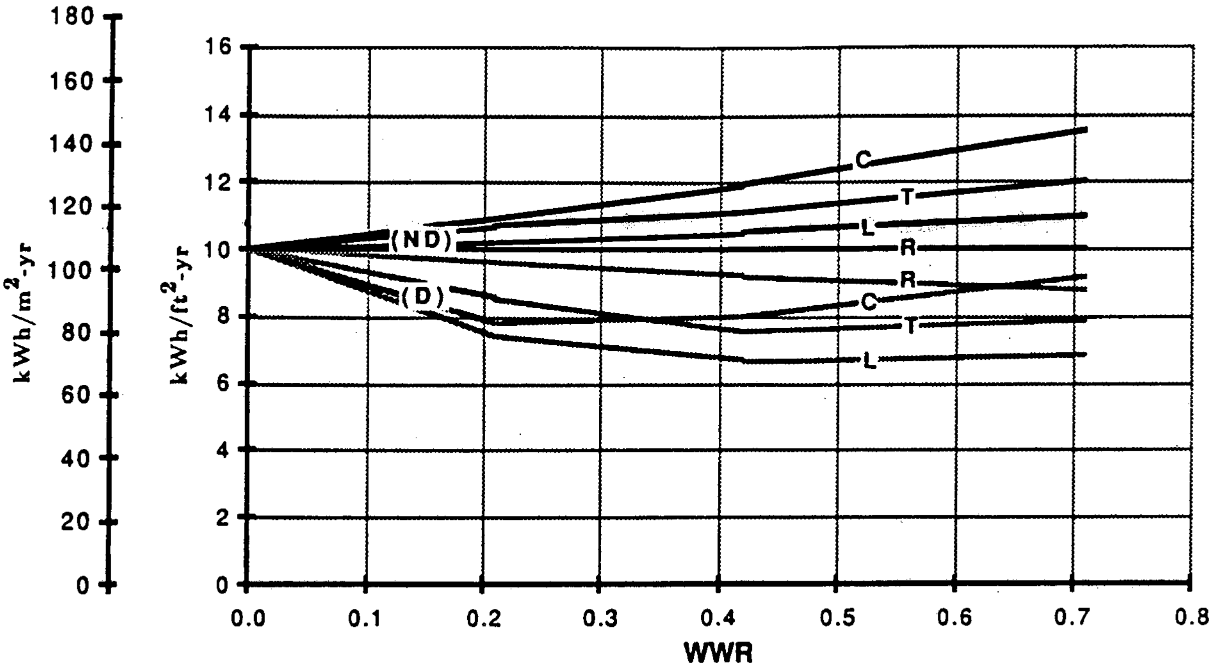


Figure 1: Total electricity use for all four perimeter zones as a function of window-to-wall ratio (WWR) for representative clear (C), tinted (T), reflective (R), and clear glazings having low-E coatings (L) in Lake Charles. Use of dimming controls (D) vs. no dimming controls (ND).

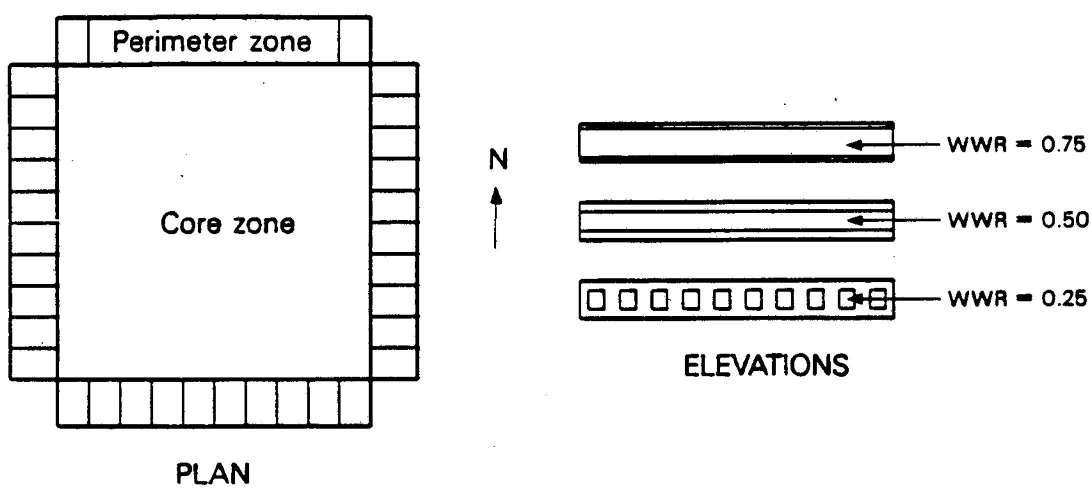


Figure 2: Plan of representative building office module, also showing alternative window-to-wall ratios (WWRs). The module consists of a 100 x 100-ft (30.5 x 30.5-m) core surrounded by 15-ft (4.6-m) perimeter zones. The perimeter zones are divided into 10 modules, each 10 ft (3.1 m) wide.

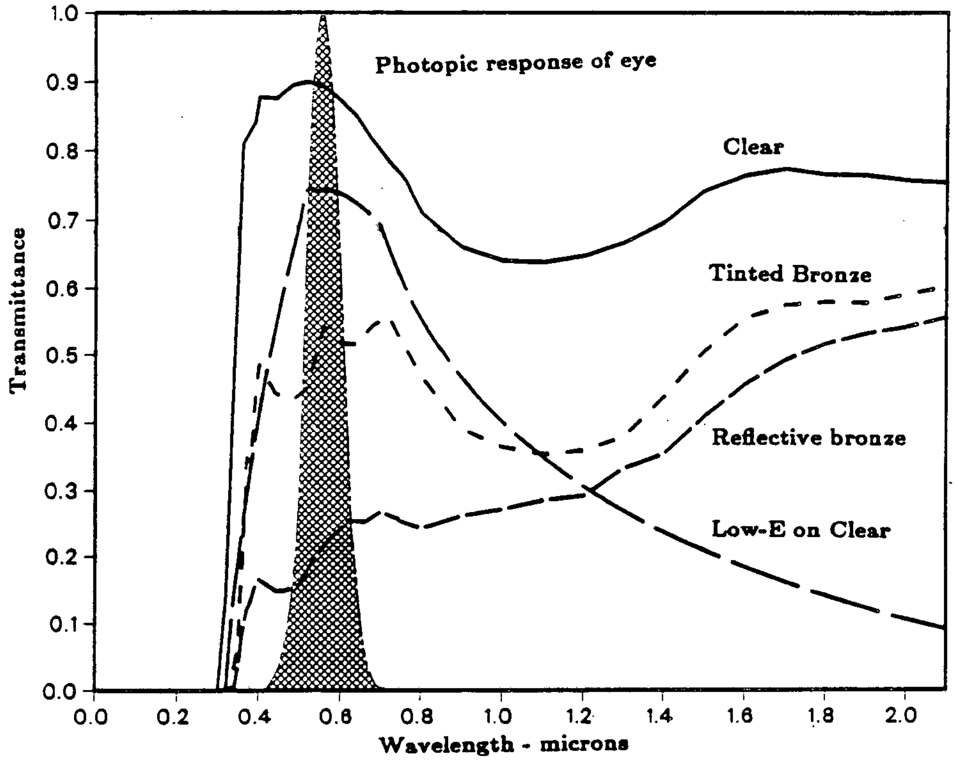


Figure 3: Spectral transmittance of representative glazing types and the photopic response of the eye.

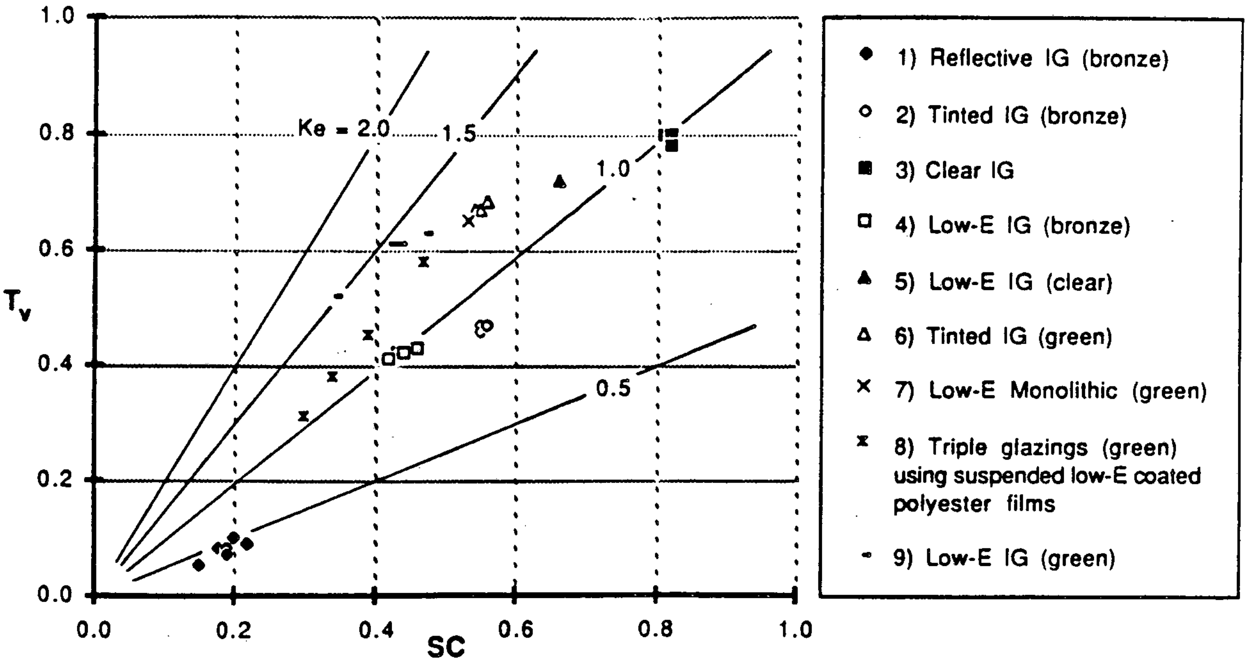


Figure 4: Visible transmittance (T_v) vs. Shading Coefficient (SC) and K_e values for representative low-E and conventional glazings.

In order to focus on the effects of A_e and K_e (or alternatively WWR, SC, and T_v), we controlled the electric light and daylight contributions in each perimeter zone office. We maintained the typically required office illuminance of 50 footcandles (538 lux), used a continuous dimming system to control electric lighting in response to varying daylight levels, and assumed a lighting power density of 1.7 W/ft^2 (18.3 W/m^2), typical for newer buildings. Other studies (Johnson et al. 1983, 1984) discuss the effects of these parameters on daylighting energy savings. Under most circumstances, effective apertures between 0.2 and 0.3 provide nearly all the practical daylighting savings in the perimeter zones we modeled; larger apertures only provide minimal extra savings on very cloudy days and in the early mornings or late afternoons (Johnson et al. 1984).

RESULTS

Thermal Effects in a Cold Climate (Madison, WI)

Figure 5a shows annual cooling energy as a function of effective aperture with continuous dimming of electric lights for the southern zone in our prototypical office building module. General results are presented for four K_e values (0.5, 1.0, 1.5, and 2.0) for both R 2 hr-ft^2-°F/Btu (.35 m^2-° C/w), typical insulated glass, and R 3.6 hr-ft^2-°F/Btu (.63 m^2-°C/w), a three-layer insulated glass unit with a low-E middle layer, glazing options. Glazings options with an R-value*of 3 hr-ft^2-°F/Btu (.53 m^2-°C/w), low-E double-glazed units, lie closer to the R3.6 than the R2 lines . Specific results for the nine glazing options in Table 1 are shown and are also presented by number in Table 2. While the overall magnitude of cooling energy in this climate is small, 3-8 kBtu/ft^2-yr (35-90 MJ/m^2), note that the effect of K_e is important, especially between K_e of 0.5 and 1.0. During daytime hours, perimeter office zones, especially on the south side, must almost always be cooled. Therefore when the outdoor temperature is lower than the interior (and the economizer is not meeting the cooling load), a glazing with a higher R-value will inhibit free cooling by conduction. Conversely, when the exterior temperature is higher than the interior, the same glazing will reduce the cooling load in the space. In Madison, for glazings with the same solar-optical properties, the overall annual effect is that a higher R-value will result in slightly higher cooling loads. However, low-E products compared with their uncoated counterparts show cooling load decreases (due to their increased K_e) that more than compensate for this small increase. Furthermore, with higher-K_e glazings, the control of solar gains is not as important and use of larger effective apertures is possible. Note that as K_e increases, energy savings diminish; changing from low to moderate K_es (e.g., from bronze to bronze with a low-E coating) is much more effective than going from moderate to high K_es (e.g., from green to green with a low-E coating).

Our findings for the north zone (see Table 2) show a smaller rise in cooling energy with increasing A_e or WWR and less dependence on either K_e or R-value. Also, the cooling energy used by fans, which is generally proportional to cooling energy for each zone, can be expected to drop similarly. On an annual basis, east and west zones will fall between north and south.

Figure 6 presents the same information for heating energy (natural gas) in Madison. Glazings that transmit the most solar gain (those with the lowest K_es) have the lowest heating energy. However, even on the south, glazing R-value is more important than K_e. For the same nine products discussed earlier, we see that low-E windows with a higher R-value (#4,5,8,9) outperform their conventional counterparts (#1,2,3,6) even though their K_es are generally higher. For the north, east, and west orientations, the effects of solar gains on heating energy will be less noticeable and R-value differences will be even more important.

Glazings with a higher R-value also have the advantage of keeping glass temperatures closer to interior temperatures (Table 1). Under winter conditions this will lead to a much more comfortable environment and less condensation on the interior glazing.

Fan electricity for heating follows the same trends as heating energy, as seen in Figure 7 and summarized in Table 2. Note that large fan heating energy savings, up to 1 kWh/ft^2 (10 kwh/m^2), can be achieved by using a glazing with a higher R-value. This is because the fan size is based on peak winter or summer conditions.

* Note that, for Figures 5 and 6, to model different R-values in a general analysis, a WWR must be specified. We choose WWR=0.75 in order to show the maximum effects. The differences between glazings with different R-values for the WWR=0.50 and WWR=0.25 cases will be proportionately less. Thus for these graphs, the wall's overall U-value only changes with glazing R-value and not with WWR.

Table 1

Glazing Properties

Generic Glazing Products	R-value* hr-ft^2-^{o}F/Btu	(m^2-^{o}C/W)	Emittance on coated (#2) surface+	SC	Tv	Ke	Interior surface temperature* ^{o}F	(^{o}C)
1) Reflective IG (bronze)	2.5	(0.44)	0.40++	0.20	0.10	0.5	49	(9.4)
2) Tinted IG (bronze)	2.0	(0.35)	- - -	0.57	0.47	0.8	45	(7.1)
3) Clear IG	2.0	(0.35)	- - -	0.82	0.80	1.0	45	(7.1)
4) Low-E IG (bronze)	3.0	(0.53)	0.15	0.42	0.41	1.0	52	(11.3)
5) Low-E IG (clear)	3.0	(0.53)	0.15	0.66	0.72	1.1	52	(11.3)
6) Tinted IG (green)	2.0	(0.35)	- - -	0.56	0.67	1.2	45	(7.1)
7) Low-E monolithic (green)**	0.9	(0.16)	0.35	0.53	0.65	1.2	12	(-11.1)
8) Triple glazing; IG (green) with low-E coated polyester film suspended in airspace***	3.6	(0.63)	0.15	0.47	0.58	1.2	53	(11.8)
9) Low-E IG (green)	3.0	(0.53)	0.15	0.41	0.61	1.5	52	(11.3)

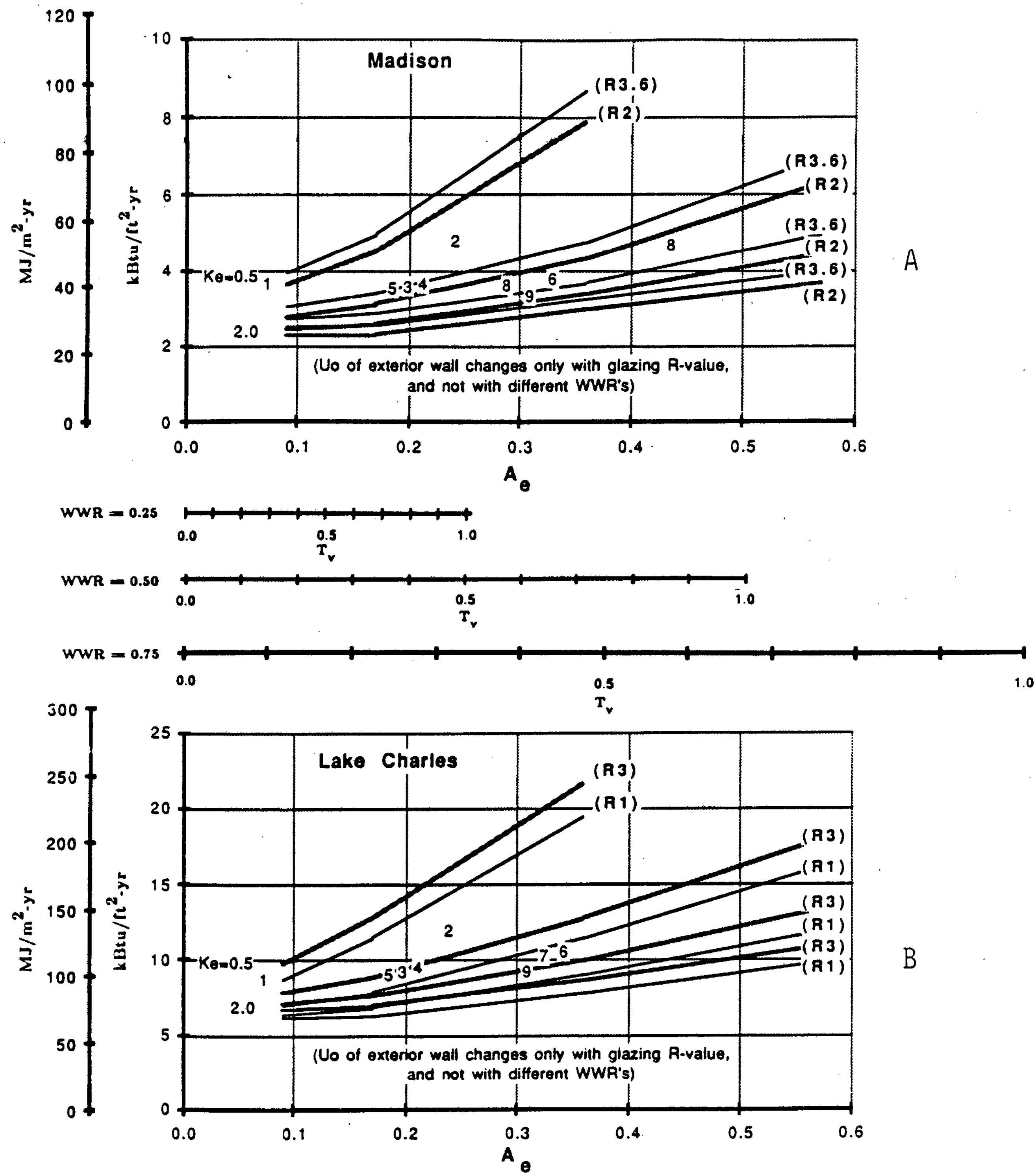
* ASHRAE winter conditions (T_o = 0^{o}F; T_i = 70^{o}F; 15 mph wind speed; nighttime)

** Estimated (Ts=0.35; Tv=0.65)

*** Gap widths assumed 5/16" (8mm); optimum R-value of 4.3 hr-ft^2-F/Btu (0.70m^2-C/W) with 1/2" (12mm) gap widths

\+ Surfaces numbered from outside to inside; all other surfaces uncoated (emittance = 0.84)

++ Emittances will vary slightly with type of reflective coating



Figures 5a and 5b: Cooling energy use as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison (Figure 5a) for both R2 hr-ft^2-F/Btu (0.35 m^2-C/W) and R3.6 hr-ft^2-F/Btu (0.63 m^2-C/W) glazings and in Lake Charles (Figure 5b) for both R1 hr-ft^2-F/Btu (0.18 m^2-C/W) and R3 hr-ft^2-F/Btu (0.53 m^2-C/W) glazings. South zone, use of continuous dimming controls. The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.

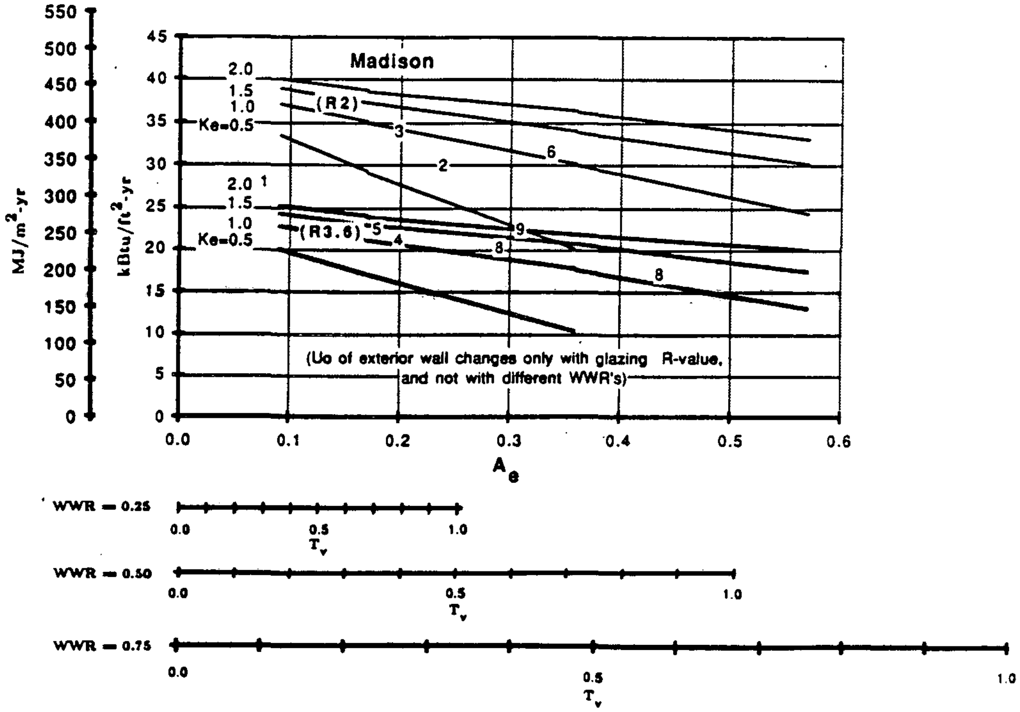


Figure 6: Heating energy use as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison for both R2 hr-ft^2-F/Btu (0.35 m^2-C/W) and R3.6 hr-ft^2-F/Btu (0.63 m^2-C/W) glazings. South zone, use of continuous dimming controls. The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.

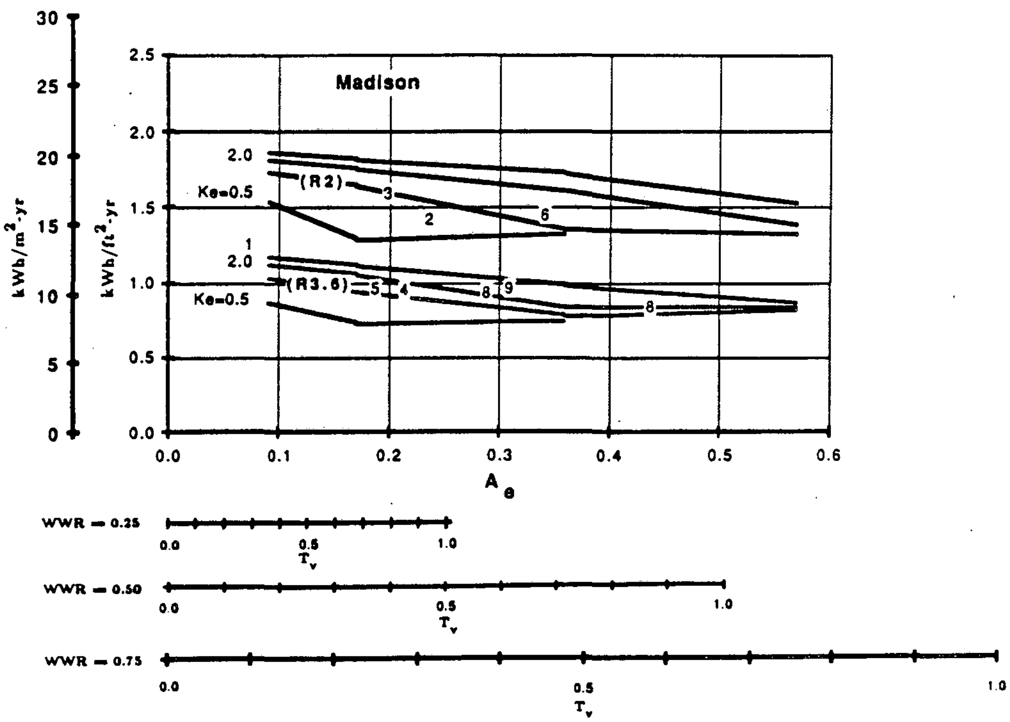


Figure 7: Fan heating energy use as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison for both R2 hr-ft^2-F/Btu (0.35 m^2-C/W) and R3.6 hr-ft^2-F/Btu (0.63 m^2-C/W) glazings. South zone, use of continuous dimming controls. The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.

Table 2

Perimeter Zone(s) Energy Use for
Representative Glazings & Window/wall Ratios
(use of daylighting controls assumed)

	Generic Glazing Products	% Electric Ltg Saved N	% Electric Ltg Saved S	Cooling KBTU/ft²* N	Cooling KBTU/ft²* S	Heating KBTU/ft²* N	Heating KBTU/ft²* S	Total KWH/ft²** N	Total KWH/ft²** S	Peak W/ft²+ all zones	Chiller ft²/ton++ all zones
	Madison, WI										
WWR=0.75	1) Reflective IG (bronze)	20	33	3.0	3.5	32.5	28.5	8.9	8.6	3.3	667
	8) Triple glazing; IG (green) with low-E coated polyester film suspended in airspace	68	68	3.4	5.0	24.3	17.2	6.4	6.9	2.6	555
WWR=0.50	2) Tinted IG (bronze)	57	60	3.5	4.5	36.5	30.5	7.9	7.9	2.9	588
	4) Low-E IG (bronze)	53	58	2.8	3.5	26.5	21.5	7.0	6.8	2.5	689
	6) Tinted IG (green)	65	65	2.7	3.7	39.0	32.0	7.1	7.0	2.5	645
	8) Triple glazing; IG (green) with low-E coated polyester film suspended in airspace	61	63	2.8	3.9	24.5	20.0	6.8	6.7	2.5	667
	9) Low-E IG (green)	62	63	2.5	3.5	27.0	22.4	6.7	6.3	2.4	714
WWR=0.25	3) Clear IG	53	58	2.5	3.6	39.2	34.2	8.0	7.3	2.7	689
	5) Low-E IG (clear)	51	56	2.7	3.4	26.5	23.8	7.5	7.0	2.5	714
	Lake Charles, LA										
WWR=0.75	1) Reflective IG (bronze)	20	33	8.0	9.0	4.3	3.8	9.3	8.6	3.6	546
WWR=0.50	2) Tinted IG (bronze)	57	60	9.0	11.5	5.3	3.5	8.0	9.0	3.7	465
	4) Low-E IG (bronze)	55	58	7.5	9.4	3.5	2.4	7.4	7.8	3.5	546
	6) Tinted IG (green)	65	65	8.2	10.5	5.7	4.0	7.2	8.3	3.5	476
	7) Low-E monolithic (green)	64	64	7.6	9.9	9.5	7.0	7.1	8.3	3.5	500
	9) Low-E IG (green)	63	63	7.5	9.4	3.5	2.5	7.0	7.5	3.4	562
WWR=0.25	3) Clear IG	53	58	7.5	9.0	5.8	4.5	7.3	7.6	3.4	540
	5) Low-E IG (clear)	51	56	7.1	8.5	3.5	3.0	7.4	7.5	3.3	588

* 1 kBtu/ft² = 11.4 MJ/m²
** 1 kWh/ft² = 10.8 kWh/m²
\+ 1 W/ft² = 10.8 W/m²
++ 1 ton/1000 ft² = 37.9 W/m²

Figure 8a compares total electricity consumption for cases with dimming (D) and no dimming (ND) of electric lighting. The results illustrate both the effect of replacing some electric lighting energy consumption with daylighting and the relationship between cooling energy and K_e. With lower K_es, cooling energy rises more steeply with A_e and the range of optimum effective apertures is much narrower. The greatest savings occur as K_e increases from 0.5 to 1.0, with diminishing returns for K_es above 1.0. A northern orientation would show even less of a difference between K_e since the total solar gain is reduced. Total electric consumption for the nine generic glazing products studied are shown by WWR in Table 2. Note that there is a large drop in cooling energy, but small increase in lighting energy, when changing from an uncoated product to the same product with a low-E coating. This is because the SC has dropped significantly while the T_v has decreased only slightly. Thus, in this case, the optimum WWR can be larger than for the case without a low-E coating. The data shown in Figure 8a is for R2 glazing. Higher-R-value glazings will decrease total electricity slightly because the fan heating electricity decreases with increasing R-value, slightly more than the increase in cooling electricity due to higher-R-value glazing.

Peak electricity demand for the perimeter zones for cases with and without daylighting controls is shown in Figure 9a. Because this is a total building peak, we must look at all four perimeter zones together (the core zone has been factored out). As in the case of net annual electricity consumption, dimming plays an important role in reducing peak demand (Selkowitz et al. 1983); further reductions can be achieved with high-K_e glazings. Note that for a typical effective aperture of 0.3, changing from a conventional reflective glazing with K_e=0.5 and no dimming of electric lights to a glazing with K_e=1.0 and dimming controls, the peak demand is reduced more than 50%, from about 5 W/ft² (53.8 W/m²) to less than 2.5 W/ft² (26.9 W/m²). For both the generic glazings and the specific glazing products (see also Table 2), we see trends in peak electric demand that are similar to those seen for total electricity consumption. The data shown in Figure 9a are for R2 glazings. Because the peak occurs in summer when the outside temperature is greater than the inside, higher R-values will add small additional peak demand savings.

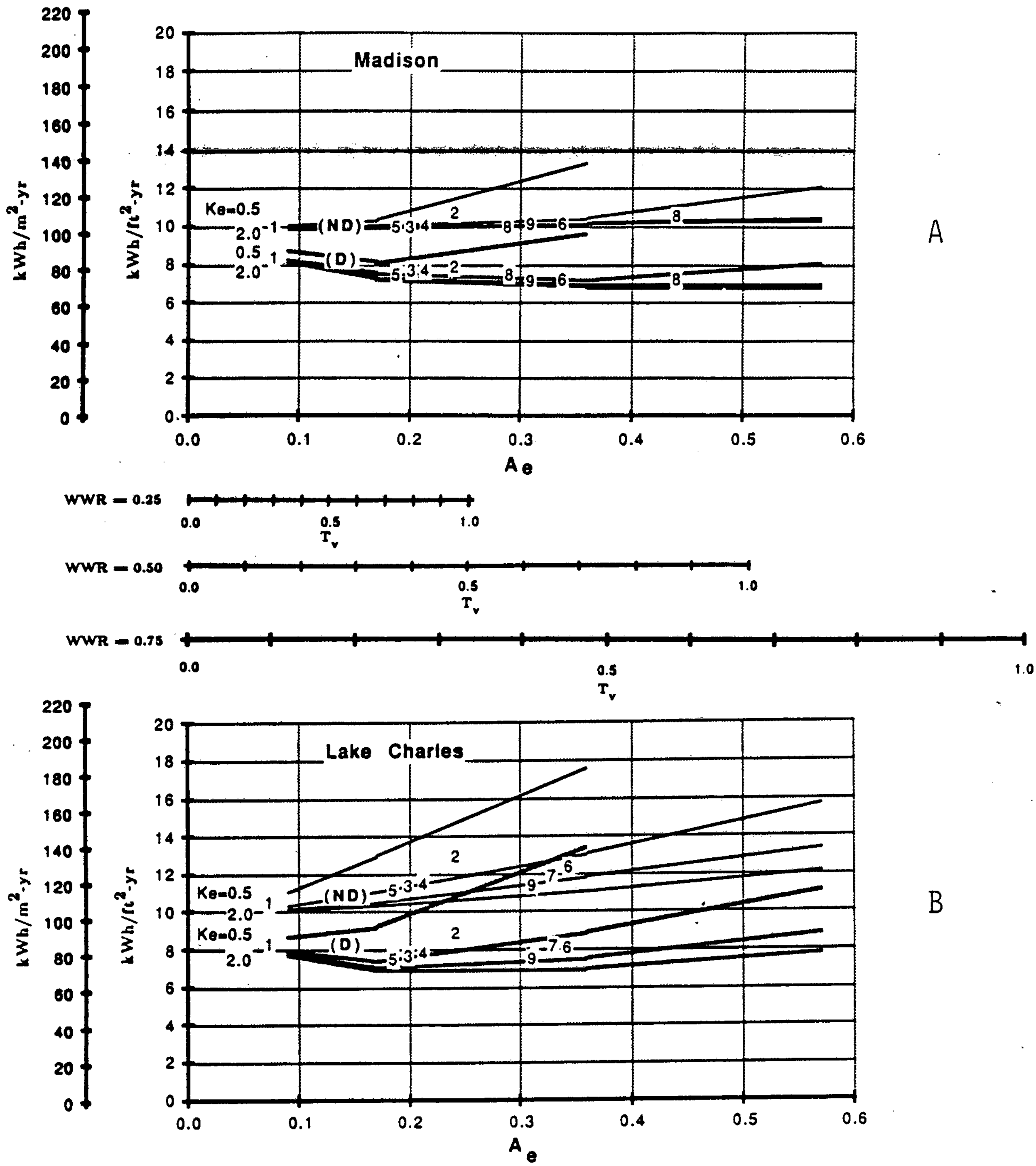
Previous studies have also addressed the savings in chiller sizes due to the use of dimming controls (Johnson et al. 1986). Figure 10a shows the added importance of K_e in sizing chillers. Increasing K_e from 0.5 to 1.0 produces the largest reduction of chiller size, but substantial additional reductions are obtained with higher K_es for higher values of A_e. Note that for an A_e of 0.3, the required chiller size can be cut by approximately 40%, 1 ton per 1000 ft² (40 W/m²), by going from a glazing of K_e=0.5 to one of K_e=1.5 (i.e., low-E on green). Given that installed cooling equipment costs approximately \$2000/ton (\$570/kw), large first-cost savings can accrue through the use of high-K_e glazings.

Thermal Effects in a Hot Climate (Lake Charles, LA)

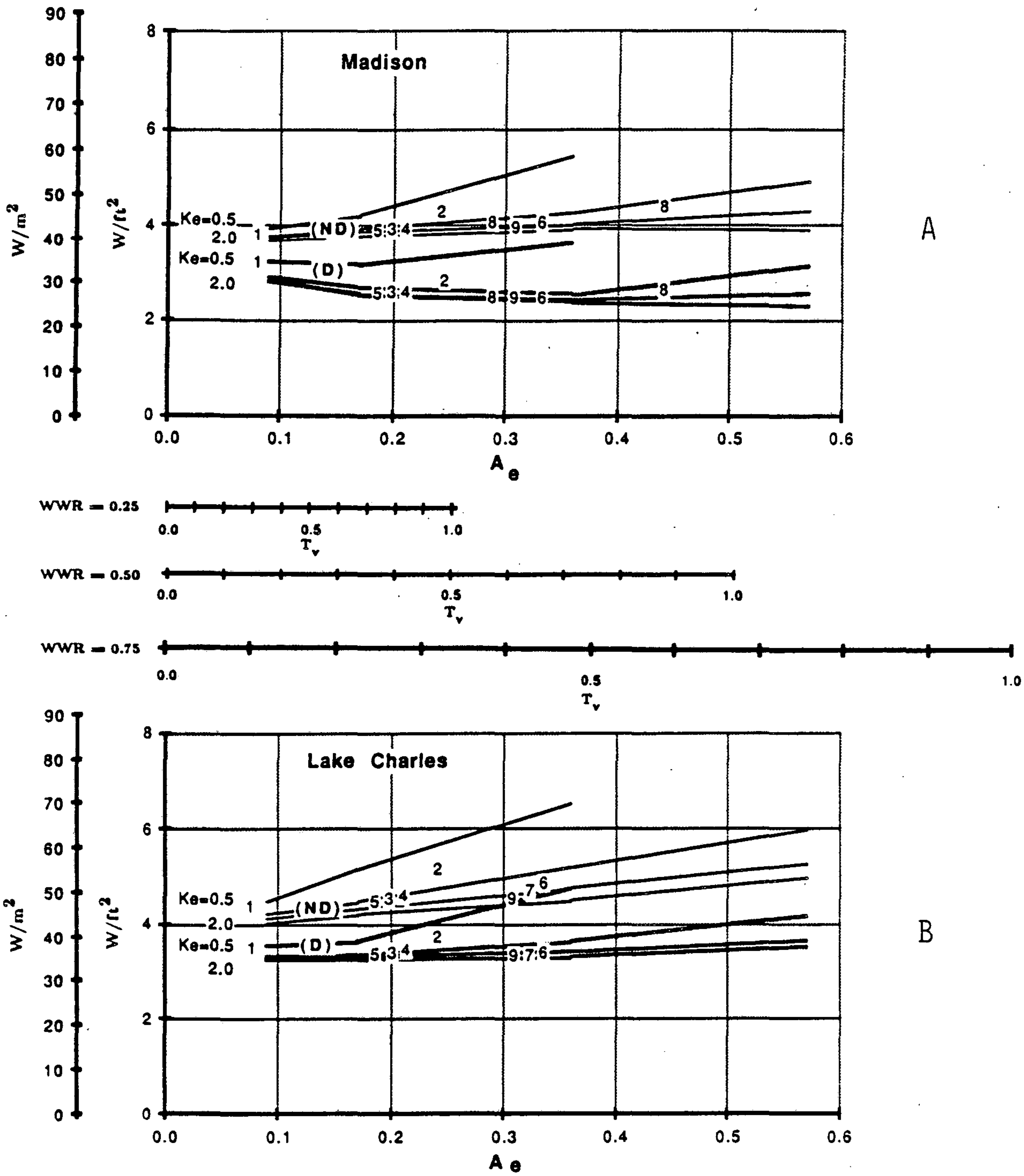
Figure 5b shows the effects of K_e and A_e on annual cooling energy in the same southern daylighted perimeter zone, modeled for Lake Charles, LA. The same general trends prevail as for Madison (Figure 5a); the absolute magnitude of cooling, however, is much larger (by a factor of 2.5) and so are the potential savings. Again, from Figure 5b and Table 2 we see that the largest savings in cooling energy are achieved by changing from low to moderate K_e. Higher K_es may offer comparatively smaller cooling savings; however, when used with larger effective apertures, greater lighting savings are possible with minimal solar gain penalties. The trends in heating energy in Lake Charles are similar to but amount to only 10-15% of those for Madison.

Figure 8b shows total electricity consumption for the south zone in Lake Charles, for cases with dimming (D) and no dimming (ND) controls. The importance of a high K_e is seen again. Since cooling energy is a more significant portion of total electricity use than in Madison, the shape of the curves takes on more of the shape of the cooling curves. Comparisons of the generic product options (Table 2) again show that to maximize total electricity savings, WWR must often be increased when a low-E coating is used in place of the same uncoated glass (to maintain the same lighting energy savings). A northern orientation will exhibit similar trends, but because solar gains are not as significant, the K_e effects will be slightly smaller (see Table 2).

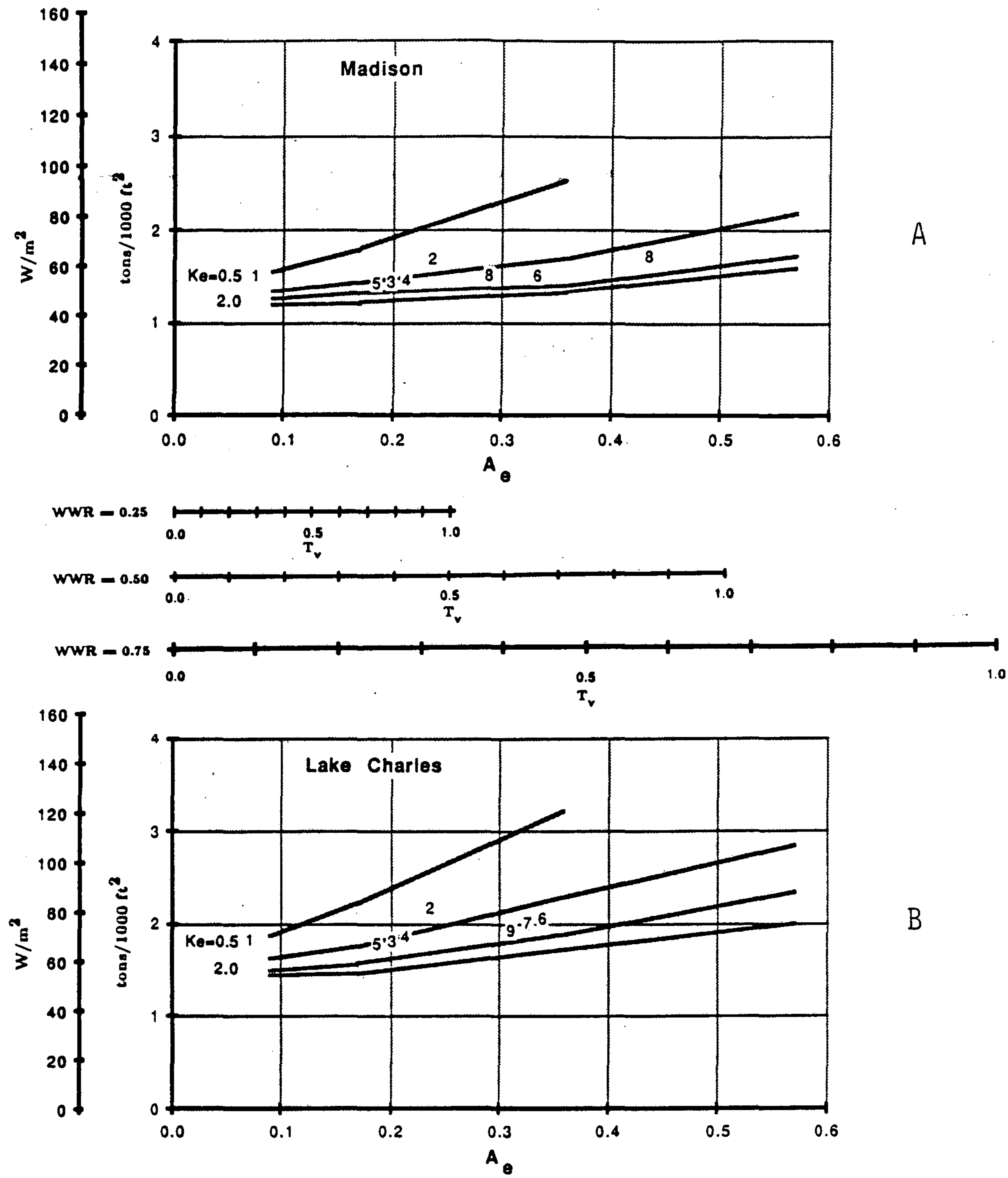
Peak electric demand for the perimeter zones in Lake Charles is shown in Figure 9b; the magnitudes are slightly larger than those in Madison because the peak day (hot, humid, sunny summer day) in Lake Charles is more severe than in Madison. Note that peak demand resulting from the use of conventional tinted or reflective bronze glazing can be cut by 30-40% by using dimming controls and a high-K_e (low-E) glazing.



Figures 8a and 8b: Total electricity use as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison (Figure 8a) and in Lake Charles (Figure 8b); south zones. Energy use does not vary noticeably with glazing R-value. Use of continuous dimming controls (D) vs. no dimming controls (ND). The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.



Figures 9a and 9b: Peak electric demand as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison (Figure 9a) and in Lake Charles (Figure 9b); all perimeter zones. Peak demand does not vary noticeably with glazing R-value. Use of continuous dimming controls (D) vs. no dimming controls (ND). The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.



Figures 10a and 10b: Chiller size as a function of effective aperture, A_e, (or WWR and T_v) and K_e in Madison (Figure 8a) and in Lake Charles (Figure 8b); all perimeter zones. Energy use does not vary noticeably with glazing R-value. Use of continuous dimming controls. The performance of each of the nine representative glazings in Table 1 is indicated by the position of its respective number.

Finally, Figure 10b shows the effects of chiller sizing in Lake Charles. The solar gain effects are more pronounced in Lake Charles than in Madison; thus chiller sizing is more sensitive to K_e variations. For equivalent A_e and K_e both the magnitude and slope of the curves for Lake Charles are greater than for Madison. Note that significant chiller (and peak) savings are still possible in going from moderate to high K_es.

CONCLUSIONS

Low-E glazings can be used in conjunction with dimming controls on electric lights to reduce energy use in nonresidential daylighted buildings. The use of too much glazing area with too high a solar transmittance can, however, compromise the savings by increasing solar heat gain (and thus required cooling energy). Cost savings can include reductions for heating, cooling, peak electric demand, and reduced cooling equipment sizes. Specific results discussed in this paper concerning the use of daylighting and different glazing materials in an office building module lead to the following conclusions:

1) Cooling energy requirements can be reduced by using glazing materials that transmit less solar radiation than conventional (i.e., reflective or tinted) glazings for the same visible light transmittance. We define an index (K_e=T_v /SC) to characterize the efficacy of a glazing system in transmitting visible light versus solar gains. Glazings currently used in office buildings typically have K_es between 0.5 (reflective glass) and 1.0, depending on tint. Low-emittance glazings, with a wide range of shading coefficients and with K_es between 1.0 and 1.5, will admit more daylight and produce lower cooling loads than conventional glazings. The maximum theoretical K_e is 2.8.

2) The largest cooling energy and total electricity reductions with perimeter zone daylighting are generally achieved with increases in K_e from 0.5 to 1.0 (i.e., going from reflective or tinted glazing to tinted or clear glazings with low-emittance coatings). (Higher K_es can, however, provide additional energy savings at larger effective apertures and further reduce peak demand and cooling equipment size requirements.)

3) A low-E IG unit in place of a similar conventional IG unit (for a given WWR) will reduce T_v and thus slightly reduce the lighting energy savings with dimming. Cooling loads from the higher K_es will, however, usually be reduced to more than offset this effect. Lighting energy savings through dimming can be increased by increasing the WWR or changing the glass type.

4) In cold climates, the increased resistance of low-E IG units significantly reduces heating costs and condensation risk and increases thermal comfort.

5) The greater insulating capabilities of low-emissivity IG units with high K_es are not detrimental to their overall cooling energy performance. While higher R-values may cause slightly higher cooling loads during some winter months (even with an economizer), they will reduce cooling loads during summer months and peak conditions. In addition, heating loads and corresponding fan electricity will be greatly reduced.

6) With dimming controls and high-K_e glazings, large first-cost savings are possible compared to conventional glazing choices. The reduced chiller and HVAC system first costs in many cases may pay for some or all of the increased glazing and lighting-control costs.

REFERENCES

Arasteh, D.; Johnson, R.; Selkowitz, S.; and Sullivan, R. 1985. "Energy performance and savings potentials with skylights". *ASHRAE Transactions,* Vol. 91, Part IA, pp. 154-179.

Curtis, R.,Birdsall, B., Buhl, W. F.,Erdem, E., Eto, J.,Hirsch, J.J., Olson, K, and Winkelmann, F. 1984. "The DOE-2 Building Energy Analysis Program," Building Energy Simulation Group, Lawrence Berkeley Laboratory Report LBL-18046, Lawrence Berkeley Laboratory, University of California, Berkeley, California.

Johnson, R.; Arasteh, D.; Connell, D.; and Selkowitz, S. 1985. "The Effect of Daylighting Strategies on Building Cooling Loads and Overall Energy Performance." In Proceedings of the ASHRAE/DOE/BTECC Conference on the Thermal Performance of the Exterior Envelopes of Buildings III, 2-5 December 1985, Clearwater Beach, FL.

Johnson, R.; Sullivan, R.; Selkowitz, S.; Conner, C.; and Arasteh, D. 1983. "Building envelope thermal and daylighting analysis in support of recommendations to upgrade ASHRAE/IES Standard 90." Lawrence Berkeley Laboratory Report LBL-16770.

Johnson, R.; Sullivan, R.; Selkowitz, S.; Nozaki, S.; Conner, C.; and Arasteh, D. 1984. "Glazing energy performance and design optimization with daylighting." *Energy and Buildings,* Vol. 6, pp. 305-317.

Selkowitz, S.; Choi, S, Johnson, R. and Sullivan, R. 1983. "The impact of fenestration on energy use and peak loads in daylighted commercial buildings." Proceedings of the 8th National Passive Solar Conference in *Progress in Passive Solar Energy Systems,* ed. J. Hayes and D. Andrejko, pp. 187-192. New York: American Solar Energy Society, Inc.

Winklemann, F.C.; and Selkowitz, S. 1986. "Daylighting Simulation in the DOE-2 Building Energy Analysis Program," *Energy and Buildings,* 8, 271.

ACKNOWLEDGMENTS

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

LAWRENCE BERKELEY LABORATORY
TECHNICAL INFORMATION DEPARTMENT
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720