U.S. Department of Commerce
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, D.C. 20234

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A Regional Economic Assessment of Selected Window Systems

Rosalie T. Ruegg
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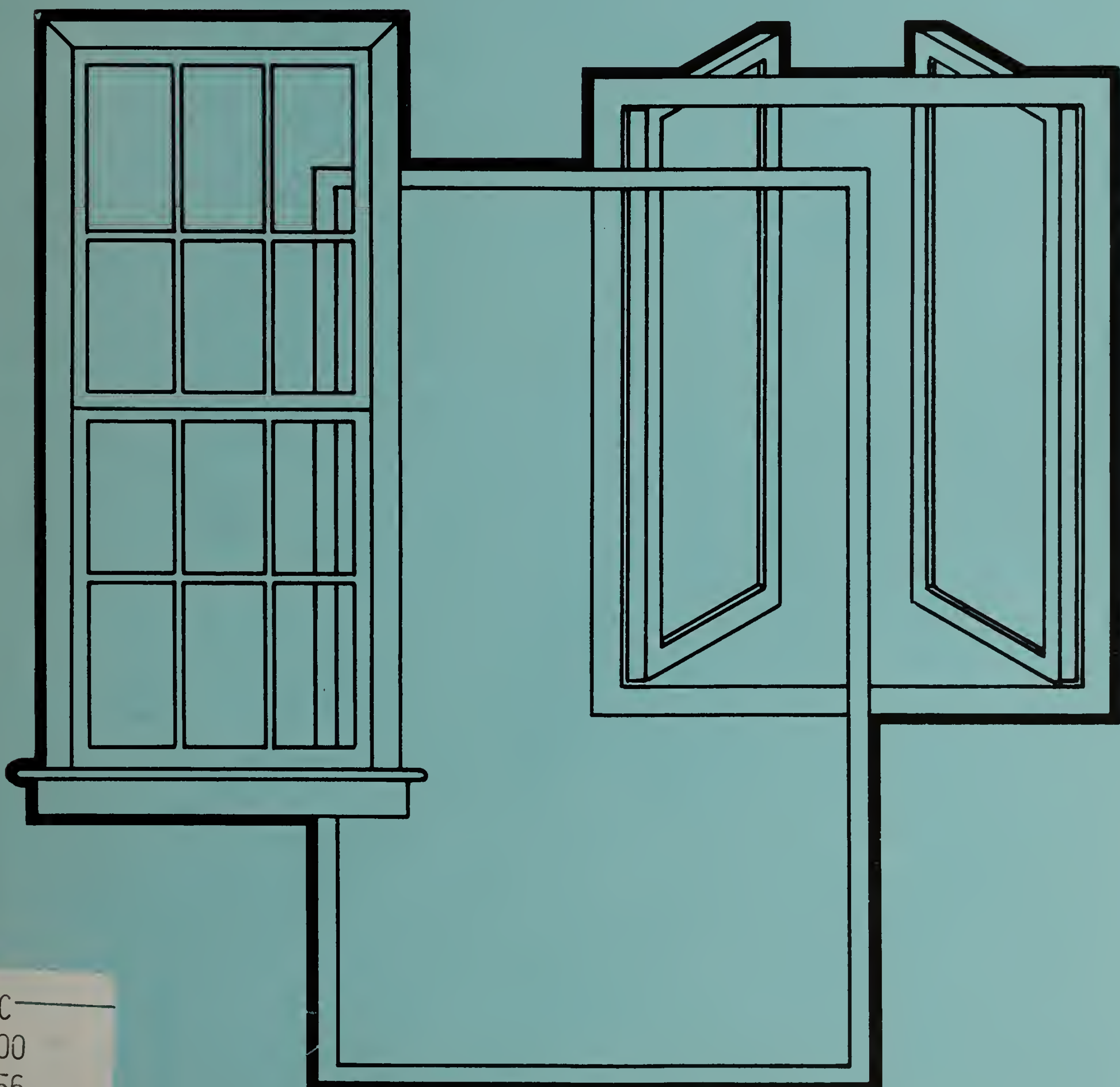

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PREFACE

The background work for preparing this report was conducted within the framework of a National Bureau of Standards (NBS) interdisciplinary research project on the energy-related performance of windows. This effort was supported jointly by NBS and U.S. Department of Energy (Mode 2 of Contract E (49-1) 3800), and by the U.S. Department of Housing and Urban Development (Contract No. Rt 193012), as a portion of the Building Energy Performance Standards Program.

This report is the fifth in a series of publications resulting from this NBS interdisciplinary project on windows. The economic model for evaluating window performance is described in an earlier report, Economic Evaluation of Windows in Buildings: Methodology [1]. The thermal model used to compute energy gains and losses through windows is described in Simplified Analysis of Thermal and Lighting Characteristics of Windows: Two Case Studies [2]. The window systems examined in this report, as well as many additional window systems not examined here, are described in Window Design Strategies to Conserve Energy [3]. An overview of findings from the interdisciplinary project was reported in A New Look at Windows [4]. An earlier NBS report, Retrofitting Existing Housing for Energy Conservation: An Economic Analysis [5], applied an economic optimization model to a group of energy conservation techniques, and identified the minimum sizes of storm windows which would be cost effective for a variety of climates and a range of current energy prices. That study, however, considered a single-family residence only, and, unlike this report, did not take into account other window choices, such as orientation, size of the primary window, the use of wind management devices such as blinds and shutters, nor the potential of using windows for daylighting.

A recent NBS report, Daylighting, Window Management Systems, and Lighting Controls [6], provides empirical data on daylight availability and interior illumination which support a finding of this report that economic savings from daylighting are potentially great.

The reader is cautioned that the quantitative results of this report are based on specific assumptions and incomplete data. The results are offered despite their limitations, in the hope that they will focus attention on the possibilities for saving energy and reducing long-term costs through the considered selection and use of windows in buildings.

ACKNOWLEDGMENTS

The authors wish to thank all of those persons who contributed to the preparation of this report. Special appreciation is extended to Dr. Harold Marshall, Leader of the Applied Economics Group, for his assistance throughout the project; to Dr. Belinda Collins, Mr. Stephen Treado, and Mr. William Hall for their helpful comments; to Ms. Kimberly Barnes for her assistance with the computer work, and to Ms. Cynthia Broussalian, Ms. Debbie Rodgers, and Mr. Philip Decker for their assistance in preparing the tables and manuscript. Credit for the cover design goes to Ms. Nan Stephens.

SI CONVERSION

Length

1 in = 0.0254 meter
1 ft = 0.3048 meter

Area

1 in^2 = 6.4516×10^{-4} $meter^2$
1 ft^2 = 0.0929 $meter^2$

Volume

1 in^3 = 1.638×10^{-5} $meter^3$
1 gal (U.S. liquid) = 3.785×10^{-3} $meter^3$
1 liter = 1.000×10^{-3} $meter^3$

Energy

1 Btu (International Table) = 1.055×10^3 joule

Power

1 Btu/hr = 0.2930 watt

Temperature

$°F = (\frac{9}{5}\ °C) + 32$

Illumination

1 ft candle = 10.76 lux

U-value

1 Btu/hr ft^2 F = 5.678 W/m^2 K

ABSTRACT

This study, the fifth in a series of reports from the National Bureau of Standards' interdisciplinary project on windows, provides guidance in selecting and using windows in buildings for greater cost effectiveness. It presents the life-cycle costs of selected window systems used in a room of a representative residence and in an office module of a representative commercial office building for nine cities in the United States, representing five heating zones and four cooling zones. The cities covered are Miami, Florida; Atlanta, Georgia; Washington, D.C.; Portland, Maine; Indianapolis, Indiana; San Antonio, Texas; Los Angeles, California; Bismarck, North Dakota; and Seattle, Washington. The results of the regional analyses are summarized, and the implications of these results are considered, both for selecting windows in new buildings and for managing windows in existing buildings. The emphasis of this report is on conveying the research findings to builders, designers, and building owners and operators -- those involved immediately with the building process. The research method is described in an earlier companion report, Economic Evaluation of Windows in Buildings: Methodology.

Key Words: building economics; daylighting; energy conservation; engineering economics; life-cycle costs; passive solar; regional analysis; thermal efficiency; windows.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

LIST OF FIGURES

In addition to their effects on energy and other measurable building costs, windows can provide a view of the outside world, an effect that is usually much more difficult to quantify.

1. INTRODUCTION

The energy crisis has stimulated increased interest in the impact of windows on the energy costs of buildings. Building energy requirements are significantly affected by window size, orientatioon, thermal resistance, accessories, and use for daylighting [1].[1] But in the concern for energy costs, other costs should not be overlooked. From an economic standpoint, it is important that buildings, including their windows, be as cost effective as possible taking into account all significant effects over the relevant time period of building use.

This report provides some of the information on windows needed for the construction and operation of cost-effective buildings. It does this by estimating and comparing the life-cycle costs of selected choices of window size, glazing, orientation, accessories, and use, and by then formulating general guidelines for cost-effective windows based on the numerical results.

It should be recognized that the choices examined are limited, the findings are dependent on specific assumptions, and the resulting guidelines are far from comprehensive. Yet, on a more positive note, many cases are treated here, and a range of dollar estimates is provided to reflect some of the uncertainty. To reflect variation in costs due to differing geographical regions and building types, window costs are examined for nine geographical regions of the United States and for two types of buildings. The nine cities selected for study and their locations are shown on the heating and cooling zone maps in figure 1.1. Five different heating zones and four different cooling zones are included.

The buildings selected for study are a one-story, single-family, brick rambler and a five-to-ten story commercial office building with curtain wall construction. The focus is on a window in one room of each building: the family-room/kitchen of the residence and an office module of the commercial building. It is assumed that windows are located on a single exterior wall of the subject room, and the orientation of the windows is changed by rotating the entire building. It is further assumed that there are no heat flows to adjoining spaces.

A range of sizes of a selected window design are examined for each of the two types of buildings in each climatic region. For the residence, the type of window selected for study is a wooden, double-hung, weatherstripped, well-fitted window. For the office building, the type of window selected is a fixed, non-operable area of glazing in an anodized aluminum frame. For the residence, window sizes of up to 60 ft^2 (5.57 m^2) are examined, and for the office, sizes of up to 90 ft^2 (8.36 m^2). As a basis of comparison, costs associated with a windowless room are estimated for both the residence and the office. For

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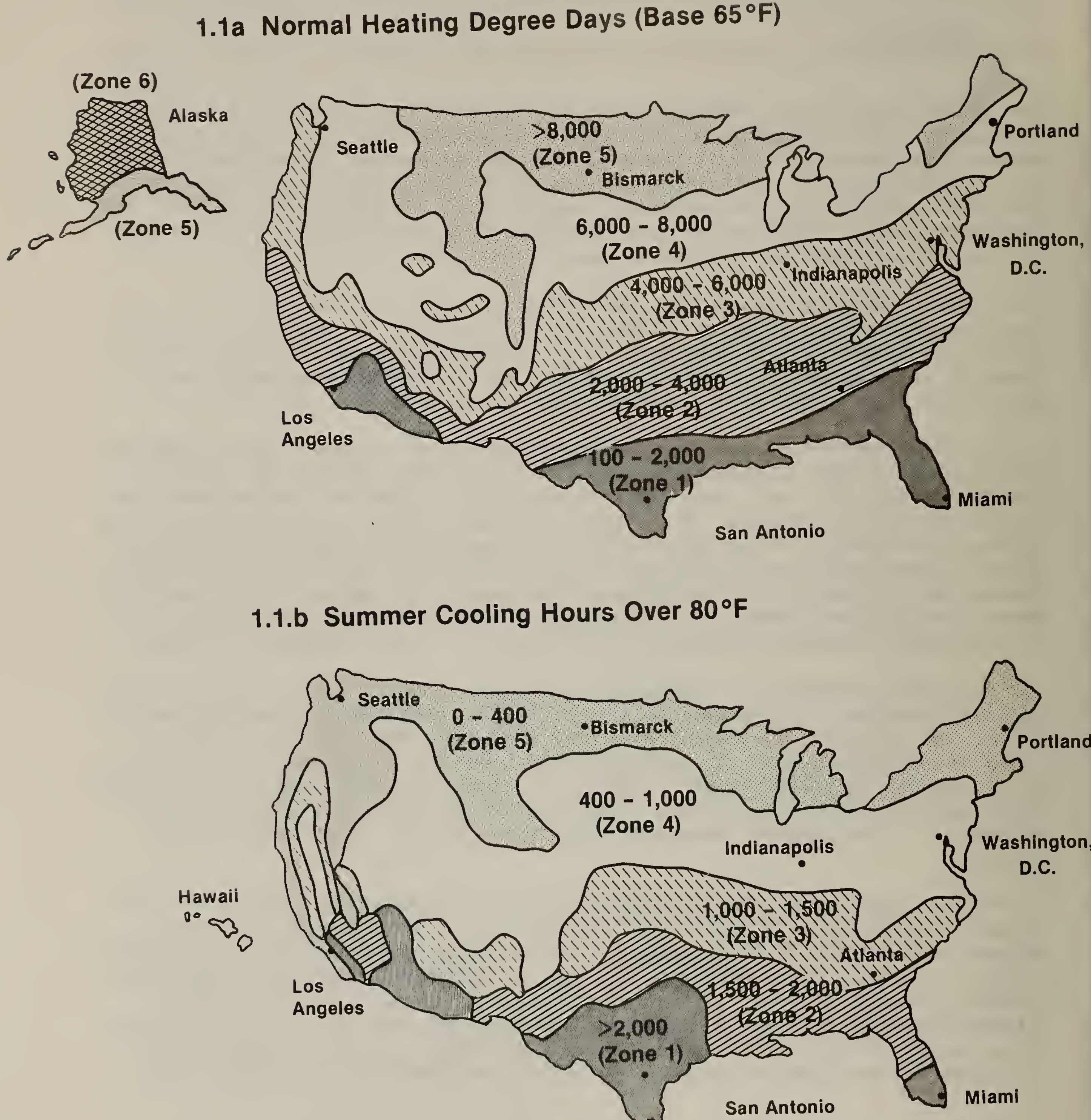
[1] Numbers in brackets refer to bibliographic materials listed at the end of part 4.

Figure 1.1 Locations Studied for Window Systems [a]



[a] This map, taken from Madeleine Jacobs and Steve Petersen's "Making the Most of Your Energy Dollars in Home Heating and Cooling," NBS Consumer Information Series 8, 1975 [7], is approximate only. For a more extensive listing of cooling hour data, see *Insulation Manual-Homes/Apartments*, NAHB Res. Found. Inc., 1971, pp. 23-35 [8].

each window size and orientation, the cost effectiveness of single and multiple glazing is evaluated.

Each alternative window system is examined for two different modes of use. For the residential windows, the two modes are as follows:

(1) Windows are "unmanaged" and not used for daylighting. That is, windows are left bare without accessories for reducing undesired heat gains and losses, the thermostat is not adjusted at night for energy conservation, and lighting requirements are met by electric lights.

(2) Windows are "managed" and used for daylighting. That is, they are equipped with venetian blinds to reduce summer daytime heat gain and thermal shutters to reduce winter nighttime heat loss, the thermostat is lowered at night during the heating season and raised at night during the cooling season to conserve energy, and daylight from the windows provides part or all of the specified lighting requirements.[1]

For the commercial windows the two modes of use are as follows:

(1) Windows are unmanaged and not used for daylighting (like mode 1 for residential windows).

(2) Windows are unmanaged, but used for daylighting. That is, they are not accessorized for reducing undesired heat gains and losses, the thermostat is not adjusted at night for energy conservation, but daylight from the windows does provide part or all of the specified lighting requirements (unlike mode 2 for residential windows).

The modes of use listed for each building type are selected for presentation from a total of four modes evaluated by the study. The modes presented give the worst and the best results, respectively, in both the residential and commercial applications. The four modes of window use that were examined for both the residential and commercial applications, from which the worst and best are selected, are the following: (a) unmananged, not used for daylighting, (b) managed, used for daylighting, (c) unmanaged, used for daylighting, and (d) manged, not used for daylighting.

While the mode of use giving the "worst case" results is the same for residential and commercial applications, the mode for the "best case" differs. For the commercial window, the most favorable results are for the unmanaged window. That is, window management is not found to be cost effective for the commercial applications, as it is for the residential cases. This finding reflects the high purchase and installation costs estimated for thermal shutters for the office building. It would be inappropriate to conclude from this finding, however, that management strategies in general are not cost

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[1] Note that the adjustment of the thermostat affects the windowless room, as well as the room with windows of varying sizes.

effective for commercial buildings, nor that venetian blinds and nighttime thermostat adjustment, the two management factors grouped with shutters, would not alone be cost effective. Other management strategies were not evaluated, and separate analysis was not performed for each factor included in the "management package."

The results pertain primarily to windows in new buildings, because the acquisition costs of the windows used in the analyses are estimated for new construction. However, some of the results also pertain to windows in existing buildings. The cost-effectiveness results for window management should hold equally for new and existing buildings, other conditions being equal. The results from the evaluation of double glazing, on the other hand, would to apply only to new buildings. The results tend not to hold for existing buildings because the costs are based on new construction. In an existing building, it would be necessary to replace the entire window in order to obtain double glazing, whereas in a new building, double glazing would be considered an optional feature available at the time the overall window system is selected. In that case, it would be necessary to take into account only the differential costs between double glazing and single glazing, as is done in these analyses.

Table 1.1 summarizes (1) the window alternatives that are examined for each of the nine regions, (2) the main economic assumptions, and (3) the measures of economic performance that are provided. The estimates of purchase and installation costs and maintenance and repair costs that are combined with estimates of energy costs to derive life-cycle costs are given in appendices A and B.

The evaluation is performed using a life-cycle cost model that takes into account over an estimated life of 25 years the costs of purchasing and installing the windows, venetian blinds, and thermal shutters (over and above the costs of a solid wall); the costs of maintenance, repair, and replacement; and the costs of energy for heating, cooling, and lighting the room. To reflect the great uncertainty about future energy prices and the importance of energy costs to window performance, lower and upper bounds of zero and 12 percent real growth, compounded annually, are assumed for future energy prices.

As was explained in earlier studies [1, 2], a deficiency of the thermal model is that it does not take into account the possibilities for natural ventilation. It is also important to note that south-facing windows are considered here without the thermal storage feature customarily included in direct-gain passive solar energy systems. Hence, the thermal performance of the south-facing windows is significantly poorer than would normally be expected of south-facing windows employed in a well designed passive solar energy system. Rather, performance is intended to be more typical of the windows in conventional "non-solar" buidings. Additionally, the costs and benefits associated with psychological and aesthetical effects of windows are not included. At the time these case studies were performed, a further deficiency was that the portion of the thermal model used to estimate the energy effects of daylighting had not yet

TABLE 1.1

WINDOW ALTERNATIVES, KEY ASSUMPTIONS, AND ECONOMIC PERFORMANCE MEASURES

FEATURE	ALTERNATIVES EXAMINED				
Window type	Residential: Wood, Double-Hung and Weatherstripped Commercial : Anodized Aluminum with Thermal Break				
Window Accessories	Venetian Blinds during Summer Days and Thermal Shutters during Winter Nights				
Building Application	18' x 15' x 8' (5.49 m x 4.57 m x 2.44 m)	Family-Room/Kitchen of Single-Family Brick Rambler; Block with Brick Veneer; 3 1/2" (8.89 cm) Insulation; U = 0.07 (1.21 W/(m·K)); Exterior Wall Area of 144 ft^2 ($13.38\ m^2$)			
	12' x 15' x 10' (3.66 m x 4.57 m x 3.05 m)	Office Module of Commercial Office Building, Curtain Wall Construction			
Window Sizes	Residential: 0, 12, 18, 30, 60 ft^2 (0, 1.11, 1.67, 2.79, 5.57 m^2) Commercial : 0, 12, 30, 60, 90 ft^2 (0, 1.11, 2.79, 5.57, 8.36 m^2)				
Orientation	S, E/W, N				
Glazing Type	Single, Double, Triple				
Mode of Window Use	Residential: (1) Bare, Not Used for Daylighting; (2) Managed, Used for Daylighting Commercial : (1) Bare, Not Used for Daylighting; (2) Bare, Used for Daylighting				
Internal Energy Loads		Lights	Equipment	Air Leakage	People
	Residential:	0.65 watts/ft^2 (7 watts/m^2)	0.52 watts/ft^2 (5.6 watts/m^2)	0.50 Air Changes/hr	0.5 people at 260 Btu/hr (76.2 W)
	Commercial:	3.25 watts/ft^2 (34.98 watts/m^2)	0.50 watts/ft^2 (5.38 watts/m^2)	0.25 Air Changes/hr	1.8 people at 260 Btu/hr (76.2 W)
		Boiler Efficiency	Cooling COP	Thermostat Adjustment	
System Operation	Residential:	0.65	2.0	72° to 62° F Winter Nights (22.2° to 16.7°C)	
	Commercial :	0.65	3.0	78° to 84° F Summer Nights (25.6° to 28.9°C)	
Economic Assumptions	Gas Heating at \$0.30 per Therm; Electric Cooling and Lighting at \$0.03 per kWh (Estimated U.S. average 1978 Prices)[a] Energy Price Escalation Rates of 0% and 12%, compounded annually not including Inflation Window Acquisition and Maintenance Costs, estimated 1978 prices[b] (See Appendices, A and B) Discount Rate of 8%, Not Including Inflation Depreciation of Commercial Investment Costs Over 25 Years Using a 150% Declining Balance Method After Taxes/Before Inflation Analysis Study Period of 25 years				
Economic Performance Measures	Life-Cycle Cost of Each Combination of Alternatives Least-Cost Window Size, Orientation, Glazing, Mode of Use, and Overall Window System Net Life-Cycle Savings for the Least-Cost System Years to Payback for Least-Cost System Breakeven Rate of Energy Price Escalation				

[a] Although these energy prices are for 1978, the built-in price escalation rate of 12 percent (upper bound) brings them closely in line with current (1981) energy prices. For example, at 12 percent per annum compound interest, a \$0.30 per therm price for gas in 1978 is equivalent to \$0.45 per therm in mid-1981. This price may be compared with current Department of Energy U.S. average price estimates for mid-1981 of \$0.44 per therm for residential purchases, \$0.40 for commercial purchases, and \$0.35 for industrial purchases. At 12 percent interest, a \$0.03 per kWh price for electricity in 1978 is equivalent to \$0.045 per kWh in mid-1981. This price may be compared with current Department of Energy U.S average price estimates for mid-1981 of \$0.057 per kWh for residential purchases, \$0.058 per kWh for commercial purchases, and \$0.042 for industrial purchases [12].

Note that energy costs related to windows may be affected by utility component pricing, not reflected in these assumptions. For example, daylightng may reduce building peak power consumption, thereby reducing utility demand changes [10].

[b] The first costs of windows and window accessories relative to initial energy prices 1978 have not changed significantly, from those assumed for 1978. Therefore, the results based on 1978 window and energy costs should be comparable to results based on 1981 costs.

been verified by laboratory and field testing [2]. However, a recent NBS study supports the validity of the daylight estimates [6].[1]

The next two parts, 2 and 3, present in detail the life-cycle cost analysis of windows for each of the nine locations, first for the residential building and then for the commercial building. Part 4 concludes the report with a summary of the findings and a discussion of the implications of these findings. Part 4 may be used independently of parts 2 and 3 as a general reference. Those who prefer an overview may wish to proceed directly to part 4; those who are interested in the results for a particular city may wish to go directly to the section in part 2 or 3 dealing with that city.

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[1] Nevertheless, it should be noted that the evaluation of monetary benefits from daylighting is based on the assumption of conventional electric lighting as the alternative; while, in a more comprehensive analysis of building system tradeoffs, lamp replacement might be another option for reducing electric lighting costs [9, 10]. The use of energy conserving lamps would then lessen the cost advantage of using daylighting. Other factors that are not taken into account here but which may be important in evaluating the benefits of daylighting are the potential loss of work resulting from unscheduled downtime of mechanical systems in windowless spaces, differences in the quality of lighting provided by different lighting sources, and the cost and reliability of controlling electric lighting in order to derive the energy savings from daylighting [6, 9, 11].

Daylighting From Well Managed Windows Can Reduce Electric Lighting Requirements and Greatly Improve the Cost Effectiveness of Windows

Double-hung Wood Windows Such as Those Assumed in the Residential Window Analysis are Widely Used in Residential Construction

2. RESIDENTIAL CASE STUDIES FOR NINE CITIES

2.1 DESCRIPTION OF BUILDING AND WINDOW SYSTEMS[1]

The residential module is assumed to be a family room/kitchen in a one-story rambler with a full basement. The overall dimensions of the house are 28 feet wide by 50 feet 6 inches long (8.53 m x 15.39 m), and the total floor area is 1414 square feet (131.36 m^2). The layout of the house including the location of windows and doors is shown in the floor plan in figure 2.1. The family room/kitchen shown shaded in the floor plan is the subject of the analysis.

The windows assumed for the economic analysis are wooden and double hung, in four sizes. Figure 2.2 shows the four window sizes in relationship to the size of the exterior wall. (Other assumptions are given in table 1.1 and in appendix A.)

All assumptions other than geographical location and window costs[2] are identical for each of the nine residential case study, and a common format is used for each: Tables of life-cycle window costs, estimated both for constant energy prices and for rapidly rising energy prices, are given. These tables show results both for single and double glazing. A separate table is given for each mode of window use: the first being for windows that are unmanaged and not used for daylighting, and the second, for windows that are both managed and used for daylighting. A third table for each city identifies the least-cost window system for each orientation.

2.2 MIAMI, FLORIDA

In Miami, where heating loads are very low (200 heating degree days) the effects of a dominant cooling load (2,400 cooling hours) on life-cycle costs are significant.

Table 2.1 gives the total estimated life-cycle costs of purchasing and installing the windows, cleaning and repairing them, and heating and cooling the room with the window system in place. The costs are based on the first mode of window use, neither managing it nor using it for daylighting.

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[1] This information, taken in abbreviated form from the companion methodological report, Economic Evaluation of Windows in Buildings: Methodology [1], is provided here for the convenience of the reader.

[2] Location Modifiers are applied to window costs to account for regional variation in labor and material costs. See appendix A for the basic window cost data.

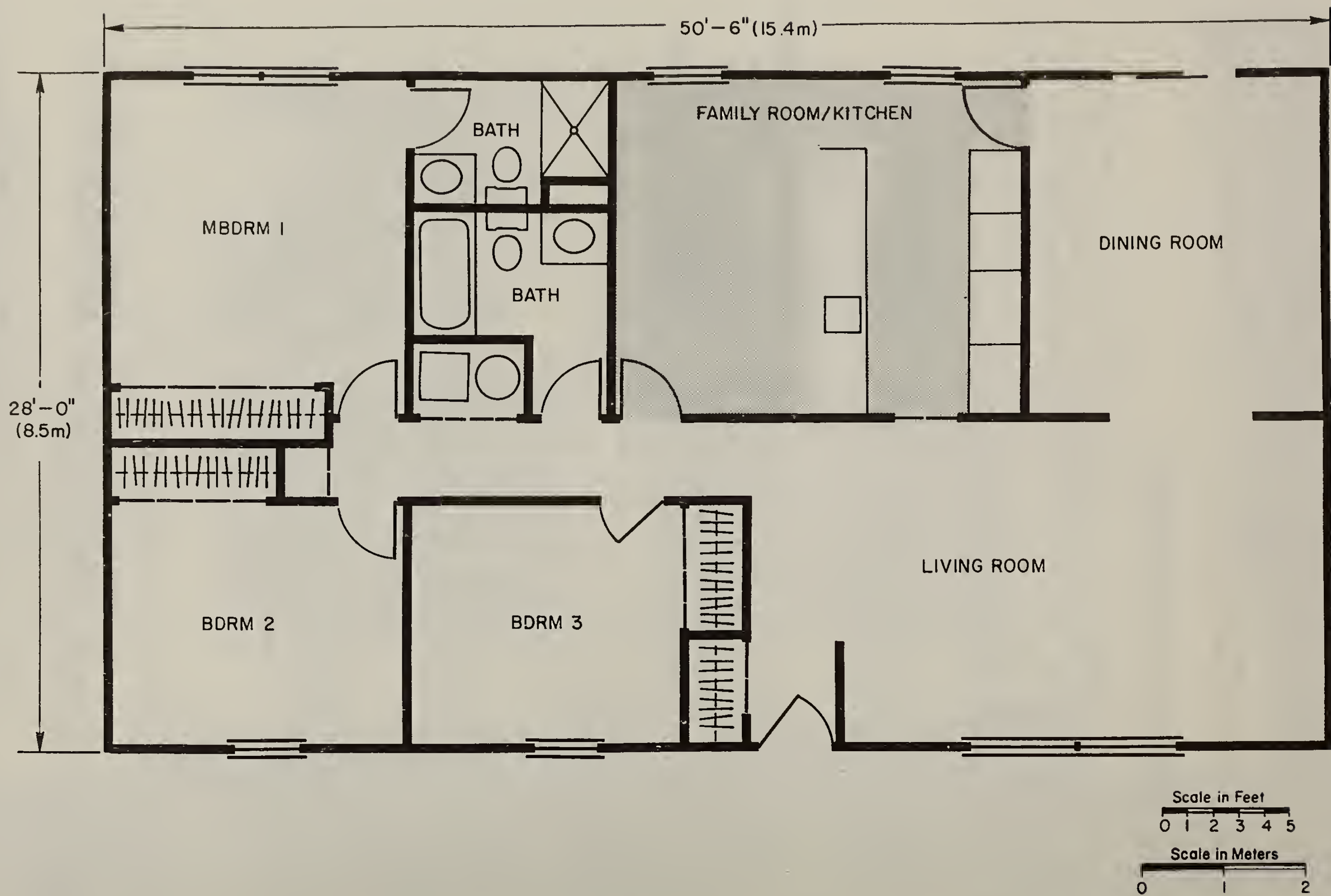

Figure 2.1 **Schematic Diagram of House with Shaded Study Module. (From Ruegg, Rosalie T. and Chapman, Robert E. *Economic Evaluation of Windows in Building: Methodology,* National Bureau of Standards Building Science Series 119, April 1979.)**

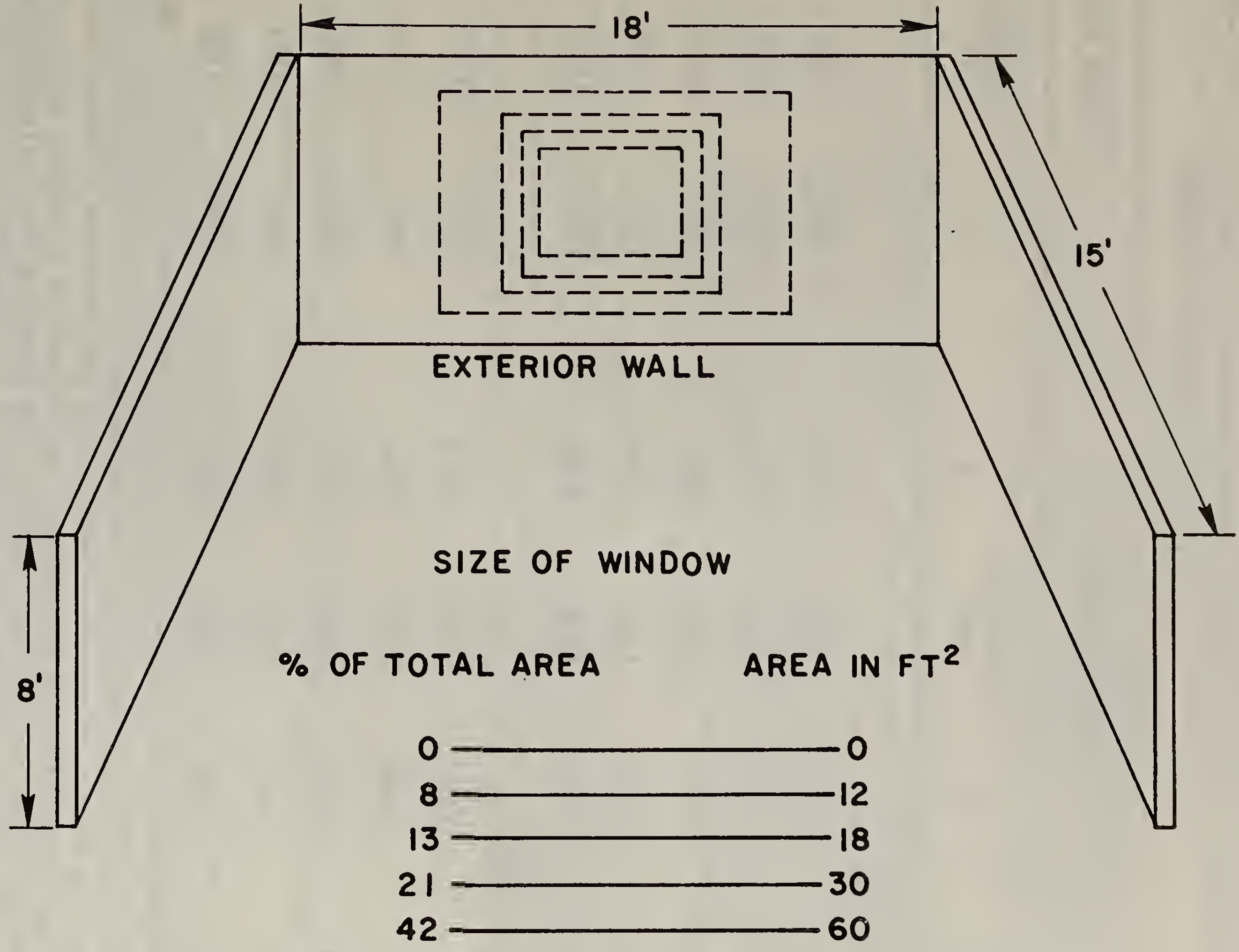

Figure 2.2 Window Sizes in Relationship to the Size of the Exterior Wall of the House

TABLE 2.1

MIAMI, FLORIDA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
Window Area		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	864	868	854	864	868	854
12	1.11	993	1016	965	1011	1032	985
18	1.67	1052	1084	1015	1074	1103	1040
30	2.79	1158	1235	1130	1227	1272	1176
60	5.57	1510	1606	1410	1594	1679	1502
Part B (FPE[b] = 12%)							
0	0	3357	3375	3319	3357	3375	3319
12	1.11	3689	3777	3581	3677	3758	3576
18	1.67	3855	3979	3712	3831	3944	3699
30	2.79	4201	4395	3988	4167	4343	3972
60	5.57	5060	5431	4671	4993	5326	4638

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting the designated family room/kitchen of the house described in section 2. They are <u>not</u> the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

Part A of table 2.1 shows that if energy prices remain constant in real dollars, life-cycle building costs are raised by both single- and double-glazed windows of all sizes examined and for all orientations.[1] However, single-glazed windows are less costly than double-glazed windows. A consequence of the heavy cooling load requirement is that windows facing east or west raise life-cycle cost more than windows facing north.[2]

Part B of table 2.1 shows that life-cycle costs are substantially higher if energy prices rise at a real rate of 12 percent compounded annually. Costs increase sharply as window area is increased. With the rise in energy prices--and without window management--double glazing is slightly more cost effective than single glazing (i.e., the net losses[3] are lower) for all window sizes and orientations.

Table 2.2 shows the total estimated life-cycle costs if daylight utilization and window management are practiced. Part A of the table shows that life-cycle costs are lower with a window than without it for window areas up to and including 18 ft^2 (1.67 m^2) in size, if real dollar energy prices remain unchanged. The savings from the 18 ft^2 (1.67 m^2) south-facing, single-glazed window exceed $100. However, as the window area is increased beyond about 30 ft^2 (2.79 m^2), the extra capital costs for management devices and window acquisition together with the poorer thermal performance more than offset the extra energy savings from increased daylighting and net losses grow rapidly.

Part B of table 2.2 shows life-cycle costs if energy prices rise at a real rate of 12 percent compounded annually. A pattern of declining life-cycle costs for windows up to 18 ft^2 (1.67 m^2) in size is revealed. Net savings are much larger than those shown in part A of the table for the same range of window size. The use of thermal shutters results in little cost difference between single and double glazing.

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[1] The reader is reminded that the benefits of natural ventilation are not taken into account in the evaluation.

[2] The temperature and solar radiation figures presented in Kusuda, T. and Ishii, K., Hourly Solar Radiation Data for Vertical Surfaces on Average Days in the United States and Canada [13], are useful for understanding why cooling loads for east-west orientations are higher than those for the other orientations.

[3] "Net savings" is defined as the positive dollar difference found by subtracting from the life-cycle costs associated with the windowless room, the costs associated with the room when it has a given window system. If this difference is negative, then "net losses" are said to result from the window. For the purpose of these comparisons, a window system is designated "cost effective" if its life-cycle cost is at all lower than that of the alternative. In the summary of section 4, however, a cost difference of less than five percent is treated as relatively insignificant.

TABLE 2.2

MIAMI, FLORIDA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND WITH DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	E/W	N	Double Glazed, Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0[c]	0	860	864	850	860	864	850
12	1.11	734	742	705	756	763	729
18	1.67	756	766	717	783	793	748
30	2.79	896	909	838	947	959	894
60	5.57	1276	1298	1170	1378	1398	1282
Part B (FPE[b] = 12%)							
0[c]	0	3342	3360	3305	3342	3360	3305
12	1.11	2483	2514	2370	2486	2516	2381
18	1.67	2470	2508	2319	2468	2504	2330
30	2.79	2645	2697	2420	2648	2696	2442
60	5.57	3255	3342	2842	3261	3340	2887

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

Table 2.3 shows the least-cost window system for each orientation, and the least-cost system of all orientations. Part A of table 2.3 shows that the least-cost window system when energy prices are constant is single glazed, 12 ft^2 (1.11 m^2) in area, and oriented to the north. Part B of table 2.3 indicates that when energy prices are rising sharply, the least-cost window system is also single glazed and located on the north, but is somewhat larger in size (18 ft^2 or 1.67 m^2) due to the greater benefit of daylighting when electricity prices are high. (In either case, however, single glazing is only slightly preferred to double glazing.) It is estimated that if energy prices escalate rapidly, the savings in lighting and cooling costs will allow the window system to pay for itself in three to four years.

2.3 SAN ANTONIO, TEXAS

The cooling load requirement (2,000 cooling hours) in San Antonio is somewhat smaller than in Miami, while the heating load (1,550 heating degree days) is larger, though still relatively modest.

Table 2.4 shows that with either level or rising constant dollar energy prices, the windows examined raise life-cycle building costs regardless of glazing type, window size, or orientation. If energy prices rise at a real rate of 12 percent compounded annually, estimated net losses are more than triple the estimated losses at constant energy prices. The table shows single glazing to be more cost effective than double glazing if energy prices are constant, net losses for single glazing averaging almost 20 percent lower than for double glazing. With the higher energy prices, the life-cycle costs for single and double glazing are nearly identical, although double glazing may offer a small advantage for larger windows. Since the cooling load requirements dominate, windows with an easterly or westerly exposure tend to have higher life-cycle costs than windows with other exposures.

As shown in table 2.5, the addition of window management and daylight utilization significantly alters the results. Part A of table 2.5 shows that with thermal shutters, venetian blinds, and thermostat adjustment, and level constant dollar energy prices, net savings are possible for all single-glazed window areas up to and including 30 ft^2 (2.79 m^2) and for all double-glazed window areas up to and including 18 ft^2 (1.67 m^2). At constant energy prices, single glazing is estimated to be somewhat more cost effective than double glazing.

Part B of table 2.5 shows that window management and daylighting increase the potential saving from windows if real energy prices rise. Estimated net savings over the 25 year period approximate $1000 for window areas smaller than 30 ft^2. The net savings from single glazing averages 5 to 10 percent higher than from double glazing.

Part A of table 2.6 shows that the window system which minimizes life-cycle costs in San Antonio under constant energy prices and other stated conditions is single glazed, north facing, and 12 ft^2 in area. (However, the difference in life-cycle costs is modest both between the 12 and 18 ft^2 (1.11 and 1.67 m^2) window areas, and between the single- and double-glazed window areas.) The least-cost window system is estimated to result in net life-cycle savings

TABLE 2.3

MIAMI, FLORIDA, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 200 HEATING DEGREE DAYS, 2400 COOLING HOURS

	Least-Cost Window Systems							
Orientation	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	734	126	5.2	< 0
E-W	M/D	12	1.11	Single	742	122	5.3	< 0
N	M/D	12	1.11	Single	705	145	4.8	< 0 [c]
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Double	2468	854	5.3	< 0
E-W	M/D	18	1.67	Double	2504	856	5.4	< 0
N	M/D	18	1.67	Single	2319	986	3.4	< 0 [c]

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Least Cost of these alternatives.

TABLE 2.4

SAN ANTONIO, TEXAS, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	770	776	764	770	776	764
12	1.11	864	889	852	885	907	874
18	1.67	905	938	890	931	961	917
60	5.57	1244	1361	1240	1323	1414	1296
Part B (FPE[b] = 12%)							
0	0	2996	3016	2969	2996	3016	2969
12	1.11	3201	3296	3154	3204	3291	3159
18	1.67	3297	3428	3242	3297	3417	3242
30	2.79	3503	3726	3457	3507	3693	3434
60	5.57	4079	4534	4061	4018	4371	3913

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting the designated family room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.5

SAN ANTONIO, TEXAS, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

	Life-Cycle Costs in Dollars					
	Single Glazed			Double Glazed		
Window Area (FT^2) (m^2)	S	Orientation E/W	N	S	Orientation E/W	N
Part A (FPE[b] = 0%)						
0[c]	764	769	757	764	769	757
12	620	630	612	647	656	639
18	625	637	617	660	671	652
30	718	734	711	780	795	771
60	985	1019	985	1108	1133	1100
Part B (FPE[b] = 12%)						
0[c]	2971	2991	2944	2971	2991	2944
12	2067	2105	2037	2094	2129	2064
18	1990	2037	1958	2025	2068	1993
30	2007	2068	1979	2067	2126	2032
60	2236	2368	2235	2348	2445	2316

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.6

SAN ANTONIO, TEXAS, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 1550 HEATING DEGREE DAYS, 2000 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	620	144	4.0	< 0
E-W	M/D	12	1.11	Single	630	139	4.8	< 0
N	M/D	12	1.11	Single	612	145	4.0	< 0 [c]
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Single	1990	981	3.3	< 0
E-W	M/D	18	1.67	Single	2037	954	3.3	< 0
N	M/D	18	1.67	Single	1958	986	3.2	< 0 [c]

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Least Cost of these alternatives.

of \$145 and to pay for itself in four years. Part B of table 2.6 shows that the window system which minimizes life-cycle costs in the face of higher real energy prices is 18 ft^2 (1.67 m^2) in size, single glazed, and located on the north side. The least-cost window area is expected to recover its investment costs in about three years and to save nearly \$1000 over the life cycle.

2.4 LOS ANGELES, CALIFORNIA

In Los Angeles the cooling load of 550 cooling hours is lower than in the preceding three cities. The heating load of 1350 heating degree days is slightly lower than in San Antonio, but higher than in Miami. Both heating and cooling load requirements are modest.

As in the previous cases, net losses result from both single- and double-glazed windows of all sizes and all orientations when windows are unmanaged and not used for daylighting. Single glazing appears in all cases somewhat more cost effective than double glazing. Orientation appears to have little effect on cost.

A comparison of Parts A and B of table 2.7 shows that net losses attributable to windows actually decrease slightly if the real rate of energy price escalation is raised from 0 to 12 percent per year, though life-cycle costs for the room in general (both with and without windows) are greatly increased. The smaller losses can be explained in terms of the climate conditions in Los Angeles, which cause a windowed room to require slightly less energy than a windowless room, even if daylight is not used as an alternative light source.[1] The life-cycle costs of the windowed room are nevertheless higher than those of the windowless room, as shown by table 2.10, because the higher acquisition and maintenance costs of the windows more than offset their lower energy costs. The room with a double-glazed window requires almost exactly the same amount of energy as the windowless room so that net losses reflect primarily the extra expenses of window acquisition and maintenance.

Part A of table 2.8 shows that if energy prices were to remain level in constant dollars and if window management and daylighting were practiced, net savings would result for all single-glazed windows up to and including 30 ft^2 (2.79 m^2) and for all double-glazed windows up to and including 18 ft^2 (1.67 m^2).

Part B of table 2.8 shows that if energy prices were to rise at a real rate of 12 percent per year, a single-glazed window of any of the sizes examined would save about \$1000 over the life, provided it were properly managed and used for daylighting. Savings are estimated at approximately 10 to 30 percent less with double-glazed windows.

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[1] From Kusuda, T. and Ishii, K., Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada [13], it can be determined from climate data that conduction losses or gains are frequently beneficial in Los Angeles.

TABLE 2.7

LOS ANGELES, CALIFORNIA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	697	702	691	697	702	691
12	1.11	757	764	750	795	801	788
18	1.67	779	786	771	830	837	822
30	2.79	839	848	829	930	938	920
60	5.57	981	998	982	1162	1174	1150
Part B (FPE[b] = 12%)							
0	0	2709	2729	2686	2709	2729	2686
12	1.11	2750	2775	2721	2804	2829	2776
18	1.67	2762	2790	2730	2837	2865	2806
30	2.79	2802	2836	2764	2934	2966	2898
60	5.57	2894	2961	2900	3158	3203	3110

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.8

LOS ANGELES, CALIFORNIA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
Window Area		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0[c]	0	689	694	683	689	694	683
12	1.11	564	570	558	604	610	598
18	1.67	568	574	562	622	628	615
30	2.79	644	671	657	759	766	753
60	5.57	945	956	956	1131	1139	1123
Part B (FPE[b] = 12%)							
0[c]	0	2680	2700	2657	2680	2700	2657
12	1.11	1777	1799	1752	1838	1860	1814
18	1.67	1678	1702	1652	1764	1787	1738
30	2.79	1633	1660	1606	1783	1809	1757
60	5.57	1748	1791	1788	2026	2057	1996

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

Part A of Table 2.9 shows that with unchanging real energy prices, the window system which minimizes life-cycle costs is 12 ft^2 and single glazed. Orientation makes little difference to costs. The least-cost window system is expected to save about $125 over the life cycle and pay for itself in five to six years.

Part B of table 2.9 shows that, with rapidly rising real energy prices, the window area which minimizes life-cycle costs is 30 ft^2 and single glazed. It is just slightly less expensive if located on the north side. These windows are estimated to save more than $1000, net, and to pay for themselves in six and a half years.

2.5 ATLANTA, GEORGIA

Atlanta has not only a substantial cooling load requirement, but also a moderate heating load requirements (2950 heating degree days, 1000 cooling hours). The balance between the two energy requirements is similar to that for Los Angeles except that the magnitudes are significantly increased.

Table 2.10 shows net losses for both single- and double-glazed windows of all sizes and for all orientations. Part A shows that with constant real energy prices, single glazing is in all cases more cost effective than double glazing, its losses averaging about 20 percent lower than double glazing.

If energy prices escalate at a real rate of 12 percent per year, part B of table 2.10 shows that net losses rise to as high as about $800. With higher energy costs, double glazing becomes somewhat more cost effective than single glazing.

Part A of table 2.11 shows that with constant real energy prices, and by combining daylight utilization with window management, all single-glazed windows up to 30 ft^2 (2.79 m^2) and all double-glazed windows up to 18 ft^2 (1.67 m^2) lower life-cycle costs. Part B of table 2.14 shows that net savings are much higher if energy prices increase at a real rate of 12 percent per year than if they are constant. All of the window areas result in sizable net savings. The life-cycle savings are not substantially different for single and double glazing.

Table 2.12 shows that the least-cost window system is single glazed and 12 ft^2 (1.11 m^2) in size if energy prices are constant in real dollars and single-glazed and 18 ft^2 (1.67 m^2) if prices rise rapidly. Costs are slightly less if the window system is located on the south side. The windows are estimated to pay for themselves in about three to four years.

2.6 WASHINGTON, D.C.

Washington, D.C. has approximately 4200 heating degree days and 1000 cooling hours which means that the effect of windows on both heating and cooling is relatively important.

TABLE 2.9

LOS ANGELES, CALIFORNIA, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 1350 HEATING DEGREE DAYS, 550 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	564	125	5.7	< 0
E-W	M/D	12	1.11	Single	570	124	5.7	< 0
N	M/D	12	1.11	Single	558	125	5.7	< 0 [c]
Part B (FPE[b] = 12%)								
S	M/D	30	2.79	Single	1633	1047	6.5	< 0
E-W	M/D	30	2.79	Single	1660	1040	6.5	< 0
N	M/D	30	2.79	Single	1606	1051	6.5	< 0 [c]

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Least Cost of these alternatives.

TABLE 2.10

ATLANTA, GEORGIA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	720	724	715	720	724	715
12	1.11	780	792	787	802	809	800
18	1.67	809	825	821	831	842	832
30	2.79	884	904	904	918	933	923
60	5.57	1075	1107	1113	1125	1151	1141
Part B (FPE[b] = 12%)							
0	0	2798	2816	2781	2798	2816	2781
12	1.11	2878	2924	2904	2886	2916	2881
18	1.67	2932	2991	2978	2919	2961	2924
30	2.79	3066	3146	3146	3021	3078	3043
60	5.57	3439	3565	3588	3279	3382	3343

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.11

ATLANTA, GEORGIA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	Single Glazed E/W	Single Glazed N	Double Glazed, Orientation S	Double Glazed E/W	Double Glazed N
Part A (FPE = 0%)							
0[b]	0	712	716	707	712	716	707
12	1.11	565	579	577	590	603	597
18	1.67	572	587	587	603	617	612
30	2.79	662	680	685	719	736	731
60	5.57	920	948	969	1028	1052	1048
Part B (FPE = 12%)							
0[b]	0	2767	2785	2751	2767	2785	2751
12	1.11	1863	1916	1909	1883	1933	1911
18	1.67	1795	1854	1854	1817	1874	1854
30	2.79	1811	1882	1899	1853	1920	1902
60	5.57	2026	2135	2218	2091	2183	2169

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.12

ATLANTA, GEORGIA, CASE STUDY: LEAST-COST WINDOW SYSTEMS --
2950 HEATING DEGREE DAYS, 1000 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	565	147	3.9	< 0[c]
E-W	M/D	12	1.11	Single	579	137	4.7	< 0
N	M/D	12	1.11	Single	577	130	4.9	< 0
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Single	1795	972	3.2	< 0[c]
E-W	M/D	18	1.67	Single	1854	931	3.3	< 0
N	M/D	18	1.67	Double	1854	897	5.0	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Least Cost of these alternatives.

Table 2.13 shows that life-cycle costs are lower with no windows than with windows if they are unmanaged and not used for daylighting. When fuel prices are assumed to remain level in constant dollars (Part A), adding a 12 ft^2 (1.11 m^2) single glazed window on the south side[1] is estimated to add \$89 to the life-cycle costs of the building; an 18 ft^2 (1.67 m^2) window, \$130; a 30 ft^2 (2.79 m^2) window \$225; and a 60 ft^2 (5.57 m^2) window, \$468. With a 12 percent real escalation rate in fuel prices (FPE) (Part B), window performance is substantially worse: a 12 ft^2 (1.11 m^2) single-glazed, south-facing window is estimated to add \$171 to life-cycle costs and a 60 ft^2 (5.57 m^2) window, nearly \$1,000. Comparing the costs for double-glazed windows with those for single-glazed windows, it may be seen that double glazing is cost effective for larger north-facing windows even if fuel prices remain constant, and it is cost effective for all window orientations if fuel prices escalate rapidly.

The data in table 2.14 reflect the effects of window management and daylighting on total life-cycle costs. From the table it may be seen that windows, effectively managed and used for daylighting, can lower life-cycle costs of the building. The faster the rise in energy prices, the more favorable the window becomes in this mode of use, because the savings in reduced lighting costs (electricity) and cooling costs (electricity) more than offset the increased costs for heating (gas).

When thermal shutters are used, double glazing is less likely to be needed. The life-cycle cost results in table 2.14 show, in fact, that double glazing is not estimated to be cost effective if energy prices remain constant in real terms. It does become cost effective, however, for north-facing windows and for large window areas if energy prices escalate rapidly. For smaller windows facing south, east, or west, the thermal shutters are estimated to provide an adequate substitute for double glazing.

Table 2.15 shows the least-cost window system for each orientation, and the least-cost system overall. For both constant and rapidly increasing fuel prices, a single-glazed window of a small-to-moderate size facing south, managed and used for daylighting, is the most cost effective. This window is estimated to save \$89 and to pay for itself in 6.6 years with constant fuel prices. When fuel prices are estimated to increase at a 12 percent real rate, the savings may be as much as \$774, with only 4.9 years to payback. This window would be cost effective even if fuel prices were to decline somewhat.

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[1] The reader is reminded that this assessment of the performance of south-facing windows does not include the provision of winter thermal storage capacity nor summer shading, both customary practices in passive solar energy design; that is, the poor performance of the bare, unmanaged window is not contradictory to the potential success of the window as a passive solar energy collector.

TABLE 2.13

WASHINGTON, D.C., RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM — EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	719	725	718	719	725	718
12	1.11	808	821	824	820	830	824
18	1.67	849	863	870	857	870	865
30	2.79	944	963	980	963	980	975
60	5.57	1187	1219	1260	1214	1239	1234
Part B (FPE[b] = 12%)							
0	0	2794	2819	2793	2794	2819	2793
12	1.11	2965	3014	3025	2924	2963	2942
18	1.67	3055	3112	3138	2976	3028	3008
30	2.79	3251	3322	3388	3121	3188	3167
60	5.57	3774	3897	4058	3474	3572	3550

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.14

WASHINGTON, D.C., RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM — EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	E/W	N	Double Glazed, Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0[c]	0	695	700	693	695	700	693
12	1.11	606	618	625	630	642	640
18	1.67	621	636	649	652	665	664
30	2.79	738	757	780	790	807	809
60	5.57	1054	1083	1135	1153	1179	1185
Part B (FPE[b] = 12%)							
0[c]	0	2703	2721	2693	2703	2721	2693
12	1.11	1974	2020	2046	1982	2027	2020
18	1.67	1930	1985	2037	1936	1986	1982
30	2.79	2000	2074	2166	2003	2067	2075
60	5.57	2333	2446	2649	2313	2412	2438

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.15

WASHINGTON, D.C., RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 4200 HEATING DEGREE DAYS, 1000 COOLING HOURS

Orientation	Least-Cost Window System: Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S[c]	M/D	12	1.11	Single	606	89	6.6	< 0
E-W	M/D	12	1.11	Single	618	82	6.8	< 0
N	M/D	12	1.11	Single	625	68	7.5	< 0
Part B (FPE[b] = 12%)								
S[c]	M/D	18	1.67	Single	1930	773	4.9	< 0
E-W	M/D	18	1.67	Single	1985	736	5.1	< 0
N	M/D	18	1.67	Double	1982	711	6.4	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Least Cost of these alternatives.

2.7 SEATTLE, WASHINGTON

In Seattle the effects of a dominant heating load (4400 heating degree days, 100 cooling hours) on window selection and use are apparent.

Table 2.16 shows that higher life-cycle costs result from both single- and double-glazed windows of all sizes and with all orientations when windows are not managed and not used for daylighting. If energy prices remain unchanged in constant dollar terms, the life-cycle costs for single- and double-glazed windows are nearly equal, although single glazing is slightly preferred for windows with a southerly exposure and for small windows with other exposures. Double glazing is less costly for moderate to large windows with a northerly exposure. These results indicate that with constant real energy prices the net losses for large windows average in excess of $500 and may run as high as $600 on northerly exposures.

Double glazing becomes more cost effective than single glazing for all windows and orientations if energy prices rise at real annual rate of 12 percent. Raising the real rate of increase in energy prices from 0 to 12 percent increases the net losses attributable to windows by 30 to 50 percent for double glazing, and in most cases by more than 100 percent for single glazing.

Table 2.17 shows a less dramatic turnaround for window cost effectiveness from adding management devices and daylight utilization than was seen in the previous case studies. If energy prices remain level in constant dollars, only small window areas of 12 ft^2 (1.11 m^2) are estimated to be cost effective, except on the south where single-glazed windows as large as 18 ft^2 (1.67 m^2) result in net savings. Net losses rise rapidly as window area is increased. As in the preceding case, the costs for single- and double-glazed windows are nearly equal, with the savings in energy from double glazing being more or less offset by the higher costs of the windows.

Part B of table 2.17 shows windows to be somewhat more attractive economically if energy prices rise sharply. For all but the largest windows, savings in electric lighting costs from daylighting more than offset the higher heating costs, resulting in net savings. With higher energy prices, double glazing is more cost effective than single glazing in every case.

Part A of table 2.18 shows that if real energy prices were to remain constant, life-cycle costs would be minimized by having a 12 ft^2 (1.11 m^2) single-glazed window, managed and used for daylighting, on the south side. Because the net savings of even the least-cost window are small, the payback period ranges from 10.8 years for a small single-glazed window on the south side to 16.7 years for the same window on the north.

Part B of table 2.18 shows that if energy prices rise rapidly, double-glazed windows of 18 ft^2 minimize life-cycle costs for all but northerly orientations. On the north side, a window size of 12 ft^2 is least costly. The least-cost windows are expected to save between $500 and $600, and are estimated to pay for themselves in 7.4 to 7.9 years.

TABLE 2.16

SEATTLE, WASHINGTON, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM — EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	625	628	625	625	628	625
12	1.11	722	734	737	735	740	739
18	1.67	764	781	791	776	782	783
30	2.79	871	898	915	888	897	900
60	5.57	1141	1191	1233	1155	1173	1187
Part B (FPE[b] = 12%)							
0	0	2430	2443	2431	2430	2443	2431
12	1.11	2616	2662	2675	2576	2596	2591
18	1.67	2708	2773	2812	2634	2658	2662
30	2.79	2936	3039	3106	2784	2821	2832
60	5.57	3536	3729	3894	3155	3224	3277

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.17

SEATTLE, WASHINGTON, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND WITH DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	E/W	N	Double Glazed, Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0[c]	0	612	612	608	612	612	608
12	1.11	573	589	603	593	601	606
18	1.67	607	626	646	623	633	643
30	2.79	761	789	822	789	801	817
60	5.57	1161	1210	1267	1207	1225	1256
Part B (FPE[b] = 12%)							
0[c]	0	2379	2380	2365	2379	2380	2365
12	1.11	1819	1878	1933	1805	1835	1854
18	1.67	1837	1912	1989	1779	1821	1859
30	2.79	2027	2136	2264	1919	1966	2028
60	5.57	2621	2812	3033	2366	2434	2554

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2) reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.18

SEATTLE, WASHINGTON, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS --
4400 HEATING DEGREE DAYS, 100 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	573	39	10.8	< 0 [c]
E-W	M/D	12	1.11	Single	589	23	12.4	< 0
N	M/D	12	1.11	Single	603	5	16.7	< 0
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Double	1779	600	7.5	.6 [c]
E-W	M/D	18	1.67	Double	1821	559	7.9	1.1
N	M/D	12	1.67	Double	854	511	7.4	< 0

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Least Cost of these alternatives.

2.8 INDIANAPOLIS, INDIANA

Indianapolis was selected for case study because it has not only a relatively heavy heating load requirement (5700 heating degree days), but also a moderately heavy cooling load requirement (750 cooling hours). It is somewhat similar to Washington, D.C. (4200 heating degree days, 1000 cooling hours), a previous case examined. However, the additional heating load requirement of Indianapolis exerts a strong influence on the comparative costs of single and double glazing and results in important differences in window selection in the two cities.

Without window management and without daylight utilization, both single- and double-glazed windows of all sizes and with all orientations result in increased life-cycle costs. As shown by part A of table 2.19, with constant real energy prices, costs are raised more than \$500 by the 60 ft^2 (5.57 m^2) window area, whether single or double glazed. Double-glazed windows are somewhat more cost effective, particularly for northerly exposures.

Part B of table 2.19 shows that if energy prices rise at a real rate of 12 percent compounded annually, net losses for single-glazed windows are more than double those experienced with constant real energy prices, rising higher than \$1500 for northerly exposures. With double glazing, the net losses are about 50 percent higher than those experienced at constant energy prices. Double glazing is in all cases more cost effective than single glazing. The net losses associated with double-glazed windows range from 30 to 50 percent lower than losses associated with single-glazed windows. However, even with double-glazed windows, life-cycle costs climb steadily and may exceed \$800 for large windows.

The addition of management devices and daylight utilization alters these results dramatically. From part A of table 2.20 it can be seen that, with constant real energy prices, net savings are estimated for all windows up to and including 18 ft^2 (1.67 m^2) in area. On the south side, the thermal shutters appear to eliminate a need for double glazing, and single glazing is cost effective. On the north side, the energy savings from adding double glazing to the thermal shutters are matched almost exactly by the higher acquisition costs, and it makes little difference from an economic standpoint whether or not double glazing is used in addition to the shutters.

If energy prices rise at a real rate of 12 percent per year, net savings are estimated for all sizes of double-glazed windows and for all single-glazed windows, except for 60 ft^2 (5.57 m^2) areas facing east, west, or north. In

TABLE 2.19

INDIANAPOLIS, INDIANA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area (FT^2)	Window Area (m^2)	Single Glazed, Orientation S	Single Glazed, Orientation E/W	Single Glazed, Orientation N	Double Glazed, Orientation S	Double Glazed, Orientation E/W	Double Glazed, Orientation N
Part A (FPE[b] = 0%)							
0	0	722	729	725	722	729	725
12	1.11	826	839	844	829	838	835
18	1.67	870	887	899	869	879	877
30	2.79	978	1001	1025	976	989	989
60	5.57	1244	1289	1340	1231	1250	1257
Part B (FPE[b] = 12%)							
0	0	2809	2836	2817	2809	2836	2817
12	1.11	3039	3092	3111	2968	3004	2992
18	1.67	3149	3214	3259	3034	3075	3066
30	2.79	3395	3486	3579	3194	3244	3243
60	5.57	4024	4200	4397	3583	3656	3684

Life-Cycle Costs in Dollars

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family-room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

TABLE 2.20

INDIANAPOLIS, INDIANA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	E/W	N	Double Glazed, Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0[c]	0	691	698	692	691	698	692
12	1.11	629	643	651	649	658	658
18	1.67	645	665	680	670	680	683
30	2.79	763	792	822	806	819	827
60	5.57	1099	1145	1208	1164	1185	1206
Part B (FPE[b] = 12%)							
0[c]	0	2688	2712	2690	2688	2712	2690
12	1.11	2075	2129	2162	2071	2105	2107
18	1.67	2039	2117	2175	2028	2066	2076
30	2.79	2130	2242	2359	2099	2151	2181
60	5.57	2568	2745	2992	2428	2512	2593

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2) reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

every case double glazing is more cost effective than single glazing, particularly for large, north-facing windows.[1]

Part A of table 2.21 shows that with constant real energy prices the window which minimizes life-cycle costs is single glazed, 12 ft^2 (1.11 m^2), located on the south side of the house, managed, and used for daylighting. This window system is estimated to pay for itself in seven to eight years.

As shown by part B of table 2.21, a double-glazed, 18 ft^2 (1.67 m^2) window area on the south side, managed and used for daylighting, is least cost if energy prices rise rapidly. This window system is estimated to pay for itself in six to seven years and to save in excess of $600 as compared with a windowless room.

2.9 PORTLAND, MAINE

The climate of Portland, Maine results in a heavy heating load requirement (7600 heating degree days), and a very modest cooling load requirement (250 cooling hours). In Portland, Maine, as well as the next city to be explained, Bismarck, North Dakota, the use of triple glazing to minimize winter heat loss will be considered. Triple glazing is assumed to be obtained by fitting a storm sash over a sealed double-glazed window.

From part A of table 2.22 it can be seen that without management and daylight utilization and with constant real energy prices, net losses result for single-, double-, and triple-glazed windows of all sizes and with all orientations. With the heavy heating load, single glazing is less cost effective than either double or triple glazing even if energy prices are constant in real terms. Net losses exceed $700 for large single-glazed windows with northerly exposures. The life-cycle costs associated with double and triple glazing are nearly equal to one another, with triple glazing slightly lower in costs for a northerly exposure. Net losses for large double- and triple-glazed windows average about $500.

Part B of table 2.22 shows that if energy prices rise at a real rate of 12 percent per year, net losses for large windows on the north exceed $2000 for single glazing, $1000 for double glazing, and approach $800 for triple glazing. With the higher future energy costs, triple glazing is the most cost-effective glazing type. For large windows on the north, triple glazing reduces net

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[1] The higher heating load requirements for Indianapolis as compared with Washington result in the following key differences in window cost effectiveness if energy prices rise rapidly: (1) In Washington all windowed areas managed and used for daylighting are estimated to produced net savings; whereas in Indianapolis, large single-glazed windows facing east, west, or north are estimated to produce a net increase in life-cycle costs. (2) In Washington single glazing is estimated to be cost effective for windows 18 ft^2 (1.67 m^2) and smaller which do not have a northerly exposure; whereas, in Indianapolis, double glazing appears better for these windows.

TABLE 2.21

INDIANAPOLIS, INDIANA, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 5700 HEATING DEGREE DAYS, 750 COOLING HOURS

Orientation	Least-Cost Window System: Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S [c]	M/D	12	1.11	Single	629	62	7.6	< 0
E-W	M/D	12	1.11	Single	643	55	8.1	< 0
N	M/D	12	1.11	Single	651	41	10.2	< 0
Part B (FPE[b] = 12%)								
S [c]	M/D	18	1.67	Double	2028	660	6.6	< 0
E-W	M/D	18	1.67	Double	2066	646	6.7	< 0
N	M/D	18	1.67	Double	2076	614	6.9	< 0

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Least Cost of these alternatives.

TABLE 2.22

PORTLAND, MAINE, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area (FT²)	(m²)	Single Glazed Orientation S	E/W	N	Double Glazed Orientation S	E/W	N	Triple Glazed Orientation S	E/W	N
Part A (FPE[b] = 0%)										
0	0	703	712	713	703	712	713	703	712	713
12	1.11	818	839	860	806	818	827	807	818	822
18	1.67	870	897	926	844	859	872	845	859	864
30	2.79	990	1027	1078	949	970	989	951	968	977
60	5.57	1291	1359	1461	1199	1230	1265	1199	1227	1242
Part B (FPE[b] = 12%)										
0	0	2734	2767	2772	2734	2767	2772	2734	2767	2772
12	1.11	3024	3108	3188	2902	2950	2985	2870	2915	2930
18	1.67	3170	3276	3390	2974	3033	3081	2925	2976	3000
30	2.79	3480	3626	3824	3145	3226	3299	3064	3129	3163
60	5.57	4286	4550	4945	3573	3693	3831	3394	3500	3559

Life-Cycle Costs in Dollars (column group heading spanning Single, Double and Triple Glazed).

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family room/kitchen of the house described in section 2. They are <u>not</u> the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

losses 28 percent below those of double glazing, and 64 percent below those of single glazing.

Table 2.23 shows the life-cycle costs associated with the windows when they are managed and used for daylight. Part A of table 2.23 shows that window management and daylighting result in modest net savings for small windows, except those on the north, if real energy prices remain constant. With thermal shutters, single glazing is slightly more cost effective for southerly exposures; double glazing for most northerly exposures. Triple glazing is estimated to be slightly more cost effective than single glazing and slightly less cost effective than double glazing for northern exposures.

From part B of table 2.23 it can be seen that with rapidly rising energy prices all but the largest windowed areas yield net savings provided they are either double or triple glazed, managed, and used for daylighting. In every case examined, triple glazing appears to be the most cost-effective type of glazing.

If energy prices rise at about the rate of general price inflation (i.e., no increase in real dollars), it appears from part A of table 2.24 that small, single-glazed windows on the south side of the house are the cost-effective choice. But if energy prices rise at a rate 12 percent faster than the rate of general price inflation, part B of table 2.24 shows that the window system which minimizes life-cycle costs is triple glazed with an area of 18 ft^2 (1.67 m^2). The least-cost, triple-glazed window system is expected to save nearly $500 in present value dollars, and to pay for itself in seven to eight years. These results suggest that even in a climate with a heavy heating load, windows which are well designed thermally, appropriately sized, oriented, and equipped with accessories, and which take advantage of natural lighting can accomplish significant reductions in life-time building costs.

2.10 BISMARCK, NORTH DAKOTA

The last city treated in the residential case studies is Bismarck, North Dakota. Bismarck has the highest heating load requirement (8850 heating degree days) of the cities examined, as well as a higher cooling load (450 cooling hours) than the other cold winter city, Portland, Maine. It offers an interesting contrast to the case study for Miami, where the cooling load requirement was very high.

Table 2.25 shows that without management or daylight utilization, windows cause life-cycle costs to rise, regardless of the type of glazing, the size, or the orientation. Part A of the table shows that, as in the previous case study, single glazing is not cost effective, even with constant real energy prices. Net losses exceed $800 for large single-glazed windows with northerly exposures. There is little difference in the life-cycle costs of double and triple glazing, although triple glazing is slightly preferred.

Part B of table 2.25 shows that if energy prices rise at a real rate of 12 percent per year, net losses for large windows on the north side of the room may exceed $2500 for single-glazing, $1200 for double glazing, and $900 for triple glazing. In all cases triple glazing is the most cost-effective type

TABLE 2.23

PORTLAND, MAINE, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
		Orientation			Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)										
0[c]	0	671	680	681	671	680	681	671	680	681
12	1.11	642	665	694	656	670	683	665	678	687
18	1.67	670	698	738	681	698	716	693	708	720
30	2.79	795	835	899	818	837	865	835	854	871
60	5.57	1126	1194	1316	1158	1186	1237	1193	1219	1245
Part B (FPE[b] = 12%)										
0[c]	0	2610	2644	2648	2610	2644	2648	2610	2644	2648
12	1.11	2161	2253	2362	2143	2195	2249	2141	2192	2225
18	1.67	2180	2289	2445	2126	2192	2264	2121	2180	2224
30	2.79	2333	2487	2738	2245	2319	2427	2222	2296	2359
60	5.57	2837	3100	3575	2608	2714	2912	2562	2661	2764

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2) reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.24

PORTLAND, MAINE, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 7600 HEATING DEGREE DAYS, 250 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	642	29	11.0	< 0 [c]
E-W	M/D	12	1.11	Single	665	15	13.1	< 0
N		0	0		681	0		
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Triple	2121	489	7.6	.6 [c]
E-W	M/D	18	1.67	Triple	2180	464	7.9	1.2
N	M/D	18	1.67	Triple	2224	424	7.6	.2

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"DR" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b Least Cost of these alternatives.

TABLE 2.25

BISMARCK, NORTH DAKOTA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
		Orientation			Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)										
0	0	753	764	766	753	764	766	753	764	766
12	1.11	882	913	938	861	880	893	861	877	885
18	1.67	941	981	1017	904	926	944	902	921	932
30	2.79	1073	1129	1191	1016	1043	1072	1011	1035	1052
60	5.57	1405	1507	1631	1281	1322	1379	1270	1307	1337
Part B (FPE[b] = 12%)										
0	0	2927	2971	2980	2927	2971	2980	2927	2971	2980
12	1.11	3271	3391	3488	3115	3186	3238	3074	3137	3169
18	1.67	3442	3595	3735	3197	3282	3354	3135	3208	3251
30	2.79	3797	4016	4253	3393	3499	3613	3283	3376	3441
60	5.57	4710	5108	5590	3870	4028	4250	3641	3783	3902

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) cleaning, recaulking and repainting the windows on a regular basis, and (3) the energy costs for heating, cooling, and lighting of the designated family-room/kitchen of the house described in section 2. They are not the life-cycle costs for the entire house. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

of glazing. With triple glazing, net losses are estimated to be less than half what they are with single glazing, and only about three-fourths what they are with double glazing.

Table 2.26 shows that managing the windows and using daylight in all cases improves the economic performance of the windows; however, attention to sizing, orientation, and glazing is also necessary to realize net dollar savings from them. If energy prices are level in constant dollars and thermal shutters are used, single glazing appears slightly more cost effective for southerly exposures, double glazing for easterly/westerly exposures, and either double or triple glazing for northerly exposures.

Part B of table 2.26 shows the impact of rapidly rising energy prices on window costs when the windows are managed and used for daylighting. With 12 percent real escalation in energy prices, it is possible to realize sizable net savings from windows, provided they are kept small to moderate in size and are either placed on the south or are double or triple glazed. For all window sizes and orientation, triple glazing is the most cost-effective type of glazing. Savings average more than \$400 for triple-glazed windows 12 to 18 ft^2 (1.11 to 1.67 m^2) in area.

As shown by part A of table 2.27, none of the window systems examined produces net savings on the north side if real energy prices are constant. For southerly exposures, the least-cost window system is 12 ft^2 (1.11 m^2) and single glazed. For easterly-westerly exposures, the least-cost window systems is 12 ft^2 (1.11 m^2) and double glazed. In both cases, net savings are trival in amount.

From part B of table 2.27, it can be seen that the window system which minimizes life-cycle costs when energy prices escalate rapidly is triple glazed, 18 ft^2 (1.67 m^2), and located on the south side. On the north side, the least-cost window system is 12 ft^2 (1.11 m^2) in area and triple glazed. Net savings from the least-cost window system for each orientation vary from just under \$400 on the north side to almost \$500 on the south, and the expected time to payback is about eight years.

TABLE 2.26

BISMARCK, NORTH DAKOTA, RESIDENTIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITH WINDOW MANAGEMENT AND DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Single Glazed Orientation S	Single Glazed E/W	Single Glazed N	Double Glazed Orientation S	Double Glazed E/W	Double Glazed N	Triple Glazed Orientation S	Triple Glazed E/W	Triple Glazed N
Part A (FPE[b] = 0%)										
0[c]	0	721	732	734	721	732	734	721	732	734
12	1.11	698	731	764	710	730	748	719	737	749
18	1.67	725	766	813	735	758	783	746	767	784
30	2.79	854	912	986	873	901	938	891	916	939
60	5.57	1193	1296	1440	1226	1265	1335	1258	1293	1334
Part B (FPE[b] = 12%)										
0[c]	0	2804	2847	2852	2804	2847	2852	2804	2847	2852
12	1.11	2373	2501	2627	2343	2420	2490	2341	2409	2456
18	1.67	2383	2545	2726	2325	2414	2510	2312	2394	2458
30	2.79	2545	2771	3058	2439	2547	2692	2414	2512	2604
60	5.57	3060	3461	4021	2827	2979	3251	2767	2903	3065

(Life-Cycle Costs in Dollars)

[a] Life-cycle costs include the present value costs of (1) purchasing and installing the windows (in excess of the costs of a brick wall section of equal size), (2) purchasing the venetian blinds and shutters, (3) cleaning, recaulking and repainting the windows on a regular basis, and (4) the energy costs of the designated room for heating, cooling, and lighting. Base-year prices are for 1978.

[b] FPE abbreviates "fuel price escalation rate."

[c] Note that the life-cycle costs for all window sizes, from 0 to 60 ft^2 (5.57 m^2), reflect the adjustment of the thermostat for energy conservation; hence, the costs for the zero window case in this table are slightly lower than in the preceding table which did not assume an adjustment in the thermostat.

TABLE 2.27

BISMARCK, NORTH DAKOTA, RESIDENTIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 8850 HEATING DEGREE DAYS, 450 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	M/D	12	1.11	Single	698	23	11.9	< 0[c]
E-W	M/D	12	1.11	Double	731	1	18.5	< 0
N	M/D	0	0		734	0		
Part B (FPE[b] = 12%)								
S	M/D	18	1.67	Triple	2312	492	7.7	.9[c]
E-W	M/D	18	1.67	Triple	2394	453	8.2	1.7
N	M/D	12	1.11	Triple	2456	396	8.2	1.2

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Least Cost of these alternatives.

Windows are a distinctive element in the commercial building facade.

3. COMMERCIAL CASE STUDIES FOR NINE CITIES

3.1 DESCRIPTION OF COMMERCIAL BUILDING AND WINDOW SYSTEMS[1]

The focus of the commercial case studies is an office module in a 5-to-10 story office building with conventional curtain wall construction. The exterior wall of the office building consists of a dark glass spandrel panel with one inch of rigid fiberglass insulation applied with a mastic. The mullions which hold the spandrel panels are dark anodized aluminum with a thermal break. The interior surface of the exterior wall is cut out and installed. The size of the cutout is determined by the size and type of glazing. The U value of the non-windowed wall is approximately 0.15.

The windows are assumed to be fixed. The framing is dark anodized aluminum with a thermal break. It is assumed that no tints or low emissivity coatings are used. All glazing is erected from the inside of the building as a stick wall; elastomeric gaskets[2] (dryset) are used on all windowed areas. Both single and double glazing are examined. Window sizes range from 0 to 90 square feet (0 to 5.57 m^2). Figure 3.1 illustrates the shape of the office module and the window sizes in relationship to the size of the exterior wall.

The floor area of the office module is 180 square feet (16.72 m^2) and the volume of the module is 1800 cubic feet (50.97 m^3). It is assumed that two people are assigned to the office during the normal working hours of 9:00 a.m. to 5:00 p.m. Their occupancy is averaged over the day and the resultant figure of 1.8 persons is used in the computer model to calculate heat loads generated by the occupants. The calculation of expected heat gains also takes into account the effects of office equipment, such as typewriters, electric adding machines/desk calculators, and computer time-sharing terminals, as well as lighting. Additional assumptions, such as lighting requirements and heating and cooling system efficiencies, are given in table 1.1, and costs of the window systems are given in appendix B.

The cities are those used for the residential case studies: Washington, D.C.; Miami, Florida; Atlanta, Georgia; Portland, Maine; Indianapolis, Indiana; San Antonio, Texas; Los Angeles, California; Bismarck, North Dakota; and Seattle, Washington. (Their locations and climatic zone designations are shown on the map in figure 1.1.)

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[1] This information, taken from the companion report, Economic Evaluation of Windows in Buildings: Methodology [1], is repeated here for the convenience of the reader.

[2] The use of elastomeric gaskets reduces the likelihood of repairs which would probably result from chemical sealants applied at the site. The elastomeric gaskets are assumed to perform satisfactorily throughout the 25 year life cycle.

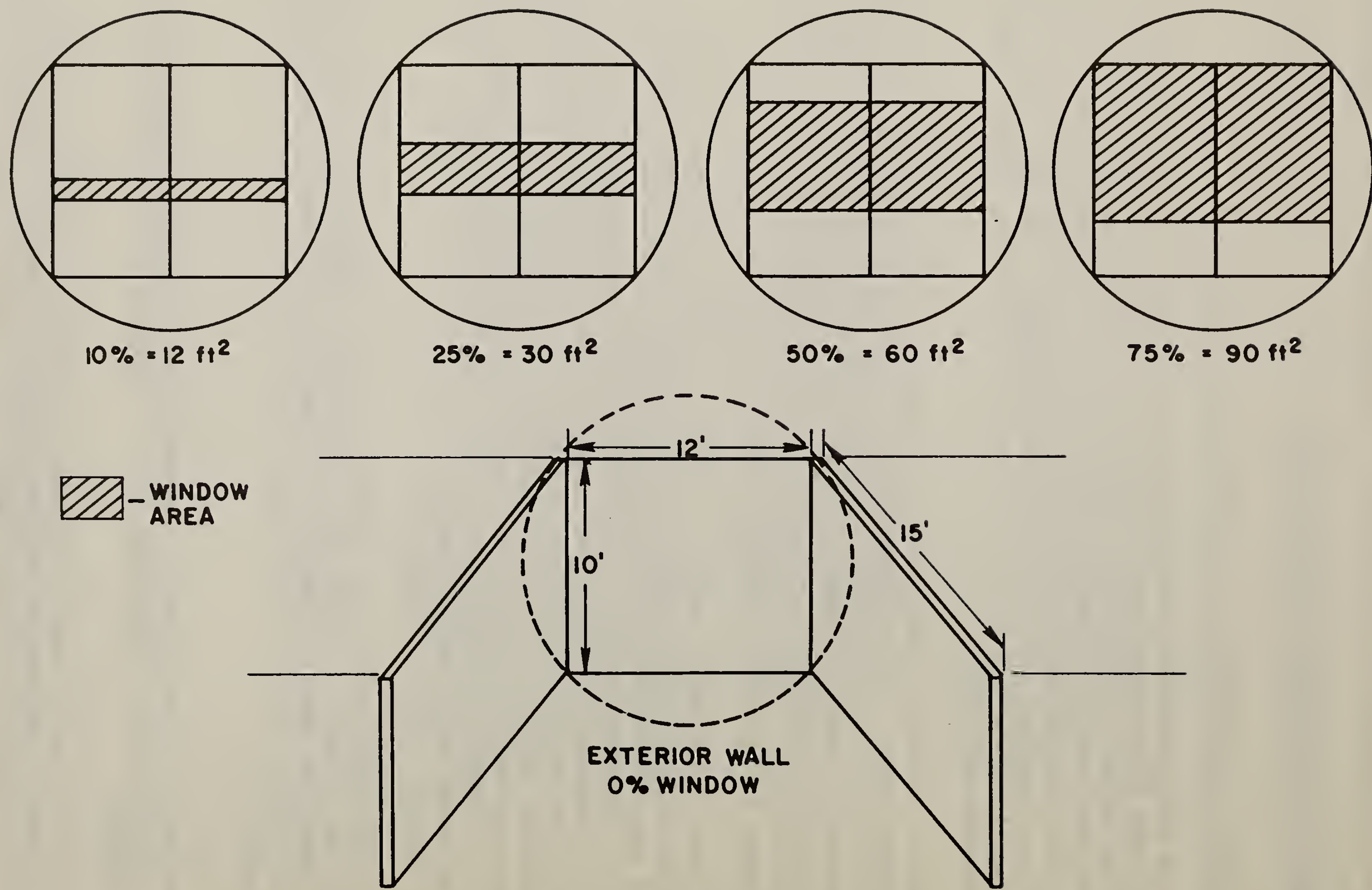

Figure 3.1 Window Sizes in Relationship to the Size of the Exterior Wall of the Office Module

Like the residential case studies, these commercial case studies do not include special passive solar energy features for south-facing windows to increase solar absorption and thermal storage. Also like the residential cases, energy savings from natural ventilation are not included; however, this is appropriate for the commercial cases since the windows are assumed fixed. It should also be noted that energy savings from daylighting requires its effective substitution for electric lighting, probably a difficult goal to achieve in an office building without the use of an automatic switching device[1] or employee energy awareness or incentive program, the cost and effectiveness of which are not included in this analysis. Regarding the utilization of solar heat gains through the windows, the following should be noted: if the thermal analysis indicates a need for heat in the office module, calculated solar heat gains through the window are treated as beneficial up to the limits of the heating requirements, ignoring the problems of overheating and the need to distribute the heat through the space.

The format in this section is the same as that in the previous section for the residential case studies. For each city, tables of life-cycle costs are given, first, for the least economically favorable mode of use examined, and, second, for the most favorable mode of use. These two tables are followed by a third table identifying the least-cost window systems. The first mode of window use--identical to that for the residential case studies--is unmanaged windows, not used for daylighting. The second mode--unlike that for the residential case studies--is unmanaged windows, used for daylighting.[2]

3.2 MIAMI, FLORIDA

Let us look first at the less advantageous results for windows: those not used for daylighting. We see from table 3.1 that in Miami, with its dominant cooling load of 2400 cooling hours, the lowest cost penalty from windows in face of rapidly rising real energy prices is for small, single-glazed windows located on the north. With constant real energy prices, windows are estimated to add little to long-run costs, regardless of their size or orientation. The higher acquisition cost of the double glazing is not estimated to be a worthwhile expense for the office window in Miami.

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[1] The use of photo-sensitive lighting controls to reduce lighting energy while maintaining required illumination through daylighting has been investigated by Treado and Kusuda [6].

[2] Although the particular window management considered here was found not to be cost effective for the commercial windows, the reader is reminded that this finding reflects the large estimated acquisition cost for commercial-grade shutters, and does not mean that blinds and thermostat adjustment are not cost effective. It is also important to keep in mind that there are many other forms of window management, not considered here, which may be cost effective.

TABLE 3.1

MIAMI, FLORIDA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
Window Area (FT^2)	(m^2)	Orientation S	E/W	N	Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1219	1222	1215	1219	1222	1215
12	1.11	1255	1262	1243	1321	1327	1309
30	2.79	1284	1298	1259	1404	1417	1381
60	5.57	1408	1433	1362	1624	1646	1582
90[c]	8.36	1297	1333	1230	1587	1620	1527
Part B (FPE[b] = 12%)							
0	0	1871	1879	1856	1871	1879	1856
12	1.11	1972	1996	1927	2029	2051	1987
30	2.79	2100	2147	2011	2197	2240	2115
60	5.57	2387	2475	2226	2557	2636	2411
90[c]	8.36	2440	2567	2207	2661	2776	2451

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

Table 3.2 shows the total life-cycle costs when daylight utilization is practiced. Part A of the table shows that small net savings result for most of the window sizes if real energy costs remain level and single glazing is used. On the other hand, all double-glazed window areas examined are estimated to produce net losses.

Part B of table 3.2 shows at least small estimated savings for all single-glazed windows, except large east and west-facing windows, if energy prices rise at a real rate of 12 percent compounded annually. The largest savings result from moderately sized, north-facing, single-glazed windows. Double glazing is not estimated to be cost effective relative to single-glazing; however, savings are estimated for moderately sized double-glazed windows.

Table 3.3 shows that rising real energy prices in Miami increase the potential net savings from daylighting, but constrain the size of the least-cost window to 30 ft^2 (2.79 m^2). The dominant cooling load in Miami dictates the north side of the building as the least-cost window orientation.

3.3 SAN ANTONIO, TEXAS

Tables 3.4 through 3.6 give the life-cycle cost results for San Antonio. These results are quite similar to those for Miami, although there is less difference in San Antonio in the costs of north- and south-facing windows. Due to the somewhat lower cooling load and higher heating load in San Antonio relative to Miami (2000 versus 2400 cooling hours, and 1550 versus 200 heating degree days, respectively), north and south orientations are about equal in life-cycle costs for San Antonio, whereas in Miami, there was a cost advantage to orienting windows to the north. Like the Miami case, orienting windows to the east or west raises costs, as does the use of double glazing.

Also like the Miami case, windows in the San Antonio office are in general estimated to raise life-cycle costs unless they are used for daylighting. This cost increase is quite small if real energy prices remain constant and if single glazing is used, and is relatively modest even if energy prices rise rapidly. Single glazing is estimated to be lower in cost than double glazing even if energy prices rise at 12 percent per year, but the advantage of single glazing is diminished as energy prices rise, and would be lost if energy prices were to rise much faster than 12 percent per year.

Daylight utilization significantly alters the life-cycle cost results. Part A of table 3.5 shows small net savings for most of the single-glazed windows if real energy prices are constant, but no savings for double-glazed windows.

Part B of table 3.5 shows that with rapidly rising energy prices, the potential for savings through daylighting is increased. Single glazing continues to be more cost effective than double glazing.

Part A of table 3.6 shows that if real energy prices are level, the window system which minimizes life-cycle costs is 90 ft^2 (8.36 m^2) in size, south facing, and single glazed. Part B of the table shows that higher energy prices raise potential savings -- the increase due to greater reductions in electric

TABLE 3.2

MIAMI, FLORIDA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
		S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1219	1222	1215	1219	1222	1215
12	1.11	1216	1223	1203	1282	1288	1270
30	2.79	1153	1167	1128	1273	1285	1250
60	5.57	1260	1285	1214	1476	1498	1434
90[c]	8.36	1171	1208	1105	1461	1494	1401
Part B (FPE[b] = 12%)							
0	0	1871	1879	1856	1871	1879	1856
12	1.11	1745	1768	1700	1801	1823	1759
30	2.79	1548	1596	1459	1645	1689	1564
60	5.57	1744	1832	1583	1914	1994	1768
90[c]	8.36	1814	1941	1580	2035	2150	1825

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.3

MIAMI, FLORIDA, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 200 HEATING DEGREE DAYS, 2400 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	U/D	30	2.79	Single	1153	66	1.2	< 0
E-W	U/D	30	2.79	Single	1167	55	1.4	< 0
N[c]	U/D	90	8.36	Single	1105	110	I[d]	< 0
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Single	1548	323	1.1	< 0
E-W	U/D	30	2.79	Single	1596	283	1.2	< 0
N[c]	U/D	30	2.79	Single	1459	397	.9	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

TABLE 3.4

SAN ANTONIO, TEXAS, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1111	1115	1110	1111	1115	1110
12	1.11	1138	1149	1137	1210	1221	1209
30	2.79	1155	1177	1153	1301	1320	1298
60	5.57	1257	1295	1255	1545	1572	1531
90[c]	8.36	1145	1198	1146	1543	1581	1521
Part B (FPE[b] = 12%)							
0	0	1719	1733	1717	1719	1733	1717
12	1.11	1780	1820	1777	1843	1881	1839
30	2.79	1851	1928	1844	1978	2043	1965
60	5.57	2048	2181	2043	2307	2404	2260
90[c]	8.36	2035	2219	2038	2391	2523	2312

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for a 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.5

SAN ANTONIO, TEXAS, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Single Glazed S	Single Glazed E/W	Single Glazed N	Double Glazed S	Double Glazed E/W	Double Glazed N
Part A (FPE[b] = 0%)							
0	0	1111	1115	1110	1111	1115	1110
12	1.11	1103	1115	1102	1176	1186	1175
30	2.79	1036	1059	1041	1183	1201	1179
60	5.57	1119	1167	1140	1406	1434	1400
90[c]	8.36	1026	1094	1055	1424	1462	1411
Part B (FPE[b] = 12%)							
0	0	1719	1733	1717	1719	1733	1717
12	1.11	1576	1617	1573	1639	1677	1636
30	2.79	1352	1433	1370	1480	1545	1467
60	5.57	1451	1620	1526	1709	1806	1688
90[c]	8.36	1450	1687	1551	1805	1938	1760

Life-Cycle Costs in Dollars (Orientation S, E/W, N for Single Glazed and Double Glazed)

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years, and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.6

SAN ANTONIO, TEXAS, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 1550 HEATING DEGREE DAYS AND 2000 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S[c]	U/D	90	8.36	Single	1026	85	I[d]	< 0
E-W	U/D	30	2.79	Single	1059	56	1.1	< 0
N	U/D	30	2.79	Single	1041	70	1.0	< 0
Part B (FPE[b] = 12%)								
S[c]	U/D	30	2.79	Single	1352	367	.9	< 0
E-W	U/D	30	2.79	Single	1433	300	1.0	< 0
N	U/D	30	2.79	Single	1370	347	1.0	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

lighting costs, and related reductions in cooling costs -- but reduce the least-cost window size due to the higher costs of undesirable heat gains and losses through larger windows.

3.4 LOS ANGELES, CALIFORNIA

For Los Angeles, with its modest heating and cooling loads (1350 heating degree days and 550 cooling hours), table 3.7 shows small net savings for large (90 ft^2) single-glazed windows on the south, even if energy prices are assumed to increase rapidly and if daylighting is not practiced.[1] Small net losses are estimated for other sizes of single-glazed windows, and somewhat larger losses for double-glazed windows of all sizes and orientations if energy prices rise rapidly. As in the Los Angeles residential case, climatic conditions cause the energy requirement for the windowed module in Los Angeles to be less than the requirement for the windowless module--apart from daylighting.

Part A of table 3.8 shows that with daylight utilization and constant real energy prices, net savings result for almost all sizes and orientations of single-glazed windows. Net losses are estimated for double-glazed windows.

Part B of table 3.8 shows that if energy prices rise at a real rate of 12 percent per year, single-glazed windows will reduce life-cycle building costs substantially if they are used for daylighting. The double-glazed windows are estimated to save considerably less.

Part A of table 3.9 shows that the window system which minimizes life-cycle costs if real energy prices are constant, is unmanaged, used for daylighting, 90 ft^2 (8.36 m^2), single glazed, and facing south. It is expected to save about $184 over the 25 year period, and, due to its lower initial investment cost, is expected to have an immediate payback.

Part B of table 3.9 shows that the window which minimizes life-cycle costs in the face of rapidly rising energy prices also is unmanaged, used for daylighting, 90 ft^2 (8.36 m^2), single glazed, and south facing. With a sharp rise in energy prices, however, the potential savings attributable to windows increases to an estimated $576, due to larger cost reductions in electric lighting and cooling costs.

3.5 ATLANTA, GEORGIA

Atlanta has not only a substantial cooling load requirement, but also a moderate heating load requirement. The balance betwen the two energy requirements is similar to that for Los Angeles except that the magnitudes are significantly increased.

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[1] Note, however, the dependency of this finding on the assumption of a lower estimated first cost for the 90 ft^2 (8.36 m^2) window wall than for other window sizes.

TABLE 3.7

LOS ANGELES, CALIFORNIA, COMMERICIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation S	E/W	N	Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1271	1276	1274	1271	1276	1274
12	1.11	1283	1293	1289	1371	1380	1376
30	2.79	1278	1295	1287	1457	1469	1459
60	5.57	1360	1384	1370	1705	1720	1700
90[c]	8.36	1184	1215	1202	1662	1681	1649
Part B (FPE[b] = 12%)							
0	0	1825	1840	1833	1825	1840	1833
12	1.11	1837	1870	1856	1924	1955	1940
30	2.79	1836	1895	1867	2024	2066	2032
60	5.57	1942	2027	1976	2310	2362	2291
90[c]	8.36	1792	1902	1856	2303	2369	2259

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.8

LOS ANGELES, CALIFORNIA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1271	1276	1274	1271	1276	1274
12	1.11	1261	1270	1266	1349	1358	1353
30	2.79	1176	1192	1190	1354	1366	1356
60	5.57	1240	1271	1281	1585	1601	1585
90[c]	8.36	1087	1130	1143	1565	1584	1560
Part B (FPE[b] = 12%)							
0	0	1825	1840	1833	1825	1840	1833
12	1.11	1658	1692	1677	1746	1777	1761
30	2.79	1378	1435	1428	1564	1606	1572
60	5.57	1386	1494	1528	1753	1806	1752
90[c]	8.36	1249	1400	1445	1759	1826	1744

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.9

LOS ANGELES, CALIFORNIA, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 1350 HEATING DEGREE DAYS, 550 COOLING HOURS

Orientation	Least-Cost Window System: Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE ($)
Part A (FPE[b] = 0%)								
S	U/D	90	8.36	Single	1087	184	I[d]	< 0[c]
E-W	U/D	90	8.36	Single	1130	146	I	< 0
N	U/D	90	8.36	Single	1143	131	I	< 0
Part B (FPE[b] = 12%)								
S	U/D	90	8.36	Single	1249	576	I	< 0[c]
E-W	U/D	90	8.36	Single	1400	440	I	< 0
N	U/D	30	8.36	Single	1428	405	1.0	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

Part A of table 3.10 shows net losses to result from all but large (90 ft^2) (8.36 m^2) south-, east-, and west-facing single-glazed windows, if real energy prices are assumed constant and daylighting is not used.[1] Single glazing appears more cost effective than double glazing for all window sizes and orientations. Net losses are slightly lower for southern exposures than for other exposures, because heating load requirements in Atlanta are somewhat more important than cooling load requirements.

If energy prices escalate at a real rate of 12 percent per year, part B of table 3.10 estimates small to moderate net losses for all windows. Single glazing and a southerly exposure remain the cost-effective choices, particularly for larger windows.

Part A of table 3.11 shows that with daylight utilization and constant real energy prices, the single-glazed windows for the most part lower life-time building costs. Single glazing and southerly orientations continue to be cost effective.

Part B of table 3.11 shows higher net savings associated with higher energy prices due to greater lighting cost savings. A large single-glazed window area on the south is estimated to save nearly \$500 in present value dollars.[2] Single glazing is generally more cost effective than double glazing, although there is only a small cost difference in large single- and double-glazed windows on the north.

Table 3.12 shows the least-cost choice to be a 90 ft^2 (8.36 m^2) single-glazed window on the south, unmanaged, and used for daylighting, whether the real rate of energy price escalation is zero or 12 percent.[3] For other than southerly orientations, a smaller window (30 ft^2) (2.79 m^2) is recommended as cost effective if energy price escalation is rapid.

3.6 WASHINGTON, D.C.

Table 3.13 shows that the windows unmanaged and not used for daylighting generally add to the life-cycle cost of the office module in Washington, D.C., with its 4,200 heating degree days and 1000 cooling hours. However, with constant real energy prices (part A of table 3.13), a large (90 ft^2 or 8.36 m^2) single-glazed window can be added to the south side with little or no estimated cost penalty, because estimated savings in framing costs for the large window offset its somewhat higher energy costs. With constant energy prices, single glazing is estimated to cost less than double glazing over the long run for all of the window sizes and orientations.

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[1] Note the dependency of this finding on lower first cost for the largest window size.

[2] Ibid.

[3] Ibid.

TABLE 3.10

ATLANTA, GEORGIA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
Window Area (FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1155	1159	1156	1155	1159	1156
12	1.11	1171	1180	1175	1238	1246	1241
30	2.79	1172	1189	1187	1297	1310	1302
60	5.57	1247	1283	1286	1479	1500	1486
90[c]	8.36	1097	1156	1162	1417	1442	1423
Part B (FPE[b] = 12%)							
0	0	1746	1760	1751	1746	1760	1751
12	1.11	1776	1807	1791	1835	1863	1847
30	2.79	1801	1860	1853	1907	1954	1926
60	5.57	1916	2044	2055	2119	2192	2141
90[c]	8.36	1807	2015	2038	2095	2184	2116

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.11

ATLANTA, GEORGIA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1155	1159	1156	1155	1159	1156
12	1.11	1143	1152	1150	1210	1218	1213
30	2.79	1065	1092	1096	1188	1203	1201
60	5.57	1127	1179	1191	1349	1379	1378
90[c]	8.36	999	1073	1090	1307	1342	1338
Part B (FPE[b] = 12%)							
0	0	1746	1760	1751	1746	1760	1751
12	1.11	1591	1622	1613	1650	1678	1662
30	2.79	1336	1433	1448	1439	1491	1485
60	5.57	1376	1560	1599	1544	1649	1644
90[c]	8.36	1287	1548	1606	1529	1653	1640

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) of area, due to estimated lower framing costs for the larger area.

TABLE 3.12

ATLANTA, GEORGIA, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 2950 HEATING DEGREE DAYS, 1000 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	U/D	90	8.36	Single	999	156	I[d]	< 0[c]
E-W	U/D	90	8.36	Single	1073	86	I	< 0
N	U/D	90	8.36	Single	1090	66	I	< 0
Part B (FPE[b] = 12%)								
S	U/D	90	8.36	Single	1287	459	I	< 0[c]
E-W	U/D	30	2.79	Single	1433	327	1.0	< 0
N	U/D	30	2.79	Single	1448	303	1.1	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

TABLE 3.13

WASHINGTON, D.C., COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
Window Area		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1248	1252	1249	1248	1252	1249
12	1.11	1270	1282	1282	1364	1371	1368
30	2.79	1284	1308	1313	1473	1486	1482
60	5.57	1392	1439	1452	1767	1789	1785
90[c]	8.36	1249	1320	1343	1769	1800	1795
Part B (FPE[b] = 12%)							
0	0	1846	1857	1848	1846	1857	1848
12	1.11	1887	1927	1927	1970	1993	1983
30	2.79	1939	2024	2043	2093	2138	2126
60	5.57	2119	2283	2331	2415	2494	2478
90[c]	8.36	2049	2296	2377	2450	2560	2541

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2), due to estimated lower framing costs for the larger area.

If real energy prices escalate rapidly (part B of table 3.13), the energy costs become more important relative to window acquisition costs, and single-glazed windows loose much of their cost advantage, particularly for north-facing windows. A sharp rise in energy prices also makes window placement on the south side more important economically. If the windows are not to be used for daylighting, it appears advisable to keep them small, single glazed, and oriented southward, from the standpoint of the costs included here.

Table 3.14 shows the opportunity for reducing long-run building costs through the use of windows for daylighting. For all single-glazed windows, as well as for double-glazed windows, the following pattern of changing costs in relationship to window size is revealed based on a rapid rise in energy prices: life-cycle costs tend first to fall as the window size is increased from zero to 30 ft^2 (2.79 m^2); costs then rise as the window size is increased further to 60 ft^2 (5.57 m^2); costs again fall as size is increased to 90 ft^2 (8.36 m^2). In the case of single glazing, the initial fall in window costs as window size is increased reflects both the lower acquisition cost for the windowed wall as compared with windowless wall and falling net energy costs due to savings from daylighting. In the case of double glazing, the initial fall in costs reflects the excess of energy savings from daylighting over the increase in window acquisition costs. As the window is doubled in size from 30 ft^2 to 60 ft^2 (2.79 to 5.57 m^2), the savings from daylighting are substantially less than doubled, and the increase in savings is exceeded by the increase in acquisition costs of both the single- and double-glazed windowed wall. Consequently, total life-cycle costs rise. Life-cycle costs fall slightly for single-glazed windows as the window is expanded from 60 ft^2 to 90 ft^2 (5.57 to 8.36 m^2), because of assumed savings in framing costs for the largest of the single-glazed windows examined.

Table 3.15 highlights the finding that escalating real energy prices increase the savings potential of the window, but reduce its least-cost size. The single-glazed, 30 ft^2 (2.79 m^2) window, comprising 25 percent of the south-facing exterior wall of the office, is estimated to be the most cost effective of the window options examined if energy prices rise sharply and if the window is used for daylighting. Because construction costs of the building are assumed to be lower with this window than without it, the window yields an immediate payback.

3.7 SEATTLE, WASHINGTON

Seattle has a relatively large heating load (4400 heating degree days) and a very small cooling load (100 cooling hours). The dominant heating load is reflected in table 3.16 by the desirability of a southerly orientation for windows and of double glazing for the larger north-facing windows in anticipation of rapid increases in energy prices. If they are not used for daylighting and if energy prices escalate, the windows are estimated to increase life-cycle costs, though not by a large amount.

Table 3.17 shows the impact on life-cycle costs of daylight utilization: Life-cycle costs can be lowered by using a window, particularly on the south.

TABLE 3.14

WASHINGTON, D.C., COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	Single Glazed E/W	Single Glazed N	Double Glazed, Orientation S	Double Glazed E/W	Double Glazed N
Part A (FPE[b] = 0%)							
0	0	1248	1252	1249	1248	1252	1249
12	1.11	1215	1227	1229	1306	1315	1313
30	2.79	1160	1189	1200	1339	1360	1362
60	5.57	1247	1299	1320	1599	1638	1643
90[c]	8.36	1103	1177	1200	1593	1646	1651
Part B (FPE[b] = 12%)							
0	0	1846	1857	1848	1846	1857	1848
12	1.11	1692	1735	1742	1765	1798	1791
30	2.79	1505	1607	1645	1620	1695	1702
60	5.57	1609	1792	1872	1825	1963	1981
90[c]	8.36	1535	1795	1915	1833	2017	2036

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.15

WASHINGTON, D.C., COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 4200 HEATING DEGREE DAYS, 1000 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	U/D	90	8.36	Single	1103	145	I[d]	< 0[c]
E-W	U/D	90	8.36	Single	1177	74	I	< 0
N	U/D	30	2.79	Single	1200	49	I	< 0
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Single	1505	341	I	< 0[c]
E-W	U/D	30	2.79	Single	1607	250	I	< 0
N	U/D	30	2.79	Single	1645	203	I	< 0

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

TABLE 3.16

SEATTLE, WASHINGTON, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area (FT²)	(m²)	Life-Cycle Costs in Dollars: Single Glazed, Orientation S	E/W	N	Double Glazed, Orientation S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1201	1202	1203	1201	1202	1203
12	1.11	1217	1224	1229	1287	1290	1292
30	2.79	1224	1242	1253	1347	1356	1359
60	5.57	1318	1355	1378	1540	1557	1562
90[c]	8.36	1172	1230	1266	1469	1495	1500
Part B (FPE[b] = 12%)							
0	0	1755	1761	1763	1755	1761	1763
12	1.11	1785	1811	1826	1840	1852	1858
30	2.79	1834	1897	1933	1902	1932	1944
60	5.57	2005	2133	2215	2108	2170	2188
90[c]	8.36	1938	2139	2265	2059	2150	2168

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.17

SEATTLE, WASHINGTON, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1201	1202	1203	1201	1202	1203
12	1.11	1210	1219	1224	1278	1282	1285
30	2.79	1162	1185	1204	1276	1290	1299
60	5.57	1246	1291	1328	1454	1480	1496
90[c]	8.36	1121	1186	1237	1402	1437	1455
Part B (FPE[b] = 12%)							
0	0	1755	1761	1763	1755	1761	1763
12	1.11	1668	1701	1718	1717	1732	1740
30	2.79	1521	1601	1669	1560	1609	1640
60	5.57	1625	1783	1912	1679	1772	1827
90	8.36	1568	1798	1976	1632	1755	1820

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

Single glazing is more cost effective than double glazing for southerly exposures; double glazing is cost effective for east, west, and northern exposures.

Table 3.18 shows that the least-cost window is single glazed, located on the south side, and used for daylighting. If energy prices were to remain about constant in real terms, it would pay to choose the largest size (90 ft^2) (8.36 m^2) window, due to its lower framing costs together with its daylighting benefits. Rapid energy price escalation gives a slight cost advantage to the more moderate window size (30 ft^2 or 2.79 m^2), due to higher heating costs. This least-cost window is estimated to save $234 and to pay for itself in just over a year.

3.8 INDIANAPOLIS, INDIANA

Indianapolis has a relatively heavy heating load requirement (5700 degree days) and a moderately heavy cooling load requirement (750 cooling hours).

Without daylight utilization, all of the window alternatives examined increase life-cycle costs. If future energy prices are level in constant dollars, part A of table 3.19 shows relatively small increases in costs, but if energy prices rise at a real rate of 12 percent compounded annually, part B shows that net losses may approach $700 for a large window area with a northern exposure. Single glazing is estimated to be cost effective for all windows if energy prices are constant, but double glazing is cost effective for large north-facing windows if energy prices escalate sharply.

From table 3.20, we can see the positive effect that daylight utilization has on total life-cycle costs. If energy prices rise at a rate of 12 percent per year, net savings result for all windows up to and including 30 ft^2 (2.79 m^2), and for south-facing, single-glazed windows up to and including 90 ft^2 (8.36 m^2). The larger windows facing east, west, or north may result in significant losses.

The relatively heavy heating load in this city has the effect of restricting the size of the least-cost window and of increasing the importance of double glazing for windows that do not face south. As shown by table 3.21, the least cost of the options is a single-glazed, 30 ft^2 (2.79 m^2) window on the south side, used for daylighting.

3.9 PORTLAND, MAINE

Portland, Maine has a heavy heating load requirement (7600 degree days), and a very modest cooling load requirement (250 cooling hours). Because of the heavy heating load, the use of triple glazing to minimize winter heat losses is considered as one of the options.

Part A of table 3.22 shows that even with the heavy heating load, single glazing is more cost effective than either double or triple glazing at constant real energy prices. Net losses exceed $600 for large, north-facing triple-glazed windows, $400 for large, north-facing double-glazed windows, and $200 for large, north-facing single-glazed windows.

TABLE 3.18

SEATTLE, WASHINGTON, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 4400 HEATING DEGREE DAYS, 100 COOLING HOURS

	Least-Cost Window System							
Orientation	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE[b] (%)
Part A (FPE[b] = 0%)								
S	U/D	90	8.36	Single	1121	80	I[d]	< 0 [c]
E-W	U/D	30	2.79	Single	1185	17	2.2	< 0
N	U/D	0	0		1203	0		< 0
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Single	1521	234	1.4	< 0 [c]
E-W	U/D	30	2.79	Single	1601	160	2.0	< 0
N	U/D	30	2.79	Double	1640	123	7.0	7.7

[a] "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

[b] FPE abbreviates "fuel price escalation rate."

[c] Indicates the least-cost alternative of those examined.

[d] I indicates an immediate payback due to estimated lower initial investment costs.

TABLE 3.19

INDIANAPOLIS, INDIANA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
		Orientation			Orientation		
Window Area (FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1230	1234	1233	1230	1234	1233
12	1.11	1258	1270	1273	1335	1343	1343
30	2.79	1278	1303	1312	1427	1443	1443
60	5.57	1395	1440	1459	1683	1710	1711
90[c]	8.36	1268	1333	1365	1659	1697	1700
Part B (FPE[b] = 12%)							
0	0	1832	1846	1842	1832	1846	1842
12	1.11	1898	1939	1949	1945	1975	1973
30	2.79	1979	2066	2097	2051	2108	2108
60	5.57	2206	2366	2433	2338	2434	2438
90[c]	8.36	2193	2422	2536	2346	2481	2490

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.20

INDIANAPOLIS, INDIANA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

		Life-Cycle Costs in Dollars					
		Single Glazed			Double Glazed		
Window Area		Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)							
0	0	1230	1234	1233	1230	1234	1233
12	1.11	1245	1258	1262	1320	1330	1331
30	2.79	1205	1230	1244	1344	1365	1370
60	5.57	1311	1359	1386	1584	1619	1628
90[c]	8.36	1207	1275	1314	1580	1628	1640
Part B (FPE[b] = 12%)							
0	0	1832	1846	1842	1832	1846	1842
12	1.11	1759	1805	1817	1800	1833	1838
30	2.79	1631	1718	1766	1668	1742	1759
60	5.57	1786	1955	2047	1865	1987	2020
90[c]	8.36	1788	2029	2165	1876	2044	2086

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to lower framing costs for the larger area.

TABLE 3.21

INDIANAPOLIS, INDIANA, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 5700 HEATING DEGREE DAYS, 750 COOLING HOURS

	Least-Cost Window System							
Orientation	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE[b] (%)
Part A (FPE[b] = 0%)								
S	U/D	30	2.79	Single	1205	25	1.9	< 0[c]
E-W	U/D	30	2.79	Single	1230	4	2.6	< 0
N	U/D	0	0		1233	0		
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Single	1631	201	1.6	< 0[c]
E-W	U/D	30	2.79	Single	1718	128	2.1	< 0
N	U/D	30	2.79	Double	1759	83	7.0	10.1

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Indicates the least-cost alternative of those examined.

TABLE 3.22

PORTLAND, MAINE, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

		Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
Window Area		Orientation			Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)										
0	0	1127	1133	1136	1127	1133	1136	1127	1133	1136
12	1.11	1155	1173	1186	1217	1230	1238	1242	1254	1260
30	2.79	1176	1212	1241	1291	1315	1330	1348	1368	1378
60	5.57	1286	1353	1408	1506	1548	1573	1654	1682	1696
90[c]	8.36	1177	1275	1356	1474	1532	1568	1697	1731	1748
Part B (FPE[b] = 12%)										
0	0	1725	1745	1756	1725	1745	1756	1725	1745	1756
12	1.11	1791	1855	1898	1811	1856	1886	1826	1866	1889
30	2.79	1875	1999	2104	1822	1967	2020	1916	1985	2020
60	5.57	2097	2333	2524	2099	2247	2334	2215	2314	2362
90[c]	8.36	2102	2447	2730	2075	2281	2404	2261	2379	2441

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

Part B of table 3.22 shows that if energy prices rise at a real rate of 12 percent per year, single glazing loses its cost advantage for all of the large (90 ft^2 or 8.36 m^2) windows--even those facing south. With the higher energy costs, double glazing tends to be the most cost-effective glazing type for most of the windows. Regardless of the type of glazing and the orientation, however, total life-cycle costs are estimated to be increased to some extent by windows not used for daylighting. These costs can be kept small by choosing small windows and placing them on the south side of the building.

Table 3.23 shows the life-cycle costs associated with the windows when daylight utilization is practiced. With daylight utilization and fuel price escalation small savings are estimated for some of the windows--primarily for small-to-moderate sized south-, east-, and west-facing windows, as well as for large, double-glazed windows on the south. With a high real rate of energy price escalation, double glazing appears to be the most cost-effective glazing type for most of the window sizes and orientations examined.

Table 3.24 emphasizes that with rapidly rising real energy prices, the economically efficient window is moderate in size, double glazed if south-, east-, or west-facing, and triple glazed if north-facing. The least-cost window is estimated to save $170 over the life cycle. Net savings of only $36 are estimated for the 30 ft^2 (2.79 m^2) triple-glazed window with a northern exposure. Thus even in a climate with a heavy heating load, moderately sized windows which are well designed thermally and utilized to take advantage of natural lighting may produce small reductions in life-cycle costs.

3.10 BISMARCK, NORTH DAKOTA

The last city treated, Bismarck, North Dakota, has the highest heating load requirement (8850 heating degree days, 450 cooling hours) of the cities examined. It may be contrasted with the first commercial location, Miami, where the heating load is small, but the cooling load requirement is very high.

Table 3.25 shows that without management or daylight utilization, windows cause life-cycle costs to rise, regardless of the type of glazing, size, or orientation. Part B of the table shows that when energy prices rise at a rate of 12 percent per year, net losses can be reduced by using double glazing on south-facing window and triple glazing on north-facing windows. Double and triple glazings have approximately equal effects on east- and west-facing windows.

Table 3.26 shows that with daylight utilization, most of the windows except those facing south have higher life-cycle costs than the windowless wall. To prevent costs from rising in the face of higher energy prices, it is necessary that the windows be carefully designed, sized and located. With 12 percent energy price escalations over and above inflation, triple glazing appears economically desirable for all window sizes and orientations, except for larger windows on the south for which double glazing is cost effective. Windows small-to-moderate in size are estimated to cost less than large windows for most of the cases examined; however, for southerly orientations, size is estimated to make little difference in costs, particularly if the windows are double or triple glazed.

TABLE 3.23

PORTLAND, MAINE, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITH DAYLIGHTING[a]

Window Area		Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
		Orientation			Orientation			Orientation		
(FT^2)	(m^2)	S	E/W	N	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)										
0	0	1127	1133	1136	1127	1133	1136	1127	1133	1136
12	1.11	1148	1166	1181	1206	1221	1231	1230	1244	1252
30	2.79	1117	1154	1190	1222	1251	1272	1275	1301	1317
60	5.57	1217	1287	1352	1420	1472	1508	1556	1598	1624
90[c]	8.36	1126	1228	1322	1401	1472	1522	1609	1664	1695
Part B (FPE[b] = 12%)										
0	0	1725	1745	1756	1725	1745	1756	1725	1745	1756
12	1.11	1680	1744	1795	1688	1741	1776	1701	1749	1777
30	2.79	1582	1714	1838	1555	1656	1731	1575	1665	1720
60	5.57	1739	1987	2215	1681	1864	1991	1756	1907	1996
90[c]	8.36	1751	2110	2437	1649	1897	2071	1781	1971	2080

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.24

PORTLAND, MAINE, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 7600 HEATING DEGREE DAYS, 250 COOLING HOURS

Orientation	Least-Cost Window System							
	Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE[b] (%)
Part A (FPE[b] = 0%)								
S	U/D	30	2.79	Single	1117	11	2.1	< 0[c]
E-W	U/D	0	0		1133	0		
N	U/D	0	0		1136	0		
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Double	1555	170	6.0	6.7[c]
E-W	U/D	30	2.79	Double	1656	89	7.0	9.0
N	U/D	30	2.79	Triple	1720	36	8.0	11.1

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Indicates the least-cost alternative of those examined.

TABLE 3.25

BISMARCK, NORTH DAKOTA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT AND WITHOUT DAYLIGHTING[a]

Window Area (FT^2)	(m^2)	Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
		Orientation S	E/W	N	Orientation S	E/W	N	Orientation S	E/W	N
Part A (FPE[b] = 0%)										
0	0	1102	1111	1114	1102	1111	1114	1102	1111	1114
12	1.11	1133	1157	1171	1176	1196	1206	1192	1211	1219
30	2.79	1156	1205	1238	1227	1262	1281	1262	1292	1306
60	5.57	1263	1355	1418	1391	1450	1483	1488	1533	1553
90[c]	8.36	1162	1298	1392	1329	1409	1456	1480	1533	1560
Part B (FPE[b] = 12%)										
0	0	1737	1769	1781	1737	1769	1781	1737	1769	1781
12	1.11	1818	1904	1952	1804	1876	1910	1807	1872	1900
30	2.79	1916	2088	2205	1852	1977	2041	1855	1961	2009
60	5.57	2152	2475	2697	2019	2227	2343	2067	2224	2296
90[c]	8.36	2183	2658	2988	1969	2249	2416	2064	2250	2344

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.26

BISMARCK, NORTH DAKOTA, COMMERCIAL CASE STUDY: LIFE-CYCLE COSTS FOR A WINDOW SYSTEM -- EVALUATED WITHOUT WINDOW MANAGEMENT BUT WITH DAYLIGHTING[a]

		Life-Cycle Costs in Dollars								
		Single Glazed			Double Glazed			Triple Glazed		
		Orientation			Orientation			Orientation		
Window Area (FT^2)	(m^2)	S	E/W	N	S	E/W	N	S	E/W	N
Part A (FPE[b] = 0%)										
0	0	1102	1111	1114	1102	1111	1114	1102	1111	1114
12	1.11	1125	1150	1167	1167	1188	1198	1183	1203	1211
30	2.79	1095	1148	1187	1160	1199	1223	1193	1227	1246
60	5.57	1190	1288	1360	1305	1372	1417	1393	1450	1482
90[c]	8.36	1106	1248	1351	1254	1347	1407	1391	1464	1504
Part B (FPE[b] = 12%)										
0	0	1737	1769	1781	1737	1769	1781	1737	1769	1781
12	1.11	1709	1797	1856	1694	1767	1804	1694	1763	1792
30	2.79	1624	1810	1946	1538	1674	1760	1531	1653	1719
60	5.57	1788	2131	2385	1609	1844	2001	1625	1825	1935
90[c]	8.36	1822	2319	2682	1543	1868	2081	1587	1841	1982

[a] Life-cycle costs include the present value costs of (1) purchase and installation for the 10' x 12' exterior wall of the office, including the spandrel panel and window, mullions, and interior curtain wall; (2) annual cleaning costs over 25 years; (3) annual insurance costs over 25 years; and (4) annual energy costs for heating, cooling, and lighting the office module over 25 years, with (5) all costs adjusted for tax deductible expenses.

[b] FPE abbreviates "fuel price escalation rate."

[c] Life-cycle costs are in some cases lower for 90 ft^2 (8.36 m^2) of window area than for 60 ft^2 (5.57 m^2) due to estimated lower framing costs for the larger area.

TABLE 3.27

BISMARCK, NORTH DAKOTA, COMMERCIAL CASE STUDY: LEAST-COST WINDOW SYSTEMS -- 8850 HEATING DEGREE DAYS, 450 COOLING HOURS

Orientation	Least-Cost Window System: Mode of Use[a]	Size (ft^2)	Size (m^2)	Glazing Type	Total Life Cycle Cost ($)	Net Life Cycle Saving ($)	Years To Payback	Minimum FPE (%)
Part A (FPE[b] = 0%)								
S	U/D	30	2.79	Single	1095	6	2.6	< 0 [c]
E-W	U/D	0	0		1111	0		
N	U/D	0	0		1114	0		
Part B (FPE[b] = 12%)								
S	U/D	30	2.79	Triple	1531	205	6.0	4.9 [c]
E-W	U/D	30	2.79	Triple	1543	116	7.0	8.2
N	U/D	30	2.79	Triple	1719	62	8.2	11.1

a "M" indicates that the window system is managed, that is, equipped with thermal shutters and venetian blinds, and that the thermostat is adjusted at night.
"D" indicates that the window system is used for daylighting.
"U" indicates that the window system is left bare and the thermostat is not adjusted.
"N" indicates that the window system is not used for daylighting and lighting is accomplished by electricity.

b FPE abbreviates "fuel price escalation rate."

c Indicates the least-cost alternative of those examined.

Table 3.27 shows that of the window choices examined for the office in Bismarck, the economically optimal is estimated to be 30 ft^2 (2.79 m^2) in size, south facing, and used for daylighting. For constant real energy prices, this window results in approximately a break-even condition if it is single glazed. But with the greater savings in lighting costs brought about by rapidly rising energy prices, this window results in present value savings of about $200 if it is triple glazed.

4. SUMMARY AND GENERAL CONCLUSIONS

Using a case study approach, this report has assessed the economic performance of conventional type windows under selected conditions in two typical spaces: a kitchen/family room in a brick rambler and an office module in a multi-story commercial building. Life-cycle costs (in present value dollars) over 25 years have been calculated based on (1) window sizes ranging from 0 to 60 ft^2 for the house and 0 to 90 ft^2 for the office; (2) orientations including south, east/west and north; (3) single, double, and, for northern locations, triple glazing; (4) a range of future energy prices, (5) locations in nine U.S. cities covering five heating zones and four cooling zones, and (6) alternative modes of window use, including (a) windows left bare (unmanaged) and not used for daylighting, (b) windows equipped with thermal shutters and venetian blinds, room thermostat adjustment (managed), and daylighting, and (c) windows unmanaged but used for daylighting.

Included in the costs are (1) purchase and installation costs of the windows in excess of the costs of a solid wall, (2) the additional costs of cleaning, recaulking, and repainting the windows on a regular basis, (3) energy costs for heating, cooling and lighting the space, and, for the commercial building, (4) tax effects. Not included in the life cycle costs are energy effects associated with natural ventilation, safety effects, psychological effects, and aesthetic effects. Also not included are those passive solar energy benefits and costs of the south-facing window that are dependent on special absorber materials and storage mass; however, passive effects estimated for the buildings as designed are included.

Changes in total life-cycle costs of the two building spaces attributable to the selected window alternatives have been assessed, and the least-cost options of those considered have been identified for each space, based on geographical location, directional orientation, and future energy prices. For each case study, conclusions have been drawn as to the least-cost window option. Further, the life-cycle data have been provided for each of the window sizes, orientations, and glazing options examined to allow the reader to interpret the case study results in light of the particular circumstances of his or her own building space and window needs. The heating and cooling zones of each city studied are indicated to assist the reader in extending the results to other regional locations.

To serve as a reference and overview, the following summary of the case study data and general conclusions are presented. It is important that the reader interpreting these data and conclusions keep in mind that there are many window designs, accessories, framing techniques, and alternative wall constructions other than those examined here. These other alternatives will likely have different costs and performances associated with them, and, hence, will differ in their cost effectiveness. These case results, however, may provide insight as to how window decisions may translate into long-term costs of owning and operating a building.

4.1 RESIDENTIAL WINDOW SUMMARY

Key results for the selected residential window systems are summarized in two tables 4.1 and 4.2. Table 4.1 shows the cost-effective window choices for each city as a function of the future rate of change in energy prices and the way the window is accessorized and used. Table 4.2 indicates the least-cost glazing for different window sizes and orientations for each city.

Looking more closely at table 4.1, one finds in column (1) the city and, in parenthesis, two numbers keyed to figure 1.1 giving the heating and cooling zones, respectively, for that city. Column (2) indicates two alternative projected rates of increase in gas and electricity prices--a zero rate in constant dollar terms, (i.e., a rate just equal to the rate of general price inflation), and a 12 percent rate compounded annually (i.e., a rate 12 percent faster than the rate of general price inflation). These two rates are intended to "bracket" the possible increase in these energy prices over the long run. Columns (3) through (7) indicate the least cost of those options examined for windows that are unmanaged and not used for daylighting. Columns (8) through (11) give the counterpart results for windows that are managed and used for daylighting.

The least-cost options for the "unmanaged, not used for daylighting" case (columns (3) through (7)) are given, even though they are in all cases inferior to the "managed, used for daylighting" case, because there are many situations in which windows cannot be successfully managed and for which effective daylighting opportunities are limited. The building owner or operator may find the information in columns (3) through (7) useful in reducing losses in this less-than-optimal case.[1]

Column (3) indicates the window size, given the type of window considered that will result in the lowest life-cycle costs of the room assuming the window is unmanaged and not used for daylighting. It may be seen that this least-cost size is in every case zero, that is, costs are estimated to be lower without the window than with it, given the assumptions of these case studies. Column (4) gives the next best window size in terms of costs, which is in every case 12 ft^2 (1.11 m^2), the smallest size examined.

Column (5) shows that the least-cost direction for orienting the windowed wall is dependent on the geographical region. In moderate to cold climates, orienting windows to the south tends to lower energy costs by taking maximum advantage of the passive solar heat gain that can be captured through the windows on winter days. Thus, the least-cost orientation for the windowed wall is shown to be south for Atlanta, Washinton, D.C., Seattle, Indianapolis, Portland, and Bismarck. In warm climate zones where it is desirable to minimize passive solar

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[1] Similarly, there often may be compelling reasons to locate windows with orientations other than those designated here as least cost, such as reasons of design, code requirements, or view. In that event, the reader may wish to refer back to the relevant case study chapter and the results for the desired orientation.

TABLE 4.1 Summary: Cost-Effective Choices for the Selected Residential Window Systems[a]

City (Heating and Cooling Zones)[b] (1)	Real Fuel Price Escalation Rate (%)[c] (2)	Unmanaged, Not Used for Daylighting						Managed, Used for Daylighting					
		Least-Cost Window Size (3)	Least-Cost Window Size Greater Than 0 (4)		Least-Cost Orientation (5)	Glazing for Least-Cost Window Greater Than 0 (6)	Impact on LCC[d] ($) (7)	Least-Cost Window Size (8)		Least-Cost Orientation (9)	Glazing for Least-Cost Window (10)	Impact on LCC[d] ($) (11)
			(ft^2)	(m^2)				(ft^2)	(m^2)			
Miami, Florida (1,1)	0	0	12	1.11	North	Single[e]	115	12	1.11	North	Single[d]	- 149
	12	0	12	1.11	North	Double[e]	271	18	1.67	North	Single[d]	-1000
San Antonio, Texas (1,1)	0	0	12	1.11	North	Single[e]	88	12	1.11	North	Single[d]	- 145
	12	0	12	1.11	North	Single[e]	185	18	1.67	North	Single[d]	- 986
Los Angeles, California (1/2, 5)	0	0	12	1.11	North	Single[e]	59[h]	12	1.11	North	Single	- 125
	12	0	12	1.11	North	Single[e]	35	30	2.79	North	Single	-1051
Atlanta, Georgia (2,3)	0	0	12	1.11	South	Single[e]	60	12	1.11	South	Single[d]	- 147
	12	0	12	1.11	South	Single[e]	80	18	1.67	South	Single[d]	- 972
Washington, D.C. (3,4)	0	0	12	1.11	South	Single[e]	89	12	1.11	South	Single[d]	- 89
	12	0	12	1.11	South	Double[e]	130	18	1.67	South	Single[d]	- 733
Seattle, Washington (3,5)	0	0	12	1.11	South	Single[e]	97	12	1.11	South	Single[d]	- 39
	12	0	12	1.11	South	Double[e]	146	18	1.67	South	Double[d]	- 600
Indianapolis, Indiana (3,4)	0	0	12	1.11	South	Single[e]	104	12	1.11	South	Single[d]	- 62
	12	0	12	1.11	South	Double[e]	159	18	1.67	South	Double[d]	- 660
Portland, Maine (4,5)	0	0	12	1.11	South	Double[e]	103	12	1.11	South	Single[e]	- 29
	12	0	12	1.11	South	Triple[g]	136	18	1.67	South	Triple[e]	- 489
Bismarck, North Dakota (5,5)	0	0	12	1.11	South	Double[f]	108	12	1.11	South	Single[e]	- 23
	12	0	12	1.11	South	Triple[g]	147	18	1.67	South	Triple[e]	- 492

[a] Summarized from the tables in section 2, and dependent on the assumptions given in table 1.1

[b] Numbers in parenthesis refer to the heating and cooling zones, respectively, as given by the heating and cooling zone map in figure 1.1.

[c] Escalation rates in excess of general price inflation.

[d] The difference in present value dollar costs with the designated windows as compared with the costs with the designated solid wall section, over a 25 year life cycle. Positive figures indicate the amount that windows add to life-cycle costs; negative figures, the amount that windows save.

[e] There is less than a 5 percent difference between the costs of single and double glazing; the least-cost choice is listed first.

[f] There is less than a 5 percent difference between the costs of single, double, and triple glazing; the least-cost choice is listed first.

[g] There is less than a 5 percent difference between the costs of double and triple glazing; the least-cost choice is listed first.

[h] The results for Los Angeles are somewhat unique among those cities examined. In Los Angeles, climate conditions are such that the windowed room has lower energy costs than the windowless room due to beneficial conduction losses and gains through the window (not taking into account natural ventilation effects). However, the lower energy costs are not sufficient in the case examined to overcome the higher acquisition and maintenance costs of the window. With higher energy price escalation, the energy savings from the window are raised, thereby offsetting more of the window acquisition and maintenance costs and reducing the amount of increase in total life-cycle costs as shown in column (7).

TABLE 4.2 Summary: Cost-Effective Glazing for the Selected Residential Windows

Cities	Fuel Price Escalation Rate (%)	South Orientation			East/West Orientation			North Orientation		
		12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)	12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)	12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)
		Unmanaged, Not Used for Daylighting								
Miami, Florida	0	S/D	S	S	S/D	S/D	S/D	S/D	S/D	S
	12	D/S	D/S	D/S	D/S	D/S	D/S	D/S	D/S	D/S
San Antonio, Texas	0	S/D	S/D	S	S/D	S/D	S/D	S/D	S/D	S/D
	12	S/D	S/D	D/S	D/S	D/S	D/S	S/D	D/S	D/S
Los Angeles, California	0	S/D	S	S	S/D	S	S	S/D	S	S
	12	S/D	S/D	S	S/D	S/D	S	S/D	S/D	S
Atlanta, Georgia	0	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S	S/D
	12	S/D	D/S	D/S	D/S	D/S	D	D/S	S/D	D
Washington, D.C.	0	S/D	S/D	S/D	S/D	S/D	S/D	S,D	D/S	D/S
	12	D/S	D/S	D	D/S	D/S	D	D/S	D/S	D
Seattle, Washington	0	S/D	S/D	S/D	S/D	D/S	D/S	S/D	D/S	D/S
	12	D/S	D	D	D/S	D	D	D/S	D	D
Indianapolis, Indiana	0	S/D	S/D	D/S	D/S	D/S	D/S	D/S	D/S	D
	12	D/S	D	D	D/S	D	D	D/S	D	D
Portland, Maine	0	D/T/S	D/T/S	D,T	D,T/S	T/D	T/D	D,T/S	T/D	T/D
	12	T/D	T/D	T/D	T/D	T/D	T	T/D	D/T	T
Bismarck, North Dakota	0	T,D/S	T/D	T/D	T/D/S	T/D	T/D	T/D	T/D	T/D
	12	T/D	T/D	T	T/D	T/D	T	T/D	T/D	T
		Managed, Used for Daylighting								
Miami, Florida	0	S/D	S	S	S/D	S	S	S/D	S	S
	12	S/D	S/D	S/D	S/D	D/S	D/S	S/D	S/D	S/D
San Antonio, Texas	0	S/D	S	S	S/D	S	S	S/D	S	S
	12	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D
Los Angeles, California	0	S	S	S	S	S	S	S	S	S
	12	S/D	S	S	S/D	S	S	S/D	S	S
Atlanta, Georgia	0	S/D	S	S	S/D	S	S	S/D	S	S
	12	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D
Washington, D.C.	0	S/D	S	S	S/D	S/D	S	S/D	S/D	S/D
	12	S/D	S/D	S/D	S/D	D/S	D/S	D/S	D/S	D
Seattle, Washington	0	S/D	S/D	S/D	S/D	S/D	S/D	S/D	D/S	D/S
	12	D/S	D	D	D/S	D	D	D/S	D	D
Indianapolis, Indiana	0	S/D	S	S	S/D	S/D	S/D	S/D	S/D	S/D
	12	D/S	D/S	T/D	D/S	D/S	D	D/S	D	D
Portland, Maine	0	S/D/T	S/D/T	S/D	S/D/T	S/D/T	D/S/T	D/T/S	D/T/S	D/T
	12	T/D/S	T/D/S	T/D	T/D/S	T/D	T/D	T/D	T/D	T
Bismarck, North Dakota	0	S/D/T	S/D/T	S/D	D/S/T	D/S/T	D/T/S	D/T/S	D/T/S	T/D
	12	T/D/S	T/D	T/D	T/D	T/D	T/D	T/D	T/D	T

Key:

S = Single-glazed windows are lower in life-cycle costs than multi-glazed windows.

D = Double-glazed windows are lower in life-cycle costs than single- or triple-glazed windows.

T = Triple-glazed windows are lower in life-cycle costs than single- or double-glazed windows.

D/S, S/D, D/T, T/D, S/D/T = First listed is slightly lower in cost, but the difference is less than 5 percent.

S/D/T = No difference at all in life-cycle costs of alternatives separated by commas.

heat gain through windows, it pays to orient windows to the north. Thus, the least-cost orientation is shown to be north for Miami, San Antonio, and Los Angeles. Easterly and westerly orientations tend not to be recommended for regions with large heating loads because they allow less solar heat gain in winter than southerly orientations. They tend not to be recommended for regions with large cooling loads because they are difficult to shade against the summer sun and, hence, result in larger heat gains in summer.

Column (6) gives the least-cost glazing for the windows of the size and orientation designated in columns (4) and (5). The least-cost choice of glazing is shown to be sensitive to the rate of fuel price escalation designated in column (2). In Washington, D.C., for example, single glazing is slightly more economically efficient for the 12 ft^2 south-facing, bare window if energy prices remain about level in constant dollars; double glazing is slightly more efficient for this window if prices rise at a rate 12 percent faster than general price inflation. If energy prices do not escalate rapidly, single glazing is recommended for the 12 ft^2 (1.11 m^2) window with the designated orientation for all but the two coldest locations, Portland and Bismarck, where double glazing is recommended. If energy prices do escalate rapidly, double glazing is recommended for the designated window in Washington, D.C., Seattle, and Indianapolis, due to their significant heating loads, and in Miami, due to its sizeable cooling load. Triple glazing is estimated to be cost effective for Portland and Bismarck.[1]

Column (7) gives the amount, in present value dollars, which the designated window system is estimated to add to the total life-cycle costs of the kitchen/family room over the 25 years.

These dollar figures are the difference between the construction, maintenance, repair, replacement, and energy costs of the room with the designated window system as compared to the room without any windows. In every case where it is unmanaged and not used for daylighting, the window system increases the life-cycle costs of the room. With the exception of Los Angeles, the costs associated with the window are greater the higher the escalation in energy prices. This is not the case for Los Angeles because a small energy saving from the window is realized there, which is enhanced by higher energy prices. The energy saving, however, is insufficient to offset the higher nonenergy costs of the window, and net losses remain.

Looking now at the estimated least-cost results for the designated managed windows used for daylighting, given in columns (8) through (11) of table 4.1, one finds that in every city it is more economical to have the designated window system than not to have a window. Column (8) shows that if real energy

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[1] Note that these are not necessarily the least-cost glazing options for other window sizes and orientations. (See table 4.2 for least-cost glazings for other window sizes and orientations.) Also note (as indicated by the table footnotes) that in these particular cases there is little difference in life-cycle costs among the glazing options.

prices remain constant, the least-cost window is 12 ft^2--the smallest of those examined--for all of the cities. But if energy prices rise rapidly, a somewhat larger window providing more benefits in daylighting is estimated to be warranted an economic grounds: 18 ft^2 (1.67 m^2) for all locations except Los Angeles, and 30 ft^2 (2.79 m^2) for Los Angeles.

These windows are estimated to be cost effective when managed and used for daylighting, because the estimated net energy savings outweigh the estimated costs for purchase, installation, maintenance, and repair. The venetian blinds and thermal shutters reduce the undesirable heat gains and losses to low levels; the designated orientation enhances passive solar gain where heating loads are dominant and reduces it where cooling loads are dominant; the savings in electric lighting costs and related reduced cooling costs more than offset remaining increased heating costs. The least-cost window size increases with higher energy price escalation, because in the relevant size range, the savings in electric lighting costs increase more with larger window size than the costs of the negative heat gains and losses.[1]

Column (9) shows no change in the least-cost orientation due to management and daylighting. A southerly orientation continues to be recommended for regions with significant heating loads, and a northerly orientation for regions where cooling loads are dominant.

As shown by column (10) the use of window accessories influences the preferred type of glazing. With thermal shutters, single glazing is more often recommended than it was for the bare windows. This is because the thermal shutters provide a partial substitute for multi-glazing and reduce its impact on energy costs. When thermal shutters are used, multi-glazing is cost effective for the designated window systems only if energy price escalation is rapid and if heating loads are large.[2] Thus, it pays to use double glazing on the 18 ft^2 (1.67 m^2) south-facing window in Seattle and Indianapolis, and triple glazing in Portland and Bismarck--in addition to thermal shutters--if energy prices escalate at a rate of 12 percent.[3]

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[1] Note that the case examples assume electric lighting and electric cooling priced at $0.03/kWh in the base year and gas heating priced at $0.30/therm in the base year, with both electricity and gas prices escalating thereafter within the bounds of zero and 12 percent real rates compounded annually. The assumption of different energy sources for lighting, cooling, and heating, with different current and/or future price relationships would change the economic tradeoffs and, hence, the least-cost window size.

[2] Again, the reader is reminded that these results apply only to the window size and orientation designated in table 4.1, multi-glazing tends to be cost effective for larger sized windows and/or for those windows with less favorable orientations.

[3] The differences in the cost effectiveness of the alternative glazings is, however, small in these particular cases.

Column (11) shows the estimated dollar savings (indicated by a minus sign as a reduction in life-cycle costs) attributable to the window systems over the 25 year life cycle. The savings range from small to large depending on the climatic region and the rate of escalation in energy prices. Potential savings from the designated window systems are greatest in the warmer climate regions, i.e., Los Angeles, Miami, San Antonio, and Atlanta, where the benefits of daylighting can be realized with less of a penalty in undesirable heat losses. Estimated net present value savings from the optimal window system are close to $1000 in each of these four cities when energy prices are assumed to escalate at a real rate of 12 percent.

Table 4.2 summarizes the case study findings regarding the optimal type of glazing. In this table, the recommended type of glazing--single (S), double (D), or triple (T)--is indicated for three of the window sizes examined--12 ft^2 (1.11 m^2), 30 ft^2 (2.79 m^2) and 60 ft^2 (5.57 m^2)--for four orientations--south, east/west, and north--and for the two real rates of energy price escalation--zero and 12 percent. In a number of cases, more than one type of glazing is indicated for a given case, e.g., S/D. This is done whenever there is less than a five percent difference between the alternatives, but the glazing type with the lowest life-cycle cost is given first. For example, with constant energy prices, single glazing (S) is designated the least-cost choice for 12 ft^2 (1.11 m^2) south-facing windows in Indianapolis, but double-glazed windows (D) perform almost as well.

Looking first at the upper part of table 4.2 at the results for unmanaged windows not used for daylighting, we find that when energy prices escalate rapidly in real terms, multi-glazing is about as cost effective or more cost effective than single glazing in most cases. The only exception for which single glazing is significantly more cost effective is for large windows in Los Angeles. Where multi-glazing is recommended, double glazing is most cost effective in all cases except Portland and Bismarck, where triple glazing tends to be somewhat more cost effective over the life-cycle.

Even if energy prices were to remain about constant in real terms, multi-glazing is estimated to be the most cost effective for all windows in Portland and Bismarck, and about as cost effective as single glazing for many of the other applications.

Looking now at the lower part of table 4.2 at the results for the designated managed windows that are used for daylighting, we can see that multiple-glazing appears less often the most cost-effective choice for managed than for unmanaged windows due to the substitution effect of thermal shutters. However, if energy prices rise rapidly in real terms, multi-glazing is estimated to be cost effective for all of the window sizes and orientations considered for the colder regions as represented by Seattle (double glazing preferred), Indianapolis (double glazing preferred), Portland (triple glazing preferred) and Bismarck (triple glazing preferred). Multi-glazing is also indicated for certain window sizes and orientations in several of the more moderate climate regions. For example, with rapid energy price escalation, double glazing--in addition to thermal shutters--is preferred for north-facing managed windows in Washington, D.C. Furthermore, double glazing is estimated to be as cost effective as single glazing for the window applications in Miami, San Antonio, and Atlanta, if energy prices rise rapidly. Note, however, that in most of the cases the difference between the glazing alternatives is relatively small.

4.2 COMMERCIAL WINDOWS SUMMARY

Tables 4.3 and 4.4 summarize key findings of the nine case studies of selected office window systems. Table 4.3, the comercial building counterpart to table 4.1, identifies the cost-effective window size, orientation, and glazing type of the alternatives considered. It also gives the estimated change in total life-cycle costs attributable to the identified window system. Columns 3-7 pertain to unmanaged windows not used for daylighting, and columns 8-11, to unmanaged windows used for daylighting.

Column (1) of table 4.3 lists the nine cities and their heating and cooling zones, keyed to Figure 1.1. Column (2) designates the assumed rate of escalation in the prices of natural gas and electricity upon which the results in the corresponding rows are based. Because future energy prices are critical to the long-run economic performance of windows, but highly uncertain in amount, the results are shown based on two rates of energy price escalation: a constant real rate and a 12 percent per annum real rate.

Looking first at the part of table 4.3 which applies to windows unmanaged and not used for daylighting, we can see from column (3) that in 14 of the 18 cases considered, it is estimated to be cheaper not to have the specified windows in the office. The exceptions are in Los Angeles, where the climate conditions cause heating and cooling costs to be lower with a window than without it, and in Atlanta and Seattle, only if energy prices remain constant in relative terms and if the construction costs are lowered by using the largest window (see Appendix B for commercial construction costs.)

Column (4) shows that if windows are nevertheless to be used, the least-cost size--with the Los Angeles exception--is the smallest size (12 ft^2) (1.11 m^2), if energy prices rise rapidly. In the cities with moderate climates, the largest window walls, with their estimated lower framing costs, are shown to be the least-cost size, but only if energy prices remain about constant relative to other prices.[1]

Column (5) shows that the least-cost orientations for windows in the commercial building, like those in the residential building, depend on the climate. In moderate-to-cold climates, orienting windows to the south tends to lower energy costs by taking maximum advantage of the solar heat gain that can be captured

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[1] Note that the least-cost size is predicated on the orientation and glazing choices designated in columns (5) and (6).

TABLE 4.3 Summary: Cost-Effective Choices for the Selected Commercial Window Systems[a]

City (Heating and Cooling Zones)[b] (1)	Real Fuel Price Escalation Rate (%) (2)	Unmanaged, Not Used for Daylighting							Unmanaged, Used for Daylighting				
		Least-Cost Window Size (ft²) (3)	(m²)	Least-Cost Window Size Greater Than 0 (ft²) (4)	(m²)	Least-Cost Orientation (5)	Glazing for Least-Cost Window Greater Than 0 (6)	Impact on LCC[d] ($) (7)	Least-Cost Window Size (ft²) (8)	(m²)	Least-Cost Orientation (9)	Glazing for Least-Cost Window (10)	Impac[t] on LCC[d] ($) (11)
Miami, Florida (1,1)	0	0	0	90	8.36	North	Single	15	90	8.36	North	Single	- 110
	12	0	0	12	1.11	North	Single/Double[e]	71	30	2.79	North	Single	- 396
San Antonio, Texas (1,1)	0	0	0	12	1.11	North	Single	26	90	8.36	South	Single	- 85
	12	0	0	12	1.11	North	Single/Double[e]	60	30	2.79	South	Single	- 366
Los Angeles, California (1/2, 5)	0	90	8.36	90	8.36	South	Single	-87	90	8.36	South	Single	- 184
	12	90	8.36	90	8.36	South	Single	-33	90	8.36	South	Single	- 575
Atlanta, Georgia (2,3)	0	90	8.36	90	8.36	South	Single	-58	90	8.36	South	Single	- 156
	12	0	0	12	1.11	South	Single/Double[e]	30	90	8.36	South	Single	- 458
Washington, D.C. (3,4)	0	0	0	90	8.36	South	Single	01	90	8.36	South	Single	- 145
	12	0	0	12	1.11	South	Single/Double[e]	41	30	2.79	South	Single	- 341
Seattle, Washington (3,5)	0	90	8.36	90	8.36	South	Single	-29	90	8.36	South	Single	- 80
	12	0	0	12	1.11	South	Single/Double[e]	30	30	2.79	South	Single/ Double[e]	- 234
Indianapolis, Indiana (3,4)	0	0	0	12	1.11	South	Single	28	30	2.79	South	Single	- 25
	12	0	0	12	1.11	South	Single/Double[e]	66	30	2.79	South	Single/ Double[e]	- 200
Portland, Maine (4,5)	0	0	0	12	1.11	South	Single	28	30	2.79	South	Single	- 10
	12	0	0	12	1.11	South	Single/Double/ Triple[f]	66	30	2.79	South	Double/ Triple/ Single[f]	- 170
Bismarck, North Dakota (5,5)	0	0	0	12	1.11	South	Single/Double[e]	31	30	2.79	South	Single	- 7
	12	0	0	12	1.11	South	Double/Triple/ Single[f]	67	30	2.79	South	Triple/ Double[g]	- 206

[a] Summarized from the tables in section 3, and based on the assumptions given in table 1.1.

[b] Numbers in parenthesis refer to the heating and cooling zones, respectively, as given by the heating and cooling zone map in figure 1.1.

[c] Escalation rates in excess of general price inflation.

[d] The difference between the total present value building costs when the designated window system is used as compared with the costs when the designated opaque curtain wall is used, taken over a 25 year life cycle. Positive figures indicate the amount that windows add to life-cycle costs; negative figures, the amount that windows save.

[e] There is less than a 5 percent difference between the costs of single and double glazing; the least-cost choice is listed first.

[f] There is less than a 5 percent difference between the costs of single, double, and triple glazing; the least-cost choice is listed first.

[g] There is less than a 5 percent difference between the costs of double and triple glazing; the least-cost choice is listed first.

TABLE 4.4 Summary: Cost-Effective Glazing for the Selected Commercial Windows

Unmanaged, But Used for Daylighting

Cities	Real Fuel Price Escalation Rate (%)	South				East/West				North			
		12 ft^2	30 ft^2	60 ft^2	90 ft^2	12 ft^2	30 ft^2	60 ft^2	90 ft^2	12 ft^2	30 ft^2	60 ft^2	90 ft^2
Miami,	0	S	S	S	S	S	S	S	S	S	S	S	S
Florida	12	S/D	S	S	S	S/D	S	S	S	S/D	S	S	S
San Antonio,	0	S	S	S	S	S	S	S	S	S	S	S	S
Texas	12	S/D	S	S	S	S/D	S	S	S	S/D	S	S	S
Los Angeles,	0	S	S	S	S	S	S	S	S	S	S	S	S
California	12	S	S	S	S	S/D	S	S	S	S/D	S	S	S
Atlanta,	0	S	S	S	S	S	S	S	S	S	S	S	S
Georgia	12	S/D	S	S	S	S/D	S/D	S	S	S/D	S/D	S/D	S/D
Washington,	0	S	S	S	S	S	S	S	S	S	S	S	S
D.C.	12	S/D	S	S	S	S/D	S	S	S	S/D	S/D	S	S
Seattle,	0	S	S	S	S	S/D	S	S	S	S/D	S	S	S
Washington	12	S/D	S/D	S/D	S/D	S/D	S/D	D/S	D/S	S/D	D/S	D/S	D
Indianapolis,	0	S	S	S	S	S	S	S	S	S	S	S	S
Indiana	12	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D	S/D	D/S	D/S	D/S
Portland,	0	S/D	S	S	S	S/D	S	S	S	S/D	S	S	S
Maine	12	S/D/T	D/T/S	D/S/T	D/S	D/S/T	D/T/S	D/T	D/T	D/T/S	T/D	D/T	D/T
Bismarck,	0	S/D/T	S	S	S	S/D/T	S/D	S	S	S/D/T	S/D/T	S/D	S/D
North Dakota	12	D,T/S	T/D	D/T	D/T	T/D/S	T/D	T/D	T/D	T/D/S	T/D	T/D	T/D

Key: S = Single-glazed windows are lower in life-cycle costs than multi-glazed windows.

D = Double-glazed windows are lower in life-cycle costs than single- or triple-glazed windows.

T = Triple-glazed windows are lower in life-cycle costs than single- or double-glazed windows.

S/D, D/S, D/T, T/D, S/D/T = First listed is slightly lower in life-cycle cost, but the difference is less than 5 percent.

S,D,T = No difference at all in life-cycle costs of alternatives separated by commas.

through the windows on winter days.[1] Hence, the least-cost orientation for the windowed wall is south for Washington, D.C., Atlanta, Seattle, Indianapolis, Portland, Bismarck, and Los Angeles. In the warmer climates it pays to orient the windows to the north to avoid undesirable solar heat gain. Thus, the least-cost orientation is shown to be north for Miami and San Antonio.

Easterly and westerly orientations tend to increase costs if heating loads are large, because they allow less solar heat gain in winter. They tend to increase costs if cooling loads are large, because they are difficult to shade against the summer sun and often result in undesirable summer heat gains.

Column (6) presents the least-cost type of glazing for the window size identified in column (4). The alternatives considered are single, double, and triple glazing. With constant real energy prices, single glazing is estimated to be the cost-effective choice for all of the cases considered, except for Bismarck for which there is no significant life-cycle cost difference between single and double glazing. With 12 percent real price escalation, single and double glazing are estimated to be about equal in cost effectiveness for all of the windows except those in Los Angeles. Additionally, triple glazing is cost effective in Portland and Bismarck.

The dollar estimates presented in column (7) are the differences between the total present value cost of construction, maintenance, repair, insurance, replacement, and energy, adjusted for income tax effects, of the office module with the designated window systems and the total cost without any window. In all of the cities except Los Angeles, the windows when not used for daylighting are estimated to add somewhat to the life-cycle costs of the module if energy prices increase rapidly. The higher the escalation in energy prices, the greater the increase in cost.

The second part of table 4.3 gives the results for unmanaged windows used for daylighting. We can see from column (8) that when daylighting is effectively used, it is more economical in all of the cities to have the designated window system than to have a windowless module. If energy prices remain constant in real terms, the estimated cost-effective window is the largest examined (90 ft^2) for Washington, D.C., Miami, San Antonio, Los Angeles, Atlanta, and Seattle. In Indianapolis, Portland, and Bismarck, the estimated cost-effective size is the moderately sized window (30 ft^2) (2.79 m^2). With rapidly rising real energy prices, the moderately sized window is estimated to be the cost-effective choice for all of the cities except Los Angeles and Atlanta, for which the largest size is estimated to be cost effective.[2]

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[1] Note the earlier caveat that this analysis does not address possible problems in distributing the available solar heat gain within the office module.

[2] Note the earlier caveat that this finding is based on the assumption of a lower first cost for the 90 ft^2 window wall than for other sizes.

Column (9), like column (5), indicates an advantage to locating windows on the south side of the building if heating loads are signficant and on the north size if cooling loads predominate.

Column (10), like column (6), shows single glazing to be the least-cost glazing choice in most cases, with the primary exception of windows in Portland and Bismarck under conditions of rapdily rising energy prices.[1]

Column (11) shows that the reductions in total life cycle costs (i.e., net savings) attributable to the windows when they are effectively used for daylighting range from small to large, depending on climate and the escalation in energy prices. Potential net savings are greatest in the mild-to-moderate climate regions, i.e., Los Angeles, Miami, San Antonio, and Atlanta. For example, net present value savings attributable to the designated least-cost window system are estimated at nearly $600 in Los Angeles if energy prices escalate at a rate of 12 percent. In contrast, net savings are estimated to be close to $200 in Portland and Bismarck.

Table 4.4 focuses on the least-cost choice of glazing for the selected office windows. Because daylighting without management has little effect on the choice of glazing, the results are given for only one of the two modes of commercial window use considered: unmanaged, used for daylighting. Where there is less than a 5 percent difference in the cost-effectiveness of glazing alternatives, all alternatives are given in order of their cost effectiveness.

For most of the designated window systems in Miami, San Antonio, Los Angeles, Atlanta, and Washington, single-glazing is estimated to be the cost-effective choice, although double glazing appears about equally cost effective for some of the smaller window sizes and for some of the north-facing windows. Double or triple glazing tends to be cost effective for the colder locations if energy prices escalate rapidly.

4.3 GENERAL CONCLUSIONS

The results of thse 18 case studies have a number of implications for cost-effective window selection and use. In broad terms, the results have demonstrated for representative window systems and buildings that long-term costs can be dramatically increased or decreased, or left largely unaffected, depending on the design, size, orientation, accessories, and use of windows in houses and office buildings. More specifically, the following general conclusions can be drawn:

(1) By providing daylighting to reduce electric lighting costs, windows can be a source of long-run energy savings and dollar savings.

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[1] The reader is again reminded that these results apply only to the window of designated size and orientation; multi-glazing tends to be cost effective in many cases for larger windows and/or for windows with less favorable orientations.

(2) The use of window accessories, such as thermal shutters and venetian blinds can significantly reduce undesirable heat gains and losses and may greatly improve the economic performance of windows, depending on the relative costs of purchasing and installing the accessories versus purchasing energy to condition the space. Based on the case studies, thermal shutters appear more likely to be cost effective for residential use, with a relatively low purchase cost and installation by the homeowner, than for commerical use, for which costs may be higher.

(3) In moderate-to-cold climates where the heating load is of prime concern, it pays to orient windows to the south, other things being equal.

(4) In warm climates where the cooling load is of prime concern, it pays to orient windows to the north, other things being equal.

(5) With energy prices rising substantially faster than the general rate of price inflation, multiple glazing will tend to be cost-effective for residential windows such as those in the illustrative brick rambler in locations with more than about 4,400 heating degree days (see fig. 1.1), regardless of their orientation and whether or not they are equipped with shutters.

(6) With rapidly rising energy prices, double glazing may be cost effective for many unmanaged residential windows like those considered here, as well as for managed residential windows facing north, in locations with as few as 2,000 heating degree days (see fig. 1.1).

(7) Double glazing may also be cost effective for residential windows in very warm climates, such as Florida, to reduce cooling loads.

(8) Multiple glazing tends to be more cost effective when used for windows not equipped with thermal shutters, and vice versa, due to substitution effects between the two.

(9) For many applications--particularly for managed windows--the higher first cost of multiple glazing may more-or-less offset its energy savings, resulting in a breakeven situation whereby the thermal performance of the building can be upgraded with little or no increase in total long-run costs.

(10) Single glazing may be cost effective for many commercial building applications, except those in very cold climates.

(11) Daylighting benefits tend to increase at a decreasing rate and may eventually reach a "saturation point" as window size is expanded. The declining incremental benefits from daylighting, together with a growing

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[1] This conclusion applies specifically to conventional windows without special passive solar features for thermal storage.

energy penalty as the window area is increased,[1] tends to constrain the size of the economically efficient window.

(12) If, due to the nature of the building, daylight utilization, window management, natural ventilation, and/or passive solar design cannot be effectively employed, it will tend to pay in both warm and cold locations to keep windows small, or even to eliminate them, apart from other considerations such as view and code and safety regulations.

(13) In all climatic regions considered, the potential for saving energy and dollars through the considered selection, management, and use of windows appears as great or greater than the potential for losses through inefficient decisions.

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[1] This conclusion applies specifically to conventional windows without special passive solar features for thermal storage.

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APPENDIX A

Estimated Costs of Purchase, Installation, Maintenance, and Repair for the Selected Window Systems in the Single-Family Residence

Table A.1 shows the estimated costs of purchasing and installing the double-hung wooden windows. Table A.2 shows the estimated costs of purchasing venetian blinds and wooden thermal shutters. Table A.3 shows the estimated costs of maintenance and repair both for the base year and over the life-cycle. All costs shown are for the Washington, D.C. area. For use in the analysis of windows in the other eight cities the cost data were adjusted by location modifiers to account for regional price differences.

Table A.1

Acqusition Costs of a Window in Excess of the Cost of a Non-Windowed Wall

Component	Dollar Costs, by Size of Area			
	12 ft^2 (1.11 m^2)	18 ft^2 (1.67 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)
Windows[a]				
Single Glazed	52.20	70.70	122.55	245.10
Double Glazed	81.80	109.36	192.61	385.23
Wall[b]	33.72	50.58	84.30	168.60
Window Cost Less Wall Cost[c]				
Single Glazed	18.48	20.12	38.25	76.50
Double Glazed	48.08	58.78	108.31	216.63

[a] Purchase prices are beginning 1978 list retail prices, reduced 10 percent to reflect a typical builder's discount, for good quality wood double-hung windows, provided by a distributor in the Washington, D.C. area. Prices are for single and multiple units of windows of available sizes which approximate the designated percentages of the exterior wall to be glazed. The 12 ft^2 (1.1 m^2) area is provided by a 3' x 3'11" window (0.9 m x 1.2 m); the 18 ft^2 (1.7 m^2) area, by a 3' x 6' (0.9 m x 1.8 m) window; the 30 ft^2 (2.8 m^2) area by two 3' x 5' (0.9 m x 1.5 m) windows; and the 60 ft^2 (5.6 m^2) area, by four 3' x 5' (0.9 m x 1.5 m) windows. An installation cost of $5.00 per window or pair of windows is used, based on an estimate given by a home builder in the Washington, D.C. area for beginning 1978. The installation cost is added to the purchase cost to arrive at the window acquisition cost.

[b] Cost of nonwindowed wall areas corresponding in size to the windowed areas are based on a price of $2.81/$ft^2$ ($30.25/$m^2$) as estimated by a home builder in the Washington, D.C. area for beginning 1978. The wall section is assumed to be face brick veneer over 8" (203 mm) cinder block with building paper sheathing, 3 1/2" (89 mm) of insulation, and 1/2" (13 mm) of painted interior drywall.

[c] The differential acqusition costs attributable to windows are estimated by taking the difference between the costs of the windows and the costs of the comparably sized wall area.

Table A.2

Cost of Window Accessories

Type of Accessory	Dollar Cost by Size of Window			
	12 ft^2 (1.11 m^2)	18 ft^2 (1.67 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)
Ventian Blinds[a]	17	20	36	72
Wooden Thermal Shutters[b]	42	51	96	192

[a] Prices shown are averages of beginning 1978 prices quoted by several low-to-moderately priced department stores. Installation is assumed to be done by the homeowner at negligible cost.

[b] Estimates are those of a Washington area building contractor for constructing, installing, and finishing solid, tightly fitting wooden shutters at the beginning of 1978. (Prices quoted by custom drapery shops in the area were considerably higher.

Table A.3

Window Maintenance and Repair Costs

Type of Maintenance and Repair	Dollar Costs by Window Area			
	12 ft^2 (1.11 m^2)	18 ft^2 (1.67 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)
Cleaning Costs				
Annual Cleaning Cost, beginning 1978[a]	1.20	1.80	3.00	6.00
Present Value Dollar Cost over 25 years[b]	13.00	19.00	32.00	64.00
Scraping, Recaulking, and Repainting Every 5th Year at 1.50/ft^2 (\$16.15/m^2)				
Recurring Cost Every 5th Year, beginning 1978 Dollars[c]	18.00	27.00	45.00	90.00
Present Value Dollar Cost Over 25 Years[d]	30.00	45.00	75.00	151.00

[a] Based on a rate of \$0.10/ft^2 (\$1.08/m^2).

[b] Based on annually recurring costs in constant dollars discounted with an 8 percent discount rate and rounded to the nearest dollar.

[c] Based on a rate of \$1.50/ft^2 (\$16.15/m^2) in beginning 1978 dollars.

[d] Based on recurring costs every 5th year in constant dollars discounted with an 8 percent discount rate and rounded to the nearest dollar.

APPENDIX B

Estimated Costs of Purchase, Installation, Maintenance, and Repair for the Selected Window Systems in the Commercial Office Building

Table B.1 provides the acquisition costs of the exterior office wall (bay). These costs include the purchase and installation prices for all glazing (spandrel panel and window), mullions, and the interior curtain wall. A 25 percent markup for contractor overhead and profit is included.

Table B.2 gives the costs of venetian blinds and insulated thermal shutters.

Table B.3 gives the estimated contract price at the beginning of 1978 for annual washing of all windows of a specified size in the office building. All costs are shown for the Washington, D.C. area. For use in the analysis of window in the other eight cities, the cost data were adjusted by location modifiers to account for regional price differences. Table B.3 also shows estimated annual insurance premiums as beginning 1978, as a proxy for repair and replacement costs, for windows of different size.

Table B.1

Commercial Case Study: Acqusition Costs[a]

Glazing Type	Dollar Cost of Wall by Size of Windows				
	0 ft^2 (0 m^2)	12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)	90 ft^2 (8.36 m^2)
Single	1238	1229	1204	1257	1009
Double	1238	1301	1323	1446	1255

[a] Cost figures are for the entire 10' x 12' (3.0 m x 3.7 m) exterior wall (bay) and include the purchase and installation costs for all glazing (spandrel panel and window), mullions, and the interior curtain wall, plus a 25 percent markup cost for contractor overhead and profit. The cost differential associated with a given window size/type is thus equal to the difference between the cost of the bay with that window size/type and the windowless bay. The area of the exterior wall is 120 ft^2 (11.1 m^2). Varations in cost among window sizes are due both to differences in framing costs and to the costs of glazing. Lower framing costs are particularly evident in the case where the window area is 90 ft^2 (8.4 m^2).

Source: A leading manufacturer and distributor of building materials provided the cost estimates.

Table B.2

Commercial Case Study: Cost of Window Accessories

Type of Accessory	Dollar Cost by Size of Window			
	12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)	90 ft^2 (8.36 m^2)
Venetian Blinds	47	47	64	95
Thermal Shutter	232	412	750	1050

[a] All costs are for beginning 1978, and reflect purchase, installation, and contractor markup.

Source: A leading manufacturer and distributor of building materials provided the cost estimates.

Table B.3

Commercial Case Study: Cleaning and Insurance Costs

Type of Cost	Dollar Cost by Window Area			
	12 ft^2 (1.11 m^2)	30 ft^2 (2.79 m^2)	60 ft^2 (5.57 m^2)	90 ft^2 (8.36 m^2)
Annual Cleaning Cost for 1977	3.10	4.10	5.80	7.50
Annual Insurance Cost for 1977[a]				
Premium[b]				
Single	0.60	1.70	4.10	5.90
Double	3.80	10.40	24.50	35.60

[a] Insurance costs are used as a proxy for repair and replacement costs.

[b] Premiums are unadjusted for regional rate differentials.

Source: Insurance costs were provided by a major insurance company, based on company rate manuals.

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This study, the fifth in a series of reports from the National Bureau of Standards interdisciplinary project on windows, provides guidance in selecting and using windows in buildings for greater cost effectiveness. It presents the life-cycle costs of selected window systems used in a room of a representative residence and in an office module of a representative commercial office building for nine cities in the United States, representing five heating zones and four cooling zones. The cities covered are Miami, Florida; Atlanta, Georgia; Washington, D.C.; Portland, Maine; Indianapolis, Indiana; San Antonio, Texas; Los Angeles, California; Bismarck, North Dakota; and Seattle, Washington. The results of the regional analyses are summarized, and the implications of these results are considered, both for selecting windows in new buildings and for managing windows in existing buildings. The emphasis of this report is on conveying the research findings to builders, designers, and building owners and operators -- those involved immediately with the building process. The research method is described in an earlier companion report, Economic Evaluation of Windows in Buildings: Methodology, NBS BSS 119.

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