DEVELOPMENT OF ECONOMIC SCALAR RATIOS FOR ASHRAE STANDARD 90.1R

Merle F. McBride, Ph.D.
Member ASHRAE

ABSTRACT

The Standing Standard Project Committee (SSPC) for Standard 90.1, "Energy-Efficient Design of New Buildings Except New Low-Rise Residential Buildings," has applied life-cycle cost economics to develop the next revision to the standard. This ensures that the criteria in the standard will be cost-effective for the building owner and that balance will be achieved among all of the components. Implementation of the economics was simplified through the development of economic scalar ratios. This simplification avoided the normal difficulty in selecting specific economic parameters and defending them for all applications. The paper presents the theoretical development of scalar ratios; an example calculation; sensitivity analyses; applications for envelope, HVAC, and lighting components; plus a method to extend it to components with short service lives.

INTRODUCTION

The American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE) Standing Standard Project Committee (SSPC) 90.1 decided that the criteria for the next revision to the standard should be based on cost-effectiveness to the building owner. The SSPC then selected life-cycle cost (LCC) analyses as the economic procedure. There were two compelling reasons for this decision. First, basing the criteria on economics ensured they were cost effective. Second, economics provided a methodology to ensure that all of the criteria were balanced. Balance means each major section of the standard (envelope, lighting, and HVAC equipment efficiencies) was contributing to the overall efficiency of the building at an appropriate level. No one section would be overly stringent while another section was too lenient. These two benefits justified the effort necessary to use economics as the basis for setting the criteria in the standard.

This was not the first application of economics in the development of a national energy standard within ASHRAE. ASHRAE Standard 90.2-1993, "Energy-Efficient Design of New Low-Rise Residential Buildings" (ASHRAE 1993), used economics and provided the background, experience, and justification for proposing that it be applied to the development of the next revision to Standard 90.1-1989, which is designated 90.1R. Although economics played an important role in establishing the criteria within the development of 90.1R, it was not the only consideration nor was it a substitute for judgment and other factors (comfort, condensation) in developing the criteria.

BACKGROUND

The ASHRAE policy for standards development requires each standard to either be revised or reaffirmed every five years. The current version of Standard 90.1-1989 was based primarily on professional judgment. Comments received from the public reviews challenged some of the criteria as not cost effective. Other comments indicated the envelope criterion was more stringent than the lighting criterion, and the heating, ventilating, and air-conditioning (HVAC) equipment efficiencies were even farther behind. The SSPC had no measure to either support or refute these charges. Therefore, when the SSPC began to develop 90.1R there was a keen interest in being able to account for and respond to economic issues, as well as the level of stringency among the major sections.

ECONOMIC METHODOLOGY

General Theory of Life-Cycle Cost Economic Analysis

The basis for the life-cycle cost economic methodology was ASTM Standard E917-93, "Standard Practice for Measuring Life-Cycle Costs of Buildings and Building Systems" (ASTM 1993). The most fundamental formula for the LCC was

$$LCC = FC + M + R + E - RV \qquad (1)$$

where

LCC = life-cycle cost ($),
FC = first cost ($),
M = maintenance and repair costs ($),
R = replacement costs ($)

Merle F. McBride is with Owens-Corning Technical Center, Granville, Ohio.

E = energy costs ($), and
RV = resale value or salvage ($).

These costs can be expressed in either constant dollars or in terms of current dollars (nominal = real + inflation). For purposes of this standard, development current dollars were selected.

Present-Value Life-Cycle Cost Economic Analysis

Expressing Equation 1 in terms of present value produced

$$PVLCC = PVFC + PVM + PVR + PVE - PVRV \quad (2)$$

where

PVLCC = present value of the life-cycle costs ($),
PVFC = present value of the first costs ($),
PVM = present value of the maintenance and repair costs ($),
PVR = present value of the replacement costs ($),
PVE = present value of the energy costs ($), and
PVRV = present value of the resale value or salvage ($).

The economic terms that vary over time were calculated by

$$PVFC = FC \times UPWF \quad (3)$$

$$PVM = M \times UPWF \quad (4)$$

$$PVR = R \times UPWF \quad (5)$$

and

$$PVE = E \times UPWF \quad (6)$$

and the uniform present-worth factor (UPWF) was determined by

$$UPWF = [(1+i)^N - 1] / [i(1+i)^N] \quad (7)$$

where

N = measure life (yrs) and
i = interest or discount rate (decimal).

The UPWFs assume a uniform rate of change for each time period. In this application, it would be on an annual basis. If the rates of change are not constant every year, probably the more realistic case, then modified uniform present-worth factors should be used. Modified assumes that the rate of change was constant for a specified number of years and then changed to another constant value for another specified period of years. The maximum number of times the rate could change would be annually. Typically, one estimates the rate of change for blocks of time such as five years or 10 years. This required a more sophisticated ability to project rates of change in the future than was warranted for the standard development. For purposes of this development, the modified uniform present-worth factors were called scalars. The term scalars was borrowed from the field of mathematics, and means the number just has a magnitude as opposed to a vector, which has both magnitude and direction. Because fuel escalation rates for heating and cooling fuels may be different, the scalars were identified as S_h for heating and S_c for cooling. Finally, the scalar for the first costs is identified as S_2.

The resale value (or salvage) occurs only once and that was at the end of the time period assumed for the economic evaluation. In this instance, the present value was determined by

$$PVRV = RV \times SPVF \quad (8)$$

where the single present-value factor (SPVF) was determined by

$$SPVF = 1/(1+i)^N \quad (9)$$

As a theoretical example of the present-value LCC analysis, assume the objective was to determine the optimum level of insulation to install in an attic. Furthermore, assume that the level of insulation was a continuous variable, available in any quantity, such as loosefill or blown insulation. Specific values were assumed for the discount rate, life, fuel escalation rate, and material costs for illustrating the concept.

LCC THE.CH3

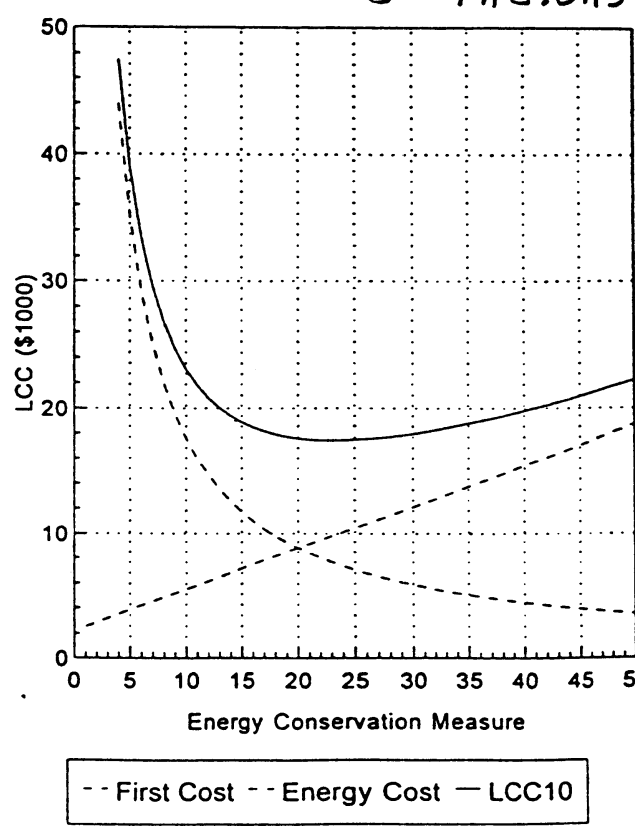

Figure 1 LCC theory.

The results are presented in Figure 1. The insulation costs were assumed to increase linearly with the level installed. The energy costs decrease as an inverse of the insulation level. The LCC was the sum of the first cost and the energy cost, assuming the insulation has no maintenance or repair cost, replacement cost, or resale cost. This was a simplified example to illustrate the concept. Returning to Figure 1, the LCC curve achieved a minimum value at an insulation level of R-23. This would establish the attic insulation criteria for the conditions and location specified.

Tax Implications on Life-Cycle Cost Economic Analysis

Federal tax laws allow businesses to deduct energy costs, interest on loans, and depreciation as operating expenses. This increases the complexity of LCC calculations because UPWFs can no longer be used. Instead, the LCC calculations must be done for each year to determine the tax benefits.

DIFFERENTIAL CALCULUS APPROACH

There was an alternative but equivalent method to the present-value LCC. The basic concept was to apply differential calculus to the process of determining a minimum value. This assumes that the curve to be optimized could be analytically described so that the first derivative could be determined. The minimum was determined by setting the first derivative to zero and solving it for the independent variable, which, in the attic example, would be the insulation level. The process will produce identical results. Equation 1 becomes

$$\frac{d(PVLCC)}{d(ECM)} = \frac{d(PVFC)}{d(ECM)} + \frac{d(PVM)}{d(ECM)} + \frac{d(PVR)}{d(ECM)} + \frac{d(PVE)}{d(ECM)} - \frac{d(PVRV)}{d(ECM)} = 0 \qquad (10)$$

where

ECM = energy conservation measure,

$\frac{d(PVLCC)}{d(ECM)}$ = differential present value of life-cycle cost ($),

$\frac{d(PVFC)}{d(ECM)}$ = differential present value of first cost ($),

$\frac{d(PVM)}{d(ECM)}$ = differential present value of maintenance and repair costs ($)

$\frac{d(PVR)}{d(ECM)}$ = differential present value of replacement cost ($),

$\frac{d(PVE)}{d(ECM)}$ = differential present value of energy costs ($), and

$\frac{d(PVRV)}{d(ECM)}$ = differential present value of resale value ($).

LCCINC.CH3

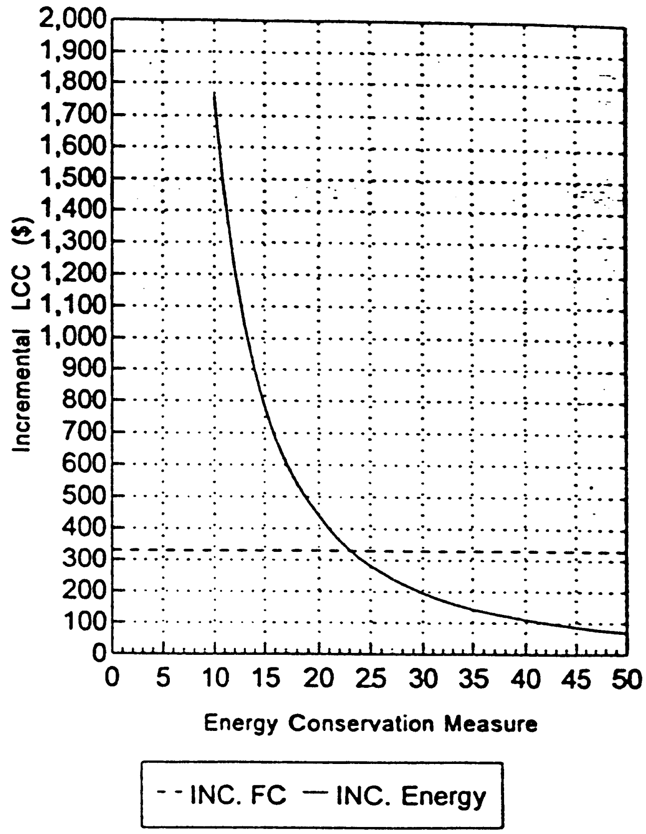

Figure 2 Incremental LCC theory.

For the attic insulation example, the differential maintenance and repair costs were zero, the differential replacement costs were zero, and the differential resale value also was zero. Under those assumptions, the results are presented in Figure 2. The differential first costs appear as a horizontal line. This means that each increment of insulation has the same cost as that of the previous one. The energy cost curve now decreases with the inverse of the square of the insulation level. The optimum occurs when the differential first cost equals the differential energy cost. Graphically, this is shown as the point where the differential energy cost curve intersects the differential first cost horizontal line. The point is R-23, which is identical to the result previously obtained.

The attic insulation example was simple because the insulation levels were assumed to be continuous. However, almost all ECM are not continuous variables but are only available at discrete values. The fundamental LCC theory can still be applied but it requires evaluation of each discrete value. The actual application of LCC in the standard development used the discrete approach.

MARGINAL OR INCREMENTAL LCC ANALYSIS

Determination of optimum levels can be calculated by two methods. One approach calculates the total LCC. In this approach, the annual energy costs for each ECM are used and all options are evaluated. The other approach calculates annual energy savings instead of using annual energy costs. The annual energy savings must be calculated as the difference between each successive ECM. This is referred to as marginal or incremental LCC. It is extremely important to recognize that the marginal approach calculates the energy savings between successive ECMs and does not calculate the energy savings for each ECM relative to a base case. For instance, in the attic insulation example, the marginal approach calculates the energy savings between each successive R-value of insulation and does not calculate the energy savings between the uninsulated base case (R-0) and the insulation level under investigation.

In equation form, the LCC analysis becomes

$$\frac{d\,(\mathrm{PVFC})}{d\,(\mathrm{ECM})} + \frac{d\,(\mathrm{PVE})}{d\,(\mathrm{ECM})} = 0 \qquad (11)$$

The incremental differences in present values of first costs and energy costs are determined as $\mathrm{ECM}_1 - \mathrm{ECM}_2$, with ECM_1 being designated as the reference and ECM_2 being designated as the next step or increment of improvement, e.g., more expensive but more energy efficient. This means that the incremental first cost will be positive, while the incremental energy cost will be negative. Rewriting Equation 11 to recognize this sign convention produces the final equation as

$$\frac{d\,(\mathrm{PVE})}{d\,(\mathrm{ECM})} = \frac{d\,(\mathrm{PVFC})}{d\,(\mathrm{ECM})} \qquad (12)$$

This means that the incremental present value of the heating and cooling energy savings must be equal to the incremental present value of the first costs to achieve the optimum. This is the general form and to actually evaluate it, specific terms need to be used. For envelope components, this requires evaluating both the heating and cooling energy savings as

$$FYS_h \cdot P_h \cdot S_h + FYS_c \cdot P_c \cdot S_c = \Delta FC \cdot S_2 \qquad (13)$$

where

FYS_h = first-year savings for heating (therms),
P_h = price of heating fuel (\$/therm),
S_h = scalar for heating (dimensionless),
FYS_c = first-year savings for cooling (kWh),
P_c = price of cooling fuel (\$/kWh),
S_c = scalar for cooling (dimensionless),
ΔFC = incremental change in first cost of ECMs (\$), and
S_2 = scalar for first costs (dimensionless).

In actual application for envelope components, Equation 13 becomes

$$\Delta U \cdot B_h \cdot \mathrm{HDD65} \cdot P_h \cdot S_h + \Delta U \cdot B_c \cdot P_c \cdot S_c = \Delta FC \cdot S_2 \qquad (14)$$

where

ΔU = incremental change in ECM U-factors (Btu/h·ft^2·°F),
B_h = heating regression coefficient (therms/ft^2·°F-day·U),
HDD65 = heating degree-days to base 65°F (°F-days),
B_c = cooling regression coefficient (kWh/ft^2·°F-day·U), and
CDD50 = cooling degree-days to base 50°F (°F-days).

Dividing Equation 14 by S_2 yields the final form as

$$\Delta U \cdot B_h \cdot \mathrm{HDD65} \cdot P_h \cdot S_h/S_2 + \Delta U \cdot B_c \cdot \mathrm{CDD50} \cdot P_c \cdot S_c/S_2 = \Delta FC \qquad (15)$$

where

S_h/S_2 = scalar ratio for heating (dimensionless) and
S_c/S_2 = scalar ratio for cooling (dimensionless).

The scalar ratios are not UPWFs or modified UPWFs but are used in a similar fashion in that they are the factors that are multiplied by the first-year energy savings to arrive at the present values. The scalar ratios are not equivalent to years for simple payback because they account for the time value of money and taxes. The scalar ratios are a simple method to use in the determination of optimum ECMs, which establish the criteria for the revision to the standard.

SPECIFICATION OF ECONOMIC VARIABLES

There are many economic variables that need to be specified to begin the actual LCC calculations. It is critical to keep in mind the relative importance of each variable as it relates to the overall analysis. For example, in Equation 15 there are significantly different degrees of precision that can be assigned to each of the variables. The incremental U-factor may be 0.001 Btu/h·ft^2·°F, the regression coefficients may be 0.1, the heating degree-days vary between 0 and 25,000, the fuel prices vary by factors of 3 to 4 across the country, and the scalar ratios may change by factors of 2 to 3 within reasonable limits of the economic parameters. This just highlights that the entire calculation procedure is not exact for every circumstance, but reasonable values can be determined and applied to develop the standard.

The basis for the selection of the economic variables was to assume a typical commercial business. Each of the economic variables will be presented.

Study Period

The study period is the economic life of the energy conservation measure under investigation. Typical values vary, depending on the specific feature. Buildings may last for 50 to 100 years but the ECMs typically will be replaced much sooner, usually associated with renovation or replacement. Common examples are 30 to 40 years for insulation, 10 to 15 years for HVAC equipment, and 5 to 15 years for lighting systems.

Discount Rate

The discount rate is the interest rate used in the discounting process. It is the required rate of return or the cost of capital. This is the rate necessary to justify raising funds to finance the project or, alternately, the rate necessary to maintain the firm's current market price per share. A typical nominal value would be 12%, but it varies depending on the particular business.

Inflation Rate

The inflation rate is the reduction in purchasing power from year to year, as measured, for example, by the percent increase in the gross national product deflator over a given year. Inflation rates can be expressed as either nominal or real but must be consistent with the approach used to define the discount rate. Typical nominal inflation rates used for energy studies range from 3% to 6% annually (Petersen 1993).

Tax Rate

The federal tax rate varies depending on amount of profit. It is 15% for profits up to $50,000, 25% for profits between $50,000 and $75,000, 34% for profits between $75,000 and $100,000, 39% for profits between $100,000 and $335,000, and 34% for profits that exceed $335,000. A typical federal tax rate is 34% for a majority of businesses. State tax rates range from 0% to 8%, with 6% being a typical value. Because state tax is deductible from federal tax liability, the combined tax rate is 38% (0.34·[1 – 0.06] + 0.06).

Loan Interest Rate

Loan interest payments are deductible from taxable income. For purposes of this economic analysis, it was assumed that the ECM would be totally financed as part of a construction loan. A nominal interest rate for commercial institutions was 12%.

Resale Value

It was assumed that the resale value of the ECM would be zero. One must recognize that there would be costs associated with removal of the ECM that would deduct from the resale value. Furthermore, capital gains tax applies if the ECM is sold for more than book value. For purposes of the incremental analysis, it was assumed to be zero.

Depreciation

Depreciation is deductible from taxable income. The Tax Act of August 1993 changed the class life for nonresidential real property placed in service after May 12, 1993, from 31 1/2 years to 39 years. The depreciation is straight line for 39 years. For purposes of the incremental analysis, it was assumed to be zero.

TABLE 1 **Economic Data and Assumptions**

Item	Value
1. Study Period (A)	30 Years
2. Discount Rate (Nominal)	12%
3. Inflation Rate	4%
4. Investment Cost Data	
a. Purchase and Installation	
b. Downpayment	
c. Loan Interest Rate	12%
d. Loan Life	30 Years
e. Yearly Loan Payment	
f. Depreciation (B)	
g. Loan Interest Payments	Deductible from taxable income
h. Resale Value (C)	
5. Recurring Operating & Maintenance Costs	Deductible from taxable income
6. Energy Costs	
a. Heating Energy Price	$5.60/MBtu
b. Cooling Energy Price	$0.08/kWh
c. Annual Heating Energy Use	
d. Annual Cooling Energy Use	
e. Annual Rate of Heating Energy Price Increase (Real)	2%
f. Annual Rate of Cooling Energy Price Increase (Real)	0%
g. Energy Costs	Deductible from taxable income
7. Federal Tax Rate	34%
8. Federal Tax Rate	6%
9. Combined Tax Rate (D)	38%

Notes:
A = 1993 Federal Tax Law specifies 39 years.
B = Building is straight line depreciation.
C = Capital gains tax apply if sold for more than book value.
D = To account for the deductibility of State tax from Federal tax liability, the combined tax rate is (0.34 x (1 – 0.06) + 0.06) = 0.38.

Operating and Maintenance Costs

Recurring operating and maintenance costs are deductible from taxable income. For purposes of the incremental analysis, these were assumed to be zero.

Energy Costs

Energy costs are deductible from taxable income. The price of energy for heating a building varies with the fuel type (gas, oil, electric) and the specific rate schedule. Typically, gas and electricity have rate schedules that vary with the amount of consumption. Furthermore, electric schedules will have demand charges. The impact of these variables is for energy prices to vary by factors of 3 to 4 across the country. For purposes of this analysis, national average fuel prices were selected. Gas was $5.60 per million Btu and electricity was $0.08 per kWh.

Heating and Cooling Systems

All buildings have a heating or cooling system and their efficiency impacts the overall energy performance and costs. For purposes of this analysis, it was assumed that the system would be a rooftop unit with a gas furnace and electric air conditioning. The heating system efficiencies investigated were 78%, 80%, 85%, 90%, and 96%, and the cooling system efficiencies investigated were energy-efficient ratios of 8.5, 8.8, 9.3, 9.8, and 10.3.

EXAMPLE CALCULATION

An example will be presented based on the economic variables and assumed values previously presented to illustrate how the detailed calculations are done. The specific assumptions are summarized in Table 1. Next, assume that the ECM incremental first cost is $1,000 and it was all financed with no down payment. The heating and cooling incremental energy requirements were each assumed to be 100 million Btu.

TABLE 2 Purchase and Installation Cost

(1) Year	(2) Down Payment, $ (A)	(3) Annual Loan Payment, $ (B)	(4) Interest Payments, $	(5) Corporate Income Tax Rate	(6) Tax Reductions from Interest Deductions, $ (4)×(5)	(7) After-Tax Payment, $ (3)–(6)	(8) Single Present Value (SPV) Factor	(9) PV of After-Tax After-Inflation Investment Financing, $ (7)×(8)
1	0	124	120	0.38	46	79	0.8929	70
2	0	124	120	0.38	45	79	0.7972	63
3	0	124	119	0.38	45	79	0.7118	56
4	0	124	118	0.38	45	79	0.6355	50
5	0	124	118	0.38	45	79	0.5674	45
6	0	124	117	0.38	44	80	0.5066	40
7	0	124	116	0.38	44	80	0.4524	36
8	0	124	115	0.38	44	80	0.4039	33
9	0	124	114	0.38	43	81	0.3606	29
10	0	124	113	0.38	43	81	0.3220	26
11	0	124	111	0.38	42	82	0.2875	24
12	0	124	110	0.38	42	82	0.2567	21
13	0	124	108	0.38	41	83	0.2292	19
14	0	124	106	0.38	40	84	0.2046	17
15	0	124	104	0.38	39	85	0.1827	15
16	0	124	101	0.38	39	86	0.1631	14
17	0	124	99	0.38	37	87	0.1456	13
18	0	124	96	0.38	36	88	0.1300	11
19	0	124	92	0.38	35	89	0.1161	10
20	0	124	88	0.38	34	91	0.1037	9
21	0	124	84	0.38	32	92	0.0926	9
22	0	124	79	0.38	30	94	0.0826	8
23	0	124	74	0.38	28	96	0.0738	7
24	0	124	68	0.38	26	98	0.0659	6
25	0	124	61	0.38	23	101	0.0588	6
26	0	124	54	0.38	20	104	0.0525	5
27	0	124	45	0.38	17	107	0.0469	5
28	0	124	36	0.38	14	111	0.0419	5
29	0	124	25	0.38	10	115	0.0374	4
30	0	124	13	0.38	5	119	0.334	4
Total PV, after-tax, purchase and installation cost								663

Notes: A = Assume loan value is $1000 with no downpayment.
B = Interest rate is 12% for 30 years.

The purchase and installation cost calculations for each year are presented in Table 2. The 30-year total present value, after-tax cost is $663. Because this was based on an assumed incremental first cost of $1,000, the scalar ($S_2$) for the purchase and installation is $663/$1,000 or 0.663.

The heating fuel cost calculations for each year are presented in Table 3. The 30-year total present value, after-tax heating fuel cost is $4,961. This was based on an average fuel price of $5.60/MBtu and 100 MBtu. The total first-year cost was then $560. The scalar for heating (S_{lh}) is $4,961/$560 or 8.86. The heating scalar ratio is simply the present value of the heating fuel cost divided by the present value of the purchase and installation cost or, in equation form, it is S_{lh}/S_2. For heating, the scalar ratio is 8.86/0.663 for a value of 13.4.

The cooling fuel cost calculations for each year are presented in Table 4. The total present value, after-tax cooling fuel cost is $16,858. This was based on an aver-

TABLE 3 Heating Fuel Costs

(1) Year	(2) Base Period Fuel Price, $/MBtu	(3) Annual Fuel Req., MBtu	(4) Fuel Price Escalation Multiplier (A)	(5) Annual Fuel Cost After Escalation, $ (2)×(3)×(4)	(6) Corporate Income Tax Rate (B)	(7) Tax Reduction from Fuel Cost Deductions, $ (5)×(6)	(8) Annual Cost After Tax and Escalation, $ (5)−(7)	(9) Single Present Value (SPV) Factor (C)	(10) PV of Annual Fuel Cost After Tax and Escalation, $ (8)×(9)
1	$5.60	100	$(1+0.06)^{1}$	594	0.38	225	368	0.8929	329
2	$5.60	100	$(1+0.06)^{2}$	629	0.38	239	390	0.7972	311
3	$5.60	100	$(1+0.06)^{3}$	667	0.38	253	414	0.7118	295
4	$5.60	100	$(1+0.06)^{4}$	707	0.38	268	439	0.6355	279
5	$5.60	100	$(1+0.06)^{5}$	749	0.38	284	465	0.5674	264
6	$5.60	100	$(1+0.06)^{6}$	794	0.38	302	493	0.5066	250
7	$5.60	100	$(1+0.06)^{7}$	842	0.38	320	522	0.4524	236
8	$5.60	100	$(1+0.06)^{8}$	893	0.38	339	554	0.4039	224
9	$5.60	100	$(1+0.06)^{9}$	946	0.38	359	587	0.3606	212
10	$5.60	100	$(1+0.06)^{10}$	1003	0.38	381	622	0.3220	200
11	$5.60	100	$(1+0.06)^{11}$	1063	0.38	404	660	0.2875	190
12	$5.60	100	$(1+0.06)^{12}$	1127	0.38	428	699	0.2567	179
13	$5.60	100	$(1+0.06)^{13}$	1194	0.38	453	741	0.2292	170
14	$5.60	100	$(1+0.06)^{14}$	1266	0.38	481	785	0.2046	161
15	$5.60	100	$(1+0.06)^{15}$	1342	0.38	509	833	0.1827	152
16	$5.60	100	$(1+0.06)^{16}$	1423	0.38	540	883	0.1631	144
17	$5.60	100	$(1+0.06)^{17}$	1508	0.38	572	936	0.1456	136
18	$5.60	100	$(1+0.06)^{18}$	1598	0.38	607	992	0.1300	129
19	$5.60	100	$(1+0.06)^{19}$	1694	0.38	643	1051	0.1161	122
20	$5.60	100	$(1+0.06)^{20}$	1796	0.38	682	1114	0.1037	116
21	$5.60	100	$(1+0.06)^{21}$	1904	0.38	723	1181	0.0926	109
22	$5.60	100	$(1+0.06)^{22}$	2018	0.38	766	1252	0.0826	103
23	$5.60	100	$(1+0.06)^{23}$	2139	0.38	812	1327	0.0738	98
24	$5.60	100	$(1+0.06)^{24}$	2267	0.38	861	1407	0.0659	93
25	$5.60	100	$(1+0.06)^{25}$	2403	0.38	912	1491	0.0588	88
26	$5.60	100	$(1+0.06)^{26}$	2548	0.38	967	1581	0.0525	83
27	$5.60	100	$(1+0.06)^{27}$	2700	0.38	1025	1675	0.0469	79
28	$5.60	100	$(1+0.06)^{28}$	2862	0.38	1087	1776	0.0419	74
29	$5.60	100	$(1+0.06)^{29}$	3034	0.38	1152	1882	0.0374	70
30	$5.60	100	$(1+0.06)^{30}$	3216	0.38	1221	1995	0.0334	67
Total PV, after tax, fuel cost									4961

Notes: A = Nominal (6%) = Actual (2%) + Inflation (4%)
B = To account for the deductibility of State tax from Federal tax liability, the combined tax rate is 0.34 × (1 − 0.06) + 0.06 = 0.38.
C = Discount Factor is 12%

age fuel price of $23.44/MBtu and 100 MBtu. The total first-year cost was then $2,344. The scalar for cooling (S_c) is $16,858/$2,344 or 7.19. The cooling scalar ratio is simply the present value of the cooling fuel cost divided by the present value of the purchase and installation cost or, in equation form, it is S_c/S_2. For cooling, the scalar ratio is $7.19/0.663 for a value of 10.8.

The difference between the heating scalar ratio (13.4) and the cooling scalar ratio (10.8) is solely attributable to the differences assumed in the fuel escalation rates (6% for heating and 4% for cooling). Considering that these scalar ratios are based on assumed constant fuel escalation rates for 30 years, they are not significantly different. Therefore, a further simplification was made by assuming that both

TABLE 4 **Cooling Fuel Costs**

(1) Year	(2) Base Period Fuel Price, $/MBtu (A)	(3) Annual Fuel Req., MBtu	(4) Fuel Price Escalation Multiplier (B)	(5) Annual Fuel Cost After Escalation, $ (2)×(3)×(4)	(6) Corporate Income Tax Rate (C)	(7) Tax Reduction from Fuel Cost Deductions, $ (5)×(6)	(8) Annual Cost After Tax and Escalation, $ (5)–(7)	(9) Single Present Value (SPV) Factor (D)	(10) PV of Annual Fuel Cost After Tax and Escalation, $ (8)×(9)
1	$23.44	100	$(1+0.04)^{1}$	2438	0.38	925	1512	0.8929	1350
2	$23.44	100	$(1+0.04)^{2}$	2535	0.38	962	1573	0.7972	1254
3	$23.44	100	$(1+0.04)^{3}$	2637	0.38	1001	1636	0.7118	1164
4	$23.44	100	$(1+0.04)^{4}$	2742	0.38	1041	1701	0.6355	1081
5	$23.44	100	$(1+0.04)^{5}$	2852	0.38	1083	1769	0.5674	1004
6	$23.44	100	$(1+0.04)^{6}$	2966	0.38	1126	1840	0.5066	932
7	$23.44	100	$(1+0.04)^{7}$	3085	0.38	1171	1914	0.4524	866
8	$23.44	100	$(1+0.04)^{8}$	3208	0.38	1218	1990	0.4039	804
9	$23.44	100	$(1+0.04)^{9}$	3336	0.38	1266	2070	0.3606	746
10	$23.44	100	$(1+0.04)^{10}$	3470	0.38	1317	2153	0.3220	693
11	$23.44	100	$(1+0.04)^{11}$	3608	0.38	1370	2239	0.2875	644
12	$23.44	100	$(1+0.04)^{12}$	3753	0.38	1425	2328	0.2567	598
13	$23.44	100	$(1+0.04)^{13}$	3903	0.38	1482	2421	0.2292	555
14	$23.44	100	$(1+0.04)^{14}$	4059	0.38	1541	2518	0.2046	515
15	$23.44	100	$(1+0.04)^{15}$	4221	0.38	1602	2619	0.1827	478
16	$23.44	100	$(1+0.04)^{16}$	4390	0.38	1667	2724	0.1631	444
17	$23.44	100	$(1+0.04)^{17}$	4566	0.38	1733	2833	0.1456	413
18	$23.44	100	$(1+0.04)^{18}$	4748	0.38	1802	2946	0.1300	383
19	$23.44	100	$(1+0.04)^{19}$	4938	0.38	1875	3064	0.1161	356
20	$23.44	100	$(1+0.04)^{20}$	5136	0.38	1950	3186	0.1037	330
21	$23.44	100	$(1+0.04)^{21}$	5341	0.38	2028	3314	0.0926	307
22	$23.44	100	$(1+0.04)^{22}$	5555	0.38	2109	3446	0.0826	285
23	$23.44	100	$(1+0.04)^{23}$	5777	0.38	2193	3584	0.0738	264
24	$23.44	100	$(1+0.04)^{24}$	6008	0.38	2281	3728	0.0659	246
25	$23.44	100	$(1+0.04)^{25}$	6249	0.38	2372	3877	0.0588	228
26	$23.44	100	$(1+0.04)^{26}$	6499	0.38	2467	4032	0.0525	212
27	$23.44	100	$(1+0.04)^{27}$	6758	0.38	2566	4193	0.0469	197
28	$23.44	100	$(1+0.04)^{28}$	7029	0.38	2668	4361	0.0419	183
29	$23.44	100	$(1+0.04)^{29}$	7310	0.38	2775	4535	0.0374	170
30	$23.44	100	$(1+0.04)^{30}$	7602	0.38	2886	4716	0.0334	157
						Total PV, after tax, fuel cost			16,858

Notes: A = Electric Price is $0.08/kWh
B = Nominal (4%) = Actual (0%) + Inflation (4%)
C = To account for the deductibility of State tax from Federal tax liability, the combined tax rate is 0.34 × (1 − 0.06) + 0.06 = 0.38.
D = Discount Factor is 12%.

the heating and cooling scalar ratios are the same. It is important to recognize that the differences in the heating and cooling scalar ratios are minor compared to the differences in fuel prices that exist around the country. National average fuel prices were used and their differences around the country exhibit significantly larger ranges in variability than those exhibited in the scalar ratios.

SENSITIVITY ANALYSIS

There are many variables contained in the calculation of scalar ratios, and each variable has reasonable ranges. This raises logical questions as to their impact. To address these concerns, an extensive sensitivity analysis was completed. Each major variable was systematically changed and scalar ratios were calculated. Fuel escalation rates (nominal) were varied from 2% to 10%. Discount rates were varied from 4% to 16%. Interest rates were varied from 6% to 16%. The economic life was varied from 1 to 50 years. The results are presented in Table 5. Typical values are presented in Figure 3.

OPTIMIZATION EXAMPLES

Application of the scalar ratio procedure allows one to determine the optimum ECM. Five examples will be presented to illustrate the application and results. For all of these examples a scalar ratio of 10 was used. The calculations were done for Knoxville because it has a reasonable amount of both heating and cooling energy loads. All of the ECMs and first costs were defined by the respective SSPC 90.1 panels so they reflect actual ECMs and costs. Before

TABLE 5 **Scalar Ratio Based on Selected Economic Variables**

Nom. Rates			Measure Life (Years)										
ESC %	Dis. %	Int. %	2	4	6	8	10	15	20	25	30	40	50
2	4	6	1.2	2.4	3.5	4.6	5.7	8.2	10.5	12.6	14.5	17.9	20.7
2	4	8	1.2	2.3	3.4	4.4	5.3	7.5	9.3	10.9	12.4	14.7	16.6
2	4	10	1.2	2.2	3.2	4.2	5.0	6.8	8.4	9.6	10.7	12.4	13.8
2	4	12	1.1	2.2	3.1	3.9	4.7	6.3	7.5	8.5	9.4	10.7	11.7
2	4	14	1.1	2.1	3.0	3.8	4.4	5.8	6.8	7.6	8.3	9.3	10.1
2	4	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.9	7.4	8.2	8.9
2	6	6	1.2	2.4	3.5	4.6	5.7	8.1	10.4	12.5	14.3	17.4	19.8
2	6	8	1.2	2.3	3.4	4.4	5.3	7.5	9.3	10.9	12.2	14.4	15.9
2	6	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.6	10.6	12.1	13.1
2	6	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.5	9.3	10.4	11.1
2	6	14	1.1	2.1	3.0	3.8	4.4	5.8	6.8	7.6	8.2	9.0	9.6
2	6	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.8	7.3	8.0	8.5
2	8	6	1.2	2.4	3.5	4.6	5.7	8.1	10.4	12.4	14.2	17.0	19.1
2	8	8	1.2	2.3	3.4	4.4	5.3	7.5	9.3	10.8	12.1	14.0	15.3
2	8	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.5	10.5	11.8	12.6
2	8	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.4	9.2	10.1	10.6
2	8	14	1.1	2.1	3.0	3.8	4.4	5.8	6.8	7.5	8.1	8.8	9.2
2	8	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.8	7.2	7.8	8.1
2	10	6	1.2	2.4	3.5	4.6	5.7	8.1	10.3	12.3	14.0	16.7	18.5
2	10	8	1.2	2.3	3.4	4.4	5.3	7.5	9.3	10.8	12.0	13.8	14.8
2	10	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.5	10.4	11.5	12.2
2	10	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.4	9.1	9.9	10.3
2	10	14	1.1	2.1	3.0	3.8	4.5	5.8	6.8	7.5	8.0	8.6	8.9
2	10	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.8	7.1	7.6	7.8
2	12	6	1.2	2.4	3.5	4.6	5.7	8.1	10.3	12.2	13.9	16.4	18.1
2	12	8	1.2	2.3	3.4	4.4	5.3	7.4	9.2	10.7	11.9	13.5	14.4
2	12	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.4	10.3	11.3	11.8
2	12	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.4	9.0	9.7	10.0
2	12	14	1.1	2.1	3.0	3.8	4.5	5.8	6.8	7.5	7.9	8.4	8.6
2	12	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.7	7.1	7.4	7.6
2	14	6	1.2	2.4	3.5	4.6	5.7	8.1	10.3	12.2	13.8	16.2	17.7
2	14	8	1.2	2.3	3.4	4.4	5.3	7.4	9.2	10.7	11.8	13.3	14.1
2	14	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.4	10.2	11.2	11.6
2	14	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.3	8.9	9.5	9.8
2	14	14	1.1	2.1	3.0	3.8	4.5	5.8	6.8	7.4	7.8	8.3	8.4
2	14	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.7	7.0	7.3	7.4
2	16	6	1.2	2.4	3.5	4.6	5.7	8.1	10.3	12.1	13.7	16.0	17.4
2	16	8	1.2	2.3	3.4	4.4	5.3	7.4	9.2	10.6	11.7	13.2	13.9
2	16	10	1.2	2.2	3.2	4.2	5.0	6.8	8.3	9.4	10.1	11.0	11.4
2	16	12	1.1	2.2	3.1	4.0	4.7	6.3	7.5	8.3	8.8	9.4	9.6
2	16	14	1.1	2.1	3.0	3.8	4.5	5.8	6.8	7.4	7.8	8.1	8.3
2	16	16	1.1	2.1	2.9	3.6	4.2	5.4	6.2	6.6	6.9	7.2	7.3
4	4	6	1.2	2.5	3.8	5.0	6.3	9.5	12.7	16.0	19.3	26.0	32.7
4	4	8	1.2	2.4	3.6	4.8	5.9	8.7	11.4	14.0	16.5	21.4	26.2
4	4	10	1.2	2.4	3.5	4.5	5.6	8.0	10.2	12.3	14.2	18.0	21.7
4	4	12	1.2	2.3	3.3	4.3	5.2	7.3	9.2	10.9	12.5	15.5	18.4
4	4	14	1.2	2.2	3.2	4.1	4.9	6.7	8.3	9.7	11.0	13.5	16.0
4	4	16	1.1	2.2	3.1	3.9	4.6	6.2	7.6	8.8	9.9	12.0	14.1
4	6	6	1.2	2.5	3.8	5.0	6.3	9.4	12.5	15.6	18.6	24.1	29.0
4	6	8	1.2	2.4	3.6	4.8	5.9	8.6	11.2	13.6	15.9	19.9	23.3
4	6	10	1.2	2.4	3.5	4.5	5.5	7.9	10.0	12.0	13.7	16.7	19.2
4	6	12	1.2	2.3	3.3	4.3	5.2	7.3	9.1	10.6	12.0	14.4	16.3
4	6	14	1.2	2.2	3.2	4.1	4.9	6.7	8.2	9.5	10.6	12.5	14.1
4	6	16	1.1	2.2	3.1	3.9	4.6	6.2	7.5	8.5	9.5	11.1	12.4

the specific examples are presented, a brief discussion of the theory will be presented.

Theory

Changes in the scalar ratio change the stringency of the optimum ECM. Higher scalar ratios produce more stringent ECMs. This is best illustrated in Figure 4, where 10 scalar ratios are presented for the same ECM. At a scalar ratio of 1, the optimum or minimum LCC is the fifth ECM. At a scalar ratio of 15, the optimum or minimum LCC is at the 25 ECM. Finally, at a scalar ratio of 45, the optimum ECM has not been reached because the LCC curve has not reached a minimum at the 50 ECM, which indicates that more stringent ECMs could be economically justified. However, they may not exist, which means that other technologies may be needed for further improvements. The examples that follow illustrate the unique results that emerge with different ECMs.

Ceilings

The ceiling batt insulation options investigated were an uninsulated base case (R-1), R-11, R-19, R-30, R-38, R-49, R-60, R-60 plus 2 in. of polyisocyanurate, and advanced R-60 plus 2 in. of polyisocyanurate. The results are presented in Figure 5. The insulation costs continuously increase by R-value, while the combined heating and cooling fuel costs continuously decrease with R-value. The LCC, which is the sum of the insulation costs and the fuel costs, reaches a minimum at R-19 for this example. It is important to note that R-30 also is close to the minimum.

TABLE 5 **Scalar Ratio Based on Selected Economic Variables *(Continued)***

Nom. Rates			Measure Life (Years)										
ESC %	Dis. %	Int. %	2	4	6	8	10	15	20	25	30	40	50
4	8	6	1.2	2.5	3.7	5.0	6.3	9.3	12.4	15.2	17.9	22.6	26.3
4	8	8	1.2	2.4	3.6	4.8	5.9	8.6	11.0	13.3	15.3	18.6	21.0
4	8	10	1.2	2.4	3.5	4.5	5.5	7.9	9.9	11.7	13.2	15.6	17.3
4	8	12	1.2	2.3	3.3	4.3	5.2	7.2	8.9	10.4	11.6	13.4	14.6
4	8	14	1.2	2.2	3.2	4.1	4.9	6.7	8.1	9.3	10.2	11.7	12.7
4	8	16	1.1	2.2	3.1	3.9	4.6	6.2	7.4	8.3	9.1	10.3	11.1
4	10	6	1.2	2.5	3.7	5.0	6.2	9.3	12.2	14.9	17.3	21.3	24.2
4	10	8	1.2	2.4	3.6	4.7	5.9	8.5	10.9	13.0	14.8	17.6	19.3
4	10	10	1.2	2.4	3.5	4.5	5.5	7.8	9.8	11.4	12.8	14.8	15.9
4	10	12	1.2	2.3	3.3	4.3	5.2	7.2	8.8	10.1	11.2	12.6	13.4
4	10	14	1.2	2.2	3.2	4.1	4.9	6.6	8.0	9.1	9.9	11.0	11.6
4	10	16	1.1	2.2	3.1	3.9	4.6	6.1	7.3	8.2	8.8	9.7	10.2
4	12	6	1.2	2.5	3.7	5.0	6.2	9.2	12.0	14.6	16.8	20.3	22.7
4	12	8	1.2	2.4	3.6	4.7	5.8	8.4	10.8	12.8	14.4	16.7	18.1
4	12	10	1.2	2.4	3.5	4.5	5.5	7.8	9.7	11.2	12.4	14.0	14.9
4	12	12	1.2	2.3	3.3	4.3	5.2	7.2	8.7	9.9	10.9	12.0	12.5
4	12	14	1.2	2.2	3.2	4.1	4.9	6.6	7.9	8.9	9.6	10.4	10.8
4	12	16	1.1	2.2	3.1	3.9	4.6	6.1	7.2	8.0	8.5	9.2	9.5
4	14	6	1.2	2.5	3.7	5.0	6.2	9.1	11.9	14.3	16.4	19.5	21.5
4	14	8	1.2	2.4	3.6	4.7	5.8	8.4	10.6	12.5	14.0	16.1	17.2
4	14	10	1.2	2.4	3.5	4.5	5.5	7.7	9.6	11.0	12.1	13.5	14.1
4	14	12	1.2	2.3	3.3	4.3	5.2	7.1	8.6	9.8	10.6	11.5	11.9
4	14	14	1.2	2.2	3.2	4.1	4.9	6.6	7.8	8.7	9.3	10.0	10.2
4	14	16	1.1	2.2	3.1	3.9	4.6	6.1	7.1	7.8	8.3	8.8	9.0
4	16	6	1.2	2.5	3.7	5.0	6.2	9.1	11.7	14.0	16.0	18.9	20.7
4	16	8	1.2	2.4	3.6	4.7	5.8	8.3	10.5	12.3	13.7	15.5	16.5
4	16	10	1.2	2.4	3.5	4.5	5.5	7.7	9.5	10.8	11.8	13.0	13.5
4	16	12	1.2	2.3	3.3	4.3	5.2	7.1	8.5	9.6	10.3	11.1	11.4
4	16	14	1.2	2.2	3.2	4.1	4.9	6.5	7.7	8.6	9.1	9.6	9.8
4	16	16	1.1	2.2	3.1	3.9	4.6	6.1	7.0	7.7	8.1	8.5	8.6
8	4	6	1.3	2.7	4.3	6.0	7.8	13.0	19.4	27.1	36.5	61.7	98.8
8	4	8	1.3	2.7	4.1	5.7	7.3	11.9	17.3	23.6	31.2	51.0	79.4
8	4	10	1.3	2.6	4.0	5.4	6.9	10.9	15.5	20.8	27.0	42.9	65.7
8	4	12	1.3	2.5	3.8	5.1	6.5	10.0	14.0	18.4	23.6	36.8	55.7
8	4	14	1.2	2.4	3.7	4.9	6.1	9.2	12.6	16.5	20.9	32.1	48.3
8	4	16	1.2	2.4	3.5	4.6	5.8	8.6	11.5	14.8	18.6	28.5	42.5
8	6	6	1.3	2.7	4.3	5.9	7.7	12.7	18.6	25.5	33.3	52.3	75.9
8	6	8	1.3	2.7	4.1	5.6	7.2	11.7	16.6	22.2	28.5	43.1	60.9
8	6	10	1.3	2.6	4.0	5.4	6.8	10.7	14.9	19.5	24.6	36.3	50.3
8	6	12	1.3	2.5	3.8	5.1	6.4	9.8	13.5	17.3	21.5	31.1	42.6
8	6	14	1.2	2.4	3.7	4.9	6.1	9.1	12.2	15.5	19.0	27.1	36.8
8	6	16	1.2	2.4	3.5	4.6	5.7	8.4	11.1	13.9	17.0	24.0	32.4
6	4	6	1.3	2.6	4.0	5.5	7.0	11.1	15.6	20.7	26.3	39.3	55.1
6	4	8	1.3	2.5	3.9	5.2	6.6	10.1	14.0	18.0	22.4	32.4	44.3
6	4	10	1.2	2.5	3.7	4.9	6.2	9.3	12.5	15.9	19.4	27.3	36.6
6	4	12	1.2	2.4	3.6	4.7	5.8	8.5	11.3	14.1	17.0	23.4	31.1
6	4	14	1.2	2.3	3.4	4.5	5.5	7.9	10.2	12.6	15.0	20.5	26.9
6	4	16	1.2	2.3	3.3	4.3	5.2	7.3	9.3	11.3	13.4	18.1	23.7
6	6	6	1.3	2.6	4.0	5.5	7.0	10.9	15.2	19.8	24.6	34.8	45.5
6	6	8	1.3	2.5	3.8	5.2	6.5	10.0	13.6	17.3	21.0	28.7	36.5
6	6	10	1.2	2.5	3.7	4.9	6.1	9.2	12.2	15.2	18.2	24.2	30.1
6	6	12	1.2	2.4	3.6	4.7	5.8	8.4	11.0	13.5	15.9	20.7	25.5
6	6	14	1.2	2.3	3.4	4.5	5.5	7.8	10.0	12.0	14.1	18.0	22.1
6	6	16	1.2	2.3	3.3	4.2	5.1	7.2	9.1	10.8	12.6	16.0	19.4

Walls

The 2 by 4 wall insulation options investigated were an uninsulated base case (R-4), R-11, R-13, R-15, R-13 plus 1.5 in. of foam sheathing, R-13 plus 2 in. of foam sheathing, and R-15 plus 2 in. of foam sheathing. The final option was in 2 × 6 walls with R-21 and 2 in. of foam sheathing. The results are presented in Figure 6. The optimum is R-13.

Slabs

The insulation options investigated were none, 2 in. of polystyrene for 2 ft, 3 in. of polystyrene for 2 ft, and 3 in. of polystyrene for 4 ft. The results are presented in Figure 7. The minimum LCC has the first ECM that has no insulation.

Fenestration

There are numerous fenestration options to evaluate. There are three key parameters to describe the performance of fenestration options. Thermal performance was characterized by the U-factor and the shading coefficient. Daylighting performance was characterized by the visible light transmittance. In this analysis, 104 fenestration options were investigated. Rather than listing all 104 fenestration options, the ranges for each parameter will be presented. The U-factors ranged from 1.21 to 0.24 Btu/h·ft^2·°F. The shading coefficients ranged from 0.95 to 0.12. The visible light transmittance ranged from 0.88 to 0.04. The results are presented in Figure 8. Because there were three key parameters describing the performance of fenestration options, the results jump around. This illustrates the need for a well-defined methodology to iden-

TABLE 5 **Scalar Ratio Based on Selected Economic Variables *(Continued)***

Nom. Rates			Measure Life (Years)										
ESC %	Dis. %	Int. %	2	4	6	8	10	15	20	25	30	40	50
6	8	6	1.3	2.6	4.0	5.4	6.9	10.8	14.8	19.0	23.1	31.1	38.3
6	8	8	1.3	2.5	3.8	5.2	6.5	9.9	13.3	16.6	19.8	25.7	30.7
6	8	10	1.2	2.5	3.7	4.9	6.1	9.1	11.9	14.6	17.1	21.6	25.3
6	8	12	1.2	2.4	3.5	4.7	5.8	8.3	10.7	12.9	14.9	18.5	21.4
6	8	14	1.2	2.3	3.4	4.4	5.4	7.7	9.7	11.5	13.2	16.1	18.5
6	8	16	1.2	2.3	3.3	4.2	5.1	7.1	8.9	10.4	11.8	14.2	16.2
6	10	6	1.3	2.6	4.0	5.4	6.9	10.6	14.4	18.2	21.8	28.2	33.2
6	10	8	1.3	2.5	3.8	5.1	6.5	9.7	12.9	15.9	18.7	23.2	26.5
6	10	10	1.2	2.5	3.7	4.9	6.1	8.9	11.6	14.0	16.1	19.5	21.8
6	10	12	1.2	2.4	3.5	4.7	5.7	8.2	10.5	12.4	14.1	16.7	18.4
6	10	14	1.2	2.3	3.4	4.4	5.4	7.6	9.5	11.1	12.4	14.5	15.9
6	10	16	1.2	2.3	3.3	4.2	5.1	7.0	8.6	10.0	11.1	12.8	14.0
6	12	6	1.3	2.6	4.0	5.4	6.8	10.5	14.1	17.6	20.7	25.9	29.5
6	12	8	1.3	2.5	3.8	5.1	6.4	9.6	12.6	15.4	17.7	21.3	23.6
6	12	10	1.2	2.5	3.7	4.9	6.1	8.8	11.4	13.5	15.3	17.9	19.4
6	12	12	1.2	2.4	3.5	4.6	5.7	8.1	10.2	12.0	13.4	15.3	16.4
6	12	14	1.2	2.3	3.4	4.4	5.4	7.5	9.3	10.7	11.8	13.3	14.1
6	12	16	1.2	2.3	3.3	4.2	5.1	7.0	8.5	9.6	10.5	11.7	12.4
6	14	6	1.3	2.6	4.0	5.4	6.8	10.3	13.8	17.0	19.8	24.1	27.0
6	14	8	1.3	2.5	3.8	5.1	6.4	9.5	12.4	14.9	16.9	19.9	21.5
6	14	10	1.2	2.5	3.7	4.9	6.0	8.7	11.1	13.1	14.6	16.6	17.7
6	14	12	1.2	2.4	3.5	4.6	5.7	8.1	10.0	11.6	12.8	14.2	14.9
6	14	14	1.2	2.3	3.4	4.4	5.4	7.4	9.1	10.3	11.2	12.3	12.8
6	14	16	1.2	2.3	3.3	4.2	5.1	6.9	8.3	9.3	10.0	10.9	11.3
6	16	6	1.3	2.6	4.0	5.4	6.8	10.2	13.5	16.4	19.0	22.8	25.1
6	16	8	1.3	2.5	3.8	5.1	6.4	9.4	12.1	14.4	16.3	18.7	20.0
6	16	10	1.2	2.5	3.7	4.9	6.0	8.6	10.9	12.7	14.0	15.7	16.4
6	16	12	1.2	2.4	3.5	4.6	5.7	8.0	9.8	11.2	12.2	13.4	13.8
6	16	14	1.2	2.3	3.4	4.4	5.3	7.4	8.9	10.0	10.8	11.6	11.9
6	16	16	1.2	2.3	3.3	4.2	5.0	6.8	8.1	9.0	9.6	10.2	10.5
8	8	6	1.3	2.7	4.3	5.9	7.6	12.5	17.9	24.0	30.5	44.6	59.5
8	8	8	1.3	2.7	4.1	5.6	7.2	11.4	16.0	20.9	26.1	36.8	47.6
8	8	10	1.3	2.6	3.9	5.3	6.8	10.5	14.4	18.4	22.5	30.9	39.3
8	8	12	1.3	2.5	3.8	5.1	6.4	9.6	13.0	16.3	19.7	26.5	33.2
8	8	14	1.2	2.4	3.6	4.8	6.0	8.9	11.8	14.6	17.4	23.0	28.7
8	8	16	1.2	2.4	3.5	4.6	5.7	8.2	10.7	13.1	15.5	20.3	25.2
8	10	6	1.3	2.7	4.3	5.9	7.6	12.2	17.3	22.6	28.1	38.7	48.1
8	10	8	1.3	2.7	4.1	5.6	7.1	11.2	15.5	19.8	24.0	31.9	38.5
8	10	10	1.3	2.6	3.9	5.3	6.7	10.3	13.9	17.4	20.8	26.7	31.7
8	10	12	1.3	2.5	3.8	5.1	6.3	9.5	12.5	15.4	18.1	22.9	26.7
8	10	14	1.2	2.4	3.6	4.8	6.0	8.7	11.4	13.8	16.0	19.9	23.1
8	10	16	1.2	2.4	3.5	4.6	5.6	8.1	10.3	12.4	14.3	17.5	20.3
8	12	6	1.3	2.7	4.2	5.8	7.5	12.0	16.7	21.4	26.0	34.1	40.4
8	12	8	1.3	2.7	4.1	5.6	7.1	11.0	14.9	18.8	22.3	28.1	32.3
8	12	10	1.3	2.6	3.9	5.3	6.7	10.1	13.4	16.5	19.2	23.6	26.5
8	12	12	1.2	2.5	3.8	5.0	6.3	9.3	12.1	14.6	16.8	20.1	22.4
8	12	14	1.2	2.4	3.6	4.8	5.9	8.6	11.0	13.1	14.8	17.5	19.3
8	12	16	1.2	2.4	3.5	4.6	5.6	8.0	10.0	11.7	13.2	15.4	16.9
8	14	6	1.3	2.7	4.2	5.8	7.5	11.8	16.1	20.4	24.3	30.7	35.1
8	14	8	1.3	2.7	4.1	5.5	7.0	10.8	14.5	17.9	20.8	25.3	28.0
8	14	10	1.3	2.6	3.9	5.3	6.6	9.9	13.0	15.7	18.0	21.2	23.0
8	14	12	1.2	2.5	3.8	5.0	6.2	9.1	11.7	13.9	15.7	18.1	19.4
8	14	14	1.2	2.4	3.6	4.8	5.9	8.4	10.6	12.4	13.8	15.7	16.7
8	14	16	1.2	2.4	3.5	4.6	5.6	7.8	9.7	11.2	12.3	13.8	14.7

tify the true optimum. In this example it is option number 25. There were two other options that were close to the optimum—numbers 7 and 57.

Lighting

The 17 lighting options analyzed are presented in Table 6. The major ECMs were T8 lamps, electronic ballasts, compact fluorescent down-lights, dimming controls, task lighting, lumen maintenance, and reflective troffers. The results are presented in Figure 9. The optimum was option 11, which was daylight dimming in open areas. Option 10 — compact fluorescent down-lights—and option 12—daylight dimming in private offices—were close to the optimum. This illustrates that different technologies can compete and this methodology evaluates each one of their respective merits of cost and performance.

SHORT-LIVED MEASURES

The details required to evaluate scalar ratios have been shown to be involved. The question arose as to whether there may be a shorter method to determine the scalar ratio for ECMs of shorter lives. One solution was to assume that a scalar ratio is "equivalent" to a uniform present-worth factor. Then one can determine the "equivalent" interest rate that would produce the original scalar ratio. It is an iterative calculation but can be determined in a short time. By knowing the "equivalent" interest rate, then the scalar ratio can be evaluated for any different economic life.

For example, a scalar ratio of eight that was determined using a 30-year economic life

TABLE 5 **Scalar Ratio Based on Selected Economic Variables *(Continued)***

Nom. Rates			Measure Life (Years)										
ESC %	Dis. %	Int. %	2	4	6	8	10	15	20	25	30	40	50
8	16	6	1.3	2.7	4.2	5.8	7.4	11.5	15.7	19.5	22.9	28.1	31.5
8	16	8	1.3	2.6	4.1	5.5	7.0	10.6	14.0	17.1	19.6	23.1	25.1
8	16	10	1.3	2.6	3.9	5.2	6.6	9.8	12.6	15.0	16.9	19.3	20.6
8	16	12	1.2	2.5	3.8	5.0	6.2	9.0	11.4	13.3	14.7	16.5	17.3
8	16	14	1.2	2.4	3.6	4.8	5.8	8.3	10.3	11.9	13.0	14.3	14.9
8	16	16	1.2	2.4	3.5	4.5	5.5	7.7	9.4	10.7	11.6	12.6	13.1
10	4	6	1.4	2.9	4.6	6.5	8.7	15.3	24.2	36.0	51.7	100.2	185.9
10	4	8	1.3	2.8	4.4	6.2	8.1	14.0	21.6	31.4	44.1	82.7	149.3
10	4	10	1.3	2.7	4.2	5.9	7.7	12.8	19.3	27.6	38.1	69.6	123.6
10	4	12	1.3	2.6	4.1	5.6	7.2	11.8	17.4	24.4	33.3	59.8	104.9
10	4	14	1.3	2.6	3.9	5.3	6.8	10.9	15.8	21.8	29.5	52.2	90.9
10	4	16	1.2	2.5	3.8	5.1	6.4	10.1	14.4	19.7	26.4	46.2	80.1
10	6	6	1.4	2.9	4.6	6.5	8.6	14.9	23.0	33.2	46.0	81.4	134.4
10	6	8	1.3	2.8	4.4	6.1	8.1	13.6	20.5	29.0	39.3	67.1	107.8
10	6	10	1.3	2.7	4.2	5.8	7.6	12.5	18.4	25.5	34.0	56.5	89.0
10	6	12	1.3	2.6	4.1	5.6	7.1	11.5	16.6	22.6	29.7	48.4	75.4
10	6	14	1.3	2.6	3.9	5.3	6.7	10.6	15.0	20.2	26.3	42.2	65.2
10	6	16	1.2	2.5	3.8	5.0	6.3	9.8	13.7	18.2	23.5	37.3	57.4
10	8	6	1.4	2.9	4.6	6.4	8.5	14.5	21.9	30.7	41.0	66.5	98.4
10	8	8	1.3	2.8	4.4	6.1	8.0	13.3	19.5	26.8	35.1	54.8	78.8
10	8	10	1.3	2.7	4.2	5.8	7.5	12.2	17.5	23.6	30.3	46.0	64.9
10	8	12	1.3	2.6	4.0	5.5	7.1	11.2	15.8	20.9	26.5	39.4	54.9
10	8	14	1.3	2.6	3.9	5.3	6.7	10.3	14.3	18.7	23.4	34.3	47.4
10	8	16	1.2	2.5	3.7	5.0	6.3	9.6	13.1	16.8	20.9	30.3	41.7
10	10	6	1.4	2.9	4.5	6.4	8.4	14.1	20.8	28.5	36.8	55.1	74.2
10	10	8	1.3	2.8	4.4	6.1	7.9	12.9	18.6	24.9	31.5	45.4	59.3
10	10	10	1.3	2.7	4.2	5.8	7.4	11.9	16.7	21.9	27.2	38.1	48.8
10	10	12	1.3	2.6	4.0	5.5	7.0	10.9	15.1	19.4	23.8	32.6	41.2
10	10	14	1.3	2.6	3.9	5.2	6.6	10.1	13.7	17.3	21.0	28.3	35.6
10	10	16	1.2	2.5	3.7	5.0	6.2	9.3	12.5	15.6	18.7	25.0	31.2
10	12	6	1.4	2.9	4.5	6.3	8.3	13.7	19.9	26.5	33.3	46.6	58.3
10	12	8	1.3	2.8	4.3	6.0	7.8	12.6	17.8	23.2	28.5	38.4	46.6
10	12	10	1.3	2.7	4.2	5.7	7.3	11.6	16.0	20.4	24.6	32.2	38.3
10	12	12	1.3	2.6	4.0	5.4	6.9	10.7	14.5	18.1	21.5	27.5	32.3
10	12	14	1.3	2.6	3.9	5.2	6.5	9.9	13.1	16.2	19.0	23.9	27.8
10	12	16	1.2	2.5	3.7	4.9	6.2	9.1	11.9	14.5	16.9	21.0	24.4
10	14	6	1.4	2.9	4.5	6.3	8.2	13.4	19.1	24.8	30.4	40.3	47.9
10	14	8	1.3	2.8	4.3	6.0	7.7	12.3	17.1	21.7	26.0	33.2	38.2
10	14	10	1.3	2.7	4.2	5.7	7.3	11.3	15.4	19.1	22.5	27.8	31.3
10	14	12	1.3	2.6	4.0	5.4	6.8	10.4	13.9	16.9	19.6	23.7	26.4
10	14	14	1.3	2.5	3.9	5.2	6.5	9.6	12.6	15.1	17.3	20.6	22.8
10	14	16	1.2	2.5	3.7	4.9	6.1	8.9	11.4	13.6	15.4	18.1	20.0
10	16	6	1.4	2.9	4.5	6.2	8.1	13.1	18.3	23.4	28.0	35.7	40.9
10	16	8	1.3	2.8	4.3	5.9	7.6	12.0	16.4	20.5	24.0	29.3	32.6
10	16	10	1.3	2.7	4.1	5.7	7.2	11.1	14.8	18.0	20.7	24.5	26.7
10	16	12	1.3	2.6	4.0	5.4	6.8	10.2	13.3	16.0	18.1	20.9	22.5
10	16	14	1.3	2.5	3.8	5.1	6.4	9.4	12.1	14.2	15.9	18.2	19.4
10	16	16	1.2	2.5	3.7	4.9	6.1	8.7	11.0	12.8	14.2	16.0	17.0

is "equivalent" to an interest rate of 12.093. Similarly, a scalar ratio of 18 that was determined using a 30-year life is "equivalent" to an interest rate of 3.673. Using these "equivalent" interest rates, scalar ratios were calculated for shorter lives. The results are presented in Table 7. Comparisons between these results and those in Table 5 (scalar ratio of 18 at a 30-year life is an 8% escalation rate, 14% discount rate, and a 10% interest rate, while a scalar ratio of eight at a 30-year life is a 4% escalation rate, 16% discount rate, and a 16% interest rate) illustrate that this approach consistently overestimates the results obtained by using the detailed calculations. Starting with a scalar ratio of 18 and evaluating it at a life of 10 years, the "equivalent" method predicts a scalar ratio of 8.2, while the detailed calculations for a 10-year life produce a scalar ratio of 6.6. The differences between the actual and the "equivalent" methods decrease as the initial scalar ratio increases. In summary, the "equivalent" method is unable to accurately predict intermediate scalar ratios for shorter lives and should not be used as a substitute for the actual calculations.

CONCLUSIONS

The application of economics in the development of an energy standard has the distinct feature of ensuring that the criteria are cost effective to building owners and that balance is achieved between the major sections of the standard. Many simplifying assumptions were made in the development of scalar ratios, but they were shown to be an easy method to use in the development of the criteria.

RECOMMENDATIONS

It is recommended that the SSPC 90.1 use the scalar ratio concept to determine the criteria for the next revision of the standard.

ACKNOWLEDGMENTS

Special thanks are extended to Mr. Stephen R. Petersen for his vision in proposing the basic concept of scalars as a tool to account for modified uniform present-worth factors when conducting life-cycle cost analyses. Furthermore, his patience, guidance, and reviews have added to the actual implementation of the concept, which would not have occurred without his assistance.

REFERENCES

ASHRAE. 1993. ASHRAE Standard 90.2-1993, Energy efficient design of new-low rise residential buildings. Atlanta, Ga.: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASTM. 1993. ASTM E 917-93, Standard practice for measuring life-cycle costs of buildings and building systems. Annual

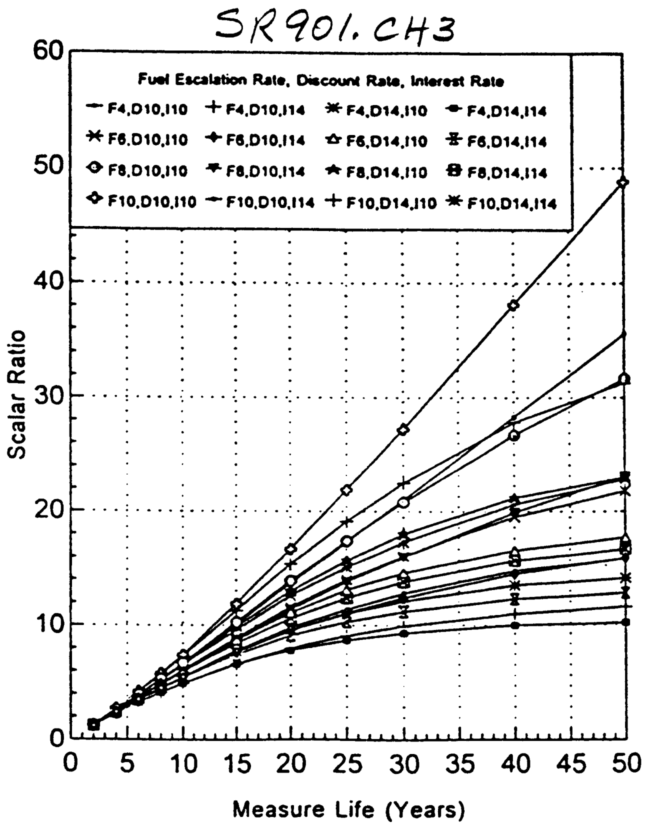

Figure 3 Scalar ratios.

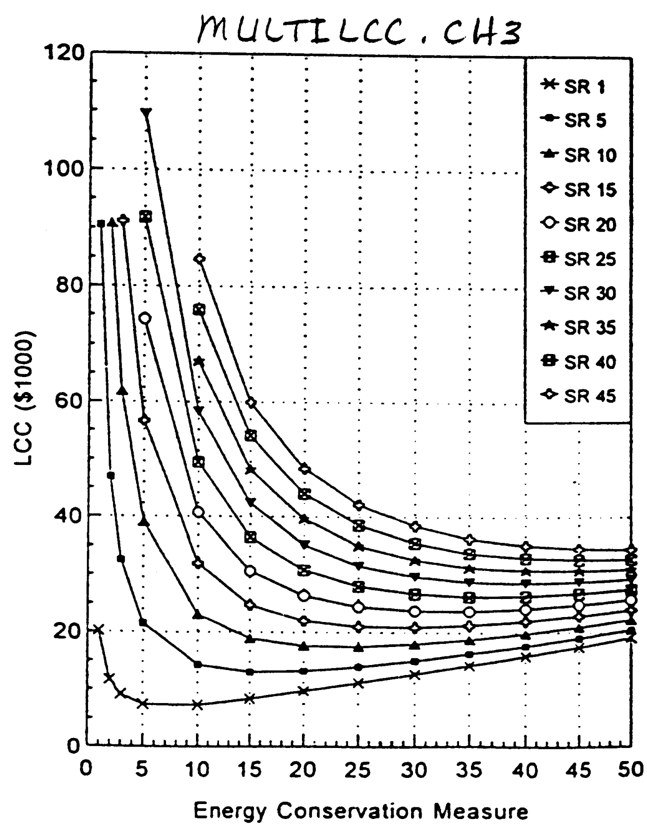

Figure 4 Life-cycle cost analysis.

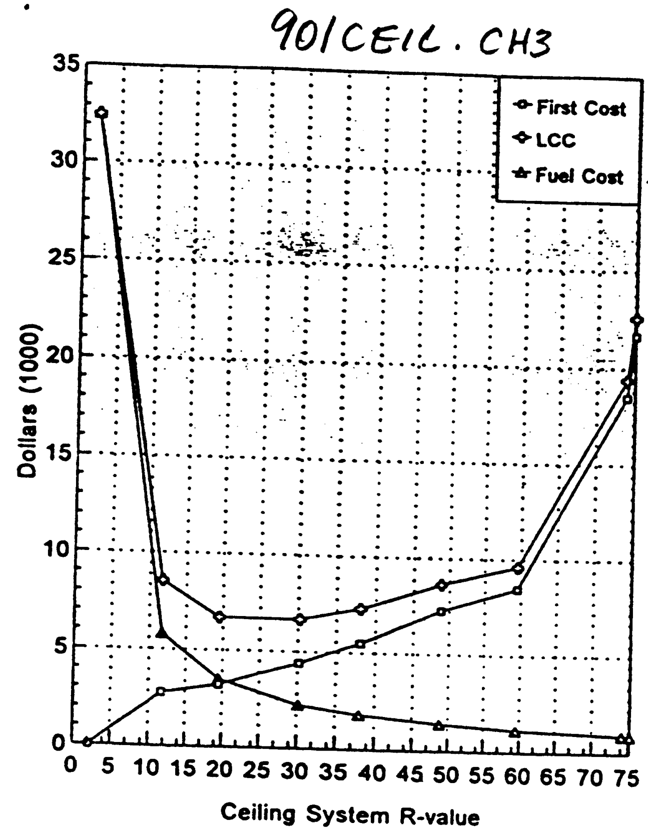

Figure 5 Office ceilings.

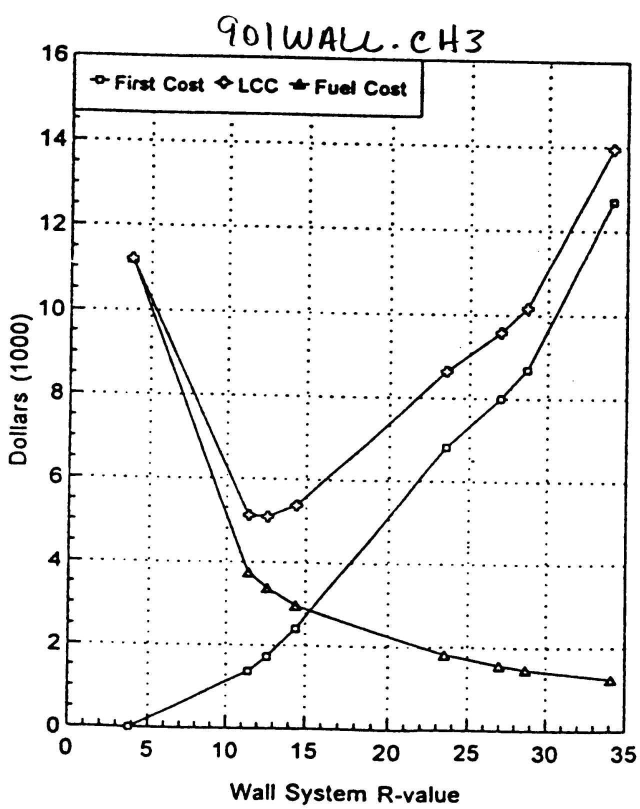

Figure 6 Office walls.

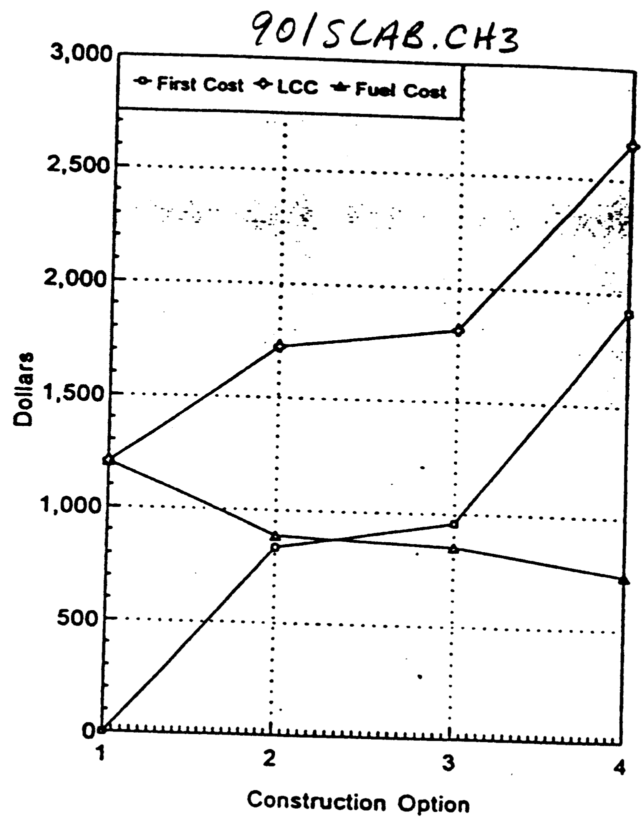

Figure 7 Office slabs.

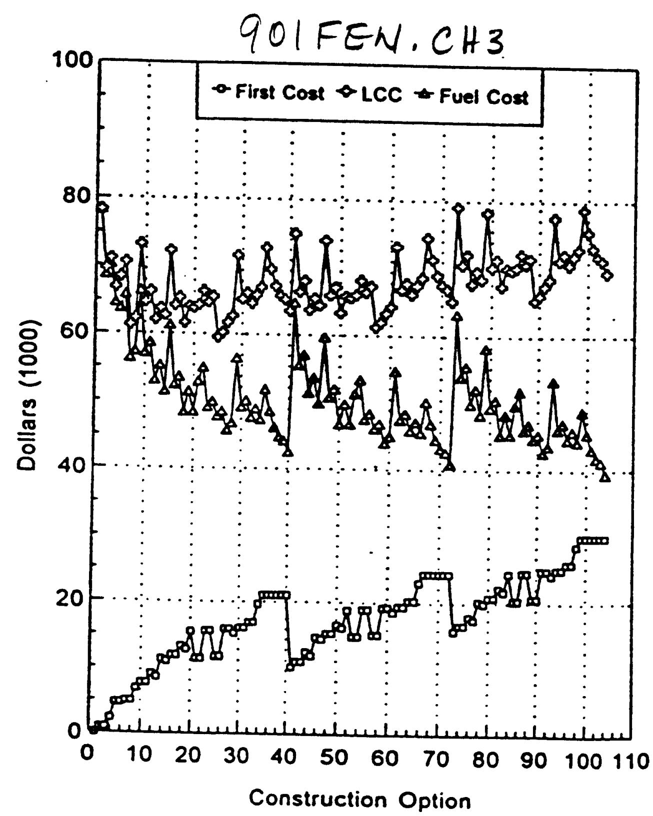

Figure 8 Office fenestration.

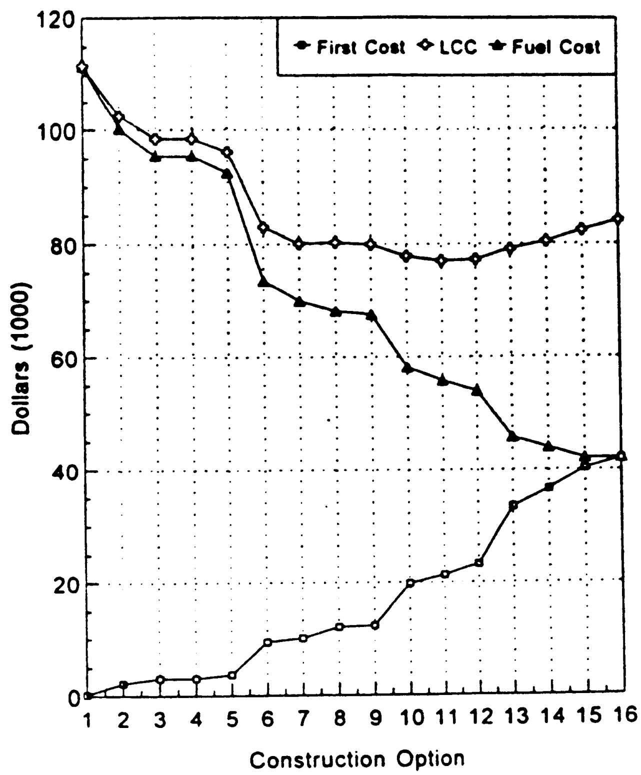

Figure 9 *Office lighting.*

TABLE 6 Office Combined Analysis

No.	Measure	Adj. W/sf Saved	Total W/sf	$/sf
0	Baseline	—	2.03	Base
1	Halogen downlights	0.15	1.88	0.01
2	T8 lamps/mag ballast—open areas	0.19	1.69	0.10
3	T8 lamps/mag ballast—private offices	0.08	1.61	0.14
4	T8 lamps/mag ballast—bathrooms, etc.	0.01	1.61	0.14
5	T8 electronic ballasts—private offices	0.05	1.56	0.17
6	Louvered troffer/T8 elec ballasts—open areas	0.32	1.24	0.43
7	Occupancy sensors—open areas	0.06	1.18	0.46
8	Occupancy sensors—private offices	0.03	1.15	0.55
9	T8 electronic ballasts—bathrooms, etc.	0.01	1.14	0.56
10	Compact fluorescent downlights	0.16	0.98	0.90
11	Daylight dimming—open areas	0.03	0.94	0.97
12	Daylight dimming—private offices	0.03	0.91	1.06
13	1-lamp fixtures + task lights—open areas	0.14	0.77	1.52
14	2-lamp fixtures + task lights—private offices	0.02	0.74	1.66
15	Lumen maintenance—open areas	0.03	0.71	1.83
16	Lumen maintenance—private offices	0.01	0.71	1.91
17	Reflective troffers	0.00	0.71	—

TABLE 7 Simple Payback Thresholds for Two Tiers

Measure Life	Tier 1	Tier 2
1	0.89	0.96
2	1.7	1.9
3	2.4	2.8
4	3.0	3.7
5	3.6	4.5
6	4.1	5.3
7	4.5	6.1
8	5.0	6.8
9	5.3	7.5
10	5.6	8.2
11	5.9	8.9
12	6.2	9.6
15	6.8	11.4
18	7.2	13
20	7.4	14
25	7.8	16
30	8.0	18

Book of Standards, vol. 04.07. Philadelphia, Pa.: American Society for Testing and Materials.

Petersen, S.R. 1993. Energy prices and discount factors for life-cycle cost analysis 1994. Annual Supplement to NIST Handbook 135 and NBS Special Publication 709. NISTIR 85-3273-8. Gaithersburg, Md.: National Institute of Standards and Technology.

15