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THE ECONOMICS OF INVESTMENT IN MOVABLE INTERIOR BLANKETS FOR FUEL CONSERVATION IN GREENHOUSES

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The Economics of Investment in Movable Interior

Blankets for Fuel Conservation in Greenhouses

by

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Abstract

A model for evaluating the economics of investment in Movable Interior Blankets for fuel conservation in greenhouses was developed. The after-tax costs and benefits of the blanket were analyzed using the Net Present Value method.

The model uses 13 input parameters to generate an estimate of the Net Present Value of the investment for its useful life. The results of two examples are reported. Sensitivity analyses were conducted to indicate the relative importance of the various input parameters. It was shown that changes in quantity or quality of crop would have very large effects on net present value. At this time, there is some disagreement regarding the effect of the blanket on crop growth. Further research is needed to substantiate and quantify the potential effect on yield and quality before the effect can be usefully included in estimates of net present value.

Other suggested areas of research include (1) improving the materials, design and use of the blankets, and (2) improving the ability to predict the performance of the blanket in specific greenhouses.

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The Economics of Investment in Movable Interior Blankets for Fuel Conservation in Greenhouses*

Introduction

The cost of fuel for heating greenhouses has increased greatly over the past few years and, in response, growers have taken various measures to minimize this cost. One such measure is the use of movable interior blankets which are pulled over the benches at night to reduce heat loss.

This report presents a framework for analyzing the costs and benefits of the blankets and has three objectives: (1) to present a model for estimating the net present value of movable interior blankets used for reducing greenhouse heating costs, (2) to suggest factors that should be considered by growers when deciding whether or not to install an interior blanket, and (3) to suggest research for improving the performance of movable interior blankets and for improving the ability to predict that performance.

Review of Literature

The use of movable interior blankets for reducing greenhouse heating costs has received attention in research publications and trade magazines. Most research publications (Albright, *et al*.; Rebuck, *et al*.; Simpkins, *et al*.; White, *et al*., 1978) and popularized accounts of research (White, *et al*., 1977; White, 1978) focus on the physical properties of blanket materials and the effects of interior blankets on heat loss. In these publications, researchers describe reductions in heat loss from experimental greenhouses attributable to the use of interior blankets. White (1978) cites similar reductions in commercial greenhouses.

In trade magazines, the costs and characteristics of alternative blanket materials and pulling systems have been compared (Ball 1977a, 1977b). These articles rely on subjective accounts about interior blankets in commercial greenhouses and on an array of alternative estimates of costs and heat savings.

The ability of interior blankets to reduce heat loss is well documented

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in research publications and described enthusiastically in trade magazines. However, most estimates of dollar savings from the use of the interior blankets are the result of casual analyses that lack the rigor of the underlying engineering analysis. The economic evaluation is commonly in terms of "payback period", the length of time required until total fuel savings from using the interior blanket matches the cost of the blanket. Published estimates (Correl and Pepper, White et al., 1977; Rebuck, et al.) of the payback for the interior blanket have been calculated by dividing the cost of the blanket by the expected annual fuel savings. These estimates do not reflect the time value of money, the possible increases in the price of fuel, nor the annual cost of owning, operating and maintaining an interior blanket. The following section describes a more comprehensive model for assessing whether or not investment in a movable interior blanket is profitable.

Present Value Analysis of Movable Interior Blankets: An Investment Decision Model

The Net Present Value Method

The costs and benefits of a movable interior blanket are spread out over the lifetime of the blanket. Since a dollar received today can be used for immediate consumption or to earn more than a dollar in the future, a dollar today is preferable to one in the future (Fisher, Aplin et al.) Accordingly, to compare costs and benefits that occur at different times, future costs and benefits should be discounted to reflect their lower relative value. The farther into the future, the more a dollar is reduced in value. The economic analysis of movable interior blankets presented in this report uses the net present value (NPV) method of investment analysis, which, unlike the payback period method, adjusts for the lower relative value of costs and benefits that occur in the future. The adjustment is made by converting future costs and benefits into equivalent present values. The present value is the amount paid or received today that would be equally preferable to the future cost or benefit. Once converted to present values, the costs and benefits of an interior blanket can be compared and the NPV can be estimated. A NPV greater than zero, indicating that time-adjusted benefits exceed time-adjusted costs, suggests that the investment should be made.

Assumptions

One assumption underlying this analysis is that the purchase of an interior blanket would not affect the financing or performance of other possible investments. The interior blanket is analyzed as being independent of all other investment opportunities. The estimates of net present value therefore indicate only the value of the interior blanket compared to the cost of capital. They do not indicate the value of the blanket compared to alternative investments.

For simplification, the model also does not include insurance costs, property taxes and accelerated depreciation. The importance of these factors for estimating net present value of interior blankets is uncertain (Ball 1977a, Casler 1979). The analysis could be modified to include these factors when they are relevant and significant. Furthermore, state investment credit is not considered in order to maintain a more general applicability for the model.

Parameters Included in the Analysis

The parameters for costs, benefits and related information used to estimate net present value of interior blankets are listed below in terms of dollars per square foot of greenhouse floor area.

H = Annual Cost of Heating Fuel. The annual cost in year 0 of fuel used to heat the greenhouse.

I = Percent Fuel Savings. The percent reduction in the amount of fuel used to heat the greenhouse resulting from the use of the interior blanket.

i = Annual Real Increase in the Cost of Fuel. The annual rate at which the price of fuel increases above the general rate of inflation.

Y = Change in Value of the Crop. Change in value of the crop due to changes in quality, quantity, and timeliness resulting from use of the interior blanket.

C_f = Cost of Fabric. The cost of the original fabric, cut, sewn and installed.

C_p = Cost of Pulling System. The cost of materials for suspending, and moving the fabric (motors, tracks, other hardware), the cost of modifying the greenhouse to allow installation and use of the blanket, the cost of installing all parts of the blanket except the fabric, the cost of professional help and the grower's own time needed to design the blanket.

n = Lifetime of the Pulling System. The number of years the interior blanket is expected to be used as dictated by durability of the pulling system, obsolesence and/or the grower's planning horizon.

x = Number of Fabrics. The number of fabrics, including the original, that is used during the lifetime of the pulling system. For example, if the fabric is replaced once during the lifetime of the system, x equals 2.

Op = Cost of Operating the Blanket. The annual cost of labor, energy and decision-making for operating the blanket.

R_a, R_p, R_f = Cost of Repair. Annual cost of repairing and maintaining the blanket. The cost of repair and maintenance may be estimated as a fixed annual amount (R_a) or as a percentage of the cost of the pulling system (R_p) and/or fabric (R_f).

r = Marginal Rate of Income Tax. The proportion of an additional dollar of gross income that is taken by income tax.

d_0 = Before-Tax Inflation-Free Discount Rate. The rate at which before-tax future income is discounted for conversion to present value. Multiplying d_0 by $(1 - r)$ provides the after-tax discount rate (d').

e_p, e_f = Proportion of Cost Eligible for Investment Credit. Federal investment credit is a deduction from income tax allowed for businesses making qualifying investments. The size of the allowed deduction varies with the cost and lifetime of the investment. For investments with lives of 7 or more years, a deduction equal to 10% of the full cost of the investment is allowed (e = 1). A deduction equal to 10% of two-thirds of the cost is allowed if the life of the item is 5 or 6 years, (e = 2/3), and 10% of one-third of the cost if the life of the item is 3 or 4 years (e = 1/3). No deduction is allowed for items with lives of less than three years (e = 0). The schedule below shows the relationship between the value of n and x and the proportion of the cost of the fabric (e_f) and pulling system (e_p) eligible for the 10% investment credit.[1]

$$e_p = 0 \text{ if } n < 3 \qquad e_f = 0 \text{ if } n/x < 3$$

$$= 1/3 \text{ if } 3 \leq n < 5 \qquad = 1/3 \text{ if } 3 \leq n/x < 5$$

$$= 2/3 \text{ if } 5 \leq n < 7 \qquad = 2/3 \text{ if } 5 \leq n/x < 7$$

$$= 1 \text{ if } n \geq 7 \qquad = 1 \text{ if } n/x \geq 7$$

Assessing Costs and Benefits

The analysis of interior blankets presented here is based on a partial budget; only costs and benefits resulting from the interior blanket were considered. The costs include additional expenses and reduced revenues; the benefits include additional revenues and reduced expenses. The projected costs and benefits associated with the interior blanket are based on the assumption that the prices of all relevant goods, inputs and services except fuel will change at the same rate. The price of fuel is assumed to increase relative to these other prices.

Using values for the parameters in the preceeding section, the NPV for the investment in the movable interior blanket may be calculated. The costs and benefits for the system are allocated to their respective time periods for the lifetime (n years) of the investment. Costs are (1) installation costs of the fabric (C_f) and pulling system (C_p) in year 0, (2) after-tax repair costs for both the fabric and the pulling system, and (3) after-tax operating costs. Benefits include (1) investment credit for both the fabric and the pulling system, (2) tax savings resulting from depreciation for both the fabric and the pulling system, and (3) after-tax fuel savings. The after-tax change in value of the crop may be either positive or negative, a matter which will be discussed later in this paper.

Costs

The purchase of the movable interior blanket is the first expense associated with investment in the blanket. Since the grower's preference for present income is assumed to equal the market rate of interest (see Appendix 1), the purchase price of the blanket can be represented as a lump-sum expense in year 0 (the year the purchase is made) regardless of whether the blanket is purchased with one payment or installments over the lifetime of the blanket. For this analysis, the purchase price of the interior blanket is separated into the price of the pulling system, C_p, and the price of the fabric, C_f. This separation is needed if the fabric has a shorter lifetime than the pulling system, since investment credit and depreciation vary with the lifetime of the item. The value for C_f should also be entered in the other years in which the fabric is replaced.

Expenses for operating and repairing the interior blanket are incurred throughout the lifetime of the blanket. After-tax repair and operating costs equal before-tax costs multiplied by the quantity one minus the marginal tax rate:

$$\text{After-tax repair cost} = (R_a + R_f C_f + R_p C_p)(1 - r)$$

$$\text{After-tax operating cost} = Op\ (1 - r).$$

In addition to these direct annual costs, the interior blanket may result in other indirect costs to the greenhouse business. Possible indirect costs of the interior blanket include reducing the efficiency or workers by interferring with their movements, increasing the maintenance needed on other equipment or structures and reducing the value of the greenhouse crop. For this analysis, the interior blanket is assumed to have no effect on the efficiency of labor or on the maintenance and use of equipment and structures.

Benefits

Investment credit which is recorded in year 1 using the convention presented by Aplin *et al.*, equals purchase price multiplied by (.1) and the proportion factor:

$$\text{Investment credit for the fabric} = C_f\ (.1)e_f$$

$$\text{Investment credit for the pulling system} = C_p\ (.1)e_p.$$

The credit for the fabric is also entered in subsequent time periods in the year after the fabric is replaced.

With straight-line depreciation, and assuming no salvage value, annual tax reductions resulting from depreciation equal purchase price divided by lifetime of the item, then multiplied by the marginal tax rate:

$$\text{Tax savings via depreciation of the fabric} = [C_f \div (n/x)]r$$

$$\text{Tax savings via depreciation of the pulling system} = [C_p \div n]r$$

The primary benefit of an interior blanket is that less fuel is needed to heat the greenhouse. The dollars saved each year depend on fuel prices and the effect of the blanket on fuel requirements. For this analysis, the amount of fuel saved by the blanket is assumed to be the same for each year in its lifetime, implying that climatic differences among years average out and fuel requirements and percent saved by the blanket are not affected by any other changes in the greenhouse. The price of fuel is assumed to increase at the same annual rate (i) throughout the lifetime of the blanket. Before-tax dollar savings for each year equals heating costs in year 0 multiplied by the percent saved by the blanket and the compound rate of increase in fuel prices. After-tax savings equal before-tax savings multiplied by one minus the marginal tax rate:

For year 1, after-tax dollar savings = $(H)(I)(1 - r)(1 + i)$

For year 2, after-tax dollar savings = $(H)(I)(1 - r)(1 + i)^2$

For year n, after-tax dollar savings = $(H)(I)(1 - r)(1 + i)^n$.

Change in Value of the Crop

The effect on the value of the crop is assumed to be zero for the basic analysis but the importance of potential negative or positive effects on the crop is discussed. After-tax change in the value of the crop equals before-tax change multiplied by one minus the marginal tax rate:

After-tax change in the value of the crop = $Y(1 - r)$,

which may assume either a negative or positive value, depending on the sign of Y. The value used for Y for quality changes is the lost or gained revenue from the lower or higher prices received for the plants. For quantity changes, or changes in timeliness, the value for Y is the price per unit of crop minus the direct (variable) costs of growing it, times the change in number of units sold per unit of time.

Calculation of Net Present Value

To adjust for the time value of money, the costs and benefits of the interior blanket were converted to present values using a discount rate representing the grower's relative valuation of present and future dollars. The basis for the discount rate used in the analysis is described in Appendix 1. For convenience, expenses and revenues were assumed to occur on the last day of the accounting year and were discounted to present value on an annual rather than a continuous basis. The costs and benefits can then be summed for each of the n years and discounted by the inflation-free, after-tax cost of capital, d' where:

$$d' = d_o(i - r).$$

The NPV of the investment is the sum of the discounted cash flow of costs and benefits for the n years of the life of the investment,

$$NPV = -C_f - \frac{C_f}{(1 + d')^{n/x}} - C_p + \frac{A_1}{(1 + d')^1} + \frac{A_2}{(1 + d')^2} + \ldots + \frac{A_n}{(1 + d')^n}$$

where A_i = Benefits minus Costs for each of the n time periods.

A Mathematical Model

The same estimate of total NPV can also be obtained without first estimating annual net cash flows by grouping cash flows by type of cost or benefit rather than by year of occurrence. Cash flows were grouped into four types: (1) savings from reduced use of fuel, (2) costs and benefits that were assumed to be proportional to purchase price of the pulling system (such as purchase price, investment credit, depreciation and in some cases repair costs), (3) costs and benefits assumed to be proportional to the purchase price of the fabric, and (4) other costs and benefits. The estimated total NPV of the blanket is the sum of the present values of the four types of cash flows. This approach is useful for determining the sensitivity of NPV to changes of various parameters in the model.

The present value of after-tax savings from reduced use of fuel over the lifetime of the interior blanket is

$$(H)(I)(1 - r)(1 + i)(1 + d')^{-1} + (H)(I)(i - r)(1 + i)^{2}(1 + d')^{-2} + \ldots +$$

$$(H)(I)(1 - r)(1 + i)^{n}(1 + d')^{-n}.$$

This series is a geometric progression, and can be represented as

$$(H)(I)(1 - r) \left[\frac{\left(\frac{1 + i}{1 + d'}\right)^{n+1} - \frac{1 + i}{1 + d'}}{\frac{1 + i}{1 + d'} - 1} \right]$$

The costs and benefits that are proportional to the purchase price of the pulling system include purchase price (C_p), investment credit ($C_p(.1)e_p$), and some costs and benefits that occur every year, such as tax savings via depreciation ($C_p\ r/n$) and in some cases repair costs ($C_pR_p(1 - r)$). For conversion to present value, a cost incurred in year 0 is not discounted; investment credit, a benefit in year 1, is discounted by $(1 + d')$. The equation for geometric progressions simplifies the calculation of total present value of recurring cash flows. For example, the total present value of tax savings via depreciation of the pulling system is the geometric progression

$(C_p\ r/n)(1 + d')^{-1} + (C_p\ r/n)(1 + d')^{-2} + \ldots + (C_p\ r/n)(1 + d')^{-n}$. This progression can be represented as $(C_p\ r/n)\ \dfrac{(1 + d')^{-(n+1)} - (1 + d')^{-1}}{(1 + d')^{-1} - 1}$,

or as $C_p\ r/n\ \dfrac{1 - (1 + d')^{-n}}{d'}$.[1/]

1/ Identifying $(C_p\ r/n)(1 + d')^{-1}$ as the first terms of a geometric progression

The total net present value of costs and benefits that are proportional to the cost of the fabric can be estimated using calculations similar to the ones used for the pulling system. If the fabric is replaced during the lifetime of the pulling system, estimates of total net present value include purchase price and investment credit for the replacement. The calculation of tax saving via depreciation is also adjusted to reflect the shorter life of the fabric. As before, the equation for geometric progressions simplifies the calculations for the fabric and for the fourth group of costs and benefits.

These equations are summarized as follows:

[1] Present Value of Fuel Savings

$$PV_s = (H)(I)(1 - r) \left[\frac{\left[\frac{1 + i}{1 + d'}\right]^{n+1} - \frac{1 + i}{1 + d'}}{\frac{1 + i}{1 + d'} - 1} \right]$$

[2] Present Value of Cost of Pulling System

$$PV_p = -C_p[1 - (r/n - R_p + R_p r)\left(\frac{1 - (1 + d')^{-n}}{d'}\right) - .1e_p(1 + d')^{-1}]$$

[3] Present Value of Cost of Fabric (when x = 2)

$$PV_f = -C_f[(1 + (1 + d')^{(-n/2)}) - (2\ r/n - R_f + R_f r)\left(\frac{1 - (1 + d')^{-n}}{d'}\right)$$

$$- .1e_f[(1 + d')^{-1} + (1 + d')^{-(n/2 + 1)}]$$

1/ leads to the simplified form $(C_p\ r/n)(1 + d')^{-1} \left[\frac{(1 + d')^{-n} - 1}{(1 + d')^{-1} - 1}\right]$,

or $(C_p\ r/n)\ \frac{(1 + d')^{-(n+1)} - (1 + d')^{-1}}{(1 + d')^{-1} - 1}$.

Multiplying by $\frac{1 + d'}{1 + d'}$ and rearranging terms gives a more commonly used

form: $\frac{1 + d'}{1 + d'} \cdot (C_p\ r/n)\ \frac{(1 + d')^{-(n+1)} - (1 + d')^{-1}}{(1 + d')^{-1} - 1}$

$= (C_p\ r/n)\ \frac{(1 + d')^{-n} - 1}{1 - (1 + d')} = (C_p\ r/n)\ \frac{(1 + d')^{-n} - 1}{-d'}$

$= (C_p\ r/n)\ \frac{1 - (1 + d')^{-n}}{d'}$.

[4] Present Value of Operating Cost, Change in Value of the Crop, and Repair Cost (as fixed R_a)

$$PV_{R_a, Op, Y} = (-R_a - Op + Y)(1 - r) \left(\frac{1 - (1 + d')^{-n}}{d'}\right)$$

[5] Net Present Value

$$NPV = PV_s + PV_p + PV_f + PV_{R_a, Op, Y}$$

Tables of the present value of one dollar and one dollar per period can be used to substitute for terms of the form:

$$(1 + d')^{-b}, \quad b = 1 \text{ or } = (n/x) + 1, \quad \text{and} \quad \frac{1 - (1 + d')^{-n}}{d'} .$$

Compared to calculating annual net present values, the calculations based on the four groupings are more convenient for use with hand calculators and for estimating the effect of changing the values assigned to the parameters. However, unlike calculations based on net annual cash flows, calculations based on the four groupings do not provide information about the time profile of costs and benefits of the interior blanket.

Analysis of Two Examples

Two example situations are analyzed to present a framework for applying present value analysis to interior blankets and to suggest which aspects are key ones for growers and researchers. Despite variability in and uncertainty about the parameters included in the analysis, the examples also provided a preliminary economic evaluation of interior blankets. These examples were chosen as representative of two classes of situations in which interior blankets are often installed.

The analysis presented here is strictly an economic analysis. The engineering and horticultural parameters such as percent fuel savings and effect on crop are not generated as part of the analysis; they are inputs to the analysis. Useful economic analysis depends on the accuracy of values assigned to those parameters. The values used in the analysis are based on information obtained from published descriptions of costs and performance of interior blankets (Ball 1977a, 1977b; Correl; Ross, et al.; Simtrac, Inc. price list) and from conversations with growers,[2/] a professional designer and installer

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2/ Four growers, who were among the early adopters of large, mechanized interior blankets, provided estimates of the costs and performance of the interior blanket.

of blankets [3] and researchers.[4]

Example One

This example is representative of professionally designed interior blankets that are motorized but manually controlled, aluminum-coated fabric suspended from tracks. For the example, the blanket is assumed to be installed in a glass house in which support posts, heating pipes and other obstructions increase the cost of installing the blanket, (Table 1).

The estimated net present value for Example 1 is -\$0.05 per square foot (Table 2), indicating that the discounted benefits of the interior blanket are slightly less than the discounted costs.[5] This estimate of net present value can be obtained more directly by using equations [1] - [5] that combine many of the steps used to describe cash flow (Table 2). Inserting values for Example 1 into equations [1] - [5]:

$$PV_s = (\$0.60)(35\%)(1 - .5)(10.27) = 1.078$$

$$PV_p = (-\$1.00)(.6836) = -0.684$$

$$PV_f = (-\$0.40)(1.1050) = -0.442$$

$$PV_{R_a, Op, Y} = (-0 - 0 + 0)(1 - .5)(8.752) = 0.00$$

$$NPV = 1.078 - 0.684 - 0.442 - 0$$

providing the same estimate of net present value, -\$0.05.

These equations are convenient for estimating changes in net value resulting from changes in values assigned to the parameters. For example, using the values for Example 1, a \$0.10 increase in the cost of the pulling system decreases net present value by \$0.07, (\$0.10 x .6836) (Equation 2). This change reflects the net effect of initial expense, tax deductions and repair costs, which are assumed to be a fixed percent of initial expense.

Similarly, a \$0.10 increase in the cost of the fabric decreases net present value by \$0.11, (\$0.10 x 1.1050), reflecting the net effect of the purchase of the original fabric and its replacement, tax deductions and repair costs (Equation 3).

3/ Employed by Simtrac, Inc., 8243 North Christiana, Skokie, Illinois 60076.

4/ Representing Cornell University, Pennsylvania State University, and Rutgers University.

5/ Subsequent analyses, using higher fuel costs and larger increases in the real cost of fuel that occurred in 1979, have indicated positive values for NPV.

Table 1. Values Used For Example I, Motorized Interior Blanket.

	Fabric	Pulling System
Cost Installed (C_f, C_p, in \$/ft.^{2})	\$0.40	\$1.00
Lifetimes (n/x, n, in years)	5 (x = 2)	10
Proportion eligible for Investment Credit (e_f, e_p)	2/3	1
Annual Repair Cost (R_f, R_p as % of C_f, C_p)	5%[a/]	5%[a/]

Annual Operating Cost (O_p) = \$0.00 per ft.^{2}

Reduction in Fuel Use (I) = 35%

Cost of Heating Fuel in Year 0 (H) = \$0.60 per ft.^{2} floor area

Annual Real Increase in Cost of Fuel (i) = 3%

Marginal Rate of Income Tax (r) = .50

Before-Tax, Inflation-Free Discount Rate (d_o) = .05

After-Tax, Inflation-Free Discount Rate (d') = $d_o(1 - r)$ = .025

Change in Value of the Crop (Y) = 0

a/ (R_a = 0)

Table 2. Cash Flow for Example I, Motorized Interior Blanket, in Dollars per Square Foot of Floor Area.

	Year										
	0	1	2	3	4	5	6	7	8	9	10
FABRIC											
Cost Installed	-0.400					-0.400					
Investment Credit		0.027					0.027				
Tax Savings via Depreciation		0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040	0.040
After-Tax Repair Cost		-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010
PULLING SYSTEM											
Cost Installed	-1.000										
Investment Credit		0.100									
Tax Savings via Depreciation		0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050	0.050
After-Tax Repair Cost		-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025
OTHER											
After-Tax Fuel Savings		0.108	0.111	0.115	0.118	0.122	0.125	0.129	0.133	0.137	0.141
After-Tax Operating Cost		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
After-Tax Change in Value of the Crop		0.00	0,00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SUMMARY											
Net Annual Cash Flow	-1.400	0.290	0.166	0.170	0.173	-0.223	0.207	0.184	0.188	0.192	0.196
Present Value of Net Annual Cash Flow	-1.400	0.283	0.158	0.158	0.157	-0.197	0.178	0.155	0.154	0.154	0.153

Net Present Value = -$0.05

If the cost of heating the greenhouse in year 0 is \$0.70 per square foot of floor area (\$0.10 higher than the previous estimate), then the net present value of the interior blanket would be increased by \$0.18, [\$0.10 x 35% x (1 - .5) x 10.27] (Equation 1).

If the interior blanket reduces fuel use by 40% rather than 35%, the 5% increase in savings increases the net present value by \$0.15, [\$0.60 (5%) (1 - .5)(10.27)] (Equation 1).

The equations can also be used to estimate the tradeoff among parameters. For example, if a grower considers using two layers of fabric to increase fuel savings, how much must fuel use be reduced to compensate for the additional cost? Using values from Example 1, an increase of \$0.40, doubling the cost of the fabric to \$0.80, reduces net present value by \$0.44 (Equation 3). Since a one percent increase in I results in a \$0.03 increase in net present value (Equation 1), the second layer of fabric must increase I by 15% (\$0.44 ÷ \$0.03) to result in a net increase in net present value.

Example Two

This example is representative of interior blankets that are designed and installed by the grower, manually operated, aluminum-coated fabric suspended from tracks. The blanket is assumed to be installed in a quonset house in which there are no obstructions to installation or use of a blanket. The values for the parameters are shown in Table 3.

The estimated net present value for Example 2 is -\$0.15 per square foot as calculated in Table 4.

Inserting the values for Example 2 into equations [1] - [5] gives:

$$PV_s = (\$0.60)(30\%)(1 - .2)(5.801) = 0.835$$

$$PV_p = (\$-0.25)(.7612) = -0.190$$

$$PV_f = (-\$0.35)(1.479) = -0.518$$

$$PV_{R_a, Op, Y} = (-.03 - .035 + 0)(1 - .2)(5.2421) = -0.273$$

$$NPV = 0.835 - 0.190 - 0.518 - 0.273$$

providing the same estimate of net present value, -\$0.15.

The effect on net present value resulting from a change in the parameters can be estimated and used in the same way that they were for Example 1. For example, if a grower suspects that the even temperature distribution and higher leaf temperatures provided by the interior blanket will increase the average annual value of the crop, how large must the increase be to result in a positive net present value for the blanket analyzed in Example 2?

Table 3. Values Used For Example 2, Manually Operated Blanket.

	Fabric	Pulling System
Cost Installed (C_f, C_p, in \$/ft.^{2})	\$0.35	\$0.25
Lifetime (n/x, n, in years)	3 ($x = 2$)	6
Proportion eligible for Investment Credit (e_f, e_p)	1/3	2/3

Annual Repair Cost (R_a) = \$0.03/ft.^{2} ($R_f = 0$, $R_p = 0$)

Annual Operating Cost (Op) = \$0.035/ft.^{2}

Reduction in Fuel Use (I) = 30%

Cost of Fuel in Year 0 (F) = \$0.60/ft.^{2}

Annual Real Increase in Cost of Fuel (i) = 3%

Marginal Rate of Income Tax (r) = .20

Before-Tax, Inflation-Free Discount Rate (d_o) = .05

After-Tax (d') = $d_o(1 - r)$ = .04

Change in Value of the Crop (Y) = 0

Table 4. Cash Flow for Example 2, Manually Operated Blanket, in Dollars per Square Foot of Floor Area.

	Year						
	0	1	2	3	4	5	6
FABRIC							
Cost Installed	-0.350			-0.350			
Investment Credit		0.012			0.012		
Tax Savings via Depreciation		0.023	0.023	0.023	0.023	0.023	0.023
PULLING SYSTEM							
Cost Installed	-0.250						
Investment Credit		0.017					
Tax Savings via Depreciation		0.008	0.008	0.008	0.008	0.008	0.008
OTHER							
After-Tax Fuel Savings		0.148	0.153	0.157	0.162	0.167	0.172
After-Tax Operating Cost		-0.028	-0.028	-0.028	-0.028	-0.028	-0.028
After-Tax Change in Value of the Crop		0.00	0.00	0.00	0.00	0.00	0.00
After-Tax Repair Cost		-0.024	-0.024	-0.024	-0.024	-0.024	-0.024
SUMMARY							
Net Annual Cash Flow	-0.600	0.156	0.132	-0.214	0.153	0.146	0.151
Present Value of Net Annual Cash Flow	-0.600	0.150	0.122	-0.190	0.131	0.120	0.119

Total Net Present Value = -\$0.15 per square foot

If the average annual value of the crop is \$4.00 per square foot of greenhouse floor area then a 1% increase in value of the crop increases the net present value of the blanket by \$0.17, [1% (\$4.00)(1 - .2)(5.2421)] (Equation 4). Assuming no change in variable costs, a 1% increase in the value of the crop is more than enough to result in a positive net present value.

Operating the blanket may have no cost if it does not increase work hours nor prevent the completion of other productive activities. For Example 2, reducing Op to \$0.00 increases net present value by \$0.15 [.035 (1 - .2)(5.2421)] (Equation 4), thereby reaching net present value equal to \$0.00, the breakeven point.

The effect on net present value resulting from a change in the lifetime (n) of the interior blanket is less obvious from the equations than the effects of changing C_f, C_p, I, and H since n appears in the equations in many places, as an exponent and linear term. The mathematical tool, partial differentiation, that was implicitly used to calculate the other effects could also be used to calculate the effect on net present value resulting from incremental changes in n. However, comparison of net present values for two values of n is best done by calculating net present value separately for each n rather than using the partial derivative. The equations are easier to use than the partial derivative and, unlike the effect of changing C_f, C_p, H and I, the effect of changing n depends on the value of n.

For Example 2, what is the effect on net present value of increasing the grower's planning horizon for the blanket from 6 to 8 years? Recalculating using equations [1]-[5], net present value is \$0.06 when n = 8 and the other parameters in Example 2 are unchanged.

$$PV_s = (\$0.60)(30\%)(1 - .2)(7.6615) = 1.103$$

$$PV_p = (-\$0.25)(.7355) = -0.184$$

$$PV_f = (-\$0.35)(1.4587) = -0.511$$

$$PV_{R_a, Op, Y} = (-.03 - .035 + 0)(1 - .2)(6.7327) = -0.350$$

This is an increase of \$0.21 over the net present value when n = 6.

The net present value of -\$0.15 estimated for Example 2 is based on the assumption that fuel prices will increase 3% per year faster than the general rate of inflation. A grower recognizing the uncertainty about future fuel prices may want to estimate the rate of increase (i) at which the net present value of the blanket would become positive. The partial derivative of net present value for incremental changes in i[6/] can be used to make this estimation. The change in i needed to increase net present value from -\$0.15 to \$0.00 can be represented as $\partial i \frac{\partial NPV}{\partial i} = \$0.15$. Using values for Example 2 and solving for ∂i, $\partial i = \frac{\$0.15}{\$2.928} = .051$. The rate of increase (i) must change by 5 percentage points, from 3% to 8%, in order for net present value of the blanket to reach the breakeven point.

Discussion of the Use of the Model and Results

Values Used For Parameters

Knowing the basis and implications of estimated costs and benefits used in the two examples is necessary for interpreting the results and using the analysis for other situations.

Annual Heating Cost

For estimating net present value, heating costs must be in the same units of measurement as the cost of the interior blanket. For the two examples, heating costs were assumed to be \$0.90 per square foot of bench area. Two-thirds of the area under the blanket was assumed to be bench area so the heating cost per square foot of area under the blanket was \$0.60. Annual heating cost for other situations varied with location, crop and type of greenhouse. With recent large increases in fuel prices, $\$.60/ft.^2$ is low. The appropriate value to use is the cost expected without the blanket in the base year, the projected year of installation.

Increasing Fuel Prices

For the two examples, the price of fuel was assumed to increase during the life of the blanket at 3% per year faster than the general rate of inflation. The 3% estimate is near the high end of the range predicted in a report by the U.S. Department of Energy (1978a). As a result of subsequent political events, the probability of reaching or exceeding a 3% rate of increase is now higher than suggested by the government report. Nonetheless, comparing fuel prices and the general rate of inflation in the recent past shows the importance of placing expectations about fuel prices within the context of other prices. For example, the U.S. Department of Energy (1978b) reports that during the two years prior to May 1978 the price of gasoline declined relative to the consumer price index. The U.S. Department of Agriculture

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$$\frac{\partial NPV}{\partial i} = (H)(I)(1-r)\, \frac{\left(\frac{1+i}{1+d'}\right)^n \left[(n+1)\left(\frac{1+i}{1+d'} - 1\right) - \frac{1+i}{1+d'}\right] + 1}{\left[\frac{1+i}{1+d'} - 1\right]^2 (1+d')}$$

reports that between February 1978 and February 1979 the general index of prices paid by farmers increased faster (13%) than the index of fuel and energy prices (11%).

Whatever the expectation about fuel prices the uncertainty about them is less damaging to the usefulness of estimating net present value than might be expected. For example, even if fuel prices increased at 6% higher than inflation, the net present value for Example 2 would be less than $0.09 higher. The effect would be greater for the longer-lived blankets, but as a source of variability the rate of price increase is overshadowed by uncertainty about other parameters such as percent fuel savings. These other parameters have a larger impact on net present value and potentially wider variation. The analysis presented here assumes implicitly that the rate of increase of fuel prices does not greatly exceed 3% higher than the general rate of inflation, but the model can accomodate any chosen rate of increase.

Fuel Savings

Results from experimental and commercial use of interior blankets suggest that a tightly sealed aluminum-coated fabric can provide 30 to 40% reduction in fuel use (Fries; Gardner; Lowman; Mears 1979; Pinchbeck; Rotz et al.; White 1978, 1979). Other fabrics and designs may provide less savings (Ball 1977a; Simpkins et al. 1978). In the future, thick blankets of solid material, tighter seals and multiple layers of aluminum-coated fabric may provide greater savings (Albright; White 1978). Refinement of criteria for deciding when to move the blanket may also provide additional savings (Seginer).

Effect on Value of the Crop

The analysis of the two examples suggests that interior blankets may not provide large positive net benefits if their only effect is to reduce heating costs. The desirability of interior blankets could largely depend on their effect on the value of the crop. Changes of only one or two percent in that value could greatly alter the net present value of an interior blanket.

Some growers (Fries; Gardner; Lowman; Pinchbeck) have reported that interior blankets have increased the value of their crop by maintaining desirable night temperatures during periods of extreme cold, by maintaining higher leaf temperatures and by resulting in a more even distribution of heat. These reports suggest that interior blankets may increase the average value of the crop and decrease the risk of loss. Alternatively, in areas where the amount of light is a limiting factor in production, productivity may be reduced if the retracted blanket shades the crop during the day (White et al. 1977; White 1978). Further research is needed to substantiate and quantify the potential effect on yield before the effect can be usefully included in estimates of net present value.

Cost of an Interior Blanket

The cost of an interior blanket varies with design, materials and the characteristics of the greenhouse in which it is installed. The estimates of cost used in Examples 1 and 2 are representative of those reported for aluminum-coated fabric on tracks by growers, manufacturers and trade magazines

(Ball 1977a, 1977b; Correl and Pepper; Fries; Gardner; Lowman; Mandel; Mears 1979; Pinchbeck; White 1979).

Partitioning total cost into cost of fabric and cost of pulling system can be done by estimating costs contributing to each during the initial installation or by estimating the cost of replacing the fabric. For using the equations, the latter method of estimation should be used since the equations are based on the assumption that the cost of replacing the fabric equals the cost of the initial fabric.

Since the analysis is based on costs per square foot of floor area, the cost of fabric that is hanging vertically must be divided by the horizontal dimensions of the blanket and included in cost per square foot of floor area. Similar adjustment is appropriate if the fabric is arched or peaked.

The major uncertainty about cost often may be the cost of modifying the greenhouse to permit installation and use of the blanket. Descriptions (Ball 1977a) of common modifications can help growers determine the extent of necessary modifications but the cost will vary according to the specific characteristics of the greenhouse and the need for professional help.

Despite uncertainty about the cost of modifications, growers should be able to obtain fairly precise estimates of cost of an interior blanket, especially as more is learned and published about the blankets. Cost estimates should therefore provide limits within which more uncertain estimates such as percent fuel savings are evaluated.

Lifetime of the Blanket

Estimating the lifetime of an interior blanket is likely to be more difficult than estimating cost. The lifetime of pulling systems made with aluminum tracks is limited more by possible obsolescence and the grower's planning horizon than by the durability of the material. The lifetime of the fabric depends on the durability of the material and the type of pulling system and greenhouse (White et al. 1977; White 1978; White et al. 1978). Even among aluminum-coated synthetic fabrics, expected lifetime varied considerably, growers predicting from 2 to 10 years (Fries; Pinchbeck). One such material, Al/Temp, is guaranteed for 3 years (Mandel). The 5-year lifetime used in Example 1 may be an overly optimistic estimate until water accumulation on the blankets can be prevented in a manner less damaging to the fabric than the common practice of puncturing the fabric to allow drainage.

Repair Cost

Repair costs vary with materials and design but can be expected to decline as both are improved. In the absence of previous experience, repair and maintenance cost for greenhouse equipment is commonly assumed to be 5% of the purchase price (Christensen). The implication that the cost of repairing an interior blanket increases in proportion to purchase price may be appropriate if higher purchase price is the result of greater complexity. It is not appropriate if higher purchase price reflects better materials and design.

The distinction between estimating repair costs as a fixed amount or as a percentage of purchase price is not important for estimating NPV of one blanket but is important for comparing two or more blankets that differ in cost. If lower rather than higher repair costs are expected for the more expensive blanket, then a fixed repair cost reduced by a percent of purchase price may be appropriate for estimating net present value.

Operating Cost

The annual operating cost of $0.035 per square foot (Table 3) estimated for Example 2 is based on the assumption of a labor requirement of 20 minutes per day for 210 days, at an hourly wage of $4, for blankets covering 8,000 square feet.

The cost of moving an interior blanket may significantly affect NPV if moving the blanket prevents completion of other work or lengthens the work day of the grower or employees. If the blanket is motorized and is moved during regular work hours, or automatically, then the cost of moving the blanket is insignificant. The cost is also insignificant for blankets that require only a few minutes during regular work hours to be moved manually.

In some greenhouses, manually operated blankets may be clearly impractical because of the size of the area and number of obstructions; in others, motorized systems may be clearly unnecessary. Between these extremes, the cost and probable performances based on purchase price, operating cost, tightness of seal and possible lag times should be compared in choosing between motorized and manually operated blankets.

In addition to the cost to move the blanket, the cost of deciding when to move it should be considered as an operating cost. With current operating practices this control cost is insignificant but could become important if recommended practices become more complex. In the future the decision to move an interior blanket may depend on light, temperature, crop development and the date. As decision making becomes more complex, growers may choose between spending more time to make decisions or purchasing an automatic control system.

Discount Rate

An appropriate discount rate for estimating net present value varies according to the grower's financial position and objectives. Appendix 1 provides some guidelines for choosing a discount rate; additional advice often may be needed. A rough estimate of discount rate can be adequate for obtaining estimates of net present value that are more useful than estimates made without discounting future income and expenses.

For the analysis, the discount rate is based on the cost of capital for investment. The grower was assumed to make investments with equal proportions of borrowed and own capital. The cost of borrowed capital was assumed to be 10%; the opportunity cost of own capital was assumed to be 16%. The resulting average cost was 13%. With an assumed inflation rate of 8%, the inflation-free cost of capital was 5%. The discount rate used in the analysis was 5% adjusted for income tax, which affects the net cost of capital to the grower.

The Decision to Purchase a Movable Interior Blanket

The model can be used by growers to estimate the net present value of an interior blanket for their particular situations. Uncertainty about costs and benefits can be handled by estimating NPV using a range of possible costs and benefits and by determining the costs and benefits for which the estimated net present value is zero, the breakeven point (Aplin et al.). Without fairly precise estimates for key parameters, the range of possible costs and benefits to be considered is unmanageably large. Cost of materials, current fuel costs and the length of the grower's planning horizon probably can be estimated more precisely than other elements in the analysis and can provide a firm basis for the analysis.

For estimating other parameters such as percent reduction in fuel use and effect on yield, the grower must rely on information about the performance of interior blankets in other commercial and experimental situations. The information available to the grower may suggest a range of possible costs and benefits. Using maximum, minimum and intermediate estimates of costs and benefits the grower can estimate a range of possible NPV's to help assess the likelihood of positive results.

The analysis presented in this report suggests that growers should focus on the following considerations when deciding whether to install an interior blanket:

(1) What are the costs and performance characteristics of fabrics and pulling systems (Ball 1977a; Correl and Pepper; Mears et al. 1977)?

(2) Will installation and use of an effective interior blanket require major greenhouse modification; and, will professional help be needed?

(3) What is the annual cost of heating the greenhouse and how much would be saved by an interior blanket? Will the savings differ from those reported for other greenhouses because of differences in location, crop, type of greenhouse or management practices?

(4) Considering durability, obsolescence and the planning horizon for the business, what is the expected lifetime of the interior blanket?

(5) How will the interior blanket affect the quality, quantity or timeliness of the crop?

(6) What are alternative uses for the money and time invested in an interior blanket? What are the investment priorities for the business? What are alternative means of reducing fuel use and providing a favorable environment for the crop?

The NPV of the blankets is certain to increase in the future unless they are superseded by alternative means of reducing heating costs. Higher fuel prices, better interior blankets and better understanding of how to use them would all increase the NPV.

Recommendations for Additional Research

Further research can contribute in at least two ways toward achieving optimal use of movable interior blankets:

(1) Improving the materials, design and use of interior blankets, and

(2) Improving the ability to predict the performance of an interior blanket in a specific greenhouse.

The first contribution increases the potential benefits of interior blankets; the second helps growers decide whether to install a blanket.

Improving Materials, Design and Use of Interior Blankets

The equations presented in this report can be used for preliminary assessment of the feasibility of a particular modification. For example, the additional fuel savings needed to offset the additional cost of using multiple layers of fabric can be estimated. The researchers' judgement about the feasibility of achieving that additional savings could contribute to decisions about development of multiple-layered blankets. Similarly, the amount a grower should be willing to pay for a modification in the blanket that would provide an additional 5% fuel savings can be estimated. This price ceiling might help guide development of modifications.

The model may help identify the parameters that are the most significant economically, but cannot help determine the best way to change those parameters. Such determination requires biological and engineering models.

The past performance of interior blankets suggests the following comments about additional research.

Materials

Improvement of fabric and pulling systems for thin blankets may be reaching a plateau (Mears 1979). Future development of heavy blankets and alternatives to movable interior blankets (Ball 1976, 1977b; Correl and Pepper; White 1978) may provide more cost effective means of saving fuel than are currently available.

Design

Condensation and resulting accumulation of water on top of the interior blanket is a common problem (Fries; Lowman; Pinchbeck; Mears 1979; White 1979) warrenting further research and the development of guidelines for design. Improvements in design may be focused on facilitating harmless drainage and/or reducing condensation. Reducing condensation by creating a more tightly sealed blanket would also increase fuel savings, a significant research objective in itself. Fuel savings, crop value, lifetime of the blanket and repair costs may all be affected by improvements that reduce condensation and water accumulation.

The effect of design on the value of the crops should receive major consideration. In addition to potential losses resulting from condensation and runoff, the value of the crop can be reduced by shading of a stored blanket (White et al 1977; White 1978). The potential reduction in income due to shading suggests that the design of blankets should minimize shading, perhaps even at the expense of some fuel savings.

The accumulation of snow on greenhouses in which interior blankets are used has been described as an important consideration in their design and use (Ball 1976, 1977a; White 1978). Retracting the blanket (Ball 1976, 1977a; White 1978) and leaving one heat pipe above the blankets (White 1978) have been recommended for preventing accumulation. Although the problem of snow accumulation may not have a large impact on the overall performance of interior blankets, some research may be warranted to determine if and how potential accumulation should influence the design and use of the blankets and heating systems.

Use

The focus of research on movable interior blankets may be shifting from technology to management (Mears 1979). The daily movement of the blanket distinguishes it from many other means of reducing heat loss. The opportunity for manipulation enhances the potential of the blanket as a tool for providing a favorable environment for the crop.

The decision to unfurl or retract the blanket is commonly made according to the influx of light or time of day. Development of more sophisticated decision rules (Seginer) that increase fuel savings and crop value offer perhaps the greatest potential for increasing the NPV of interior blankets. Development of these rules, however, may await greater understanding of the physiology of crop growth and the economics of uncertainty.

Increasing the Predictability of Performance

To help growers predict the performance of an interior blanket in their greenhouses, research should focus on parameters for which precise estimates are the most important and the most difficult for the growers to make. Use of the net present value equations reveals the importance of precise estimates for fuel savings, effect on crop and lifetime of the blanket. Growers have little basis for estimating these parameters for their greenhouses without an understanding of how environment, crop, greenhouse and management affect performance of interior blankets (Simpkins et al. 1976, 1978; White 1978). The range and breakeven methods for handling uncertainty are of little use unless the grower knows the range of likely values and the likelihood of reaching the breakeven point. Controlled experiments and surveys can help determine parameter values for a variety of greenhouse situations.

Appendix 1. Selecting A Discount Rate.

Use of the present value method for analyzing investment in an interior blanket requires selection of an appropriate discount rate for converting future costs and benefits into present values. The appropriate discount rate depends on the relative value of present and future income to the grower and opportunities for other investments. If the grower is assumed to have acquired a preferred combination of present and future income then the relative values of present and future income is equal to the relative costs of obtaining more of each. If relative value and cost were not equal then a more preferred combination of income could be obtained. Therefore, the selection of a discount rate that reflects relative value can be made on the basis of the relative cost.

The market rate of interest is a baseline for this cost but there is no single market rate of interest that is equally appropriate for all investments and all investors. Also, the amount of present income that can be obtained by the investor at one rate may be limited.

Over the long run for most investors, investments are made with a combination of borrowed capital and the investor's own capital. The cost of making an investment is therefore a combination of the cost of borrowed capital and the opportunity cost of using own income for the investment rather than other purchases. A discount rate reflecting the realtive value of present income should reflect this combined cost.

For the analysis of the interior blanket, the costs of borrowed and own capital are assumed to be 10% and 16% annual rates of interest, respectively. The higher rate for the use of own capital reflects the greater risk of loss faced by individuals investing in their own businesses than by lending institutions, which get first claim on the borrower's assets. Investments were assumed to be made with equal proportions of borrowed and own capital so the combined cost of capital was set at 13%.

Comparison of present and future income and selection of a discount rate are complicated by inflation, which causes a disparity between the nominal and real value of future income relative to present income. Equivalent estimates of net present value can be obtained by using costs, benefits and discount rate all in terms of nominal dollars, or by using costs, benefits and discount rate in terms of real purchasing power. The choice of nominal or real values is arbitrary but must be made consistently throughout the analysis.

Real values are used in the analysis of the interior blankets. All costs and benefits are in inflation-free 1979 dollars. An inflation-free discount rate of 5% was used in the analysis since the 13% nominal cost of present income translates into an approximately 5% real cost when inflation is assumed to be 8%.

The discount rate used in the analysis was also adjusted for income tax. This adjustment is appropriate since income from investments and interest from savings deposits are both taxed and interest paid on loans is tax deductible. In the analysis, costs and benefits were adjusted for tax payments and deductions and were converted to present values using a discount rate adjusted by the grower's marginal income tax bracket.

The discount rate for analyzing an investment can also be adjusted to reflect risk and uncertainty and the opportunities for other investments (Aplin et al.). The analysis presented in this report does not compare the interior blanket to other investment opportunities. Uncertainty about the net benefits of interior blankets was addressed using range and breakeven analyses. Consequently, the discount rate was not adjusted for either of these considerations.

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