ENERGY AND COST EFFECTIVENESS OF DESIGN ALTERNATIVES FOR AN ADMINISTRATION BUILDING IN KANSAS

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ABSTRACT - Energy simulations of an 11,000 square foot Army administration building to be constructed in Kansas were used to determine the most cost effective design alternatives. The energy savings were determined by simulating the building using the Building Loads Analysis and System Thermodynamics (BLAST) energy analysis program and the CEL-1 lighting program. This study was used to determine the cost effectiveness of using energy analysis programs to evaluate design alternatives.

A site-adapted standard design for a battalion headquarters and classroom. building was used to determine the energy savings and life-cycle savings of several design alternatives. Envelope alternatives included daylighting control, increased glazing, increased insulation, and reorientation. Four mechanical system types were considered to reduce the annual energy cost: multizone, dual duct variable volume (30% minimum air fraction), dual duct variable volume (20% minimum air fraction), and single duct variable volume. For each of these system types, a variety of additional options were evaluated including return air and enthalpy economy cycles, outside air controlled deck temperatures, zone controlled deck temperatures, and fixed deck temperatures. Both the variation in operating cost and the variation in life-cycle cost were calculated. Of the envelope alternatives, only reorientation of the building saved both operating cost and total life-cycle cost. Several other alternatives reduced operating cost but increased the total life-cycle cost. The variable volume fan systems reduced operating costs, but some increased life-cycle cost at the same time. The most effective alternatives were variable volume fan systems without expensive controllers. This is due primarily to high initial costs and relatively low fuel costs for the location; the first cost could not be recovered in energy cost saved.

This investigation also showed that if input models for energy analysis models are ordinarily created in the course of project design, as is true for Army designs, these models can be used to identify design alternatives which significantly reduce energy and total life-cycle costs at small expense. If the models do not already exist, the expense of developing the model solely for the evaluation of design alternatives may not be recovered in saved energy cost.

INTRODUCTION

Published Army design guidance for new facilities requires that each new facility designed for the Army be shown by the designer to be life-cycle cost effective and to comply with a published design energy budget for that facility. For most Army designs, compliance with the energy budget is shown by performing an energy analysis of the facility [1,2] using an hourly energy analysis program such as the Building Loads Analysis and System Thermodynamics (BLAST) [3] program and others. Typically, the analysis is performed after the facility design has been completed and the use of the energy analysis program to evaluate design alternatives to reduce the life-cycle cost of the facility does not have a major impact on the design. The objective of this study was to determine whether an energy analysis program could be effectively utilized during the design of the facility to improve both the energy efficiency and the life-cycle cost of the building.

DISCUSSION

A typical Army administration building design project, an 11000 square foot battalion headquarters and classroom building to be constructed in Kansas, was selected for the study. The original design produced by the designer for the project was a site adaptation of an existing standard design for a battalion headquarters and classroom building. An energy analysis of the design had been performed after the site adaptation was completed using the BLAST energy analysis program, and the design had been shown to comply with the design energy budget for the facility. This study used the BLAST program and the energy analysis model of the battalion headquarters building developed by the designer to identify energy and life-cycle cost effective alternatives to the original design which would be acceptable to the building owner/user.

The floor plan for the site-adapted standard design for the battalion headquarters building is shown in Figure 1. The building includes 11000 square feet of flat built-up roof and 5500 square feet of exposed R-13 exterior wall. The long axis of the building is oriented North-South so all the building's windows face East or West. The windows are double glazed with approximately 12% of the east exterior wall and 10% of the west exterior wall glazed. The building is served by a multizone fan system with zone-controlled deck temperatures and an enthalpy economy cycle operating year-round. Fuel costs to be used for life-cycle cost analyses on all buildings at this installation are extremely low. The natural gas unit charge is \$0.00252/kBtu and the electricity unit charge is \$0.0436/kWh (\$0.01278/kBtu). Escalation rates were calculated from data specified in the Federal Register[4] to be UPW*=17.042 for natural gas and UPW*= 12.767 for electricity for a 25 year project life.

The first step in identifying energy and life-cycle cost effective alternatives to the original design was to develop a list of possible building envelope and mechanical system modifications which would be acceptable to the building owner/user. Functional and maintenance constraints of the user severely restricted the envelope options which were available. Maintenance considerations also severely limited the mechanical system types and control options acceptable to the user. The acceptable potential envelope design modifications are shown in Table 1.

TABLE 1
BUILDING DESIGN ALTERNATIVES
ENVELOPE

* base case - standard building as designed
* daylighting control on lights in rooms with windows
* daylighting control, east and west glazing increased by 50%
* daylighting control, east and west glazing increased by 100%
* heavy insulation (R22) in walls
* super insulation (R38) in walls
* facility rotated 90 degrees

MECHANICAL SYSTEM
System type
* multizone
* dual duct variable volume (30% min)
* dual duct variable volume (20% min)
* single duct variable volume

Deck temperature reset controller
* zone controlled
* outside air (OA) controlled
* fixed setpoint

Economizer
* enthalpy (full year operation)
* enthalpy (cooling season operation)
* return air (full year operation)
* return air (cooling season operation)
*no economy cycle

Because the designer had not performed a daylighting analysis of the facility, a CEL-1 [5] input model had to be created for this study. As is usual for Army designs, an energy analysis model had been developed so that only small modifications to an existing input model were required to study the alternatives. Using the BLAST energy analysis model developed by the designer and the CEL-1 model created for this study, the design alternatives identified above were individually analyzed. Costs savings for the alternatives were computed as differences from the standard case (delta costs). In this way, it was not necessary to calculate the total life-cycle cost of the facility before the design was complete. The standard design then becomes the zero case for easier evaluation of the data. Both the variation in operating cost and the variation in life-cycle cost were calculated.

RESULTS

Figure 2 shows the savings generated by the envelope alternatives considered. Only one alternative, rotation of the building, produced a savings in both life-cyle cost (LCC) of energy and total life-cycle cost. Rotation moved the long axis of the building from North-South to East-West which provided better use of the available solar gain. Because this change incurs no first cost, the small savings in life-cycle energy costs results in a small total life-cycle savings. All other alternatives involved some increase in first cost which could not be

FIGURE 1 STANDARD DESIGN

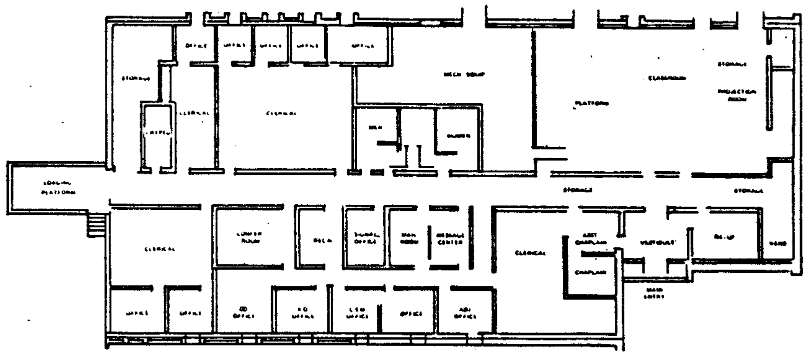
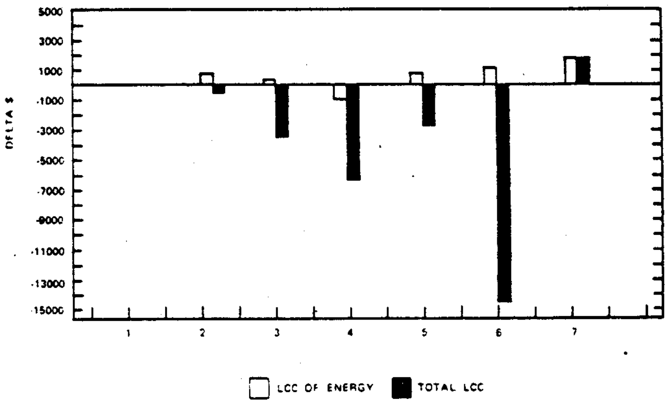


FIGURE 2·
ENVELOPE VARIATIONS – DELTA LIFE CYCLE SAVINGS



1 base case – standard building as designed
2 daylighting control on lights in rooms with windows
3 daylighting control, east and west glazing increased by 50%
4 daylighting control, east and west glazing increased by 100%
5 heavy insulation (R22) in walls
6 super insulation (R38) in walls
7 facility rotated 90 degrees

offset by the life-cycle savings in energy. The critical component in this situation is probably the anticipated cost of fuel. If energy costs are expected to be very high, more in-depth and costly investigations may be made into envelope variations. For this particular facility, the fuel costs are low, so that only the most economical energy conservation alternatives reduced total life-cycle cost. Minor modifications to the envelope reduced energy life-cycle cost only slightly and increased total life-cycle cost.

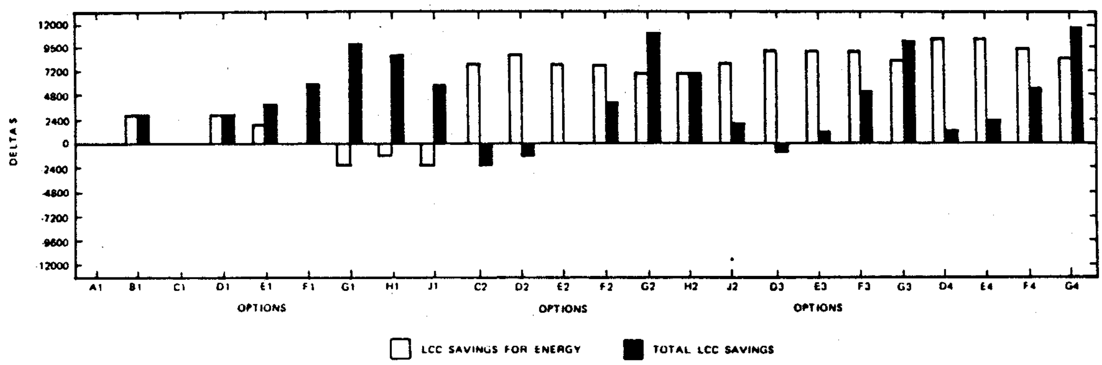
After the envelope alternatives had been analyzed, the "best" envelope design, alternative 7, was selected and the fan system alternatives were evaluated only for that envelope alternative. Fan system alternatives provided more opportunities for cost reduction as shown in Figure 3. The original list of fifteen control options (three deck temperature reset controls each with five economizer schemes) for each sytem type was quickly reduced. Only nine control combinations were actually studied as shown in Figure 3. Full year operation of both economizers for OA-controlled and fixed setpoint decks, were never evaluated since early tests verified that the economy cycle works against energy conservation outside the cooling season. Enthalpy economy cycles were eliminated because they did not prove to be substantially better than return air economy cycles and their unreliability in the field has been documented.[6] The cooling season enthalpy economy cycle for systems with zone controlled decks were modeled simply to show the effect of enthalpy economizers if they performed properly. They were not considered valid alternatives and are provided for information purposes only. Alternatives H3, J3, H4, J4 were not analyzed because a pattern which made it possible to deduce the effect of those alternatives became clear. Return air economy cycles were not showing significantly more energy cost savings than no economy cycle and the added first cost of the economizer reduced the total life-cycle savings. The number of studies required to give the information needed was reduced from 60 to 24. From the information obtained from the final list of fan system alternatives, the best alternative can be chosen based on either energy life-cycle cost reduction or total life-cycle cost reduction. Percent reduction in total energy consumption is also shown in Table 2.

TABLE 2
FAN SYSTEM OPTIONS
SAVINGS

options	delta life-cycle savings energy ($)	delta life-cycle savings total ($)	percent difference in total energy consumption (%)
A1	-	-	-
B1	3400	3400	-16
C1	-400	-400	+ 1
D1	3100	3100	-15
E1	1700	3700	-14
F1	100	6100	-12
G1	-2500	9500	-6
H1	- 600	9400	-8
J1	1800	5800	-14
C2	7700	-2200	-21
D2	8600	-1300	-26
E2	8400	500	-25
F2	8300	4400	-27
G2	7400	9500	-25
H2	7100	7200	-24
J2	8000	2100	-26
D3	8800	-1100	-26
E3	8600	700	-26
F3	8700	4800	-28
G3	8100	10200	-27
D4	10200	600	-26
E4	9600	2000	-26
F4	8800	5200	-28
G4	8400	10800	-27

If reduction in energy life-cycle cost was the primary criteria for evaluating alternatives, the high savings options are D4, a single duct variable volume system with zone controlled deck temperatures and a return air economizer operating only during the cooling season, or E4, a single duct variable air volume system with zone controlled deck temperatures and no economizer. These are not the most life-cycle cost effective alternatives, however. The most life-cycle cost effective alternatives are G4, a single duct variable volume system with fixed deck temperatures and no economizer, or G3, a dual duct variable volume system (20% min) with fixed deck temperatures and no economizer. If simple reduction in energy consumption were the objective of this study, the percent change in energy consumption data shows that the largest reduction in energy consumption (28%) is given by the

FIGURE 3
MECHANICAL SYSTEM VARIATIONS – DELTA LIFE CYCLE SAVINGS



SYSTEM TYPE

1 MULTIZONE
2 DUAL DUCT VARIABLE VOLUME (30% MIN)
3 DUAL DUCT VARIABLE VOLUME (20% MIN)
4 SINGLE DUCT VARIABLE VOLUME

CONTROLLERS

	DECK RESET CONTROL	ECONOMIZER
A	ZONE-CONTROLLED	ENTHALPY (FULL YEAR OPERATION)
B	ZONE-CONTROLLED	ENTHALPY (COOLING SEASON OPERATION)
C	ZONE-CONTROLLED	RETURN AIR (FULL YEAR OPERATION)
D	ZONE-CONTROLLED	RETURN AIR (COOLING SEASON OPERATION)
E	ZONE-CONTROLLED	NONE
F	OA-CONTROLLED	NONE
G	FIXED SETPOINT	NONE
H	FIXED SETPOINT	RETURN AIR (COOLING SEASON OPERATION)
J	OA-CONTROLLED	RETURN AIR (COOLING SEASON OPERATION)

dual duct variable volume system (20% min) and single duct variable volume system with outside air controlled deck temperatures and no economizer. These are closely followed, however, by most of the other variable volume systems.

The dollar value of fuel which could be saved in this case is very small even if the amount of fuel saved is substantial. Therefore,any significant expenditure for model building is difficult to justify if cost is the only criterion. The energy analysis model was already built, however, so the actual computer costs for investigating the energy impact of the alternatives was minimal. Excluding the cost of developing the input model to the daylighting study, the computer costs are less than $200 and labor time required to modify the energy analysis model and analyze the data should be less than two work weeks.

CONCLUSIONS

*If energy analysis models are already being created, as they are for all Army and many private sector designs, using them to determine the effectiveness of many design alternatives is relatively simple and economical.

*When energy analysis models do not exist or are not required for other reasons and the cost of energy at the location is small, the cost of developing computer models to study design alternatives may not be recovered.

*Significant reduction in both life-cycle cost of energy and total life-cycle cost can be identified by using energy analysis computer programs to aid in the decision process.

*When a large number of possible design alternatives have been identified, using engineering judgement to identify redundant studies during the course of the investigation as data becomes available can allow for a large amount of information for a small expense of time and money.

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