An Energy Responsive Building Application for New Commercial Construction

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The design team of a multipurpose college facility in Steamboat Springs, Colorado followed an *Energy Responsive Building (ERB) Design Process* for integrating energy efficiency into the building. Through this process, the Colorado Mountain College Multipurpose Building evolved from a design estimated to use nearly 110,000 Btus per square foot (Btu/sf) or 1,180 megajoule per square meter (MJ/m2) to a more efficient design at just over 70,600 Btu/sf (759 MJ/m^2). This 36 percent site energy reduction will save the college at least $17,000 annually.

More significantly, the ERB approach helped steer the design team away from a relatively inefficient alternative proposed for saving capital costs. This alternative included replacing the original evaporative cooling and hydronic heating system with a relatively inefficient, less expensive HVAC system. Comparing the final ERB design against the reference case with this relatively inefficient HVAC system results in over 3.8 billion Btus (4,000 GJ) and $48,000 saved annually. Even with the oversized heating equipment, this results in a simple payback of 4.7 years and nearly a 24 percent rate of return (ROR) over most of the equipment's economic life.

The ERB process (Robbins, 1990) was founded to assure energy efficiency considerations are included in the design of new construction projects. The ERB process accomplishes this by following the same general phased approach used in a typical building design. The final product from this process is a cost-effective yet practical design that optimizes efficiency within the framework of the other architectural requirements. The CMC Multipurpose Building design demonstrates these benefits of using the ERB process for new construction programs.

Introduction

A college located in the relatively cold mountain climate of Steamboat Springs, Colorado, wished to incorporate energy efficiency into their proposed Multipurpose Building. This college facility is designed as a 45,000 sf (4,200 m^2) building that houses faculty offices, science and computer labs, a library, and a gym/meeting room. The Project's architects and the college hired an independent building energy consultant for advice on designing a cost-effective "energy responsive building (ERB). To do this, the design team followed an ERB design process to help create an energy efficient building.

This paper focuses on the energy use and costs associated with this final energy efficient design. First, I present some information on the ERB process and its application to the CMC Multipurpose facility. The intent of this paper, however, is not on the details to implementing this process. Next, I discuss the energy analysis involved in the design process. This is followed by final economic analysis results for the ERB measures as compared to a base case without these measures. Finally, I conclude with a brief summary of the ERB process "in action" and its significance to new construction projects.

What Is Energy Responsive Building (ERB) Design?

A prime reason for integrating energy efficiency into a new facility is to avoid "lost opportunities" by conserving energy, dollars, and environmental resources before it is built. The ERB process avoids these lost opportunities through cooperation with an architectural design team. This involves analyzing energy efficiency opportunities throughout the phased architectural design process--from "pre-design analysis" to "design development," and on through the "post-occupancy phase." Additionally, a key aim of the ERB design process is for the corresponding utility bill savings to outweigh the incremental costs of energy efficiency measures over an acceptable time period. The design can include more energy efficiency measures with early involvement in the design process since it generally costs less to include them in the design than in later retrofit situations. Thus, the ERB process compliments the phased architectural design process to arrive at an efficient, cost-effective, and practical building design.

How did the ERB process direct the design toward an efficient, yet practical final product? In general, we introduced energy efficiency measures into the design following the *ERB Analysis Process* shown in Figure 1. This diagram shows the steps followed through each phase of the design process leading to the final ERB design. More specifically, it shows the conceptual and actual steps followed for analyzing energy efficiency aspects of the Multipurpose facility.

A reference pre-design energy model was built as the first step of the ERB process. We did this to simulate how the building would use energy if constructed using typical practices. This "PDA Reference" model (see Figure 1) also included initial design features the design team was fairly sure would be in the final product. For building components unknown at the time, we made assumptions based on local construction practices. Next, we set pre-design ERB goals for guiding the design toward an energy efficient building. This is shown as step 2 in Figure 1.

How did we decide what energy efficiency measures to plug into the initial design? As an initial thrust, we presented an array of opportunities for initial consideration. These ranged from efficient lighting systems to heat recovery approaches, and from daylighting techniques to air destratification. All of these measures were screened for their potential savings and approximate cost-effectiveness to determine which energy efficiency measures to plug into the design.

Most of this screening occurred during the “schematic design phase.” As the design process shifted into this phase, the design team altered certain features of the building for reasons not related to energy efficiency. These changes are referred to as “non-ERB changes” in Figure 1. Thus, screening potential ERB goals required incorporation of ERB measures into an altered reference building. In other words, the original base case “shifted to the right” (Figure 1) and had to be updated for new design changes to the building’s form or function. Conceptually, this altered reference building would be the “Updated” PDA Reference shown in Figure 1.

From here, the ERB analysis process could proceed by analyzing the ERB Goals (step 3) filtered out from the schematic design phase. Since the main objective is to arrive at a final ERB design, the analysis fast-tracked directly to step 3 by including the desired energy efficiency measures into the schematic design phase’s ERB energy model. Finally, the last step involved analyzing the most acceptable and cost-effective ERB features as part of the final design in the design development phase.

How Energy Efficient Is the Design?

Detailed energy analysis is the backbone of the ERB process. It involves performing computer energy simulations, reviewing building plans, and performing hand calculations to determine energy savings. For performing computer simulations on the CMC building, we used an hourly computer energy simulation program. This program quickly performs energy calculations for each hour of the year using weather data and inputs describing the building. Additional computer processing tools also were developed to enhance and supplement the simulation process.

This section presents results of the energy analysis process which illustrate the importance of energy analysis for justifying the installation of energy efficiency measures. First, I describe the pre-design analysis reference building (referred to as the "Original PDA Reference"). This is followed by a description of the latest design development ERB model (referred to as the "DD ERB Design"). Discussions of both models present relative energy use and corresponding utility bill results.

"Original" Schematic Design Reference Building

We first analyzed energy use characteristics for the CMC Multipurpose Building in February, 1991. This analysis involved creating a pre-design energy model using parameters describing the anticipated components of the early design. ERG used this model as the original reference building for comparison to subsequent ERB designs (refer to steps 1 and 2).

Of the many components targeted for efficiency improvements, Table 1 lists the key components of this reference which the design team later changed in the final ERB design. In addition, this table describes the HVAC system the design team considered replacing with a less efficient system for budgetary reasons. Thus, the original reference actually included a relatively efficient evaporative cooling and hydronic heating system with VAV ventilation. This introduces a common problem with determining justifiable savings: what is the “base case?” I will come back to this problem later in this section.

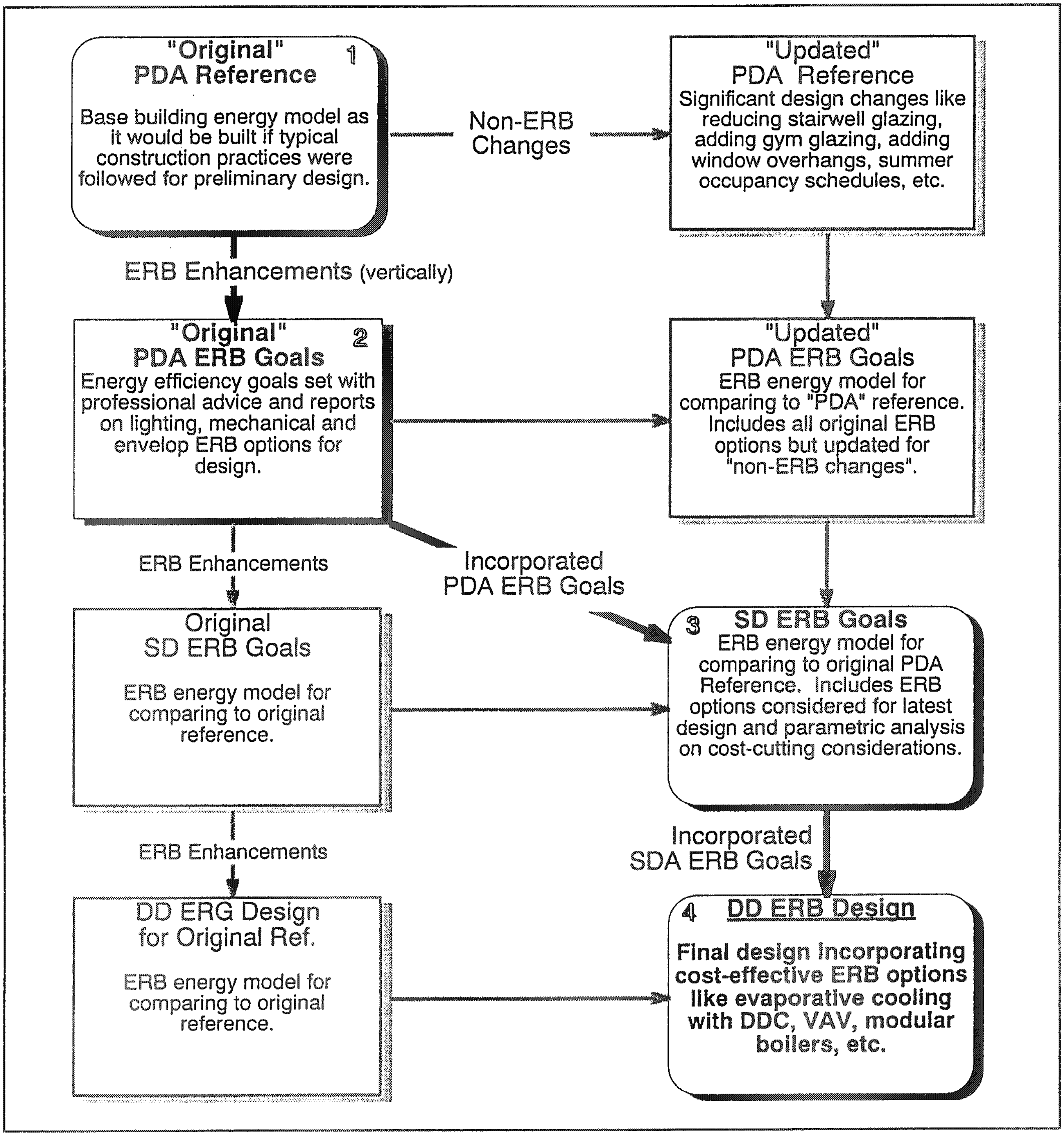

Figure 1. ERB Analysis Process for the CMC Multipurpose Building

Table 1. Key Pre-Design Analysis Reference Building Characteristics

Anticipated PDA Reference Components:

- R-12 insulated exterior walls
- R-15 insulated roof
- R-14 insulated ground floor above crawl space
- R-8.3 perimeter insulation around basement walls
- Typical lighting system resulting in 2 watts per square foot
- Standard HVAC controls
- Direct/indirect evaporative cooling with hydronic heating sized in accordance with ASHRAE Standard 90.1

Considered during design development:

- roof-top heating/ventilation units with constant volume DX cooling to replace PDA Reference HVAC system

The original reference building would have used nearly 110,000 Btu/sf (1,180 MJ/m^2), resulting in over $57,000 in annual utility costs (using relatively low 1991 utility rates[1]). Of this cost, lighting accounts for the greatest share at over 44%, or over $25,000 (Figure 2). However, lighting only accounts for the second greatest share of site energy use at 26% (20,600 Btu/sf or 307 MJ/m^2). Heating has the greatest share of annual energy use at 46% (50,600 Btu/sf or 544 MJ/m^2), yet it only accounts for approximately 14% of the total annual utility costs.

Heating accounts for a relatively small portion of the utility costs, but almost one-half of the energy use because overall electricity rates are about five to six times higher than natural gas rates. Therefore, ERB measures focused on electric end-uses, which likely would prove more

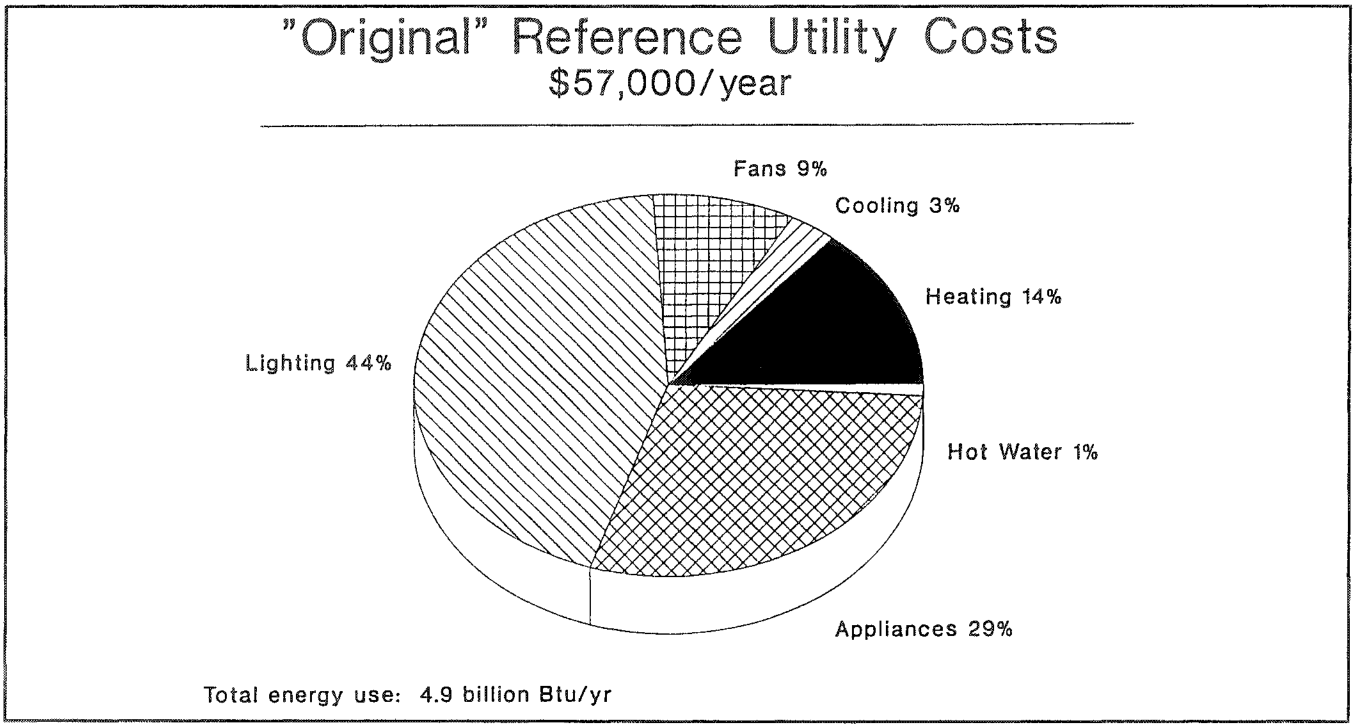

Figure 2. Pre-Design Analysis Reference Annual Utility Costs by End-Use

cost-effective than natural gas end-uses. However, we did not ignore ERB measures for saving natural gas since many opportunities exist for improving heating efficiencies. Further, the cost of natural gas may increase at a greater rate than electricity in the future[2].

Final Design Development Building

After analyzing the energy use characteristics of the original reference case, the ERB process shifted quickly toward creating an efficient and cost-effective final design. This involved performing additional computer energy analysis for assessing the potential impact of ERB measures on the schematic design. The design team then decided on the appropriate ERB measures for the final design (refer to steps 3 and 4 in Figure 1).

Table 2 lists the key components of the ERB goals which the design team changed from the original reference building. These changes then were incorporated into the design development ERB. Notice that the HVAC system is identical to the original reference except for the removal of *indirect* evaporative cooling. This change resulted as a compromise from budgetary pressures to replace the entire evaporative cooling and hydronic heating system with the less expensive roof-top system (see Section 5.2.3).

The final ERB design will use just over 70,600 Btu/sf (759 MJ/m^2), resulting in under $40,000 in annual utility costs. Of this cost, appliances such as computers and copiers account for the greatest share at over 41%, or over $16,000 (Figure 3). Although the ERB process targets all end-uses, equipment represents a vast opportunity that the architectural team did not address. Instead, it was left to the owners to install efficient general equipment. Appliances, however, only account for the second greatest share of energy use at 26% (18,500 Btu/sf or 199 MJ/m^2). Heating, on the other hand, has the greatest share of annual energy use at nearly 38% (26,600 Btu/sf or 286 MJ/m^2), yet it only accounts for approximately 11% of the total annual utility costs.

The ERB design significantly improved its energy efficiency in comparison to the original reference case. Annual energy use decreased by nearly 36% (39,300 Btu/sf or 422 MJ/m^2 site energy), resulting in annual utility bill savings of over $17,300 (Figure 4). Of this decrease, lighting accounted for the greatest bill savings at approximately $11,000 (not including heating and cooling effects). On a pure energy basis, heating decreased most significantly--by nearly 48% (24,100 Btu/sf or 259 MJ/m^2). This even includes the added heating requirements which compensates for the decreased lighting loads.

What Is the "Real" Base Case?

The design team seriously targeted the HVAC system later in the design development phase as an area for possible budget cuts. An alternative system included replacement of the base system with less efficient roof-top packaged units with forced air heat. The original reference

Table 2. Key Design Development ERB Characteristics

- R-16 insulated exterior walls
- R-30 insulated roof
- R-25 insulated ground floor above crawl space
- R-12.5 perimeter insulation around basement walls
- Highly efficient lighting system resulting in 1.2 watts per square foot:
  - T-8 lamps with specular reflectors and electronic ballasts,
  - occupancy sensors
  - step dimming
- DDC "smart control" of space temperatures and HVAC equipment schedules using an energy management system (EMS)
- Outside air reset on boiler
- Highly efficient modular boiler system
- Direct evaporative cooling with hydronic heating[3]

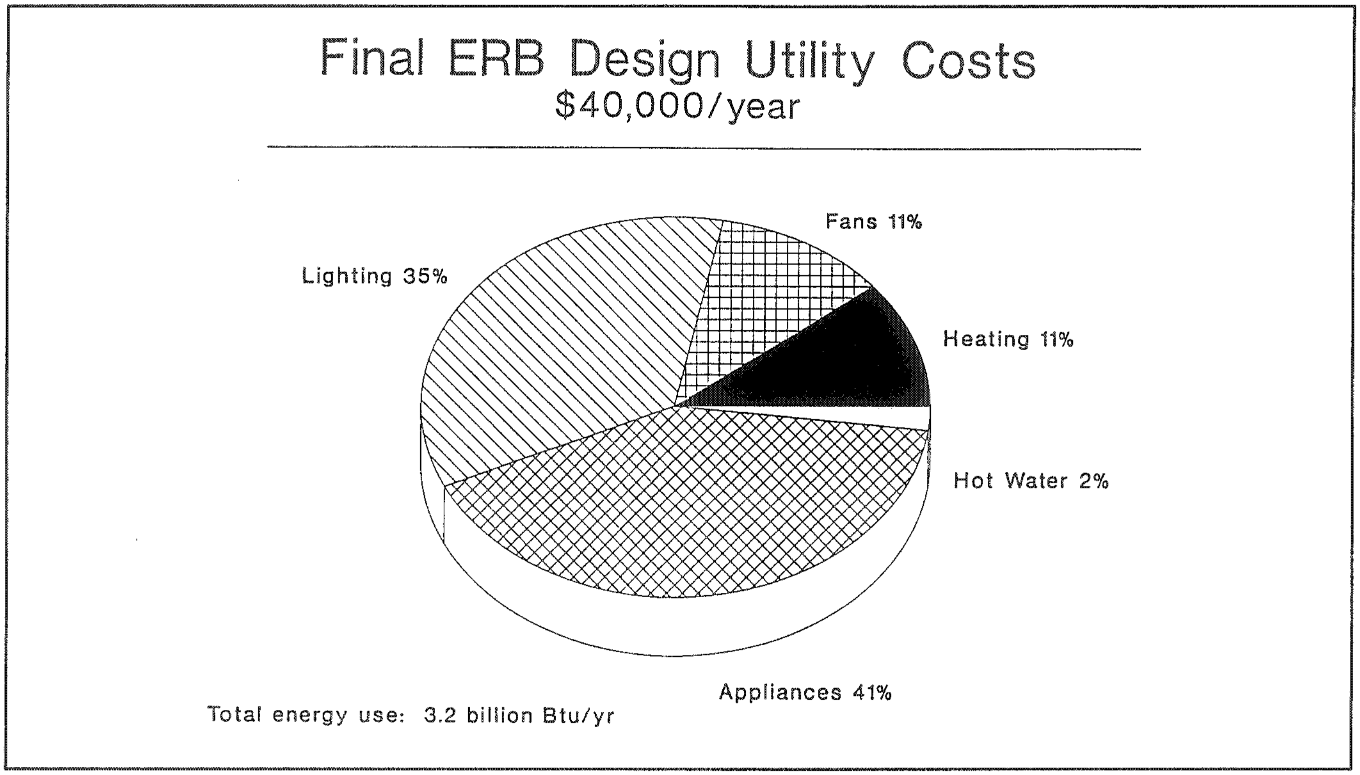

Figure 3. Design Development ERB Annual Utility Costs by End-Use

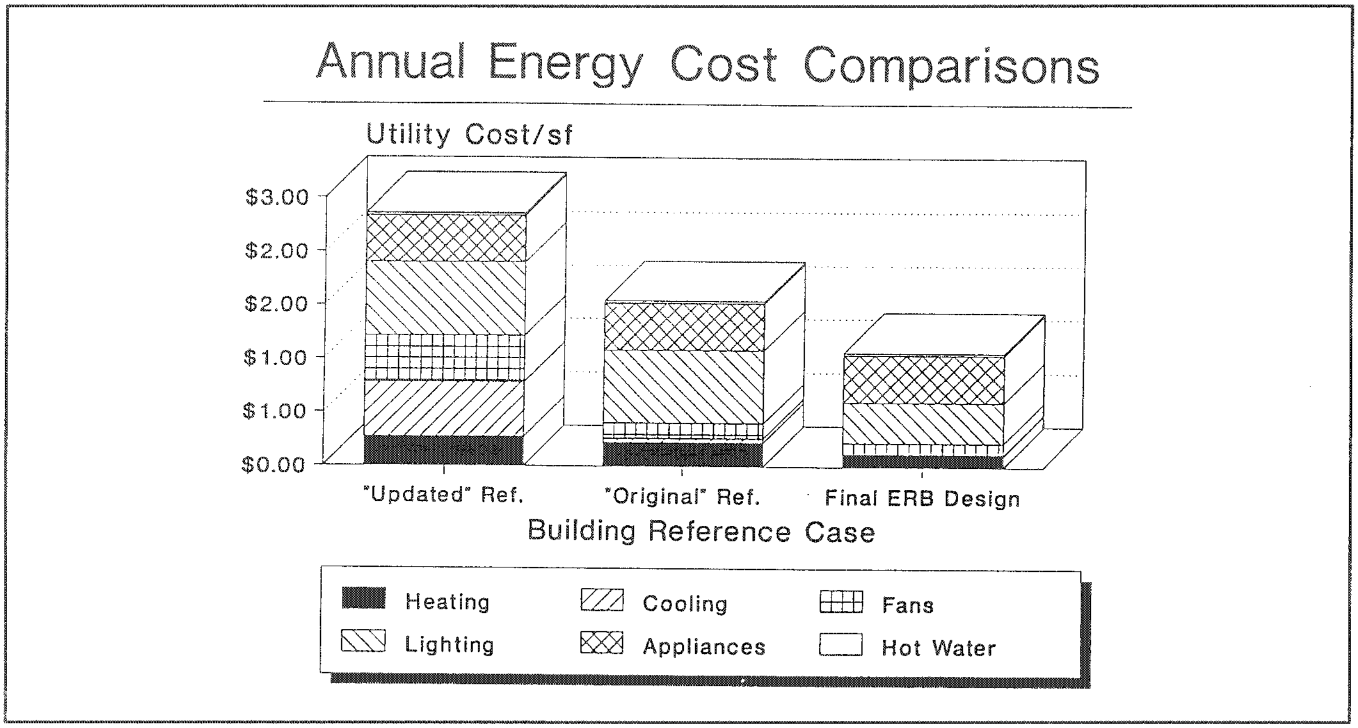

Figure 4. Annual Energy Cost Comparisons by End-Use

building would have used significantly more energy if this relatively inefficient system were chosen. In fact, the PDA Reference would have increased its energy use to nearly 156,000 Btu/sf (1,680 MJ/m^2), resulting in over $90,000 in annual utility bills. This particular design case is referred to as the "Updated" PDA Reference in Figure 1, or simply the "updated reference building."

Comparing the final ERB design to this updated reference building with the more typical HVAC system results in even greater savings. As Figure 4 shows, annual energy use is nearly 55% (85,000 Btu/sf or 916 MJ/m^2) less in the final ERB design. This results in utility bill savings of almost $50,000 annually. Thus, installing the more efficient system with evaporative cooling and VAV saves about $31,000 per year by itself (not including controls).

As this paper illustrates, specifying the appropriate base case for determining energy and dollar savings is not a trivial task. For the client, we emphasize the original reference case to show "where we were" as compared to "where we ended up." And although the updated reference case is presented, it somewhat represents an exaggerated case to the client - even though it represents "where we would have been" without the ERB process.

The updated reference case becomes very useful, and is justified, when using it as a reference for a state or utility loan, grant, or rebate. This is because many programs require savings estimates based on comparisons to more typical HVAC systems. Consequently, using the updated reference case as the "base case" more closely resembles typical building construction including a more typical HVAC system.

But Is It Cost-Effective?

A main objective of the ERB design process is to create a building which *cost-effectively* incorporates energy efficiency into its design. The energy efficiency measures integrated into the final ERB design meet this objective. Table 3 shows results for the annual utility bill savings and incremental installation costs. This table also shows the energy savings associated with key "packages" of related ERB measures.

On an individual basis, the HVAC measures are the most cost-effective in comparison with the roof-top unit/forced air system considered during the later stages of the design process. As Table 3 shows, the HVAC system combined with controls and insulation measures (i.e., all non-lighting measures) saves over $0.80/sf ($8.61/m^2) or $36,000 annually. The upgraded lighting system also is cost-effective on an individual basis--saving nearly $0.33/sf ($3.55/m^2) annually. This estimate includes the cost of added heating requirements and the savings from reduced cooling needs.

The "final ERB" in Table 3 combines all of the ERB measures into the same case. Note that the combined effect of all of these measures together is *not* the same as simply adding the measures together. In brief, this is because of the interaction between the different measures. For instance, the HVAC and controls will save a little less than shown since 1) the lighting upgrades reduce the "individual" cooling savings and 2) insulation reduces the individual heating savings. The reduced cooling savings when combined with lighting is slight, however, since down-sizing, the cooling plant effectively reduces the impact of seasonal changes in efficiency (compared to the original reference case).

On an overall basis, Table 4 show results of the life-cycle economic analysis performed for the college Multipurpose Building.[4] These results show the simple and life-cycle (or actual) payback periods. In addition, the net present value (NPV) per square foot, internal rate of return (ROR), and the benefit-to-cost ratio (B/C) over a 15-year span are shown. Finally, Table 4 presents the 15-year levelized annual cost (LAC) of saved energy; this may be thought of as the cost of conserved energy.

Table 4 shows two cases for the different funding mechanisms of: 1) paying for the incremental costs of the ERB measures up front ("w/No Loan") and 2) obtaining an Institutional Loan Program (ILP) grant for the incremental cost from the state. Both cases prove cost-effective. The first case involves paying for all incremental costs (including this ERB study) without using borrowed funds. The second case involves obtaining a Colorado State ILP loan for the incremental cost of the ERB measures. These loans are available for energy conservation projects at a six percent interest rate payable over a term determined by the payback period.

Both cases include all estimated incremental costs for incorporating the ERB measures listed previously in Table 2. These costs amount to approximately $229,000 including consultation fees for the ERB analysis. The cost of the ERB study, however, was not included in the loan for the analysis with an ILP grant. This is because the Colorado Office of Energy Conservation will only pay for incremental *installation* costs.

Table 3. Estimated Costs and Savings of ERB Measures

ERB Case	Annual Utility Bill $/sf ($/sq. m)	Utility Cost Savings $/sf ($/sq. m)	Added Installed Cost $/sf ($/sq. m)	Simple Payback in Years
Updated Reference Building with ...				
RTUs w/Forced Air	$1.96 ($20.0)	Not applicable since this is the base case.		
Lighting Upgrades	$1.64 ($16.7)	$0.33 ($3.4)	$1.53 ($15.6)	4.7
HVAC and Other	$1.15 ($11.7)	$0.81 ($8.3)	$3.02 ($30.8)	3.7
Final ERB Design	$0.88 ($9.0)	$1.08 ($11.0)	$4.56 ($46.5)	4.2

Table 4. Design Development ERB Economic Analysis Results

Funding	Payback in Years		15-Year Economic Indicators			
Mechanism	Simple	Life-Cycle	NPV/sf	ROR	B/C	LAC[a]
w/No Loan	4.7	5.9	$5.00	23.6%	2.0	$7.14 ($6.77)
w/ILP Grant	4.7	5.2	$5.47	48.0%	2.2	$7.85 ($7.44)

(a) LAC is the levelized annual cost of saved energy in $/mmBtu ($/GJ).

Conclusion

The CMC Multipurpose Building represents an ideal example of how energy efficiency can be integrated into the building design process. By using the ERB design process successfully, a cost-effective, efficient and practical building is the end-product. Further, lost opportunities for conserving energy are avoided with this process since ERB measures are included from the first phases of the design process.

Some utility design assistance DSM programs provide a few of the features formally specified in the ERB Design process. Few, if any, are so intimately involved with the entire design process, however. Such involvement typically works to the utility's advantage. This is because energy efficiency consultants are accepted as part of the design team from the beginning, thus becoming an accepted and influential player in the design process. The CMC project is a successful example of this situation--even without the availability or influence of any local utility DSM programs.

Summary results reflecting the impact of the ERB Process on the Colorado Mountain College project show that the College can expect to save approximately 126,000 kWh, over 80 kW in peak demand, and nearly 1,000 MCF[5] natural gas per year. This amounts to approximately 1.77 billion Btus (1,870 GJ) annually and $17,300 in annual utility costs. Moreover, this is only for the ERB measures included in the design since the original building plan. *The savings for all ERB measures including the reference HVAC system amounts to over 3.86 billion Btus (nearly 4,100 GJ) and nearly $50,000 annually.* This is for the comparison to what probably would have been built without influence from the ERB process. These utility bill savings likely will increase over the life of the facility as utility rates rise.

At this level of annual utility bill savings, CMC will experience at least a 5.9-year actual payback. Over a 15 year span, the net savings in today's dollars will amount to at least $225,000. This is equivalent to spending $7.85 for every mmBtu[6] saved annually in today's dollars (levelized over 15 years). In addition, this is without an ILP loan. With an ILP loan, the incremental "investment in energy efficiency" costs $7.14/mmBtu. In comparison, the College can expect to spend well over twice as much ($16.32/mmBtu per year levelized over the next 15 years) to provide the facility with power and heat.

The unit cost difference between energy savings and energy purchases proves how investing wisely in energy efficiency is cost-effective. This is especially true when the design team is focused toward incorporating it into the building from the initial phases of the design process. The Energy Responsive Building Design Process is an effective method for meeting this energy efficiency objective. Moreover, it exists as a formalized, cost-effective method for utility new construction programs.

Acknowledgements

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Endnotes

1. 1991 electricity rates of $0.067/kWh and natural gas rates of $0.356/Therm.

2. From several sources including Houston Lighting & Power, Texas and the Ministry of Energy, Mines and Petroleum Resources in British Columbia, Canada.

3. Heating plant was sized larger (at over two times) than for the "Original" Reference case at the request of the mechanical engineers.

4. Economic analysis results were determined based on a few assumptions: a) using a 10% discount rate, b) using a 3% annual escalation rate in electricity costs, and c) using a 5% annual escalation rate in natural gas costs.

5. MCF = 1,000 cubic feet.

6. mmBtu = millions of Btus.

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