Saving Energy in Historic Buildings: Balancing Efficiency and Value

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Energy modeling and life-cycle costing can help identify simple steps to make a historic building more energy efficient, addressing both preservation and sustainability concerns.

By now the slogan of the National Trust for Historic Preservation that "the greenest building is the one already built" is widely known. In an era of increased environmental awareness and rising fuel prices, however, the question is how can historic building stock be made more energy efficient in a manner respectful of its historic integrity and character. The other challenge is to find those improvements that, in the quest to save energy (and, by extension, money), do not in the long run cost more than they save. There are an increasing number of "sustainable solutions" in the marketplace today, but not all are good investments, provide tangible benefits, or are appropriate approaches for historic buildings. Often common sense, trained historic and/or aesthetic judgment, and the studies and assurances of those marketing the solutions are used to determine what interventions are appropriate. In addition, practical and objective analysis tools are needed in the process, and that is the benefit of including energy modeling and life-cycle costing in assessing potential changes. These calculation tools can help all of those involved in a project to understand which solutions truly offer energy and operating-cost savings.

Fig. 1. Swift Hall at Vassar College. Originally built in 1902, the structure retains much of its original appearance and building fabric. Image by Voith & Mactavish Architects, LLP.

Energy Modeling

The use of computers to simulate annual energy consumption began as a result of the energy crisis in the 1970s. After the United States Department of Energy (DOE) was created by President Jimmy Carter, algorithms were developed to simulate the annual energy consumption of a building. These calculations were refined and further developed over the years, with the DOE-2 simulation algorithms gaining wide acceptance in the industry throughout the 1990s. Currently, use of these energy-modeling tools has become standard for any project that is pursuing Leadership in Energy and Environmental Design (LEED) certification from the United States Green Building Council. There are many energy-modeling software programs in use today, including Energy Plus, developed jointly by the University of Illinois and the Lawrence Berkeley National Laboratory.[1]

The basic concept of the energy model is to virtually create (or, in the case of preservation, recreate) a building, delineating not only its physical form but other performance and usage variables. The simulation process includes a virtual model of the building geometry, the building materials and their characteristics, and the types of mechanical systems and lighting, along with other systems that may consume energy. The patterns of the occupants and their activity levels are added to the virtual model, and finally the weather-data files that reflect the particular locale are referenced for a complete hour-by-hour simulation of a typical meteorological year.[2]

Depending on the size of the building, creating this baseline model can be a process that takes 40 hours for a small, straightforward building, such as a suburban office building, to hundreds of hours for a large, complex edifice, such as a monumental campus building. Regardless of project size, the process is typically the same, although larger buildings tend to leverage the effort and cost of the model to greater effect since the improvements can produce larger energy savings. Once the baseline information has been entered and an existing-conditions model created, it is then possible to calculate the building's current energy-use footprint and to track what percentage of that consumption can be attributed to each of the building's components.

Before performing any analysis, however, this initial calculation should first be cross-checked against any energy bills or other records that may exist to help normalize the model to the actual operation of the building and to allow for more accurate predictions in the future comparisons.[3] For example, energy loss through air infiltration can constitute a sizable percentage of the overall total, ranging anywhere from less than 5 percent in a newly constructed building with careful air-barrier detailing to 40 percent or more in an old, poorly maintained building that has numerous gaps and openings at such locations as foundations, sill plates, windows, doors, sheathing, flues, and eaves.

Next, it is appropriate to start the process of creating scenarios to understand the energy-use implications of various improvements that could be proposed. The most beneficial approach is to first select a series of potential interventions and model each of them individually, so as to understand the independent impact of each accurately. Since it takes time to generate the model and run the simulation for each variable, project budgets typically require judiciousness in selecting each option. Some of the more common scenarios to explore include:

- replacing the lamps, fixtures, and/or controls for lighting.
- replacing the mechanical plant with new methods of heat generation and distribution and/or upgrading the system controls.
- installing insulation in the attic, between roof rafters, in walls, dormers, and the basement and sealing locations of air infiltration.
- restoring or replacing single-glazed windows or supplementing them with storm windows.

While running individual models can give an excellent perspective on the effectiveness of various improvements compared to the existing conditions, the additional step of creating combination scenarios is critical to properly determine the impact that a series of improvements may have on the energy consumption in a rehabilitated historic building. These combined scenarios look at the overall effect of several simultaneous interventions, showing how these changes work together. Some combinations will create increased energy savings, while others may work in opposition to each other. For example, converting light fixtures from old incandescent lamps to efficient fluorescent fixtures with electronic ballasts will greatly reduce electrical demand for lighting and could reduce summer air-conditioning costs but will also increase the need for winter mechanical heating to compensate for the loss of heat generated by the old lamps. Once the combination scenarios are created and simulated, the project team will have a truer understanding of the approximate energy savings that can be generated by the proposed improvements and can do so in a manner that does not inadvertently bias the results for the first few improvements that are modeled in an additive process.

Life-Cycle Costing

The energy simulation is only one part of the larger quest of finding the appropriate project scope that achieves energy savings in a manner that is both cost effective and respectful of the historic character of the building. These goals can best be achieved by employing the process of life-cycle costing, which incorporates the results of the energy-simulation modeling into a cost analysis of a proposed project over an extended period of time. Life-cycle costing is a version of life-cycle assessment, which had its beginnings roughly 40 years ago, although it could be said that informal, common-sense versions of it have existed for much longer.[4] The basic concept is to determine the true cost of installing a particular material or system when projected through the expected life span of the building. While there are other sources for more complete information on life-cycle costing that detail the process even further, the following are the four most important factors in endeavoring to answer this question:

- *Cost of manufacture and installation.* Otherwise known as the "first cost," this is the typical construction cost that is carefully scrutinized during design to find the lowest-cost option for meeting a particular need and budget. The first cost includes the harvesting of materials, their fabrication into the final product, installation in the building, and their transportation during all of the stages. Many projects consider only this cost in selecting a material or system for a project.
- *Cost of operation.* Some systems consume electricity or burn fuel, and some are more efficient than others in their use of that energy. Some also require personnel to operate or monitor the equipment, and this labor carries a dollar value. Costs of operation are a regular, ongoing expense that should be predictable, although recent experiences with fuel costs, for example, show that it is susceptible to some degree of uncertainty.
- *Cost of maintenance.* All systems and objects require some level of maintenance and repair, with an associated cost for both the materials and labor, either for in-house staff or contracted servicing. These costs do not always occur on an annual basis, but for the purposes of life-cycle cost analysis they can be normalized to an annual frequency in order to predict the anticipated costs related to maintenance.
- *Cost of replacement.* Many elements of a building must be replaced at

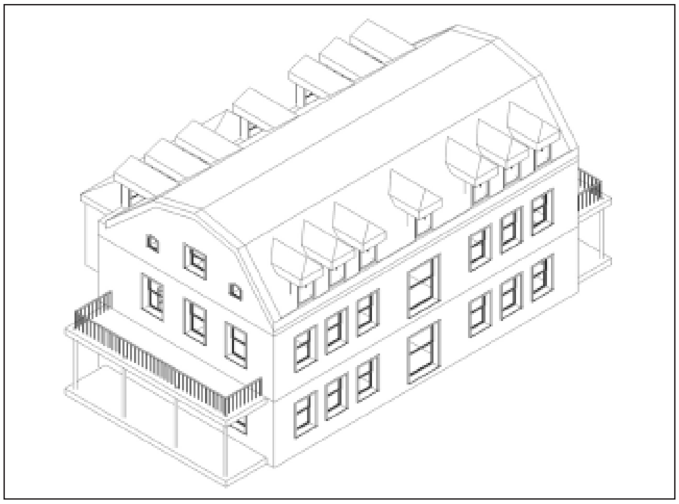


Fig. 2. An axonometric wire diagram of Swift Hall. The wire diagram allows the designer to confirm that the parameters used in the energy model match the existing conditions. Image by Bruce E. Brooks & Associates.

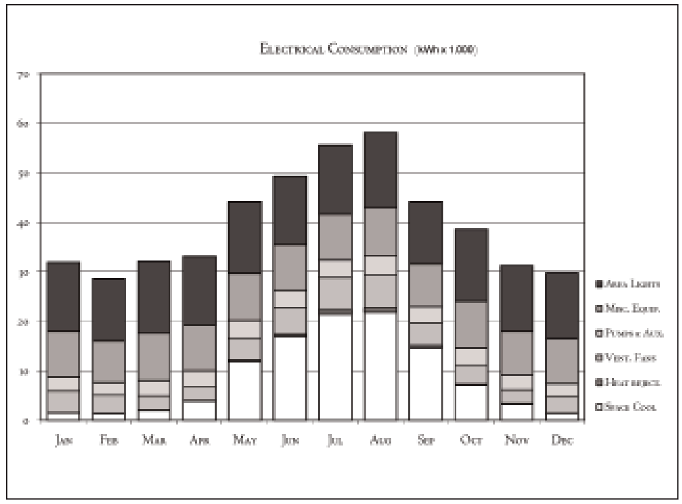


Fig. 3. Monthly energy-use patterns can be broken down by equipment, month, fuel type, and other parameters to help analyze possible areas for energy savings. All images by the author, unless otherwise noted.

some point (or several points) in its history. Depending on what is being replaced, the cost of this work can be substantial, including not only the new material and the labor to install it, but also the cost of temporary provisions during the work, potential lost productivity, and disposal of the defunct item. The choice of materials can have a great impact on the frequency of those replacements, as, for example, asphalt shingle roofing may have a lifespan of 25 years, whereas slate roofing can last for more than 100 years.

An important variable in the life-cycle cost analysis is the time period under consideration. Different groups will have their own criteria when determining the life cycle and will define it to suit their situation. For example, a developer may not care that a hot-water heater must be replaced in its eleventh year, whereas the facilities department at a university may work under a 30-year planning cycle. In contrast, the preservationist may have the longest perspective of all, considering ways to help the historic resource last as long as possible, which could include several life cycles for various materials. It is common, however, to look at periods of 25 years or more when doing an analysis, so that maintenance and replacement costs over the full life cycle of the equipment or system are taken into account.

Case Study: Swift Hall at Vassar College

The following case study serves as a useful illustration not only to demonstrate the practical application of the above concepts but also to point out the roughly half-dozen improvements that can be performed in a historic building to achieve the triad of energy efficiency, cost effectiveness, and protection of historic integrity.

Swift Hall at Vassar College in Poughkeepsie, New York, dates to 1902, when it was built to the designs of the noted architectural firm of York and Sawyer as the college infirmary (Fig. 1). It consisted of three floors of wards and private rooms, along with a kitchen, dining room, and parlor on the first floor, all occupying roughly 6,100 square feet of climate-controlled space. In 1941 the building was converted for use as departmental offices and classrooms for the history department, which has occupied it since then.

Very little has changed in Swift Hall from the original design. While some of the third-floor wards were divided to create offices and some of the bathrooms converted into small offices, the building basically retains its original configuration and materials, thus maintaining its historic integrity. The building is solid masonry construction with stone foundations and 12-inch-thick brick walls. The interior plaster is applied directly to the brick and lacks any insulation. The mansard roof is punctuated with numerous dormers and covered with slate and asphalt shingles installed over wood sheathing. There is a low attic beneath the central part of the roof, which is uninsulated. The 60 windows in the building retain the original, single-glazed, six-over-six double-hung wood sash; they lack any type of weatherstripping or storm windows. Heat is provided by steam radiators and convectors connected to the campus's central steam system. Controls are limited to localized, non-electric control valves. Cooling is restricted to a limited number of window-mounted air-conditioning units. Lighting is a combination of incandescent and fluorescent fixtures of various ages and architectural styles.

As a result of these conditions, it is difficult to maintain a consistent temperature in the building; it varies not just seasonally but also from room to room. Despite this and other functional limitations, the building is a much-loved and central part of the history department, and the college's desire was to rehabilitate the building in a historically sensitive manner to improve its energy efficiency and basic comfort requirements while also better meeting life-safety requirements and the department's program needs.

Energy Modeling

The simulation of the annual energy use for Swift Hall — including the esti-

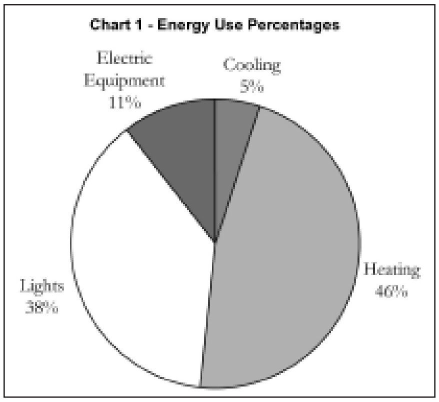


Fig. 4. Energy usage at Swift Hall broken down by building systems.

mated annual fuel consumption used to create steam for heating and annual electricity consumption for lighting, power, and cooling — resulted in an annual energy cost of $2.66 per square foot (Fig. 2). This amount is significantly higher than the United States average for this type of building. According to the Energy Information Administration, which provides the official energy statistics for the U.S. government, the Northeast regional average is $1.74 per square foot for all commercial buildings and even less for educational buildings.[5]

The energy simulation also provides information about where the energy is being used (Fig. 3). For example, the output indicates that for the existing building, the two primary consumers of energy are lighting at approximately 38 percent and heating at 46 percent of the annual energy use (Fig. 4). Air-conditioning is a very low value of 5 percent, due to the reliance on a limited number of window units and reduced summertime occupancy. Therefore, a reasonable conclusion is that the best areas to focus on reducing energy consumption is with the lighting, either through more efficient fixtures and/or reducing the hours lights are used, and with the heating, either by improving the efficiency of the mechanical system and/or the building envelope.

Several scenarios were simulated in order to determine how much savings would be possible for each potential intervention. For each of these scenarios, an hour-by-hour simulation of operations allows an objective analysis of the impact, rather than reliance on the designer's traditions or rules of thumb. It is important to simulate each scenario in the model because the focus is on the performance of the entire building, not just that of a particular element, so the overall impact on an annual basis can be used to compare the cost and savings of various options.

The model not only will show the changes in the total energy consumption for each scenario compared to the baseline existing condition but also can show the amount of change in each energy category (Fig. 5). While typically considered on an annual cycle, the model can also provide information broken down into other groupings, such as seasonal consumption of different fuel sources, to help explain how use patterns during a typical school year can impact energy consumption. Based on the scenarios considered for this building, the most promising measures to improve energy performance, along with other subjective benefits including improved occupant comfort, were upgrading lighting controls and fixtures, insulating the attic and spaces between the rafters on the top floor, improving the zone control of the heating system, and refurbishing the historic windows.

The improvements to the lighting system were simulated through two scenarios. The first would involve the addition of lighting controls, such as occupancy sensors to keep the lights off unless people are in the room. The addition of these controls alone resulted in an anticipated annual energy savings for the building of approximately $2,250, or 14 percent. The second scenario would involve replacing older lighting fixtures with newer fluorescent fixtures with a few exceptions, such as the lobby chandelier, combined with more efficient controls. This more extensive intervention resulted in a predicted reduction of 50 percent of the lighting bill, representing an annual savings of nearly $3,350, or 22 percent over the total-energy-bill baseline.[6]

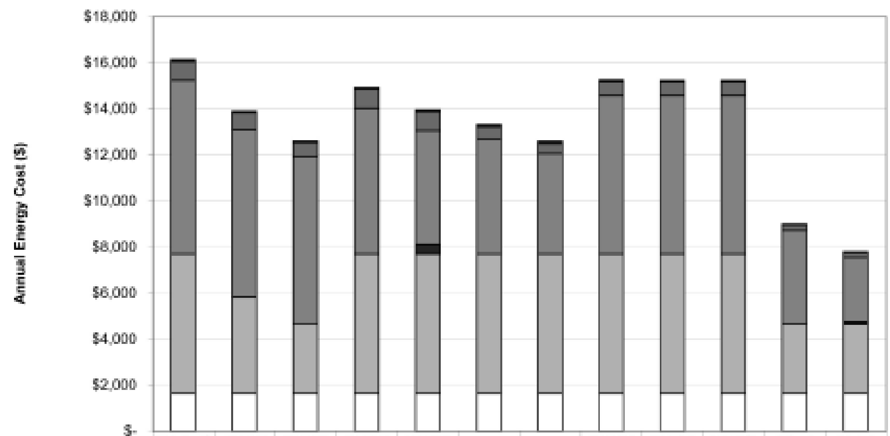
Addressing the issue of reducing the annual cost of heating the building while improving its overall comfort level for occupants was pursued along two parallel tracks — the efficiency of the heating system in producing and controlling the heat and the ability of the building envelope to retain the heat supplied. The existing heating system, which uses the campus's central steam plant, is reasonably efficient in converting fuel into useable heat (in the low 70 percent efficiency range), but it has limited controls. The lack of controls creates an unevenness in distribution that causes significant occupant discomfort and wasted energy. For example, it is not uncommon in older buildings with steam systems for occupants to resort to opening a window in the winter to compensate for a surplus of heat in a room, thereby negating any gains made in the efficiency of the window. The efficiency of the existing heating system could be improved either by upgrading the controls and zone dampers, which would improve comfort levels along with a modeled savings of $1,200, or 7.5 percent, in annual energy costs, or by replacing the entire system with a high-efficiency hot-water system, resulting in calculated savings of $2,200, or 13.5 percent in annual energy costs.

The second scenario for reducing the annual heating costs would be to improve the thermal efficiency of the building envelope, addressing infiltration and the insulating properties of the walls, windows, and attic/roof. For this building insulating the walls was not considered an option given the solid masonry construction.[7] The energy-model simulation did, however, include several scenarios for the windows, which comprise roughly 15 percent of the surface area of the building envelope, typical for a building of this era. As in many historic buildings the windows are a weak point in the thermal envelope. Single-pane windows provide little resistance to heat transfer, and the gaps around older windows allow significant leakage of outside air into the building.

The first scenario to be modeled would be refurbishing the existing single-glazed wood windows to assure a tight fit when locked, installing weather-stripping, and providing storm windows.[8] This approach improves the effective U-value of the window assembly from roughly 1.1 to 0.5 and greatly decreases air infiltration around the units, which should reduce anticipated energy costs by $900, or 5.5 percent, annually. New energy-efficient windows, either wood or vinyl, with double-glazing and low-e glass, reduce the assembly U-value further to approximately 0.35.

However, since so much of the existing heat loss is due to leakage and the low-e glass is actually a detriment in winter because it reduces solar heat gain, this option provides similar overall modeled energy savings of $900, or 5.5 percent, annually. In contrast to the windows, large energy savings and comfort gains can be realized by providing insulation in the attic and venting the attic in the summer.[9] Swift Hall has a small attic over the central portion of the building; insulating and adding active summer venting just at this location was calculated to reduce annual energy costs by $2,850, or 17.5 percent.[10] If the insulation were also installed in between the roof rafters where there is no attic, the anticipated savings would increase to $3,550, or 22 percent.

The ideal energy-savings solution, of course, would be to combine these approaches and possibly others. It is not possible, however, to simply add up the percentage savings for each of the chosen improvements, as the total savings available decreases with each additional measure. For example, improving the thermal efficiency of the building envelope would reduce the savings to be found by replacing the boiler. Creating an energy model that combines all of the chosen elements together, however, will provide an accurate picture of the overall savings. For example, a scenario that includes replacing the lighting fixtures and controls, upgrading the existing steam-boiler control system, adding attic insulation and venting, and installing weatherstripping and storm windows would produce a calculated savings of $7,100, or 44 percent, of the annual energy cost of the building. This approach would result in an annual energy bill of approximately $9,000, which averages out to a value of $1.50 per square foot, which is 16 percent below the Northeast average. In comparison, a more intensive effort that would include replacing the lighting fixtures and controls, installing a new high-efficiency boiler and hot-water heating system, adding insulation and venting to the attic and insulation between the roof rafters where there is no attic, and installing new energy-efficient windows would produce an anticipated savings that is only 10 percent higher ($8,350, or 52 percent, of the annual energy



	[Existing]Swift Hall-Steam	[ALT1A] Lighting Controls	[ALT1B] Lighting Upgrade	[ALT2A] Htg Controls	[ALT2B] HW system	[ALT3A] R-30 Attic	[ALT3B] R-30 Roof	[ALT4A] Window Refurb +	[ALT4B] Wood Window	[ALT4C] Vinyl Window	[Minor] 1A+2A+3A+4A	[Major] 1B+2B+3B+4B
Air System Fans	$90	$78	$70	$90	$90	$112	$112	$83	$73	$73	$49	$40
Cooling	$822	$743	$597	$822	$822	$531	$426	$592	$586	$586	$238	$219
Heating	$7,532	$7,266	$7,266	$6,325	$4,951	$4,977	$4,353	$6,878	$6,878	$6,878	$4,074	$2,782
Pumps	$-	$-	$-	$-	$399	$-	$-	$-	$-	$-	$-	$120
Lights	$6,065	$4,183	$3,033	$6,065	$6,065	$6,065	$6,065	$6,065	$6,065	$6,065	$3,005	$3,005
Electric Equipment	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634	$1,634

Fig. 5. Simulation results for each scenario tested using the energy model, showing not only total annual energy costs but also how each energy component of the building would be affected by the proposed change.

cost). While a 10 percent savings is a definite, measurable benefit, it is important to determine whether this additional savings is worth the added expense necessary to achieve it. The answer to that question lies in the life-cycle costing for the proposed project.

Life-Cycle Costing

As outlined above, there are four major components that contribute to the life-cycle cost of a material or system — first cost, operation, maintenance, and replacement. The selection of one alternative over another will have an economic impact on the institution not only at the time of construction but also over the lifetime of the building. A life-cycle cost analysis will consider and compare the first-year investment; the annual operating costs, including energy, repairs, and maintenance; and any necessary replacement at the end of the system's life.

However, the value of a dollar spent on a building improvement today is greater than the value of that same dollar in the future, due to its potential to earn interest if it were invested rather than spent. This concept is often referred to as the "time value of money," and future investments and expenses should be discounted to the equivalent present value for comparison.

The life-cycle cost analysis, therefore, takes into account anticipated values for inflation, energy-cost changes, and interest rates. By applying these factors to the life-cycle components over a set period of time, it is possible to determine a net present value (NPV) for the material or system. To understand whether or not a particular set of initiatives makes sense financially, one can compare the NPV of the proposed undertaking against the NPV of doing nothing; the option with the lowest NPV represents the best approach strictly from a cost basis. Other metrics can also be used to compare the options. The annual equivalent payment (AEP) would represent the annual amortization cost for the difference in net present value. It is important to recognize that these are the financial indicators only and that typically a project will have other benefits as well, such as improved appearance or comfort, ease of use, occupant satisfaction, and reduced demands on maintenance staff or service contractors.

The life-cycle cost analysis includes several financial variables, which can be adjusted to observe how sensitive the analysis is to any particular factor. As applied to the case study the values were as follows. The annual rate of inflation

Table 1. Life-Cycle Analysis Overall Comparisons

	First-Year Costs				25-Year Values			Annual Equivalent Payment Savings		Annual Equivalent Energy Savings	
	Project	Energy	Maintenance	Payback	NPV	AEP	AEE				
Lighting Upgrades											
Full Lighting Upgrade	$70,000	$12,600	$16,000	11	$594,787	$46,528	$20,600	$2,573	5.2%	$7,376	26.4%
Lighting-Controls Upgrade	$10,000	$13,904	$17,000	4	$582,025	$45,530	$22,731	$3,571	7.3%	$5,244	18.7%
Existing Lighting Maintained	$0	$16,143	$17,500		$627,679	$49,101	$27,976				
Heating System Upgrades											
New High-Efficiency System	$250,000	$13,961	$9,500	18	$685,217	$53,602	$22,825	-$4,501	-9.2%	$5,151	18.4%
Upgrade Existing Controls	$95,000	$14,936	$14,500	17	$642,310	$50,246	$24,419	-$1,145	-2.3%	$3,557	12.7%
Existing Central Steam Maintained	$0	$16,143	$17,500		$627,679	$49,101	$27,976				
Attic Insulation and Summer Venting											
Full-Roof Insulation/Venting	$22,000	$12,590	$18,000	6	$582,472	$45,565	$20,583	$3,536	7.2%	$7,392	26.4%
Attic-Only Insulation/Venting	$10,000	$13,319	$18,000	4	$586,387	$45,871	$21,775	$3,230	6.6%	$6,200	22.2%
Existing - No Insulation/ Venting	$0	$16,143	$17,500		$627,679	$49,101	$27,976				
Window Upgrades											
New Vinyl Windows – 20-Year Cycle	$90,000	$15,236	$12,500	none	$658,501	$51,512	$24,909	-$2,411	-4.9%	$3,066	11.0%
New Vinyl-Clad Windows	$150,000	$15,236	$12,500	19	$667,289	$52,200	$24,909	-$3,099	-6.3%	$3,066	11.0%
New Wood Windows – 40-Year Cycle	$150,000	$15,236	$15,500	none	$717,055	$56,093	$24,909	-$6,992	-14.2%	$3,066	11.0%
Refurbish and Add Interior Storms	$51,000	$15,252	$15,500	14	$623,993	$48,813	$24,935	$288	0.6%	$3,040	10.9%
Existing Wood Windows Maintained	$0	$16,143	$17,500		$627,679	$49,101	$27,976				
Combination Projects											
Major Intervention Scope*	$492,000	$7,800	$6,500	none	$734,992	$57,496	$12,752	-$8,395	-17.1%	$15,223	54.4%
Minor Intervention Scope*	$166,000	$9,000	$11,500	11	$535,467	$41,888	$14,714	$7,213	14.7%	$13,262	47.4%
Existing Conditions Maintained	$0	$16,143	$17,500		$627,679	$49,101	$27,976				

* Major scope includes upgrades to lighting and controls, installing insulation and venting at the attic and rafters, a new high-efficiency boiler, and new wood windows.

* Minor scope includes upgrades to lighting and controls, installing insulation and venting at the attic, upgrading the controls of the existing heating system, and refurbishing the existing windows and installing storm windows.

was set at the commonly accepted value of 3 percent. Decreasing the rate typically will lower the NPV and reduce the relative savings. The cost of energy was assumed to rise at 5 percent per year, recognizing that energy prices will continue to increase but at a rate somewhere between the high percentages of the past few years and the relatively stable values that preceded them. A higher rate will increase the NPV and increase the resultant annual savings. The interest rate, also known as the discount rate, was set at a relatively conservative value of 6 percent. Increasing the rate typically will lower the NPV values and decrease the impact of the large initial investments.

The various scenarios analyzed for the case study are presented in Table 1, including both existing conditions and a series of potential improvements in the building's energy consumption. The first columns allow a simple comparison of the initial investment, the annual energy costs, and the annual maintenance costs of the proposed improvement versus the cost of doing nothing. The payback column indicates the year in which the initial investment in the project is "paid for" out of the annual energy and maintenance savings. The next set of columns show 25-year values that include the time value of money impacts over the 25-year study period, including the anticipated annual savings in all expenses, as well as just the energy portion of those costs. What is striking is that while all of the suggested improvements offer definite projected energy savings (none is less than 10 percent), only some of them are able to translate the energy savings into overall life-cycle cost savings, due mostly to the difficulty of overcoming high initial-investment costs of some of the improvements.

Reviewing the table and each area of potential improvement studied, it becomes clear that two of the most effective projects that can be undertaken at a historic building such as Swift Hall are upgrading the light fixtures and controls to improve efficiency and insulating and ventilating the attic. These results are not surprising, since both are relatively inexpensive undertakings that also result in high energy savings. In contrast, two projects that are often touted for their energy-saving benefits, upgrading the heating system and replacing windows, are unable to fully recapture their steep initial investment costs with energy and maintenance savings.

In the case of the heating system, upgrading the controls of the existing central steam system carries only a slight projected annual cost increase ($1,145), which can be justified easily by the improved comfort for the occupants and the reduced workload for maintenance personnel. Installing a new high-efficiency boiler, in contrast, has a much steeper anticipated annual cost increase ($4,500) to accompany the higher energy savings. It could be argued, however, that the benefits of this heating-system upgrade would last longer than the 25-year-life cycle period of the study, decreasing the cost impact of the new system.

In contrast to the other systems described above, the benefits of window replacement are, at best, questionable.[11] Given the relatively low overall energy savings offered by the various forms of window improvements, the only option that makes clear economic sense is to refurbish the historic wood windows and install storm windows, and even this course of action is barely a break-even undertaking according to the financial analysis. Replacement with painted wood windows is a very costly approach, due not only to the cost of purchasing and installing the new units but also due to need for periodic painting. New wooden windows also lack the durability of historic windows made with old-growth lumber. Vinyl-clad windows can eliminate the need for painting but still are not able to achieve cost savings compared to keeping the originals. Replacement with solid vinyl windows is not any better. They are cheaper than wood windows and do not require painting, but they have a relatively short lifespan; the cheapest versions will last less than 10 years before the vinyl becomes brittle and the joints open up, but even the more expensive models will be hard pressed to last much beyond 20 or 25 years before failure becomes problematic. The short replacement cycle for these windows overwhelms their initial lower cost and reduced maintenance costs, and the unwitting property owners typically will find themselves replacing them before the windows have finished paying for themselves.

Finally, comparing the combination projects, one can now see that the anticipated additional 10 percent in energy savings offered by the major intervention scope over the minor intervention scope is not a particularly good investment from a financial perspective. The high cost of the new boiler and new windows create such a high project cost that the savings in energy and maintenance costs offered by these options cannot overcome them. In contrast, the minor scope — lighting upgrades, attic insulation and venting, upgraded heating controls, window refurbishing, and storm windows — offers not only substantial energy savings but also significant savings in annual expenses compared to the option of doing nothing. These interventions also carry the additional benefit of being more respectful of the character of the historic building, creating the ideal scenario of saving energy while saving history.

Conclusion

As can be seen from the case study, it is entirely possible to meet the goals of improved energy efficiency in a manner that is both cost-effective and sensitive to the historic character of the building. By using energy modeling, it is possible to better understand the inherent properties of a particular historic resource that cause it to perform differently from new construction and thereby to design improvements that use those features to their best advantage. It also allows the designer to use life-cycle costing to better understand the cost implications of a particular intervention over the long term, which will help in decision-making if the loss of historic material or character cannot be justified by improvements in energy performance. Combined with other considerations not discussed in this article, such as the aesthetic, historical, environmental, and functional impacts of any chosen course of action, these tools can help the conscientious building owner, architect, engineer, or preservationist make the argument that sometimes using the newest materials or technology is not the most appropriate course of action in a rehabilitation project and that maintaining and restoring historic buildings is often the most sustainable step to take.

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Notes

1. Energy Efficiency and Renewable Energy (EERE) Division of the U.S. Department of Energy (DOE) Building Energy Software Tools Directory, http://apps1.eere.energy.gov/buildings/tools_directory.

2. Marc Rosenbaum, "Understanding the Energy Modeling Process: Simulation Literacy 101," in *The Pittsburgh Papers: Best of Green-Build 2003* (Pittsburgh: BuildingGreen, Inc., in assoc. with the U.S. Green Building Council, 2003), 99–108.

3. Checking the energy model for the existing building against actual billings is an important step, as the assumptions made in the model can impact the results; particularly for larger buildings, the variations could have a measurable impact. This ability to verify usage is also an advantage that existing buildings have over new buildings. It is also worth noting that the computer model is limited in accuracy when simulating unusual system types or building properties. For example, one of the benefits of older masonry buildings is their inherent thermal mass, but this feature is not accommodated well in the current software. Reviewing the actual energy use against the energy model can help identify and address such issues.

4. Scientific Applications International Corporation (SAIC), *Life Cycle Assessment: Principles and Practice*, EPA/600/R-06/060 (Springfield, Va.: U.S. Dept. of Commerce, Technology Administration, National Technical Information Service, 2006), 4.

5. Average $1.51 per square foot for all commercial buildings, $1.71 for office buildings, $1.22 for education buildings, based on 2003 data, which is the most recent available. Energy Information Administration of the United States, Department of Energy, Commercial Building Energy Consumption Survey (CBECS), 2003 CBECS Detailed Tables, Table C2A "Total Energy Expenditures by Major Fuel for All Building Types, 2003." See http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/2003set14/2003pdf/c2a.pdf.

6. All of the percentage savings from this energy model are derived by comparing the energy savings from a particular intervention to the overall building energy consumption. Therefore, since lighting accounts for 38 percent of the building's energy costs and since electricity has a less efficient energy-per-unit cost ratio than other fuel sources, a reduction of 50 percent of energy costs in the lighting calculates to an overall energy savings of 22 percent.

7. It is possible to insulate solid masonry walls by installing interior studs and insulation. However, this is a very expensive and invasive approach, which consumes square footage, alters the historic appearance of the interiors, and may have the potential to cause long-term damage to the masonry wall by reducing the ability of the wall to dry out. For a more in-depth review of this topic, see William B. Rose, "Should the Walls of Historic Buildings Be Insulated," *APT Bulletin* 36, no. 4 (2005): 13–18.

8. While not performed in this case study, there are additional window-improvement variables that could be modeled where appropriate. For example, the effects of adding a reflective solar film or storm windows with low-e glass could be considered. The benefits of using glass with different solar heat-gain coefficients at different building exposures could also be determined using the model.

9. When considering additional insulation in a historic building, a full understanding of moisture migration through the building envelope is important. For a review of the principles involved refer to the *ASHRAE Fundamentals Handbook 2009*, Mark S. Owen, ed., chapters 25, 26, and 27, "Heat, Air, and Moisture Control in Building Assemblies – Fundamentals," "Heat, Air, and Moisture Control in Building Assemblies – Materials," and "Heat, Air, and Moisture Control in Building Assemblies – Examples" (Atlanta: American Society of Heating Refrigeration and Air-Conditioning Engineers, 2009), 25.1–27.13.

10. In this case study, the active ventilation was modeled for summertime ventilation to reduce temperature build-up in the attic. While it would increase electricity usage in the summer, it would be inoperable and closed in the winter. It is distinct from the passive ventilation system for condensation control that is already present and would remain unchanged.

11. For a more comprehensive discussion of aesthetic, performance, maintenance, and environmental issues with replacement windows, see Walter Sedovic and Jill H. Gotthelf, "What Replacement Windows Can't Replace," *APT Bulletin* 36, no. 4 (2005): 25–29.