CONSORTIUM for BUILDING ENERGY INNOVATION

REPORT

Title: State of the Art in Enclosure Technologies and Integrated Systems for 50% Energy Savings in Existing Commercial Buildings

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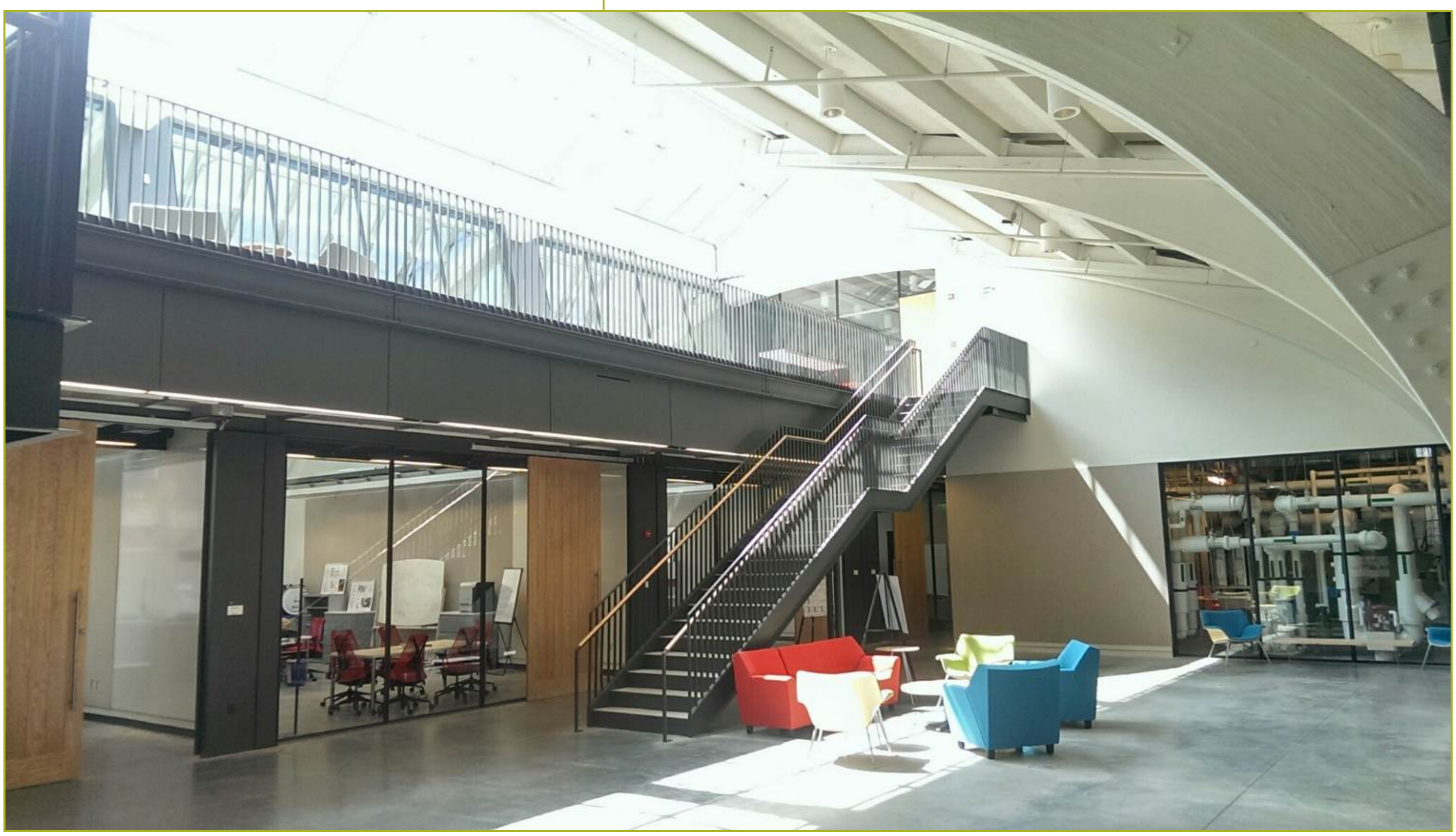

CBEI was referred to as the Greater Philadelphia Innovation Cluster (GPIC) HUB at the time this report was developed.

Report Abstract

CBEI facilitated integrated visioning, expert workshops and design charettes for Building 661, which contributed to the development of a report on enclosure technologies with an emphasis on engaging the building systems and systems integration critical to high performance retrofits. The report is focused on typical (older) small commercial buildings.

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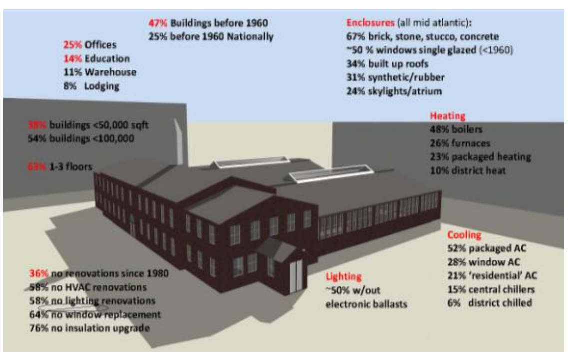

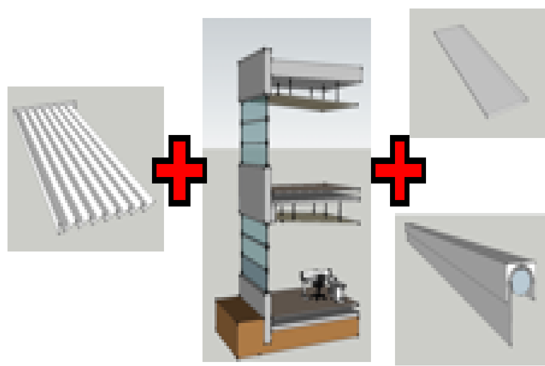

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Expert Workshop, Integrated Technologies, Task 3, Technological Specifications,
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EXECUTIVE SUMMARY

The Integrated Technologies Task (GPIC Task 3) is focused on identifying key technologies, integrated systems, and performance metrics and approaches for achieving 50% energy savings in existing buildings; both in support of the future headquarters of the GPIC at the Philadelphia Navy Yard (Building 661) and for broader applicability in retrofit and new construction projects in the Great Philadelphia Innovation Cluster (GPIC) region. The organization and facilitation of integrated visioning, expert workshops and design charettes for Building 661 contributed to this prioritized State-of-the-Art report on Enclosure - with an emphasis on engaging the building systems and systems integration critical to high performance retrofits.

The State of the Art Report is focused on typical (older) small commercial buildings in the GPIC region, and built on four critical inputs:

1. CBECs and CoStar data sets on where the energy is being lost given the characteristics and the condition of the existing commercial buildings.
2. Recent energy retrofit guidelines and research related to small commercial buildings from DOE and the National Labs, ASHRAE, Building Green and others.
3. GPIC partner recommendations for effective energy retrofit actions, gathered in the expert workshop and in numerous collaborative exchanges.
4. GPIC member research findings from the first year of effort from Tasks 2 and 3.
5. Iterative and compounded energy simulation of 21 enclosure retrofit options developed by the expert workshop.

The report is not a definitive study on how to achieve 50% energy savings. Instead, it is the first generation profile of the available and cost-effective technologies and integrated systems that provide measurable energy savings for existing buildings.

This report is matched by a GPIC Research Roadmap report, with a number of recommendations and actions that are equally important to mention in this State-of-the-Art report. For example, the Research Roadmap establishes a critical action to "Approach existing building retrofits holistically. Similar to airplane design engineering approaches, holistic design focuses on the impact that one component or subsystem upgrade has on the whole system performance. For example, individual solutions for envelope, lighting, and HVAC systems have not yielded the full results. The system performance driven approach to building renovation requires developing subsystem architectures and coordinated, dynamic and adaptive controls to meet internal and envelope loads and to produce measurable improvement in the indoor environment, all within a market acceptable economic model. The systems performance approach requires a radical change in equipment selection wherein selection is based on whole building performance metrics rather than component efficiencies. Achieving significant energy efficiency improvements in existing buildings will require a fundamentally new approach to retrofit design." (Wagner, Baxendell, & Sweetser, 2012).

In the Enclosures, Lighting, HVAC and Control chapters of this report, the GPIC team has been working to identify energy efficient components, processes and systems, and their performance metrics, from energy to cost-benefits, for high performance renovation projects with broader applicability in retrofit and new construction in the GPIC region.

Existing Building Stock Breakdown of Energy Uses

The state of the existing commercial building challenge in the United States has been profiled from the 2003 DOE Commercial Building Energy Consumption Survey (CBECS) data base, beginning with the site energy loads for the four most prevalent commercial building types in the US: offices, warehouses, lodging, and education, with load breakdowns by building system (Figure 1).

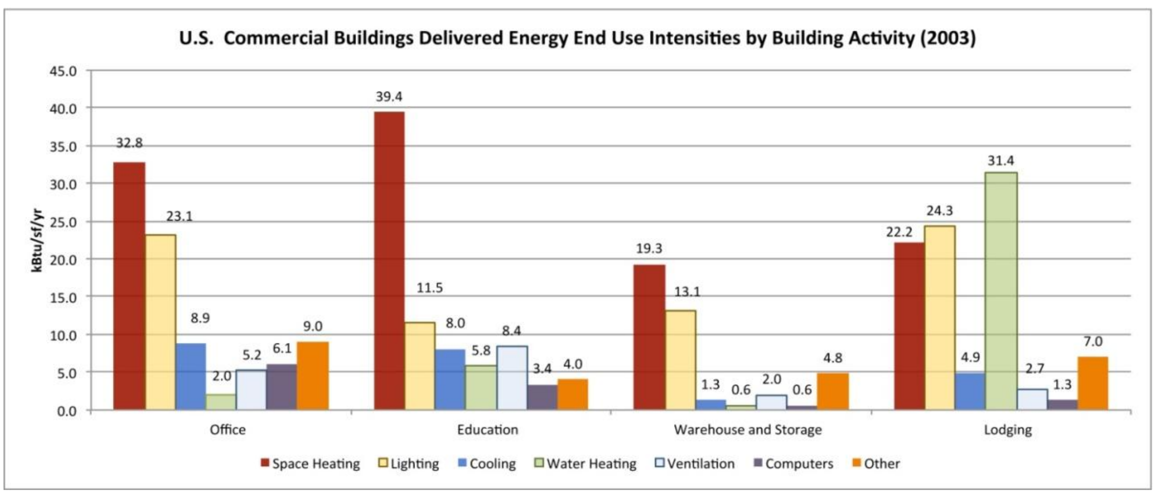

Figure 1 Heating and lighting are the dominant energy loads in four building types (CBECS 2003)

From this database, a representative subset of 33 Mid-Atlantic office buildings were further analyzed to determine regional energy load breakdowns for lighting, heating, cooling, ventilation, hot water, plug loads and other energy uses in offices, considering both site and source energy (Figure 2). It is critical to note that heating is still the dominant site energy load in office buildings in our region. This places a significant demand on the building enclosure, as well as retrofits for heating and ventilation systems. If source energy loads were to be a focus, for cost savings and peak load management, then lighting energy would be the largest source energy load in office buildings in our region, with significant variability in the Mid-Atlantic building stock that appears to be linked to the self-reported percent of spaces that are daylit in the building. These existing energy use factors contribute to the recommendations for energy efficiency that follow in this report.

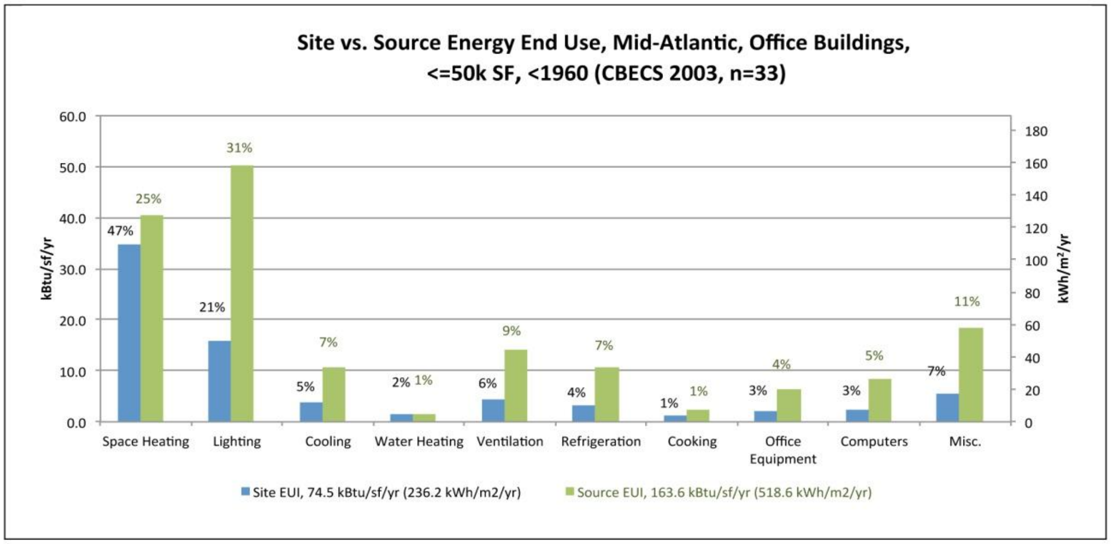

Figure 2 Lighting dominates source energy loads = CO2 and cost consequences (CBECS , 2003)

A GPIC Task 3 study entitled *Renovating Schools into High Performance Facilities* (Gunasingh, Aziz, Loftness, & Cochran, 2011) evaluated the Energy Use Intensity (EUI) for 68 Pittsburgh, PA Public School (PPS) buildings and evaluated the range of renovation and retrofit strategies and their impact on the existing building's energy use intensity (EUI). The analysis and recommendations were based on school building utility data, Pittsburgh School District Facility Conditions Report, field visits, interviews, Facility Manager survey responses, and published research. The research analysis identified school facility EUI (kBTU/Sq.Ft.) for each school and compared their energy consumption with the region average (Figure 3). Region average was identified using CBECS data for both Elementary school and High School buildings (averages identified in blue in Figure 3 below). Energy IQ from Lawrence Berkeley National Laboratory and CBECS data from the Department of Energy were also instrumental in energy benchmarking analysis.

Given the range of gas and electric energy use in the Pittsburgh Public Schools (PPS), statistical analysis revealed a number of significant findings for investments in building upgrades for energy efficiency. Building characteristics and upgrades were evaluated against measured electricity, fuel, and water consumption. The following identifies the most significant findings of the PPS District:

- Renovated buildings consumed on average 30% less gas compared with existing buildings and buildings that received additions.
- Buildings with narrow floor plates consumed on average 17% less electricity.

- Schools with East-West axis (predominate windows on the north and south facades) consumed on average 28% less electricity.
- Schools with roof insulation consumed on average almost 10% less gas compared with those without insulation.
- Naturally ventilated schools consumed on average 21% less electricity.
- Schools with a Building Automation System (BAS) consumed on average 9% less gas.

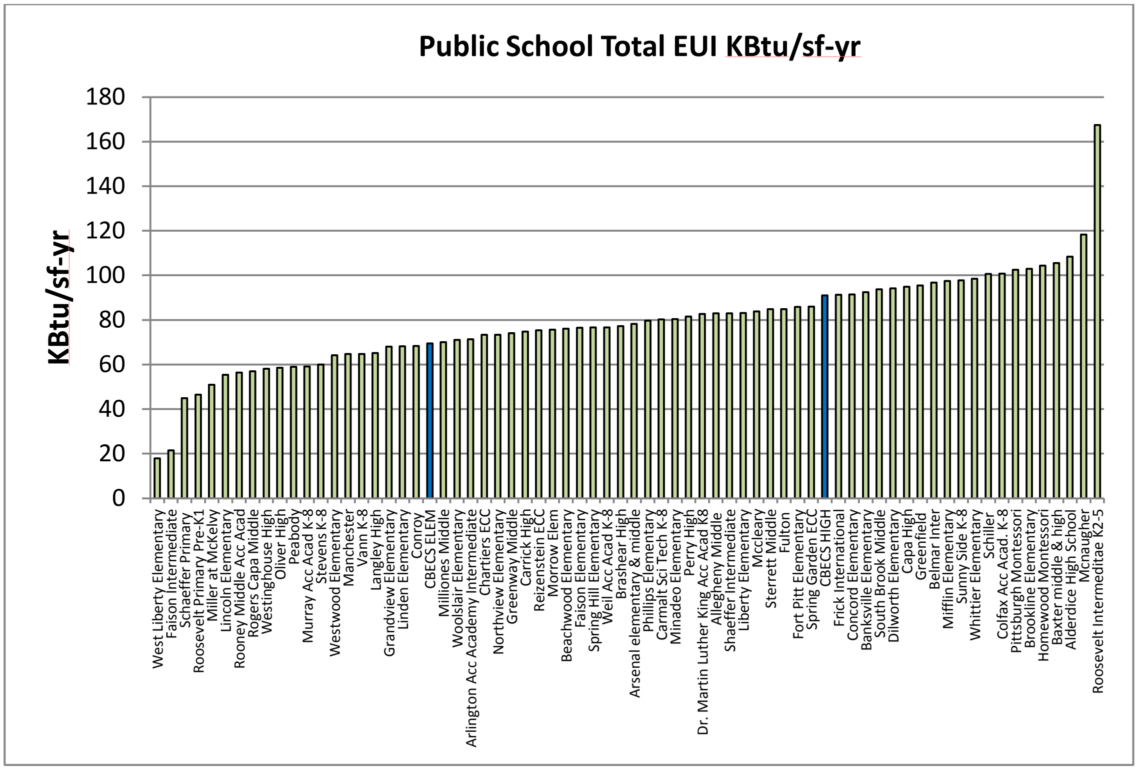

Figure 3 Pittsburgh Public School building EUI   (Gunasingh, Aziz, Loftness, & Cochran, 2011)

This finding shows the importance of commercial building renovations to achieve significant reductions in energy consumption. They also identify crucial renovation focus areas to achieve reductions in commercial energy consumption. The utility savings can provide additional financial resources to public school districts.

Condition of the Existing Building Stock

Equally significant for energy retrofits is the physical and technical condition of existing building systems, and an understanding of those elements most in need of updating or replacement. Again, the Mid-Atlantic subset of the CBECS data base provides an overview of the physical attributes of the enclosure, HVAC, lighting and other systems that could be expected in an energy retrofit (Figure 4), to be discussed in greater detail in the four sections of this report.

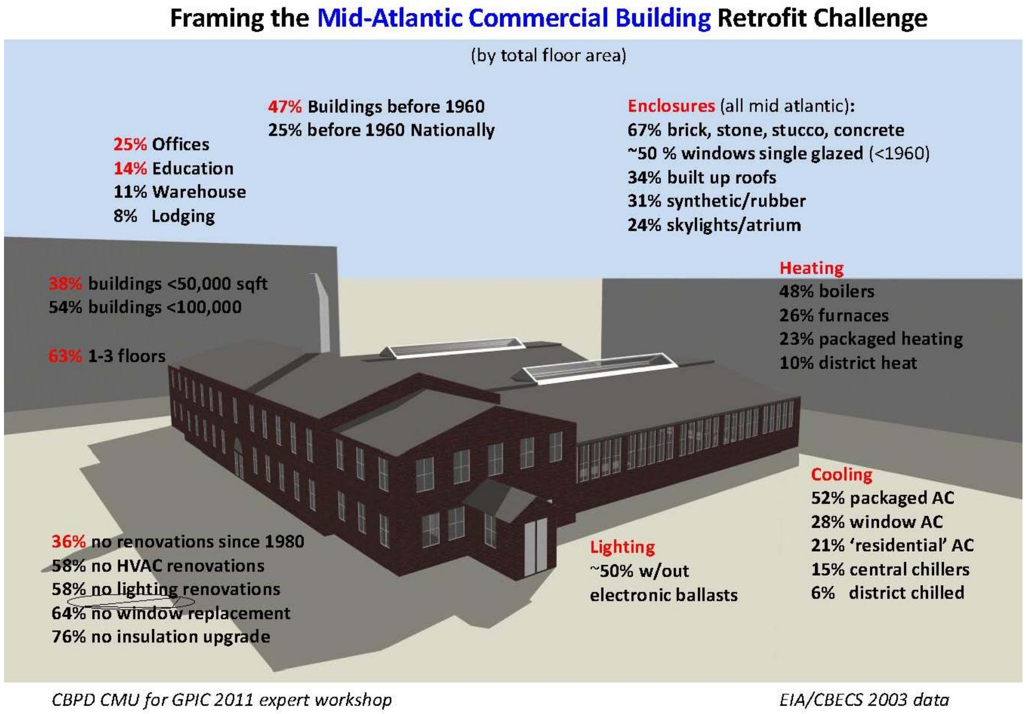

Figure 4 The physical attributes of existing buildings in the Mid-Atlantic region (Loftness, Aziz, Lam, Lee, & Cochran, 2011)

A separate study undertaken for GPIC by Robust Systems and Strategy LLC identified a number of critical characteristics in the existing building stock, also through CBECS data base analysis (Figure 5) that will prioritize retrofit recommendations and impact payback calculations. Most significantly, the likelihood that almost 50% of our commercial building stock is still single pane windows, has no effective shading of those windows, and underutilizes daylight. Relative to mechanical systems, well over half the buildings have packaged air conditioning units, that most likely are dated, and no advanced controls.

	% Stock	Template	Window Type	Reflective Glass	Awnings	Heating System	AC System	VAV	Econ-omizers	Sky Lights	% Daylit
1	5%	I	Single pane	No	No	Space heaters	Packaged AC units	Yes	Yes	Yes	0
2	4%	I	Single pane	No	No	Heat pumps for heating	Heat pumps for cooling	No	No	No	0
3	6%	I	Double pane	No	No	Boilers inside	Central chillers inside	Yes	Yes	No	0
4	13%	I	Double pane	No	Yes	Furnaces hot air	Resid-type central AC	No	No	No	10
5	38%	II	Single pane	No	No	Packaged heating units	Packaged AC units	No	No	No	0
6	3%	II	Double pane	Yes	Yes	Space heaters	Packaged AC units	No	No	Yes	0
7	16%	II	Double pane	No	Yes	Packaged heating units	Packaged AC units	Yes	Yes	No	0
8	12%	II	Double pane	No	Yes	Heat pumps for heating	Heat pumps for cooling	Yes	Yes	No	0
9	3%	II	Double pane	No	No	Boiler	Central chillers inside	Yes	Yes	No	30

Figure 5 Significant combinations of attributes of CBECS buildings in the Mid-Atlantic region (Otto, 2011)

This research team also evaluated the CoStar data base of buildings, and identified that operating expenses average at $7 per square foot, substantially higher than present payback calculations have assumed (Figure 6).

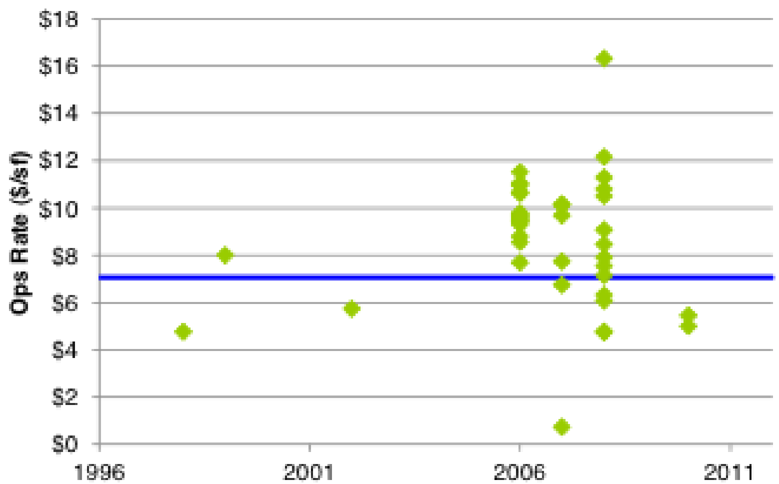

Figure 6 Operating expenses of CoStar buildings in the Mid-Atlantic region (Otto, 2011)

These factors continue to be critical to setting prioritized actions for building owners and decision makers, and providing them with cost-benefit input, efforts ongoing in GPIC Task 4.

State of the Art in Enclosure Technologies and Integrated Systems for 50% Energy Savings in Existing Commercial Buildings

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Heating, cooling and lighting energy consumption can be significantly reduced with high performance enclosure upgrades. A well-designed integration of enclosure improvements with HVAC and lighting system controls can significantly reduce energy consumption while improving occupant comfort, health and satisfaction.

Enclosure system upgrades can provide a significant opportunity to achieve energy efficiency in office buildings. The analysis of mid-Atlantic office buildings in CBECS (2003) shows that more than two thirds of the buildings have not had windows replaced *or* seen any upgraded wall or roof insulation in the last 30 years (Figure 7).

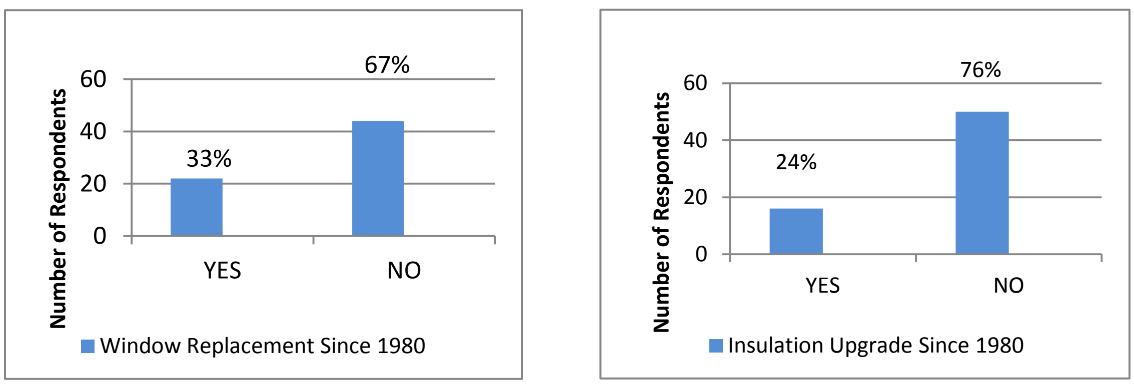


Figure 7 Two-thirds of Mid-Atlantic offices have not had window or wall improvements (CBECS 2003)

Energy Saving Enclosure System Retrofits for Existing Commercial Buildings in the NE

Given the age of our building stock and the significant energy losses due to building enclosures, improving the building's roof, walls and windows is a critical step to 50% energy reduction in building energy use. During the GPIC Expert Workshop in March, the enclosure breakout group identified five key recommendations for achieving the highest level of energy efficiency through enclosure systems:

1. **Daylighting**, for both task and ambient needs, as long as possible (also recommended by the lighting breakout session).
2. **Natural ventilation**, during comfort periods with manageable humidity (with the understanding that humidity and cost restrictions may be problematic for near-term retrofit applications).
3. **Significant insulation** for the enclosure (roof, walls, floor, and windows/skylights), possibly to the PassivHaus standards to eliminate perimeter heat.
4. **Control strategies** for daylight redirection, shading and glare control, cooling and ventilation, with expert recommendation/feedback to enable the occupant/user to make better decisions for higher comfort levels and lower-energy consumption.
5. **Systems integration**, most critically integrating window replacements with electric lighting, mechanical conditioning, and appropriate controls to maximize the use of passive strategies.

A GPIC Task 3 study entitled *Towards Carbon Neutrality in Existing Buildings: High Performing Enclosures for Building Renovation* (Serra, Aziz, Loftness, & Cochran, 2011) analyzed the retrofit strategies undertaken in 28 renovated, high-performing building enclosures in heating-dominated climates (Figure 8). Each renovation strategy was analyzed for its impact on total building EUI, heating, and cooling loads. Additionally, the study determined the benefits accomplished beyond energy efficiency such as economic and social benefits. These analyses and recommended strategies were utilized to propose a set of economically viable and energy efficient enclosure renovation solutions for an existing dormitory on Carnegie Mellon University's campus, Donner Hall.

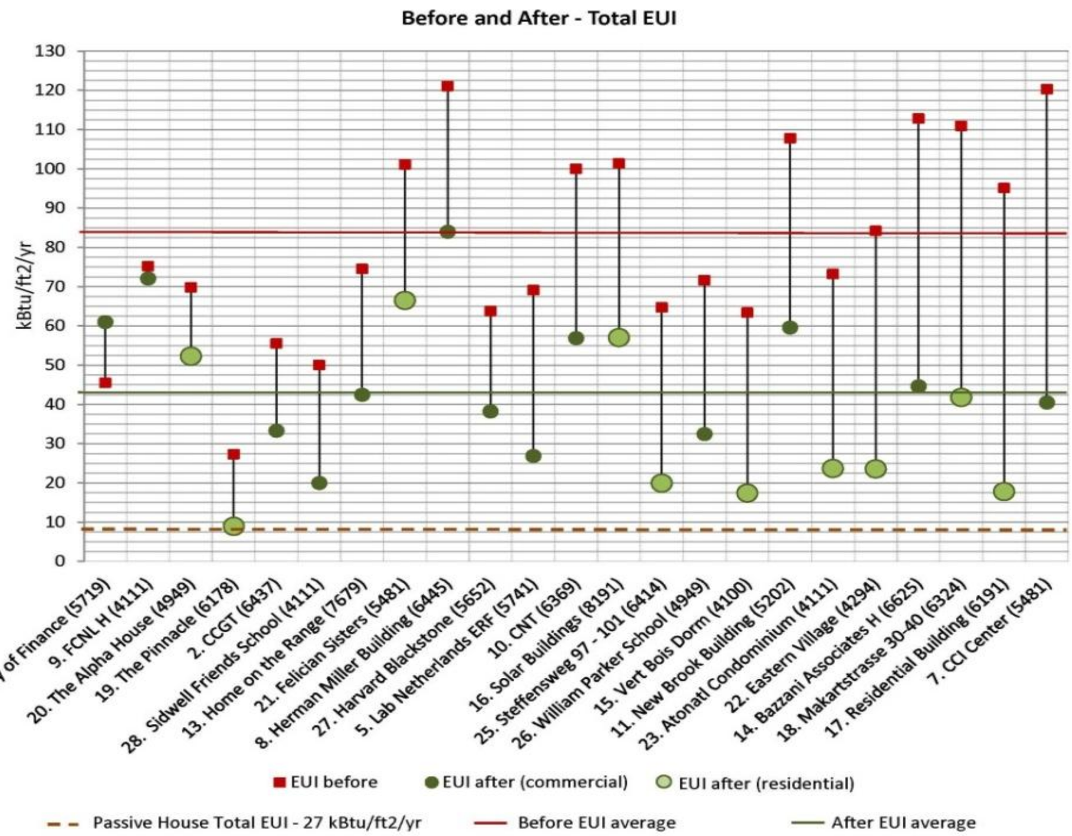


Figure 8 Analysis of retrofit strategies undertaken in 28 renovated building enclosures (Serra, Aziz, Loftness, & Cochran, 2011)

Based on the measured energy savings in these 28 case buildings, the five (5) best practices for measurably improving energy efficiency proved to be:

1. Added insulation for heat gain/heat loss control.
2. Operable windows for natural ventilation.
3. Shading/glare control and passive solar utilization, through a combination of fixed external shading and internal blinds.
4. Improved windows for heat gain/heat loss control.
5. Daylighting through the integration of windows, blinds, furniture and ceilings.

Subsequent evaluations of a number of national studies and guidelines for energy efficient retrofits reinforce these recommendations and help to clarify priorities for building enclosure improvements, referenced throughout this document. Several recent guidelines were invaluable to this effort:

- Pacific Northwest National Laboratory, PECL. (2011). *Building Technologies program, Advanced Energy Retrofit Guide, Practical Ways to Improve Energy Performance, Office Buildings* (Pacific Northwest National Laboratory, PECL, 2011).

- ASHRAE, The AIA, IESNA, New Buildings Institute, DOE. (2008). *Advanced Energy Design Guide for Small Office Buildings, Achieving 30% Energy Savings Over ANSI/ASHRAE/IESNA Standard 90.1-1999 .* Atlanta: ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2008).

- *ANSI/ASHRAE/USGBC/IES Standard 189.1-2009, Standard for the Design of High-Performance Green Buildings Except Low-Rise Residential Buildings First Public Review Draft.* (2010). Atlanta: ASHRAE (American Society of Heating, Refrigerating and AIr-conditioning Engineers, 2010).

- Next 10. (2010). *Untapped Potential of Commercial Buildings Energy Use and Emissions, Capturing Wasted Energy: Efficiency, Retrofits, Barriers.* California: Next 10 (Next 10, 2010).

This state of the art report, a first generation report that will be refined each year, is focused on five enclosure retrofits for energy efficiency and improved indoor environmental quality that should be considered by every building owner:

1. **Upgrade building air tightness, without eliminating the potential for natural ventilation.**
2. **Upgrade roof insulation and reflectivity, considering integrated solutions.**
3. **Upgrade window layers for effective daylighting and shading.**
4. **Upgrade windows and perimeter HVAC systems for thermal performance and ventilation.**
5. **Upgrade wall insulation as possible.**

Enclosure 1: Upgrade building air tightness, without eliminating the potential for natural ventilation.

The age of the commercial building stock in the GPIC region is associated with not only the lack of wall, floor and occasionally roof insulation, but with significant air infiltration. In a 2005 study of 201 buildings entitled *Airtightness of Commercial Buildings in the U.S.*, Emmerich and Persily identified that infiltration losses in commercial buildings are as significant as residential, with average air exchanges of 28.4 $m^3/h{\cdot}m^2$ at 75 Pa for the 201 buildings with the highest leakage in buildings that are 1 story in height (See Figure 9) (Emmerich & Persily, 2005).

TABLE 1
Summary of Building Characteristics and Airtightness Data

		Air Leakage at 75 Pa ($m^3/h{\cdot}m^2$)			
Dataset	#	Mean	Standard Deviation	Min	Max
NIST	9	15.1	11.5	3.9	43.3
FSEC	88	41.7	34.3	4.0	168
Brennan	23	14.0	13.3	2.7	60.6
ACoE	79	19.7	10.3	3.4	63.4
PSU	2	9.8	0.4	9.5	10.1
All buildings	**201**	**28.4**	**35.8**	**2.7**	**168**

Figure 9 Infiltration losses in Commercial Buildings in the U.S (Emmerich & Persily, 2005)

A separate study by the same authors, concluded that the annual cost savings are largest in the heating dominated climates, with potential gas savings for heating of greater than 40 % and electrical savings for cooling of greater than 25%, by tightening the building envelope to meet ASHRAE infiltration minimums. The GPIC Roadmap also proposes this as a critical action for future development, with recommendations to *Benchmark Air Leakage Rates on Existing buildings by Construction Type and Building Use, and develop robust solutions.*

In 2011, GPIC Task 2 completed detailed simulation-based parametric analysis to understand the relative impact of four major enclosure strategies: air tightness, roof insulation, wall insulation, and window specifications. Entitled *One-Factor-At-a-Time (OTA) Evaluation of Building Enclosure Measures for Building 661* (Karaguzel & Lam, 2012) this report concludes that reducing infiltration could be the most effective energy saving strategy for existing buildings. Using EnergyPlus with an existing baseline model as the energy performance benchmark, this team evaluated the relative effectiveness of various enclosure design options through simulation (See Figure 10). This parametric analysis approach is defined as the one-factor-at-a-time (OTA) method in which all possible input variables are kept constant at their initial values (which are the ones assumed for the selected benchmark model) during perturbation of a specific independent variable. In four building decision arenas, a list of 21 enclosure measures were investigated, comparing existing condition energy uses to ASHRAE 90.1 and stepped improvements up to state of the art retrofit limits (ASHRAE, 2007).

- External Walls – Thickness of thermal insulation layer (m).
- Roofs – Thickness of thermal insulation layer (m).
- Infiltration Rate – Uncontrolled air flow rate per unit area of external surfaces ($m^3/s\text{-}m^2$).
- Glazing Type – Varying configurations of glazing units identified with overall performance indicators of U-factors (W/m^2K), Solar Heat Gain Coefficient (SHGC), and Visible Transmittance.

Of these 21 enclosure choices, three reductions in infiltration rate were simulated, 0.10 ac/h (super-tight envelope), 0.60 ac/h (moderately tight envelope), and 0.24-0.44 ac/h (DOE reference model-compliant envelope). It can be concluded from Figure 10 that envelope infiltration rates have significant effects on space heating energy with 15% to 30% reductions in the combined heating, cooling and ventilation loads in existing commercial buildings in our region.

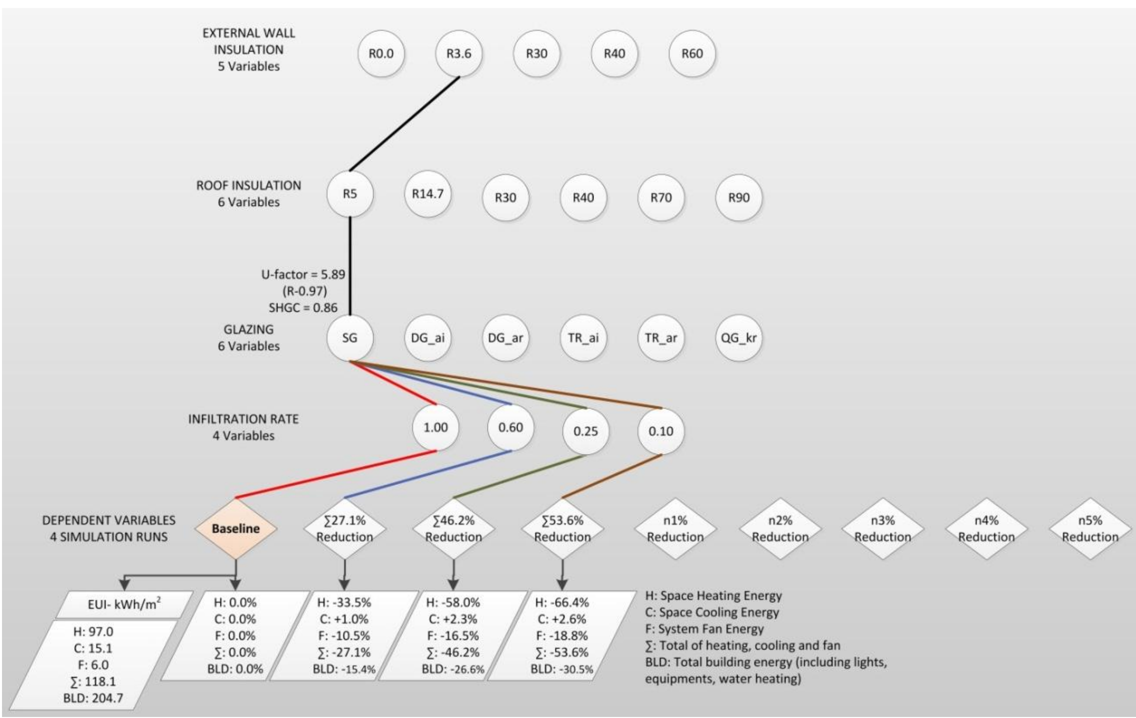


Figure 10 Parametric tree for infiltration rate alternatives (Karaguzel & Lam, 2012)

Another GPIC study evaluated field measured energy savings relative to different retrofit actions in residential construction in the Pittsburgh region (Tanski, Loftness, Aziz, & Cochran, 2011). In collaboration with ACTION-Housing, Inc., a local Pittsburgh non-profit organization weatherizing low-income homes in the Pittsburgh region, a team at CMU investigated weatherization techniques that consistently reduced heating (gas) consumption in residential buildings. Small residential buildings were investigated due to the partnership with Action Housing and because they represented similar construction typologies to small commercial buildings. The research evaluated measures taken to improve comfort, safety and energy performance, the cost of these measures, and the annual natural gas consumption of a representative sampling of 23 homes in the Pittsburgh region before and after weatherization to determine what measures had the greatest impact on reducing natural gas consumption. While roof insulation achieved the highest energy savings, to be discussed further, the next major energy savings were due to infiltration reduction through a host of measures: caulking at all enclosure junctures, weatherstripping of all operable units, sealing gaps and major holes, and others (see Figure 11). The field measurements revealed that the greater the number of measures taken, the greater the reduction in energy use, with an average of 4.36 measures resulting in an impact of 6.22 MCF (5.7 %) reduction per home (Tanski, Loftness, Aziz, & Cochran, 2011).

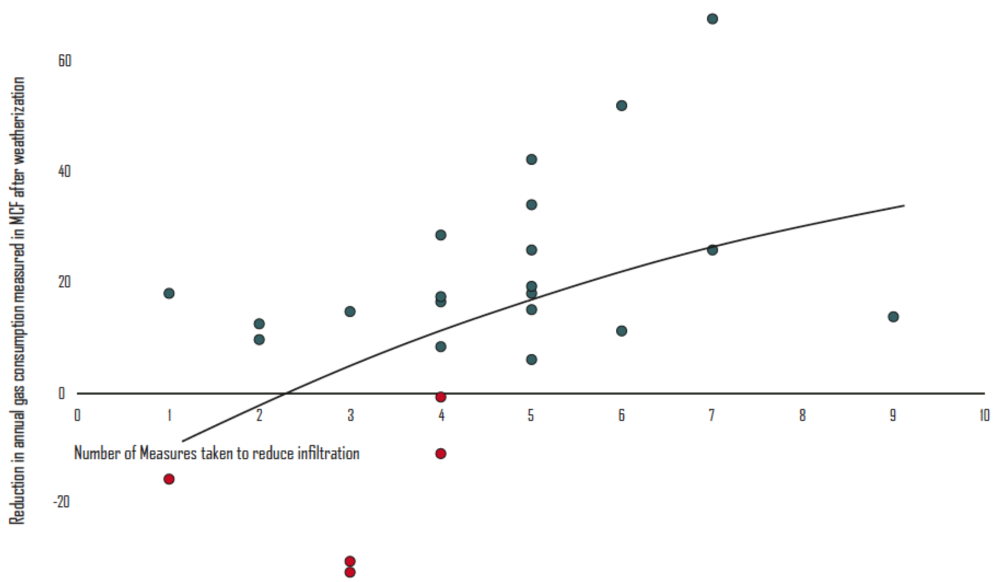


Figure 11 Effect of measures taken to reduce infiltration on annual gas consumption (Tanski, Loftness, Aziz, & Cochran, 2011)

While weatherization techniques can measurably reduce infiltration for residential and small commercial buildings, improving air tightness in larger commercial buildings requires additional tools and skills. The Corps of Engineers, ERDC-CERL, in collaboration with IMCOM and industry, developed the nation's first building air tightness standard for new facilities and major renovations. The standard requires the building envelopes of office buildings, office portions of mixed office and open space (e.g., company operations facilities), dining, barracks, and instructional/training facilities to be designed and constructed with a continuous air barrier to control air leakage into (or out of) the conditioned space, and has been implemented in more than 250 buildings. This new requirement is estimated to result in energy savings of 5% to 25%

depending on climate conditions, and will help reduce the risk of mold and mildew in buildings located in humid climates (US Army Corps of Engineers, 2008).

To identify the most egregious locations of air leakage in existing buildings, and to confirm that contracted work complies with the 2012 IECC that the building envelope does not exceed a maximum air leakage rate of 0.40 cfm/ft^2, field test methods are used similar to those for residential construction. Small commercial projects typically are able to use blower door systems for providing air leakage testing for the building. Large buildings can use blower door systems but if the pressure differential cannot be met by the fan power available, multipoint tests may need to be used to demonstrate compliance with the IECC. Both horizontal and vertical glazing and doors also have maximum air leakage requirements in today's standards (2012 IECC). The US DOE EERE allows energy auditors to use thermography—or infrared scanning—to detect thermal defects and air leakage in building envelopes. Thermographic scans are also commonly used with a blower door test running. The blower door helps exaggerate air leaking through defects in the building shell. Such air leaks appear as black streaks in the infrared camera's viewfinder. Building thermography is an excellent tool for identifying gaps in insulation and major areas of infiltration, and can also identify moisture in structures, risk of condensation, structural challenges, voids and buried services. Over the fast few years, the equipment, applications, software and understanding connected with thermography have all developed at an astonishing rate. As the technology has gradually become integrated into mainstream practices, a corresponding demand for application guides, standards and thermographer training has arisen.

In a recent report entitled *Advanced Energy Retrofit Guide, Practical Ways to Improve Energy Performance, Office Buildings,* DOE's PNNL gives the following recommendations: Reduce envelope leakage (Department of Energy, 2011). Minimize air infiltration to 1.0 cfm/ft^2 and less by sealing, caulking and placing weather-strip to the following areas:

- Joints around fenestration and door frames.
- Junctions between walls and foundations, between walls at building corners, between walls and structural floors or roofs, and between walls and roof or wall panels.
- Openings at penetrations of utility services through roofs, walls, and floors.
- Site-built fenestration and doors.
- Building assemblies used as ducts or plenums.
- Joints, seams, and penetrations of vapor retarders.
- All other openings in the building envelope.

The mandate to minimize air infiltration to 1.0 cfm/ft^2 also applies to a building's entrance doors (with 0.4 cfm/ft^2 for revolving doors). The addition of a vestibule at the entrance with self-closing devices is critical to separate conditioned space from the exterior. The vestibules should be designed in a way that the interior and exterior doors do not open simultaneously (Department of Energy, 2011).

Enclosure 2: Upgrade roof insulation and reflectivity, considering integrated solutions

Roof replacements are recurring projects for building owners, averaging 20-25 years, suggesting that 4-5% of the GPIC region's building owners and managers are in the process of selecting new roof materials. The State of Pennsylvania Climate Change Action Plan calls for three alternative considerations in commercial roof replacement - light colored highly insulated roofs with excellent payback and very manageable costs; green roofs with high costs but measurable benefits in reducing heat island effect and offering carbon sequestration as well as major aesthetic advantages; and photovoltaic roofs with the highest cost but obvious benefits as a distributed energy source (DEP, 2009). Given that a significant number of existing commercial buildings in the Mid-Atlantic are less than 3 stories, significant annual and peak energy savings can be achieved by replacing aging roofs with light colored highly insulated roofs. The critical performance metrics for roofs will be resistance to heat loss and heat gain (R-value of the integrated assembly), solar reflectance index (SRI), water management (storm runoff capture), and longevity related to life cycle cost.

The *One-Factor-At-a-Time (OTA) Evaluation of Building Enclosure Measures* (Karaguzel & Lam, 2012)*,* varying the insulation value of the roof assembly and the solar reflectance index, identified that introducing R30 (4 inches) insulation can result in a 19.8% reduction in heating energy and a 17.1% reduction in total energy. The research also demonstrated that 65% of the maximum possible energy gains can be achieved by implementing an ASHRAE 90.1 2004 compliant roof assembly or R-14.7 (2 inches), however given the modest increases in material and installation costs, and the life cycle heating and cooling assembly, the R-30 assembly should be the baseline. As demonstrated in Figure 12, most space heating improvements occurred when insulation was added to provide a R30 roof. There were additional modest reductions in space heating energy consumption for R-40, R-70 and R-90 roofs. Increasing the roof insulation level up to the super-insulated category of R-90, compare with R-5, can provide a 23% reduction in space heating energy, and the combined total energy gain is 14.8% with this alternative as shown in Figure 13. Figure 13 also show marginal variations observed for R-40, R-70 and R-90 insulation alternatives.

As demonstrated in Figure 14, glazing also provides heating and cooling energy reduction opportunities. Multiple glazing options were modeled in EnergyPlus to identify the impact of glazing renovation activities. A building with a R-5 roof and window glazing specifications that include a U-factor of 0.47 and SHGC of 0.20 can obtain a 13.6% heating energy and 24.8% cooling energy reduction, resulting in an overall 12.2% total building energy reduction when compared with baseline building (Karaguzel & Lam, 2012).

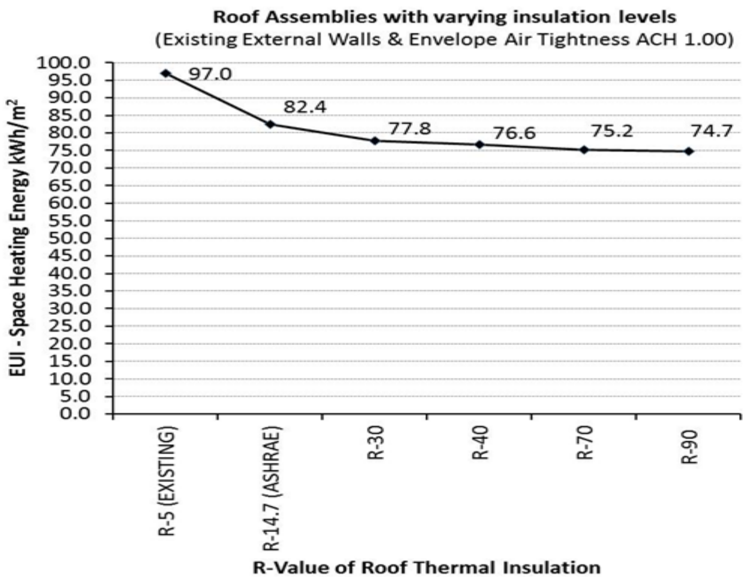


Figure 12 Effects of roof thermal insulation thickness on space heating energy consumption (Karaguzel & Lam, 2012)

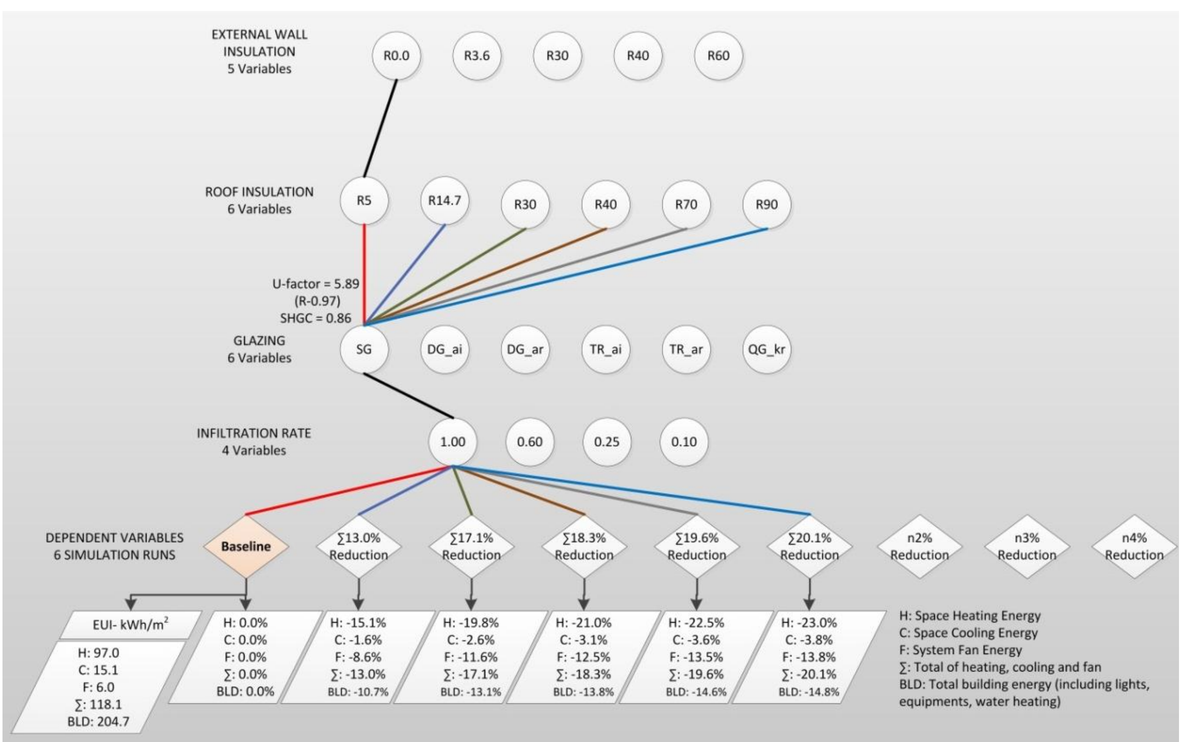


Figure 13 Parametric tree for roof thermal insulation alternatives (Karaguzel & Lam, 2012)

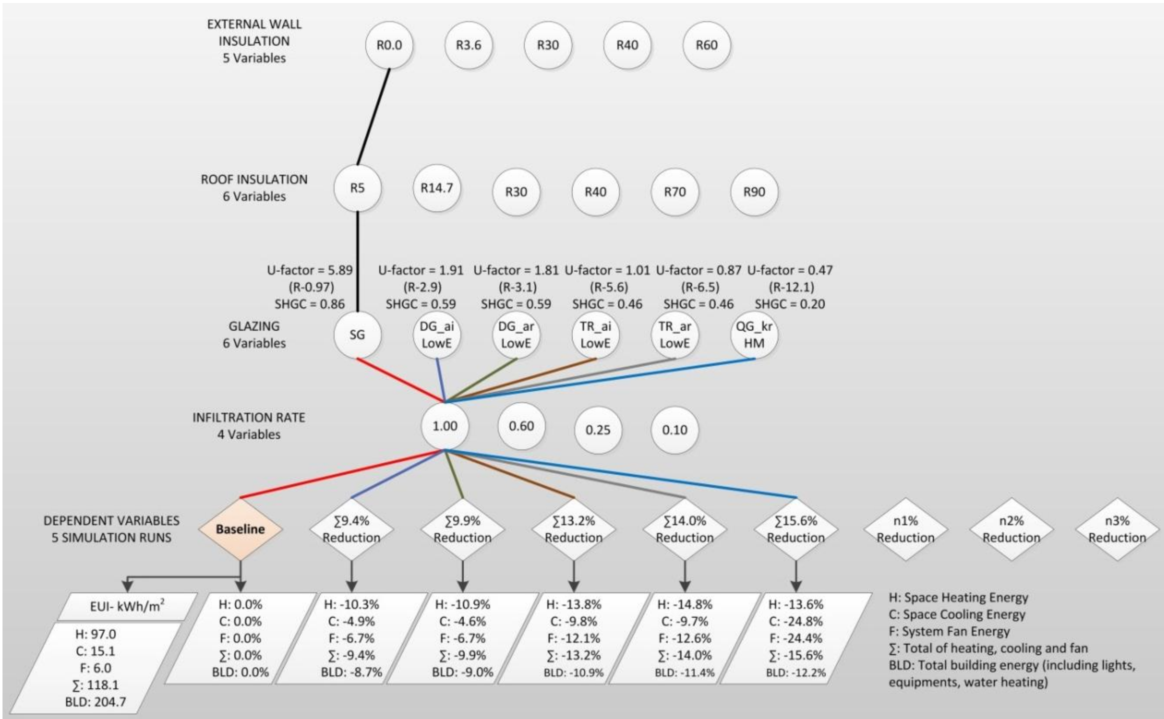


Figure 14 Parametric tree for glazing alternatives (Karaguzel & Lam, 2012)

The CMU/ ACTION-Housing study that investigated weatherization techniques that will reduce gas consumption in residential buildings identified roof insulation as the most effective heating energy saving strategy, exceeding even infiltration reduction (Tanski, Loftness, Aziz, & Cochran, 2011). Homes or small commercial buildings of similar construction typologies in which insulation was added to the attic saw an average reduction of 21.4 MCF (15%) from their annual gas bill, while those where insulation was not added saw an average reduction of only 0.2 MCF despite several other measures being taken.

Insulating roofs in residential and small commercial buildings where there is easy access to the floor of the attic or unheated space should be undertaken immediately. In addition to heating and cooling energy savings, thermal comfort will improve for the building occupants, and peak cooling loads may be measurably reduced as well. If there is mechanical equipment, ducts or pipes in this exposed area, it will be important to insulate these as well to ensure the energy savings.

For flat roof commercial buildings, an exterior application of insulation at the time of roof refinishing is the most common retrofit approach (Figure 15). When the waterproof roofing membrane is integrated with the R-30 insulation, there is simultaneously an opportunity to select a highly reflective surface coating, or cool roof, to further reduce air conditioning loads.

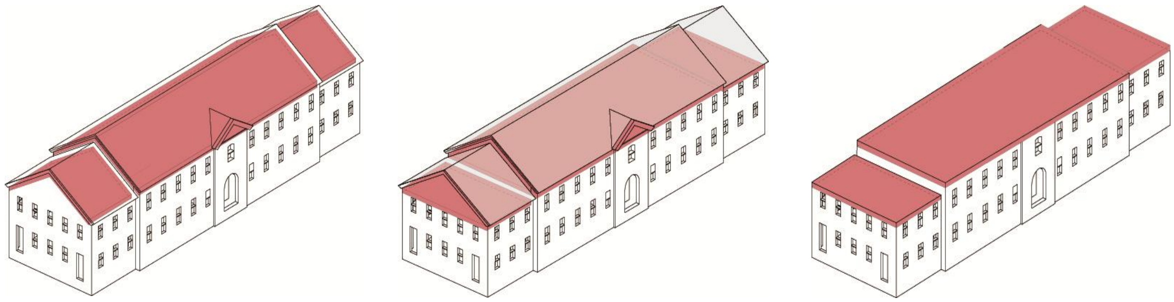


Figure 15 Three common roof insulation variations in retrofit applications

The Department of Energy EERE published cool roof standards in 2010 (Urban & Roth, 2010) and completed region by region assessments of the costs and benefits. Cool roofs have higher reflectances and higher emittances than conventional grey, brown or black roofing materials. Originally, color was a determinant of reflectance, however, advances in coatings have resulted in a wide array of choices in roof color while achieving both of these critical properties (Urban & Roth, 2010) The Department of Energy has developed a Solar Reflectance Index (SRI) seen in Figure 16, to support product comparisons, with a goal of achieving the highest SRI possible, especially in low buildings with air conditioning.

Table 1: Typical Minimum Cool Roof Requirements, California Energy Commission[2]

Roof Type	Solar Reflectance [3-year aged]	AND	Thermal Emittance [new or aged]	OR	Solar Reflectance Index (SRI) [3-year aged]
Low sloped	0.55		0.75		64
Steep sloped	0.20		0.75		16

Cool roof requirements depend on the roof's slope. Low sloped roofs have a pitch of 9.5° or less (2:12 rise over run), while steep sloped roofs have a pitch greater than this. Requirements are usually less stringent for steep sloped roofs. Some heavier roofs – such as those with concrete pavers, ballast, or vegetation – also have less stringent cool roof standards. The weight of these roofs causes them to heat up more slowly, and during the night some of that stored heat is returned to the outdoor environment.

Figure 16 Criteria for Cool Roof Selection (Urban & Roth, 2010)

The selection of these coatings does not have to cost more than conventional roofing, and should be a requirement in any bid package. The EERE study identified no or slight cost premiums of 0-75 cents a square foot, with energy and system benefits that will ensure less than a 3 year payback seen in Figure 17. Given that the life of most commercial roofs is 20-25 years, the cost-benefit of this action is clear. Oak Ridge National Labs has created a free on-line roof saving calculator at http://www.roofcalc.com/ that will help in the specification of your replacement roof for the most cost effective energy savings (Oak Ridge National Laboratory; Lawrence Berkeley National Laboratory, 1999).

Table 4: Cool vs. Hot Roofs, Typical Expected Savings and Premiums

	Cool vs. Hot Roof	Notes
Upfront Savings (Costs)	$/ft^2 roof area	
Installed Cost	(0.00-0.75)	Material cost premium. As shown in Tables 5 & 6, most cool options have only a slight cost premium or none at all.
Rebates	0.00-0.20	Rebates are available in select locations, check here: http://www.coolroofs.org/codes_and_programs.html.
HVAC Downsizing	0.00-0.07	Reductions in peak cooling capacity tend to be modest, and are only possible when cool roofing coincides with HVAC replacement and reductions enable use of smaller AC systems.
Annual Savings (Costs)	$/ft^2/yr roof area	
Cooling Energy	0.00-0.13	Varies by location, insulation levels, HVAC equipment and efficiency, and utility rates. Estimate energy cost savings with the Roof Savings Calculator: http://www.roofcalc.com. Snow on roofs can reduce the heating energy penalty.
Heating Energy	(0.00-0.03)	

Figure 17 Comparison of expected savings from cool and hot roofs (Urban & Roth, 2010)

Commercial buildings with flat roofs have other considerations to add to roof insulation and solar reflectivity. The GPIC Research Roadmap action related specifically to enclosures recommends "Examine passive and active envelope strategies by building construction type and use." The near term efforts related to this action include the cost-benefits of value added roof replacements and the value of increased R values, reflective surfaces, skylights for daylighting, and rooftop HVAC upgrades.

Roofs are often home to mechanical equipment, often aging and inefficient equipment and ducts sitting in direct sunshine. **Rooftop HVAC** replacement should be considered alongside roof replacement, to significantly improve efficiencies and air quality, to reduce noise and maintenance costs, and to ensure that the roofing membrane is continuous with appropriate flashing around long term roof penetrations such as HVAC components.

Roofs also present major opportunities for daylighting through **transparent and/or translucent skylight**s integrated with reflectors and ceiling surfaces that reflect and diffuse that light for effective distribution. The optimization of skylight design and specifications must balance heat loss and heat gain (R), daylighting (Tvis) without direct glare or brightness contrast, shading (SHGC) and natural ventilation (cfm and solar assisted cfm). Today, retail and other commercial buildings are rediscovering the benefits of daylighting for both lighting energy savings and for increased customer and occupant benefits.

Roofs offer the opportunity for **solar energy collection** as a renewable energy source. The Expert Workshop recommended consideration of three possible strategies: a ventilated or aspirated solar roof for passive heating in winter and roof cooling in summer (eg. SolarWall™); solar thermal assemblies on the roof for renewable heating and hot water; and solar electric PV roof assemblies for electric power generation. These strategies should be considered, as all other technological approaches, only if their relative cost-effectiveness in the five to ten year timeframe can be justified as acceptable to the local retrofit market.

Although it does not affect building energy use directly, the expert workshop identified roof and site **water collection** as an energy savings strategy for further discussion since it reduces the demand for energy intensive treated water that must be pumped long distances. All roof upgrades in the mid-Atlantic region should be designed to catch roof water for on-site non-potable end-uses such as landscape irrigation, cooling tower water or evaporative roof spraying, or even as grey water sources for toilets. In addition to the energy use for water treatment and distribution, building retrofits to reduce storm water runoff can alleviate major health challenges in the combined storm-sewer systems that dominate the region. If the roof replacement project is a surface that can be seen from adjacent buildings and spaces, a green roof could be considered. Green roofs can capture 70% of the storm water, reduce heating and cooling loads by 15%, reduce peak cooling loads by 79%, and provide visual delight for a community of users (CMU Center for Building Performance/ABSIC, 2008). The City of Chicago has an aggressive cool and green roof campaign that is transforming the image of that city.

In a study entitled "A comparison of Conventional, White and Green Roofs, using 50-year Present Values" published in the 2011 *NRC Guidelines for Federal Facilities* (Wan, Sproul, & Rosenfeld, 2011) Art Rosenfeld of LBNL concludes that:

- Both white (highly reflective) and green (vegetated) roofs, because they have 20 or 30 year services lives, are cheaper life-cycle than conventional black bitumen roofs, but white wins by ~\$120/m^2 (\$10/ft^2); and should be the norm for the future.
- In a climate with uncomfortably hot summer days, both white and green are about equally effective in reducing the heat load on the building space below the roof and in mitigating the urban heat island. But when it comes to cooling the whole earth (to offset the heating effect of CO_2) per unit area of roof white is about three times as effective as green.
- A notable advantage of a green roof is that it retains up to 70% of incident rainwater, which subsequently evaporates; cooling the roof itself, the building below, and the city. In cities which pay for storm water retention this can be worth ~\$10/m^2 (~\$1/ft^2) over 50 years. This can be a useful attribute with a lesson for conventional roof design. ALL designers of roof systems should consider the "cost effectiveness of retaining rainwater in a cistern at ground level and using it as grey water, irrigation water for the grounds, or even cooling tower water" (Wan, Sproul, & Rosenfeld, 2011). "ALL" roofs includes particularly white roofs.

Enclosure 3: Upgrade window layers for effective daylighting and shading

Exterior and interior window layers can be a very effective strategy for energy conservation, by maximizing daylight without glare, providing shade, and improving the window's thermal resistance to heat loss and heat gain.

Depending on the size of the existing windows, and whether they have clerestories, **light redirection** could be in the form of light shelves, louvers, or blinds located externally or internally with the ability to redirect daylight to the ceiling for more balanced daylight distribution. These louvers must be specified to provide effective daylighting without direct glare or 'brightness contrast' glare, and they should also provide seasonally appropriate shading.

Manually controllable interior or exterior **shading** devices would maximize shading only when it is needed, without compromising the benefits of passive solar heating when it is needed. These shades should also not compromise the contributions of daylight and should help to manage glare while ensuring views to the outside. Alternatively, or in combination, trees and trellises can be introduced for seasonal shading – just when it is needed. Shading with landscape requires careful specification of plant type and a commitment to ongoing maintenance.

Finally, storm windows for single glazed buildings, or **night insulation**, in the form of insulated shutters, roller shades or louvers may also prove cost effective if they serve multiple purposes such as blackout curtains, external storm protection, or even rolling elements for space definition.

For each of these layers, manual and automatic control schemes may be important to maximize their energy benefit including:

1. Weather responsive control strategies that allow the building to react according to seasonal and daily changes.
2. User-based control (that could be automated with manual override) with intelligent feedback (to inform the occupant of the most energy effective strategies, for daylighting, natural ventilation and heat loss/gain).
3. Controls for daylight redirection, glare and shading as an integral part of the lighting control system.
4. Controls for ventilation that include manually controlled operable windows for occupant ventilation and automated control for night ventilation (skylights and other roof devices), with expert feedback for caution.
5. Night insulation controls to ensure that windows and skylights reduce winter heat loss and summer heat gain whenever occupants are out of the building.

Daylighting and Shading Technologies and Systems

Many existing buildings were designed to be predominantly daylit. They have generous windows with clerestories and high ceilings to ensure that even the furthest desk in the room is effectively illuminated. Corridors receive borrowed light over transoms, from skylights and windows at their ends. Even service rooms are often on the outside wall with windows for daylighting. This “historic” advantage should not be lost in a building renovation. If it has already been compromised by previous renovations, it should be re-enabled through integrated design.

CBECs data reveals an average of 13% reduction of total energy use in those buildings that have a measurable level of dayliting with the electric lights off; buildings with no exclusively daylit spaces have total source energy loads of at 211.7 kBTU/sf/yr versus buildings with some daylit spaces have an average of 184.3 kBTU/sf/yr of total source energy (CBECS , 2003). Moreover, buildings that can harness daylight in more than 75% of their spaces see a reduction of 21% in total energy consumption (heating, cooling, lighting, plug loads combined) compared to those that have less than 25% of daylit spaces (Figure 18) (Loftness, Aziz, Lam, Lee, & Cochran, 2011).

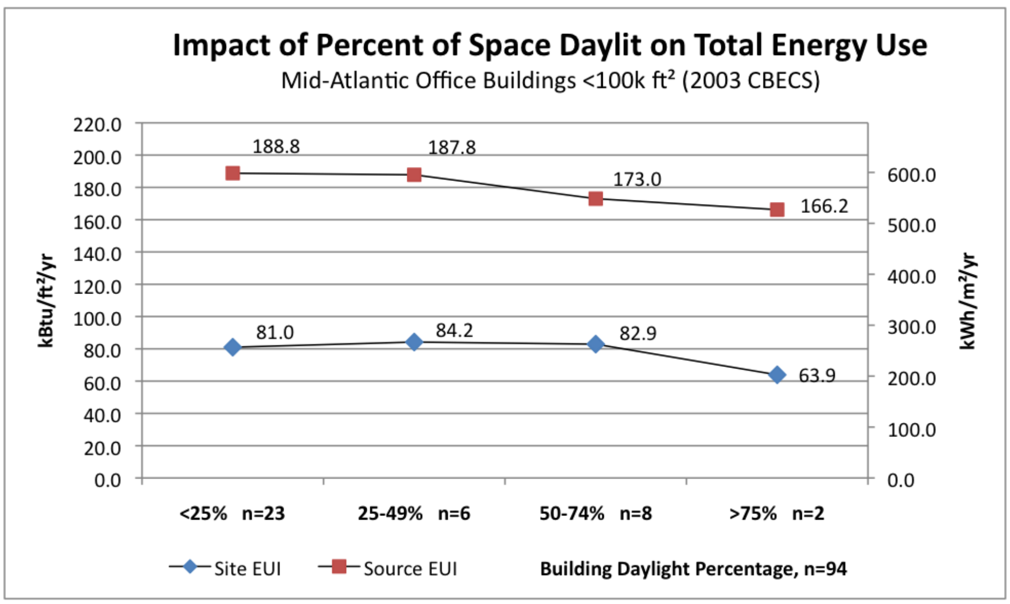


Figure 18 The highest daylight contributions result in the lowest energy use (CBECS , 2003)

Daylight redirection devices are invaluable for effective daylighting and glare control in deeper spaces, and exterior and interior light reflectors should be considered. Today, external light shelves positioned above standing views in buildings with taller windows are beginning to be introduced to reflect light deeper into the space, while providing shade from solar overheating to minimize cooling loads during the summer).

A GPIC study of the lighting, heating and cooling benefits of a range of external and internal layers in combination with daylight dimming of the electric lighting system demonstrate that at least 20% of total energy use can be saved (Ahmadi & Loftness, 2011). This study (Figures 19 and 20), using Energy Plus and Daysim to evaluate choices for a new, energy efficient building under construction for Phipps Conservatory, demonstrated the significant value of introducing external and internal light shelves and trellises in combination with internal shading blinds or mesh shades, for lighting, cooling and heating load reduction. Starting from an energy efficient baseline building A01, Ahmadi et al identified 20-25% further reductions in energy use with combined internal and external shades and light redirection devices .

Figure 19 Starting for an energy efficient baseline building (Ahmadi & Loftness, 2011)

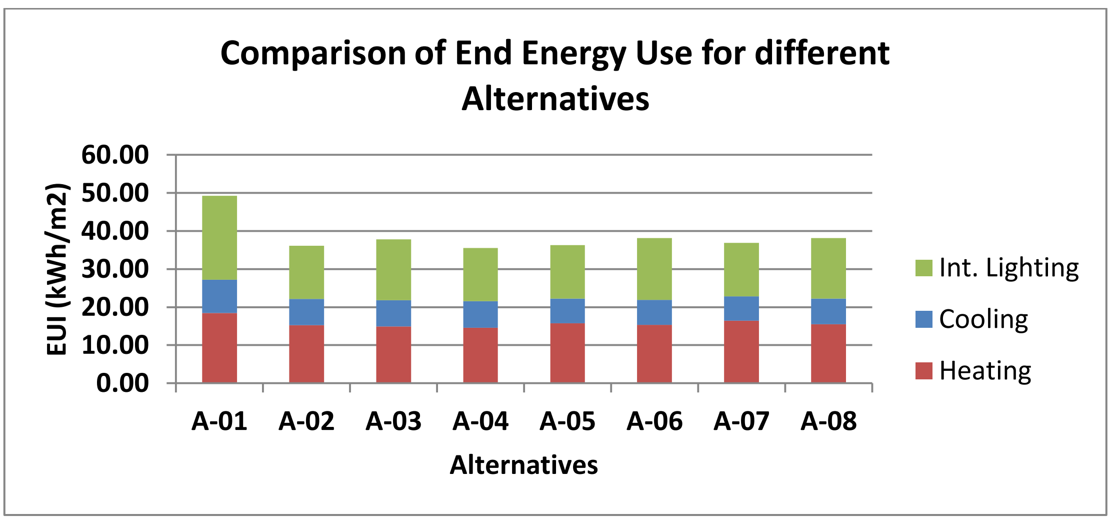


Figure 20 Energy End Use Comparisons. (Ahmadi & Loftness, 2011)

Simulation results from another GPIC research study show that even a simple external louver can have a significant impact on energy use and day lighting performance (Khowal, Loftness, Aziz, & Cochran, 2011). The report recommends that all spaces which have windows be equipped with day lighting controls and occupancy sensors, so that all interior lights would switched off when there is enough daylight to reach the illuminance set point or when a space is un-occupied. A comparison between the chosen exterior louver (59 inch [1.2 meter] deep horizontal louvers at a 41 degree tilt) and the vegetated external louver shows that the latter performs slightly better regarding the lighting and thermal performance of the building (Khowal, Loftness, Aziz, & Cochran, 2011). It was also determined that internal light shelves are most effective if combined with external light shelves; see Figures 21 and 22.

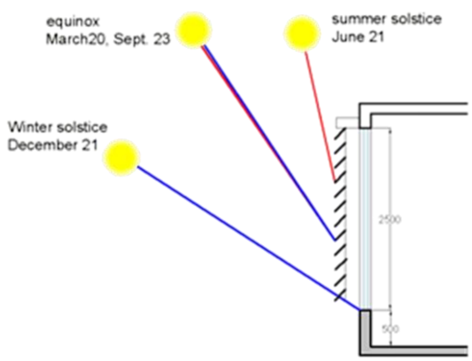


Figure 21 *External louver design & sun angles*

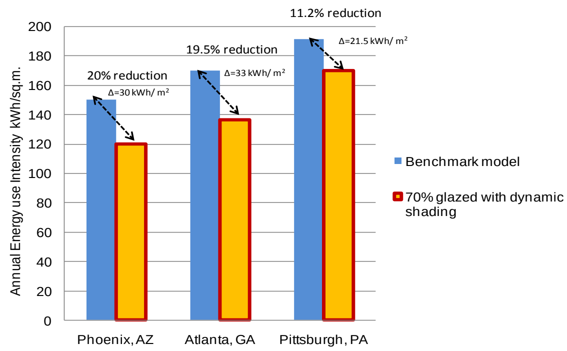


Figure 22 Annual Energy Intensity simulation results

In a 2009 publication entitled *High Performance Building Façade Solutions* for the California Energy Commission PIER and the Department of Energy, Lee et al. completed extensive field testing of a range of exterior and interior shading and light redirection devices (Lee, et al., 2009). Each of the innovative shading systems were designed specifically to address one or more of the critical performance requirements of shading, daylighting, glare control and views, while addressing practical constraints such as low cost, durability, maintenance, user acceptability, ease of manufacturability, and other factors.

The results "demonstrated that exterior Venetian blinds or roller shades can deliver energy and peak demand savings benefits at aggressive net zero-energy levels of performance. These systems are robust, fairly mature, and practical. Applicability is limited to low- to mid-rise buildings where local winds are of low velocity for the majority of the year: the systems must be retracted if winds exceed 30 miles per hour. These systems have been used throughout the EU over many decades in new and retrofit applications, in air-conditioned and non-conditioned buildings, and enable use of low-energy cooling strategies such as natural ventilation, radiant cooling, etc. Monitored data indicated that average daytime cooling loads due to the window could be reduced by 78-94% compared to conventional interior shading systems and peak cooling loads could be reduced by 71-84% or 17.2-33.2 W/m^2-floor (1.6-3.1 W/ft^2-floor) given a large-area, south-facing window in a 4.57 m (15 ft) deep perimeter zone in a sunny climate. Lighting energy use was 53-67% of ASHRAE 90.1-2004 prescribed levels" (Lee, et al., 2009).

A Department of Energy National Lab, LBNL is the center of lighting and enclosure design research, and maintains a web-site to support decisionmakers in the specification and purchase of windows and components that may be added to windows to maximize performance (http://www.commercialwindows.org/). A Facade Design Tool lets you choose the design conditions of a window and rank and compare the performance data in terms of annual energy, peak demand, carbon, daylight illuminance, glare, and thermal comfort. After a location, building type, and orientation have been selected, you have the choice to Refine & Explore or Compare the performance data of window design options that you define in terms of orientation, window area, daylight controls, interior shades, exterior shades, and window type (U of M; LBNL, 2011).

At the very least, manual internal venetian blinds should be introduced in building retrofits to provide effective shading from both sun high in the sky and reflected light from paving below the window, without eliminating daylight contributions and views. As seen in Figure 23, the shading contributions of venetian blinds, even in the down but open position are substantial, and become even higher if the blinds are angled to fully block low angle sun. In a 1996 study entitled *Solar Heat Gain Coefficient of Complex Fenestrations With a Venetian Blind for Differing Slat Tilt Angles,* published in ASHRAE Transactions, J. H. Klems and J.L. Warner study the effective shading benefits of horizontal venetian blinds in different positions, even in overcast sky conditions.

Slat Tilt	Interior Blind		Between-pane blind	
	$SHGC_{DS}$	$SHGC_{DG}$	$SHGC_{DS}$	$SHGC_{DG}$
Closed (skylight excluding)	0.37	0.38	0.22	0.24
45° (skylight excluding)	0.47	0.60	0.34	0.59
Open (horizontal)	0.61	0.60	0.56	0.54

Figure 23 SHGC For Diffuse Sky And Ground-Reflected Solar Radiation For Clear Double Glazing With Venetian Blinds. Shading benefits of horizontal venetian blinds in various positions (Klems & Warner, 1996)

The 2009 LBNL report reinforces these findings of shading benefits, and the commensurate contributions to effective daylighting if effectively adjusted. "With daylight dimming controls, lighting energy savings were significant compared to a non- dimming case. *All* innovative interior shading systems yielded average savings on the order of 43-69%, or an average lighting power density (LPD) of 0.31-0.38 W/ft^2-floor in a 4.57-m- (15-ft-) deep perimeter zone over the 6:00-18:00 period" (Klems & Warner, 1996).

A level of innovation in venetian blind design in the past few years offers even greater performance benefits. While shading is determined by reflectivity and geometry of the blinds, so is light redirection (see Figures 24 and 25). The newest generation venetian blinds are often inverted and shaped to act as light shelves as well as shades. “Daylight-optimized louver geometries thus ensure solar heat control based on the sun’s angle of incidence without the need for continuous readjustment of the louvers in line with the incident sunlight. On the outer section of the louver, the high summer sun is mono-reflectively redirected back into the sky (protective function) and on the inner section of the louver, low incident sun in winter is directed inside (supply function). The blinds only need to be closed when the sun is very low and grazing light between the louvers causes glare. The geometries of these blinds and their degree of separation are established based on climate, latitude, and orientation” (Koester, 2012).

Figure 24 Light redirecting blinds maximize daylight contribution (Koester, 2012)

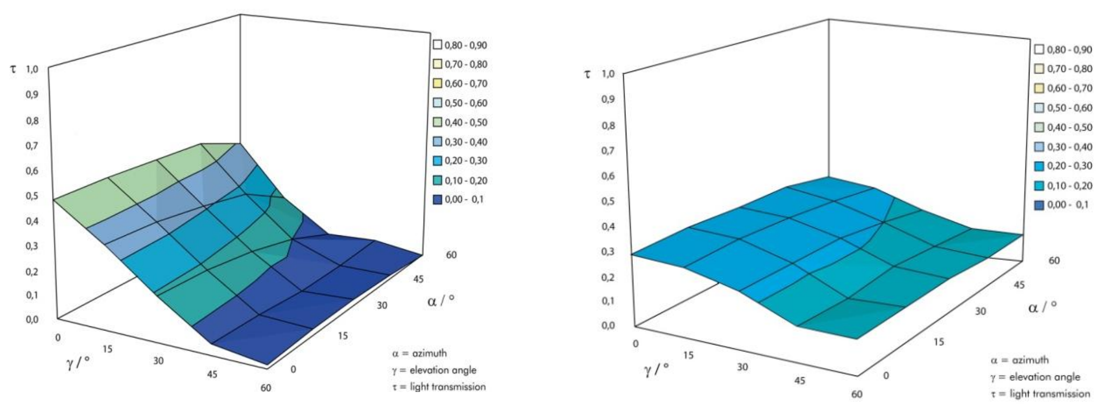


Figure 25 Daylight-optimized louver geometries ensure solar heat control based on the sun’s angle of incidence (Koester, 2012)

Blinds that distribute daylight by using the ceiling as a reflector and diffuser, ensure that the entire office, classroom, or warehouse receives a critical level of light. The window itself and the nearest workstations are no longer overlit, and the high angle sun in summer is reflected away to reduce cooling loads.

Controls are critical to effective daylighting, shading and glare control

To achieve the highest energy savings, controls are needed to dynamically control light redirection, glare, shading, and passive solar gain given seasonal and daily variations in outdoor environmental conditions. These controls can be manual, such as for awnings or blinds, they can be locally automated with electric switches, or they can be centrally managed through building automation systems to balance the lighting, shading and passive solar heating benefits. The innovations in façade controls will be included in the future State of the Art report on controls.

Both passive and active controls for façade components must be carefully integrated with the electric lighting controls to ensure energy savings. Electric lighting controls should be integrated with daylighting controls to balance a number of critical design goals:

- Ensure minimum daylight levels for a maximum number of hours dependent on orientation, weather, external and internal layers/positions, glass type, layout of furniture, color of interior surfaces.
- Ensure maximum daylight levels whenever desired by occupant and/or valuable for passive solar heating (without glare, brightness contrast or user dissatisfaction), dependent on orientation, weather, external and internal layers/positions, glass type, layout of furniture, color of interior surfaces, mass of interior surfaces, tasks of individual users, age/health of users.
- Ensure minimum electrical light levels for maximum number of hours, given occupancy and task.

A GPIC study of the interrelationship of ambient and task lighting controls with venetian blind controls, with and without user involvement, quantified a number of these benefits. *The Impacts of Real-time Knowledge Based Personal Lighting Control on Energy, Dr. Yun Gu 2011* found that manual controls of all three elements – blinds, task lights and overhead lights – provided a combined average of 43% energy savings over fixed ceiling based task-ambient lighting with benefits for both computer and paper based tasks (Figure 26). Not only did users select significantly lower levels, especially given the predominance of computer tasks, they recorded measurably higher user satisfaction. Offering expert feedback to the users through a dashboard, about the value of opening blinds, or dimming ambient light levels and using task as an alternative, resulted in a 64% energy savings over our typical office baseline of uniform lighting without controls, and again more occupant satisfaction over the baseline.

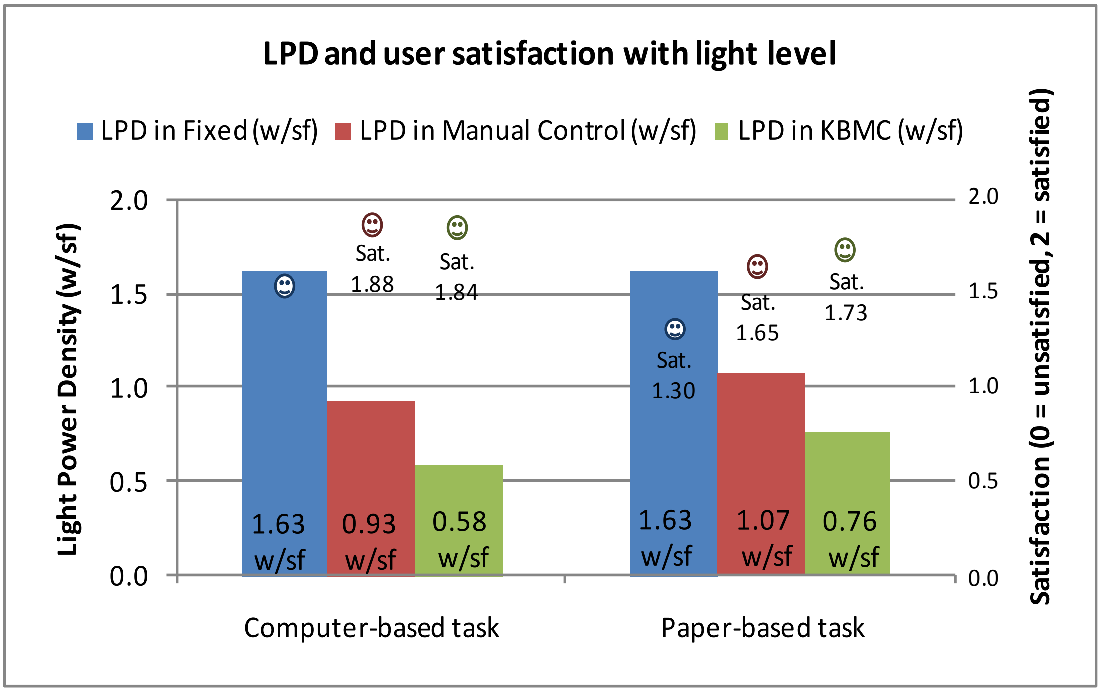
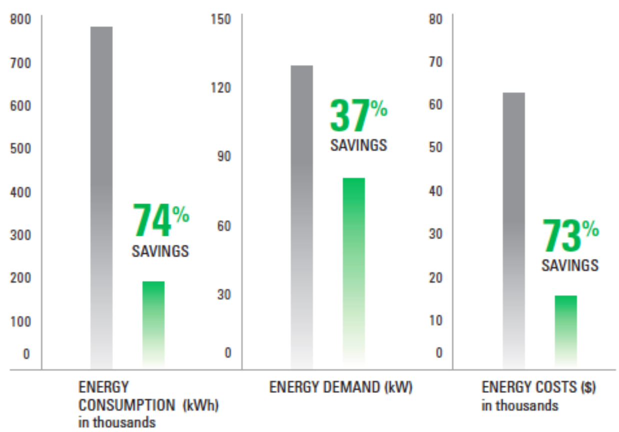


Figure 26 Manual Control of blinds, task and overhead lighting provide energy savings over fixed ceiling based task ambient lighting (Gu, 2011)

Lighting control companies, such as Lutron and Encellium, have been accumulating measured field data that reinforces the value of maximizing daylight and occupancy control, with examples of 74% lighting energy savings and 37% peak energy load reductions shown in Figure 27 below (Encelium, 2005). Further discussion of innovative lighting controls will be addressed in a future State of the Art report.



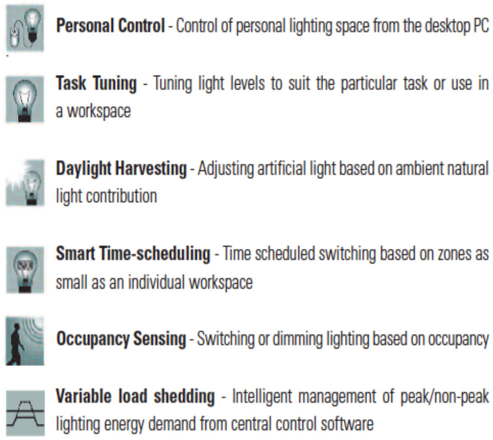


Figure 27 Energy Savings obtained by maximizing daylight and occupancy control (Encelium, 2005)

Enclosure 4: Upgrade windows and perimeter HVAC systems for thermal performance and ventilation

A separate study by Robust Systems and Strategy LLC of CBECS identified that over 50% of the existing 2-4 story buildings in our region are masonry facades with 20% glass area (punched windows), and over 47% are still single glazed (Otto, 2011). These building conditions suggest serious evaluation of window replacement for energy efficiency and thermal comfort, especially if the perimeter heating units are also ready for replacement.

In the consideration of window replacements for thermal performance, CBECS data reveals that effective daylighting must be a critical factor in decision-making, including the importance of maintaining appropriate window to wall ratios. Existing facilities with glazed areas between 26%-50% have the lowest lighting energy consumption. Facilities that are highly glazed at 51-75% glass, however, compromise lighting energy performance even though they perform better than buildings with 11-25% glass (Figure 28). With appropriate design for glare control, shading and views, as well as effective integration with electric lighting controls, a maximum use of daylight can significantly reduce overall energy consumption, and must remain a critical component of window retrofits (CBECS , 2003) (Loftness, Aziz, Lam, Lee, & Cochran, 2011).

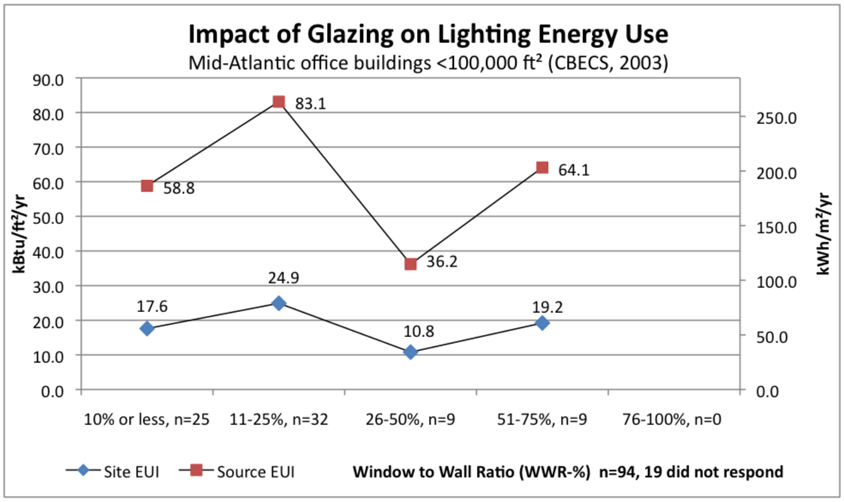


Figure 28 Window area and specification has a significant impact on lighting energy (CBECS , 2003)

The expert workshop reiterated the value of the NFRC window performance rating, that stipulates that any window replacement performance specification must include U-factors, visible transmission, solar heat gain coefficients, acoustic rating, and air infiltration ratings, emphasizing that different façade orientations warrant different window specifications. In addition, it is important to recognize that solar heat gain coefficients can be adjustable with dynamic exterior or interior shading devices to optimize for passive solar heating in winter and shading in summer. Similarly, U-factors can be variable through the introduction of night insulation systems which can serve dual purposes for light redirect, blackout, and even white boards for building occupants.

The expert workshop identified that cost-effective energy performance will be achieved by multiple glazings, low-e coatings, argon gas filled assemblies, and thermally broken frames and spacer technologies. Different types of gases were discussed, but Argon was chosen due to its performance, availability and cost.

Three materials for **window frames** were identified as appropriate – each to be evaluated for thermal performance in the integrated assembly:

1. Urethane Pultruded Composite Frame
2. Fiberglass Pultruded Composite Frame
3. Insulated, Thermally broken Aluminum Frame

While pultruded composite frames are long lasting and often the lowest heat conductors, insulated and thermally broken aluminum frames are still considered the cost-competitive solution for commercial window replacements.

Design and specification of **window spacers** are equally critical performance criteria in window selection, and the expert workshop recommended aluminum spacers for the operating solution. While thermoplastic and “improved metal” materials are low heat conductors, they were not recommended as the operational solution due to cost. Silicone, with better R-value than aluminum, could be a cost-effective solution.

As a research and demonstration project, four **other technologies** were proposed: vacuum windows, air flow windows (integrated with the perimeter heating system); thermo or electro-chromic glazings, and high resistance translucent/transparent glazing for daylighting with privacy and reduced heat loss and heat gain. Each of these technologies may have critical relevance in specific locations in the façade or roof apertures.

A GPIC Task 3 project, *Comparative Study of Glazing Systems Employing Transparent and Translucent Insulation for Building 661* (Memari & Ariosto, 2011) involved an investigation of several different glazing systems and the effects of their use on annual energy use for residential and commercial buildings across several different climates.

The glazing systems explored in this study included:

Advanced Glazings Solera S, L
BMS Makrolon 5M/25-20 Multiwall Unit
Duo-Gard Triple Wall Multiwall Unit with Nanogel
Guardian Climaguard 71/38
Pilkington SPACIA STII VIG
PPG Solarban 70xL, 60, 80
PPG Solarban R100, z50
PPG Sungate 400, 500
PPG Clear Uncoated Insulated Glass Unit (IGU)
PPG Monolithic Clear Glass
Southwall Heat Mirror Insulated Glass Unit (IGU)

The investigation was conducted using four different energy modeling software packages: Energy 10, RESFEN, COMFEN, and DesignBuilder. In all climates areas, the vacuum insulated glazing (Pilkington SPACIA STII) was found to be the best performer. In addition, it was found that IGU's with low-e coatings perform differently based on climate and based on the exact properties of the coating itself. In mixed-climates, it was found that an uncoated IGU can perform better than some low-e coatings. It is, therefore, important for building envelope designers to understand the specific properties of these coatings before specifying them. For the translucent systems, the glazing with honeycomb insulation material (Advanced Glazing Solera S) was found to be the top performer, particularly for heating dominated climates. However, since this system is translucent, it may not be appropriate for all applications.

In addition to these performance specifications for the window assembly, **window operability** is also a critical decision. As long as windows remain operable, natural ventilation can continue to be a significant contributor to cooling and ventilation of buildings whenever the conditions are right, for energy savings and user satisfaction.

Based on information obtained from Climate Consultant version 5.1, with the ASHRAE Standard 55-2004 using the Predicted Mean Vote (PMV) Model, and the Philadelphia International Airport TMY3 weather file, the climate in Philadelphia, PA is within the comfort zone 10% of the time (See Figure 29, comfort range identified in green) (ASHRAE, 2004). This analysis assumes comfortable temperatures between 68.5 F to 75.7 F in the winter, up to 80.1 F in the summer and a maximum humidity ratio of 0.012.

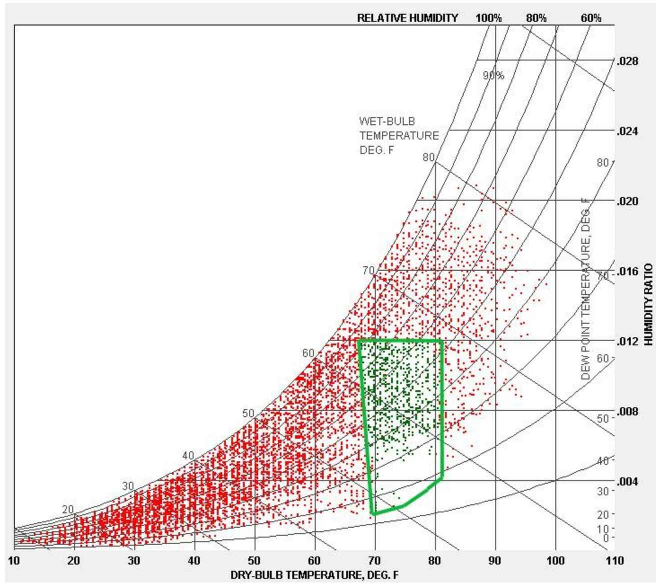


Figure 29 Philadelphia Weather analysis; Psychrometric Chart (Loftness, Aziz, Lam, Lee, & Cochran, 2011)

Once factors such as ventilation rates, internal heat gain, occupancy density, building area, heating and cooling set points, and building use were factored into the preliminary analysis; natural ventilation, or a hybrid or mixed mode ventilation system may be a viable option for use in Building 661. Based on results from the NIST *Climate Suitability Tool*, using the Philadelphia International Airport TMY3 weather file, natural ventilation or a fan-powered economizer system in the Building 661, for example, may be effective 55% of the year.

Two types of window operability were identified at the expert workshop in support of natural ventilation - awning windows and tilt-turn windows that allow dual positions (See Figure 30) (swung open as a casement, tilted in as a hopper). For historic districts, both of these window types can continue to represent the highly mullioned windows that are traditional.

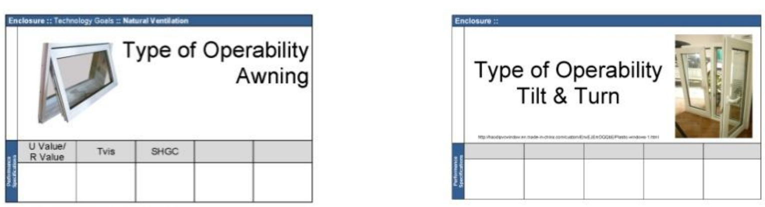


Figure 30 Window Operability (Loftness, Aziz, Lam, Lee, & Cochran, 2011)

Double hung windows were eliminated because they cannot achieve the same level of air tightness due to the lack of a fixed overlap of the window with the frame. Casement windows, while airtight, were eliminated because they cannot be used during rain showers. Awning windows, on the other hand, are airtight and can be opened during rain showers for ventilation and cooling. Tilt and turn windows (a combination of in-swing casement and hopper) allow for a choice in aperture and air flow for different environmental conditions, and can be easily cleaned from the inside. Though common in Europe, the availability of dual action hardware in the U.S. may make this alternative less feasible. If larger window areas are being re-glazed, a combination of window types could be considered, using simulation to ensure the highest level of natural ventilation through cross and stack air flows.

Window replacement is often a costly undertaking, especially if it is not viewed as a daylighting, passive solar heating, shading and natural ventilation unit. For single glazed buildings that are not curtainwalls, the most cost-effective strategy for retrofit may be in adding storm windows with better thermal, shading and daylight properties (Loftness, Aziz, Lam, Lee, & Cochran, 2011).

It is critical that any window replacements or storm windows that are added do not compromise daylighting and views. Solar films that do not have high visible light transmission are not an effective retrofit strategy because daylighting and heating energy loads are significantly higher in the GPIC region than cooling loads. A far more effective strategy for reducing summer cooling, rather than dark glass, is to introduce external shading such as awnings or blinds or trellises that can differentiate between undesirable high sun angles in summer and desirable low sun angles in winter, or internal shading with blinds or roller shades that can be modified season by season.

It is also critical that any window replacements consider the perimeter heating or cooling units that sit below the window. If the windows are in need of replacement, most likely the perimeter HVAC systems are also reaching the end of their useful life. These are critically linked decisions. The size of the perimeter mechanical unit is determined by the quality of the window and wall that it is trying to neutralize with heating or cooling. The ventilation of the rooms may be dependent on air intake within or near windows, especially in buildings that have no central ventilation system. The opportunity to maximize the thermal performance of the window and minimize the size of the perimeter mechanical unit creates a completely different economic calculation for the energy retrofit. If either of these components, the windows or the perimeter heating/cooling units, need replacement, they should be replaced together to achieve the highest performance outcomes. This opportunity will be further explored in the future State of the Art reports.

Enclosure 5: Upgrade insulation in walls and floors

In addition to roof and window upgrades, minimizing conductive heat loss and heat gain in a building's walls and floors also offers both significant energy savings and improved comfort for the occupant. Codes and standards increasingly demand higher thermal resistances for roofs, walls, floors and windows in new buildings, but addressing the walls and floors of existing buildings is a greater challenge. At times there is historic value to the exterior façade, quality finishes inside, and significant cost consequences to reframing openings and stairs if insulation is added. Nonetheless, there are measurable steps that can be taken beyond increasing the façade air tightness.

- Floor slabs can be insulated at their edges with perimeter "trench" insulation.
- Framed walls can be insulated within the walls.
- Non-historic interiors allow for the introduction of insulation on the interior of the façade, reframing exterior windows to create a visually and thermally superior building.
- Non-historic exteriors allow for the introduction of insulation and new facia on the exterior of the building to create a visually and thermally superior building.

High performance insulation materials must be specified to achieve the highest resistance possible for the integrated assembly including thermal bridging, and address Cradle to Cradle™ environmental standards. Various spray insulation, board insulation, and cellulose products can meet these goals, as described in Figure 31 from BuildingGreen (Wilson, 2012). Performance metrics must be set specifically for roofs, walls, and foundation floors. In addition, the integration of thermal mass to absorb solar heat gain in winter or absorb nighttime cooling in summer should be considered in retrofitting the existing wall and floor assemblies.

Key Environmental and Performance Factors for Insulation Materials cont.

Insulation Type	R-value Per Inch*	Estimated Installed Cost Per ft² for R-19**		Vapor Permeability†	Air Barrier‡	Environmental Notes (see below for legend)
		Low end	High end			
RIGID BOARDSTOCK						
Polyisocyanurate	6–6.5	$2.47	$3.20	Class III: Semi-Permeable Class I: Impermeable (Foil-faced)	Air barrier material	High global warming potential for urethane-core SIPs Chlorinated flame retardant (otherwise fairly inert) Toxic manufacturing process
Extruded polystyrene (XPS)	4.8–5	$3.99	$4.37	Class II: Semi-Permeable (>1″) Class III (<1″)	Air barrier material	High global warming potential for urethane-core SIPs Brominated flame retardant (otherwise fairly inert) Toxic manufacturing process
Expanded polystyrene (EPS)	3.7–4.5	$4.04	$4.32	Class II Vapor Retarder	Not an air barrier	Brominated flame retardant
Mineral wool	2.4–3.3	$1.80		Class III Vapor Retarder	Not an air barrier	Choose low-emitting products
Fiberglass	3.6–4.5	$4.72	$5.61	Class III Vapor Retarder	Not an air barrier	Formaldehyde binders are common
Cellular glass	3.0	$6.20	$7.50	Class I Vapor Retarder (Vapor barrier)	Air barrier material	

About the Environmental Notes

Green indicates significant **recycled content** or renewable material. Red indicates little or no recycled content and fossil-fuel-based materials in typical products.

Green indicates low **embodied energy**. Red indicates high embodied energy and/or embodied carbon.

Green indicates relatively low **toxic emissions** during use from typical products. Red indicates potential high toxic emissions from typical products.

Red indicates high toxic emissions during manufacturing or application.

Blue in all cases indicates ambiguity—explanatory notes are provided in all cases.

Notes are provided for red indications in some cases.

Please see page 77 for endnotes.

Figure 31 Environmental and Performance Factor for different Insulation Materials (Wilson, 2012)

On grade, below grade and exposed floors should also be insulated and thermally separated from outdoor air and ground conditions since they create conductive discomfort for building occupants, especially in small buildings and below grade occupied spaces. If additional height cannot be introduced, a level of thermal insulation can be achieved by adding perimeter insulation at the outside of the building slab and extending that insulation several feet into the ground to create a thermally isolated area below the slab. OakRidge National Labs has published climate specific standards for edge insulation (Thornton, Wang, Huang, Lane, & Liu, 2010) . ASHRAE 90.1-2007 does not call for perimeter edge insulation in climate 5 (the GPIC climate) unless the slab itself is heated, but does call for an R10 edge insulation extended two feet into the ground in harsher climates (Thornton, Wang, Huang, Lane, & Liu, 2010). Some floor areas can be engineered as thermal storage for passive solar heat gain, possibly incorporating phase change materials in a surface refinishing, or integrating a radiant heating and cooling system. Alternatively, the floors can be used as a structural base for introducing raised floors, decoupling the occupant from the thermal mass.

An airtight and highly insulated enclosure is key to significantly reducing energy consumption, so building owners that aspire to reduce energy use should pursue super-insulated enclosures through significantly increased insulation, reduction of thermal bridging, and a high level of air tightness. This will dramatically reduce the size of the mechanical systems and possibly eliminate or reduce the need for perimeter heating. PassivHaus US at http://www.passivehouse.us provides excellent tools and guidelines for the super-insulation of existing small commercial buildings (Passive House Institute US, 2011)

There are numerous examples of energy retrofits in the GPIC region or pursuing 'PassivHaus' standards (Klingenberg, Kernagis, & James, 2009). The PassivHaus standards that are applicable to commercial building retrofits for performance often adopt:

1. A combination of internal and external insulation to reduce thermal bridging
2. Whole building air barriers, with commissioning before move in
3. Moisture management in enclosure assemblies
4. "Cool walls" that have optimum reflectivity and ventilation against solar gain

Conclusions

This state of the art report, a first generation report that will be refined each year, is focused on five enclosure retrofits for energy efficiency and improved indoor environmental quality that should be considered by every building owner:

1. Upgrade building air tightness
2. Upgrade roof insulation and reflectivity, considering integrated solutions
3. Upgrade window layers for effective daylighting and shading
4. Upgrade windows and perimeter HVAC systems for thermal performance and ventilation
5. Upgrade insulation in walls and floors

These guidelines, discussed in the order of greatest payback potential, have been assembled based on:

1. CBECs and CoStar data sets on where the energy is being lost given the characteristics and the condition of the existing commercial buildings.
2. Recent energy retrofit guidelines and research related to small commercial buildings from DOE and the National Labs, ASHRAE, Building Green and others.
3. GPIC partner recommendations for effective energy retrofit actions, gathered in the expert workshop and in numerous collaborative exchanges.
4. GPIC member research findings from the first year of effort from Tasks 2 and 3.
5. Iterative and compounded energy simulation of 21 enclosure retrofit options developed by the Expert Workshop.

State of the Art recommendations will be developed in Year 2 of the GPIC hub to provide decisionmakers in the GPIC region with the most up-to-date and strategic investments for energy retrofit.

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