Making Your Historic Building Energy Efficient: Volume 2 Technical Details
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Prepared by:
Synertech Systems Corporation
www.SynertechSystemsCorp.com
Tom Wilson, Larry Kinney, Wyncia Clute

Acknowledgement

This report was prepared by the Synertech Systems Corporation under an agreement with the Office of Environmental Affairs of the City of Boulder, Colorado as a supplement to a four-page brochure bearing the same title.

A number of people have responded to earlier drafts of the document, offering suggestions and clarifications that were useful in preparing this version of the report. All comments were offered in the spirit of joining in a common effort to enhance the usefulness of this document in helping buildings become more energy efficient while preserving their historical character and architectural integrity.

We appreciate the practical wisdom shared and suggestions made by others, most of which have been integrated into the text. However, the opinions expressed herein are those of the Synertech Systems Corporation's staff and do not necessarily reflect the views of anyone else or the organizations they represent.

Larry Kinney
August 2007

Foreword

In 2004, the important topic of historic preservation and energy efficiency in Boulder's older building stock reached a pinnacle of discussion in Boulder. Accordingly, Boulder's City Council directed two organizations, the Landmarks Preservation Advisory Board and Environmental Advisory Board, to research, analyze, and recommend how these two program areas that Boulder cares deeply about can find compatibility, where guidelines acknowledge both as important issues affecting the city's historic buildings.

The topic of whether to preserve existing material or replace it with more highly-efficient material in our designated or landmark buildings received a lot of worthy attention. This question was vetting through the Boards, experts, and professionals in the historic preservation and energy efficiency fields, as well as with the community and the State Historical Society. We tried to turn over all the stones to understand this important, quite delicate topic.

With the city's passing of the Climate Action Plan in 2006 and its Historic Preservation Program, the overseeing boards and Council spent many hours discussing how both programs can coexist. All parties agree that the guidelines for Historic Preservation should clarity the criteria for measures being considered for restoration, rehabilitation, retrofitting, and remodeling of historic structures.

It was recommended by the Boards and directed by Council that city staff create resources for building owners who live in historic districts, and in designated and land marked buildings, to be able to access information on how to make their historic buildings more energy efficient without jeopardizing their historic character or the integrity of the buildings' original architectural significance. This document is part of the effort to provide useful information to all parties.

We welcome your comments and hope the information provided can inform you about your older home or building's performance. As energy prices increase, it is the city's aim to assist people with making energy efficiency retrofits that make good sense.

Chairs of the Landmark's and Environmental Advisory Boards

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Appendix A
Adding Performance Value to a Historic Preservation Project

Introduction

When planning any building or remodeling project, it is possible to "add performance value" in many different ways—comfort, convenience, health, safety, durability, energy efficiency, economic efficiency, resource conservation, waste reduction, future home value, personal and home security, etc. Thus, there are many opportunities for contractors to define and expand their services and contracts in ways that materially benefit homeowners. Similarly, there are demands and goals that a homeowner can reasonable make of a contractor who claims to have expertise in both energy (building performance) and historic preservation.

The goal of the material in this appendix is to stimulate discussion of ways to recognize value-added options that make sense for a given historic preservation project. This process begins at the planning stage with the contractor listening to what the homeowner *really* wants and presenting complementary alternatives and add-ons to optimize the construction package in the interests of all. Since many of the referenced activities involve little extra cost and take place when the household is already disrupted by remodeling, this is the best time to take a holistic approach to a project.

This *systems thinking or whole house* approach can also help to prevent awkward and expensive callbacks. As contractors (and customers) focus on how the flow of air, heat and moisture will change and interact based on various work scenarios, problems with comfort, moisture, indoor air quality, etc. should be minimized.

The following outline is organized largely by typical remodeling job categories and there is inevitable repetition. It always makes sense to do the best possible job of air sealing, so reminders of this key element in any retrofit work will hopefully make each list most useful. Some areas, such as assuring appropriate products/materials, compliance with code, fire, and worksite safety, are self-evident.

Clear communication and accurate documentation are important from start to finish. Use detailed notes, contracts, drawings, equipment/installation specifications, written change orders, etc. to assure common understandings and expectations. Digital photographs of pre-existing site conditions plus in-progress and finished work can help to avoid or at lease simplify disputes. Further, photo records are useful for practical and social purposes.

Beyond the design, workflow, and legal/contractual issues, it is important to incorporate advanced diagnostics and test one's way in and out of all major retrofits. The work may appear impeccable, but if the house as a whole does not perform well, the project will not be successful. Commissioning, a term usually used in conjunction with larger residential, commercial or industrial projects, simply refers to the process of using building performance diagnostics at the end of a project to assure that the whole building functions to all appropriate standards.

The following is written as friendly advice to contractors, but the aim is to be useful to homeowners as well.

General principles of historic restoration

Values other than energy efficiency - Recognize that energy efficiency or performance may not be the primary focus of your clients and issues such as historic value, sentimentality and long-term durability and preservation must be respected.
Identify - Besides being an energy sleuth, you also have to seek clues to the original structure and determine when various modifications occurred. Then you and the homeowner have to agree on what is worth preserving and develop overall restoration guidelines.
Do no harm - As you retrofit an historic structure, try to avoid doing any irreparable damage or make changes that can't be undone. Cutting in new doorways or replacing existing building elements may be unacceptable. If you must cover an existing surface (say with insulation and new siding) do so with care. Future owners may remove it to reveal the original façade.
Retain style - If building parts must be replaced or added, do everything possible to retain the original look, especially from the exterior. Do not side a house with "historical" simulated log siding or install Doric columns on a 1930's bungalow porch.
Optimize strong points - Historic buildings are often the best of their era. Maintain and make use of the original design elements - large-south-facing windows, transoms, high thermal mass, high ceilings, etc. - which made these homes comfortable to their original inhabitants.
Moisture issues - Pay particular attention to moisture migration issues that may cause long-term damage to older, aging wooden parts.
Repair rather than replace - Take the time to repair original features such as doors and windows rather than replace them with new, even if the look is the same. A well-adjusted double hung window or door may not need any weather-stripping to be acceptably air tight.
Replace only what you must - If window sashes can not be saved, try to maintain the window jamb and trim and simply replace the sashes with historically accurate units.
Use original materials - Avoid plastic look-alikes and consider having wooden storm sashes made instead of aluminum storms or replacement windows. Re-glaze windows with linseed oil-based putty and consider original paint and varnish formulations.
Retain proportions – Do not enlarge or reduce window size in the name of energy efficiency if it will deface the building.
Mechanicals - Use great care in installing new pipes, ducts and wiring. Place vents, power-vent exhaust pipes and air conditioners inconspicuously, preferably hidden by shrubbery or architectural detail. Consider using unused chimneys as chases for new mechanicals.
Electrical - Upgrade the electrical system while still retaining historic fixtures. Test electrical circuits before and after other interventions, such as insulation blown in sidewalls. Note that modern compact fluorescents are compatible with many traditional lamps and fixtures.
Landscaping - Carry the historic restoration process to the out-of-doors and replant an appropriate array of deciduous and evergreen trees, shrubs, and vines to provide windbreaks and maintain solar exposure.

Additions

Air sealing - Observe standard precautions for energy-efficient new construction. In original parts of the house, air seal on the interior and identify all framing bypasses. Use a blower door and, if possible, gain access to an infrared scanner both before beginning the project and before leaving. Pay particular attention at interfaces between newer and original elements of the structure.
Insulation - Ensure that the walls of the addition are deep enough to achieve higher R-values and build to exceed Green Points new construction standards.
Windows/doors - Install high quality windows and doors. These are more comfortable and can usually be ordered to match existing windows and doors. Avoid uninsulated steel doors and any units lacking thermal breaks. Use low-e glass for north, east, and west-facing windows, but consider maximizing the solar heat gain coefficients of south-facing windows.
Movable insulation - This is especially valuable for much used evening spaces or large glass areas. Be aware of the practical challenges of very cold surfaces attracting moisture/frost deposition.
Reorientation - Balance fixed and moveable glass for view and ventilation. Consider locating primary window openings on the southern side.
Moisture control - Observe good building practices and pay particular attention at roof and building intersections with the original structure. Allow moisture-laden materials such as green lumber, wet-spray insulation, plaster, and cement time to dry before enclosing. Use permeable building wrap and focus on source reduction.
Roof configuration - Install wide overhangs if the design can support them. These offer some of the easiest and most attractive moisture controls it. Solar electric (PV) or hot water systems can be integrated at the design stage.
Ventilation, filtration - Install additional ventilation as needed to serve the added living space. Use quiet (low-sone), high-efficiency fans vented to the exterior with rigid ducting. If adding ductwork or auxiliary heating system, consider a whole-house air-to-air heat exchanger (a heat recovery ventilation system). If members of the household have respiratory problems - allergies, asthma, etc. - incorporate HEPA level filtration.
Use of space - Rethink the use of all spaces in the house. Shift living activities (sleeping, reading, watching TV, etc.) to make use of the most comfortable areas for each.
Universal design - Adapt to the needs of the elderly. Studies show that many members of the aging population would prefer handicapped access and related features built into remodeling projects in all parts of the house, although kitchens and bathrooms remain key locations
Partitions, doors, zone - Isolate additions from rest of house with zoned heating system for better temperature control and energy savings.
Passive solar - Consider incorporating greenhouses, Trombe walls, sunspaces, and direct gain solar systems into additions. Match increased glazing with added thermal mass and shading devices to achieve good thermal control.
Landscaping - Use care not to unnecessarily remove existing mature trees that provide shade and wind buffers. Avoid obstructing airflow around outdoor central air condensing units with vegetation, decks, or enclosures.
Lighting - Plan lighting strategies to make use of efficient fixtures and size the lighting capacity to meet the intended use of the space. Select and install exterior lighting so as to avoid causing light pollution for neighbors.

Daylighting - Incorporate natural lighting for general space illumination. Careful placement of windows, especially high on the wall, will allow for deep light penetration. Plan to avoid glare and overheating.
Buffer zones - Place closets and storage spaces along the north wall. Plan for open areas on the south wall for active living spaces.
Vestibules - Consider re-routing entrances and traffic patterns. Air lock entries are much easier to plan into a new building section than to retrofit into an existing structure.
HVAC - Determine if the present heating system can support the additional load of the new space. Options include a separate system for the addition. (Avoid merely installing cheap electric resistance baseboard heaters; electricity costs almost three times more than gas.) A well-designed addition along with effective upgrading of the rest of the house could actually reduce heating and cooling loads, allowing for downsizing the present systems. Choose the most efficient options for long-term energy savings.
Distribution systems - Zone additions with separate thermostats, dampers or circulation pumps. Assure quality connections to existing piping and ductwork.
Fuel switching - If added building size requires a new or auxiliary heating system, select fuel source wisely for efficiency, availability, and projected energy costs.

Vertical expansion (second or third floor)

Insulation, air sealing - Adjust wall thickness and attic/ceiling depth for increased insulation levels. Make sure the band joist between floors is both thoroughly air sealed and insulated. Urethane foam is a good choice here. Control bypasses in connecting walls. Pay particular attention to roofline corners and intersections.
Ceiling/roof details - Use this opportunity to optimize the roof configuration for maximum insulation levels using energy trusses and shading with well-designed roof overhangs.
Clerestory, dormers, and skylights - Choose auxiliary natural lighting systems for proper orientation, with a view to attractive aesthetic and energy performance. These add valuable daylighting, solar gain and ambience. Skylights have a tendency to overheat in the summer and should be fitted with shading devices.
Vapor barriers - Detail as accurately as you would in any new construction.
Use of space - Rethink the use of all spaces in the house. For banked homes, reverse the normal pattern and put bedrooms on the cooler lower level with the living space on the warmer second floor.
Partitions, doors, etc. - Install doors between floors to control the flow of conditioned air.
Passive solar space heating - Incorporate thermo-siphoning air collectors, Trombe walls, or direct gain solar systems into new exterior wall surfaces as practical.
Buffer zones - Place closets and storage spaces along north wall. Open south wall for active living spaces.
HVAC - Incorporate separate zoning of upstairs heat delivery loops to allow better temperature control and energy savings. Whole house fans (covered with tightly sealed insulating shutters in the winter) should be incorporated into cooling strategies.

Kitchens

Air sealing - Thoroughly air seal the kitchen to save energy and enable enhancing the control of ventilation air. Interior air sealing is most easily done when old cabinets, appliances, and fixtures are removed. Thoroughly sheetrock all wall surfaces before adding tongue and groove paneling, cabinets, dishwashers, etc. Air seal all plumbing and electrical chases at top and bottom before installing appliances.
Insulation - Insulate behind cabinets, dishwashers, etc. Assure plumbing chases are well isolated from exterior freezing temperatures by running plumbing on interior walls when practical.
Windows - Use high-R units (low U-value) as higher moisture levels in kitchens can produce condensation on poor-quality windows.
Doors and storm doors - Be sure that exterior doors to kitchens are well insulated and weather stripped. Kitchen entrances often become the main entry for family and friends and get lots of use. Combination screen doors allow summer venting.
Moisture problems - Correct deterioration from previous leakage problems – do not just cover them up. Address the source, not just the symptom.
Reorientation - Take advantage of easterly orientations if feasible. Kitchens and breakfast areas are particularly pleasant if they can make use of the eastern morning sunlight.
Air Quality - Incorporate high-performance, low-noise, variable speed, outside venting range hood exhaust fans. These are essential for venting moisture, unpleasant cooking fumes, as well as gas range combustion gases.
Use of space - Connect and sitting areas when practical. This allows for using the kitchen's natural warmth and can form an agreeable gathering place for friends and family.
Partitions/doors - Isolate summertime kitchen heat from other living space to relieve cooling loads from the rest of house.
Vapor barriers - Use moisture-impermeable materials, especially in areas of high relative humidity closest to sources of moisture.
Lighting - Ensure that recessed lights are I.C. rated and thoroughly air sealed. Use compact fluorescent bulbs to cut operating costs and reduce summer heat gain. Make sure all dropped soffits are sealed from the roof or second floor structures.
Greenhouse/sunspace - Consider installing kitchen extensions with attractive sitting areas. If done properly these can at least maintain their own in terms of energy use. Herb and fresh vegetable gardening can be a natural side benefit of the project.
Passive solar space heating - Consider installing direct gain systems for quick morning heat-up.
Energy-efficient appliances - Install ENERGY STAR® labeled appliances and look for possible rebates. A modest initial increase in purchase price can result in greatly reduced operating costs (of water and electricity) and longer life.
Water filtration - Consider installing reverse osmosis or other filtration systems if water quality is an issue.

Bathrooms

Air sealing - Air seal when old cabinets, sinks, tub and toilet fixtures are removed. Thoroughly finish all wall surfaces before adding cabinets, paneling, shower stalls, etc. Air seal all plumbing chases and around exhaust fans and light fixtures. Keeping moisture out of building cavities is critical.
Insulation - Install additional insulation to save energy and to help maintain warm interior surface temperatures. Even with well-designed and operated venting, high humidity levels in baths can lead to serious condensation if surfaces are cold. Insulating the space around tubs offers a comfort premium and keeps water hot longer.
Windows - Install low-e, inert-gas-filled double-or triple-glazed units with insulated frames and fiberglass or clad frame surfaces to resist condensation and moisture deterioration.
Mechanical ventilation - Install high-quality, low-noise exhaust fans with working off-cycle dampers vented to the outside. These are a first line of defense against bathroom moisture build-up. Wiring the fan control to the light switch or to a humidistat ensures that venting occurs when conditions require it. Using a timer on the ventilation system keeps it from running unduly long.
Air quality - Consider installing a small exhaust fan that is integrated into the toilet seat then vented outdoors. This ventilates close to the source of odors. Proper plumbing ventilation (vent stack) is a must.
Vapor barriers - Install excellent vapor barriers with care in this high moisture area.
Lighting - Consider color rendition when choosing lighting for mirror fixtures. Many attractive lighting fixtures that are also energy efficient are widely available.
Daylighting - Incorporate natural light into bathrooms whenever practical. Glass block wall sections can act as impermeable surfaces that are easy to clean, allow light penetration, and preserve privacy. Tubular and conventional sky lights are also welcome, but installing insider shutters to limit nighttime energy losses in the winter provide welcome savings and comfort.
Water conserving fixtures -Install low-flow toilets and shower heads. These save on water and sewage charges and energy costs for hot water. Very comfortable shower heads that use less than two gallons per minute are widely available.
Hot tubs, jacuzzis, saunas and spas - Ensure that high-quality, insulated covers are available and are routinely used. These reduce evaporation, moisture loads into the space, and energy costs for hot tubs. Insulate tub cabinets. Consider weight, location, fuel source, heater size, controls, and timers.

Basements

Moisture control - Ensure that proper exterior drainage and sealing of all leakage sites is accomplished before any resurfacing is considered. Make sure the foundation is well drained with no possibility of seepage or flooding. Under-floor drainage mats can work, but are expensive. Basement moisture concerns are notoriously difficult to deal with. ***If you can not guarantee there will be no future moisture seepage, do not finish the basement!***
Vapor barriers - Recognize the need for maintaining drying potential as well as isolating insulation from the source of any moisture. The choice of when and where to apply vapor barriers in basement is problematic and needs to be accomplished with careful attention to the circumstances of the home.

Air sealing - Pay special attention to foundation wall penetrations, band joist cavities, the sill plate, and chimney and plumbing chases.
Insulation - Add rigid insulation or at least foam boards under finished wall materials, a strategy that is usually safer than fiberglass batts for moisture concerns. Consider insulated decking under finished floor. Carpeting directly on concrete is asking for trouble.
Upgrade windows/doors - Install good quality, efficient windows that conform to egress codes. Basement windows and doors are typically abysmal from an energy perspective, but improving them can play a key role in achieving good home performance.
Ventilation - Avoid using natural ventilation to cool or dry basements. Warm air will inevitably condense in a cooler basement and cause problems such as mold and mildew.
Air quality - Thoroughly clean and/or remove material from basements. Dampness, mildew, and related odors and growths are the most common air quality problems. Test for radon. Over use of synthetic paneling and carpeting can result in high formaldehyde levels. Furnace-induced negative pressures can cause the intrusion of soil gasses and back drafting flues. Have the house tested for worst-case depressurization.
Radon mitigation - Test for radon before you start a basement or crawl space project. Thoroughly sealing wall penetrations and lining walls and floor with sealed polyethylene before finishing can help isolate the living space from radon sources as well as moisture. Cover and seal sump pits. Provide a well-sealed port for future sub-slab ventilation if needed to control radon.
Use of space - Make use of cooler basement temperatures for relief from summer heat. Exercise, spa, or recreation rooms may have special plumbing, electrical or communication needs. If adding a bedroom, ensure that it meets code egress requirements.
Asbestos mitigation - Watch for exposed boiler and pipe insulation. Consider enclosing it and isolating it behind permanent living space walls and ceilings.
Daylighting - Consider enlarging basement widows and employing strategic reflectors to add valuable light.
Lighting - Consider installing ceiling or wall-washing lighting (fluorescent tubes boxed against walls shining towards a white/light colored ceiling) to add affordable ambience. Use efficient fixtures and bulbs.
Space and Water Heating Appliances - Consider replacing all atmospherically-vented combustion appliances within the living space with ENERGY STAR® power vented or closed-combustion, high-efficiency units. Add quality filtration for air and/or water.

Attics

Air sealing - Pay careful attention as this can be particularly tricky around complex room lines. Do not rely on polyethylene to seal under tongue and groove ceiling materials. Sheetrock or install insulation board first and then add paneling. Pay particular attention to roof line corners and intersections. Do not forget the floor in the kneewall and its connections to the rest of the framing.
Add insulation - Insulate all accessible building cavities with cellulose blown to high density. Spray-on cellulose or urethane foam offers options. Usually only limited thickness of insulation can be installed between rafters. Addition of foam boards underneath the sheetrock is an option for achieving higher R-values. Assure continuous insulation and air sealing between roof line, kneewalls, floors, and eves.

Windows and storm windows - Install systems that can be opened from the top. If equipped with screens, they allow full summer ventilation.
Clerestory/skylights - Install **s**outh-facing clerestories (or dormers) to add valuable space and improve ambiance and solar gain without contributing significantly to summer overheating.
Use of space - ensure availability of egress in case of emergency. Added space may be more suitable for an office, study, storage, craft, or meditation room than for a bedroom.
Lighting - Avoid recessed lights or any details that penetrate the ceiling/air barrier. Install fixtures that can use compact fluorescent lights.
Moisture control - Ensure that all roof leakage and flashing is repaired before attic is finished.
Vapor barriers - Install with special care since stack effect air pressure differences are high in attic areas. Good control of air leakage and a tight vapor barrier keeps insulation and roof decking dry.
Partitions and interior doors - Allow the upstairs to be isolated from airflows from the living space below by zoning heating and cooling.

Garage conversion to living space

Passive solar space heating - Consider adding passive solar to garage conversions. Most attached garages have three exposed sides, so the likelihood of one of them is facing more or less south is over 75%. Designing this face for a large direct gain aperture (using the mass of the original garage floor) with a tile covering for required thermal mass could make this space at least "energy neutral" as to its impact on overall heating needs. Other options include adding a greenhouse/sunspace.
Air sealing - Accomplish air sealing on interior surfaces after insulation is installed. Seal all connections to attached structures.
Insulation - Consider increasing wall depth or adding a layer of foam on interior surfaces before sheetrocking to enhance R-value. Also, consider insulating over the slab with rigid board insulation such as Blue Board before installing sub-flooring and a finished floor.
Air quality - Seal with special care since long-time build-up of petroleum products and other chemical residue in concrete floors can result in residual air quality problems.
Fuel switching - In some cases, separate space heaters may be more effective than trying to extend the present system. Small, closed-combustion gas-fired heaters of 5,000 to 15,000 Btu/hour may be a good energy efficient choice.

Built-ins (bookshelves, closets, cabinets)

Air sealing - Ensure that drawers built into kneewalls and other building cavities are effectively sealed at their backsides. Finish walls with sheetrock or plaster before installing built-ins. A frequently-found problem is the area above kitchen cabinets that opens into a dropped soffit in the attic.
Insulation - Install several inches of foam behind cabinet linings. This takes up minimal space and can eliminate complaints about cold surfaces and closets.
Buffering - Place bookshelves and closets against north-facing walls.

Ventilation - Consider undercutting doors or adding louvers to provide circulation and allow heated air to temper closets, thereby helping to avoid dampness and mildew.

Redecorating

Vapor barriers - Caulk trim, seal penetrations, and paint walls with a water vapor impermeable paint on the interior. Adding film (poly) vapor barriers in the wall is often difficult if not impossible except in a gut rehab.
Surface materials - Plan for maintenance and future repair of all surfaces, including floors, walls, ceilings, or counters. Consider thermal properties and indoor air quality implications. Cleaning products recommended for some brands of hardwood floors are more toxic and objectionable than others, so choose carefully.
Air sealing - Seal with interior caulking in preparation for painting operations. Seal all original walls and ceiling surfaces before installing paneling, dropped ceilings, etc.
Insulation - Install an inch or two of high-R-value foam board insulation before installing paneling as an inexpensive way of adding insulation with little loss of floor space. Consider drilling and installing sidewalls with cellulose blown to high density from the interior before repaneling, plastering or painting.
Movable insulation - Install decorator designs for curtains, shades, and shutters to achieve improved aesthetics, comfort, and energy savings.
Air quality - Avoid excessive use of unsealed paneling, particleboard, carpet, and composite wood products. These can lead to high levels of formaldehyde and other noxious fumes. Carpets play host to dust mites. Volatile organic chemicals are emitted by many furnishing and can sometimes be allowed to outgas before installation.
Mitigation - Enclose lead and asbestos-laden materials behind new surfaces whenever practical. This may be cheaper and less dangerous than attempted removal.

Re-siding

Air sealing - Install a vapor-permeable air barrier membrane under the siding but only if detailed properly. It is more valuable as a drainage plane than an air barrier.
Insulation - Install an exterior foam sheathing to add R-value, but watch for possible moisture problems. Foam board over an uninsulated frame wall is fairly ineffective. Blow the sidewall with cellulose first and then add your foam board. Holes in original siding will then be hidden. Careful air sealing from the interior is still critical.
Moisture control - Use caution regarding use of non-breathing siding materials or assemblies. Be scrupulous with flashing details to eliminate moisture penetration and provide a drainage plane. Remember water flows downhill and shingle-lapping of all flashing materials is the only assurance of durability. Do not expect caulk to keep out moisture. "Breathable" or vapor permeable construction is called for on the outside.
Asbestos mitigation - Ensure that special precautions are taken in the removal and/or replacement of "slate" asbestos siding.
Greenhouse/sunspace - Consider a greenhouse or a sunspace as an alternative to applying siding, especially for south-facing masonry surfaces.

Trombe wall - Consider a Trombe wall as an alternative to covering south-facing masonry surfaces.

Window replacement (also see Appendix C)

Air sealing - Ensure that new windows meet industry standards for air (and water) tightness. Air seal between new window jambs and rough framing with low-expansion foam fully filling the cavity. Do not use high expansion foam which could deflect the jamb. Do not forget original weight cavities or other framing details surrounding the window.
Moisture control - Ensure effective use of drip caps and exterior flashing. Integrate any housewrap or drainage plane material carefully. Shingle all flashing materials to shed water to the exterior. Do not rely on caulk to protect against exterior rain penetration. Seal interior joints to eliminate air movement and moisture condensation.
Glass selection - Select the best quality, low-e windows for spaces where you spend the most time. For basements or other rarely used spaces, the added cost may not be justified. Non-coated glass may be more suitable for south-facing windows to optimize solar gain but nighttime insulated shutters or shades may be necessary. Tinted windows are generally more suitable for warmer climates or for un-shaded, west-facing windows where air conditioning loads may be a primary concern.
Durability - Choose windows for long-term durability. Some plastic channels and weather stripping age badly from ultraviolet (UV) radiation.
Maintenance - Choose windows with a view to ease of maintenance and cleaning.
Insulation - Insulate any cavities resulting from changing window sizes. Low-expansion foam both Air seals and insulates.
Clerestory/skylights - Choose south-facing clerestories whenever practical. Skylights have a tendency to overheat spaces in summer. West-facing is worst.
Awnings and overhangs - Install operable awnings when practical. They can be the best defense against summer overheating.
Movable Insulation - Well-designed curtains and drapes can be an attractive option for upgrading limited thermal resistance and comfort of even the best window units. Insulated shutters should be coming on the market soon.
Daylighting - Place windows high on the wall to allow for deep light penetration. Plan to avoid glare and overheating.
Reorientation - Enlarge window sizes to the south and reduce on north and west sides when practical.
Ventilation - Develop a whole house ventilation strategy. Operable windows, both high and low, wisely located and operated, can greatly reduce air conditioning load.

Re-roofing

Moisture/ice dams - Make sure the primary causes of the deteriorated roof is corrected before re-roofing. Test for bypasses, thermal bridges, and moisture migration that contributed to the original problem. Eliminate all penetrations through the ceiling, especially around unsealed recessed lights.
Materials selection - Select colors to respect esthetics and energy considerations. Light-colored shingles reduce summer cooling load and last longer. Consider insurance and fire implications. For "hot roofs" with insulation right up to the sheathing, select shingle types that provide guarantees for such installations.
Insulation - Consider foam laminates for new roof decking over cathedral ceilings. Alternately, install cellulose to high density in cathedral ceilings and slopes.
Clerestory/skylight - Avoid over-use of skylights as they may lead to summer overheating and condensation due to cold winter nighttime surface temperatures. South-facing clearstories provide the same benefits as skylights without the liabilities.
Daylighting - Consider the significant advantages of clerestory or skylights for getting light deep into dark corners of stairwells and other spaces below.
Asbestos mitigation - Observe precautions in working with older "tile" roofs.
Active solar hot water - Coordinate the installation of solar panels with the shingling work.
Photovoltaics - Examine the option of using integrated shingle/solar electric (PV) materials instead of each alone. This can yield substantial esthetic and economic benefits.
Chimney flashing - Ensure that the chimney flashing will last as long as your shingles. Reusing existing flashing is often problematic.
Chimney removal - Take advantage of re-roofing to removing unused chimneys. Remove the masonry down to the ceiling height and thoroughly air seal both the chimney and its chase and insulate over the top. Be sure to consider historic and aesthetic issues when removing chimneys.
Venting - Install matched ridge and soffit vents as part of the re-roofing job. Make sure the sheathing is cut through to the full opening required. Ensure that all kitchen and bath fans are connected directly to dedicated vent caps at the exterior either at gable ends, through the roof or, if necessary, at the eaves. Do not merely dead-end them at a roof vent.

Foundation repair

Air sealing - Repoint the foundation masonry, seal the foundation to the sill plate, and seal other holes from water and air flow. For fieldstone foundation walls, sprayed-on urethane or poured concrete "sister" foundations may be the only viable solution.
Insulation - Decide whether to insulate on the exterior with extruded styrene foam boards or on the interior with fiberglass or foam boards, assuming a smooth foundation wall surface. Foamed in-place urethane is becoming more economically attractive, and a material such as GrailCoat® (www.grailcoat.com) can be used on the outside to achieve a very viable stucco-like seal. In general, better overall comfort and energy efficiency is achieved by insulating on the outside of the foundation.
Radon mitigation - Air seal and insulate at the floor level and slightly pressurize the basement or crawl space. These tactics save energy and frequently solve radon problems at the same time.

If testing shows that radon still remains, installing a sub-slab depressurization system with associated fan may be the best solution to a radon problem.
Moisture control - Install an effective drainage system around foundation. Sometimes this completely relieves interior moisture problems and freeze bulges. Consider excavating to add sub-surface drainage, an exterior moisture barrier, drainage plane and digid board insulation designed for this environment. Repair roof gutter and leaders and correct poor site drainage slopes.
Vapor barrier - Install over bare earth in crawl spaces to reduce dampness from rising up into insulation and living space above. Use at least 8-mil plastic that is reinforced. Seal tightly to top of foundation wall with foam or acoustic sealant.
Crawlspace entry, management - Provide access if needed in ways that avoid mechanical damage to ground cover, etc. If mechanicals are in the crawlspace, locate to make it easy to change filters, etc. Position lights/switches wisely.
Landscaping - Employ shrubs or similar plantings to buffer wind loads but ensure that they are not so close to the foundation wall that they prevent adequate airflow and drying of the foundation.

Garage addition

Buffer Zones - Use the garage as a wind break and buffer on the north or west sides of the house to protect those most vulnerable areas
Vestibules - Be creative in providing access between garage and home. Since most access to the house will likely be from the garage, either a direct-connect door passage (using an exterior quality insulated door) or an "enclosed breezeway" or other vestibule/mudroom space buffering the house can act as an airlock entry to blasts of cold air from the exterior. Care should be taken to meet fire code restrictions and isolate garage spaces thoroughly to reduce transmission of toxic fumes and carbon monoxide into the living spaces - a prime source of indoor air pollution in homes with attached garages.
Lighting - Install high efficiency driveway and security lights, including low-voltage systems that are powered by photovoltaic cells. Be aware of light pollution implications. Motion sensors and photo switches can be set up to be smart controllers.
Passive solar heating - Consider simple passive solar strategies to temper garage temperatures allowing for easier winter car starting and comfortable use of garage/shop spaces.

Security

Windows/doors - Consider installing tempered glass, double glazing, sash locks, and storm or heavy insulated doors, all of which resist forced entry. Be aware of the egress issues with bars and gates.
Lighting - Carefully design exterior lighting systems to provide better light at reduced operating costs. Amber lights preserve night vision, reduce glare, and do not attract insects. Direct light away from house towards shadowed areas while respecting light pollution concerns of your neighbors. Lights shining on or into the home inhibit inhabitants' night vision and illuminates the house to potential intruders. There is little evidence that yard lights or other exterior lighting

improves security in rural locations. Control exterior lighting with motion sensors. Fit interior lights left on for security reasons with compact fluorescent light (CFL) bulbs.

Electrical work

Air tighten - Seal wiring penetrations as you go to eliminate unwanted bypasses. S-fuses or reduced circuit breaker amperage may be required if insulation is to be installed over older small gauge wiring.
Lighting - Select fixtures that accept the new compact fluorescents. Replace recessed lights with I.C.-rated units and air seal canisters to ceiling surfaces. Alternately replace recessed lights with surface-mounted fixtures such as wall washers and sconces.
Appliances - Upgrade appliances for features, efficiency, operating cost, maintenance and durability. Look for the ENERGY STAR® on everything you buy.
Fuel Switching - Consider replacing electrical resistance appliances such as baseboards, space heaters, clothes dryers, and water heaters with vented natural gas units.
Smart House Technology - Plan for tomorrow's appliance and communication loads today. If occupants are looking to operate the house remotely, wire in the option. If there is talk of future use as a wet space, include ground fault interrupters in outlets or circuit breaker boxes.

Plumbing

Air sealing - Seal plumbing chases and wall penetrations against air leakage.
Insulation - Ensure that the thermal envelope is on the exterior side of all pipe runs to reduce chances of pipe freezing.
Moisture control - Fix plumbing leaks to eliminate moisture problems at their source and stop waste.
Venting - Install high-efficiency, low-noise, exterior vented bath fans on all bathroom jobs.
Piping - Install thermal bridge/anti-siphoning valves on both hot and cold pipes from water heater.
Pipe Insulation - Insulate long runs and/or lines that get turned on and off frequently (like to the kitchen sink).
Water heaters - Buy the highest quality insulated tank models or an instant demand water heater. Makes sure all gas-fired units are either power-vented or closed combustion. Be alert to noise issues. Naturally vented water heaters should be avoid whenever possible in favor of closed combustion appliances.
Water conserving fixtures - Use water saving showerheads, faucet fixtures, and toilets.

Insulation

Roof/flashing repairs - Make minor repairs to existing roof leaks and failed flashing. If roof is approaching failure, have the homeowner re-roof before proceeding.
Moisture issues - Recognize that even moderate air leakage into attics from high-moisture locations such as baths, kitchens or damp basements can be devastating.

Exhaust vents - Make sure all exhaust fans are firmly connected with metal ducting to an exterior vent hood and the back-drafter damper is clean and fully functional.
Attic vents - Evaluate the house for meeting standard rule-of-thumb/code vent requirements but recognize that building science may allow us to seek other solutions. Be prepared to defend your decisions to by-the-book code officials.
Define the thermal envelope - Reducing the volume of heated space is less important than reducing the surface area to be insulated. For example, this means that capping the top of an attic stairwell is more effective than insulating the stairs, door and stairwell sidewalls.
Electric - Test circuits throughout the home using a tool that places a 15 amp load on a circuit and measures voltage drop. Voltage drops of over 5% should be addressed. Retest after the insulation job. Include the fuse/circuit breaker box within the thermal envelope.
Recessed lights - Inspect proper wattage in all recessed lights; replace with compact fluorescents if possible. Air seal and insulate over I.C. rated fixtures.
Air sealing - Perform blower door-aided air sealing before installing any insulation. Check the effectiveness.
Convective loops - Seal rigid board stock over all dropped soffits, stairway cavities, open partition walls, plumbing and chimney chases, etc., even if they are not sources of air leakage from the house.
Framing cavities - Never install insulation - loose fill or batts - over attic flooring or batt insulation over open ceiling cavities. Install cellulose at high density into all such cavities first, then add insulation on top to optimal levels.

Landscaping

Shelter belts - Plant non-deciduous trees optimally set back from the north and west (windward) facades of the home. These can provide significant wind-caused convective losses.
Daylighting - Plant with an eye towards the future size and shade footprint. Remove south-side evergreens and lower branches of hardwoods to allow more useful light and solar gain.
Shade/cooling - strive for plantings that provide shading of east and west facades of the home, but avoid compromising the safety of roofs by large overhanging branches.
HVAC - Avoid obstructing airflow to AC condensing coils with decks, enclosures, or plants. Install the condenser on the north side when practical.
Solar Systems– Avoid shadowing solar systems as much as possible. Shadows from trees, satellite dishes, architectural details, nearby buildings, etc. can hugely interfere with projected efficiencies of photovoltaics, space heating, or solar hot water systems.

Appendix B
Undertaking Retrofit Measures

Sequence for air sealing work

The general contractor may choose to watchdog air-sealing activities or may assign one skilled laborer to follow each subcontractor and perform relevant air sealing activities at the most opportune time (when building elements are most exposed and accessible). It is an increasingly common practice among energy-conscious homeowners having a house built or remodeled to go around at the end of each working day and perform all the necessary chinking and air sealing that contractors may overlook.

If a blower door test done by the energy auditor is used to measure air-leakage levels, one can establish suitable reduction goals and priorities and a practical order for air sealing work.

Much air sealing of homes is accomplished most effectively on the inside of the conditioned envelope. In many cases, air sealing is accomplished as an integral part of the insulation process, as in installation with high density cellulose. In all cases, the aim is to gain control of these unwanted sources of infiltration (drafts) and exfiltration (conditioned air escaping) by restoring the building shell or envelope.

Figure B-1 shows a graphic of a home with a number of typical air leakage sites indicated by numbers. The text that follows recommends tactics for effectively air sealing each kind of leakage area.

Figure B-1. Graphic illustrating areas where retrofit air sealing and tactical insulation measures area are sometimes required.

Attic

Air leakage from the house into the attic must be controlled as a first priority. Any point which penetrates the ceiling can be a source of air leakage, and besides the visible sites, there may be many hidden areas, or bypasses. All gaps must be sealed with an appropriate material that takes into consideration movement, the need for access, and fire, electrical, and safety hazards. Since attic leakage sites are often connected to other leakage areas that are less accessible and in other parts of the building, it is easier to focus attention on stopping these airflows at the top of the house. If air cannot escape here, it can not be drawn into the lower leakage sites.

No exhaust fans from kitchen or bath or other vented devices should exhaust into the attic space. All must be carried to the outside. Whole-house fans should only be installed if there is ample venting out of the attic and if the fan vent can be adequately sealed with an air-tight, insulated cover in winter.

Leakage sites that must be addressed include: interior chimneys and flues (masonry and metal) plumbing stacks and chases, electrical fixtures and wires, partition walls, exhaust fans, ducts or plenums, perimeter walls, party walls, dropped ceilings, clothes chutes, dumbwaiters, built in furniture and storage closets, and attic accesses.

Referring to identifying numbers on the above graphic, here are some shorthand recommendations on how to air seal each area.

1 Staircase Ceiling
Cover opening with sheetrock or reinforced cardboard (or plywood for large openings) caulked and nailed to joists, taking special care to seal ends with similar material. Insulate to standard depth. Alternately, fill cavity full with blown insulation.

2 Recessed Light
Most older recessed lights are both very air leaky and a potential fire hazard since they can easily overheat and ignite surrounding insulation and building materials. Replace these lights with either surface-mounted fixtures appropriate to the home's era or install Underwriters' Laboratory- approved insulated (I.C.) recessed fixture for use under insulation. Seal around the rims when installing. (See p 3-14 on lighting retrofits.)

3 Chimney Chase
Fire code calls for an air space between the chimney and any combustible building materials. Seal the opening in the attic with metal flashing caulked and nailed to the surrounding joists and seal the flashing to the chimney with high temperature caulk. Establish a barrier at least 2 inches from chimney to hold back any insulation. Air leakage up a fireplace can be controlled using glass doors, but a chimney top damper is far more effective. The combination is better yet. Unused holes or openings in masonry chimneys should be filled in with a compatible cement-like material. Chases around furnace flues and chimneys should be sealed with sheet metal and high-temperature caulk.

4 Electric Wires and Box
Fill wire holes through framing members with siliconized acrylic latex caulk or urethane foam. Seal boxes that penetrate ceiling. Flag boxes before insulating in case later maintenance is needed. All junction boxes should have covers - do not fill them with insulation. If you are not sure of the condition and capacity of the installed electrical circuits, have them inspected by an electrician or test with a circuit tester that measures percent voltage drop under a 15 amp load before insulating. (See Section 2, p 2-11.)

5 Balloon-Framed Walls
Older houses may have balloon framed walls which are typically open to both the attic and the basement. Fill exterior walls with high density blown cellulose insulation. Some can be reached

from the attic. Interior walls can be sealed with cardboard caulked and stapled in place or walls may be sealed top and bottom with fiberglass-filled plastic trash bag "pillows." In some cases interior walls can be blown full of insulation.

6 Attic Entrance

Consider this opening as important as your front door. Weather strip with appropriate material and use hardware to secure door. Caulk trim on interior and insulate the back if practical.

7 Partition Wall Top Plate

Seal seams at plate and plaster/sheetrock with urethane caulk (or urethane foam if gaps are large).

8 Plumbing Vent Chase

Seal around pipe with clamps and special neoprene collars designed for that purpose or use plastic sheeting mechanically fastened around pipe and sealed to ceiling with staples and acoustical caulk.

9 Exhaust Fan

Extend vent hose through gable end or roof and install a good-quality backdraft damper/vent hood. Seal edges of fan unit to ceiling with urethane or siliconized acrylic latex caulk. Kitchen and bathroom exhaust fans should also have a back-draft damper, and be installed so air cannot leak around the fan housing. Piping should extend to a dedicated vent hood through the roof, out a soffit, or through a side wall. The pipe should be solid metal ducting or metal expansion hose drawn tight so there are no sags to collect condensed water vapor. The pipe should be insulated where it passes through unheated spaces.

Basement or Crawl Space

10 Dryer Vent

Replace the vent hood with an improved design unit. Dryer vent hoods should be replaced with magnetically latching units, pipe connections should be sealed with *metallic* duct tape, and other building penetrations should be caulked with a high-performance sealant.

11 Plumbing/Utility Penetrations

A variety of service penetrations occur at header and foundation walls. Dryer vents, water pipes, gas pipes, oil filler pipes, Freon lines to outside condensers, TV cables, and most other penetrations can be sealed using standard practices.

For air-leakage purposes, all penetrations should be sealed from the inside where practical. Exterior openings should be sealed to block water leaks. Large gaps in stone, block, or concrete walls should be filled with cementatious material, and a bead of caulk run at the joint of the opening and the filler. Backer rod/stuffage should be used similarly around penetrations in wood frame and other construction types. Flexible sealants should be chosen that continue to seal in spite of the expansion and contraction of surrounding materials.

Electrical service entrances require special care. If the service entrance is accessible from the inside, the gap where it penetrates the wall should be caulked. If the conduit passes straight into the back of the service panel, the pipe should be sealed from the outside where it passes through the wall. Foam or sealant should never be installed inside electrical conduit.

12 Sill Plate

Seal to foundation with urethane caulk where most accessible. Alternately include the sill plate as part of a more comprehensive foundation insulation system.

13 Rim Joist

The intersection of the main floor and joist header area is particularly susceptible to air leakage at the framing intersections, around service penetrations in the header areas, and at the basement ceiling where penetrations lead to the upper floors of the house or attic.

Air leakage should be controlled at the joint of the foundation and the sill plate, between the exterior sheathing and the sill plate, at the joint of the header and each joist, between the top of the header and the subfloor, from the basement into the header cavity through the open-face of the header area, and through subfloor cracks from the header cavity. The appropriate types of caulk and sealant should be used for bonding dissimilar surfaces. (Polyurethane caulk is often appropriate for this joint unless it is larger than 1/4 inch, in which case urethane foam is a good choice.) The entire length of the joint between the sill plate and the top of the foundation wall should be sealed.

In a balloon-frame configuration, if a fire stop blocks the stud cavity at the main floor it should be caulked in place. If no fire stop exists, batt insulation should be installed in the header space to completely fill the area so it will be slightly compressed when blocking is installed. Blocks of rigid insulation (like polyisocyanurate) should be cut and fit tightly into cavities between joists, subfloor, and foundation wall and thoroughly caulked in place. Fire resistant material should be applied to blocking if needed.

In standard platform framing, a uniform bead of sealant should be applied to all visible joints within each box sill header area. This includes the joints between the header and the sill plate, the header and the subfloor, the header and the joists, and the joists and the sill plate. At the joint where the main support beam meets the foundation wall, the sill plate and end joists should also be sealed with a compatible caulking material.

In non-standard joist/header intersections, a combination of stuffage and polyurethane foam should be used to isolate wall cavities from under-floor leakage.

In slab-on-grade applications, header air-sealing should focus at the interior floor/wall joint. If the crack is large, backer rods should be used before applying sealant. If there is sufficient clearance, the sill/slab joint should be caulked from the exterior as well. Penetrations into the main and upper floors should be sealed.

A recent advancement in insulation technology has enabled fully insulating the entire rim joist area with 2-part urethane spray foam. This insulates and air seals at the same time. Check with your local building/fire code, however, because some restrictions may apply. Never apply this material next to areas where high heat or open flames might cause it to ignite.

14 Bathtub Opening
Block air movement with reinforced cardboard, caulked and stapled to floor members.

15 Basement Windows and Doors
Make operable but air seal as with doors and windows in living space. In terms of energy usage, such openings are more important than the front door because stack-effect infiltration forces are greater toward the bottom of the conditioned envelope.

16 Block Wall Cavities
Fill tops with urethane foam or mortar plaster.

17 Water Heater/Furnace Flue Connections
Replace deteriorated pipe. Assure connections stay put by securing joints with stainless steel hex head screws. Seal at chimney with non-asbestos furnace cement or high temperature caulk. Consider replacing appliances with closed-combustion systems to eliminate the need for the chimney and combustion air inlets otherwise required by codes.

18 Ductwork
Mechanically close open seams and reconnect open ducts, boots, and registers. Clean with alcohol solution and seal with dead-soft aluminum tape (not duct tape) or seal all joints with a combination of duct mastic and fiberglass mesh tape.

19 Plumbing Chase
Seal around pipe with urethane foam, duct wrap, or polyethylene as practical. If the pipe is plastic, it will expand and contract with temperature changes. To ensure a through seal while allowing noiseless movement of the pipe, apply a thin coat of oil or petroleum jelly around the pipe before applying foam.

20 Leakage Between Basement and Crawlspace
Seal as appropriate with urethane foam, caulk, weather-stripped hatches, etc., as appropriate to the situation.

21 Floor Boards
Support floor insulation with high tensile strength air barrier material (Tyvek™, Typar™, or equivalent) sealed carefully around edges with acoustical sealant and battens. Protect barrier material from ultra-violet radiation. Alternately, seal the floor from the interior by putting down a new floor surface (plywood, vinyl, etc.) over building paper/air barrier.

Exposed floors may be those over enclosed unheated spaces such as floors over crawl spaces, sleeper floors, or floors over unheated porches, garages, etc. Floors may also be exposed directly to the exterior environment if they are part of an overhang or cantilever, or a house sitting on pillars or posts. Floors must be evaluated for potential moisture damage and required ventilation in crawlspaces, or for mechanical system combustion needs before undertaking air sealing.

All service penetrations should be sealed through the floors. This applies to plumbing chases, electrical and gas lines, furnace supply and return air ducts, balloon frame interior walls, and unsealed, unused, or incompletely capped plumbing, chimney, or flue openings. For the most part, penetrations can be sealed at either the top or bottom of the floor, depending on which is easier and more aesthetically acceptable. Backer rods or foam material should be used if the gap is too large to caulk, or if the joint is subjected to large amount of movement due to thermal expansion or contraction. Service penetrations should be sealed at the attic, too.

If new flooring is to be installed, the whole floor surface should be sealed using an air/vapor barrier. If polyethylene is used, it should be sealed to the floor surface with a continuous bead of acoustical sealant and mechanical fasteners (staples), then the poly should be brought up the wall and sealed with acoustical sealant on the wall so that it will be concealed behind the baseboard in the finished applications. Seams and intersections should be sealed with acoustical sealant.

Overhangs should be addressed from both the outside and inside where possible. Air sealing should be accomplished before insulating. If the cavity is open to the exterior, an air/vapor barrier can be installed on the underside of the floor and sealed with acoustical sealant and mechanical fasteners. It may be helpful to install an air barrier material such as Tyvek (tm) after the insulation is installed and before any enclosing finish materials are applied. If there is blocking between the joists, it should be caulked and sealed to each joist, floor section, and plate. If there is no blocking or header isolating the interior and exterior floor section, blocking (sections of polystyrene foam insulation, foil-faced-foam, or drywall painted with air/vapor barrier paint) should be installed between each joist and caulked in place. If the cavity is accessible from the inside it should be filled with insulation, the spaces between joists should be blocked, and the subfloor joists sealed above the cantilever section so that the sub floor can serve as an air barrier. This intersection is frequently a major source of air leakage through the floor or into the wall, particularly in the case of modified balloon-framed homes,

Living area

Cracks and gaps in the interior surfaces should be sealed. This includes the joint between the wall and ceiling. If new drywall is to be installed, proper drywall procedure should be used to seal all cracks on flat surfaces. If paneling or another interior covering surface is to be installed, all cracks and gaps in existing wall surfaces should be caulked or standard drywall procedure employed to seal large cracks before new covering is installed.

Alternately, installing a continuous air/vapor-retarding film between the old and the new wall surface (caulking edges with acoustic sealant) may be advisable. Caulk used to seal small cracks should be installed continuously and be free of bumps and gaps. Moldings should be carefully removed and reinstalled or replaced. Sealing should be accomplished behind interior trim whenever possible, rather than simply caulking the face surfaces.

A third alternative is to perform all air sealing activities at the original interior wall surfaces and then use two-inch furring strips to form a free air space/chase. Then a new interior surface should be added over the furring strips. No wiring, plumbing, etc. passing within this air space should be allowed to penetrate the air barrier surface.

Gaps between floor boards where they penetrate the wall should be controlled independently from sealing the bottom plate to the finished floor. Depending on the type of subfloor--plywood/composite board, tongue and groove, shiplap, or square-edged boards--it is likely that it extends under the soleplate, where it may form a channel that allows direct leakage.

22 Windows

Air leakage that occurs at primary windows which separate a heated/conditioned space from unconditioned space should be controlled. When treating a primary window unit (except where certain styles of spring loaded sashes, metal sashes, or integral weather stripping prohibit it), the following conditions apply:

- Window jamb and frames on replacement windows should be caulked and sealed at the time of installation to prevent air from moving between the head, sill or side frames and the rough opening. If an interior air/vapor retarder is used, it should be carefully sealed to the window jamb.

- Replacement windows should be rated to meet highest industry quality standards for air leakage for the particular type of unit.

- If existing windows are to remain, all gaps between the window frame and rough opening should be sealed with compressed fiberglass, stuffage, caulk, or non-expanding polyurethane insulation. In the case of the latter, the best job may be achieved by insulating the closed cavity, but with the other applications, the interior trim must be removed first. Non-expanding foam is needed because expanding foam could cause the window frames to bulge and the windows rendered inoperable.

- Operable window sashes should be adjustable and operate freely at all times of the year. Exceptions are sashes which have been painted shut (and where the paint seal will not be broken) and windows with existing permanent security bars.

- All meeting rails on double hung windows should touch snuggly and be flush when in the closed position. There should be a functional sash lock for every 36 inches of meeting rails. No sash lock should be shimmed or mortised.

- All operating sashes should have an effective and functional sash control system such as spring bolts, spring "wedge," or sash counterweights. Sash counterweight ropes which are badly worn or missing should be replaced with 80 pound test sash cord.

- Window channel replacements should be sealed to the window jamb, weather stripped and properly adjusted and tensioned to hold sashes securely.

- Pulley seals should be installed and mechanically fastened wherever possible.

- Any casing, stop, brick mold, stool or other window trim should be carefully adjusted and mitered. It should be tightly attached to the jamb and sealed to the wall.

- Window weather strip should be applied to existing windows so that it provides a continuous seal. It should be mitered to fit snugly in the corners and be mechanically fastened every four inches or according to manufacturers' instructions. Weather strip should be of the correct dimension and of high quality. Weather strip should not interfere with the operation of the window.

- Storm windows should be tight enough to trap air in the cavity between the storm and primary windows, but should also be provided with weep holes for drainage of rainwater or other trapped moisture. Exterior storm windows should not be tighter than interior prime windows. Combination inserts should operate smoothly.

- Interior storm windows should be treated as *de facto* primary windows from the perspective of air sealing, and be provided with gasketing and fasteners that provide an airtight seal against the primary window frame. Emergency egress and maintenance issues should be discussed with the homeowner before installation.

Appendix C contains a number of suggestions for rehabilitating and installing doors and windows in historic homes.

23 Laundry Chutes
Seal with appropriate gasket material.

24 Stairwell
Caulk risers, treads, and sidewall junctions as needed. Consider blowing inaccessible stairwell sections with high-density cellulose insulation.

25 Kneewall/Framing Intersection
Isolate the knee wall from the living space with a tight-sealing door or panel. Insulate sloped roof/ceiling section with high-density blown insulation. Insulate vertical kneewall with fiberglass batts or rigid insulation. Insulate the floor with high-density blown insulation, being sure to seal off the floor cavity between living spaces with tightly-packed insulation.

26 Built-in Dresser
In an unconditioned space, build bureau with cardboard or plastic stapled and caulked to drawer-guide framing members. Insulate and seal at roof rafters.

27 Chimney Penetration
Seal with high-temperature caulk and sheet metal.

28 Built-in Cabinet
Caulk perimeter of cabinet and interior hardware slots with siliconized acrylic latex. Alternately, remove cabinet, seal wall chase, and replace cabinet.

29 Holes in Plaster Walls

Patch smaller holes with Durabond™ patching plaster or a fiberglass-reinforced patch kit. Large deteriorated sections can be covered with sheetrock screwed through to framing members. In some extreme cases gut rehab may be necessary but it should be recognized that this will change significantly the interior look from the original plaster walls. Care must be taken to maintain original trim and attempt to reproduce the original look as much as possible.

30 Furnace Registers

Reinforce large gaps with sheet metal and screws. Clean surfaces with alcohol solution and seal with J-channel, dead-soft aluminum tape, or duct mastic.

31 Doors

A primary door is one which separates conditioned space from unconditioned space. In addition to doors leading directly to the outside, this includes doors leading to unconditioned porches, attics, cellars, hallways, etc.

All primary doors should:

- Be properly adjusted in the frame so that they open and close smoothly during all seasons.
- Have adequate hardware and hinges to support them.
- Be held firmly in the closed position by the latch and strike plate.
- Have all glass, molding, and panel inserts caulked or sealed against infiltration. Mail slots should be sealed or covered with an interior flap.
- Be weather stripped to provide a continuous seal with a high quality product. This includes the side, top, and bottom of the door. Weather strip should be adjustable and must allow the door to operate freely when installed.
- Have a solid sill and threshold.

Door trim and framing should be solid and treated similarly to windows. Air sealing work should take place behind interior trim whenever possible. The door sill should be sealed to the floor side jamb of the door.

Finally, sliding glass doors should be weather stripped and hardware upgraded, if necessary, to provide a firm seal.

32 Baseboards, Coves, and Interior Trim

Gaps between the bottom plate of the wall and the floor, including leakage behind baseboards must be sealed. Where appropriate, baseboards should be removed and reinstalled without damage. Backer rod must be used if the gap exceeds the shrinkage tolerance of caulk or foam products. Baseboards should be firmly reinstalled and surfaces left clean and free of smudges and excess sealant. Caulk on interior with clear siliconized acrylic latex caulk.

33 Plumbing Access Panel

Weather-strip if possible. If not, caulk with silicone caulk using bond-breaker tape on one surface and screw in place.

34 Sink Plumbing Penetrations

Gaps around utility penetrations should be sealed where they penetrate into either exterior or interior walls. If new fixtures are to be installed, penetrations should be sealed during installation to limit air intrusion.

Plumbing penetrations should be sealed at the points where they enter both the attic and the basement/crawl space sewer outlet as well as at exterior walls. However, urethane foams should never surround electrical wiring since its good insulating properties in combination with its flammability could cause a fire hazard.

35 Dropped Soffit

Caulk all open seams from the interior or try to seal from above with board stock and urethane foam or caulk. If covering is impossible, consider filling with blown insulation (not if light fixtures are present).

36 Electrical Outlets

Newly-installed electrical receptacles (switches and outlets) should be detailed to prevent air-leakage or enclosed in plastic airtight boxes designed for that purpose. Existing electrical boxes should be sealed at their edges to the finished wall surface and be leveled as necessary. Foam switch plates, receptacle gaskets, and childproof plugs should be installed on all fixtures lacking airtight boxes. Foam, sealants, or insulation materials should not be placed inside the electrical box.

Place gaskets behind cover plates as required.

37 Electrical Fixtures

Recessed lighting fixtures should be replaced with I.C. units that are approved by UL for insulated spaces, or surface-mounted fluorescent box fixtures should be employed. Non I.C. recessed light fixtures are both an energy hog and a fire hazard and should never be used with ceiling insulation.

Caulk fixtures to interior surfaces with clear siliconized acrylic latex caulk.

Exterior

Direct air leaks are those that pass into the exterior wall from outside, and from there can move directly into the heated rooms around cracks in the molding, utility penetrations, light switches, etc. Such air leaks are best dealt with at the interior surfaces using sealants, gaskets, and/or air/vapor barriers. Caulking on the exterior of the home is primarily done as a remedy against water penetration between dissimilar materials.

Carefully-installed insulation of exterior walls with tightly-blown cellulose has proven to be remarkably effective in stopping air flow in and through walls. It is particularly important that no voids or air chases be left, and that all insulation is installed to the manufacturers' specified density or even slightly greater. The positive impact on both the convective and conductive losses/gains of the building improve the cost effectiveness of sidewall insulation beyond conventional calculations (Figure B-2).

Figure B-2. Drilling sidewalls and installing cellulose to high density using the tube method lowers both convective and conductive losses.

Fiberglass insulation will not, in and of itself, stop air leakage through a wall. Further, poor installation techniques can allow air movement which can significantly reduce its insulating effectiveness. Fiberglass batt installations should be carefully inspected before being enclosed to ensure that there are no paths for convective loops.

Indirect air leaks are those that occur when an air leakage path exists between an exterior wall and a heated space by traveling through partition walls, intermediate enclosed floors, plumbing, electrical, ventilation and heating chases or registers, pocket doors, dropped soffits, etc. Indirect air leakage should be controlled at either or both of the following points depending on access and economic feasibility:

The outer end of the air-leakage path is where it passes through the exterior wall envelope. All leakage connections/intersections where partition walls and intermediate floors join the exterior walls can be easily sealed if the building is undergoing a gut rehab. Penetrations through the exterior wall should be sealed as indicated in the direct leakage section.

If the interior building surfaces are to be left largely intact, then air sealing should take place at the inner end of the air leakage path where the air passes out of the heated space. This should include, but not be limited to:

- Electrical receptacles in partition walls and intermediate ceilings and floors;
- Gaps between drywall and doors on partition walls;
- Gaps at the bottom plates of interior partition walls.
- Drywall cracks and gaps at the tops of partition walls and elsewhere.

- Gaps between floorboards in the subfloors, around electrical services, plumbing, vents, ducts, and chimneys where they penetrate intermediate floors; and
- Gaps between stairs and walls in stairwells.

38 Porch Framing Intersection
Gain access and blow all connecting cavities with high density cellulose (if the blower door indicates that the porch is connected thermally to the home's conditioned envelope Figure B-3).

Figure B-3. Checking porch ceiling to see to what degree it is thermally connected to the inside of the dwelling.

39 Missing Siding and Trim
Restore or replace damaged sections with matching replacement siding, prime all sides of wooden materials, and caulk for water penetration. When possible, stabilize existing details with special epoxy-based wood restorers. If replacement is necessary, match the original profile as closely as possible even though this may mean custom millwork.

40 Additions, Dormers and Overhangs
Take special care to understand framing details and fill all cavities with high-density blown insulation. Seal interior surfaces as required. The more complex the profile, the greater is the likelihood of overlooking an important detail or air leakage path.

41 Unused Chimney
Stop air flow with a fiberglass-filled poly bag stuffed down to ceiling line even with the insulation in the attic. Cap off top with sheet metal. Seal at bottom as appropriate. Maintain the exterior profile of existing chimneys as important historical and aesthetic details. Do not cover a brick chimney with synthetic siding materials.

42 Floor Joist
Fill with cellulose insulation blown to high-density as part of the wall insulation job.

Materials considerations

Which materials are best for achieving long-lasting retrofit for a historic home? The kinds of considerations that are of concern to the rehabilitation contractor include thermal performance, durability, fire safety concerns, how well the material stands up to moisture stresses, its structural performance, impact on health, visual and aesthetic concerns, and considerations regarding the ability to apply the product. Not all considerations are applicable to all products, of course, but each is probably a significant consideration for some item used regularly.

A full discussion of these issues is in Appendix E.

Lighting

As discussed in Section 2, there are several options for solving the energy problems posed by recessed lighting fixtures. If cans already exist, the retrofitter has four choices:

- Remove the can and seal up the hole, insulating above the sealed-up space;
- Seal up the space, insulate, put a plug into the electric socket, and install a surface-mounted fixture in its place;
- Use the existing can, but build a large fireproof box around it in the attic, then seal and insulate the box; or
- Replace the old can with one that is sealed and can be insulated with impunity, or install a retrofit device over the old can that achieves the same result.

This last option, which is well within the reach of do-it-yourself homeowners, is illustrated in Figures B-4–B-6. In this case, ordinary non-IC (Insulated Ceiling) cans were retrofitted with a completely air sealed reflector-and-ballast system that accommodates pin-style compact fluorescent bulbs by the PowerLux Corporation (www.powerlux.com). A simple plug screws in the socket of the existing recessed light fixture; then the new assembly snugs up against the ceiling via spring-like wires that connect to the can. A touch of clear caulk around the edge finishes the ten minute installation job nicely.

The reflector is efficient but has a glare-reducing ring around its base. The perimeter houses the electronics for its ballast, which keeps it cool - thereby extending its lifetime several fold over systems which include the ballast within the fixture. Finally, this combination of features enables fully insulating on top of the can, thereby eliminating convective and conductive losses, while retaining an efficient source of largely glare-free light.

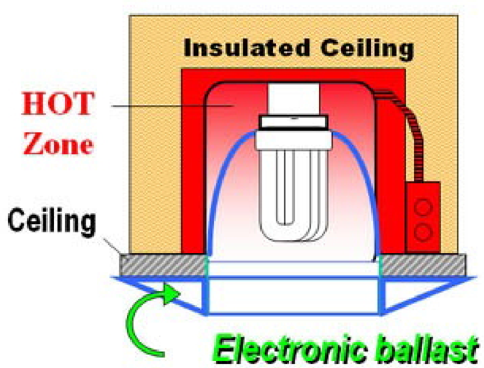

Figure B-4. Diagram of PowerLux retrofit system for recessed fixtures in top floor ceilings.

Figure B-5. Installing the PowerLux system.

Figure B-6. Installation complete. A thin bead of clear caulk (latex acrylic with silicone) was used at the interface of fixture and ceiling followed by a damp cloth. Then 12 inches of fiberglass was installed over the fixture, matching the other insulation in the attic.

Clothes dryer vent

Some people think they can save energy by venting their clothes dryer into their basements instead of outside. Even in dry Boulder this is a very bad idea and can lead to several potential problems. For one, the excessive amounts of moisture dumped into the basement are not helpful. This moisture condenses on cold water pipes, adds to the general dampness or, worst case, can be drawn into building cavities where is condenses and can lead to building deterioration. Many people intentionally do not vent their dryers on the assumption that they are saving heat and energy. In fact, the opposite is often true as the warm moist air from the dryer vent is simply drawn back in through the clothes dryer and it takes considerably longer to get the clothes dry, thereby using more energy than were the dryer properly vented. Additionally, the fibers blown into the air from the dryer can contribute to negative indoor air quality and health. And finally, if you use bleach with your laundry, the evaporated chlorine gases - besides being poisonous - can lead to extreme corrosion and rapid deterioration of the heat exchanger in your furnace leading to expensive furnace replacement costs and potentially life-threatening carbon monoxide poisoning.

Heating, ventilating and air conditioning systems

Boilers

A number of historic buildings in Boulder use gas-fired boilers that feed hydronic distribution systems. No doubt there are also two-pipe low pressure steam systems in our town, but they are most likely quite rare. Hydronic systems transfer heat from combusting gases to water in the boiler, then heat radiators of one variety or another. These in turn supply heat to both objects and human beings in the conditioned space both by convection and by radiation. The larger the surface area of the radiant heating system, the lower the temperature of the supply water from the boiler has to be, and the better the system efficiency of the heating system.

Many older boilers are somewhat massive and not very well insulated, so they have substantial standby losses and over system efficiencies of around 75% or so. New, efficient boilers direct a great deal of energy onto a small volume of water, which is quickly heated and moved into the distribution system. The heat transfer surfaces in these modern boilers are optimized to extract as much heat from the burning gases as practical, so the products of combustion are cooled to the point of giving up even more of their heat through condensation. This improves the burning efficiency to 90% or so, and since the boilers are low in mass, standby losses are minimized as well. Finally, such modern boilers may be vented via PVC pipe through the sidewall of a home, thereby avoiding losses associated with large chimneys. Some bring in combustion air from the outside as well, pre-heating it with exhaust air. Finally, many low mass (or tankless boilers) have variable firing rates, with allows the output of the boilers to match the needs of the house. Sometimes a separate zone of the boiler is set aside for the production of domestic hot water, thereby eliminating the need for a separate hot water boiler.

Given the availability of modern, much more efficient boilers, it is usually worthwhile to consider replacing older boilers if the economics are favorable.

Adding radiant surface area and zoning

Adding additional radiation surface area is also sometime desirable. This can be in the form of additional old-style radiators, smaller baseboard units, or integrating larger radiant surfaces into the floor, sidewalls, or ceiling. (Hot air rises, but radiant heat may be directed like light in any direction.) Adding radiant surface area via any one of these means can enable better comfort and increase the overall efficiency of the heating system by allowing it to be run at lower temperatures.

If the system is not presently separated into several zones, it is worthwhile zoning the system into two or more distribution networks, each controlled by its own multi-setback electronic thermostat This enables heating different areas to different temperatures at different times, thereby ensuring comfort while minimizing waste due to excessive temperatures in unoccupied spaces.

Dealing with radiators

Controls

Hot water radiator systems have the advantage that the amount of heated water circulating through each radiator can be controlled as easily as controlling the water flowing out of a kitchen tap. Turning the knob clockwise restricts water flow, allows the radiator to run cooler, and delivers more heat to other parts of the house. It may take a few tries to get the whole system set up so it is "balanced."

Radiator covers

Many radiators are covered with ill-fitting boxes that don't fit tightly against the exterior wall but have such tight grillwork that they allow but little heat into the living space.

The purpose of a radiator cover is not (primarily) to hide an “ugly” radiator. Since a great deal of the heat that comes off of a radiator results in convective air currents that pass up through its elements, the idea of the radiator cover is to direct the hot air current away from the cold glass above and allow that heat to move on out into the living space. This only functions properly if the sides and the top of the cover fit tightly against the rear wall and the window sill. In addition, there must be room for free air flow to the radiator from the bottom and out the front at the top. Tight metal grillwork greatly constricts this air flow, overheating the air within the box and increasing the heat loss through the exterior walls. A well-designed radiator cover used in conjunction with heavy insulating curtains that make a tight seal against the top of the cover or the window sill can be quite effective.

Reflectors
Mounting a reflective surface behind radiators enhances radiant heat transfer, efficiency, and comfort. There are commercial insulating sheets with reflective surfaces on the market, although they are somewhat expensive. Foam insulation boards that are combustible should not be left exposed in the living space. Thermo-ply reflective construction sheathing is a better choice. This is a foil-covered reinforced cardboard sheet used in the building trades. Installation consists in cutting it to size and sliding it behind the radiator, being careful to ensure that it does not actually touch the radiator. The high conductivity of the foil will draw off heat from the radiator rather than reflecting it.

Painting
It is possible to improve the quality, and to a modest extent the quantity of the heat delivered to a living space by ensuring that radiators are painted a color that is a good emitter in the infrared. This will maximize radiant heat transfer (versus convective), raising efficiency and comfort. Most dark colors work well, as does a flat white acrylic, whose emissivity is 0.9. Silver is a very poor choice of colors for radiators; its emissivity is only about 0.25.

Bleeding
Homes heated with a hot water boiler and cast iron radiators require periodic bleeding of the radiators, especially in areas that are hard to heat. Air gets trapped in the supply lines and collects at the top of the radiators, displacing the hot water that would otherwise deliver heat from the boiler. While the boiler is firing and the circulating pump is running, a radiator key is used to open the small valve at the top of each radiator in turn. If air is present, there will be a hissing sound of escaping air, followed shortly by a stream of water replacing the air, at which point the valve should be closed. The use of a sauce pan will help avoid scalding and wetting the floor. This operation should be repeated every month or so, then less frequently if no air is found.

Water heaters
Next to space heating, making hot water is the most energy-consuming process in most homes. Water and energy both can be saved by using less. This can be done quite painlessly by installing special flow-reducing aerators for your faucets, reduced-flow shower heads, altering patterns of dishwashing, or taking a shower with a friend. Eliminating drips can help enormously.

Keeping the thermostat on your water heater set at the lower setting (125°F or lower) provides more than enough hot water for most families. Higher setting than that waste energy, shorten the lifetime of the heater and run the risk of scalding (Figure B-7).

Figure B-7. Adjustments of hot water heater thermostats need to be confirmed by measuring temperature at the sink. The heater on the right is much more efficient that conventional heaters because it is closed combustion.

Adding insulation to an electric hot water heater can be quite cost effective and does not risk fire. Instead of using a kit, it is easy to make use of a 3 1/2 or 6 inch thick roll of fiberglass and wrap it around, over and under (if possible) the tank. It can be held in place with duct tape and wire. The doorways that provide access to the thermostat should be marked with a magic marker on the fiberglass to facilitate finding them.

Since losses from conventional gas-fired hot water heaters are predominated by are flow through the pipe on the inside, using an insulation kit designed for the job is recommended.   CAUTION: It is critical to keep the insulation away from the hood on the flue pipe at the top of the water heater and to leave an open space at the bottom of the heater to ensure there is adequate combustion air to feed the gas flame.

Periodic draining of about a gallon of water from the faucet at the bottom of the hot water heater tank flushes out the sediment that can sometimes collect at the bottom of the tank. This raises the efficiency of heat transfer.

Gas hot water heaters are generally quite inefficient - on the order of 55% system efficiency-- but since electricity costs almost three times as much as gas on a Btu/$ basis, gas is the fuel of choice in most cases. Modern tankless gas-fired systems approach 85 to 90% efficiency and since they are closed combustion devices, they can help lower overall convective losses in buildings.

Solar hot water systems

Solar domestic hot water systems (DHW) are among the most proven and cost effective options available for homeowners. Unlike whole-house active solar heating systems, water heating systems provide useful energy all through the year and because the size and number of the panels required is significantly less than a whole-house system they may be more easily integrated into an exterior façade. Generally solar panels on the front elevation of the home or on the roof where they would significantly detract from the overall visual appearance of the home should be discouraged. In many cases, however, solar panels can be placed on the rear of the home or at another location where they would not be considered an "eyesore" by the aesthetically sensitive.

Placement of solar panels on a remote building such as a garage or even freestanding is sometimes a viable option, particularly because modern pipe insulation keeps thermal losses low. Certainly care should be made in mounting and plumbing any such system such that there is not the danger of destroying any structural members or damage though water leaks, etc. Since most solar systems are mounted on brackets rather than being directly built into the structure of the home itself, they could usually be removed at a later date should a future homeowner wish to restore the original aesthetic - or upgrade the solar system.

Furnaces

Modern condensing appliance not only combust fuels at higher efficiencies, but also extract more heat from the combustion process by cooling gases to the point that the relative humidity in the final heat exchanger reaches 100%. This causes condensation, thereby releasing additional heat and further cooling exhaust fumes. This makes the exhaust gases sufficiently cool that they may be safely power vented through a plastic pipe at the side of the house. This eliminates what would otherwise be standby losses up a chimney, so the AFUE is the same as the combustion efficiency, typically 90% or greater.

It is generally possible to save from 15% to 30% by replacing and older style furnace or boiler with atmospheric burners with a condensing one, especially if the retrofit allows for blocking off an existing chimney. If air sealing, insulation, and other efficiency measures are undertaken that result in a more efficiency conditioned envelope, a smaller, more efficient furnace may be installed, saving more energy, space, and money.

Steady-state efficiency

The US Environmental Protection Agency sets minimum efficiency standards for appliances, furnaces, air conditioners and similar equipment. These standards affect only equipment that is to be sold, not that which is already installed. Many older furnaces still in operation ad functioning well have efficiencies between 65% and 70%. More recently, as of 1992, furnace efficiency must be greater than 78%. Modern, state-of-the-art equipment has efficiencies in the mid-90% range. However, these very high furnace efficiency numbers only tell part of the story. A 1992 ASHRAE study found that systems with a 92.5% efficient condensing furnace can have system efficiencies as low as 62% largely due to duct leakage, uninsulated ducts, and frequent unit cycling. The point being, prior to replacing an existing furnace with a higher efficiency unit, verify that the existing *system* is functioning properly, then purchase the most efficient furnace appropriate for the application. In a climate such as ours here in Colorado, this will likely be a condensing furnace.

When evaluating the benefits of replacing an existing furnace with a new, more efficient model, a quick estimate of the energy savings can be calculated by: Percent energy savings = 1 - (η_{old} / η_{new}) where eta (η) is the Greek letter used to represent efficiency.

If the existing furnace is 65% efficient and the new units being considered are a standard 80% efficient model ($\eta_{standard}$) and a high 93% efficient model (η_{high}), the estimated savings are:

Percent energy savings η_{high} = 1 - (65% / 93%) = 30%
Percent energy savings $\eta_{standard}$ = 1 - (65% / 80%) = 19%

So if the cost to heat a dwelling is currently $400 per year, the η_{high} furnace would save about $120 per year ($400 x 30%) while the $\eta_{standard}$ furnace would save about $76 per year ($400 x 19%). The economic benefit of the high efficiency furnace would be a savings of $44 per year.

When the annual savings are divided by the first cost, the project return on investment is calculated. Assuming the furnace is to be replaced the installation costs are part of the deal and will occur whether the new furnace is a standard efficiency model or high efficiency condensing unit so this cost will be left out of the current analysis.

The average price for sixteen models of 92% to 93% efficient condensing furnaces and sixteen models of 80% efficient furnaces were obtained from various web sites. The average price for the high efficiency units is $1,305 while that of the standard efficiency units is $921. Therefore the incremental cost is $384. With the estimated annual savings of $44 per year between the new options the simple payback on the higher cost, higher efficiency furnace is on the order of 8-9 years with an annual return on investment (ROI) of about 11.5%--at current fuel prices, a very conservative estimate for a product expected to last 25 years. Assuming 3% fuel escalation over the 25 year life of the furnace, the price of natural gas will double. The average price will be approximately 1.45 times the current rate. Using this number the ROI increases to over 16%.

Furnace controls
Modern furnace controls offer important energy savings compared to older units, which were generally either off or on, zero heat or 100% of the unit's capacity. Today's state-of-the-art controls communicate more with the thermostat to provide just enough heat energy to satisfy the load. In doing so, the controls neither allow the furnace to overheat the dwelling, nor let it cool unduly before providing another shot of heat. Instead the furnace controls modulate the heat output either in multiple steps or continuously over its operating range.

Several benefits are achieved. First, the output more nearly matches the load and therefore the dwelling stays at a more steady temperature. Second, since less heat is being delivered to the space the blower can operate at a lower speed. The benefit of this is less power consumption and much quieter operation due to reduced air noise. Last, when warm air is delivered to a space at lower velocities there is typically less stratification, the warm air stays lower rather than shooting straight to the ceiling. While there is still some stratification it is reduced and comfort is higher with less energy use.

The benefits of operating at a lower level are achieved only if the duct system is tight and well insulated, and the entire system is balanced so no area is pressurized and none depressurized. If these conditions do not hold, then the instantaneous air exchange rate of the dwelling increases whenever the air handler comes on, sometimes quite dramatically (a factor of two or even three). In all events, it is important to seal the ducts and verify that all areas of the buildings are balanced, but when installing a system that has longer air handler run times, it is crucial.

Supply air temperature
Furnaces typically provide a “fixed” temperature increase to the air being heated, rather than heating it to a specific temperature. The design temperature increase depends on a number of factors including the total capacity, current specific heating output, and steady-state efficiency. In addition to the temperature rise designed by the manufacturer, the installation and system can also have a significant effect on the temperature rise. Ducts that are too small, closed registers, blocked return air grills, and any other restriction in air flow - *including dirty filters* - tend to increase the temperature rise. These blockages reduce the air velocity allowing it to spend more time in contact with the heat exchanger. The results are increased flue gas temperatures and a loss in furnace efficiency since the hot combustion gasses can not “give up” their heat energy as effectively.

Checking the temperature rise across a furnace is a straight forward process. The auditor allows the unit to come to steady-state operation, inserts a thermometer or thermocouple into the air stream in the supply and return ducts and reads the two temperatures. The temperature rise is the difference in these two temperatures. However, the real questions are: what is the meaning of these temperatures and how this information is used. Many furnaces have an average temperature rise of between 52°F and 55ºF, with the lower end of this range corresponding with lower efficiency furnaces (80%) and the upper end with higher efficiency units (92-94%). This average came from furnaces with temperature rises ranging from 25ºF to 80ºF depending on the operating conditions, firing rate, blower speed, etc. Ideally, the manufacturers’ specifications are available to fully commission new furnace installations.

At high-fire the temperature rise is much tighter, ranging from 55ºF to 80ºF, still a large spread. If the temperature rise is outside this range during full load operation something is likely amiss and should be looked into, the problem(s) identified, and corrective action taken.

Combustion air and exhaust venting
Many new furnaces allow for two-pipe sealed combustion and venting or a single pipe for venting and using indoor air for combustion. Condensing furnaces can, and often do require PVC piping or an equivalent, non-corroding pipe since the condensate can be slightly acidic. *Always follow the manufacturer’s recommendations for the exhaust venting.* This includes appropriate materials, vent total length, number of elbows and fittings, pipe diameter, grade in horizontal sections, and other specifics set forth in the installation instructions.

When possible, sealed combustion systems are desirable for the efficiency increase in the system as a whole. Many code jurisdictions (including Boulder's) require very large combustion air supply pipes, often 2 – 8" diameter ducts delivering ambient temperature air to the furnace. Sealed combustion furnaces of 40,000 Btu/hr to 120,000 Btu/hr range typically require piping of only 1½" to 3" diameter. The open combustion systems spill cold air into the dwelling requiring additional heat to warm it. System efficiencies may be reduced several percentage points by the strict requirement for combustion air supply pipes in open combustion systems.

Frequently the home's water heater is co-located with the furnace. If a sealed combustion furnace is used there may still be a code requirement for outside combustion air for the water heater unless it too is a sealed combustion unit. If open combustion air is used in the furnace and DHW heater, the colder air temperature in this space will also increase heat loss from the water heater tank and pipes. Under certain circumstances, freezing can occur.

Cooling with a Furnace
For homes in which duct work from the furnace is mostly in the basement, an inexpensive cooling technique is to use the circulating system of the furnace for summer cooling/air circulation. By turning off the ignition switch to the furnace burner and activating the circulation fan (on low speed is usually adequate), it is possible to create low energy-use air circulation. This uses uninsulated ductwork in the basement (or crawl space) as an air-to-air heat exchanger to dump the heat from the house into the basement without actually circulating basement air into the living space. Thus the mustiness of the basement stays put, but the coolness is transferred to the occupied spaces upstairs. If the ducts are insulated in the basement/crawl space or if uninsulated duct ducts run through a hot attic, this system will not work.

Ventilation fans
In shopping for ventilation fans, it is important to ensure the fan meets mechanical needs, but is also ENERGY STAR rated (www.energystar.gov/index.cfm?c=vent_fans.pr_vent_fans). Kitchen, bathroom, and utility fans rated by ENERGY STAR are quieter and more efficient (both the fan and motor that runs it) than average fans. In the case of those which include lighting, typically no units using inefficient incandescent bulbs carry the ENERGY STAR label. Modern electronic controls allow for greater efficiency at lower fan speeds (Figure B-8).

Overhead fans
If it is deemed important to replace an existing fan, remembering that such fans do not increase comfort or heat distribution in most circumstances, several very energy efficient overhead fans are now available in the market place. Invented at the Florida Solar Energy Center by building scientist Danny Parker, these are marketed under the brand name of Gossamer Wind and are available at such outlets as Home Depot. (See www.ceiling-fans-ceiling-fans.com/resources/Types_Gossamer-Wind.htm). In addition, ENERGY STAR rates ceiling fans according the above-mentioned figure of merit. The Casablanca Fan company has a model called "Concentra" which produces almost 300 cfm per watt at low speed, far and away the best performance of the fans listed on the ENERGY STAR website (www.energystar.gov/ia/products/prod_lists/ceiling_fans_only_prod_list.xls).

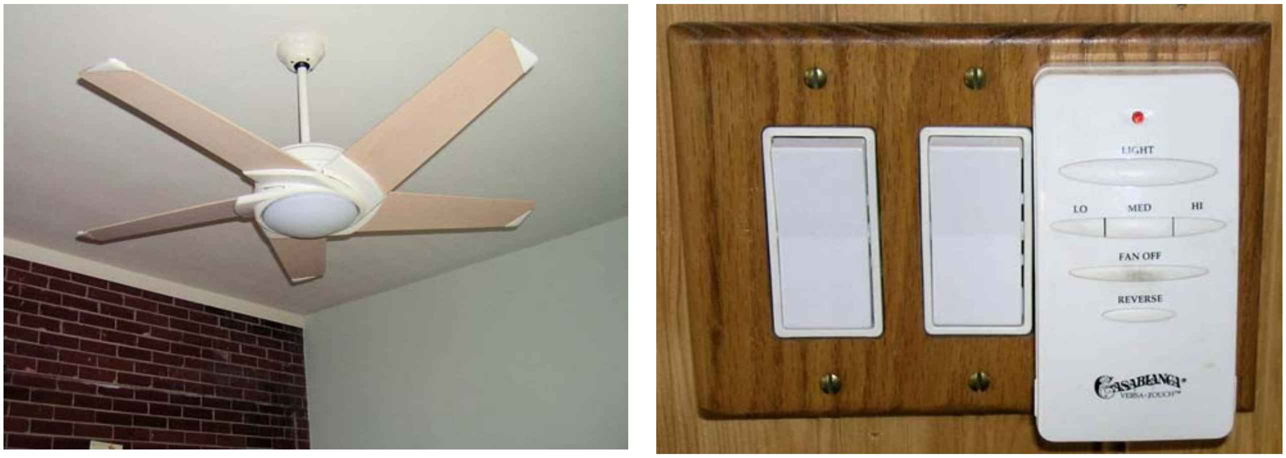

Figure B-8. The controls for this fan allow for reversing flow and setting at three speeds.

Summer venting

Cooling in Boulder's climate should begin with keeping direct beam sunlight from coming in the insulated envelope. This can be accomplished with simple overhangs or awnings on the south, and some combination of foliage, vertical blinds, outsider shutters, and the like on the east and west. The flatirons plan a key role in keeping direct beam sun from causing overheating toward the end of summer days.

Ventilation can be a very effective means of cooling in the summer if it is done properly. Ventilation does not mean opening up the entire house. The primary aim is to bring relatively cool dry air into the house and exhaust warmer air. Further, ventilation creates air movement, which cools the skin by means of evaporation.

Boulder has clear skies for much of the year, which means that it has high diurnal temperature swings. Since the sky is rarely insulated by cloud cover, as soon as the sun goes down, the earth radiates to the clear sky above and temperatures drop rapidly. As soon as the outdoor air temperature drops below indoor air temperature, opening windows at the bottom and top of the home will allow it to thermo-siphon, bringing cool air in at the bottom and exhausting warm air at the top. Selecting which windows to open should depend on areas that particularly need cooling and the wind (open at the bottom in the direction of incoming wind (windward side) and out at the top on the other (leeward) side.

Power venting

Using a window fan or (preferable) whole house fan aids the natural ventilation process with an expenditure of electric energy that is far less than that of conventional air conditioning. Selecting a fan with large diameter blades and running it slowly is most efficient and makes less noise. A wind-up timer that costs $15 can be used to automatically turn off a fan in the wee hours. Finally, it is critically important to install an insulating shutter or similar device to cover the hole in the insulated and conditioned envelope during cold periods.

Evaporative coolers

Modern evaporative coolers can take care of all of the rest of the cooling needs of most homes in Boulder once attention is given to blocking direct beam sunshine and judicious ventilation. There are a range of options for installing evaporative coolers that do not require rooftop mounding. These include mounting in attics, on the ground, and through windows or in walls. Evaporative coolers can function as simple ventilators which blow air into the home in the direction of either open windows or special back-drafters called "up ducts" in the ceilings of upper stories, into vented attics. They provide more coolth in the cooling mode when media is moistened with water. This lowers the temperature of the air substantially while raising its relative humidity. The result is comfortable, fresh air at a fraction of the energy use of conventional compressor-based air conditioning systems, typically less by a factor of 4 to 5 (Figure B-9).

Figure B-9. Two varieties of modern, efficient evaporative coolers.

Appliances

Refrigerators and freezers

Section 2 included a discussion of measuring the energy efficiency of refrigerators and freezers. Setting thermostats to keep frozen food at 5 ºF and the fresh food compartments at 38 ºF will ensure food safety. If deemed cost effective, buying new units which are ENERGY STAR-qualified is strongly recommended - as is disposing of the old inefficient units in environmentally-appropriate ways.

Washing machines

Very substantial advances in energy efficiency and water use have been made in the world of washing machines available to Americans in recent years and the cost is coming down. If people presently wash with cold water and hang laundry out, the payback is elusive. If they wash in warm or hot water and utilize a clothes dryer, the combined energy savings may be as great as 50%. This energy use is defined by a Modified Energy Factor (MEF) which includes the energy needed to run the machine, heat the water, and fuel the clothes dryer. The higher the MEF, the more efficient is the machine.

The primary consideration in either front or top-loading ENERGY STAR-qualified machines is the reduced use of water - 18 to 25 gallons per load compared to the 40 (or more) used by a standard machine. While savings depend on sufficiency and cost of supply and waste treatment, EPA has developed a Water Factor to help shoppers make informed decisions. It expresses the gallons of water used per cycle based on the washer size in cubic feet. For example, a 3.0 cubic foot washer using 27 gallons per cycle has a water factor or 9. The lower the Water Factor, the better. See www.energystar.gov/index.cfm?c=clotheswash.pr_clothes_washers.

Front loading machines are by nature more energy and water efficient, and modern units may be purchased which cost very little more than wasteful units and that save substantial water and electricity while producing clean clothes (Figure B-10).

Figure B-10. This new front loading washing machine costs little more than machines that do not carry the ENERGY STAR label.

Renewable energy

Except for passive solar systems, most renewable energy systems require an add-on to the exterior of the building which may or may not be compatible with the aesthetic concerns of a home within a historic district

Photovoltaic systems
Photovoltaic (PV) or electric-solar systems, like solar hot water systems, usually consist of moderately sized separate panels attached to the roof or mounted on a free-standing structure. Hence, many of the same aesthetic concerns apply. However, piping electricity a hundred feet from a garage to the home is neither a substantial source of inefficiency nor expense, so most homes can avoid aesthetic problems while ensuring solar arrays can have adequate south-facing solar access. The most important energy consideration is to ensure that demand for electricity is as low as practical via the myriad energy efficiency tactics discussed above. Investing in an ENERGY STAR refrigerator before sizing a PV array rather than sizing the PV array to meet the energy “needs” of an inefficient refrigerator is more cost effective by a factor of five to ten fold.

Passive Solar
Unlike solar DHW or PV systems, most passive solar systems do not rely on add-on collector panels but, rather, make use of the house itself to both collect solar heating energy during the winter and effectively shade the home from unwanted solar gain during the summer months. Being an architectural system, many well-designed historic homes are already more-or-less passive solar homes. If a home has significant south-facing windows, a sun-room, a south-facing patio door or an enclosed porch oriented roughly to the south, the home is already a passive solar structure. Wide overhanging eaves that provide substantial shade on exterior walls and windows in summer are also characteristics of passive solar homes.

Even if a home did not originally come with these amenities, an addition or modification could include them. This could add valuable living space while reducing energy bills by making enhanced use of the abundant solar energy available in Boulder. Of course, any additions or modifications should be compatible with the style and era of the historic home. A fancy Italianate sunroom stuck onto a 1930’s art deco home is no more appropriate than a '50s picture window and aluminum awning stuck onto the side of a Craftsman-style home.

Appendix C
High Density Cellulose Insulation Installation Guidelines

- Understand what the client needs and knows about their house.
- Evaluate initial air leakage, R-values, and structural characteristics. What is the dominant framing style?
- Be sure the building shell is weather tight.
- Document any conditions in need of repair before work is begun. Examine and repair like roof and plumbing leaks; check CO on all combustion appliances and perform worst case spill test. Is an upgrade to sealed combustion furnaces, boilers, or hot water heaters needed?
- Define the thermal envelope. Work to make sure framing connections are airtight between building sections. Consider the issues of temperature and space conditioning. Understand how porches and building additions connect.
- Note the location of major wall air leakage sites, i.e. the ceiling-joist connection at the porch roof, flat roof connections, plumbing chaseways on an outside wall, slanted roof cavities crossing joist volumes, and any place the air barrier can't be inspected and may be discontinuous.
- Inspect the interior for places where insulation might blow into the house. This includes large holes in the plaster, loose paneling, back plastered walls, pocket doors, missing wall sections under sinks, stairwells, and the like.
- Plan access, timing, production, and job-site strategies. Think of options if the weather gets bad, or obstacles arise. Discuss the possibility of drilling from inside with the clients.
- Prioritize the energy conservation work to be done. Think about savings estimates compared to actual energy usage. Estimate blower-door-measured airflow (CFM50) reduction and worst-case depressurization after work. Forecast the need for mechanical ventilation. Is the house a good candidate?
- Insulate sidewalls from attic when practical.
- Using the tube in the wall method, get the job done, ensuring that insulation is installed at a consistently high density to limit hidden air leaks and bypasses. This often uses about 30% more material than just filling the cavity.
- Probe 100% of the cavities as a part of blowing.
- Do not leave any wall or attic voids or bypasses.
- Expect the unexpected. When insulating walls, one never knows what the framing details will be. Open cavities, firestops, bracing, blockers, interconnected chases and air leak paths are common.
- Always seal major bypasses before insulating the attic.
- Recheck air leakage; continue air sealing to reach desired closure.
- If below tightness limit for size or occupancy, order mechanical ventilation to bring up to ASHRAE recommendations.
- Check natural and induced draft appliances for backdrafting. Order repairs necessary to eliminate backdrafting.
- Perform worst-case spillage test and repairs needed after all tightening and fan changes.
- Leave the site clean and the client happy.

Appendix D
Windows and Doors

Energy analysis

Introduction
A number of people are interested in exploring the virtues and depravities of replacing older windows or retrofitting existing windows with better-quality glazing. This issue is of particular importance to those in interested in historic preservation. Aesthetics, comfort, structural consideration, and a sense of tradition play important roles in such explorations. In addition, energy consumption and costs merit consideration. Thanks to modern modeling techniques and information required from suppliers of glazing products by the National Fenestration Research Council, it is possible to explore energy use and energy cost issues on their own.

Method
To illustrate something of a practical range of options, it is useful to define five glazing types, all of which are assumed to be installed in wooden frames. The information shown below was produced by using RESFEN (for “Residential Fenestration”) software using historical weather data from Denver. RESFEN runs a detailed hour-by-hour analysis of the energy flow through windows and sums up heating and cooling energy and costs by façade (since solar exposure plays a key role). For purposes of this analysis, the assumption is that electricity costs $0.10 per kWh and gas costs $1.10 per therm. These are approximately the current costs to residential consumers in Xcel’s service territory. To express them both in a common unit, a million British thermal units (MMBtu), electricity costs $29.30 per MMBtu and gas $11.00 per MMBtu, where a MMBtu is approximately the energy equivalent of a person year of labor.

To compute net costs of energy associated with the windows, the analysis assumes a gas furnace whose system efficiency is 70% and whose air conditioning system has a seasonal energy efficiency rating of 8.0, numbers that are likely to be good approximations for older homes and associated distribution systems in the area.

The analysis assumes that windows with wooden frames that are quite tight but have no shading. There are 75 square feet of windows on each of four facades of a home, which would amount to about 15% glazing area on the walls of a 2,000 square foot home. The cases examined are shown in Table D-1.

Table D-1. Five cases examined defined

Case	Description	U factor	Solar Heat Gain Coefficient
1	Single-glazed clear	0.93	0.78
2	Double-glazed clear	0.55	0.59
3	Double-glazed Low E	0.36	0.53
4	Double-glazed Low EE	0.34	0.34
5	Triple glazed Super Alpin	0.12	0.29

Results

Annual costs are illustrated in Figure D-1.

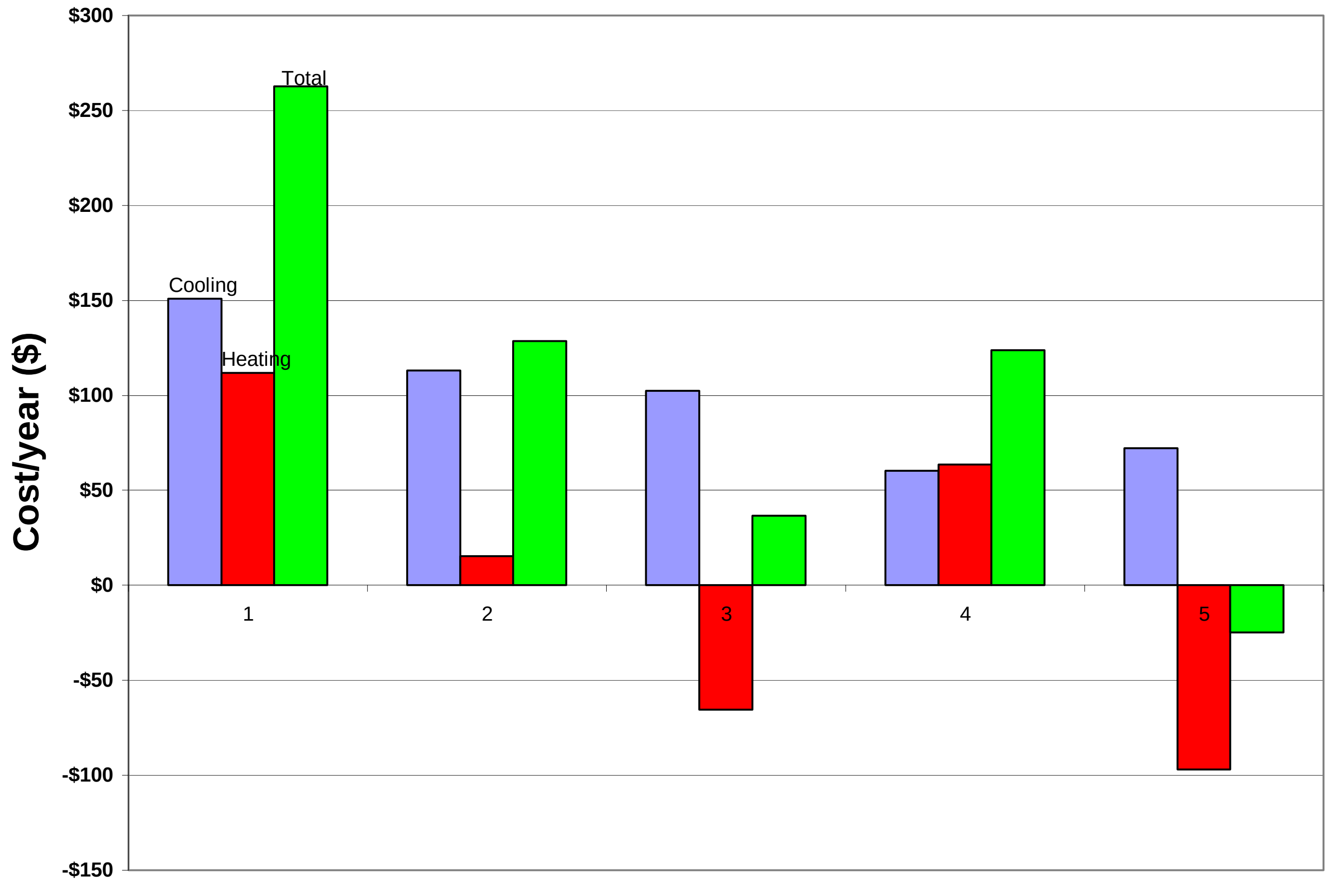

Figure D-1. Annual costs for the five glazing types consisting of 300 square feet of windows evenly distributed on four facades of a residential structure. Case 1 is single glazing; Case 2 is clear double glazing, Case 3 is low E double glazing, Case 4 is low EE double glazing, and Case 5 is triple glazing very low U. Blue denotes cooling costs, red heating costs, and green total annual space conditioning costs due to windows alone.

Note that solar gain raises cooling costs and lowers heating costs. Since single glazing has the highest solar gain, it has the highest cooling costs. However, since it also has the highest U factor (lowest R value), its wintertime losses are also highest, so heating costs are higher than the other cases.

To reiterate, these numbers reflect energy use associated with 75 square feet of glazing on each façade. Accordingly, one can derive good estimates for a residence whose window areas (including frames) are different from 75 square feet by simply multiplying the numbers in the boxes corresponding to the appropriate façade by the actual square feet divided by 75.
In general, comfort on cold winter nights is an inverse function of U factors and comfort on hot summer days is an inverse function of SHGCs. Accordingly, single glazing is decidedly worse case in considering comfort, as well as energy use and associated cost.

Double-hung window rehab

The standard recommendation for sealing windows is to install "weather-stripping." Unfortunately, in most cases weather-stripping is ineffective at stopping air leaks, interferes with window operation, induces greater conductive heat loss and condensation problems, is unsightly or will not last more than a season or two, or any combination of the above. Fortunately, we do not have to "add-on" anything to make most double-hung windows seal tightly.

One clean, flat wood surface pressed tightly against another clean, flat wood surface will create a seam which, for all intensive purposes, is airtight, yet can slide against one another when the tension is released. This is the principle of a double-hung window. The purpose of the sash lock is to provide that tension - not keep out burglars. If sash locks are not kept fully closed, the two sashes will not be drawn together in the middle at the meeting rails, nor will they be forced either up or down to fit tightly in the window jamb. If the top sash is paint-sealed to the frame while not in its full-closed position, the meeting rails will not be flush in the middle and the tight seal will be impossible. If the window stop is not adjusted firmly against the sash, there will not be a tight seal along the sides. If the edge surfaces which are supposed to slide smoothly against one another are blotched with globs of paint, again, the window will not seal.

A lot of things can go wrong with double-hung windows - and they usually do. Fortunately, a not-too-difficult rehab procedure can bring one of these tired soldiers back into full service.

The first stop in the rehabilitation process is to dismantle the window. The lower sash is held in place with the window stops—the vertical pieces of wood trim nailed or screwed to the sides of the window jamb. To facilitate this removal, use a razor knife to cut the bead of paint along the seam between the stop and the jamb. Then take a small pry-bar or a chisel and pry off this trim. Stubborn finishing nails can be driven through the stop with a hammer and a nail set. With the stop removed from one side, the lower sash can be removed.

If the upper sash is painted shut (and is <u>really</u> shut - all the way up) it may be left in place. If it is not all the way closed or does not seal tightly along the sides, it too should be removed. To do this, it is necessary to remove the parting head, the rectangular strip of wood that runs up the side of the jamb between the two window sashes. This strip of wood is not supposed to be nailed in place, but sometimes they are. If it is sealed in with paint, a razor knife is needed. Since the lip on the meeting rail of the upper sash protrudes over the parting bead, it is best to lower the upper sash all the way down and begin removing the parting bead from the top. Bending the parting bead out beyond the window jamb and pulling upward will enable it to clear the meeting rail. Once one of the parting bead is removed, the upper sash can be pulled out.

In removing a sash, it will have to be detached from the sash cords (assuming they have not long-since broken.) The rope may be attached with a small nail or simply with a knot or spring-like device wedged into a hole in the side of the sash. It should be pried out, being careful the rope does not get away and be pulled down through the pulley by the sash weight. Spearing a nail through the end of the rope will keep this from happening.

A little trap door held in place with a screw is down towards the bottom of the jamb on either side. It is the sash-weight pocket door which can be opened to get at the sash weights to attach new ropes or chains if needed.

Retrofitting the now-removed sashes consists in large measure of cleaning all parts and getting it back to original condition. The edges of all elements should be clean, smooth and free of paint in order to make a tight, free-sliding surface. Don't forget the meeting rails. Attack these surfaces with a rasp, a Surefoam, sandpaper, paintscraper or even a plane, as appropriate. The object is to get off the globs of paint that keep the window from operating properly. If the parting bead or the window stop are in such bad a condition that they are unusable, you can buy a new stock at any lumberyard or recouperate parts from windows in recycling yards. Once down to raw wood, paint these sliding surfaces with boiled linseed oil or, better yet, seal them with a high quality paste wax.

The best time to re-glaze sashes or do any other repair work (like strengthening the frames, etc.). is when the sashes are out and on the workbench. Once everything is ship-shape, simply reassemble as it came apart. Do not nail in the parting bead. When remounting the window stop, drive the finishing nails in new holes and set the stop so it is snug against the sash, but not so tight that the sash won't move. It sounds like a lot of work, but it really is not that hard. It should take less than an hour per window, and there is satisfaction having rehabilitated windows back to their original condition. The windows are tight, and the repair is permanent. And it cost but little.

Sash locks

Sash locks are poorly named. They are not really locks but latches. If these latches are not fully closed, neither are the windows. If they are missing, buy new ones; they are quite inexpensive. Sash locks should be installed so that they are hard to close; that is, they should close only under tension. The complex spiral of the latch pushes up and down at the same time it pulls the two sashes together. It is an elegantly simple design that saves energy quite cost effectively.

Counter-weight boxes

In blower door testing of older homes with conventional double-hung windows, it is frequently found that there is very substantial air leakage around the pulleys associated with the counter weights. Such weights routinely slide up and down in otherwise empty boxes to either side of the windows. Of course, these are not insulated because that would impede the movement of the weights. Nor do they tend to be adequately air sealed, with the consequence that substantial convective losses occur.

The following paragraphs describe a technique that holds promise for solving this problem in a somewhat elegant way, although the authors of this document have yet to try it out. The procedure is as follows: Carefully remove the inside of the casement associated with the area where the counter weights move. Then replace the cords on the weights with new cording. Next, cut a PVC pipe (whose inside diameter is slightly larger than the outside diameter of the weigh) to a length that is slightly longer than the distance from the top of the pulley to the bottom of the weight when the window is fully open. Slot the top to keep it from impeding the movement of the pulley. Also, pre-drill the PVC pipe to allow a screwdriver to pass through the pipe and secure the pipe to the inside of the weight box at bottom and top using a pair of wood screws. Then use duct tape to cover the top and bottom of the pipe. When all weights in the box are similarly treated, fill the enclosure with two-part, non-expanding urethane foam, securing the cover over the box right away.

In spite of its name, the foam does expand slightly. It also acts both as an excellent insulator and as an air seal. With the configuration as described, the window should work nicely for a long time, yet the window system should have substantially lower convective and conductive losses.

Figure D-2 is a photograph of double hung windows in a historic home in Boulder that are quite leaky. Figure D-3 shows details of weight boxes with up to four weights installed.

Figures D-2 and D-3. An effective procedure for air sealing and insulating the weight box while retaining good functionality of the windows could be a useful retrofit for a wide range of windows in older homes. Assessing the practicality or the process and energy savings should be done well.

Glazing windows

There are usually a number of windows in need of reglazing in older homes. Although cracks around the edge of each pane may seem small, they can add up to be a significant source of cold air infiltration. Even more importantly, if this loose putty is allowed to go unattended, the panes will become progressively looser until soon there is more and more glass breakage. It is a classic case of “a stitch in time...” Reglazing also performs miracles in stiffening an otherwise unsound window sash. Although this process can be accomplished with the window left in place, it is often easier (particularly for second story windows) to remove the sash and do the work on a bench top.

As indicated in the analysis at the outset of this appendix, there are clear advantages of reglazing with double-glazed panes, particularly with a low-E coating. Using krypton as an inert gas allows even more insulating value to the panes, and also allows the panes to be closer together than is possible with other inert gases or air. This option makes it easier to fit the new glazing into the space formerly occupied by single glazing.

The first stop is to remove all loose putty. Prying the putty away from the wood with a putty knife is safer than trying to pry away from the glass. Liquid paint remover can sometimes soften hard putty. Use of a propane torch can cause the glass to crack and can be a fire hazard, but in some cases it’s the only practical choice. Be careful!

Although there are several options for glazing materials including latex caulks and synthetic compounds, traditional glazing or painter’s putty made with linseed oil is preferred for wood sashes. Application is easier and it lasts longer. In order to seal completely around the edge of the glass and to form a cushion for the glass to sit on, spread a thin film of putty along the rabbet. Make sure the glass is cut 1/8 inch smaller than the opening in the frame (to allow for expansion and contraction) and press it firmly into the bed of putty with even finger pressure along the edge of the glass. Hold the glass in place with glazier’s push points driven into the sides of the rabbet with a putty knife. Make sure that the push points lay flat against the surface of the glass. If they are set in crooked there is a good likelihood of glass breakage. Place glazing points about every six inches apart.

Apply glazing putty around the edge of the glass with a putty knife. Apply slightly more than is actually needed and go over the bead of putty several times, holding the putty knife at about a 45 degree angle. By keeping the knife held firmly against the glass and the edge of the rabbet, the putty will be firmly set into the space around the glass and the excess putty will squeeze out the sides. This excess need not be wasted as it can be reused elsewhere. Try to make the glazing job as neat as possible. Be careful, particularly in corners since any cracks or seams in the putty will allow water to enter which can then freeze, expand, and break out the putty.

Once satisfied with the putty job, take a soft cloth and a small amount of whiting (powdered caulk, available at your paint store) and lightly rub the putty and the glass surface. The whiting absorbs excess oils, cleans the glass, and begins to set the putty.

After a couple of days when the putty has begun to harden, it is best to seal the putty and the woodwork with a good quality trim enamel. It is easier and quicker to paint over the edge of the glass and then do back and scrape off the excess with a razor blade scraper than it is to carefully around each pane of glass "cutting in" with a small paintbrush. This method also seals the glass better. Be careful to avoid applying excess paint around the edges of the sash that run against the window stops, since this will inhibit the sash from sealing tightly.

Doors

Restoring/re-hanging

Exterior door can be a substantial source of infiltration into a home. Some government pamphlets convey the impression that installing weather stripping will solve the problem in a hurry. Unfortunately, for the most part, the problems with badly leaking doors cannot be solved with weather stripping, and more often than not weather stripping causes more problems than it solves by keeping the door from closing as it should.

If weather stripping isn't the answer, what is? Actually, there is no one answer; every door has to be evaluated and dealt with on its own merits (or demerits). It is not possible to successfully weather strip or gasket a door if it doesn't swing smoothly and latch tightly. Similarly, one cannot make a door swing smoothly if the door itself is falling apart or is warped out of shape.

At first glance a door may seem to be a very simple device. But re-hanging or otherwise repairing an older door can be complicated.

Before looking at what can be wrong with a door, it is useful to consider a door for which everything is right. The door itself should be a flat rectangular surface which is rigid, without cracks or holes and be dimensionally stable (does not shrink or swell with changes in the weather.) The door jamb, the frame in which the door is hung, should also be a firm rectangular structure defining an opening just slightly larger than the door itself (about 1/8 inch clearance on the top and both sides.) Ideally the frame should be square and plumb in two directions (that is it should not be leaning in or out, and neither should it be cocked sideways.) Most exterior doors are hung with three butt hinges recessed flush into rabbets in both the edge of the door and the jamb. The hinges ought to be directly in line above one another, with the hinge pin or pivot point set a predetermined distance from the face of the door to allow for adequate clearance for a free swing. Additionally, the other edge of the door (the latch side) is usually beveled so that the leading edge can clear the face of the jamb as it swings close.

With all of this need for clearance on the sides, one might wonder how a door is supposed to seal. In fact, the seal is not intended to be on the sides of the door at al. When the door is fully closed, the front face of the door should meet flush against the door stops on both sides and the top. It is only at the bottom where there is a seal against the door sill or saddle. Finally, in order to deep a door firmly closed against the stops, it is necessary to have a working latch or lock mechanism mounted in the door and a striker plate (or keeper) set into the door jamb in the proper position to hold the door where it should be when closed.

This sounds like a long list of door-related mechanical and energy issues - and most are inter-related. Let us take an example of a door with a very simple problem: the screws have come loose on the top hinge. This could have been caused by the exuberance of a young child playing Tarzan on a handy doorknob or simply normal wear and tear. The proper maintenance response would be to tighten the screws with a screwdriver. If the wood had stripped out (as is often the case), packing the screws holes with slivers of wood and carpenter's glue will restore its holding ability. If this basic maintenance task is long ignored, however, let's see what can happen...

First, the three hinges will now no longer be in a straight line. This means the door will bind and not swing freely. Since the door is not firmly attached at the top, it will be loose against the stops when closed. The door will rattle and cold winds will easily slide by. Since the top of the door is now sagging, there may well be a visible gap where the top edge missed the top door stop. The sagging door also fouls up the 1/8 clearance on the sides so that the top of the latch side of the door may be rubbing against the door jamb. The bottom of the door may also be rubbing against the sill on the side furthest from the hinges. If this rubbing is too great, it is keeping these corners from closing all the way to the door stop - thereby opening a gap for infiltration. The tension on the door from all this rubbing may be forcing the door to warp out of shape, or even worse, cause the door to start coming apart at the joints, which in turn makes the binding even worse. This added warping and straining at the joints will cause any glass in the door to loosen up and perhaps eventually crack. This allows water to penetrate the gaps in the exterior painted surface, collect inside the joints of the door, and begin rotting the wood. The rubbing of the door bottom will soon wear on the sill below, causing it to deform. And since the door is now cocked out of alignment, the door latch no longer engages with the striker plate on the jamb, preventing the door from being latched. All for want of the simple maintenance of tightening a couple of screws.

What is worse is that the most common recommendations for solving this problem usually only make things worse. Weather stripping this door will only make it harder to close, aggravating all the rest of the problems. The "Mr. Fix-it" approach is to take the door off its hinges and plane or cut off the corners that are binding. Any time wood is removed from a door, however, a permanent change is made. Further, if the hinge is still loose, the door will just sag even more. And when the original offending hinge is repaired, the modified no longer makes a tight fit against the stops.

In short, when dealing with problems with a door, first look for and solve the source of the problems; do not merely treat the symptoms.

Replacing storm doors

Aluminum storm doors have little justification in terms of energy savings and most detract from the esthetics of historic buildings. The average payback for these units over a decent, wood primary door is something like 50 years. If a doorway is used for ventilation in the summer, the best choice is to install a lightweight wooden screen door.

If a home already has a decent wood-framed storm door, it is worth the effort to keep it maintained. Storm doors often show simple pay-back periods of twenty to fifty years, because of the relatively small area being insulated (an average of 21 sq.ft.) and high cost of materials (ranging from $100-$500)! As an air tightening measure, a much more effective operation is to upgrade and seal the primary door, leaving the storm door as simply a secondary barrier to create a dead air space. However, if a purchase or repair of a storm door is in order, attention must be given to the requirements for safety glazing. If an acrylic plastic is used, fastening systems must allow for the extreme movement of the plastic with changes in temperature, while still maintaining an airtight seal.

Vestibules are included in this category. Since upgrading or adding a vestibule can create a buffer zone that both slows the conductive losses through the entire enclosed wall section and creates an effective air-lock entry, this is a measure that has interesting potential. Since the material requirements rely on commercial availability, the opportunity exists to make use of commonly-available, translucent, rigid fiberglass materials and site-orientation that take advantage of radiant (solar) heat gains as part of a strategy to further offset the structure's conductive losses. Size and placement should allow for emergency egress, and since vestibules are usually not part of the thermal envelope (or they would be called “additions”), it is generally inappropriate to insulate them.

Appendix E
Materials Considerations

Introduction

Which materials are best for achieving long-lasting retrofit for a historic home? The kinds of considerations that are of concern to the rehabilitation contractor include thermal performance, durability, fire safety, how well the material stands up to moisture stresses, its structural performance, impact on health, visual and aesthetic concerns, and installation tactics. A summary table of these issues follows:

Thermal performance
- Thermal Conductivity/Resistance
- Density
- Effects of Aging
- Specific Heat
- Emittance/ Absorptivity
- Temperature Limits
- Convective Bypasses
- Air Permeability
- Reflectivity
- Light and Solar Transmission

Fire properties
- Flame Spread
- Smoldering
- Smoke Developed
- Fuel Contributed
- Rate of Burning
- Toxicity of Fumes
- Retardation
- Leaching of Fire Retardants

Durability/aging
- Outgassing
- Chemical Stability
- Ultra-violet Degradation
- Moisture Absorption
- Biological Decay
- Hot/Cold Cycles
- Flexibility
- Resistance to Shrinkage
- Flammability
- Surface Characteristics
- Resistance to Corrosion

Moistureimpact

- Water Absorption
- Water Adsorption
- Permeance to Water Vapor
- Capillary Action
- Solubility

  Leaching Action
- Hydrolysis
- Impact of corrosion

Structural issues

- Compressive Strength
- Tensile Strength
- Shear Resistance
- Rigidity
- Elasticity
- Flexure
- Open Cell/Closed Cell
- Friability (crumbles)
- Impact Resistance
- Fiber Structure/Direction
- Joinery/Fastening System
- Adhesive Characteristics

Health effects

- Animal/Bird Habitat
- Fungus/Molds/Bacterial Growth
- Odor
- Toxicity
- Carcinogens
- Particulates/Fibers
- Itching/Allergies
- Outgassing
- Sharp or Dangerous

Management considerations

- Performance
- Versatility
- Visual/aesthetic
- Ease of Installation
- Installation time
- Special Tools & Equipment
- Adjustability
- Availability
- Quantity, Turn-around Time,
- Spare Parts/Repair, Locale

- Shelf Life and Storage Limitations
- Vendor Service- Guarantees, Testing,
- Specifications, Standards - Cost
- Client Use, Complexity, Ease of Operation

Visual/aesthetic concerns
- Colorfast
- Paintability
- Coherence with Existing Structure
- Consumer Acceptance
- Physical Design Limitations

Key considerations

When retrofitting any building, the aesthetics and compatibility of materials is a key consideration. While a great deal of the interior sealing work is hidden behind baseboards, mopboards, trim and ceiling molding, or is in attics and basements, a certain portion of the work will be visible, and needs to be as unobtrusive as possible. This is particularly true of historic sites. New mortar and cement must be compatible with the existing type - often a soft Portland cement - to avoid future deterioration. Modern aluminum and vinyl weatherstrip may be quite out of place on elegant, turn-of-the-century woodwork. In some cases, not disturbing, or reusing existing materials is the only way to maintain the overall appearance of the structure.

A good rule-of-thumb when choosing air sealing materials is to go with the best quality available, particularly for materials that undergo regular operating stresses such as window and door weather strip and hardware. The perceived savings from using inexpensive or substandard materials is likely to be more than offset by failure due to environmental exposures, inadequate fastening systems, poor flexibility, short elastic "memories", etc.

All materials should be evaluated to assure that they pose no air quality, safety, or fire hazard in a particular application.

Surface preparation is important to the success of all air sealing efforts. Dirty, lumpy, or deteriorated surfaces should be cleaned and smoothed to promote adhesion, and prevent air from sneaking between surface irregularities.

Caulks and sealants
The range of caulks and sealants used in air sealing has increased in recent years, making it ever more important that the proper material is specified for a given job. Caulking should be applied to minimize its visibility so that the bead is continuous and uniform in size, free of bumps and gaps and clean in appearance.

Most caulks are marketed (and hence evaluated) simply on the basis of its "lifetime" or how long the products are supposed to stay in place (under ideal conditions). A more comprehensive list of product concerns might look something like this:

- Elasticity
- Non-hardening
- Adhesion
- Cohesion
- Compatibility
- Mildew/Mold Resistance
- Shrinkage
- Expansion
- Paintability
- Painting Requirements-
- Color
- Transparency
- Curing Temperature
- Curing Moisture Requirements
- Surface Preparation
  Substrate Priming
- U.V. Resistance
- Thermal Stress Resistance
- Abrasion Resistance
- Structural Adhesion (Gluing)
- Clean-Up Requirements (Solvents)
- Outgassing
- Toxicity to Installers and Clients
- Packaging: Cartridge Size,
  Bulk, Aerosol
- Maintenance Replacement
- Capability - Slump-Self-Leveling-Flow
- Shelf Life
- Pot Life
- Curing Time
- Surface Skinning
- Application Temperature
- Application Moisture Limits
- Application Techniques
- Joint Width
- Joint Depth
- Tooling Depth
- Toolability
- Multi-use Adaptability
- Cost and Availability

Although we don't often see a list of concerns this long, many of these issues are at least subconsciously considered by most contractors when they select materials. Shelf life is not usually a written specification, but if caulking material purchased three months ago is no longer functional, switching brands may be appropriate. Similarly, if complaints that a solvent-release caulk is giving both contractors and clients headaches, toxicity due to out gassing should be an over-riding criterion for its non-use—at least as an interior caulk.

Regardless of the sealant that is chosen, the need for surface preparation cannot be overemphasized. Surface preparation may be modest or extensive, but at the very least, both surfaces must be cleaned prior to application of any caulk or sealant or the joint is likely to fail.

The characteristics of the joint will affect the choice of sealant. The adhesive qualities, elasticity, curing time, temperature limitations, priming requirements, gap size, resistance to moisture, color matching and paintability, emissions during curing and ability to withstand joint movement are all factors to be considered in choosing the proper sealant.

The range of performance is wide, and a material can fall within the rather general category of "elastomerics" based largely on flexibility, though there are many other characteristics to be considered in product selection. It is also a challenge to determine what category many of the new chemical compounds fall into since labeling may be purposefully vague for proprietary reasons.

Some sealants are appropriate for the stresses and conditions encountered in interior applications and others that can be used only in exterior environments. With the redirection of sealing efforts to the inside of the heating or cooling envelope, a wide range of siliconized acrylic products are being used successfully. For exterior work, or places where two rough or different substrates are to be joined, a higher performance polyurethane or specialty formulation is most often used. Many of the high performance caulks are primarily for commercial or industrial use and carry safety or hazard warnings in their standards. This is often related to the release of solvents during curing. The recommendations focus on maintaining "adequate ventilation" during installation, with the implicit limitations for some residential applications. The clean-up requirements may also be limiting due to the toxic nature of the chemicals needed. Manufacturers or vendors should be queried regarding toxicity or use if there is any question. All caulking materials should be installed in accordance with the manufacturer's guidelines regarding temperature and ventilation of the work space. It is also important to inform the client that there may be associated odors, and discover if they have any particular allergies or sensitivities that might further dictate choice of materials.

Backer materials are a necessary adjunct to caulk when sealing large gaps (usually greater than 1/4"). Backer material is forced into a crack or gap and provides a support surface which makes it easier to get good contact with both sides of the crack. It also reduces the amount of sealant that might otherwise be used, enables proper shaping of the bead of the sealant, and helps the sealant to tolerate greater joint movement.

There are many forms and types of backer material - flexible rods, hollow tubes, and tear-off sheets to name a few. The various products may be made of polyethylene bubble-pack, closed cell polyurethane sheets, neoprene, or EPDM rubber. An important design feature of backer materials is that they provide a surface to which the sealant will not adhere. This allows the sealant to pull away from the backer rod, while still adhering to the sides of the crack when stressed.

"Stuffage" or cavity fillers are blocking materials used to fill large gaps or cavities which may be subsequently faced with another material. Tightly-compressed fiberglass, flexible cushion foam, sheet polyethylene bubble material, wood, poly sheeting, extruded or expanded polystyrene board (blueboard or beadboard), rigid foil-faced fiberglass duct board, flexible foil or vinyl-faced duct wrap, sheet metal, and canned polyurethane foam can all be used to good advantage. Some, such as polyurethane foam, are used to fill irregular holes with great success, while others, such as sheet metal, provide protection around chimneys and in high temperature applications. Exposure to sunlight, solvents, and combustibility are limitations to be considered when using extruded polystyrene, but the material has the advantage of simultaneously providing a vapor barrier and thermal protection when applied.

An interesting note in the Federal standards for glazing materials regarding glazing materials is the difference between "putty," a linseed-oil and whiting-based compound (note that lead-whiting is no longer an allowable additive) which is specified for wood sashes, and "glazing compound" which is specified for backbedding and face glazing of metal sashes!

Air barriers/vapor barriers

The issue of moisture accumulation and migration in buildings is gathering importance and attention in planning retrofit strategies. The Recommended Practice for Selection of Vapor Barriers for Thermal Insulation standard is very informative, and sheds some light on the broader issues through a good discussion of vapor pressure and location of vapor barriers.

Although recent research has indicated that control of air flow out of and within our structures is the most critical factor in avoiding damaging condensation problems, another important consideration is the relationship between the permeance of the interior versus exterior surfaces of any building section in question. We have included below a representative list of perm ratings to illustrate this characteristic of many common materials.

A material may be selected to act as a vapor barrier (or vapor retarder, as they are becoming known) if it has a permeance rating not greater than one (1.0). A better rule of thumb requires comparing the relative permeability of building surfaces on the interior and exterior of the thermal envelope. The goal is the keep the interior surfaces five times less permeable (lower perm rating) than the exterior surfaces.

The perm rating of some common materials are provided here to illustrate the range of values. The information is primarily extracted from the *2005 ASHRAE Handbook of Fundamentals* and is ordered from lowest permeance to highest.

Built-up hot tar roofing	.00
Foil-faced insulation	.002
Cross-laminated polyethylene, 4 mil	.02
Aluminum foil, 0.35 mil	.05
Polyethylene, 6 mil	.06
Fiberglass-reinforced acrylic plastic	.12
Plywood, exterior glue 3/4"	.23

Kraft-faced insulation	.4
Concrete, 8"	.4
Latex "vapor barrier" paints	.45
Enamel on smooth plaster, two coats	.5 -1.5
Brick, 4"	.8
Vinyl, 4 mil	.8 - 1.4
Extruded polystyrene	1.1
Plywood, interior glue 1/4"	1.9
Expanded polystyrene (beadboard)	2. - 5.8
Concrete Block, 8"	2.4
Polyurethane board stock	2.5 - 4
15 lb felt	4.0
Cellulostic Fiber Sheathing	5.0 - 50
Exterior acrylic house & trim paint	5.5
Plaster on wood lath	11
Gypsum wall board	50
Spun-bond-olefin (Tyvek tm; Parsec tm)	94
Mineral wool	116

Aluminum siding

When examining options for home improvements, people often consider installing aluminum siding. The strong opinion of the authors of this report is DO NOT DO IT!

Aluminum siding is sold with several different justifications. Perhaps the most attractive is that it relieves the homeowner of the chore of periodic painting. This is true - for a while. But no siding surface will last forever. The same defense used to be used for other substitute siding materials like asbestos tiles, asphalt shingles, and fake brick. The problem with all these maintenance-free materials is that once something goes wrong with them, you can not fix them unless you add on another layer of a different siding material. The problem with that strategy is that the more layers tacked on to the outside of a building, the less able it is to “breathe.” This runs the risk of building up pockets of moisture condensation within the walls.

The most fallacious claim made about aluminum siding is that it will save energy. The R-value of aluminum, that is the measurement of its ability to stop the conductive flow of heat, is so small it is hardly measurable, like .0007 per inch. Even foam backer boards to the siding add little real energy saving potential - particularly when measured against the cost of such an installation.

The worst thing about this material is that it makes the task of home maintenance nearly impossible to accomplish. Aluminum siding does not solve problems like holes in the conditioned envelope; it just covers them up and makes them almost impossible to repair properly. Further, because the cold metal is so prone to promoting moisture condensation which can eventually rot out walls, caulking on the outside of the house may make the problem worse. To stop the airflow into a sided house by sealing up the cracks and seams on the outside also stops the out-flow of water vapor, trapping it right behind the siding.

In short, the attempt to reduce home maintenance chores by adding aluminum siding merely makes it impossible to maintain the home.