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Strategy Guideline: Energy Retrofits for Low-Rise Multifamily Buildings in Cold Climates

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April 2013

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Unless otherwise noted, all figures and photos were created by IBACOS.

Definitions

ACH	Air changes per hour
ACH_{50}	Air changes per hour at 50 Pascals of pressure, calculated by multiplying CFM_{50} by 60 and dividing by the volume of the building
ACH_n	Natural air change rate, approximated by modifying the ACH_{50} value with factors to reflect local wind speeds, external shielding such as trees, and the height and size of the building
AFUE	Annual fuel utilization efficiency
BLPM	Brushless permanent magnet (motor)
CFM	Cubic feet per minute
CFM_{50}	Cubic feet per minute at 50 Pascals of house pressure measured with a blower door
DOE	U.S. Department of Energy
IECC	International Energy Conservation Code
IRC	International Residential Code
RESNET	Residential Energy Services Network
SF	Square foot

Executive Summary

This Strategy Guideline explains the benefits of evaluating and identifying energy efficiency retrofit measures that could be made during renovation and maintenance of multifamily buildings. It focuses on low-rise multifamily structures (three or fewer stories) in a cold climate. These benefits lie primarily in reduced energy use, lower operating and maintenance costs, improved durability of the structure, and increased occupant comfort.

This Strategy Guideline focuses on retrofit measures for three typical building maintenance categories:

1. Roof repair or replacement
2. Exterior wall repair or gut rehab
3. Heating system maintenance.

All buildings are assumed to have a flat ceiling and a trussed roof, wood- or steel-framed exterior walls, and one or more single or staged boilers.

When making retrofits in any of these categories, consider extraneous factors such as the age of the building occupants (e.g., housing for senior citizens requires higher heating levels), historic preservation, and available financial assistance.

Estimated energy savings realized from the retrofits will vary, depending on the size and condition of the building, the extent of efficiency improvements, the efficiency of the heating equipment, the cost and type of fuel, and the climate location.

1 Introduction

This Strategy Guideline highlights the benefits of identifying potential opportunities for energy efficiency retrofit measures to be completed at the time of routine building maintenance or non-energy-related repairs. Routine maintenance, whether for repairs or replacement, provides important opportunities to address the energy efficiency of the building and its subsystems. Traditionally, energy efficiency improvements are not considered or are overlooked when maintenance plans are created and executed. When energy-related improvements are combined with maintenance or repair operations, significant savings are captured: reductions in energy use are realized, operating and maintenance costs are reduced, and structures become more durable. Energy efficiency improvements can also be implemented more cost effectively if they are coordinated with concurrent maintenance or repair work than if postponed and addressed under an independent scope of work.

This Strategy Guideline can serve as a reference for building owners, developers, and facilities personnel engaged in the routine maintenance of residential multifamily buildings to help them develop the thought processes needed to identify opportunities for incorporating energy efficiency measures in their work. It may also be useful for initiating discussion and collaboration between contractors and building owners. Affordable housing agencies likewise may find this Strategy Guideline useful when they are involved in these types of renovations.

Although the basic principles outlined in this Strategy Guideline apply to most buildings in cold climates, the focus is on low-rise multifamily structures (three or fewer stories) in cold and very cold climates.[1] This Strategy Guideline addresses energy efficiency improvement opportunities and potential savings associated with three typical, non-energy efficiency-related building maintenance categories:

1. Roof replacement or repair
2. Exterior wall repair or gut rehab
3. Heating system maintenance.

The basic building component assemblies are assumed to be a flat ceiling and a trussed roof, wood- or steel-framed exterior walls, and one or more single or staged boilers. Figure 1 depicts the two basic multifamily building types modeled for the energy efficiency savings analysis sections.

[1] Cold and very cold climates typically are defined as regions with more than 5,400 heating degree days (65°F) and fewer than 12,600 heating degree days (Building America 2011).

Figure 1. 5-unit town house (left); 31-unit double-loaded corridor multifamily buildings (right)

(Housing Vermont 2010)
(Photos courtesy Efficiency Vermont)

2 Roof Repair or Replacement

2.1 Energy Efficiency Opportunities

When a roof needs repair or replacement, use the opportunity to consider energy efficiency measures that may be implemented concurrently with the scheduled repairs. In many cases, roof repairs are required because of underlying energy performance problems such as poor insulation or air sealing. Taking steps to create an energy efficient roof assembly will reduce operating costs, provide increased occupant comfort, improve the durability of the roof, and reduce long-term maintenance costs. Figure 2 shows the same roof before and after air sealing penetrations between the conditioned space and any unconditioned roof cavities. The ice dams and icicles shown in the left photo are formed when heat from the conditioned space escapes into the attic, warming the roof surface and melting the adjacent snow. The resultant meltwater flows down to the roof edge, where, if the ambient temperature is below freezing, it refreezes and causes an ice dam. By reducing the heat loss through air sealing and insulation, the roof is no longer artificially warmed, and ice dam and icicle formation is minimized.

Figure 2. Before (left) and after (right) air sealing penetrations into any unconditioned roof cavities

(Housing Vermont 2010)
(Photos courtesy Efficiency Vermont)

To help guide where and what energy efficiency improvements might be incorporated into roof repairs, evaluate the condition of the attic insulation, roofing materials, sheathing, air sealing, and exterior flashing details (if applicable) to assess what conditions may have contributed to the damage. Ask the following questions:

1. Is mold or rot present in the framing or roof sheathing?
2. Is the insulation discolored?
3. Is there excessive ice damming in winter?
4. Is there frost on the underside of the roof sheathing in winter?
5. Is the roofing material damaged, and if so, where?

Figure 3 shows visual evidence of poor air sealing and insulation performance. The photo on the left shows mold growing on the underside of the roof sheathing. This happens when warm, moist air condenses on the cold sheathing surface. The photo on the right shows fibrous insulation discoloration caused by the filtering of particulates as air passes through it.

Figure 3. Mold growing on the underside of roof sheathing (left) (DOE 2011); discoloration of insulation (right)

(Left photo courtesy U.S. Department of Energy; right photo courtesy Efficiency Vermont)

These symptoms are indicative of poor air sealing or insulation levels (usually both). Both conditions can result in long-term energy performance and durability issues in the structure. To address these symptoms and to increase the long-term durability of the roof assembly, ensure proper air sealing and adequate insulation levels. Section 2.2 provides an in-depth discussion of the building science associated with these energy efficiency measures.

Building Science Principle –
Warm air has a greater capacity to carry moisture than cold air. When warm, moist air is allowed to migrate (leak) into a cold space, the moisture in the air condenses on the cold surface. This excess moisture eventually may lead to mold and rot, which degrade the structure.

2.2 Building Science in Energy Efficiency Measures

The need for roof repair often is a symptom of poor insulation performance, which, in turn, is symptomatic of air leakage. As air moves through or around the insulation, the heat or moisture it carries prematurely degrades all or part of the roof assembly. Signs of air leakage and poor insulation performance include wet, moldy, or rotting roof joists; discolored insulation; ice dams; snow or ice melting and freezing down the exterior walls of the building; water damage on the interior of the building; and the inability to maintain comfortable thermostat settings in some or all areas of the building. When making roof repairs, it is important to engage in preventive maintenance, which will reduce maintenance and energy costs.

2.2.1 Air Seal

Air sealing is a preventive maintenance measure that saves in energy costs and roof maintenance. When a significant investment is being made in the roof, attending to its energy performance protects that investment. Occupant comfort also is increased greatly when a building is properly air sealed. Reducing air leakage can be much more difficult during retrofit than during new construction because many penetrations in existing buildings are covered with insulation or are inaccessible. Depending on the nature of the roof repair work, scheduling energy retrofit work concurrently may provide easier access to these areas.

The first step in creating an energy efficient roof structure is to define the thermal boundary, which separates conditioned (intentionally heated) space from unconditioned (unheated) space (see Figure 4). The thermal boundary (insulation) should be in direct contact with the air barrier, a continuous impermeable barrier that prevents undesirable air movement across the thermal boundary.

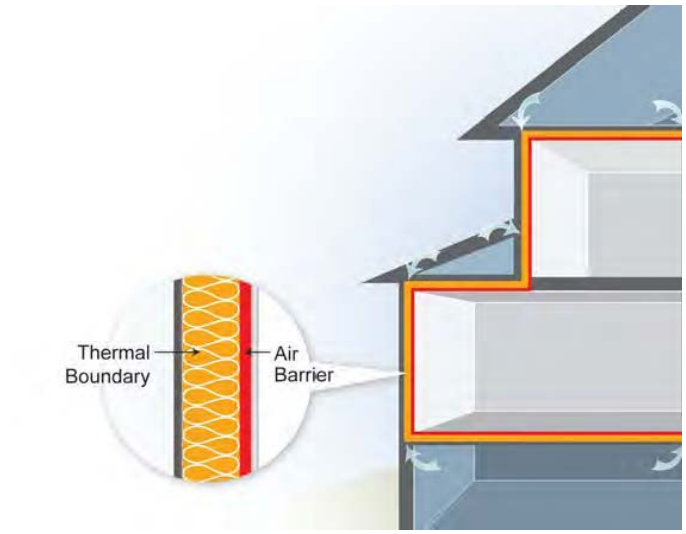

Figure 4. The thermal boundary and air barrier separate the unconditioned space from the conditioned space of a structure, preventing air infiltration indicated by the arrows (DOE 2011)

(Courtesy U.S. Department of Energy)

In Figure 4, the attic space is unconditioned. In buildings where the attic space is considered to be conditioned, the thermal boundary and air barrier would extend upward along the roof assembly. The thermal boundary must be continuous around the building envelope.

Once the thermal boundary has been defined, all penetrations between the conditioned space and the unconditioned space should be sealed. These openings can include the following:

- Plumbing, electrical, and mechanical chases, and other areas (e.g., attic hatches) open to the attic space.
- Gaps between the top plate of exterior walls and the rim or band joists. Figure 5 demonstrates the use of spray foam to effectively air seal and insulate this area.
- Recessed lighting fixtures.

Figure 5. The air sealing benefits of spray foam make it a great option to insulate around rim or band joists

(Photo courtesy Efficiency Vermont)

Any remaining air gaps can be identified by using a blower door in conjunction with an infrared camera or smoke pencil. Such diagnostic techniques also allow the effectiveness of air sealing efforts to be verified. Gaps should be filled with appropriate materials such as caulk, foam, or gaskets. Only fire-rated sealants should be used around chimneys, flues, and other fire-rated assemblies, designed to meet the requirements of the appropriate International Residential Code (IRC 2012, Chapter 3, Section R302) (IRC 2012) and ASTM standards (ASTM E84-12, ASTM E136-11, and ASTM E814-11a) (ASTM 2012, 2011a, and 2011b, respectively).

Building codes are beginning to quantify maximum whole-building air leakage standards and are quickly becoming more aggressive in their requirements. The 2009 International Energy Conservation Code (IECC) includes an optional testing requirement of fewer than 7 air changes per hour at 50 Pascals of pressure (ACH_{50}). This equates to roughly 1 cubic foot per minute (CFM) at 50 Pascals of pressure per square foot (CFM_{50}/SF) of floor area. The 2012 IECC includes mandatory testing of air leakage and verification of no more than three ACH_{50} in climate zones 3 through 8 (DOE 2010). ENERGY STAR® Version 3 requires fewer than four ACH_{50} for cold climates (approximately 0.50 CFM_{50}/SF of floor area). A reasonable target for most existing multifamily buildings is an air leakage rate of no greater than 0.60 CFM_{50}/SF of exterior surface area when performing a whole-building retrofit. These target values should be considered when air sealing the attic. Roof assemblies contribute largely to the overall air leakage in a building. Thorough air sealing efforts to provide high levels of airtightness are

- ✓ Use a blower door during air sealing to be sure all major gaps have been adequately sealed.
- ✓ If a blower door test is not feasible, follow a comprehensive air sealing checklist such as the ENERGY STAR Thermal Enclosure Checklist (see Appendix A).
- ✓ Always conduct an air leakage inspection before installing insulation.

particularly important to affordable housing projects to ensure long-term affordability to occupants.[2]

Links to detailed reports on specific air sealing strategies and air leakage testing for multifamily buildings, as well as examples and illustrations of air sealing methods related to roof repair or replacement, can be found in Steven Winter Associates (2010), Dentz et al. (2012), and Appendix A.

2.2.2 Insulate

Adding more insulation to an attic without first addressing air leakage can actually exacerbate the above-mentioned problems. For example, adding insulation to an attic with penetrations remaining unsealed does not prevent moist air from reaching the roof decking, but that surface is now more likely to be cold enough to cause condensation, which causes mold growth and other durability issues.

Once the attic space has been air sealed, more insulation may be added to increase the thermal efficiency of the roof assembly. Improving the quantity and quality of insulation in the roof assembly is an investment that is repaid in energy savings and reduced maintenance. Attic insulation slows the transmission of heat through the roof. When a roof is covered in snow, excessive heat loss can be observed in patchy bare spots on the roof and ice dams forming at the eaves. When evaluating the attic space for installing insulation, pay attention to the amount of insulation to be installed and to how and where it is installed.

At minimum, current local code requirements (if applicable) must be met. Many state and municipal building codes are based on the IECC. In cold climates, the 2009 IECC requires a minimum R-38 in climate zone 5 and R-49 in climate zones 6 through 8. The 2012 IECC requires a minimum of R-49 in climate zones 5 through 8 (DOE 2010). ENERGY STAR recommends insulating attic spaces in the range of R-49 to R-60 in cold climates.[3]

As with air sealing, higher levels of insulation may be warranted in certain circumstances to achieve near- and long-term affordability (Shapiro 2011). For insulation to perform as it is rated, complete coverage and proper installation are critical. The goal when installing insulation is to achieve a Grade I installation per the Residential Energy Services Network (RESNET) Mortgage Industry National Home Energy Rating Standards (RESNET 2006). Grade I is defined most simply as insulation installed according to the manufacturer’s instructions. Poorly installed insulation (Grade II or Grade III) can reduce the efficiency of the thermal boundary at the roof assembly by as much as 40%.

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[2] *A Roadmap for Housing Energy Affordability* (Shapiro 2011) was sponsored by the MacArthur Foundation to address energy efficiency, building durability, and affordability needs in the Vermont affordable rental housing stock. Although this roadmap is directed to Vermont-specific needs, the basic lessons are applicable to any cold-climate multifamily housing.

[3] ENERGY STAR recommended insulation levels for retrofitting existing wood-framed buildings (ENERGY STAR 2011b).

Although Grade I installation can be achieved with batt insulation, it is very difficult. Consider using a loose-fill insulation to reduce gaps and compression. When using loose-fill products, it is important to account for the settled density when specifying the final desired R-value. (R-value is a measure of thermal resistance, or how well a material prevents heat loss. It is the reciprocal of the U-value, which is the overall heat transfer coefficient that describes how well a building element conducts heat.) Complete coverage of insulation is as important as the overall quantity and quality of insulation. Even small gaps in insulation greatly affect the overall thermal efficiency of the entire assembly. Ideally, continuous insulation should cover the framing to prevent thermal bridging, which is the conductive transmission of heat through the framing structure.

Grade I Insulation –
In practice, Grade I ceiling insulation fills the cavity uniformly and is in complete contact with the surface it is intended to insulate. There are no substantial gaps or voids around any obstructions such as electrical boxes or wiring.

Attic areas that are commonly left uninsulated or underinsulated are access hatches and the intersections of roof rafters and exterior walls (over the wall top plate at the eaves). Reduced levels of insulation, even in relatively small areas of the attic, dramatically affect the overall R-value of the assembly. Where there are sloped roof assemblies (the thermal boundary is at the roof deck), consider strategies such as rigid and spray foam products that allow for greater insulation values per inch.

Is insulating the attic hatch really that important?
An uninsulated attic hatch can reduce the R-value of the entire assembly by 15%. Here's how to calculate it:

Type	R-Value	U-Value (1/R)	Area	UA (Heat Loss) (Area × U)
Ceiling	38	0.03	1990	52.37
Hatch	1	1.00	10	10.00
			Total Area:	**Total UA:**
			2000	63.37
		Area/UA = Average R-value		
		2000/63.67 = **R-32**		

If the attic is unconditioned space, ventilation should also be assessed. Proper ventilation in the attic is important for moving excess moisture out of the building and maintaining the durability of the roof. Almost all buildings with attic spaces will have a combination of soffit and gable vents, or a ridge vent and eave or soffit vents that run the entire length of the roof line. Some designers or builders will install insulation baffles (or rafter vents) into the roof joists to allow for ventilation from the eave upward to the ridge vent. In this design, the insulation contractor may need to install blocking to prevent the insulation from entering the eave but still allow for insulation all the way to the junction between the sloped roof and the eave. Follow local code requirements for proper attic ventilation.

2.3 Risks and Other Considerations

When deciding whether to implement energy efficiency measures in a multifamily building, the following factors should be considered and then incorporated into the planning process:

- **Whole-building mechanical ventilation.** When the roof assembly has been properly air sealed and insulated, it is critical to ensure that the occupied areas of the building are receiving adequate ventilation. Whole-building mechanical ventilation is essential to indoor air quality and building durability. Ventilation and controls should be installed to meet ASHRAE Standard 62.2 (ASHRAE 2010). ENERGY STAR-qualified products should be used because they provide the same or better performance as standard products but use significantly less energy.

- **Air distribution systems.** Sealing ductwork found in attics or completely moving the ductwork into conditioned space could be considered to increase the distribution efficiency of a forced air system.
- **Blower door-assisted air sealing.** Separately scheduling air sealing contractors and energy consultants to conduct blower door testing in combination with air sealing can be difficult. A certified contractor who is trained in the use of a blower door and who conducts blower door-assisted air sealing can reduce scheduling conflicts and ensure that the job is done right the first time.[4]
- **Nonflammable materials.** Air sealing in multifamily buildings requires the use of nonflammable materials based on the fire separation assemblies in the building.
- **Evaluate the space conditioning systems.** As the building shell becomes significantly more energy efficient by reducing infiltration and adding insulation, heating and cooling loads are reduced. It is important to evaluate the space conditioning systems to ensure optimal performance and sizing of those systems.
- **Occupant age.** Elderly occupants typically require higher heating levels than do younger occupants. In these cases, higher thermal efficiency levels may be warranted.
- **Historic preservation.** In some cases, historic preservation guidelines may restrict or confine efficiency measures. Near- and long-term affordability may not be achievable under current historic preservation guidelines.
- **Financial assistance.** Various state and federal incentives may be available for energy efficiency retrofit work. Review current resources that may be available. For example, information on state-level incentives is provided in the Database of State Incentives for Renewables & Efficiency (DSIRE 2011). Information on federal incentives is provided by the Tax Incentives Assistance Project (TIAP 2011).

2.4 Estimated Energy Savings

Estimated energy savings depend on many factors, making it difficult to provide average savings estimates. Savings will vary, depending on the size and baseline conditions of the building, the extent of the efficiency improvements, the efficiency of the heating equipment, the cost and type of fuel, and the climate location. With those caveats, some broad assumptions can be made, and a range of savings estimates can be provided as a guide for the impact of these efficiency measures.

The following two examples provide estimated savings for completing air sealing and insulation work in 5-unit and 31-unit low-rise multifamily buildings. Both buildings are located in a cold climate (7,859 heating degree days at 65°F), and both buildings have flat ceilings and truss roof structures. Heating systems are assumed to be oil boilers having an 80% annual fuel utilization efficiency (AFUE). Air leakage has been reduced by 20%, and attic insulation has been increased from R-25 (a typical value for poorly installed existing attic insulation) to R-60.

[4] The Building Performance Institute provides individual professional certification and company accreditation for home performance and weatherization retrofit work standards (BPI 2011).

2.4.1 Example 1: 5-Unit Town House Building

Air sealing penetrations into the attic space to reduce the overall infiltration rate from 1.51 CFM_{50}/SF exterior shell (10 ACH_{50}) to 1.20 CFM_{50}/SF exterior shell (8 ACH_{50}) will save roughly 35 MMBtu annually. Bringing the total flat attic insulation from R-25 to R-60 will save an additional 14 MMBtu annually. Together the two measures provide a total building energy savings of approximately 50 MMBtu. Assuming the average annual consumption is 250 MMBtu (a rough average for this building type in a cold climate), this equates to roughly a 20% reduction in annual energy consumption. Installation and labor costs will vary widely by location but would likely be in the range of $10,000 to $15,000. Maintenance costs would also likely be reduced by improving the efficiency of the roof structure, and occupants would be more comfortable.

2.4.2 Example 2: 31-Unit Double-Loaded Corridor

Air sealing penetrations into the attic space to reduce the overall infiltration rate from 2.07 CFM_{50}/SF exterior shell (10 ACH_{50}) to 1.66 CFM_{50}/SF exterior shell (8 ACH_{50}) will save roughly 136 MMBtu annually. Bringing the total flat attic area insulation from R-25 to R-60 will save an additional 33 MMBtu annually. Together the two measures provide a total building energy savings of about 170 MMBtu. Assuming the average annual consumption is 2,000 MMBtu (a rough average for this building type in a cold climate), this equates to roughly an 8% reduction in annual energy consumption. Installation and labor costs will vary widely by location but would likely be $25,000 to $40,000. Maintenance costs would also likely be reduced by improving the efficiency of the roof structure, and the occupants would be more comfortable.

- ✓ Greater savings will be realized in buildings with lower baseline conditions (more savings are captured from adding R-19 to an existing R-19 roof than by adding R-19 to an existing R-38 roof).
- ✓ Consider the savings realized from energy efficiency improvements in comparison with fuel prices. It is important to think about life cycle benefits when evaluating the investment cost of energy efficiency improvements.

3 Wall Repair or Gut Rehab

3.1 Energy Efficiency Opportunities

When the exterior walls of a building are in need of repair or a gut rehab, use the opportunity to consider energy efficiency measures that may be implemented concurrently with the scheduled repairs. In many cases, wall repairs are required because of underlying energy performance problems such as poor insulation and air sealing. Taking steps to create an energy efficient wall assembly will reduce building operating costs, increase occupant comfort, improve the durability of the exterior walls, and reduce long-term maintenance costs. Figure 6 shows excessive mold growth on interior walls and on the interior side of the exterior wall sheathing in a wood-framed wall assembly that was improperly air sealed and insulated.

Figure 6. Mold growth on the inside surface of exterior walls (left) and inside the wall cavity (right). Both conditions are likely caused by an improperly air sealed and insulated wood-framed wall assembly.

(BSC 2008)
(Left photo courtesy Building Science Corporation)

To help guide where and what energy efficiency improvements might be incorporated into the exterior wall repairs, evaluate the condition of the wall insulation, exterior wall sheathing, air sealing, and exterior wall flashing details to assess what conditions may have contributed to the damage. Ask the following questions:

- Is mold or rot present in the wall framing or sheathing?
- Is the insulation discolored?
- Is there frost or condensation on the walls or glazing in winter?

- Has the exterior cladding been damaged?
- Are any unsealed penetrations visually apparent through the wall assembly?
- Is there any discoloration of the interior or exterior wall sheathing that would indicate water intrusion?
- Is the insulation completely filling the cavity space and in full contact with the air barrier?

Visual evidence of poor air sealing and insulation performance is shown in Figure 7. The image on the left shows mold growth on the interior walls as a result of poor air sealing at the floor. The image on the right shows fibrous insulation discoloration caused by the filtering of particulates as air passes through it. These symptoms are indicative of poor air sealing or insulation levels (usually both). To address these symptoms and to increase the long-term durability of the wall assembly, ensure proper air sealing and adequate insulation levels.

Figure 7. Signs of poor air sealing and insulation performance

(BSC 2008, Housing Vermont 2010)
(Left photo courtesy Building Science Corporation; right photo courtesy Efficiency Vermont)

The condition of the fenestration (doors and windows) should also be evaluated at this time. A lack of or damage to flashing material (such as sheet metal installed to protect the window framing and to direct moisture away from the opening) may have led to water entering the wall assembly, causing mold and other structural water damage. The wall assembly should be evaluated and addressed as a whole. Section 3.2 provides an in-depth discussion of the building science associated with these energy efficiency measures.

3.2 Building Science in Energy Efficiency Measures

An excellent opportunity to address thermal and infiltration issues at the building core is presented when extensive repair or replacement of drywall on the interior side of exterior walls is required. Exterior walls typically are retrofitted for one of three reasons:

1. Damage
2. Space reconfiguration
3. Energy efficiency upgrades.

This type of renovation allows for the removal of old, ineffective wall insulation or the addition of insulation if none was originally installed. Before replacing the insulation, examine the wall assemblies for air leakage and other factors that compromise the assemblies' long-term durability. Improperly sealed walls allow moisture-laden air to move through and around insulation. This moisture condenses on cold surfaces, eventually leading to mold and deterioration of building assemblies such as wood-framed walls. Properly air sealing and replacing the insulation improves the thermal efficiency of the building and protects investments made to the building structure.

3.2.1 Air Seal

In exterior wall repair or gut rehab projects, any insulation in the cavity needs to be removed and either reinstalled or replaced with new or higher quality product. Before reinsulating the wall cavity, the exterior sheathing will be exposed and the penetrations (including window and door openings) will be visible. This is a good opportunity to evaluate the air sealing details and the condition of the exterior wall that could have contributed to the damage and durability issues on the interior surface of the wall.

Proper air sealing before the insulation is replaced is critical. Air leakage affects occupant comfort by providing a path for cold air to leak into the building, allows heat to escape the building shell, and allows moisture to condense on the building. It also compromises the effectiveness of the space conditioning system.

- ✓ Use a blower door during air sealing to be sure all major gaps have been adequately sealed.
- ✓ If a blower door test is not feasible, follow a comprehensive air sealing checklist such as the ENERGY STAR Thermal Bypass Checklist (see Appendix B).
- ✓ Always conduct an air leakage inspection before installing insulation.
- ✓ In buildings with balloon frame construction, air sealing between floors stops airflow and reduces fire hazards.

All penetrations through the exterior walls must be sealed at both the interior surface (drywall) and the exterior surface (sheathing) to prevent air leakage from both directions. Use a durable material such as caulk or foam. Acrylic latex or silicone caulk is suitable for gaps smaller than ½ in. Higher grade silicone or polyurethane caulks should be used where the sealant will be exposed to weather. For large gaps and penetrations, a urethane-based spray foam is appropriate. Use minimally expanding spray foam around door and window rough openings to prevent warping of the frame. Use only fire-rated sealants around chimneys, flues, and other fire-rated assemblies, designed to meet the requirements of the appropriate International Residential Code (IRC 2012, Chapter 3, Section R302) (IRC 2012) and ASTM standards (ASTM E84-12, ASTM E136-11, and ASTM E814-11a) (ASTM 2012, 2011a, and 2011b, respectively).

Penetrations through exterior walls and other conditions are likely to be in the following locations and would benefit from detailed air sealing efforts:

- Plumbing or electrical penetrations
- Dryer duct or bath fan duct penetrations

- Behind tubs or showers located on exterior walls where insulation may be missing or where seams and access openings have old or cracked sealant (or none at all)
- Bottom edge of sheetrock sealed to the subfloor on exterior walls
- Around windows and door rough openings
- Bulkheads located on exterior walls.

The interior surface (drywall) is a key component of the thermal boundary system and air barrier. Once insulation has been reinstalled and the wall cavity has been enclosed, complete air sealing of the drywall is a critical detail. Any remaining air gaps can be identified by using a blower door in conjunction with an infrared camera or smoke pencil. Figure 8 shows examples of poor air sealing around doors and windows. In the photo on the left, fibrous insulation has been jammed into the gap above the door frame. Fibrous insulation is not an air barrier; it acts only as a filter and allows air to move freely between the interior and exterior. In the photo on the right, the gap between the window and the rough opening is not sealed at all. By contrast, Figure 9 shows two examples of good air sealing with low-expansion spray foam.

Figure 8. Poor air sealing around windows (ENERGY STAR 2011c)

(Left photo courtesy Efficiency Vermont; right photo courtesy U.S. Department of Energy)

Figure 9. (Left) Good air sealing around windows and (right) between drywall and subfloor (Photos courtesy Efficiency Vermont)

Building codes are beginning to quantify maximum air leakage standards and are quickly becoming more aggressive in their requirements (see Section 2.2.1 for further discussion on building code air change requirements). A reasonable target for most existing multifamily buildings is an air leakage rate of no greater than 0.60 CFM_{50}/SF of exterior surface area when performing a whole-building retrofit. These target values should be considered when air sealing the exterior walls. Infiltration can be reduced considerably by air sealing exterior walls. Thorough air sealing efforts to achieve high levels of airtightness are particularly important to affordable housing projects to provide near- and long-term affordability to occupants (Shapiro 2011). Links to detailed reports on specific air sealing strategies and air leakage testing for multifamily buildings, as well as examples and illustrations of air sealing methods related to wall repair and gut rehab, can be found in Steven Winter Associates (2010), Dentz et al. (2012), and Appendix B.

3.2.2 Fenestration Replacement or Repair

During wall repair or a gut rehab of the exterior walls, evaluate the condition of the fenestration (windows and doors). Determine if the current condition of the fenestration has contributed to damage of the exterior wall assembly. Assess the flashing, integration with the drainage plane, and air sealing around the fenestration. Is moisture damage visible on the wall around the windows? What is the condition of the thermal break in the window frames? Is condensation visible on the walls or between glazing units?

When it is determined that windows need to be replaced because of excessive damage or operability issues, energy savings opportunities may be addressed at the same time by specifying windows with better performance values. At minimum, select windows that meet local code requirements. For increased efficiency, consider upgrading to ENERGY STAR-qualified windows. Replacing windows for energy savings alone typically is not cost effective.

If only slight modifications or repairs are required, restoring existing windows may be a more economical approach. A number of actions may be considered that can improve the energy efficiency of the windows while executing the restoration:

- Check for loose glass and failing casing, rails, sash, or muttons, and repair as necessary.
- For double-hung windows, repair or install new sash locks at the junction between the upper and lower rails as well as on the left and right sides of the window jam.
- Install weather stripping at the bottom sill to provide additional air sealing and ensure that flashing remains effective. Bulk moisture should drain away from building materials (the job of window flashing), and interior moisture should not have an opportunity to condense on building materials (the job of air sealing). Remember that air sealing done incorrectly or in the wrong place (say, the exterior instead of the interior) and improper flashing can create further problems such as trapping water inside the wall assembly.
- Add interior and exterior storms when possible to improve window performance.
- Properly retrofit single-pane windows (these can perform as well as standard double-pane replacement windows).

There are many variables to consider when evaluating the best strategy for window repair, rehabilitation, or replacement, and attention should be paid to flashing details to preserve window and building wall durability (Baker 2012; BSC 2012).

3.2.3 Insulate

Once the exterior walls have been adequately air sealed, insulation can be installed. Improving the thermal efficiency of the exterior wall assembly is an investment that is repaid in reduced operating and maintenance costs. However, reinsulating or adding insulation to a wall assembly that was previously uninsulated will change the dynamics of the building enclosure. For example, if the original condition was a leaky wall assembly with no insulation, the exterior sheathing may have seen moisture from indoor air, but the sheathing may have remained warm enough (from lack of insulation) so that condensation did not occur. If insulation is now properly installed but not properly air sealed, air can still leak into the cavity, introducing moisture into the assembly. Insulated walls will thermally isolate the exterior sheathing from the conditioned space. In this condition, there is a greater potential for condensation and durability issues. Therefore, it is critical to thoroughly evaluate the details of the entire wall assembly and retrofit measures.

> **Grade I Insulation –**
> In practice, Grade I insulation fills the cavity uniformly and is in complete contact with the surface it is intended to insulate. There are no substantial gaps or voids around any obstructions such as electrical boxes or wiring.

At minimum, insulate exterior walls to current local code standards (if applicable). In cold climates, the 2009 IECC requires a minimum of R-20 in climate zones 5 and 6. R-21 is required in climate zones 7 and 8. The 2012 IECC requires a minimum of R-20 in climate zone 5. Climate zones 6 through 8 require a minimum of R-20 cavity insulation plus R-5 continuous insulation (or R-13 cavity plus R-10 continuous) (DOE 2010). Shapiro (2011) recommends exterior wall insulation ranging from code levels up to R-36 for very poorly performing multifamily structures to meet near- and long-term affordability goals. For insulation to perform as it is rated, complete coverage and proper installation are critical. As with attic insulation, the goal when installing wall insulation is to achieve a Grade I installation per the RESNET Standards (RESNET 2006).

Poorly installed wall insulation (Grade II or Grade III) can reduce the thermal efficiency of the wall assembly by as much as 20%.

> **Effective R-Values –**
> An R-21 fiberglass batt does not equate to an R-21 wall assembly. Cavity insulation in a 2 × 6 wall rated at R-21 typically equates to a wall assembly R-value ranging from R-18 (Grade I) to R-14 (Grade III), depending on the type of framing and the quality of the insulation installation. The better the installation quality, the higher the effective R-value will be.

Consider alternative cavity insulation options such as dense-pack cellulose or two-part spray foam products that provide air sealing benefits in addition to insulation. In standard construction, nearly 20% of the wall system is framing, not insulation. Thermal bridging occurs through the framing studs that are not covered with insulation because heat transfers easily through uninsulated stud framing to the outdoors. This has a large impact on the overall R-value of the wall assembly. Identifying strategies that can reduce the overall impact of the framing can provide significant benefits to the overall performance of the assembly and the energy efficiency of the building. Continuous rigid insulation on the inside or outside of exterior walls reduces thermal bridging through the wall framing and is especially critical in steel-framed structures.

Figure 10 shows examples of proper installation of rigid foam, which may be installed on the interiors or exteriors of walls. Cap nails should be used, and all seams should be sealed completely.

Figure 10. Proper installation of continuous rigid foam (ENERGY STAR 2011c), showing the use of cap nails and proper sealing of seams

(Photos courtesy U.S. Department of Energy)

3.3 Risks and Other Considerations

As with repairing or replacing the roof, risks and other factors should be considered and incorporated into the planning process when undertaking any major shell improvement (see Section 2.3 for more information).

3.4 Estimated Energy Savings

Estimated energy savings depend on many factors, making it difficult to provide average savings estimates. Savings will vary, depending on the size and baseline conditions of the building, the degree of the efficiency improvements, the efficiency of the heating equipment, the cost and type of fuel, and the climate location. With those caveats, some broad assumptions can be made, and a range of savings estimates can be provided as a guide for the impact of these efficiency measures.

- ✓ Greater energy savings will be realized in buildings with poorer-performing conditions.
- ✓ Consider the savings realized from energy efficiency improvements in comparison with fuel prices. It is important to think about life cycle benefits when evaluating the investment cost of energy efficiency improvements.

Examples of energy savings are again provided based on a 5-unit and a 31-unit low-rise multifamily building in a cold climate. The wall system of both buildings is 2 × 6 wood studs with a brick façade. Heating systems are assumed to be oil boilers having an 80% AFUE. Air leakage has been reduced by 10%, and wall insulation has been increased from R-13 to R-20. Savings from window replacements assume single-pane with storm windows or double-pane wood-frame (U-factor 0.49) baseline windows upgraded to ENERGY STAR-qualified (U-factor 0.30) windows.

3.4.1 Example 1: 5-Unit Town House Building

Air sealing penetrations through the exterior walls to reduce the overall infiltration rate from 1.51 CFM_{50}/SF exterior shell (10 ACH_{50}) to 1.35 CFM_{50}/SF exterior shell (9 ACH_{50}) will save roughly 17 MMBtu annually. Bringing the exterior wall insulation from R-13 to R-20 will save an additional 24 MMBtu annually. Together the two measures provide a total build energy savings of approximately 41 MMBtu. Assuming the average annual consumption is 250 MMBtu (a rough average for this building type in a cold climate), this equates to approximately a 16% reduction in annual energy consumption. Installation and labor costs will vary widely by location but would likely be $10,000 to $15,000. In addition to the annual energy cost savings, maintenance costs would likely be reduced by improving the efficiency of the wall assembly, and occupants would be more comfortable. If windows also are being replaced, an additional 26 MMBtu may be saved annually. Costs associated with the installation of new ENERGY STAR-qualified windows may range from $30,000 to more than $60,000. The cost of window restoration can run approximately 75% less than replacement costs; similar levels of energy savings would be realized.

3.4.2 Example 2: 31-Unit Double-Loaded Corridor

Air sealing penetrations through the exterior walls to reduce the overall infiltration rate from 2.07 CFM_{50}/SF exterior shell (10 ACH_{50}) to 1.87 CFM_{50}/SF exterior shell (9 ACH_{50}) will save roughly 68 MMBtu annually. Bringing the exterior wall insulation from R-13 to R-20 will save an additional 62 MMBtu annually. Together the two measures provide a total building energy savings of about 130 MMBtu. Assuming the average annual consumption is 2,000 MMBtu (a rough average for this building type in a cold climate), this equates to approximately a 7% reduction in annual energy consumption. Installation and labor costs will vary widely by location but would likely be $25,000 to $40,000. In addition to annual energy cost savings, maintenance costs would likely be reduced by improving the efficiency of the wall assembly, and occupants would be more comfortable. If windows also are being replaced, an additional 67 MMBtu may be saved annually. Costs associated with the installation of new ENERGY STAR-qualified windows may range from $90,000 to more than $150,000. The cost of window restoration can run approximately 75% less than replacement costs; similar levels of energy savings would be realized.

4 Boiler Maintenance and Retrofit

4.1 Energy Efficiency Opportunities

The renovation of an existing building is an opportune time to assess the condition of the heating system. Whether for space reconfiguration or improvements to the enclosure, renovation provides an excellent opportunity to upgrade the heating system. An evaluation of the existing heating unit should include the age of the system. When the heating system is 20 years old or older, replacement is recommended. Additionally, if the existing heating system is inefficient or performs poorly, replacement should be considered. If the heating system is going to be replaced, the building heat load should be recalculated. When renovations include improvements to the building shell, the design loads of the building can change significantly. For this reason, it is important to improve the performance of the shell before considering replacement of heating systems. Oversizing heating systems, particularly oil-fired or condensing equipment, will effectively degrade efficiencies. Note that the building airtightness (air changes per hour) is a critical factor in the building load calculation. If possible, a blower door test should be performed to determine actual building leakage. Once the design load is known, the next important consideration is the new unit's rated thermal efficiency (provided as the AFUE). Select a boiler that, at minimum, meets ENERGY STAR boiler requirements. The boiler also should include the controls as discussed below.

Figure 11 shows a typical heating unit for a multifamily building. With such a system, a lack of microprocessor controls provides a good opportunity for retrofit.

Figure 11. Typical multifamily heating unit without microprocessor controls (Klein 2011)

(Photo courtesy Gary Klein, Affiliated International Management, LLC)

Regular heating system maintenance and service are important components of the operation and maintenance functions of a building. The manufacturer guidebook recommendations for regular maintenance should be followed and will include cleaning combustion chambers, heat exchange surfaces, and nozzles; ensuring adequate combustion air intake; checking for sufficient venting; replacing filters; and performing combustion efficiency tests. System maintenance extends the life of the equipment and prevents gas leaks (from fittings, unions, and valves); carbon monoxide poisoning (from cracked furnace heat exchangers, faulty flues, or backdrafting); and fires (from faulty controls or faulty wiring). It also helps to keep the system operating at its rated efficiency level. With regular maintenance and service, a boiler can remain in operation and perform effectively for approximately 20 years.

While maintaining an existing system, some retrofit measures or upgrades should be considered to further improve its overall efficiency. Retrofit opportunities exist to improve the overall efficiency of the heating system by adding microprocessor controls to existing boilers. Many types of controls are available, ranging from simple to full direct digital controls. These controls provide the ability to adjust the output of the boiler based on external conditions and demand. The building owner should select controls based on the size and age of the boiler system and the facility personnel's level of comfort with the controls.

When a boiler is scheduled for routine maintenance or repair, the following should be considered to increase its energy efficiency and performance:

- Outdoor reset controls
- Domestic hot water priority
- Brushless permanent magnet (BLPM) circulator pumps with integrated variable frequency drive
- Staging controls for multiple boilers
- Warm-weather shutdown controls
- Building-wide thermostat setback controls.

✓ Require system commissioning to ensure proper installation and performance testing.

✓ In all units, use programmable thermostats protected with lock boxes in common areas or remotely located.

✓ Models that have easy-to-read displays and that can provide intuitive adjustments are particularly important for elderly occupants.

✓ All occupants should be provided with instructions on the use of new thermostats.

4.2 Building Science in Energy Efficiency Measures

Boiler microprocessor controls can be added and programmed to improve the overall efficiency of the heating system. The following controls, which could reside within a single device, are recommended for retrofits:

- Outdoor reset controls are used to modulate boiler water temperature in inverse proportion to the outdoor temperature, thereby minimizing the potential for overheating and wasted heat.
- Domestic hot water priority is for systems with direct hot water storage tanks. This control will reset the boiler water temperature to 180°F during the period of time the hot water tank is calling for heat. Once the call for heat ends, the boiler water temperature will reset to the temperature calculated by the outdoor reset controller. The result is the

ability to meet domestic hot water needs without keeping boiler water temperatures hotter than necessary to meet space heating needs.

- Pump demand controls allow a variable flow heating loop. Upgrade to a loop pump with a BLPM motor and an integrated variable frequency drive with a built-in pressure sensor. Circulator pumps that use BLPMs are more efficient because they lack brushes that add friction to the motor and can modulate their speed to match the load. Pumping energy then is minimized while meeting needs.
- Boiler staging lead/lag controls are used when multiple boilers are present to provide only as much boiler capacity as is needed. Controls are programmed so that the lead boiler alternates to ensure uniform "wear and tear" of the boilers. As with the other recommended controls, wasted heat as a result of excess heating is minimized for important savings without sacrificing the ability to meet legitimate needs.
- Warm-weather shutdown controls also may be incorporated as a fail-safe mechanism to ensure boilers are not firing when the outside temperature rises above a preset outdoor temperature (60°–65°F is recommended). This fail-safe control ensures that reset control strategies are further optimized for additional savings.
- Building-wide thermostat setback controls allow the building owner to set back the thermostat temperature settings in the common halls and the tenant units. This control sequence would require that thermostats and boiler controls can "talk" to each other. This strategy helps to minimize overheating during periods of typical inactivity such as the early morning hours when comfort zone temperatures are not needed. Common halls also may be kept cooler than tenant units for additional savings.

Figure 12 shows a replacement boiler with integrated processor controls and associated water flow control.

Figure 12. Replacement boiler with microprocessor controls (left); associated water flow control (right)

(Housing Vermont 2010)
(Photos courtesy Efficiency Vermont)

4.3 Risks and Other Considerations

When a heating system is 20 years old or older, it should be replaced with ENERGY STAR-qualified units that have integrated controls (as described previously). Oil boilers should have an AFUE rating of 85% or greater. Propane and natural gas boilers should have an AFUE of 90% or greater. ENERGY STAR boilers use approximately 10% less energy than boilers that meet federal minimum standard efficiency levels (ENERGY STAR 2011a). If replacing the boiler, consider installing a modulating output boiler. Modulating boilers can match exactly the building load by adjusting the burn rate, which allows for low-load operation with no sacrifice in fuel efficiency. Additional guidance on boiler maintenance and retrofitting for multifamily buildings can be found in Dentz and Henderson (2012), Choi et al. (2013), and Appendix C.

Proper Sizing of Heating Systems –
When installing new heating equipment, ensure that proper sizing calculations are performed and that equipment selection guidelines are followed.

Oversized heating systems are energy inefficient and can reduce occupant comfort, indoor air quality, and the overall durability and performance of the equipment. Oversized equipment short-cycles, meaning the equipment turns on and off more frequently than it was designed to do. This increased cycling leads to greater rates of equipment failure. Additionally, the system does not perform at its rated efficiency level. Comfort issues arise when the heating system does not stay on long enough to uniformly heat a space.

Performing updated system sizing calculations is critical after improvements are made to the building shell. Guidance on accurately calculating heating and cooling loads can be found in Rutkowski (1995 and 2006) and in Appendix C.

If the boiler system is going to be replaced, it is critical to reevaluate the heating and cooling demands of the building because other improvement and retrofit activities could have changed the load profile and conditioning needs throughout the space. There is also no guarantee that the original equipment was sized and selected accurately. Load calculations and equipment sizing and selection should be completed in accordance with Air Conditioning Contractors of America Manual J and Manual S (Rutkowski 2006 and 1995, respectively).

If the building has a steam boiler that is 15 years old or older, significant savings could be realized by converting it to a hot water boiler. One study reported savings of more than 60% from converting an old steam-heating system to a hydronic distribution system including high efficiency condensing boilers, indirect-fired domestic hot water, and zone valves (Nolden 1995).

In some buildings, the heating demand in different zones cannot be sufficiently controlled. This can result in building operators overheating some units to ensure that other units receive enough heat. In these circumstances, the most expensive option would be to add zone valves and new wall thermostats to each unit as described above. However, a lower cost option would be to install thermostatic radiator valves that regulate the flow of hot water to the radiator based on the temperature in the room and the occupant's desired set point.

4.4 Estimated Savings

The estimated savings for retrofitting boilers will vary greatly, depending on the heating system and what controls are applied. The savings ranges provided here are based on various studies and analyses showing achievable savings when these types of controls are installed.

Examples of energy savings are again provided based on a 5-unit and a 31-unit low-rise multifamily building. The roof and wall improvements discussed are assumed to have been made, thereby lowering the heat load of the building. The savings from retrofitting controls and pumps assume that the heating systems are oil boilers with an 80% AFUE.

- Adding outdoor reset controls to a single boiler can save approximately 5% in annual heating energy consumption (DTE Energy 2011a and 2011b). This would amount to approximately 8–12 MMBtu in energy savings for the 5-unit building and 25–30 MMBtu for the 31-unit building. A typical install cost is roughly $1,000.
- Adding boiler staging and outdoor reset controls typically saves about 10% in annual heating energy consumption (DTE Energy 2011a and 2011b). This would amount to approximately 16–24 MMBtu in energy savings for the 5-unit building and 50–60 MMBtu for the 31-unit building. A typical install cost is roughly $1,500.
- Upgrading to a BLPM circulator pump with integrated pump demand controls can provide savings ranging from 400 kWh/yr for small applications such as the 5-unit building (less than 1.25 amps) to more than 2,000 kWh/yr for larger applications such as the 31-unit building (more than 5 amps), assuming the primary loop circulator runs constantly during the heating season. On average, this represents a savings of 70% to 80% over standard circulator pumps (VEIC 2011). Typical install costs range from $1,000 to $2,000, depending on the size of the motor and local labor rates.
- A number of effective thermostatic control devices are available to assist building operators and tenants with advanced scheduling of temperature setbacks (or setup for

cooling applications). The potential for savings can be significant, although the magnitude and persistence of the savings rely on appropriate behavior and effective programming of the devices. Installing five programmable thermostats in the 5-unit building would cost approximately $250 to $500, depending on the sophistication of the thermostats and could save 8–12 MMBtu. In the 31-unit building, more advanced thermostat and central remote management of heating, ventilation, and air-conditioning controls could be considered, which could cost $3,000 to $5,000 and could provide an additional 50–100 MMBtu in heating savings and 500–1,000 kWh in cooling savings.

5 Retrofit Measure Strategy Guideline Overview

Figure 13 through Figure 15 provide an overview of each common building retrofit measure. Tied to each retrofit measure are the recommended energy efficiency measures that could be implemented at the time of retrofit, as well as important points to keep in mind when performing these retrofits. Potential energy savings ranges are provided for each energy efficiency retrofit measure.

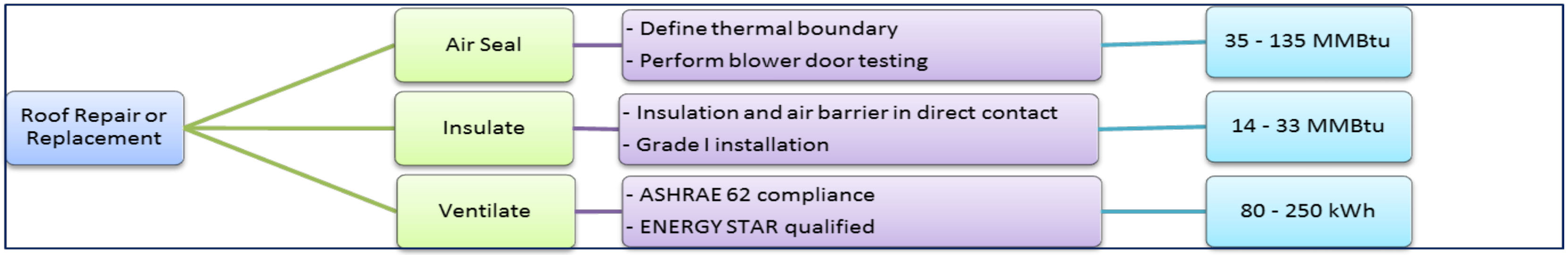

Figure 13. Roof repair or replacement retrofit measure

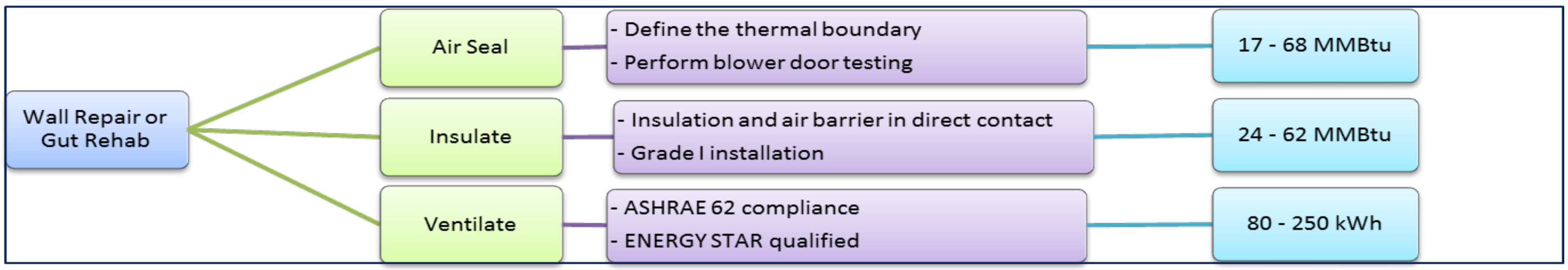

Figure 14. Wall repair or gut rehab retrofit measure

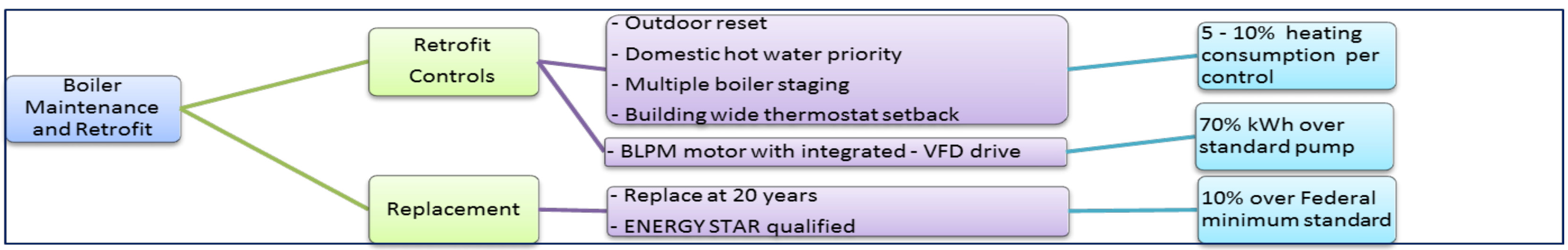

Figure 15. Boiler maintenance and retrofit measure

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