### Pipe Insulation

###### Description

This measure provides rebates for installation of ≥1” or ≥2” fiberglass, foam, calcium silicate or other types of insulation with similar insulating properties to existing bare pipe on straight piping as well as other pipe components such as elbows, tees, valves, and flanges for all non-residential installations.

Default per linear foot savings estimates are provided for the both exposed indoor or above ground outdoor piping distributing fluid in the following system types (natural gas fired systems only):

* Hydronic heating systems (with or without outdoor reset controls), including:
  + boiler systems that do not circulate water around a central loop and operate upon demand from a thermostat (“non-recirculation”)
  + systems that recirculate during heating season only (“Recirculation – heating season only”)
  + systems recirculating year round (“Recirculation – year round”)
* Domestic hot water
* Low and high-pressure steam systems
  + non-recirculation
  + recirculation - heating season only
  + recirculation - year round

Process piping can also use the algorithms provided but requires custom entry of hours.

Minimum qualifying nominal pipe diameter is 1.” Indoor piping must have at least 1” of insulation and outdoor piping must have at least 2” of insulation and include an all-weather protective jacket. New advanced insulating materials may be thinner and savings can be calculated with 3E Plus.

This measure was developed to be applicable to the following program types:  RF, DI

If applied to other program types, the measure savings should be verified.

###### Definition of Efficient Equipment

The efficient case is installing pipe wrap insulation to a length of pipe. Indoor piping must have at least 1” of insulation (or equivalent R-value) and outdoor piping must have at least 2” of insulation (or equivalent R-value) and include an all-weather protective jacket. Minimum qualifying pipe diameter is 1.” Insulation must be continuous and contiguous over fittings that directly connect to straight pipe, including elbows and tees.[[1]](#footnote-1)

###### Definition of Baseline Equipment

The base case for savings estimates is a bare pipe. Pipes are required by new construction code to be insulated but are still commonly found uninsulated in older commercial buildings.

###### Deemed Lifetime of Efficient Equipment

The measure life is assumed to be 15 years.[[2]](#footnote-2)

###### Deemed Measure Cost

Actual costs should be used if known. Otherwise the deemed measure costs below based on RS Means[[3]](#footnote-3) pricing reference materials may be used.[[4]](#footnote-4) The following table summarizes the estimated costs for this measure per foot of insulation added and include installation costs:

|  |  |  |
| --- | --- | --- |
| **Insulation Thickness** | | |
|  | **1 Inch (Indoor)** | **2 Inches (Outdoor)** |
| Pipe- RS Means # | 220719.10.5170 | 220719.10.5530 |
| Jacket- RS Means # | 220719.10.0156 | 220719.10.0320 |
| Jacket Type | PVC | Aluminum |
| Insulation Cost per foot | $9.40 | $13.90 |
| Jacket Cost per foot | $4.57 | $7.30 |
| **Total Cost per foot** | **$13.97** | **$21.20** |

###### Loadshape

N/A

###### Coincidence Factor

N/A

Algorithm

###### Calculation of Savings

###### Electric Energy Savings

N/A

###### Summer Coincident Peak Demand Savings

N/A

###### Natural Gas Savings

Δtherms per foot[[5]](#footnote-5) = [((Qbase – Qeff) \* EFLH) / (100,000 \* ηBoiler)] \* TRF

= [Modeled or provided by tables below] \* TRF

Δtherms = (Lsp + Loc,i) \* Δtherms per foot

Where:

EFLH = Equivalent Full Load Hours for Heating

= Actual or defaults by building type provided in Section 4.4, HVAC end use

For year round recirculation or domestic hot water:

= 8,766

For heating season recirculation, hours with the outside air temperature below 55°F:

| **Zone** | **Hours** |
| --- | --- |
| Zone 1 (Rockford) | 5,039 |
| Zone 2 (Chicago) | 4,963 |
| Zone 3 (Springfield) | 4,495 |
| Zone 4 (Belleville/ | 4,021 |
| Zone 5 (Marion) | 4,150 |
| Zone 1 (Rockford) | 5,039 |

Qbase = Heat Loss from Bare Pipe (Btu/hr/ft)

= Calculated where possible using 3E Plusv4.0 software. For defaults see table below

Qeff = Heat Loss from Insulated Pipe (Btu/hr/ft)

= Calculated where possible using 3E Plusv4.0 software. For defaults see table below

100,000 = conversion factor (1 therm = 100,000 Btu)

ηBoiler = Efficiency of the boiler being used to generate the hot water or steam in the pipe

= 81.9% for water boilers [[6]](#footnote-6)

= 80.7% for steam boilers, except multifamily low-pressure [[7]](#footnote-7)

= 64.8% for multifamily low-pressure steam boilers [[8]](#footnote-8)

TRF = Thermal Regain Factor for space type, applied only to space heating energy and is applied to values resulting from Δtherms/ft tables below [[9]](#footnote-9)

= See table below for base TRF values by pipe location

May vary seasonally such as: TRF[summer] \* summer hours + TRF[winter] \* winter hours where TRF values reflecting summer and winter conditions are apportioned by the hours for those conditions. TRF may also be adjusted by building specific balance temperature and operating hours above and below that balance temperature.[[10]](#footnote-10)

|  |  |  |
| --- | --- | --- |
| **Pipe Location** | **Assumed Regain** | **TRF, Thermal Regain Factor** |
| Outdoor | 0% | 1.0 |
| Indoor, heated space | 85% | 0.15 |
| Indoor, semi- heated, (unconditioned space, with heat transfer to conditioned space. E.g.: boiler room, ceiling plenum, basement, crawlspace, wall) | 30% | 0.70 |
| Indoor, unheated, (no heat transfer to conditioned space) | 0% | 1.0 |
| Location not specified | 85% | 0.15 |
| Custom | Custom | 1 – assumed regain |

Lsp = Length of straight pipe to be insulated (linear foot)

= actual installed ((linear foot)

Loc,I = Total equivalent length of the other components (valves and tees) of pipe to be insulated

= Actual installed (linear foot). See table “Equivalent Length of Other Components – Elbows and Tees” for equivalent lengths.

The heat loss estimates (Qbase and Qeff) were developed using the 3E Plus v4.0 software program.[[11]](#footnote-11) The energy savings analysis is based on adding 1-inch (indoor) or 2-inch (outdoor) thick insulation around bare pipe. The thermal conductivity of pipe insulation varies by material and temperature rating; to obtain a typical value, a range of materials allowed for this measure were averaged. For insulation materials not in the table below, use 3E Plusv4.0 software to calculate Qbase and Qeff.

|  |  |  |
| --- | --- | --- |
| **Insulation Type** | **Conductivity  (Btu.in / hr.ft2.ºF @ 75F)** | **Max temp (ºF)** |
| Polyethylene foam | 0.25 | 200 |
| Flexible polyurethane-based foam | 0.27 | 200 |
| Fiberglass | 0.31 | 250 |
| Melamine foam | 0.26 | 350 |
| Flexible silicon foam | 0.40 | 392 |
| Calcium silicate | 0.40 | 1200 |
| Cellular glass | 0.31 | 400 |
| Average conductivity of all these materials  (Btu.in / hr.ft2.ºF @ 75ºF) | 0.31 |  |

The pipe fluid temperature assumption used depends upon both the system type and whether there is outdoor reset controls:

|  |  |
| --- | --- |
| **System Type** | **Fluid temperature assumption**  **(**°**F)** |
| Hot Water space heating with outdoor reset - Non recirculation | 145 |
| Hot Water space heating without outdoor reset - Non recirculation | 170 |
| Hot Water space heating with outdoor reset – Recirculation heating season only | 145 |
| Hot Water space heating without outdoor reset – Recirculation heating season only | 170 |
| Hot Water space heating with outdoor reset – Recirculation year round | 130 |
| Hot Water space heating without outdoor reset – Recirculation year round | 170 |
| Domestic Hot Water | 125 |
| Low Pressure Steam | 225 |
| High Pressure Steam | 312 |

|  | **Indoor Insulation, Hot Water** | **Indoor Insulation, Low Pressure Steam** | **Indoor Insulation, High Pressure Steam** | **Domestic Hot Water** | **Outdoor Insulation, Hot Water** | **Outdoor Insulation, Low Pressure Steam** | **Outdoor Insulation, High Pressure Steam** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Insulation thickness (inch) | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| Temperature, Fluid in Pipe (ºF) | 170 (w/o reset)  145 (w/ reset heat)  130 (w/reset year) | 225 | 312 | 125 | 170 (w/o reset)  145 (w/ reset heat)  130 (w/reset year) | 225 | 312 |
| Av. steam pressure (psig) | n/a | 10.9 | 82.8 | n/a | n/a | 10.9 | 82.8 |
| Operating Time (hrs/yr) | 2,746 (non-recirc)  5,039 (recirc heating season)  8,760 (recirc year round) | | | | | | |
| Ambient Temperature (ºF)[[12]](#footnote-12) | 75 | 75 | 75 | 75 | 48.6 | 48.6 | 48.6 |
| Wind speed (mph)[[13]](#footnote-13) | 0 | 0 | 0 | 0 | 9.4 | 9.4 | 9.4 |
| **Pipe parameters** | | | | | | | |
| Pipe material | Copper | Steel | Steel | Copper | Copper | Steel | Steel |
| Pipe size for Heat Loss Calc | 2” | 2” | 2” | 2” | 2” | 2” | 2” |
| Outer Diameter, Pipe, actual | 2.38” | 2.38” | 2.38” | 2.38” | 2.38” | 2.38” | 2.38” |
| Heat Loss, Bare Pipe (from 3EPlus) (Btu/hr.ft) | 114 (w/o reset)  78 (w/ reset heat)  58 (w/reset year) | 232 | 432 | 52 | 460 (w/o reset)  363 (w/ reset heat)  306 (w/reset year) | 710 | 1101 |
| **Insulation parameters** | | | | | | | |
| Outer diameter, insulation | 4.38” | 4.38” | 4.38” | 4.38” | 4.38” | 4.38” | 4.38” |
| Average Heat Loss, Insulation (from 3EPlus) (Btu/hr.ft) | 24 (w/o reset)  17 (w/ reset heat)  13 (w/reset year) | 40 | 70 | 13.25 | 21 (w/o reset)  16 (w/ reset heat)  13 (w/reset year) | 32 | 52 |
| **Annual Energy Savings** | | | | | | | |
| Boiler / Water Heater efficiency | 81.9% | 80.7% (64.8% for MF) | 80.7% | 67% | 81.9% | 80.7% (64.8% for MF) | 80.7% |
| Annual Gas Use, Base Case (therms/yr/ft) | 3.8 (w/o reset)  4.8 (w/ reset heat)  6.2 (w/reset year) | 7.9 (non recirc)  14.5 (recirc heat)  25.2 (recirc year) | 14.7 (non recirc)  27.0 (recirc heat)  46.9 (recirc year) | 6.76 | 15.4 (w/o reset)  22.5 (w/ reset heat)  32.7 (w/reset year) | 24.1 (non recirc)  44.3 (recirc heat)  77.0 (recirc year) | 37.5 (non recirc)  68.7 (recirc heat)  119.5 (recirc year) |
| Annual Gas Use, Measure case (therms/yr/ft) | 0.8 (w/o reset)  1.1 (w/ reset heat)  1.4 (w/reset year) | 1.4 (non recirc)  2.5 (recirc heat)  4.4 (recirc year) | 2.4 (non recirc)  4.4 (recirc heat)  7.6 (recirc year) | 1.73 | 0.7 (w/o reset)  1.0 (w/ reset heat)  1.4 (w/reset year) | 1.1 (non recirc)  2.0 (recirc heat)  3.4 (recirc year) | 1.8 (non recirc)  3.2 (recirc heat)  5.6 (recirc year) |
| Annual Gas Savings (therms/yr/ft) | 3.0 (w/o reset)  3.7 (w/ reset heat)  4.8 (w/reset year) | 6.5 (non recirc)  12.0 (recirc heat)  20.8 (recirc year) | 12.3 (non recirc)  22.6 (recirc heat)  39.3 (recirc year) | 5.0 | 14.7 (w/o reset)  21.4 (w/ reset heat)  31.3 (w/reset year) | 23.1 (non recirc)  42.3 (recirc heat)  73.6 (recirc year) | 35.7 (non recirc)  65.5 (recirc heat)  113.9 (recirc year) |

Heat = heating season only, year = year round

Values below must be multiplied by the appropriate Thermal Regain Factor (TRF). All variables were the same except for hours of operation in the calculation of the default savings per foot for the various building types and applications as presented in the table below:

Savings Summary for Indoor pipe insulation by System Type and Building Type (Δtherms per foot) (continues for 3.5 pages)

|  |  |  | **Annual therm Savings per linear foot (therm /ft)**  **(2" pipe / 1" insulation for hot water, 2" insulation for steam)** | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **System Type** | **Building Type** | **Zone 1 (Rockford)** | **Zone 2 (Chicago)** | **Zone 3 (Springfield)** | **Zone 4 (Belleville)** | **Zone 5**  **(Marion)** |
| Indoor | Hot Water Space Heating with outdoor reset – non-recirculation | Assembly | 1.32 | 1.36 | 1.21 | 0.81 | 1.24 |
| Assisted Living | 1.25 | 1.22 | 1.07 | 0.79 | 0.95 |
| College | 1.13 | 1.06 | 0.95 | 0.53 | 0.63 |
| Convenience Store | 1.10 | 1.01 | 0.90 | 0.65 | 0.72 |
| Elementary School | 1.32 | 1.29 | 1.13 | 0.78 | 0.95 |
| Garage | 0.73 | 0.72 | 0.63 | 0.50 | 0.56 |
| Grocery | 1.19 | 1.19 | 1.04 | 0.65 | 0.78 |
| Healthcare Clinic | 1.17 | 1.20 | 1.05 | 0.71 | 0.75 |
| High School | 1.37 | 1.38 | 1.23 | 0.88 | 1.03 |
| Hospital - CAV no econ | 1.31 | 1.35 | 1.15 | 0.99 | 1.12 |
| Hospital - CAV econ | 1.33 | 1.37 | 1.17 | 1.01 | 1.15 |
| Hospital - VAV econ | 0.54 | 0.51 | 0.39 | 0.23 | 0.25 |
| Hospital - FCU | 0.98 | 1.12 | 0.91 | 1.07 | 1.44 |
| Hotel/Motel | 1.31 | 1.27 | 1.14 | 0.78 | 0.96 |
| Hotel/Motel - Common | 1.19 | 1.21 | 1.15 | 0.93 | 0.98 |
| Hotel/Motel - Guest | 1.30 | 1.26 | 1.13 | 0.75 | 0.93 |
| Manufacturing Facility | 0.78 | 0.75 | 0.70 | 0.42 | 0.47 |
| MF - High Rise | 1.13 | 1.12 | 1.02 | 0.87 | 0.87 |
| MF - High Rise - Common | 1.35 | 1.31 | 1.17 | 0.81 | 1.04 |
| MF - High Rise - Residential | 1.09 | 1.08 | 0.99 | 0.85 | 0.83 |
| MF - Mid Rise | 1.23 | 1.25 | 1.07 | 0.79 | 0.90 |
| Movie Theater | 1.35 | 1.33 | 1.24 | 0.94 | 1.12 |
| Office - High Rise - CAV no econ | 1.50 | 1.52 | 1.38 | 0.93 | 1.01 |
| Office - High Rise - CAV econ | 1.55 | 1.58 | 1.45 | 1.00 | 1.10 |
| Office - High Rise - VAV econ | 1.13 | 1.15 | 0.95 | 0.56 | 0.63 |
| Office - High Rise - FCU | 0.83 | 0.82 | 0.71 | 0.37 | 0.39 |
| Office - Low Rise | 1.06 | 1.06 | 0.84 | 0.51 | 0.59 |
| Office - Mid Rise | 1.17 | 1.18 | 0.99 | 0.63 | 0.70 |
| Religious Building | 1.19 | 1.11 | 1.07 | 0.78 | 0.89 |
| Restaurant | 1.00 | 1.00 | 0.90 | 0.68 | 0.81 |
| Retail - Department Store | 1.03 | 0.95 | 0.89 | 0.58 | 0.66 |
| Retail - Strip Mall | 0.99 | 0.91 | 0.81 | 0.56 | 0.60 |
| Warehouse | 1.08 | 1.01 | 1.04 | 0.65 | 0.80 |
| Unknown | 1.15 | 1.14 | 1.01 | 0.73 | 0.84 |
| Hot Water Space Heating without outdoor reset – non-recirculation | Assembly | 1.96 | 2.00 | 1.79 | 1.19 | 1.83 |
| Assisted Living | 1.84 | 1.80 | 1.58 | 1.16 | 1.40 |
| College | 1.67 | 1.56 | 1.40 | 0.78 | 0.93 |
| Convenience Store | 1.62 | 1.50 | 1.33 | 0.95 | 1.06 |
| Elementary School | 1.95 | 1.90 | 1.68 | 1.16 | 1.40 |
| Garage | 1.08 | 1.06 | 0.93 | 0.74 | 0.82 |
| Grocery | 1.76 | 1.75 | 1.54 | 0.96 | 1.15 |
| Healthcare Clinic | 1.73 | 1.77 | 1.55 | 1.05 | 1.11 |
| High School | 2.02 | 2.03 | 1.82 | 1.30 | 1.52 |
| Hospital - CAV no econ | 1.93 | 1.99 | 1.69 | 1.46 | 1.65 |
| Hospital - CAV econ | 1.96 | 2.03 | 1.73 | 1.50 | 1.70 |
| Hospital - VAV econ | 0.80 | 0.76 | 0.57 | 0.34 | 0.37 |
| Hospital - FCU | 1.45 | 1.65 | 1.35 | 1.58 | 2.13 |
| Hotel/Motel | 1.93 | 1.87 | 1.69 | 1.16 | 1.41 |
| Hotel/Motel - Common | 1.75 | 1.78 | 1.69 | 1.38 | 1.45 |
| Hotel/Motel - Guest | 1.92 | 1.86 | 1.66 | 1.11 | 1.37 |
| Manufacturing Facility | 1.15 | 1.11 | 1.03 | 0.62 | 0.69 |
| MF - High Rise | 1.67 | 1.65 | 1.50 | 1.28 | 1.28 |
| MF - High Rise - Common | 1.99 | 1.93 | 1.73 | 1.19 | 1.54 |
| MF - High Rise - Residential | 1.61 | 1.60 | 1.46 | 1.26 | 1.23 |
| MF - Mid Rise | 1.82 | 1.84 | 1.59 | 1.17 | 1.33 |
| Movie Theater | 1.99 | 1.96 | 1.83 | 1.39 | 1.66 |
| Office - High Rise - CAV no econ | 2.21 | 2.24 | 2.04 | 1.37 | 1.49 |
| Office - High Rise - CAV econ | 2.29 | 2.33 | 2.14 | 1.48 | 1.63 |
| Office - High Rise - VAV econ | 1.67 | 1.70 | 1.40 | 0.83 | 0.93 |
| Office - High Rise - FCU | 1.22 | 1.21 | 1.04 | 0.55 | 0.58 |
| Office - Low Rise | 1.56 | 1.56 | 1.24 | 0.76 | 0.87 |
| Office - Mid Rise | 1.73 | 1.74 | 1.47 | 0.94 | 1.04 |
| Religious Building | 1.75 | 1.65 | 1.58 | 1.15 | 1.32 |
| Restaurant | 1.48 | 1.48 | 1.33 | 1.01 | 1.19 |
| Retail - Department Store | 1.52 | 1.40 | 1.31 | 0.85 | 0.97 |
| Retail - Strip Mall | 1.46 | 1.35 | 1.19 | 0.82 | 0.89 |
| Warehouse | 1.59 | 1.49 | 1.53 | 0.96 | 1.18 |
| Unknown | 1.70 | 1.68 | 1.50 | 1.07 | 1.25 |
| Hot Water with outdoor reset | All buildings, Recirculation heating season only (Hours below 55F) | 3.73 | 3.68 | 3.33 | 2.98 | 3.08 |
| Hot Water w/o outdoor reset | All buildings, Recirculation heating season only (Hours below 55F) | 5.51 | 5.43 | 4.92 | 4.40 | 4.54 |
| Hot Water with outdoor reset | All buildings, Recirculation year round (All hours) | 4.79 | 4.79 | 4.79 | 4.79 | 4.79 |
| Hot Water w/o outdoor reset | All buildings, Recirculation year round (All hours) | 9.58 | 9.58 | 9.58 | 9.58 | 9.58 |
| Domestic Hot Water | DHW circulation loop | 5.02 | 5.02 | 5.02 | 5.02 | 5.02 |
| LP Steam – non-recirculation | Assembly | 4.25 | 4.36 | 3.89 | 2.59 | 3.97 |
| Assisted Living | 4.01 | 3.92 | 3.44 | 2.53 | 3.04 |
| College | 3.64 | 3.40 | 3.04 | 1.69 | 2.02 |
| Convenience Store | 3.52 | 3.26 | 2.89 | 2.07 | 2.32 |
| Elementary School | 4.24 | 4.13 | 3.64 | 2.52 | 3.05 |
| Garage | 2.34 | 2.31 | 2.03 | 1.62 | 1.79 |
| Grocery | 3.83 | 3.81 | 3.34 | 2.08 | 2.49 |
| Healthcare Clinic | 3.76 | 3.85 | 3.36 | 2.29 | 2.42 |
| High School | 4.39 | 4.42 | 3.96 | 2.82 | 3.30 |
| Hospital - CAV no econ | 4.20 | 4.33 | 3.69 | 3.17 | 3.60 |
| Hospital - CAV econ | 4.25 | 4.41 | 3.76 | 3.26 | 3.70 |
| Hospital - VAV econ | 1.74 | 1.65 | 1.24 | 0.75 | 0.81 |
| Hospital - FCU | 3.15 | 3.60 | 2.93 | 3.44 | 4.63 |
| Hotel/Motel | 4.19 | 4.07 | 3.67 | 2.51 | 3.07 |
| Hotel/Motel - Common | 3.81 | 3.87 | 3.68 | 3.00 | 3.15 |
| Hotel/Motel - Guest | 4.18 | 4.05 | 3.62 | 2.42 | 2.98 |
| Manufacturing Facility | 2.49 | 2.41 | 2.23 | 1.35 | 1.51 |
| MF - High Rise | 4.52 | 4.46 | 4.07 | 3.46 | 3.47 |
| MF - High Rise - Common | 5.38 | 5.22 | 4.68 | 3.23 | 4.17 |
| MF - High Rise - Residential | 4.37 | 4.34 | 3.94 | 3.41 | 3.33 |
| MF - Mid Rise | 4.94 | 4.99 | 4.30 | 3.16 | 3.60 |
| Movie Theater | 4.33 | 4.26 | 3.98 | 3.03 | 3.61 |
| Office - High Rise - CAV no econ | 4.81 | 4.88 | 4.45 | 2.98 | 3.24 |
| Office - High Rise - CAV econ | 4.97 | 5.07 | 4.66 | 3.21 | 3.54 |
| Office - High Rise - VAV econ | 3.64 | 3.71 | 3.06 | 1.81 | 2.01 |
| Office - High Rise - FCU | 2.66 | 2.62 | 2.27 | 1.20 | 1.26 |
| Office - Low Rise | 3.40 | 3.39 | 2.69 | 1.65 | 1.89 |
| Office - Mid Rise | 3.77 | 3.78 | 3.19 | 2.03 | 2.26 |
| Religious Building | 3.82 | 3.58 | 3.43 | 2.51 | 2.87 |
| Restaurant | 3.21 | 3.22 | 2.89 | 2.19 | 2.60 |
| Retail - Department Store | 3.31 | 3.04 | 2.86 | 1.86 | 2.12 |
| Retail - Strip Mall | 3.17 | 2.94 | 2.59 | 1.79 | 1.93 |
| Warehouse | 3.46 | 3.23 | 3.33 | 2.08 | 2.56 |
| Unknown | 3.70 | 3.66 | 3.26 | 2.34 | 2.71 |
| LP Steam | All buildings, Recirculation heating season only (Hours below 55F) | 11.99 | 11.81 | 10.70 | 9.57 | 9.88 |
| LP Steam | All buildings, Recirculation year round (All hours) | 20.84 | 20.84 | 20.84 | 20.84 | 20.84 |
| HP Steam – non-recirculation | Assembly | 8.02 | 8.22 | 7.34 | 4.89 | 7.49 |
| Assisted Living | 7.56 | 7.39 | 6.49 | 4.77 | 5.73 |
| College | 6.87 | 6.42 | 5.73 | 3.18 | 3.81 |
| Convenience Store | 6.65 | 6.14 | 5.45 | 3.91 | 4.37 |
| Elementary School | 8.00 | 7.79 | 6.87 | 4.75 | 5.76 |
| Garage | 4.42 | 4.35 | 3.82 | 3.05 | 3.38 |
| Grocery | 7.22 | 7.19 | 6.30 | 3.93 | 4.70 |
| Healthcare Clinic | 7.09 | 7.27 | 6.35 | 4.32 | 4.57 |
| High School | 8.28 | 8.34 | 7.48 | 5.33 | 6.23 |
| Hospital - CAV no econ | 7.92 | 8.16 | 6.95 | 5.98 | 6.79 |
| Hospital - CAV econ | 8.03 | 8.32 | 7.09 | 6.14 | 6.98 |
| Hospital - VAV econ | 3.28 | 3.12 | 2.35 | 1.41 | 1.53 |
| Hospital - FCU | 5.95 | 6.79 | 5.53 | 6.50 | 8.73 |
| Hotel/Motel | 7.91 | 7.69 | 6.93 | 4.74 | 5.79 |
| Hotel/Motel - Common | 7.18 | 7.30 | 6.95 | 5.65 | 5.94 |
| Hotel/Motel - Guest | 7.89 | 7.64 | 6.83 | 4.57 | 5.62 |
| Manufacturing Facility | 4.70 | 4.55 | 4.22 | 2.55 | 2.84 |
| MF - High Rise | 6.85 | 6.76 | 6.16 | 5.25 | 5.26 |
| MF - High Rise - Common | 8.15 | 7.91 | 7.09 | 4.89 | 6.31 |
| MF - High Rise - Residential | 6.62 | 6.57 | 5.97 | 5.17 | 5.04 |
| MF - Mid Rise | 7.48 | 7.57 | 6.51 | 4.79 | 5.46 |
| Movie Theater | 8.16 | 8.04 | 7.52 | 5.71 | 6.80 |
| Office - High Rise - CAV no econ | 9.07 | 9.20 | 8.39 | 5.62 | 6.12 |
| Office - High Rise - CAV econ | 9.38 | 9.57 | 8.80 | 6.06 | 6.67 |
| Office - High Rise - VAV econ | 6.86 | 6.99 | 5.76 | 3.41 | 3.80 |
| Office - High Rise - FCU | 5.02 | 4.95 | 4.27 | 2.27 | 2.38 |
| Office - Low Rise | 6.41 | 6.40 | 5.08 | 3.11 | 3.56 |
| Office - Mid Rise | 7.12 | 7.12 | 6.03 | 3.84 | 4.27 |
| Religious Building | 7.20 | 6.75 | 6.46 | 4.73 | 5.41 |
| Restaurant | 6.06 | 6.08 | 5.46 | 4.13 | 4.90 |
| Retail - Department Store | 6.25 | 5.74 | 5.39 | 3.51 | 4.00 |
| Retail - Strip Mall | 5.98 | 5.54 | 4.89 | 3.37 | 3.63 |
| Warehouse | 6.53 | 6.09 | 6.29 | 3.93 | 4.84 |
| Unknown | 6.97 | 6.91 | 6.14 | 4.41 | 5.11 |
| HP Steam | All buildings, Recirculation heating season only (Hours below 55F) | 22.62 | 22.28 | 20.18 | 18.05 | 18.63 |
| HP Steam | All buildings, Recirculation year round (All hours) | 39.32 | 39.32 | 39.32 | 39.32 | 39.32 |

Savings Summary for Outdoor pipe insulation by System Type and Building Type (Δtherms per foot) (continues for 3.5 pages)

|  |  |  | **Annual therm Savings per linear foot (therm /ft)**  **(2" pipe / 1" insulation for hot water, 2" insulation for steam)** | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Location** | **System Type** | **Building Type** | **Zone 1 (Rockford)** | **Zone 2 (Chicago)** | **Zone 3 (Springfield)** | **Zone 4 (Belleville)** | **Zone 5**  **(Marion)** |
| Outdoor | Hot Water Space Heating with outdoor reset – non-recirculation | Assembly | 7.58 | 7.77 | 6.94 | 4.62 | 7.08 |
| Assisted Living | 7.14 | 6.98 | 6.13 | 4.51 | 5.42 |
| College | 6.49 | 6.07 | 5.41 | 3.01 | 3.60 |
| Convenience Store | 6.28 | 5.80 | 5.15 | 3.70 | 4.13 |
| Elementary School | 7.56 | 7.36 | 6.50 | 4.49 | 5.44 |
| Garage | 4.18 | 4.11 | 3.61 | 2.88 | 3.19 |
| Grocery | 6.82 | 6.80 | 5.96 | 3.72 | 4.44 |
| Healthcare Clinic | 6.70 | 6.87 | 6.00 | 4.09 | 4.32 |
| High School | 7.83 | 7.88 | 7.07 | 5.03 | 5.89 |
| Hospital - CAV no econ | 7.49 | 7.71 | 6.57 | 5.65 | 6.41 |
| Hospital - CAV econ | 7.59 | 7.86 | 6.70 | 5.81 | 6.60 |
| Hospital - VAV econ | 3.10 | 2.95 | 2.22 | 1.33 | 1.44 |
| Hospital - FCU | 5.62 | 6.42 | 5.23 | 6.14 | 8.26 |
| Hotel/Motel | 7.47 | 7.26 | 6.55 | 4.48 | 5.47 |
| Hotel/Motel - Common | 6.79 | 6.90 | 6.57 | 5.34 | 5.61 |
| Hotel/Motel - Guest | 7.46 | 7.22 | 6.45 | 4.32 | 5.31 |
| Manufacturing Facility | 4.45 | 4.30 | 3.98 | 2.41 | 2.69 |
| MF - High Rise | 6.48 | 6.39 | 5.83 | 4.96 | 4.97 |
| MF - High Rise - Common | 7.70 | 7.48 | 6.70 | 4.62 | 5.96 |
| MF - High Rise - Residential | 6.26 | 6.21 | 5.64 | 4.89 | 4.77 |
| MF - Mid Rise | 7.07 | 7.15 | 6.15 | 4.53 | 5.16 |
| Movie Theater | 7.71 | 7.60 | 7.10 | 5.40 | 6.43 |
| Office - High Rise - CAV no econ | 8.57 | 8.70 | 7.93 | 5.31 | 5.78 |
| Office - High Rise - CAV econ | 8.86 | 9.04 | 8.32 | 5.73 | 6.31 |
| Office - High Rise - VAV econ | 6.48 | 6.61 | 5.45 | 3.22 | 3.59 |
| Office - High Rise - FCU | 4.75 | 4.67 | 4.04 | 2.14 | 2.25 |
| Office - Low Rise | 6.06 | 6.05 | 4.80 | 2.94 | 3.36 |
| Office - Mid Rise | 6.73 | 6.73 | 5.70 | 3.63 | 4.03 |
| Religious Building | 6.80 | 6.38 | 6.11 | 4.47 | 5.11 |
| Restaurant | 5.73 | 5.75 | 5.16 | 3.90 | 4.63 |
| Retail - Department Store | 5.91 | 5.42 | 5.09 | 3.31 | 3.78 |
| Retail - Strip Mall | 5.65 | 5.23 | 4.62 | 3.19 | 3.44 |
| Warehouse | 6.18 | 5.76 | 5.94 | 3.71 | 4.57 |
| Unknown | 6.59 | 6.53 | 5.81 | 4.17 | 4.83 |
| Hot Water Space Heating without outdoor reset – non-recirculation | Assembly | 9.59 | 9.83 | 8.77 | 5.85 | 8.96 |
| Assisted Living | 9.04 | 8.83 | 7.76 | 5.70 | 6.86 |
| College | 8.21 | 7.68 | 6.85 | 3.80 | 4.56 |
| Convenience Store | 7.95 | 7.34 | 6.52 | 4.68 | 5.22 |
| Elementary School | 9.56 | 9.32 | 8.22 | 5.68 | 6.89 |
| Garage | 5.28 | 5.20 | 4.57 | 3.65 | 4.04 |
| Grocery | 8.63 | 8.60 | 7.54 | 4.70 | 5.62 |
| Healthcare Clinic | 8.47 | 8.70 | 7.59 | 5.17 | 5.47 |
| High School | 9.90 | 9.97 | 8.94 | 6.37 | 7.45 |
| Hospital - CAV no econ | 9.47 | 9.76 | 8.31 | 7.15 | 8.11 |
| Hospital - CAV econ | 9.60 | 9.95 | 8.48 | 7.35 | 8.34 |
| Hospital - VAV econ | 3.93 | 3.73 | 2.80 | 1.68 | 1.82 |
| Hospital - FCU | 7.11 | 8.12 | 6.61 | 7.77 | 10.45 |
| Hotel/Motel | 9.45 | 9.19 | 8.29 | 5.67 | 6.92 |
| Hotel/Motel - Common | 8.59 | 8.73 | 8.31 | 6.76 | 7.10 |
| Hotel/Motel - Guest | 9.44 | 9.13 | 8.16 | 5.47 | 6.72 |
| Manufacturing Facility | 5.63 | 5.44 | 5.04 | 3.05 | 3.40 |
| MF - High Rise | 8.19 | 8.08 | 7.37 | 6.27 | 6.29 |
| MF - High Rise - Common | 9.74 | 9.46 | 8.48 | 5.85 | 7.54 |
| MF - High Rise - Residential | 7.92 | 7.86 | 7.14 | 6.18 | 6.03 |
| MF - Mid Rise | 8.94 | 9.05 | 7.78 | 5.73 | 6.53 |
| Movie Theater | 9.76 | 9.61 | 8.99 | 6.83 | 8.14 |
| Office - High Rise - CAV no econ | 10.84 | 11.01 | 10.03 | 6.72 | 7.32 |
| Office - High Rise - CAV econ | 11.21 | 11.44 | 10.52 | 7.25 | 7.98 |
| Office - High Rise - VAV econ | 8.20 | 8.36 | 6.89 | 4.07 | 4.54 |
| Office - High Rise - FCU | 6.00 | 5.91 | 5.11 | 2.71 | 2.84 |
| Office - Low Rise | 7.67 | 7.65 | 6.08 | 3.72 | 4.25 |
| Office - Mid Rise | 8.51 | 8.52 | 7.21 | 4.59 | 5.10 |
| Religious Building | 8.61 | 8.07 | 7.73 | 5.66 | 6.47 |
| Restaurant | 7.25 | 7.27 | 6.53 | 4.94 | 5.85 |
| Retail - Department Store | 7.47 | 6.86 | 6.44 | 4.19 | 4.78 |
| Retail - Strip Mall | 7.15 | 6.62 | 5.85 | 4.03 | 4.35 |
| Warehouse | 7.81 | 7.29 | 7.52 | 4.69 | 5.78 |
| Unknown | 8.34 | 8.26 | 7.35 | 5.27 | 6.11 |
| Hot Water with outdoor reset | All buildings, Recirculation heating season only (Hours below 55F) | 21.38 | 21.06 | 19.07 | 17.06 | 17.61 |
| Hot Water without outdoor reset | All buildings, Recirculation heating season only (Hours below 55F) | 27.05 | 26.64 | 24.13 | 21.58 | 22.28 |
| Hot Water with outdoor reset | All buildings, Recirculation year round (All hours) | 31.30 | 31.30 | 31.30 | 31.30 | 31.30 |
| Hot Water without outdoor reset | All buildings, Recirculation year round (All hours) | 47.02 | 47.02 | 47.02 | 47.02 | 47.02 |
| LP Steam – non-recirculation | Assembly | 15.01 | 15.38 | 13.73 | 9.15 | 14.02 |
| Assisted Living | 14.14 | 13.82 | 12.15 | 8.93 | 10.73 |
| College | 12.85 | 12.01 | 10.72 | 5.95 | 7.13 |
| Convenience Store | 12.44 | 11.49 | 10.20 | 7.32 | 8.17 |
| Elementary School | 14.96 | 14.58 | 12.86 | 8.88 | 10.78 |
| Garage | 8.27 | 8.14 | 7.15 | 5.71 | 6.32 |
| Grocery | 13.51 | 13.46 | 11.80 | 7.36 | 8.79 |
| Healthcare Clinic | 13.26 | 13.61 | 11.88 | 8.09 | 8.56 |
| High School | 15.50 | 15.60 | 13.99 | 9.97 | 11.66 |
| Hospital - CAV no econ | 14.82 | 15.27 | 13.01 | 11.19 | 12.70 |
| Hospital - CAV econ | 15.02 | 15.57 | 13.27 | 11.50 | 13.06 |
| Hospital - VAV econ | 6.14 | 5.84 | 4.39 | 2.64 | 2.85 |
| Hospital - FCU | 11.13 | 12.71 | 10.35 | 12.16 | 16.35 |
| Hotel/Motel | 14.80 | 14.38 | 12.97 | 8.87 | 10.84 |
| Hotel/Motel - Common | 13.45 | 13.66 | 13.00 | 10.58 | 11.12 |
| Hotel/Motel - Guest | 14.77 | 14.29 | 12.78 | 8.56 | 10.52 |
| Manufacturing Facility | 8.80 | 8.51 | 7.89 | 4.77 | 5.32 |
| MF - High Rise | 15.97 | 15.76 | 14.37 | 12.23 | 12.26 |
| MF - High Rise - Common | 18.99 | 18.44 | 16.53 | 11.39 | 14.71 |
| MF - High Rise - Residential | 15.43 | 15.31 | 13.92 | 12.05 | 11.75 |
| MF - Mid Rise | 17.43 | 17.63 | 15.17 | 11.16 | 12.72 |
| Movie Theater | 15.27 | 15.05 | 14.07 | 10.69 | 12.73 |
| Office - High Rise - CAV no econ | 16.97 | 17.22 | 15.70 | 10.51 | 11.45 |
| Office - High Rise - CAV econ | 17.55 | 17.91 | 16.47 | 11.35 | 12.49 |
| Office - High Rise - VAV econ | 12.83 | 13.09 | 10.79 | 6.37 | 7.11 |
| Office - High Rise - FCU | 9.40 | 9.26 | 8.00 | 4.25 | 4.45 |
| Office - Low Rise | 12.00 | 11.97 | 9.51 | 5.82 | 6.66 |
| Office - Mid Rise | 13.32 | 13.33 | 11.28 | 7.18 | 7.98 |
| Religious Building | 13.47 | 12.64 | 12.10 | 8.86 | 10.13 |
| Restaurant | 11.34 | 11.38 | 10.21 | 7.73 | 9.16 |
| Retail - Department Store | 11.69 | 10.74 | 10.08 | 6.56 | 7.48 |
| Retail - Strip Mall | 11.19 | 10.36 | 9.15 | 6.31 | 6.80 |
| Warehouse | 12.23 | 11.40 | 11.77 | 7.35 | 9.05 |
| Unknown | 13.05 | 12.93 | 11.50 | 8.25 | 9.57 |
| LP Steam | All buildings, Recirculation heating season only (Hours below 55F) | 42.33 | 41.69 | 37.76 | 33.78 | 34.86 |
| LP Steam | All buildings, Recirculation year round (All hours) | 73.59 | 73.59 | 73.59 | 73.59 | 73.59 |
| HP Steam – non-recirculation | Assembly | 23.24 | 23.81 | 21.26 | 14.16 | 21.70 |
| Assisted Living | 21.89 | 21.40 | 18.80 | 13.82 | 16.61 |
| College | 19.90 | 18.60 | 16.60 | 9.22 | 11.04 |
| Convenience Store | 19.26 | 17.79 | 15.79 | 11.33 | 12.65 |
| Elementary School | 23.16 | 22.57 | 19.91 | 13.75 | 16.69 |
| Garage | 12.80 | 12.60 | 11.08 | 8.84 | 9.78 |
| Grocery | 20.91 | 20.83 | 18.26 | 11.39 | 13.61 |
| Healthcare Clinic | 20.53 | 21.07 | 18.39 | 12.53 | 13.25 |
| High School | 23.99 | 24.15 | 21.66 | 15.43 | 18.05 |
| Hospital - CAV no econ | 22.94 | 23.64 | 20.14 | 17.32 | 19.66 |
| Hospital - CAV econ | 23.25 | 24.10 | 20.54 | 17.80 | 20.22 |
| Hospital - VAV econ | 9.51 | 9.03 | 6.79 | 4.08 | 4.42 |
| Hospital - FCU | 17.24 | 19.67 | 16.02 | 18.82 | 25.31 |
| Hotel/Motel | 22.90 | 22.27 | 20.08 | 13.74 | 16.77 |
| Hotel/Motel - Common | 20.81 | 21.15 | 20.13 | 16.38 | 17.21 |
| Hotel/Motel - Guest | 22.87 | 22.13 | 19.78 | 13.24 | 16.28 |
| Manufacturing Facility | 13.63 | 13.18 | 12.21 | 7.38 | 8.24 |
| MF - High Rise | 19.85 | 19.59 | 17.86 | 15.20 | 15.24 |
| MF - High Rise - Common | 23.60 | 22.92 | 20.55 | 14.16 | 18.28 |
| MF - High Rise - Residential | 19.18 | 19.03 | 17.30 | 14.98 | 14.61 |
| MF - Mid Rise | 21.67 | 21.92 | 18.86 | 13.87 | 15.81 |
| Movie Theater | 23.64 | 23.29 | 21.78 | 16.55 | 19.71 |
| Office - High Rise - CAV no econ | 26.27 | 26.66 | 24.30 | 16.28 | 17.73 |
| Office - High Rise - CAV econ | 27.16 | 27.72 | 25.49 | 17.57 | 19.33 |
| Office - High Rise - VAV econ | 19.87 | 20.26 | 16.70 | 9.87 | 11.00 |
| Office - High Rise - FCU | 14.54 | 14.33 | 12.38 | 6.57 | 6.89 |
| Office - Low Rise | 18.58 | 18.53 | 14.72 | 9.00 | 10.31 |
| Office - Mid Rise | 20.61 | 20.64 | 17.46 | 11.12 | 12.36 |
| Religious Building | 20.85 | 19.56 | 18.72 | 13.71 | 15.67 |
| Restaurant | 17.55 | 17.61 | 15.81 | 11.96 | 14.18 |
| Retail - Department Store | 18.10 | 16.63 | 15.61 | 10.16 | 11.58 |
| Retail - Strip Mall | 17.32 | 16.04 | 14.17 | 9.77 | 10.53 |
| Warehouse | 18.93 | 17.65 | 18.21 | 11.37 | 14.02 |
| Unknown | 20.20 | 20.01 | 17.80 | 12.77 | 14.81 |
| HP Steam | All buildings, Recirculation heating season only (Hours below 55F) | 65.53 | 64.54 | 58.45 | 52.29 | 53.97 |
| HP Steam | All buildings, Recirculation year round (All hours) | 113.92 | 113.92 | 113.92 | 113.92 | 113.92 |

For insulation covering elbows and tees that connect straight pipe, a calculated surface area will be assumed based on the dimensions for fittings given by ANSI/ASME B36.19. The surface area is then converted to an equivalent length of pipe that must be added to the total length of straight pipe in order to calculate total savings. Equivalent pipe lengths are given in 1” increments in pipe diameter for simplicity. In the case of pipe diameters in between full inch diameters, the closest equivalent length should be used. The larger pipe sizes mostly apply to steam header piping, which has the most heat loss per foot.

**Calculated Surface Areas of Elbows and Tees**

| **Nominal Pipe Diameter** | **Calculated Surface Area (ft)** | |
| --- | --- | --- |
| **90 Degree Elbow[[14]](#footnote-14)** | **Straight Tee[[15]](#footnote-15)** |
| 1” | 0.10 | 0.13 |
| 2” | 0.41 | 0.39 |
| 3” | 0.93 | 0.77 |
| 4” | 1.64 | 1.21 |
| 5” | 2.57 | 1.77 |
| 6” | 3.70 | 2.44 |
| 8” | 6.58 | 3.95 |
| 10” | 10.28 | 5.98 |
| 12” | 14.80 | 8.34 |

**Equivalent Length of Other Components – Elbows and Tees (Loc)**

|  |  |  |
| --- | --- | --- |
| **Nominal Pipe Diameter** | **Equivalent Length of Other Components (ft)** | |
| **90 Degree Elbow** | **Straight Tee** |
| 1” | 0.30 | 0.38 |
| 2” | 0.66 | 0.63 |
| 3” | 1.01 | 0.84 |
| 4” | 1.40 | 1.03 |
| 5” | 1.76 | 1.22 |
| 6” | 2.13 | 1.41 |
| 8” | 2.91 | 1.75 |
| 10” | 3.65 | 2.13 |
| 12” | 4.44 | 2.50 |

For insulation around valves or flanges, a surface area from ASTM standard C1129-12 will be assumed for 2” pipes. For 1” pipes, which weren’t included in the standard, a linear-trended value will be used. The surface area is then converted to an equivalent length of either 1” or 2” straight pipe that must be added to the total length of straight pipe in order to calculate total savings.

**Calculated Surface Areas of Flanges and Valves**

| **Valves** | | | | |  | **Flanges** | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Class (psi)** | **150** | **300** | **600** | **900** |  | **Class (psi)** | **150** | **300** | **600** | **900** |
| **NPS (in)** | **ft2** | **ft2** | **ft2** | **ft2** |  | **NPS (in)** | **ft2** | **ft2** | **ft2** | **ft2** |
| 1 | 0.69 | 1.8 | 1.8 | 2.4 |  | 1 | 0.36 | 0.36 | 0.4 | 1.23 |
| 2 | 2.21 | 2.94 | 2.94 | 5.2 |  | 2 | 0.71 | 0.84 | 0.88 | 1.54 |
| 2.5 | 2.97 | 3.51 | 3.91 | 6.6 |  |  |  |  |  |  |
| 3 | 3.37 | 4.39 | 4.69 | 6.5 |  | 3 | 1.06 | 1.32 | 1.36 | 1.85 |
| 4 | 4.68 | 6.06 | 7.64 | 9.37 |  | 4 | 1.44 | 1.83 | 2.23 | 2.64 |
| 6 | 7.03 | 9.71 | 13.03 | 15.8 |  | 6 | 2.04 | 2.72 | 3.6 | 4.37 |
| 8 | 10.3 | 13.5 | 18.4 | 23.8 |  | 8 | 2.92 | 3.74 | 4.89 | 6.4 |
| 10 | 13.8 | 18 | 26.5 | 32.1 |  | 10 | 3.68 | 4.8 | 6.93 | 8.47 |
| 12 | 16.1 | 24.1 | 31.9 | 41.9 |  | 12 | 5.01 | 6.34 | 7.97 | 10.43 |

**Equivalent Length of Other Components - Flanges and Valves (Loc)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ANSI Class (psi)** | **Equivalent Length of Other Components (ft)** | | | |
| **1” Valve** | **1” Flange** | **2” Valve** | **2” Flange** |
| 150 | 3.56 | 1.05 | 3.56 | 1.14 |
| 300 | 4.73 | 1.05 | 4.73 | 1.35 |
| 600 | 4.73 | 1.16 | 4.73 | 1.42 |
| 900 | 8.37 | 3.57 | 8.37 | 2.48 |

###### Water Impact Descriptions and Calculation

N/A

###### Deemed O&M Cost Adjustment Calculation

N/A

###### Measure Code: CI-HVC-PINS-V04-160601

1. *ASHRAE Handbook—Fundamentals*, 23.14; Hart, G., “Saving energy by insulating pipe components on steam and hot water distribution systems”, *ASHRAE Journal*, October 2011 [↑](#footnote-ref-1)
2. Measure Life Report, Residential and Commercial/Industrial Lighting and HVAC Measures, GDS Associates, June 2007.

   <http://neep.org/uploads/EMV%20Forum/EMV%20Studies/measure_life_GDS%5B1%5D.pdf> [↑](#footnote-ref-2)
3. RS Means 2008. Mechanical Cost Data, pages 106 to 119 [↑](#footnote-ref-3)
4. RS Means 2010: “for fittings, add 3 linear feet for each fitting plus 4 linear feet for each flange of the fitting” [↑](#footnote-ref-4)
5. This value comes from the reference table “Savings Summary by Building Type and System Type.” The formula and the input tables in this section document assumptions used in calculation spreadsheet “Pipe Insulation Savings 2013-11-12.xlsx” [↑](#footnote-ref-5)
6. Average efficiencies of units from the California Energy Commission (CEC). [↑](#footnote-ref-6)
7. Ibid. [↑](#footnote-ref-7)
8. Katrakis, J. and T.S. Zawacki. “Field-Measured Seasonal Efficiency of Intermediate-sized Low-Pressure Steam Boilers”. ASHRAE V99, pt. 2, 1993. [↑](#footnote-ref-8)
9. Thermal regain for *residential* pipe insulation measures is discussed in Home Energy Services Impact Evaluation, prepared for the Massachusetts Residential Retrofit and Low Income Program Area Evaluation, Cadmus Group, Inc., August 2012 and Andrews, John, Better Duct Systems for Home Heating and Cooling, U.S. Department of Energy, 2001. Recognizing the differences between residential and commercial heating systems, the factors have been adjusted based on professional judgment. This factor would benefit from additional study and evaluation. [↑](#footnote-ref-9)
10. Thermal Regain Factor\_4-30-14.docx [↑](#footnote-ref-10)
11. 3E Plus is a heat loss calculation software provided by the NAIMA (North American Insulation Manufacturer Association). [↑](#footnote-ref-11)
12. DOE Weather Data. <http://apps1.eere.energy.gov/buildings/energyplus/weatherdata/4_north_and_central_america_wmo_region_4/1_usa/USA_IL_Aurora.Muni.AP.744655_TMY3.stat> Ibid. [↑](#footnote-ref-12)
13. Ibid. [↑](#footnote-ref-13)
14. Based on the dimensions for diameter, long radius, and short radius given by ANSI/ASME 36.19 [↑](#footnote-ref-14)
15. Based on the center to face and diameter dimensions given by ANSI/ASME B36.19 [↑](#footnote-ref-15)