B-42

David Timberlake, P.E.
Chairman

Mary Fallin
Governor

Oklahoma Uniform Building Code Commission

PUBLIC COMMENT FORM FOR THE ADOPTION OF BUILDING/CONSTRUCTION CODES PROPOSED CHANGE TO THE INTERNATIONAL RESIDENTIAL CODE®

INSTRUCTIONS: Please type or print clearly. Form must be signed. Any form not signed or filled out completely, may not be considered. Each requested change must be on a separate form.

1. **Submitters Contact Information:**

Name: Kelly Parker Date: 8/04/15
Company: Guaranteed Watt Saver Systems Inc.
Address: 6444 NW Expressway, Suite 836A
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2. **Do you feel this proposed change will increase the cost of construction?** ☐ Yes ☒ No

3. **Which are of the code needs revision?**
Section: Chapter 11 Table: Figure: Page No:

4. **Please check the appropriate box:**

☐ Revise as follows ☐ Delete as follows ☐ Add new text as follows ☒ Delete with substitute

Show the proposed NEW, REVISED, OR DELETED TEXT in legislative format, (line through text to be deleted and underline text to be added or revised).

Delete all of Chapter 11 from the 2015 International Residential Code and replace with the following attachment.

Supporting information: State purpose and reason for the change and provide substantiation to support proposed change.

2009 Chapter 11 Energy Efficiency needs to be better defined and more effective for Oklahoma. Oklahoma citizens deserve an efficient built home.

5. Signature: Kelly Parker

Send completed "Public Comment Form" to:
Oklahoma Uniform Building Code Commission, PO Box 12540, Oklahoma City, OK 73157
Email to: Shawnta.Mitchell@oubcc.ok.gov or Fax to: 405-521-6504

Part IV-Energy Conservation
CHAPTER 11
ENERGY EFFICIENCY

SECTION N1101
GENERAL

N1101.1 Scope. This chapter regulates the energy efficiency for the design and construction of buildings regulated by this code.

Note: The text of the following Sections N1101.2 through N1105 is extracted from the 2012 edition of the International Energy Conservation Code—Residential Provisions *and has been editorially revised to conform to the scope and application of this code. The section numbers appearing in parenthesis after each section number are the section numbers of the corresponding text in the* International Energy Conservation Code—Residential Provisions.

N1101.2 (R101.3) Intent. This code shall regulate the design and construction of buildings for the effective use and conservation of energy over the useful life of each building. This code is intended to provide flexibility to permit the use of innovative approaches and techniques to achieve this objective. This code is not intended to abridge safety, health or environmental requirements contained in other applicable codes or ordinances.

N1101.3 (R101.4.3) Additions, alterations, renovations or repairs. Additions, alterations, renovations or repairs to an existing building, building system or portion thereof shall conform to the provisions of this code as they relate to new construction without requiring the unaltered portion(s) of the existing building or building system to comply with this code. Additions, alterations, renovations or repairs shall not create an unsafe or hazardous condition or overload existing building systems. An addition shall be deemed to comply with this code if the addition alone complies or if the existing building and addition comply with this code as a single building.

Exception: The following need not comply provided the energy use of the building is not increased:

1. Storm windows installed over existing fenestration.
2. Glass only replacements in an existing sash and frame.
3. Existing ceiling, wall or floor cavities exposed during construction provided that these cavities are filled with insulation.
4. Construction where the existing roof, wall or floor cavity is not exposed.
5. Reroofing for roofs where neither the sheathing nor the insulation is exposed. Roofs without insulation in the cavity and where the sheathing or insulation is exposed during reroofing shall be insulated either above or below the sheathing.
6. Replacement of existing doors that separate *conditioned space* from the exterior shall not require the installation of a vestibule or revolving door, provided, however, that an existing vestibule that separates a *conditioned space* from the exterior shall not be removed.
7. Alterations that replace less than 50 percent of the luminaires in a space, provided that such alterations do not increase the installed interior lighting power.
8. Alterations that replace only the bulb and ballast within the existing luminaires in a space provided that the *alteration* does not increase the installed interior lighting power.

N1101.4 (R101.4.5) Change in space conditioning. Any nonconditioned space that is altered to become *conditioned space* shall be required to be brought into full compliance with this chapter.

N1101.5 (R101.5.1) Compliance materials. The *building official* shall be permitted to approve specific computer software, worksheets, compliance manuals and other similar materials that meet the intent of this code.

N1101.6 (R101.5.2) Low-energy buildings. The following buildings, or portions thereof, separated from the remainder of the building by *building thermal envelope* assemblies complying with this code shall be exempt from the *building thermal envelope* provisions of this code:

1. Those with a peak design rate of energy usage less than 3.4 Btu/h·ft^2 (10.7 W/m^2) or 1.0 watt/ft^2 (10.7 W/m^2) of floor area for space conditioning purposes.
2. Those that do not contain *conditioned space*.

N1101.7 (R102.1.1) Above code programs. The *building official* or other authority having jurisdiction shall be permitted to deem a national, state or local energy-efficiency program to exceed the energy efficiency required by this code. Buildings *approved* in writing by such an energy-efficiency program shall be considered in compliance with this code. The requirements identified as "mandatory" in Chapters 4 and 5 of this code, as applicable, shall be met.

N1101.8 (R103.2) Information on construction documents. Construction documents shall be drawn to scale upon suitable material. Electronic media documents are permitted to be submitted when *approved* by the *building official*. Construction documents shall be of sufficient clarity to indicate the location, nature and extent of the work proposed, and show in sufficient detail pertinent data and features of the building, systems and equipment as herein governed. Details shall include, but are not limited to, as applicable, insulation materials and their *R*-values; fenestration *U*-factors and SHGCs; area-weighted *U*-factor and SHGC calculations; mechanical system design criteria; mechanical and service water heating system and equipment types, sizes and efficiencies; economizer description; equipment and systems controls; fan motor horsepower (hp) and controls; duct sealing, duct and pipe insulation and location; lighting fixture schedule with wattage and control narrative; and air sealing details.

N1101.9 (R202) Defined terms. The following words and terms shall, for the purposes of this chapter, have the meanings shown herein.

ABOVE-GRADE WALL. A wall more than 50 percent above grade and enclosing *conditioned space.* This includes between-floor spandrels, peripheral edges of floors, roof and basement knee walls, dormer walls, gable end walls, walls enclosing a mansard roof and skylight shafts.

ACCESSIBLE. Admitting close approach as a result of not being guarded by locked doors, elevation or other effective means (see "Readily *accessible*").

ADDITION. An extension or increase in the *conditioned space* floor area or height of a building or structure.

AIR BARRIER. Material(s) assembled and joined together to provide a barrier to air leakage through the building envelope. An air barrier may be a single material or a combination of materials.

AUTOMATIC. Self-acting, operating by its own mechanism when actuated by some impersonal influence, as, for example, a change in current strength, pressure, temperature or mechanical configuration (see "Manual").

BASEMENT WALL. A wall 50 percent or more below grade and enclosing *conditioned space.*

BUILDING. Any structure used or intended for supporting or sheltering any use or occupancy, including any mechanical systems, service water heating systems and electric power and lighting systems located on the building site and supporting the building.

BUILDING SITE. A contiguous area of land that is under the ownership or control of one entity.

BUILDING THERMAL ENVELOPE. The basement walls, exterior walls, floor, roof, and any other building elements that enclose *conditioned space* or provides a boundary between *conditioned space* and exempt or unconditioned space.

***C*-FACTOR (THERMAL CONDUCTANCE).** The coefficient of heat transmission (surface to surface) through a building component or assembly, equal to the time rate of heat flow per unit area and the unit temperature difference between the warm side and cold side surfaces (Btu/h · ft^2 · °F) [W/(m^2 · K)].

CONDITIONED FLOOR AREA. The horizontal projection of the floors associated with the *conditioned space.*

CONDITIONED SPACE. An area or room within a building being heated or cooled, containing uninsulated ducts, or with a fixed opening directly into an adjacent *conditioned space.*

CONTINUOUS AIR BARRIER. A combination of materials and assemblies that restrict or prevent the passage of air through the building thermal envelope.

CRAWL SPACE WALL. The opaque portion of a wall that encloses a crawl space and is partially or totally below grade.

DEMAND RECIRCULATION WATER SYSTEM. A water distribution system where pump(s) prime the service hot water piping with heated water upon demand for hot water.

DUCT. A tube or conduit utilized for conveying air. The air passages of self-contained systems are not to be construed as air ducts.

DUCT SYSTEM. A continuous passageway for the transmission of air that, in addition to ducts, includes duct fittings, dampers, plenums, fans and accessory air-handling equipment and appliances.

ENCLOSED SPACE. A volume surrounded by solid surfaces such as walls, floors, roofs, and openable devices such as doors and operable windows.

ENERGY ANALYSIS. A method for estimating the annual energy use of the *proposed design* and *standard reference design* based on estimates of energy use.

ENERGY COST. The total estimated annual cost for purchased energy for the building functions regulated by this code, including applicable demand charges.

ENERGY SIMULATION TOOL. An *approved* software program or calculation-based methodology that projects the annual energy use of a building.

ENTRANCE DOOR. Fenestration products used for ingress, egress and access in nonresidential buildings, including, but not limited to, exterior entrances that utilize latching hardware and automatic closers and contain over 50-percent glass specifically designed to withstand heavy use and possibly abuse.

EXTERIOR WALL. Walls including both above-grade walls and basement walls.

FENESTRATION. Skylights, roof windows, vertical windows (fixed or moveable), opaque doors, glazed doors, glazed block and combination opaque/glazed doors. Fenestration includes products with glass and nonglass glazing materials.

FENESTRATION PRODUCT, SITE-BUILT. A fenestration designed to be made up of field-glazed or field-assembled units using specific factory cut or otherwise factory-formed framing and glazing units. Examples of site-built fenestration include storefront systems, curtain walls, and atrium roof systems.

HEATED SLAB. Slab-on-grade construction in which the heating elements, hydronic tubing, or hot air distribution system is in contact with, or placed within or under, the slab.

HIGH-EFFICACY LAMPS. Compact fluorescent lamps, T-8 or smaller diameter linear fluorescent lamps, or lamps with a minimum efficacy of:

1. 60 lumens per watt for lamps over 40 watts;
2. 50 lumens per watt for lamps over 15 watts to 40 watts; and
3. 40 lumens per watt for lamps 15 watts or less.

INFILTRATION. The uncontrolled inward air leakage into a building caused by the pressure effects of wind or the effect of differences in the indoor and outdoor air density or both.

INSULATING SHEATHING. An insulating board with a core material having a minimum *R*-value of R-2.

LOW-VOLTAGE LIGHTING. Lighting equipment powered through a transformer such as a cable conductor, a rail conductor and track lighting.

MANUAL. Capable of being operated by personal intervention (see "Automatic").

PROPOSED DESIGN. A description of the proposed building used to estimate annual energy use for determining compliance based on total building performance.

READILY ACCESSIBLE. Capable of being reached quickly for operation, renewal or inspection without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders or access equipment (see "*Accessible*").

REPAIR. The reconstruction or renewal of any part of an existing building.

RESIDENTIAL BUILDING. For this code, includes detached one- and two-family dwellings and multiple single-family dwellings (townhouses) as well as Group R-2, R-3 and R-4 buildings three stories or less in height above grade plane.

R-VALUE (THERMAL RESISTANCE). The inverse of the time rate of heat flow through a body from one of its bounding surfaces to the other surface for a unit temperature difference between the two surfaces, under steady state conditions, per unit area ($h \cdot ft^2 \cdot °F/Btu$) [$(m^2 \cdot K)/W$].

SERVICE WATER HEATING. Supply of hot water for purposes other than comfort heating.

SKYLIGHT. Glass or other transparent or translucent glazing material installed at a slope of less than 60 degrees (1.05 rad) from horizontal. Glazing material in skylights, including unit skylights, solariums, sunrooms, roofs and sloped walls is included in this definition.

SOLAR HEAT GAIN COEFFICIENT (SHGC). The ratio of the solar heat gain entering the space through the fenestration assembly to the incident solar radiation. Solar heat gain includes directly transmitted solar heat and absorbed solar radiation which is then reradiated, conducted or convected into the space.

STANDARD REFERENCE DESIGN. A version of the *proposed design* that meets the minimum requirements of this code and is used to determine the maximum annual energy use requirement for compliance based on total building performance.

SUNROOM. A one-story structure attached to a dwelling with a glazing area in excess of 40 percent of the gross area of the structure's exterior walls and roof.

THERMAL ISOLATION. Physical and space conditioning separation from *conditioned space(s)*. The *conditioned space*(s) shall be controlled as separate zones for heating and cooling or conditioned by separate equipment.

THERMOSTAT. An automatic control device used to maintain temperature at a fixed or adjustable set point.

***U*-FACTOR (THERMAL TRANSMITTANCE).** The coefficient of heat transmission (air to air) through a building component or assembly, equal to the time rate of heat flow per unit area and unit temperature difference between the warm side and cold side air films ($Btu/h \cdot ft^2 \cdot °F$) [$W/(m^2 \cdot K)$].

VENTILATION AIR. That portion of supply air that comes from outside (outdoors) plus any recirculated air that has been treated to maintain the desired quality of air within a designated space.

VISIBLE TRANSMITTANCE [VT]. The ratio of visible light entering the space through the fenestration product assembly to the incident visible light, visible transmittance, includes the effects of glazing material and frame and is expressed as a number between 0 and 1.

WHOLE HOUSE MECHANICAL VENTILATION SYSTEM. An exhaust system, supply system, or combination thereof that is designed to mechanically exchange indoor air with outdoor air when operating continuously or through a programmed intermittent schedule to satisfy the whole house ventilation rates.

ZONE. A space or group of spaces within a building with heating or cooling requirements that are sufficiently similar so that desired conditions can be maintained throughout using a single controlling device.

N1101.10 (R301.1) Climate zones. Climate zones from Figure N1101.10 or Table N1101.10 shall be used in determining the applicable requirements in Sections N1101 through N1105. ~~Locations not in Table N1101.10 (outside the United States) shall be assigned a climate zone based on Section N1101.10.2.~~

N1101.10.1 (R301.2) Warm humid counties. Warm humid counties are identified in Table N1101.10 by an asterisk.

~~**N1101.10.2 (R301.3) International climate zones.** The climate zone for any location outside the United States shall be determined by applying Table N1101.10.2(1) and then Table N1101.10.2(2).~~

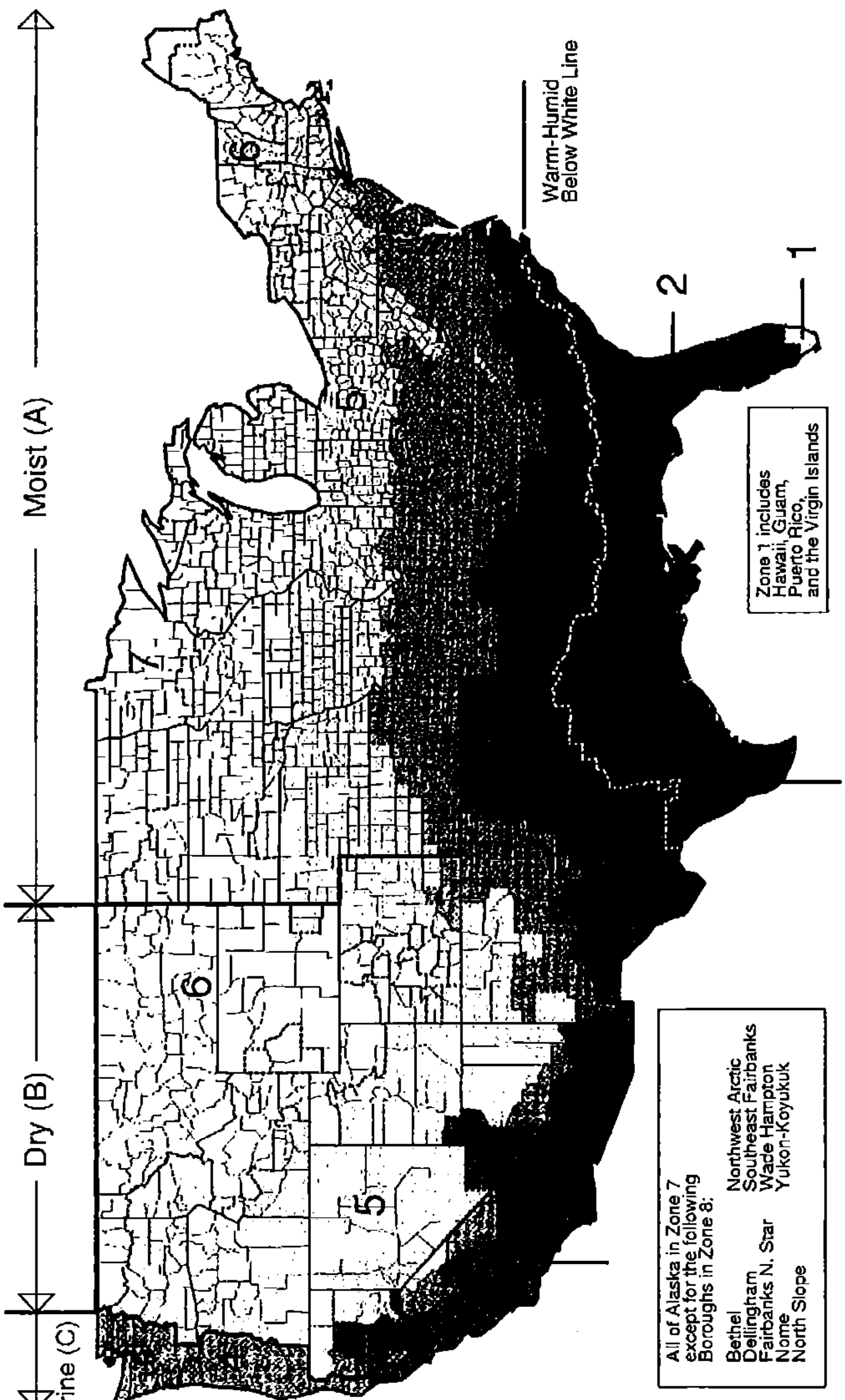

FIGURE N1101.10 (R301.1)
CLIMATE ZONES

**TABLE N1101.10 (R301.1)—continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY**

5A Ashland
5A Ashtabula
5A Athens
5A Auglaize
5A Belmont
4A Brown
5A Butler
5A Carroll
5A Champaign
5A Clark
4A Clermont
5A Clinton
5A Columbiana
5A Coshocton
5A Crawford
5A Cuyahoga
5A Darke
5A Defiance
5A Delaware
5A Erie
5A Fairfield
5A Fayette
5A Franklin
5A Fulton
4A Gallia
5A Geauga
5A Greene
5A Guernsey
4A Hamilton
5A Hancock
5A Hardin
5A Harrison
5A Henry
4A Highland
5A Hocking
5A Holmes
5A Huron
5A Jackson
5A Jefferson
5A Knox
5A Lake
4A Lawrence
5A Licking
5A Logan
5A Lorain
5A Lucas
5A Madison
5A Mahoning
5A Marion
5A Medina
5A Meigs
5A Mercer
5A Miami
5A Monroe
5A Montgomery
5A Morgan
5A Morrow
5A Muskingum
5A Noble
5A Ottawa
5A Paulding
5A Perry
5A Pickaway
4A Pike
5A Portage
5A Preble
5A Putnam
5A Richland
5A Ross
5A Sandusky
4A Scioto
5A Seneca
5A Shelby
5A Stark
5A Summit
5A Trumbull
5A Tuscarawas
5A Union
5A Van Wert
5A Vinton
5A Warren
4A Washington
5A Wayne
5A Williams
5A Wood
5A Wyandot

OKLAHOMA

3A Adair
3A Alfalfa
3A Atoka
4B Beaver
3A Beckham
3A Blaine
3A Bryan
3A Caddo
3A Canadian
3A Carter
3A Cherokee
3A Choctaw
4B Cimarron
3A Cleveland
3A Coal
3A Comanche
3A Cotton
3A Craig
3A Creek
3A Custer
3A Delaware
3A Dewey
3A Ellis
3A Garfield
3A Garvin
3A Grady
3A Grant
3A Greer
3A Harmon
3A Harper
3A Haskell
3A Hughes
3A Jackson
3A Jefferson
3A Johnston
3A Kay
3A Kingfisher
3A Kiowa
3A Latimer
3A Le Flore
3A Lincoln
3A Logan
3A Love
3A Major
3A Marshall
3A Mayes
3A McClain
3A McCurtain
3A McIntosh
3A Murray
3A Muskogee
3A Noble
3A Nowata
3A Okfuskee
3A Oklahoma
3A Okmulgee
3A Osage
3A Ottawa
3A Pawnee
3A Payne
3A Pittsburg
3A Pontotoc
3A Pottawatomie
3A Pushmataha
3A Roger Mills
3A Rogers
3A Seminole
3A Sequoyah
3A Stephens
4B Texas
3A Tillman
3A Tulsa
3A Wagoner
3A Washington
3A Washita
3A Woods
3A Woodward

OREGON

5B Baker
4C Benton
4C Clackamas
4C Clatsop
4C Columbia
4C Coos
5B Crook
4C Curry
5B Deschutes
4C Douglas
5B Gilliam
5B Grant
5B Harney
5B Hood River
4C Jackson
5B Jefferson
4C Josephine
5B Klamath
5B Lake
4C Lane
4C Lincoln
4C Linn
5B Malheur
4C Marion
5B Morrow
4C Multnomah
4C Polk
5B Sherman
4C Tillamook
5B Umatilla
5B Union
5B Wallowa
5B Wasco
4C Washington
5B Wheeler
4C Yamhill

PENNSYLVANIA

5A Adams
5A Allegheny
5A Armstrong
5A Beaver
5A Bedford
5A Berks
5A Blair
5A Bradford
4A Bucks
5A Butler
5A Cambria
6A Cameron
5A Carbon
5A Centre
4A Chester
5A Clarion
6A Clearfield
5A Clinton
5A Columbia
5A Crawford
5A Cumberland
5A Dauphin
4A Delaware
6A Elk
5A Erie
5A Fayette
5A Forest
5A Franklin
5A Fulton
5A Greene

N1101.11 Interior design conditions. The interior design temperatures used for heating and cooling load calculations shall be a maximum of 72°F (22°C) for heating and minimum of 75°F (24°C) for cooling.

N1101.12 Identification. Materials, systems and equipment shall be identified in a manner that will allow a determination of compliance with the applicable provisions of this code.

N1101.12.1 Building thermal envelope insulation. An *R*-value identification mark shall be applied by the manufacturer to each piece of *building thermal envelope* insulation 12 inches (305mm) or greater in width. Alternately, the insulation installers shall provide a certification listing the type, manufacturer and *R*-value of insulation installed in each element of the *building thermal envelope*. For blown or sprayed insulation (fiberglass and cellulose), the initial installed thickness, settled thickness, settled *R*-value, installed density, coverage area and number of bags installed shall be *listed* on the certification. For sprayed polyurethane foam (SPF) insulation, the installed thickness shall be *listed* on the certification. The insulation installer shall sign, date and post the certification in a conspicuous location on the job site.

N1101.12.1.1 Blown or sprayed roof/ceiling insulation. The thickness of blown-in or sprayed roof/ceiling insulation (fiberglass or cellulose) shall be written in inches (mm) on markers that are installed at least one for every 300 square feet ($28m^2$) throughout the attic space. The markers shall be affixed to the trusses or joists and marked with the minimum initial installed thickness with numbers a minimum of 1 inch (25 mm) in height. Each marker shall face the attic assess opening. Spray polyurethane foam thickness and installed *R*-value shall be *listed* on certification provided by the insulation installer.

N1101. 12.2 Insulation mark installation. Insulating materials shall be installed such that the manufacturer's *R*-value mark is readily observable upon inspection.

N1101.12.3 Fenestration product rating. *U*-factors of fenestration products (windows, doors and sky-lights) shall be determined in accordance with NFRC 100 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled *U*-factor shall be assigned a default *U*-factor from Table N1101.5(1), Table N1101.5(2). The solar heat gain coefficient (SHGC) and *visible transmittance* (VT) of glazed fenestration products (windows, glazed doors and skylights) shall be determined in accordance with NFRC 200 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled SHGC or VT shall be assigned a default SHGC or VT from table N1101.5(3).

N1101.12.4 (R303.1.4) Insulation product rating. The thermal resistance (*R*-value) of insulation shall be determined in accordance with the U.S. Federal Trade Commission *R*-value rule (CFR Title 16, Part 460) in units of h x ft^2 x °F/Btu at a mean temperature of 75°F (24°C).

N1101.13 (R303.2) Installation. All materials, systems and equipment shall be installed in accordance with the manufacturer's installation instructions and this code.

N1101.13.1 (R303.2.1) Protection of exposed foundation insulation. Insulation applied to the exterior of basement walls, crawlspace walls and the perimeter of slab-on-grade floors shall have a rigid, opaque and weather-resistant protective covering to prevent the degradation of the insulation's thermal performance. The protective covering shall cover the exterior insulation and extend a minimum of 6 inches (153 mm) below grade.

N1101.14 (R303.3) Maintenance information. Maintenance instructions shall be furnished for equipment and systems that require preventive maintenance. Required regular maintenance actions shall be clearly stated and incorporated on a readily accessible label. The label shall include the title or publication number for the operation and maintenance manual for that particular model and type of product.

N1101.16 (R401.3) Certificate. A permanent certificate shall be completed and posted on or in the electrical distribution panel by the builder or registered design professional or insulation trade contractor. The certificate shall not cover or obstruct the visibility of the circuit directory label, service disconnect label or other required labels. The certificate shall list the predominant *R*-values of insulation installed in or on ceiling/roof, walls, foundation (slab, *basement wall,* crawl space wall and/or floor) and ducts outside conditioned spaces; *U*-factors for fenestration and the solar heat gain coefficient (SHGC) of fenestration, and the results from any required duct system and building envelope air leakage testing done on the building. Where there is more than one value for each component, the certificate shall list the value covering the largest area.

TABLE N1101.5(1)
DEFAULT GLAZED FENESTRATION U-FACTORS

FRAME TYPE	SINGLE PANE	DOUBLE PANE	SKYLIGHT	
			Single	Double
Metal	1.2	0.8	2	1.3
Metal with thermal break	1.1	0.65	1.9	1.1
Nonmetal or metal clad	0.95	0.55	1.75	1.05
Glazed block	0.6			

TABLE N1101.5(2)
DEFAULT DOOR U-FACTORS

DOOR TYPE	U-FACTOR
Uninsulated metal	1.2
Insulated metal	0.6
Wood	0.5
Insulated, nonmetal edge, max 45% glazing, any glazing double pane	0.35

TABLE N1101.5(3)
DEFAULT GLAZED FENESTRATION SHGC

SINGLE GLAZED		DOUBLE GLAZED		GLAZED BLOCK
Clear	Tinted	Clear	Tinted	
0.8	0.7	0.7	0.6	0.6

SECTION N1102
BUILDING THERMAL ENVELOPE

SECTION N1102
BUILDING THERMAL ENEVELOPE

N1102.1 Insulation and fenestration criteria. The *building thermal envelope* shall meet the requirements of Table N1102.1.1 based on the climate zone specified in Table N1101. 10.

N1102.1.1 R-value computation. Insulation material used in layers, such as framing cavity insulation and insulating sheathing, shall be summed to compute the component R-value. The manufacturer's settled R-value shall be used for blown insulation. Computed R-values shall not include an R-value for other building materials or air films.

N1102.1.2 U-factor alternative. An assembly with a *U*-factor equal to or less than that specified in Table N1102.1.2 shall be permitted as an alternative to the R-value in Table 1102.1.1.

N1102.1.3 Total UA alternative. If the total building thermal envelope UA (sum of U-factor times assembly area) is less than or equal to the total UA resulting from using the U-factors in Table N1102.1.2 (multiplied by the same assembly area as in the proposed building) the building shall be considered in compliance with Table N1102.1.1. The *UA* calculation shall be done using a method consistent with the ASHRAE *Handbook of Fundamentals* and shall include the thermal bridging effects of framing materials. The SHGC requirements shall be met in addition to UA compliance.

TABLE N1102.1.1 (R402.1.1)
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION *U*-FACTOR[b]	SKYLIGHT[b] *U*-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING *R*-VALUE	WOOD FRAME WALL *R*-VALUE	MASS WALL *R*-VALUE[i]	FLOOR *R*-VALUE	BASEMENT[c] WALL *R*-VALUE	SLAB[d] *R*-VALUE & DEPTH	CRAWL SPACE[c] WALL *R*-VALUE
~~1~~	~~NR~~	~~0.75~~	~~0.25~~	~~30~~	~~13~~	~~3/4~~	~~13~~	~~0~~	~~0~~	~~0~~
~~2~~	~~0.40~~	~~0.65~~	~~0.25~~	~~38~~	~~13~~	~~4/6~~	~~13~~	~~0~~	~~0~~	~~0~~
3	0.35	0.55	0.25	38	13	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49		8/13	19	10/13	10, 2 ft	10/13
~~5 and Marine 4~~	~~0.32~~	~~0.55~~	~~NR~~	~~49~~	~~20 or 13 + 5[h]~~	~~13/17~~	~~30[g]~~	~~15/19~~	~~10, 2 ft~~	~~15/19~~
~~6~~	~~0.32~~	~~0.55~~	~~NR~~	~~49~~	~~20 + 5 or 13 + 10[h]~~	~~15/20~~	~~30[g]~~	~~15/19~~	~~10, 4 ft~~	~~15/19~~
~~7 and 8~~	~~0.32~~	~~0.55~~	~~NR~~	~~49~~	~~20 + 5 or 13 + 10[h]~~	~~19/21~~	~~38[g]~~	~~15/19~~	~~10, 4 ft~~	~~15/19~~

For SI: 1 foot = 304.8 mm.

a. *R*-values are minimums. *U*-factors and SHGC are maximums. When insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed *R*-value of the insulation shall not be less than the *R*-value specified in the table.

b. The fenestration *U*-factor column excludes skylights. The SHGC column applies to all glazed fenestration.
Exception: Skylights may be excluded from glazed fenestration SHGC requirements in Climate Zones 1 through 3 where the SHGC for such skylights does not exceed 0.30.

c. "15/19" means R-15 continuous insulation on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "15/19" shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. "10/13" means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.

d. R-5 shall be added to the required slab edge *R*-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in Zones 1 through 3 for heated slabs.

e. There are no SHGC requirements in the Marine Zone.

f. Basement wall insulation is not required in warm-humid locations as defined by Figure N1101.10 and Table N1101.10.

g. Or insulation sufficient to fill the framing cavity, R-19 minimum.

h. First value is cavity insulation, second is continuous insulation or insulated siding, so "13 + 5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding. If structural sheathing covers 40 percent or less of the exterior, continuous insulation *R*-value shall be permitted to be reduced by no more than R-3 in the locations where structural sheathing is used – to maintain a consistent total sheathing thickness.

i. The second *R*-value applies when more than half the insulation is on the interior of the mass wall.

N1102.2 Specific insulation requirements.

N1102.2.1 Ceilings with attic spaces. When Section N1102.1 would require R-38 in the ceiling, R-30 shall be deemed to satisfy the requirement for R-38 wherever the full height of uncompressed R-30 insulation extends over the wall top plate at the eaves. Similarly R-38 shall be deemed to satisfy the requirement for R-49 wherever the full height of uncompressed R-38 insulation extends over the wall top plate at the eaves. This reduction shall not apply to the U-factor alternative approach in Section N1102.1.2 and the Total UA alternative in Section N1102.1.3.

N1102.2.2 Ceilings without attic spaces. Where Section N1102.1 would require insulation levels above R-30 and the design of the roof/ceiling assembly does not allow sufficient space for the required insulation, the minimum required insulation for such roof/ceiling assemblies shall be R-30. This reduction of insulation from the requirements of Section 1102.1.1 shall be limited to 500 square feet (46 m^2) of ceiling area. This reduction shall not apply to the U-factor alternative approach in Section N1102.1.2 and the Total UA alternative in Section N1102.1.3.

N1102.2.3 Access hatches and doors. Access doors from *conditioned spaces* to unconditioned spaces (e.g., attics and crawl spaces) shall be weather-stripped and insulated to a level equivalent to the insulation on the surrounding surfaces. Access shall be provided to all *equipment which prevents* damaging or compressing the insulation. A wood framed or equivalent baffle or retainer is required to be provided when loose fill insulation is installed, the purpose of which is to prevent the loose fill insulation from spilling into the living space when the *attic* access is opened and to provide a permanent means of maintaining the installed R-value of the loose fill insulation.

N1102.2.4 Mass walls. Mass walls, for the purposes of this chapter, shall be considered above-grade walls of concrete block, concrete, insulated concrete form (ICF), masonry cavity, brick (other than brick veneer), earth (adobe, compressed earth block, rammed earth) and solid timber/logs.

N1102.2.5 Steel-frame ceilings, walls and floors. Steel frame ceilings, walls and floors shall meet the insulation requirements of Table N1102.2.5 or shall meet the U-factor requirements in Table N1102.1.2. The calculation of the U-factor for a steel-frame envelope assembly shall use a series-parallel path calculation method.

> **Exception:** In climate zones 1 and 2, the continuous insulation requirements in Table N1102.2.5 shall be permitted to be reduced to R-3 for steel frame wall assemblies with studs spaced at 24 inches (610 mm) on center.

N1102.2.6 Floors. Floor insulation shall be installed to maintain permanent contact with the underside of the subfloor decking.

N1102.2.7 Basement walls. *Exterior walls* associated with conditioned basements shall be insulated from the top of the *basement wall* down to 10 feet (3048 mm) below *grade* or to the *basement* floor, whichever is less. Walls associated with unconditioned basements shall meet this requirement unless the floor overhead is insulated in accordance with Sections N1102.1 and N1102.2.6.

N1102.2.8 Slab-on-grade floors. Slab-on-grade floors with a floor surface less than 12 inches below *grade* shall be insulated in accordance with Table N1102.1.1. The insulation shall extend downward from the top of the slab on the outside or inside of the foundation wall. Insulation located below *grade* shall be extended the distance provided in Table N1102.1.1 by any combination of vertical insulation, insulation extending under the slab or insulation extending out from the building. Insulation extending away from the building shall be protected by pavement or by a minimum of 10 inches (254 mm) of soil. The top edge of the insulation installed between the *exterior wall* and the edge of the interior slab shall be permitted to be cut at a 45-degree (0.79 rad) angle away from the *exterior wall*. Slab-edge insulation is not required in jurisdictions designated by the code official as having a very heavy termite infestation.

TABLE N1102.1.2
EQUIVALENT U-FACTORS[a]

CLIMATE ZONE	FENESTRATION U-FACTOR	SKYLIGHT U-FACTOR	CEILING U-FACTOR	FRAME WALL U-FACTOR	MASS WALL U-FACTOR[b]	FLOOR U-FACTOR	BASEMENT WALL U-FACTOR	CRAWL SPACE WALL U-FACTOR
~~1~~	~~1.20~~	~~0.75~~	~~0.035~~	~~0.082~~	~~0.197~~	~~0.064~~	~~0.360~~	~~0.477~~
~~2~~	~~0.65~~	~~0.75~~	~~0.035~~	~~0.082~~	~~0.165~~	~~0.064~~	~~0.360~~	~~0.477~~
OK 3	0.50	0.65	0.035	0.082	0.141	0.047	0.091[c]	0.136
OK 4 except Marine	0.35	0.60	0.030	0.082	0.141	0.047	0.059	0.065
~~5 and Marine 4~~	~~0.35~~	~~0.60~~	~~0.030~~	~~0.060~~	~~0.082~~	~~0.033~~	~~0.059~~	~~0.065~~
~~6~~	~~0.35~~	~~0.60~~	~~0.026~~	~~0.060~~	~~0.060~~	~~0.033~~	~~0.059~~	~~0.065~~
~~7 and 8~~	~~0.35~~	~~0.60~~	~~0.026~~	~~0.057~~	~~0.057~~	~~0.033~~	~~0.059~~	~~0.065~~

a. Nonfenestration U-factors shall be obtained from measurement, calculation or an approved source.

b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in zone 1, 0.14 in zone 2, 0.12 in zone 3, 0.10 in zone 4 except Marine and the same as the frame wall U-factor in Marine zone 4 and in zones 5 through 8.

c. Basement wall U-factor of 0.360 in warm-humid climates as defined by Figure N1101.2 and Table N1101.2.

TABLE N1102.2.5
STEEL-FRAME CEILING, WALL AND FLOOR INSULATION (R-VALUE)

WOOD FRAME R-VALUE REQUIREMENT	COLD-FORMED STEEL EQUIVALENT R-VALUE[a]
Steel Truss Ceilings[b]	
R-30	R-38 or R-30 + 3 or R-26 + 5
R-38	R-49 or R-38 + 3
R-49	R-38 + 5
Steel Joist Ceilings[b]	
R-30	R-38 in 2 x 4 or 2 x 6 or 2 x 8 R-49 in any framing
R-38	R-49 in 2 x 4 or 2 x 6 or 2 x 8 or 2 x 10
Steel Framed Wall	
R-13	R-13 + 5 or R15 + 4 or R-21 + 3 or R-0 + 10
R-19	R-13 + 9 or R-19 + 8 or R-25 + 7
R-21	R-13 + 10 or R-19 + 9 or R-25 + 8
Steel Joist Floor	
R-13	R-19 in 2 x 6 R-19 + R-6 in 2 x 8 or 2 x 10
R-19	R-19 + R-6 in 2 x 6 R-19 + R-12 in 2 x 8 or 2 x 10

For SI: 1 inch = 25.4 mm.

a. Cavity insulation R-value is listed first, followed by continuous insulation R-value.

b. Insulation exceeding the height of the framing shall cover the framing.

N1102.2.9 Crawl space walls. As an alternative to insulating floors over crawl spaces, insulation of crawl space walls shall be permitted when the crawl space is not vented to the outside. Crawl space wall insulation shall be permanently fastened to the wall and extend downward from the floor to the finished *grade* level and then vertically and/or horizontally for at least an additional 24 inches (610 mm). Exposed earth in unvented crawl space foundations shall be covered with a continuous Class I vapor retarder. All joints of the vapor retarder shall overlap by 6 inches (152 mm) and be sealed or taped. The edges of the vapor retarder shall extend at least 6 inches (152 mm) up the stem wall and shall be attached to the stem wall.

N1102.2.10 Masonry veneer. Insulation shall not be required on the horizontal portion of the foundation that supports a masonry veneer.

N1102.2.11 Thermally isolated sunroom insulation. The minimum ceiling insulation R-values shall be R-19 in zones 1 through 4 and R-24 in zones 5 though 8. The minimum wall R-value shall be R-13 in all zones. New wall(s) separating the sunroom from *conditioned space* shall meet the *building thermal envelope* requirements.

N1102.3 Fenestration

N1102.3.1 U-factor. An area-weighted average of fenestration products shall be permitted to satisfy the *U*-factor requirements.

N1102.3.2 Glazed fenestration SHGC. An area-weighted average of fenestration products more than 50 percent glazed shall be permitted to satisfy the solar heat gain coefficient (SHGC) requirements.

N1102.3.3 Glazed fenestration exemption. Up to 15 square feet (1.4 m²) of glazed fenestration per *dwelling unit* shall be permitted to be exempt from *U-factor* and SHGC requirements in Section N1102.1. This exemption shall not apply to the *U*-factor alternative approach in Section N1102.1.2 and the Total UA alternative in Section N1102.1.3.

N1102.3.4 Opaque door exemption. One side-hinged opaque door assembly up to 24 square feet (2.22 m²) in area is exempted from the *U*-factor requirement in Section N1102.1.1. This exemption shall not apply to the *U*-factor alternative approach in Section N1102.1.2 and the Total UA alternative in Section N1102.1.3.

N1102.3.5 Thermally isolated sunroom U-factor. For zones 4 through 8 the maximum fenestration *U*-factor shall be 0.50 and the maximum skylight U-factor shall be 0.75. New windows and doors separating the sunroom from *conditioned space* shall meet the *building thermal envelope* requirements.

N1102.3.6 Replacement fenestration. Where some or all of an existing fenestration unit is replaced with a new fenestration product, including sash and glazing, the replacement fenestration unit shall meet the applicable requirements for *U*-factor and solar heat gain coefficient (SHGC) in Table N1102.1.1.

N1102.4 Air Leakage.

The building thermal envelope shall be constructed to limit air leakage in accordance with the requirements of Sections N1102.4.1 through N1102.4.4. These provisions take effect on January 1st of 2018.

N1102.4.1 Installation.
The components of the *building thermal envelope* as listed in Table N1102.4.2, shall be installed in accordance with the manufacturer's instructions and the criteria listed in Table N1102.4.2, as applicable to the method of construction. An *approved* third party shall inspect all components and verify compliance. An approved written report of the results shall be signed by the party viewing the work and a copy provided to the building official.

N1102.4.1.2 Testing.
The building or dwelling unit shall be tested and verified as having an air leakage rate of not exceeding 7 air changes per hour. Testing shall be conducted with a blower door at a pressure of 0.2 inches w.g. (50 Pascals) Testing shall be conducted by an approved third party. A written report of the results of the test shall be signed by the party conducting the test and provided to the *building official.* Testing shall be performed at any time after ~~creation~~ of all penetrations of the *building thermal envelope.* SEALING

During testing:
1. Exterior windows and doors, fireplace and stove doors shall be closed, but not sealed, beyond the intended weather-stripping or other infiltration control measures;
2. Dampers including exhaust, intake, makeup air, backdraft and flue dampers shall be closed, but not sealed beyond intended infiltration control measures;
3. Interior doors, if installed at the time of the test, shall be open;
4. Exterior doors for continuous ventilation systems and heat recovery ventilators shall be closed and sealed;
5. Heating and cooling systems, if installed at the time of the test, shall be turned off; and
6. Supply and return registers, if installed at the time of the test, shall be open.

N1102.4.3 Fireplaces. New wood-burning fireplaces shall have gasketed doors and outdoor combustion air.

N1102.4.4 Fenestration air leakage. Windows, skylights and sliding glass doors shall have an air infiltration rate of no more than 0.3 cubic foot per minute per square foot *[1.5(L/s)/m^2],* and swinging doors no more than 0.5 cubic foot per minute per square foot [2.5 *(L/s)/m^2]* , when tested according to NFRC 400 or *AAMA/WDMA/CSA* 101/*I.S.2/* A440 by an accredited, independent laboratory, and listed and *labeled* by the manufacturer.

Exception: Site-built windows, skylights and doors.

N1102.4.5 Recessed lighting. Recessed luminaires installed in the *building thermal envelope* shall be sealed to limit air leakage between conditioned and unconditioned spaces. All recessed luminaires shall be IC-rated and *labeled as* meeting ASTM E 283 when tested at 1.57 psi (75 Pa) pressure differential with no more than 2.0 cfm (0.944 *L/s)* of air movement from the *conditioned space* to the ceiling cavity. All recessed luminaires shall be sealed with a gasket or caulk between the housing and the interior wall or ceiling covering.

SECTION N1103
SYSTEMS

N1103.1 Controls. At least one thermostat shall be installed for each separate heating and cooling system.

N1103.1.1 Programmable thermostat. Where the primary heating system is a forced air furnace, at least one thermostat per *dwelling unit* shall be capable of controlling the heating and cooling system on a daily schedule to maintain different temperature set points at different times of the day. This thermostat shall include the capability to set back or temporarily operate the system to maintain zone temperatures down to 55°F (13°C) or up to 85°F (29°C). The thermostat shall initially be programmed with a heating temperature set point no higher than 70°F (21°C) and a cooling temperature set point no lower than 78°F (26°C).

N1103.1.2 Heat pump supplementary heat. Heat pumps having supplementary electric-resistance heat shall have controls that, except during defrost, prevent supplemental heat operation when the heat pump compressor can meet the heating load.

N1103.2 Ducts.

N1103.2.1 Insulation. Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.

Exception: Ducts or portions thereof located completely inside the *building thermal envelope.*

N1103.2.2 Sealing. Ducts, air handlers, filter boxes and building cavities used as ducts shall be sealed. Joints and seams shall comply with Section M1601.4. Duct tightness shall be verified by either of the following beginning January 1st of 2017:

1. **Post-construction test:** Leakage to outdoors shall be less than or equal to 8 cfm (3.78 *L/s)* per 100 ft^2 (9.29m^2) of conditioned floor area or a total leakage less than or equal to 12 cfm (5.66*L/s*) per 100 ft^2 (9.29m^2) of conditioned floor area when tested at a pressure differential of 0.1 inch w.g. (25 Pa) across the entire system including the manufacturer's air handler end closure. All register boots shall be taped or otherwise sealed during the test.

2. **Rough-in test:** Total leakage shall be less than or equal to 6 cfm (2.83 *L/s)* per 100 ft^2 (9.29 m^2) of conditioned floor area when tested at a pressure differential of 0.1 inch w.g. (25 Pa) across the roughed in system, including the manufacturer's air handler enclosure. All register boots shall be taped or otherwise sealed during the test. If the air handler is not installed at the time of the test, total leakage shall be less than or equal to 4 cfm (1.89 *L/s)* per 100 ft2 (9.29 m^2) of conditioned floor area.

Exception: The total leakage test is not required for ducts and air handlers located entirely within the building thermal envelope.

TABLE N1102.4.2
AIR BARRIER AND INSULATION INSPECTION

COMPONENT	CRITERIA
Air barrier and thermal barrier	Exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with building envelope air barrier. Breaks or joints in the air barrier are filled or repaired. Air-permeable insulation is not used as a sealing material.
Ceiling/attic	Air barrier in any dropped ceiling/soffit is substantially aligned with insulation and any gaps are sealed Attic access (except unvented attic), knee wall door, or drop down stair is sealed.
Walls	Corners and headers are insulated. Junction of foundation and sill plate is sealed.
Windows and doors	Space between window/door jambs and framing is sealed.
Rim joists	Rim joists are insulated and include an air barrier.
Floors (including above garage and cantilevered floors)	Insulation is installed to maintain permanent contact with underside of subfloor decking. Air barrier is installed at any exposed edge of floor.
Crawlspace walls	Insulation is permanently attached to walls. Exposed earth in unvented crawlspaces is covered with Class I vapor retarder with overlapping joints taped.
Shafts, penetrations	Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.
Narrow cavities	Batts in narrow cavities are cut to fit, or narrow cavities are filled by sprayed/blown insulation.
Garage separation	Air sealing is provided between the garage and conditioned spaces.
Recessed lighting	Recessed light fixtures are airtight, IC rated and sealed to drywall. Exception-fixtures in conditioned space.
Plumbing and wiring	Insulation is placed between outside and pipes. Batt insulation is cut to fit around wiring and plumbing, or sprayed/blown insulation extends behind piping and wiring.
Shower/tub on exterior wall	Showers and tubs on exterior walls have insulation and an air barrier separating them from the exterior wall.
Electrical/phone box on exterior wall	Air barrier extends behind boxes or air sealed type boxes are installed.
Common wall	Air barrier is installed in common wall between dwelling units.
HVAC register boots	HVAC register boots that penetrate building envelope are sealed to subfloor or drywall.
Fireplace	Fireplace walls include an air barrier.

N1103.2.3 Building cavities. Building framing cavities shall not be used as supply ducts.

N1103.3 Mechanical system piping insulation. Mechanical system piping capable of carrying fluids above 105°F (40°C) or below 55°F (13°C) shall be insulated to a minimum of R-3

.**N1103.4 Circulating hot water systems.** All circulating service hot water piping shall be insulated to at least R-2. Circulating hot water systems shall include an automatic or *readily accessible* manual switch that can turn off the hot water circulating pump when the system is not in use.

N1103.5 Mechanical ventilation. Outdoor air intakes and exhausts shall have automatic or gravity dampers that close when the ventilation system is not operating.

N1103.6 Equipment sizing. Heating and cooling *equipment* shall be sized as specified in Section M1401.3.

N1103.7 Snow melt system controls. Snow- and ice-melting systems supplied through energy service to the building shall include automatic controls capable of shutting off the system when the pavement temperature is above 50°F (10°C) and no precipitation is falling and an automatic or manual control that will allow shutoff when the outdoor temperature is above 40°F (5°C) .

N1103.8 Pools. Pools shall be provided with energy conserving measures in accordance with Sections N1103.8.1 through N1103.8.3.

N1103.8.1 Pool heaters. All pool heaters shall be equipped with a *readily accessible* on-off switch to allow shutting off the heater without adjusting the thermostat setting. Pool heaters fired by natural gas or LPG shall not have continuously burning pilot lights.

N1103.8.2 Time switches. Time switches that can automatically turn off and on heaters and pumps according to a preset schedule shall be installed on swimming pool heaters and pumps.

Exceptions:
1. Where public health standards require 24-hour pump operation.
2. Where pumps are required to operate solar- and waste-heat-recovery pool heating systems.

N1103.8.3 Pool covers. Pools heated to more than 90°F (32°C) shall have a pool cover with a minimum insulation value of R-12.

Section N1104
Lighting Systems

N1104.1 lighting equipment. A minimum of 50 percent of the lamps in permanently installed lighting fixtures shall be *high-efficacy lamps.*

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Sensitivity Analysis of Installation Faults on Heat Pump Performance

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Sensitivity Analysis of Installation Faults on Heat Pump Performance

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ABSTRACT

Numerous studies and surveys indicate that typically-installed HVAC equipment operate inefficiently and waste considerable energy due to different installation errors (faults) such as improper refrigerant charge, incorrect airflow, oversized equipment, leaky ducts. This study seeks to develop an understanding of the impact of different faults on heat pump performance installed in a single-family residential house. It combines building effects, equipment effects, and climate effects in a comprehensive evaluation of the impact of installation faults on a heat pump's seasonal energy consumption through simulations of the house/heat pump system.

The study found that duct leakage, refrigerant undercharge, oversized heat pump with nominal ductwork, low indoor airflow due to undersized ductwork, and refrigerant overcharge have the most potential for causing significant performance degradation and increased annual energy consumption. The effect of simultaneous faults was found to be additive (e.g., duct leakage and non-condensable gases), little changed relative to the single fault condition (e.g., low indoor airflow and refrigerant undercharge), or well-beyond additive (duct leakage and refrigerant undercharge). A significant increase in annual energy use can be caused by lowering the thermostat in the cooling mode to improve indoor comfort in cases of excessive indoor humidity levels due to installation faults.

The goal of this study was to assess the impacts that HVAC system installation faults had on equipment electricity consumption. The effect of the installation faults on occupant comfort was not the main focus of the study, and this research did not seek to quantify any impacts on indoor air quality or noise generation (e.g., airflow noise from air moving through restricted ducts). Additionally, the study does not address the effects that installation faults have on equipment reliability/robustness (number of starts/stops, etc.), maintainability (e.g., access issues), or costs of initial installation and ongoing maintenance.

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4.3.1 Building Enclosure Air Leakage

The AIM-2 infiltration model (Walker and Wilson, 1998; ASHRAE, 2009a) relates infiltration to wind and indoor-outdoor temperature difference for each time step. All simulations in this study used coefficients representing shelter from buildings located across the street. An equivalent leakage area (ELA) of 0.0633 m^2 (98.1 in^2) was chosen to provide the desired seven air changes per hour (ACH) at 50 pascal pressure differential (ACH50 for the main zone in each building model).

The attic used the same AIM-2 equations to determine leakage as a function of wind and temperature difference. The attic ELA was set to be 0.366 m^2 (567 in^2) for each of the climate zones, or about 5 times the leakage rate for the HERS 100 house (Fugler, 1999). In houses with basements, that zone was assumed to have no leakage to outdoors.

4.3.2 Duct Leakage and Thermal Losses

For the slab-on-grade houses, the ducts were modeled to be in the attic space and all the air leakage and thermal losses/gains go into that zone. The details of the duct model are given in Appendix A. For houses with basements, there is no duct leakage to the attic (all leaks are assumed to be into the conditioned space, so they are ignored). Duct leakage was assumed to be 10 % of flow, or 6 % on the supply side and 4 % on the return side. Duct insulation was assumed to be R(SI)-1.1 (R-6) with a supply duct area of 50.5 m^2 (544 ft^2) and a return duct area of 9.3 m^2 (100 ft^2) for a 10.6 kW (3-ton) unit. The duct areas were increased and decreased proportionally based on the size (or nominal tonnage) of the heat pump unit.

4.3.3 Moisture and Thermal Gains

The scheduling or profile of internal heat and moisture generation was taken from the Building America Benchmark Definition (Hendron, 2008). Sensible gains from all sources were assumed to be 76.7 MJ/day (72.7 kBtu/day).

Internal moisture generation from all sources was specified as 5.4 kg/day (12 lb/day), or less than half of the ASHRAE Standard 160 moisture generation rate of 14.2 kg/day (31.2 lb/day) for a three-bedroom house (ASHRAE, 2009b). The ASHRAE 160 value is meant to be a 'worst case' design condition and therefore would not be expected to correspond to average conditions.

4.3.4 Moisture and Thermal Capacitance

Moisture storage in the building materials and furnishings and the rate of mass transfer into storage are important hygrothermal parameters affecting the diurnal swings in indoor humidity. Building material moisture storage was modeled with a simple lumped parameter method with mass factor added to the air node in the zone model:

$$C\ \frac{dw_i}{dt} = m \cdot (w_i - w_o) + Q_{internal} - Q_{AC,latent} \qquad (4.1)$$

The moisture capacitance term is usually set to a multiple of the air mass inside the house. The Florida Solar Energy Center used more detailed moisture models including Effective Moisture Penetration Depth (EMPD) to show that reasonable factors for the air mass multiplier are 20 to 30 times the air mass (EPA, 2001).

As a result of the calibration efforts (Appendix C in Rudd et al., 2013), a 30x multiplier for moisture capacitance was used for the main zone and the basement. The attic used a moisture capacitance factor of 15x.

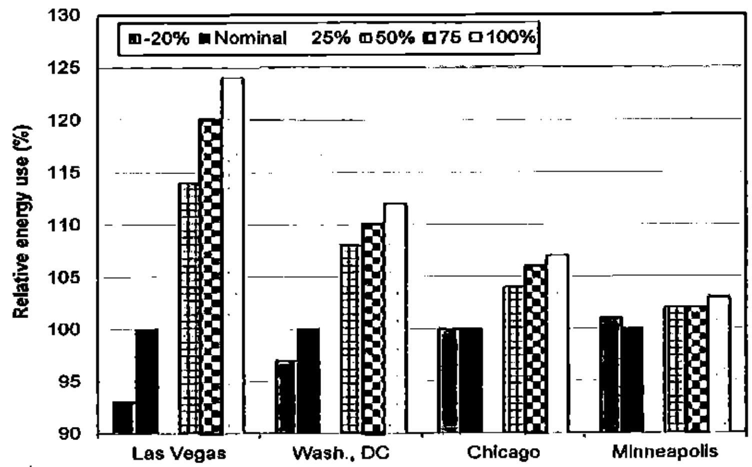

Figure 5.2. Annual energy use for houses with basement for different heat pump sizings, scenario (2)

5.2.3 Effect of Duct Leakage

Per the earlier discussion in Section 4.3.2, the effect of duct leakage has been evaluated only for slab-on-grade houses where ducts were installed in the attic (i.e., in the unconditioned space). The baseline houses include ducts in the attic with a leakage rate of 10 % (leakage distributed 60 % on the supply side and 40 % on the return side) as well as thermal losses through the duct wall. Table 5.9 compares this base case to other levels of duct leakage with the thermostat set at the default set point temperature (Table 4.8). The entry '0 % & No thermal' in the left most column denotes an idealistic installation with zero air leakage and no thermal loss (i.e., an insulation with an infinite R). For all other simulation cases the duct insulation is assumed to be R(SI)-1.1 (R-6).

As expected, the baseline duct losses increase energy use in the baseline houses; our simulations showed a 20 % and 30 % increase for the cooling climates and heating climates, respectively, compared to the 0 % leak case. As the duct leakage increases, energy use increases by at least 8 % for the cooling climates and by 12 % for the heating climates for each 10 % increment in the duct leakage fault. A slight improvement of the cooling COP shown with the increasing fault level is caused by a somewhat higher refrigerant saturation temperature (and pressure) in the evaporator when the air returning to the indoor section is at higher temperature due to duct losses. This COP improvement, however, can't compensate for the significant increase in the cooling load, which is the cause of the increased energy use.

Table 5.10 shows the effect of duct leakage on annual energy use for the slab-on-grade house from lowering the cooling set point by 1.1 °C (2.0 °F). For completeness, the table includes all studied locations, although houses in Houston and Washington, DC, are most likely to be operated at a lowered set point temperature to improve the indoor comfort. Table 5.11 shows simulation results for the indoor set point temperature lowered by an additional 1.1 °C (2.0 °F), i.e., by 2.2 °C (4.0 °F) below the default value for the house in Houston.

Reducing the set point results in a lower number of hours with relative humidity above 55 % for small levels of duct leaks only (Tables 5.10 and 5.11). For large levels of duct leakage, the number of hours with relative humidity above 55 % actually increases. This result is caused by the fact that lowering the set point requires longer operational runtimes (with correspondingly higher energy consumption and duct leakage) and, depending on the ratio of sensible to latent capacities, lowering the indoor temperature may actually increase the relative humidity, although the indoor comfort might improve due to a lower dry-bulb temperature.

Table 5.9. Effect of duct leakage on annual energy use for a slab-on-grade house at default cooling set point

Houston	Hours Above 55 % RH	AC Runtime (h)	Htg Runtime (h)	Backup Heat Runtime (h)	AHU Fan Runtime (h)	AC COP (-)	AC SHR (-)	AC Energy (MJ)	Htg Energy (MJ)	AHU Fan Energy (MJ)	TOTAL ENERGY (MJ)	Total Costs	Relative Energy
0 % & No thermal	1,715	1,555	588	0.3	2,142.9	4.3	0.789	13,007	6,623	4,339	24,700	$583	79%
0 % Leak	1,537	1,794	665	2.1	2,479.0	4.3	0.812	15,046	7,761	5,020	28,559	$674	91%
10 % Leak	1,512	1,981	749	5.1	2,730.6	4.3	0.785	16,660	8,637	5,629	31,457	$743	100%
20 % Leak	1,632	2,160	815	9.4	2,975.1	4.4	0.787	18,179	9,363	6,025	34,317	$810	109%
30 % Leak	1,922	2,327	883	17.5	3,209.7	4.5	0.753	19,574	10,393	6,500	37,198	$878	118%
40 % Leak	2,738	2,489	953	35.6	3,441.7	4.5	0.743	20,922	11,773	6,970	40,397	$954	128%
50 % Leak	3,364	2,649	1,032	61.8	3,681.0	4.6	0.734	22,231	13,578	7,454	43,995	$1,039	140%

Las Vegas	Hours Above 55 % RH	AC Runtime (h)	Htg Runtime (h)	Backup Heat Runtime (h)	AHU Fan Runtime (h)	AC COP (-)	AC SHR (-)	AC Energy (MJ)	Htg Energy (MJ)	AHU Fan Energy (MJ)	TOTAL ENERGY (MJ)	Total Costs	Relative Energy
0 % & No thermal	-	1,536	688	0.3	2,204.6	3.7	1.000	15,941	8,763	5,207	30,642	$1,072	78%
0 % Leak	-	1,817	786	0.3	2,602.5	3.7	1.000	18,952	10,273	6,147	36,104	$1,284	92%
10 % Leak	-	1,966	865	0.3	2,831.1	3.7	0.999	20,531	11,261	6,687	39,200	$1,372	100%
20 % Leak	-	2,114	951	1.2	3,065.4	3.8	0.998	22,081	12,339	7,241	42,393	$1,484	108%
30 % Leak	-	2,261	1,054	3.7	3,315.3	3.8	0.998	23,580	13,718	7,831	45,861	$1,605	117%
40 % Leak	-	2,405	1,170	8.6	3,575.4	3.9	0.997	25,028	15,353	8,445	49,558	$1,735	126%
50 % Leak	-	2,549	1,290	22.7	3,838.7	3.9	0.996	26,444	17,362	9,067	53,605	$1,876	137%

Washington, DC	Hours Above 55 % RH	AC Runtime (h)	Htg Runtime (h)	Backup Heat Runtime (h)	AHU Fan Runtime (h)	AC COP (-)	AC SHR (-)	AC Energy (MJ)	Htg Energy (MJ)	AHU Fan Energy (MJ)	TOTAL ENERGY (MJ)	Total Costs	Relative Energy
0 % & No thermal	280	944	1,532	12.9	2,476.3	4.4	0.801	6,301	15,111	4,179	26,322	$1,031	73%
0 % Leak	175	1,100	1,803	54.5	2,902.7	4.4	0.823	7,361	19,093	4,898	32,084	$1,257	89%
10 % Leak	253	1,207	1,971	89.0	3,178.0	4.5	0.809	8,098	21,759	5,363	35,952	$1,408	100%
20 % Leak	368	1,314	2,133	134.8	3,446.8	4.5	0.799	8,825	24,760	5,817	40,133	$1,572	112%
30 % Leak	523	1,419	2,294	192.5	3,712.5	4.6	0.791	9,528	28,180	6,265	44,704	$1,751	124%
40 % Leak	814	1,523	2,457	270.0	3,979.2	4.6	0.786	10,216	32,335	6,715	49,997	$1,958	139%
50 % Leak	1,165	1,625	2,595	382.3	4,219.9	4.7	0.781	10,884	37,541	7,121	56,278	$2,204	157%

Chicago	Hours Above 55 % RH	AC Runtime (h)	Htg Runtime (h)	Backup Heat Runtime (h)	AHU Fan Runtime (h)	AC COP (-)	AC SHR (-)	AC Energy (MJ)	Htg Energy (MJ)	AHU Fan Energy (MJ)	TOTAL ENERGY (MJ)	Total Costs	Relative Energy
0 % & No thermal	203	815	2,288	70.0	3,103.7	4.5	0.819	5,369	24,753	5,238	36,092	$1,283	71%
0 % Leak	190	943	2,639	187.4	3,582.0	4.6	0.839	6,217	32,197	6,045	45,190	$1,607	88%
10 % Leak	189	1,031	2,833	281.2	3,863.9	4.6	0.827	6,818	37,118	6,520	51,186	$1,820	100%
20 % Leak	192	1,119	3,007	394.4	4,125.5	4.6	0.818	7,410	42,561	6,962	57,664	$2,050	113%
30 % Leak	220	1,208	3,150	532.6	4,358.0	4.6	0.812	8,003	48,636	7,354	64,725	$2,301	126%
40 % Leak	310	1,296	3,285	697.0	4,581.3	4.7	0.806	8,591	55,589	7,731	72,642	$2,583	142%
50 % Leak	427	1,386	3,408	900.9	4,793.6	4.7	0.801	9,174	63,693	8,090	81,888	$2,912	160%

Minneapolis	Hours Above 55 % RH	AC Runtime (h)	Htg Runtime (h)	Backup Heat Runtime (h)	AHU Fan Runtime (h)	AC COP (-)	AC SHR (-)	AC Energy (MJ)	Htg Energy (MJ)	AHU Fan Energy (MJ)	TOTAL ENERGY (MJ)	Total Costs	Relative Energy
0 % & No thermal	15	711	2,902	216.9	3,613.5	4.5	0.838	4,670	36,410	6,098	47,909	$1,437	69%
0 % Leak	13	822	3,258	443.5	4,079.6	4.4	0.856	5,407	47,766	6,885	60,769	$1,824	88%
10 % Leak	13	897	3,432	612.5	4,328.9	4.5	0.846	5,912	55,105	7,305	69,053	$2,072	100%
20 % Leak	15	973	3,577	802.2	4,550.0	4.5	0.839	6,421	62,936	7,678	77,767	$2,333	113%
30 % Leak	27	1,050	3,698	1,009.5	4,748.5	4.6	0.833	6,937	71,179	8,013	86,861	$2,606	126%
40 % Leak	48	1,127	3,816	1,234.7	4,942.6	4.6	0.829	7,444	80,060	8,341	96,676	$2,897	140%
50 % Leak	89	1,207	3,940	1,483.7	5,152.5	4.7	0.825	7,964	89,955	8,695	107,345	$3,220	155%

Note: All simulation cases account for thermal losses along with leakage losses except the case denoted '0 % & No thermal'.

Table 5.29 Levels of individual faults used in Figure 5.11

Fault Type	Fault Level (%)
Heat Pump Sizing (SIZ)[a]	+ 50
Duct Leakage (DUCT)	30
Indoor Coil Airflow (AF)	- 36
Refrigerant Undercharge (UC)	- 30
Refrigerant Overcharge (OC)	+ 30
Non-Condensable Gases (NC)	10
Electric Voltage (VOL)	+ 8
TXV Undersizing (TXV)	- 40

(a) Oversize scenario (2) described in Section 5.2.2.

Simulation results show no drastic differences in the effect of installation faults on energy use in a slab-on-grade house and a basement house, except for the duct leakage fault. For the slab-on-grade house, this fault has the potential to result in a higher increase in energy use that any other fault. The impact of this fault is higher for the heating dominated climate (Chicago and Minneapolis, 26 %) than for the cooling dominated climate (Houston, 18 %). Obviously, duct leakage will also result in some increase of energy use for the basement house; however, the model we used would not discern this effect.

The second most influential fault is refrigerant undercharge. For the 30 % undercharge fault level, the energy use increase is of the order of 20 % irrespective of the climate and building type. Refrigerant overcharge can also result in a significant increase in energy use, (10 ~16) % at the 30 % overcharge fault level. Improper indoor airflow can affect similar performance degradation.

Equipping a house with an oversized heat pump has a small effect if the air duct is oversized accordingly (which may be the case with a new construction). However, if the air duct is too restrictive and the nominal indoor airflow is maintained by adjusting the fan speed (scenario (2)), a 15 % increase in energy use for the house in Houston is predicted.

The cooling TXV undersized fault has also the potential to significantly increase the energy use. The effect of this fault will be most pronounced in localities with a high number of cooling mode operating hours. The cooling mode TXV undersized by 40 % results in (9 ~ 14) % more energy used in Houston as compared to a (3 ~ 5) % in Chicago.

The impact of the remaining faults – non-condensables and improper voltage – is under 4 %. The non-condensables and improper voltage faults, however, represent a substantial risk for durability of equipment and are very important to be diagnosed during a heat pump installation.