ADDENDA

ANSI/ASHRAE/IES Addendum cp to
ANSI/ASHRAE/IES Standard 90.1-2013

Energy Standard for Buildings Except Low-Rise Residential Buildings

Approved by the ASHRAE Standards Committee on June 25, 2016; by the ASHRAE Technology Council on June 29, 2016; by the IES Board of Directors on June 27, 2016; and by the American National Standards Institute on June 30, 2016.

This addendum was approved by a Standing Standard Project Committee (SSPC) for which the Standards Committee has established a documented program for regular publication of addenda or revisions, including procedures for timely, documented, consensus action on requests for change to any part of the standard. The change submittal form, instructions, and deadlines may be obtained in electronic form from the ASHRAE website (www.ashrae.org) or in paper form from the Senior Manager of Standards.

The latest edition of an ASHRAE Standard may be purchased on the ASHRAE website (www.ashrae.org) or from ASHRAE Customer Service, 1791 Tullie Circle, NE, Atlanta, GA 30329-2305. E-mail: orders@ashrae.org. Fax: 678-539-2129. Telephone: 404-636-8400 (worldwide), or toll free 1-800-527-4723 (for orders in US and Canada). For reprint permission, go to www.ashrae.org/permissions.

© 2016 ASHRAE ISSN 1041-2336

ASHRAE

IES Illuminating ENGINEERING SOCIETY

Approved American National Standard ANSI www.ansi.org

ASHRAE Standing Standard Project Committee 90.1
Cognizant TC: 7.6, Systems Energy Utilization
SPLS Liaison: Roger Hedrick
ASHRAE Staff Liaison: Steven C. Ferguson
IES Liaison: Rita M. Harrold

Drake Erbe*, *Chair*	Harry Misuriello*	John Dunlap
Thomas Culp*, *Vice-Chair*	Frank Morrison*	Chuck Foster
Richard, Lord*, *Vice-Chair*	Frank Myers*	Sam Francis
Peter Baselici *	Ron Nickson*	John Green
Sean Beilman*	Tim Peglow*	Chad Groshart
Jeff Boldt*	Eric Richman*	David Handwork
Ernie Conrad*	Steve Rosenstock*	Stan Harbuck
Charles Cottrell*	Bob Ross*	Mike Houston
Jay Crandall*	Marty Salzburg*	Richard Hermans
Craig Drumheller*	Leonard Sciarra*	Michael Ivanovich
Jim Garrigus*	Frank Stanonik*	Hy Kaplan
Jason Glazer*	Wayne Stoppelmoor*	Neil Leslie
Krishnan Gowri*	Christian Taber*	Merle McBride
Pekka Hakkarainen*	William Talbert*	Benjamin Meyer
Susanna Hanson*	Steven Taylor*	Keith Nelson
Richard Heinisch*	Martha VanGeem*	Steve Orlowski
Ned Heminger*	McHenry Wallace*	Amy Schmidt
Dave Herron*	Jerry White*	David Shepherd
Scott Hintz*	Jeremy Williams*	Don Surrena
John Hogan*	Karim Amrane	Stephen Szoke
Jonathan Humble*	Gary Ash	Mike Tillou
Itzhak Maor*	Joseph Brooks	Doug Tucker
Chris Mathis*	Don Brundage	Richard Watson
Michael Mehl*	Brandon Damas	Jason Wilen

** Denotes voting member at time of publication.*

*** PROOF ***

ASHRAE STANDARDS COMMITTEE 2015–2016

Douglass T. Reindl, *Chair*
Rita M. Harrold, *Vice-Chair*
James D. Aswegan
Niels Bidstrup
Donald M. Brundage
John A. Clark
Waller S. Clements
John F. Dunlap
James W. Earley, Jr.
Keith I. Emerson
Steven J. Emmerich
Julie M. Ferguson
Walter T. Grondzik
Roger L. Hedrick
Srinivas Katipamula
Rick A. Larson
Lawrence C. Markel
Arsen K. Melikov
Mark P. Modera
Cyrus H. Nasseri
Heather L. Platt
David Robin
Peter Simmonds
Dennis A. Stanke
Wayne H. Stoppelmoor, Jr.
Jack H. Zarour
Julia A. Keen, *BOD ExO*
James K. Vallort, *CO*

Stephanie C. Reiniche, *Senior Manager of Standards*

*** PROOF ***

SPECIAL NOTE

This American National Standard (ANS) is a national voluntary consensus standard developed under the auspices of ASHRAE. *Consensus* is defined by the American National Standards Institute (ANSI), of which ASHRAE is a member and which has approved this standard as an ANS, as "substantial agreement reached by directly and materially affected interest categories. This signifies the concurrence of more than a simple majority, but not necessarily unanimity. Consensus requires that all views and objections be considered, and that an effort be made toward their resolution." Compliance with this standard is voluntary until and unless a legal jurisdiction makes compliance mandatory through legislation.

ASHRAE obtains consensus through participation of its national and international members, associated societies, and public review.

ASHRAE Standards are prepared by a Project Committee appointed specifically for the purpose of writing the Standard. The Project Committee Chair and Vice-Chair must be members of ASHRAE; while other committee members may or may not be ASHRAE members, all must be technically qualified in the subject area of the Standard. Every effort is made to balance the concerned interests on all Project Committees.

The Manager of Standards of ASHRAE should be contacted for:

a. interpretation of the contents of this Standard,
b. participation in the next review of the Standard,
c. offering constructive criticism for improving the Standard, or
d. permission to reprint portions of the Standard.

DISCLAIMER

ASHRAE uses its best efforts to promulgate Standards and Guidelines for the benefit of the public in light of available information and accepted industry practices. However, ASHRAE does not guarantee, certify, or assure the safety or performance of any products, components, or systems tested, installed, or operated in accordance with ASHRAE's Standards or Guidelines or that any tests conducted under its Standards or Guidelines will be nonhazardous or free from risk.

ASHRAE INDUSTRIAL ADVERTISING POLICY ON STANDARDS

ASHRAE Standards and Guidelines are established to assist industry and the public by offering a uniform method of testing for rating purposes, by suggesting safe practices in designing and installing equipment, by providing proper definitions of this equipment, and by providing other information that may serve to guide the industry. The creation of ASHRAE Standards and Guidelines is determined by the need for them, and conformance to them is completely voluntary.

In referring to this Standard or Guideline and in marking of equipment and in advertising, no claim shall be made, either stated or implied, that the product has been approved by ASHRAE.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

(This foreword is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

FOREWORD

Addendum p provides a U-factor calculation procedure for metal building wall assemblies with filled cavity insulation systems and adds U-factor values to Table A3.2.3, calculated using this procedure. This addendum does not change the criteria of the standard.

This addendum makes proposed changes to the current standard. These changes are indicated in the text by underlining (for additions) and ~~strikethrough~~ (for deletions) except where the reviewer instructions specifically describe some other means of showing the changes.

Addendum cp to 90.1-2013

Modify the standard as follows (I-P):

A3.2 Metal Building Walls

A3.2.1 General. For the purpose of Section A1.2, the base assembly is a wall where the insulation is compressed between metal wall panels and the metal structure. Additional assemblies include continuous insulation, uncompressed and uninterrupted by framing. Insulation exposed to a conditioned space or semiheated space shall have a facing with seams overlapped or sealed. ~~and all insulation shall be continuously sealed to provide a continuous air barrier~~.

A3.2.2 Rated R-Value of Insulation for Metal Building Walls

A.3.2.2.1 Single Layer Compressed. The first rated R-value of insulation is for insulation compressed between metal wall panels and the steel structure.

A.3.2.2.2 Continuous Insulation. For assemblies with continuous insulation, the continuous insulation is installed on the outside or inside of the girts, uncompressed and uninterrupted by the framing members.

A3.2.2.3 Single Layer in Cavity. The insulation is installed in the cavity between the girts, not compressed by the framing. A membrane or facing, installed separately or adhered to the insulation, is installed inside of the girts to form a continuous layer. A thermal spacer block or thermal break strip between the girts and metal wall panels is required when specified in Table A3.2.3.

A3.2.2.4 Double Layer. The first rated R-value of insulation is for insulation installed in the cavity between the girts, not compressed by the framing. The second rated R-value of insulation is for insulation compressed between metal wall panels and the steel structure. A membrane or facing, installed separately or adhered to the insulation, is installed inside of the girts to form a continuous layer. A thermal spacer block or thermal break strip between the girts and metal wall panels is required when specified in Table A3.2.3.

A3.2.3 U-Factors for Metal Building Walls. U-factors for metal building walls shall be taken from Table A3.2.3 or determined in accordance with Section A9.2, provided the average girt spacing is at least 52 in. U-factors for metal building wall assemblies with average girt spacing less than 52 in. shall be determined in accordance with Section A9.2.

Table A3.2.3 Assembly U-Factors for Metal Building Walls (I-P)

Insulation System	Rated R-Value of Insulation	Overall U-Factor for Entire Base Wall Assembly	Overall U-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing)								

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

Continuous Insulation Only			R-6.5	R-9.8	R-13	R-15.8	R-19	R-22.1	R-25	R-32	R-38
	R-0 ~~None~~	1.180	0.136	0.094	0.072	0.060	0.050	0.044	0.039	0.030	0.026
~~Single Layer of Mineral Fiber~~											
Single Compressed Layer	R-10	0.186	0.084	0.066	0.054	0.047	0.041	0.036	0.033	0.027	0.023
	R-11	0.185	0.084	0.066	0.054	0.047	0.041	0.036	0.033	0.027	0.023
	R-13	0.162	0.079	0.063	0.052	0.046	0.040	0.035	0.032	0.026	0.023
	R-16	0.155	0.077	0.062	0.051	0.045	0.039	0.035	0.032	0.026	0.022
	R-19	0.147	0.075	0.060	0.050	0.044	0.039	0.035	0.031	0.026	0.022
Single Layer in Cavity	R-25[a]	0.059	0.044	0.039	0.035	0.032	0.029	0.027	0.025	0.021	0.019
	R-30[b]	0.052	0.042	0.037	0.033	0.031	0.028	0.026	0.024	0.021	0.019
Double Layer	R-25 + R-10	0.047									
	R-25 + R-16	0.042									
	R-25 + R-10[c]	0.039									
	R-30 + R-16	0.039									

(Multiple R-values are listed in order from inside to outside)

a. A minimum R-0.375 thermal spacer block or thermal break strip is required when installed without continuous insulation.

b. A minimum R-0.75 thermal spacer block or thermal break strip is required when installed without continuous insulation.

c. A minimum R-3 thermal spacer block is required.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

A9.2 Required Procedures. Two- or three-dimensional finite difference and finite volume computer models shall be an acceptable alternative method to calculating the thermal performance values for all assemblies and constructions listed below. The following procedures shall also be permitted to determine all alternative U-factors, F-factors, and C-factors.

a. Roofs

1. Roofs with insulation entirely above deck: testing or series calculation method.
2. Metal building roofs: testing, or for single-layer, and double-layer systems, calculation method in Section A9.4.5.
3. Attic roofs, wood joists: testing or parallel path calculation method.
4. Attic roofs, steel joists: testing or parallel path calculation method using the insulation/framing layer adjustment factors in Table A9.2-1 or modified zone calculation method.
5. Attic roofs, concrete joists: testing or parallel path calculation method if concrete is solid and uniform or isothermal planes calculation method if concrete has hollow sections.
6. Other attic roofs and other roofs: testing or two-dimensional calculation method.

b. Above-Grade Walls

1. Mass walls: testing or isothermal planes calculation method or two-dimensional calculation method. The parallel path calculation method is not acceptable.
2. Metal building walls: testing, or for ~~single layer~~single layer compressed, single layer in cavity, and double-layer systems, calculation method in Section A9.4.5.
3. Steel-framed walls: testing or parallel path calculation method using the insulation/framing layer adjustment factors in Table A9.2-2 or the modified zone method.
4. Wood-framed walls: testing or parallel path calculation method.
5. Other walls: testing or two-dimensional calculation method.

c. Below-Grade Walls
1. Mass walls: testing or isothermal planes calculation method or two-dimensional calculation method. The parallel path calculation method is not acceptable.
2 Other walls: testing or two-dimensional calculation method

d Floors
2. Mass floors: testing or parallel path calculation method if concrete is solid and uniform or isothermal planes calculation method if concrete has hollow sections.
2 Steel joist floors: testing or modified zone calculation method.
3 Wood joist floors: testing or parallel path calculation method or isothermal planes calculation method.
4 Other floors: testing or two-dimensional calculation method.

e Slab-on-Grade Floors
No testing or calculations allowed.

A9.4.5 Metal Building U-Factor Equations. For single-layer metal building roof and single layer compressed metal building wall systems, the calculation procedure outlined in Section A9.4.5.1 shall be used to calculate the assembly U-factor. For double-layer metal building roof ~~and wall~~ systems, the calculation procedure outlined in Section A9.4.5.2 shall be used to calculate the assembly U-factor. For single layer in cavity and double layer metal building wall systems, the calculation procedure outlined in Section A9.4.5.3 shall be used to calculate the assembly U-factor. The calculation procedures outlined in this section shall not be used for other metal building roof and wall systems.

A9.4.5.1 Single Layer Roof and Single Layer Compressed Wall. The U-factor of metal building roofs or walls that are insulated with a single layer of fiberglass insulation (see Figure A9.4.5.1) shall be calculated using the procedure outlined in this section. The procedure assumes the insulation is compressed over the purlin or girt. There may also be a thermal spacer block present.

(The remainder of Section A9.4.5.1 is unchanged.)

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

A9.4.5.2 Double Layer~~s~~ Roof. The U-factor of metal building roofs that are insulated with double layers of fiberglass insulation (see Figure A9.4.5.2-1) shall be calculated using the procedure outlined in this section. The procedure assumes the insulation is compressed over the purlin and there may be a thermal spacer block present.

(The remainder of Section A9.4.5.2 is unchanged.)

Insert new Section A9.4.5.3 which is not shown as underlined, though it's being proposed as a new section, because the underlined equations may not be clear. All equations and figures are new:

A9.4.5.3 Single Double Layer Filled Cavity or Liner System Wall. The U-factor of metal building walls that are insulated with multiple layers of mineral fiber insulation (see Figure A9.4.5.3-1) shall be calculated using the procedure outlined in this section. For double layer walls, the procedure assumes the insulation is compressed between the wall panel and girt. There may also be a thermal spacer block or continuous insulation present. Air spaces may also exist depending on the specific drape profiles.

There are nine steps in the calculation process:

Step 1 - Characterize the thermal conductivity of the mineral fiber insulation.
Step 2 - Define the parabolic profiles for each insulation layer.
Step 3 - Calculate the R-values for insulation and air spaces in cavity both outside and inside insulation layers, including air films.
Step 4 - Calculate the R-value inside the girt and adjacent to the web.
Step 5 - Calculate the R-value outside the girt.
Step 6 - Add the R-values inside and outside the girt including air films.
Step 7 - Calculate the overall insulation assembly using the R-values in Steps 3 and 6.
Step 8 - Calculate the U-factor from the finite element analysis results.
Step 9 - Calculate the U-factor for any continuous insulation if present.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

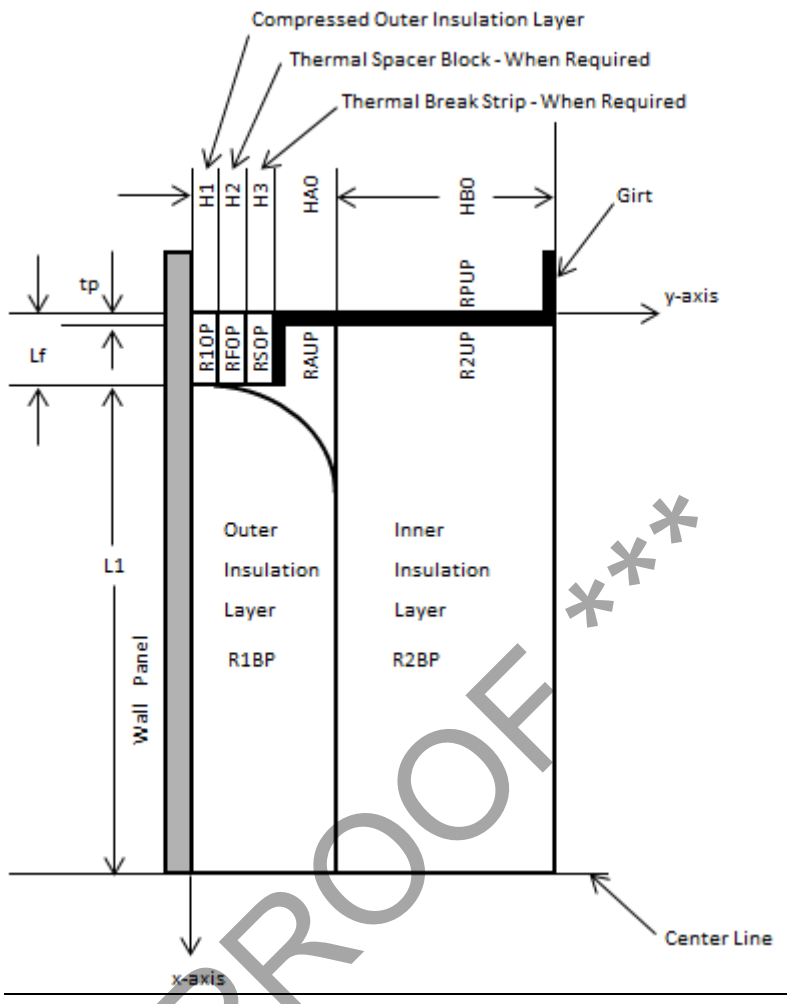


FIGURE A9.4.5.3-1 – Geometry of single cavity layer or double layer wall

Step 1: The thermal conductivity of the mineral fiber insulation is represented by a thermal curve of the form in Equation A9.4.21:

$$k = A + B\frac{\rho_o \delta_o}{y} + C\frac{y}{\rho_o \delta_o} \qquad \text{(A9.4.21)}$$

where

k	= thermal conductivity, Btu-ft/h-ft^2-^{o}F
ρ_o	= nominal density, lb/ft^3
δ_o	= nominal thickness, ft
y	= thickness of insulation, ft
A	= 0.014917
B	= 0.0004377
C	= 0.00056897

Step 2: Assume that each layer of mineral fiber has a parabolic profile defined by Equation A9.4-22:

$$\frac{y - Y_o}{Y_m - Y_o} = \frac{x}{X_m}\left(2 - \frac{x}{X_m}\right) \qquad \text{(A9.4-22)}$$

where

x = distance from edge of girt, ft

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

y = distance from edge of wall panel, ft
Y_o = insulation thickness at x=0, ft
Y_m = insulation thickness at $x=X_m$, ft

Step 3: Calculate R-values for the insulation and air spaces in the cavity both inside and outside insulation layers, including air films.

Because the configuration can possibly consist of both mineral fiber insulation and an air space, the composite is given by Equation A9.4-23:

$$R = \frac{1}{X_a}\int_0^{X_a} \left[\frac{y}{k_a} + \frac{Y_m - y}{k}\right] \mathrm{dx} + \frac{Y_m}{k(Y_m)} \qquad \text{(A9.4-23)}$$

where

k_a = thermal conductivity of air, Btu-ft/h-ft^2-°F

The trapezoidal integration method is used to evaluate the integral and calculate *R* and is given by Equation A9.4-24:

$$\int_a^b f(x)\mathrm{dx} \approx \frac{1}{2}\sum_{k=1}^{N}(x_{k+1} - x_k)(y_k + y_{k+1}) \qquad \text{(A9.4-24)}$$

where

x_k = point to analyze along the x-axis, ft
x_{k+1} = point ahead of the point being analyzed, ft
y_k = thickness at point being analyzed, ft
y_{k+1} = thickness at point ahead of the point being analyzed, ft

The integral represents the combined R-value of the air space and insulation over the region $0 < x < X_a$. Because the thermal conductivity of air is independent of the thickness, Equation 9.4.24 can be simplified using the air space mean thickness, Y_a, to produce Equation A9.4-25:

$$R = \frac{Y_a}{K_a} + \frac{1}{X_a}\int_0^{X_a}\left[\frac{Y_m - y}{K}\right]dx + \frac{Y_m}{K(Y_m)} \qquad \text{(A9.4-25)}$$

However, if the air space is characterized by convection instead of conduction then the term Y_a/k_a can be replaced by the R-value for convection (R-0.92 h-ft^2-°F/Btufor walls). Adding the inside and outside layers is expressed in Equation A9.4-26:

$$R_{BP} = R1BP + R2BP \qquad \text{(A9.4-26)}$$

Add the air film resistances at the exterior, R_{AT} and interior, R_{AB} which are defined as Equation A9.4-27:

$$R_{AB} = \frac{1}{h_{AB}} \qquad \text{(A9.4-27)}$$

where

h_{AB} = air film heat transfer coefficient at the exterior, Btu/h-ft^2-°F

$$R_{AT} = \frac{1}{h_{AT}} \qquad \text{(A9.4-28)}$$

where

h_{AT} = air film heat transfer coefficient at the interior, Btu/h-ft^2-°F

The sum of the R-values for the insulation and air films beyond the girt are expressed in EquationA9.4-29.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

$$R_{BP+air} = R_{BP} + R_{AB} + R_{AT} \quad \text{(A9.4-29)}$$

Step 4: Calculate the R-values inside the girt and adjacent to the web.

The R-values inside the girt are the air space (RAUP) added in series with the insulation (R2UP); their combined value is then added in parallel to RPUP. Depending on the thickness of the air space, it can be modeled as conduction as shown in Equation A9.4-30:

$$\text{RAUP} = \frac{H3}{k_a} \quad \text{(A9.4-30)}$$

where

H3 = thickness of the air space, ft

k_a = thermal conductivity of air, Btu-ft/h-ft^2-°F

When appropriate the air space can be modeled as convection which is a constant R-0.92 h-ft^2-°F/Btu for walls.

The R-value for R2UP is expressed in Equation A9.4-31. The insulation thickness is also not limited by the girt height and can extend beyond it.

$$R2\text{UP} = \frac{H4}{A + B\frac{\rho_0 \delta_0}{H4} + C\frac{H4}{\rho_0 \delta_0}} \quad \text{(A9.4-31)}$$

where

H4 = thickness of the mineral fiber at x = 0, ft

The R-value of the web, RPUP is calculated using 26.2 h-ft^2-°F/Btu as the thermal conductivity of the girt in Equation A9.4-32:

$$\text{RPUP} = \frac{\text{WebHeight}}{k_p} \quad \text{(A9.4-32)}$$

where

k_p = thermal conductivity of the girt, Btu-ft/h-ft^2-°F

WebHeight = height of the girt, ft

The addition of the air space and insulation in series are combined to be in parallel with the girt, which is expressed as Equation A9.4-33:

$$\frac{L_f}{\text{RUP}} = \frac{L_f - t_p}{\text{RAUP} + R2\text{UP}} + \frac{t_p}{\text{RPUP}} \quad \text{(A9.4-33)}$$

Equation A9.4-33 can be rearranged and solved for RUP as presented in Equation A9.4-34:

$$\text{RUP} = \frac{(\text{RAUP} + R2\text{UP})\,\text{RPUP}}{(L_f - t_p)\text{RPUP} + t_p(\text{RAUP} + R2\text{UP})} L_f \quad \text{(A9.4-34)}$$

Because the thickness of the girt is significantly less than the flange width, L_f, Equation A9.4-34 can be simplified as Equation A9.4-35. However it is important to note that RUP will be close to 2 or lower (depending on how the air is modeled) because of the significant effects of the steel girt.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

$$\mathrm{RUP} = \frac{(\mathrm{RAUP}+R2\mathrm{UP})\,\mathrm{RPUP}}{L_f\,\mathrm{RPUP}+t_p(\mathrm{RAUP}+R2\mathrm{UP})}L_f \qquad \text{(A9.4.35)}$$

Step 5: Calculate the R-value outside the girt.

Typical construction above the girt consists of a thermal spacer block and compressed mineral fiber insulation. These two insulations are in series and the total R-value, R_{OPI}, is expressed as Equation A9.4-36. If there is thermal break tape present it is included as the third insulation in this series.

$$R_{\mathrm{OPI}} = \frac{H1}{k_f} + \frac{H2}{k_I} \qquad \text{(A9.4-36)}$$

where

H1 = thickness of thermal spacer block, ft
H2 = thickness of compressed mineral fiber insulation, ft
k_f = thermal conductivity of the thermal spacer block, Btu-ft/h-ft^2-°F
k_I = thermal conductivity of the compressed mineral fiber insulation, Btu-ft/h-ft^2-°F

The impact of the thermal bridging associated with the outside of the girt and the insulation is to reduce the thermal resistance of the insulation. The reduction is calculated using Equation A9.4-37:

$$R_{\mathrm{OP}} = R_{\mathrm{OPI}}\frac{1}{\left[1+\frac{2(H_1+H_2)}{\pi L_f}\right]} \qquad \text{(A9.4-37)}$$

Step 6 – Add the R-values inside and outside the girt including air films.

The total thermal resistance associated with the girt is the sum of the R-values inside and outside the girt as shown in Equation A9.4-38:

$$R_{TP} = R_{UP} + R_{OP} \qquad \text{(A9.4-38)}$$

The next calculation is to add the inside and outside air film coefficients using Equation A9.4-39:

$$R_{TP+air} = R_{TP} + R_{AB} + R_{AT} \qquad \text{(A9.4-39)}$$

Step 7: Calculate the overall insulation assembly using the R-values in Steps 3 and 6.

The overall insulation system R-value is determined using Equation A9.4-40:

$$R_{\mathrm{insul-sys}} = \frac{(2L_1 + L_f)R_{\mathrm{BP+air}}R_{\mathrm{TP+air}}}{2L_1R_{\mathrm{TP+air}} + L_fR_{\mathrm{BP+air}}} \qquad \text{(A9.4-40)}$$

Step 8: Calculate the U-factor from the finite element analysis results.

The overall U-factor for the insulation assembly is determined using Equation A9.4-41:

$$U_{adj} = \frac{1}{0.8672R_{insul-sys} + 1.132} \qquad \text{(A9.4-41)}$$

where

U_{adj} = adjusted overall U-factor represented by the correlation with the finite element modeling, Btu/h-ft^2-°F

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

Step 9: Calculate the overall U-factor for any continuous insulation if present.

If there is any continuous insulation present, first calculate the R-value adjacent to the flange using Equation A9.4-42:

$$R_{\mathrm{BFci}} = R_{\mathrm{ci}} \frac{1}{\left[1 + \frac{2(h_{\mathrm{ci}})}{\pi L_f}\right]} \qquad \text{(A9.4-42)}$$

where

R_{BFci} = thermal resistance of continuous insulation adjacent to the flange, h-ft^2-°F/Btu

R_{ci} = thermal resistance of the continuous insulation, h-ft^2-°F/Btu

h_{ci} = thickness of the continuous insulation, ft

Next, calculate the area-weighted R-value for the continuous insulation using Equation A9.4-43:

$$R_{\mathrm{oci}} = \frac{(2L_1 + L_f)R_{\mathrm{BPci}}R_{\mathrm{ci}}}{2L_1 R_{\mathrm{BPci}} + L_f R_{\mathrm{ci}}} \qquad \text{(A9.4-43)}$$

where

R_{oci} = overall thermal resistance of continuous insulation, h-ft^2-°F/Btu

Finally, calculate the overall U-factor using Equation A9.4-44:

$$U_o = \frac{1}{\frac{1}{U_{\mathrm{adj}}} + R_{\mathrm{oci}}} \qquad \text{(A9.4-44)}$$

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

Modify the standard as follows (SI):

A3.2 Metal Building Walls

A3.2.1 General. For the purpose of Section A1.2, the base assembly is a wall where the insulation is compressed between metal wall panels and the metal structure. Additional assemblies include continuous insulation, uncompressed and uninterrupted by framing. Insulation exposed to a conditioned space or semiheated space shall have a facing with seams overlapped or sealed. ~~and all insulation shall be continuously sealed to provide a continuous air barrier~~.

A3.2.2 Rated R-Value of Insulation for Metal Building Walls

A.3.2.2.1 Single Layer Compressed. The first rated R-value of insulation is for insulation compressed between metal wall panels and the steel structure.

A.3.2.2.2 Continuous Insulation. For assemblies with continuous insulation, the continuous insulation is installed on the outside or inside of the girts, uncompressed and uninterrupted by the framing members.

A3.2.2.3 Single Layer in Cavity. The insulation is installed in the cavity between the girts, not compressed by the framing. A membrane or facing, installed separately or adhered to the insulation, is installed inside of the girts to form a continuous layer. A thermal spacer block or thermal break strip between the girts and metal wall panels is required when specified in Table A3.2.3.

A3.2.2.4 Double Layer. The first rated R-value of insulation is for insulation installed in the cavity between the girts, not compressed by the framing. The second rated R-value of insulation is for insulation compressed between metal wall panels and the steel structure. A membrane or facing, installed separately or adhered to the insulation, is installed inside of the girts to form a continuous layer. A thermal spacer block or thermal break strip between the girts and metal wall panels is required when specified in Table A3.2.3.

A3.2.3 U-Factors for Metal Building Walls. U-factors for metal building walls shall be taken from Table A3.2.3 or determined in accordance with Section A9.2, provided the average girt spacing is at least 1.32 meters. U-factors for metal building wall assemblies with average girt spacing less than 1.32 meters shall be determined in accordance with Section A9.2.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

Table A3.2.3 Assembly U-Factors for Metal Building Walls (SI)

Insulation System	Rated R-Value of Insulation	Overall U-Factor for Entire Base Wall Assembly	Overall U-Factor for Assembly of Base Wall Plus Continuous Insulation (Uninterrupted by Framing)								
Continuous Insulation Only			R-1.1	R-1.7	R-2.3	R-2.8	R-3.3	R-3.9	R-4.4	R-5.6	R-6.7
	R-0 ~~None~~	6.70	0.773	0.53	0.41	0.34	0.29	0.25	0.22	0.17	0.15
~~**Single Layer of Mineral Fiber**~~											
Single Compressed Layer	R-1.8	1.06	0.48	0.37	0.31	0.27	0.23	0.21	0.19	0.15	0.13
	R-1.9	1.05	0.48	0.37	0.31	0.27	0.23	0.21	0.19	0.15	0.13
	R-2.3	0.920	0.45	0.36	0.30	0.26	0.23	0.20	0.18	0.15	0.13
	R-2.8	0.880	0.44	0.35	0.29	0.26	0.22	0.20	0.18	0.15	0.13
	R-3.3	0.835	0.43	0.34	0.28	0.25	0.22	0.20	0.18	0.15	0.13
Single Layer in Cavity	R-4.4[a]	0.335	0.25	0.22	0.20	0.18	0.16	0.15	0.14	0.12	0.11
	R-5.3[b]	0.295	0.24	0.21	0.19	0.18	0.16	0.15	0.14	0.12	0.11
Double Layer	R-4.4 + R-1.8	0.267									
	R-4.4 + R-2.8	0.238									
	R-4.4 + R-1.8[c]	0.221									
	R-5.3 + R-2.8	0.221									

(Multiple R-values are listed in order from inside to outside)

a. A minimum R-0.07 thermal spacer block or thermal break strip is required when installed without continuous insulation.

b. A minimum R-0.13 thermal spacer block or thermal break strip is required when installed without continuous insulation.

c. A minimum R-0.5 thermal spacer block is required.

*** PROOF ***

A9.2 Required Procedures. Two- or three-dimensional finite difference and finite volume computer models shall be an acceptable alternative method to calculating the thermal performance values for all assemblies and constructions listed below. The following procedures shall also be permitted to determine all alternative U-factors, F-factors, and C-factors.

a. Roofs
   1. Roofs with insulation entirely above deck: testing or series calculation method.
   2 Metal building roofs: testing, or for single-layer, and double-layer systems, calculation method in Section A9.4.5.
   3 Attic roofs, wood joists: testing or parallel path calculation method.
   4 Attic roofs, steel joists: testing or parallel path calculation method using the insulation/framing layer adjustment factors in Table A9.2-1 or modified zone calculation method.
   5 Attic roofs, concrete joists: testing or parallel path calculation method if concrete is solid and uniform or isothermal planes calculation method if concrete has hollow sections.
   6 Other attic roofs and other roofs: testing or two-dimensional calculation method.

b. Above-Grade Walls
   1. Mass walls: testing or isothermal planes calculation method or two-dimensional calculation method. The parallel path calculation method is not acceptable.

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

2 Metal building walls: testing, or for ~~single layer~~single layer compressed, single layer in cavity, and double-layer systems, calculation method in Section A9.4.5.
3 Steel-framed walls: testing or parallel path calculation method using the insulation/framing layer adjustment factors in Table A9.2-2 or the modified zone method.
4 Wood-framed walls: testing or parallel path calculation method.
5 Other walls: testing or two-dimensional calculation method.

c. Below-Grade Walls
1. Mass walls: testing or isothermal planes calculation method or two-dimensional calculation method. The parallel path calculation method is not acceptable.
2 Other walls: testing or two-dimensional calculation method

d Floors
1. Mass floors: testing or parallel path calculation method if concrete is solid and uniform or isothermal planes calculation method if concrete has hollow sections.
2 Steel joist floors: testing or modified zone calculation method.
3 Wood joist floors: testing or parallel path calculation method or isothermal planes calculation method.
4 Other floors: testing or two-dimensional calculation method.

e Slab-on-Grade Floors
1. No testing or calculations allowed.

A9.4.5 Metal Building U-Factor Equations. For single-layer metal building roof and single layer compressed metal building wall systems, the calculation procedure outlined in Section A9.4.5.1 shall be used to calculate the assembly U-factor. For double-layer metal building roof ~~and wall~~ systems, the calculation procedure outlined in Section A9.4.5.2 shall be used to calculate the assembly U-factor. For single layer in cavity and double layer metal building wall systems the calculation procedure outlined in Section A9.4.5.3 shall be used to calculate the assembly U-factor. The calculation procedures outlined in this section shall not be used for other metal building roof and wall systems.

A9.4.5.1 Single Layer Roof and Single Layer Compressed Wall. The U-factor of metal building roofs or walls that are insulated with a single layer of fiberglass insulation (see Figure A9.4.5.1) shall be calculated using the procedure outlined in this section. The procedure assumes the insulation is compressed over the purlin or girt. There may also be a thermal spacer block present.

(The remainder of Section A9.4.5.1 is unchanged.)

A9.4.5.2 Double Layer~~s~~ Roof. The U-factor of metal building roofs that are insulated with double layers of fiberglass insulation (see Figure A9.4.5.2-1) shall be calculated using the procedure outlined in this section. The procedure assumes the insulation is compressed over the purlin and there may be a thermal spacer block present.

(The remainder of Section A9.4.5.2 is unchanged.)

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution,
or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

Insert new Section A9.4.5.3 which is not shown as underlined, though it's being proposed as a new section, because the underlined equations may not be clear. All equations and figures are new.

A9.4.5.3 Single Double Layer Filled Cavity or Liner System Wall. The U-factor of metal building walls that are insulated with multiple layers of mineral fiber insulation (see Figure A9.4.5.3-1) shall be calculated using the procedure outlined in this section. For double layer walls the procedure assumes the insulation is compressed between the wall panel and girt. There may also be a thermal spacer block or continuous insulation present. Air spaces may also exist depending upon the specific drape profiles.

There are nine steps in the calculation process:

Step 1 - Characterize the thermal conductivity of the mineral fiber insulation,

Step 2 - Define the parabolic profiles for each insulation layer,

Step 3 - Calculate the R-values for insulation and air spaces in cavity, both outside and inside insulation layers including air films,

Step 4 - Calculate the R-value inside the girt and adjacent to the web,

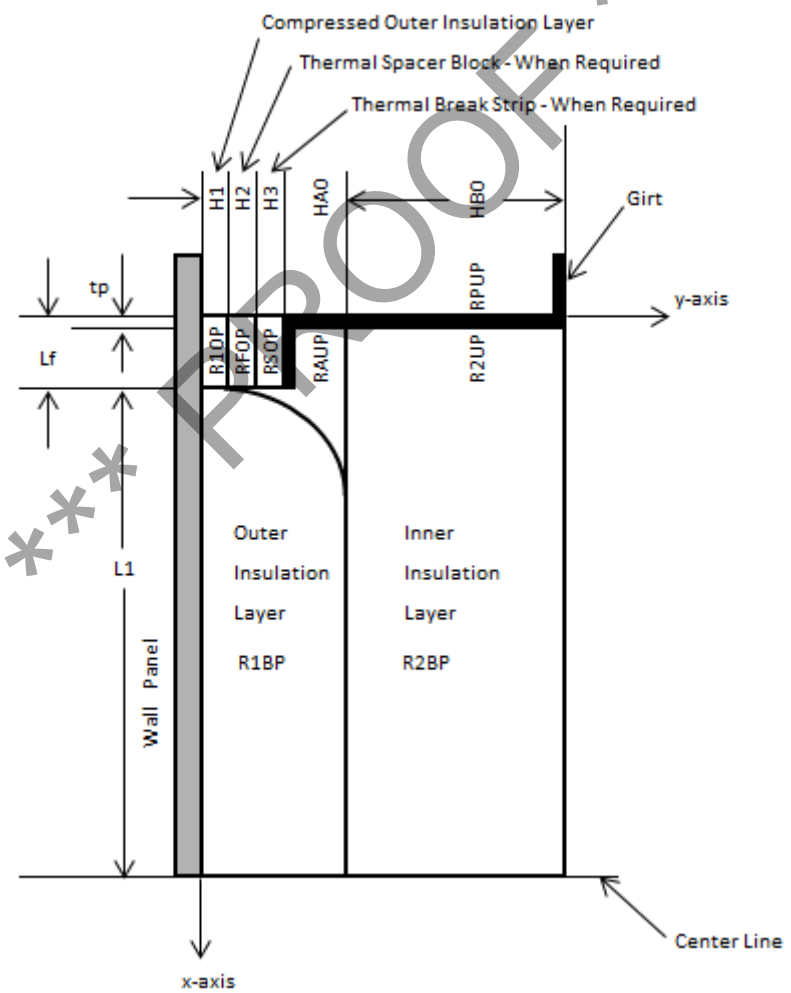
Step 5 - Calculate the R-value outside the girt,

Step 6 - Add the R-values inside and outside the girt including air films,

Step 7 - Calculate the overall insulation assembly using the R-values in Steps 3 and 6,

Step 8 - Calculate the U-factor from the finite element analysis results,

Step 9 - Calculate the U-factor for any continuous insulation if present.



*** PROOF ***

FIGURE A9.4.5.3-1 – Geometry of single cavity layer or double layer wall

Step 1 - The thermal conductivity of the mineral fiber insulation is represented by a thermal curve of the form in Equation A9.4.21.

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

$$k = A + B\frac{\rho_o \delta_o}{y} + C\frac{y}{\rho_o \delta_o} \qquad \text{(A9.4.21)}$$

where

k	= thermal conductivity, W/m-ºC
ρ_o	= nominal density, kg/m^3
δ_o	= nominal thickness, m
y	= thickness of insulation, m
A	= 0.00258168
B	= 0.000047295
C	= 0.157740033

Step 2 - Assume that each layer of mineral fiber has a parabolic profile defined by Equation A9.4-22

$$\frac{y - Y_o}{Y_m - Y_o} = \frac{x}{X_m}\left(2 - \frac{x}{X_m}\right) \qquad \text{(A9.4-22)}$$

where

x	= distance from edge of girt, m
y	= distance from edge of wall panel, m
Y_o	= insulation thickness at x=0, m
Y_m	= insulation thickness at x=X_m, m

Step 3 - Calculate R-values for the insulation and air spaces in the cavity, both inside and outside insulation layers including air films.

Since the configuration can possibly consist of both mineral fiber insulation and an air space the composite is given by Equation A9.4-23.

$$R = \frac{1}{X_a}\int_0^{X_a}\left[\frac{y}{k_a} + \frac{Y_m - y}{k}\right]\mathrm{dx} + \frac{Y_m}{k(Y_m)} \qquad \text{(A9.4-23)}$$

where

k_a	= thermal conductivity of air, W/m-ºC

The trapezoidal integration method is used to evaluate the integral and calculate R and is given below by Equation A9.4-24.

$$\int_a^b f(x)\mathrm{dx} \approx \frac{1}{2}\sum_{k=1}^{N}(x_{k+1} - x_k)(y_k + y_{k+1}) \qquad \text{(A9.4-24)}$$

where

x_k	= point to analyze along the x-axis, m
x_{k+1}	= point ahead of the point being analyzed, m
y_k	= thickness at point being analyzed, m
y_{k+1}	= thickness at point ahead of the point being analyzed, m

The integral represents the combined R-value of the air space and insulation over the region $0 < x < X_a$. Since the thermal conductivity of air is independent of the thickness Equation 9.4.24 can be simplified using the air space mean thickness, Y_a to produce Equation A9.4-25.

$$R = \frac{Y_a}{K_a} + \frac{1}{X_a}\int_0^{X_a}\left[\frac{Y_m - y}{K}\right]dx + \frac{Y_m}{K(Y_m)} \qquad \text{(A9.4-25)}$$

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

However, if the air space is characterized by convection instead of conduction then the term Y_a/k_a can be replaced by the R-value for convection (R-0.16 m^2-°C/W for walls)

Adding the inside and outside layers is expressed in Equation A9.4-26

$$R_{BP} = R1BP + R2BP \qquad \text{(A9.4-26)}$$

Add the air film resistances at the exterior, R_{AT} and interior, R_{AB} which are defined as:

$$R_{AB} = \frac{1}{h_{AB}} \qquad \text{(A9.4-27)}$$

where

h_{AB} = air film heat transfer coefficient at the exterior, W/m^2°C

$$R_{AT} = \frac{1}{h_{AT}} \qquad \text{(A9.4-28)}$$

where

h_{AT} = air film heat transfer coefficient at the interior, W/m^2-°C

The sum of the R-values for the insulation and air films beyond the girt are expressed in EquationA9.4-29.

$$R_{BP+air} = R_{BP} + R_{AB} + R_{AT} \qquad \text{(A9.4-29)}$$

Step 4 - Calculate the R-values inside the girt and adjacent to the web.

The R-values inside the girt are the air space (RAUP) added in series with the insulation (R2UP) and their combined value is then added in parallel to RPUP. Depending upon the thickness of the air space it can be modeled as conduction, see Equation A9.4-30.

$$RAUP = \frac{H3}{k_a} \qquad \text{(A9.4-30)}$$

where

H3 = thickness of the air space, m

k_a = thermal conductivity of air, W/m-°C

When appropriate the air space can be modeled as convection which is a constant R-0.16 m^2-°C/W for walls.

The R-value for R2UP is expressed in Equation A9.4-31. The insulation thickness is also not limited by the girt height and can extend beyond it.

$$R2UP = \frac{H4}{A + B\frac{\rho_o \delta_o}{H4} + C\frac{H4}{\rho_o \delta_o}} \qquad \text{(A9.4-31)}$$

where

H4 = thickness of the mineral fiber at x=0, m

The R-value of the web, RPUP is calculated using 45.3 W/m-°C as the thermal conductivity of the girt in Equation A9.4-32.

$$RPUP = \frac{WebHeight}{k_p} \qquad \text{(A9.4-32)}$$

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

where

k_p = thermal conductivity of the girt, W/m-°C
WebHeight = height of the girt, m

The addition of the air space and insulation in series are combined to be in parallel with the girt which is expressed as Equation A9.4-33.

$$\frac{L_f}{\text{RUP}} = \frac{L_f - t_p}{\text{RAUP} + R2\text{UP}} + \frac{t_p}{\text{RPUP}} \qquad \text{(A9.4-33)}$$

Equation A9.4-33 can be rearranged and solved for RUP as presented in Equation A9.4-34.

$$\text{RUP} = \frac{(\text{RAUP}+R2\text{UP})\,\text{RPUP}}{(L_f - t_p)\text{RPUP} + t_p(\text{RAUP}+R2\text{UP})} L_f \qquad \text{(A9.4-34)}$$

Since the thickness of the girt is significantly smaller than the flange width, L_f, Equation A9.4-34 can be simplified as Equation A9.4-35. However it is important to note that RUP will be close to 0.35 or lower (depending on how the air is modeled) because of the significant effects of the steel girt.

$$\text{RUP} = \frac{(\text{RAUP}+R2\text{UP})\,\text{RPUP}}{L_f\,\text{RPUP} + t_p(\text{RAUP}+R2\text{UP})} L_f \qquad \text{(A9.4.35)}$$

Step 5 – Calculate the R-value outside the girt.

Typical construction above the girt consists of a thermal spacer block and compressed mineral fiber insulation. These two insulations are in series and the total R-value, R_{OPI} is expressed as Equation A9.4-36. If there is thermal break tape present it is included as the third insulation in this series.

$$R_{\text{OPI}} = \frac{H1}{k_f} + \frac{H2}{k_I} \qquad \text{(A9.4-36)}$$

where

H1 = thickness of thermal spacer block, m
H2 = thickness of compressed mineral fiber insulation, m
k_f = thermal conductivity of the thermal spacer block, W/m-°C
k_I = thermal conductivity of the compressed mineral fiber insulation, W/m-°C

The impact of the thermal bridging associated with the outside of the girt and the insulation is to reduce the thermal resistance of the insulation. The reduction is calculated using Equation A9.4-37.

$$R_{\text{OP}} = R_{\text{OPI}} \frac{1}{\left[1 + \frac{2(H1+H2)}{\pi L_f}\right]} \qquad \text{(A9.4-37)}$$

Step 6 – Add the R-values inside and outside the girt including air films.

The total thermal resistance associated with the girt is the sum of the R-values inside and outside the girt as shown in Equation A9.4-38.

$$R_{TP} = R_{UP} + R_{OP} \qquad \text{(A9.4-38)}$$

The next calculation is to add the inside and outside air film coefficients using Equation A9.4-39.

*** PROOF ***

© ASHRAE (www.ashrae.org). For personal use only. Additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

$$R_{TP+air} = R_{TP} + R_{AB} + R_{AT} \quad \text{(A9.4-39)}$$

Step 7 - Calculate the overall insulation assemble using the R-values from steps 3 and 6.

The overall insulation system R-value is determined using Equation A9.4-40.

$$R_{\text{insul-sys}} = \frac{(2L_1 + L_f)R_{\text{BP+air}}R_{\text{TP+air}}}{2L_1R_{\text{TP+air}} + L_fR_{\text{BP+air}}} \quad \text{(A9.4-40)}$$

Step 8 - Calculate the U-factor from the finite element analysis results,

The overall U-factor for the insulation assembly is determined using Equation A9.4-41.

$$U_{adj} = \frac{1}{0.8672R_{insul-sys} + 0.1994} \quad \text{(A9.4-41)}$$

where

U_{adj} = adjusted overall U-factor represented by the correlation with the finite element modeling, W/m^2-^{o}C

Step 9 - Calculate the overall U-factor for any continuous insulation if present.

If there is any continuous insulation present, first calculate the R-value adjacent to the flange using Equation A9.4-42.

$$R_{\text{BFci}} = R_{\text{ci}}\frac{1}{\left[1 + \frac{2(h_{\text{ci}})}{\pi L_f}\right]} \quad \text{(A9.4-42)}$$

where

R_{BFci} = thermal resistance of continuous insulation adjacent to the flange, m^2-^{o}C/W

R_{ci} = thermal resistance of the continuous insulation, m^2-^{o}C/W

h_{ci} = thickness of the continuous insulation, m

Next, calculate the area weighted R-value for the continuous insulation using Equation A9.4-43.

$$R_{\text{oci}} = \frac{(2L_1 + L_f)R_{\text{BPci}}R_{\text{ci}}}{2L_1R_{\text{BPci}} + L_fR_{\text{ci}}} \quad \text{(A9.4-43)}$$

where

R_{oci} = overall thermal resistance of continuous insulation, m^2-^{o}C/W

Finally, calculate the overall U-factor using Equation A9.4-44.

$$U_o = \frac{1}{\frac{1}{U_{\text{adj}}} + R_{\text{oci}}} \quad \text{(A9.4-44)}$$

*** PROOF ***

*** PROOF ***

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted Standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the Standards and Guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive Technical Committee structure, continue to generate up-to-date Standards and Guidelines where appropriate and adopt, recommend, and promote those new and revised Standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date Standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating Standards and Guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

*** PROOF ***

ASHRAE · 1791 Tullie Circle NE · Atlanta, GA 30329 · www.ashrae.org

8/16