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Office of the State Fire Marshal - Engineering Division
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Calculating Wall U-Factors for Compliance with Table R402.1.4

Code: 2018 Energy Conservation Code **Date:** July 31, 2019
Section: R402.1.4

Question:
What wall components are assumed for the base wall assemblies in Table R402.1.4?

Answer:
The U-factors for Zone 3,4,5 are 0.077, 0.077, 0.061, respectively. The basic wall assembly used to set these values is described in this document. Please keep in mind this is not the only permissible way the wall can be built, but it will give the reader an idea of how the value was determined, and the general formula to calculate the U-factor for a wooden stud wall.

Unlike the R-value Table R402.1.2, the U-factor table **does** allow the user to "build a wall" and include not only the insulation materials, but also the framing and building materials such as gypsum, structural sheathing, and air films. The U-factor value is representative of the entire wall assembly, so the areas dedicated to framing and the less insulative qualities it provides also need to be accounted for. In simple terms, it is a weighted average, and the math has to be done correctly.

> **R402.1.4 U-factor alternative**. An assembly with a U-factor equal to or less than that specified in Table R402.1.4 shall be permitted as an alternative to the R-value in Table R402.1.2.

The basic wall assemblies that are assumed to achieve the various U-factors for Zone 3, 4, and 5 are tabulated on the following page.

Zone 3: Refer to Figure 2 and Figure 3 for illustrations of sample wall

	Component	Thickness	R-value
1	Outside Air film	N.A.	0.25[1]
2	3/8" plywood siding (T1-11)	3/8"	0.59
3	1 layer 15-lb felt	Neg.	0.06[2]
4	Structural plywood sheathing	5/8"	0.77
5	2x4 framing	3.5"	4.38
6	R-15 Cavity insulation	3.5"	15
7	Interior gypsum	1/2"	0.45
8	Interior Air film	N.A.	0.68
Total		(Do not directly add R-values, use parallel path method)	

Table 1: Zone 3 Wall Materials

Zone 4: Same as Zone 3.

Zone 5: Refer to Figure 5 and Figure 6 for illustrations of sample wall

	Component	Thickness	R-value
1	Outside Air film	N.A.	0.25
2	3/8" plywood siding (T1-11)	3/8"	0.59
3	1 layer 15-lb felt	Neg.	0.06
4	Structural plywood sheathing	½"	0.62
5	2x6 framing	5.5"	6.88
6	R-19 Cavity insulation	5.5"	19
7	Interior gypsum	1/2"	0.45
8	Interior Air film	N.A.	0.68
Total		(Do not directly add R-values, use parallel path method)	

Table 2: Zone 5 Wall Materials

Using the parallel path method, and the values shown in the preceding Tables, here are the U-factors for these wall assemblies:

Zone 3 – U=0.077 Btu/h-ft^2-ºF
Zone 4 – U=0.077 Btu/h-ft^2-ºF
Zone 5 – U=0.061[3] Btu/h-ft^2-ºF

[1] This correlates with the value used in ResCheck. Many times, you will see this as R=0.17. The difference is negligible, and this document stays with the ResCheck value so that the results and sample problems are easier to follow for anyone wishing to reproduce them.
[2] Most building wraps have negligible R-value, as does builder's felt, but the value was the "magic value" that makes the assembly come out to the U-0.077 overall value, so it is included. Many times it is ignored.
[3] In order to get the exact value, it was necessary to assume ½" plywood instead of the 5/8" plywood used for Zone 3 and 4. If 5/8" plywood is used in Zone 5, the U-factor would be U=0.060. This is slightly "better" than the U=0.061 in the table, but the goal was to show at least one assembly that meets the published values.

In Figure 1, page 4, the wall material values shown in Table 1 (page 2) are entered into the formula that is required for performing the parallel flow method. See Figure 1 for the formula and the results. Pictures of the sample wall are shown in Figures 2 and 3, page 5. Air films are not shown. This is the method used for wooden stud walls. This method is described in full in the ASHRAE Handbook of Fundamentals and is also described in the ResCheck User's Manual[i]. Although there is not a 2018 NC-Specific ResCheck, the user's manual still has valuable descriptions and data in it that can be utilized. The formula format and variable description follows the variables used in ResCheck for the most part, but in developing this document, some of the variables were simplified because there were some values that were "lumped together" in the ResCheck documentation, which makes it difficult for subsequent users to see where all the values actually come from and reproduce the results. In an effort to avoid this, and to make it transparent where all the values come from, the variables were changed slightly and expanded from the variable description used in the ResCheck example shown in Appendix A.2.1 Wood-frame walls.

The values and variables are all visible. Effort was taken to not embed or hide any variables or constants in the formulas that would make it difficult for a second reader to audit or verify the inputs, outputs, and formulas.

There are limits to the spreadsheet. It is only set up for the parallel heat flow path, thus the walls to be analyzed are basically limited ones with wooden construction. It is also limited as to how many different layers of insulation can be input, but if one is handy with Excel, more can be added if done correctly. The basic assumption is for walls that are "standard" framed. If advanced framing, or advanced framing with insulated headers are desired to be used, the basic spreadsheet would not handle that. If one is handy with Excel the formula can be expanded for advanced framing and for advanced framing with insulated headers.

There are no protections on the spreadsheet available at the following location: Code Enforcement Resources Webpage[ii]. Use it at your own risk. Unlike ResCheck, there is no way to audit the spreadsheet or its results unless the actual electronic version is available.

Finally, there are always slight variations in even legitimate sources for the R-values of air films, plywood, framing, etc. When provided by the REScheck user's manual, those values were used. If not, the ASHRAE Handbook of fundamentals was used. Some of the values and thickness were not documented as well as hoped in the ResCheck user's manual, but by trial-and-error and cross-checking with tables provided in ResCheck, the values chosen for the materials identified are solid assumptions.

Similarly, see Figure 4, page 5, that illustrates the parallel flow calculations for a wood-frame wall in Zone 5. It is followed by pictures of a sample wall, in Figures 5 and 6. Air films are not shown in the pictures.

Figure 1: Zone 3 and Zone 4 Wall U-factor Calculations

		Parallel Flow Method								
		Heat flow across framing			**Heat flow inbetween framing**					
	Wall Uo =	(% wall Framing)		+	(1 - % wall framing)					
		(Roaf + Rs + R_{felt} + Rsi + Rss + Rg + Rw + Riaf)			(Roaf + Rs + R_{felt} + Rsi + Rss + Rg + Ri + Riaf)					
	Wall Uo =	25%		+	75%					
		7.18	h-ft^2-F/Btu		17.8	h-ft^2-F/Btu				
	Zone 3 and Zone 4 Wall Values									
	Wall Uo =	**0.077**	Btu/h-ft^2-F							
	Variable Descriptions									
	% wallframing	= percent of wall that is studs, plates, headers (25% for 16" O.C., 22% for 24" O.C.)								
	Uo	= U overall of the wall								
	Roaf	= Resistance of outside air film			Roaf	= Resistance of outside air film				
	Rs	= Resistance of siding, if any*			Rs	= Resistance of siding, if any*				
	R_{felt}	= Resistance of felt			R_{felt}	= Resistance of felt				
	Rsi	=Resistance of insulated sheathing, if any			Rsi	=Resistance of insulated sheathing, if any				
	Rss	= Resistance of structural sheathing (OSB, plywood)			Rss	= Resistance of structural sheathing (OSB, plywood)				
	Rw	= Resistance of Framing inside wall (2x4, 2x6, etc)			Ri	= Resistance of cavity insulation (R-13, R15, R-19, etc)				
		(R_{2x4} = 4.38, R_{2x6} = 6.88)								
	Rg	=Resistance of indoor gypsum 1/2"			Rg	=Resistance of indoor gypsum 1/2"				
	Riaf	= Resistance of indoor air film			Riaf	= Resistance of indoor air film				
	Data input Section:									
	% wallframing =	25%			(1 - % wallframing) =	75%				
	Roaf =	0.25			Roaf =	0.25				
	Rs =	0.59			Rs =	0.59				
	R_{felt} =	0.06			R_{felt} =	0.06				
	Rsi =	0			Rsi =	0				
	Rss =	0.77			Rss =	0.77				
	Rw =	**4.38**			Ri =	15	Z3 = R15	Z4 = R15	Z5 = R19	
	Rg =	0.45			Rg =	0.45				
	Riaf =	0.68			Riaf =	0.68				
	*	Not all sidings add resistance, ventilated claddings, (rain screens, some brick veneers)								
		are designed to allow and depend upon air currents to pass behind them to eliminate water								
		build up. As such, they do not add to the thermal resistance of the assembly. They perform other								
		important functions, however.								
Miscellaneous Values and Source										
	2x4 stud	R=4.38	Appendix A.8 of ResCheck Technical Manual							
	2x6 stud	R=6.88	Appendix A.8 of ResCheck Technical Manual							
	Rss	R = 0.83	Appendix A.8 of ResCheck Technical Manual,							
	Rs =	0.59	This equates to 3/8" (0.375") Wood, plywood, lapped, from Table 4, Chapter 22.9, 1993 Fundamentals Handbook							
5/8" Plyw	Rss =	0.83	This equal 5/8" plywood, Douglas Fir (0.77) per Table 4, Chapter 22.9, 1993 Fundamentals Handbook.							
	R_{felt} =	0.06	This is the R-value of 15-lb builders felt. Please note it is a very small value, but it "makes the numbers work"							
1/2" plyw	Rss =	0.62	This is the R-value of 0.5 inc Douglas Fir Plywood. Table 4, Chpter 22.9, 1993 Fundamentals Handbook.							
			This is the value that gets the U-factor to exactly U=0.061 in Zone 5.							
Assumptions built-in to REScheck 4.0 and later versions:										
The basic wall materials in a wood-frame wall are assumed to be : plywood siding, plywood structural sheathing,										
and foam insulation sheathing on the framing exterior, batt insulation, wood framing, and 1/2" gypsum on the										
interior. The entire wall is assumed to be covered at the specified R-value.										

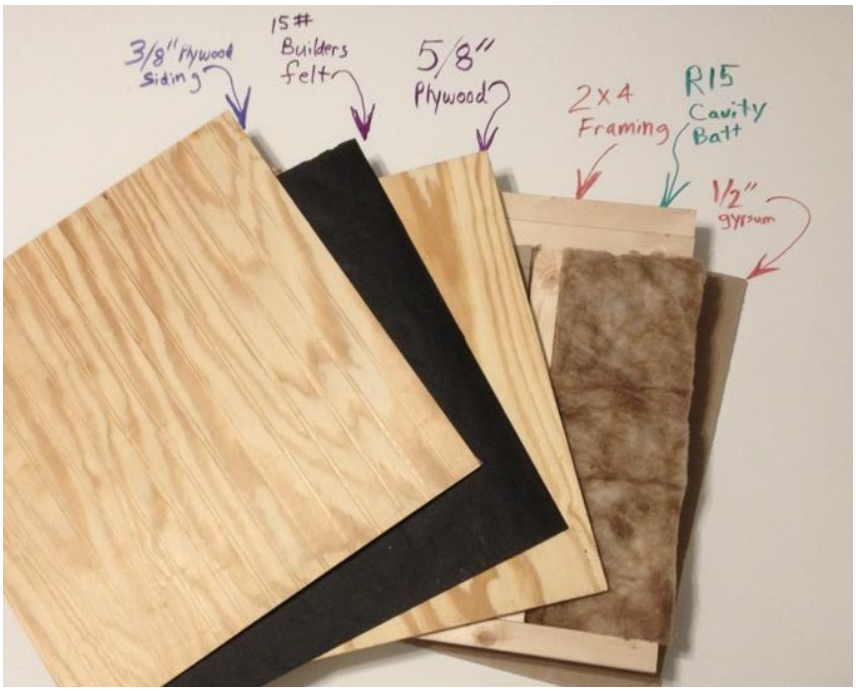

Figure 2: Sample Wall - Zone 3 and Zone 4

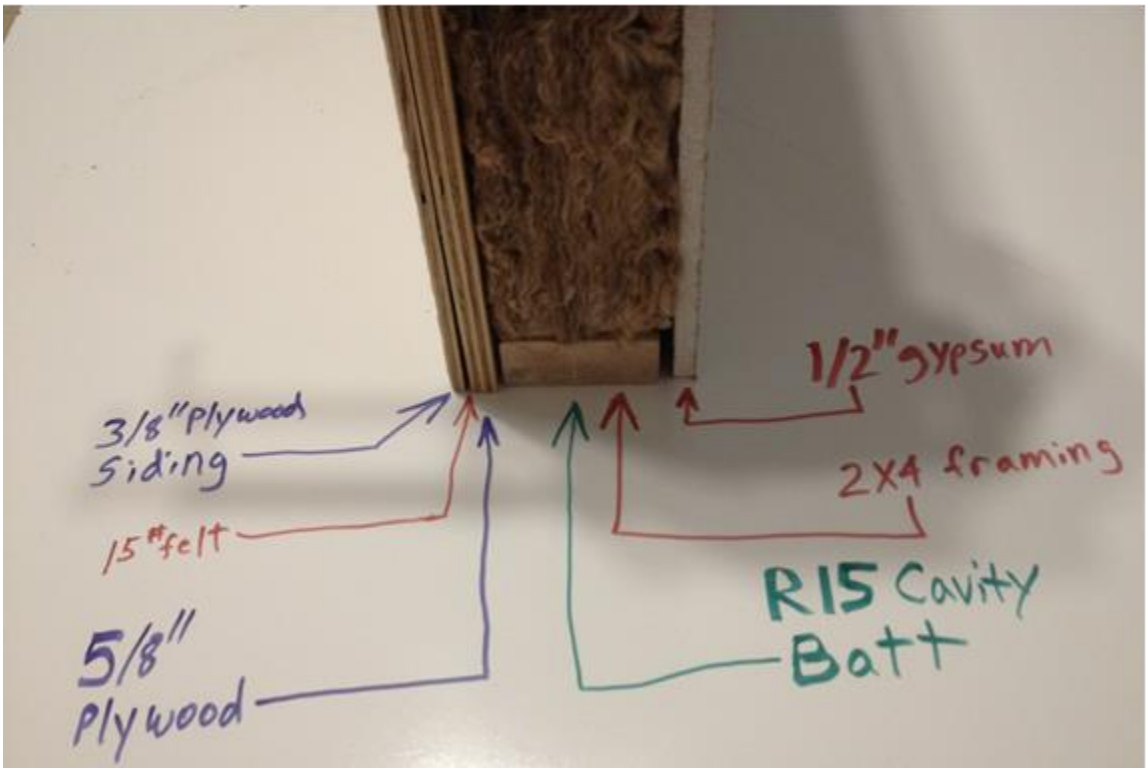

Figure 3: Sample Wall – Zone 3 and Zone 4 Cross Section

Figure 4: Zone 5 Wall U-factor Calculation

		Parallel Flow Method								
		Heat flow across framing			**Heat flow inbetween framing**					
	Wall Uo =	(% wall Framing)		+	(1 - % wall framing)					
		(Roaf + Rs + R_{felt} + Rsi + Rss + Rg + Rw + Riaf)			(Roaf + Rs + R_{felt} + Rsi + Rss + Rg + Ri + Riaf)					
	Wall Uo =	25%		+	75%					
		9.53	h-ft^2-F/Btu		21.65	h-ft^2-F/Btu				
	Zone 5 Wall Value									
	Wall Uo =	**0.061**	Btu/h-ft^2-F							
	Variable Descriptions									
	% wallframing	= percent of wall that is studs, plates, headers (25% for 16" O.C., 22% for 24" O.C.)								
	Uo	= U overall of the wall								
	Roaf	= Resistance of outside air film			Roaf	= Resistance of outside air film				
	Rs	= Resistance of siding, if any*			Rs	= Resistance of siding, if any*				
	R_{felt}	= Resistance of felt			R_{felt}	= Resistance of felt				
	Rsi	=Resistance of insulated sheathing, if any			Rsi	=Resistance of insulated sheathing, if any				
	Rss	= Resistance of structural sheathing (OSB, plywood)			Rss	= Resistance of structural sheathing (OSB, plywood)				
	Rw	= Resistance of Framing inside wall (2x4, 2x6, etc)			Ri	= Resistance of cavity insulation (R-13, R15, R-19, etc)				
		(R_{2x4} = 4.38, R_{2x6} = 6.88)								
	Rg	=Resistance of indoor gypsum 1/2"			Rg	=Resistance of indoor gypsum 1/2"				
	Riaf	= Resistance of indoor air film			Riaf	= Resistance of indoor air film				
	Data input Section:									
	% wallframing =	25%		(1 - % wallframing) =	75%					
	Roaf =	0.25			Roaf =	0.25				
	Rs =	0.59			Rs =	0.59				
	R_{felt} =	0.06			R_{felt} =	0.06				
	Rsi =	0			Rsi =	0				
	Rss =	0.62			Rss =	0.62				
	Rw =	**6.88**			Ri =	19	Z3 = R15	Z4 = R15	Z5 = R19	
	Rg =	0.45			Rg =	0.45				
	Riaf =	0.68			Riaf =	0.68				
	*	Not all sidings add resistance, ventilated claddings, (rain screens, some brick veneers)								
		are designed to allow and depend upon air currents to pass behind them to eliminate water								
		build up. As such, they do not add to the thermal resistance of the assembly. They perform other								
		important functions, however.								
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	Rss	R = 0.83	Appendix A.8 of ResCheck Technical Manual,							
	Rs =	0.59	This equates to 3/8" (0.375") Wood, plywood, lapped, from Table 4, Chapter 22.9, 1993 Fundamentals Handbook							
5/8" Plyw	Rss =	0.83	This equal 5/8" plywood, Douglas Fir (0.77) per Table 4, Chapter 22.9, 1993 Fundamentals Handbook.							
	R_{felt} =	0.06	This is the R-value of 15-lb builders felt. Please note it is a very small value, but it "makes the numbers work"							
1/2" plyw	Rss =	0.62	This is the R-value of 0.5 inc Douglas Fir Plywood. Table 4, Chpter 22.9, 1993 Fundamentals Handbook.							
			This is the value that gets the U-factor to exactly U=0.061 in Zone 5.							
Assumptions built-in to REScheck 4.0 and later versions:										
The basic wall materials in a wood-frame wall are assumed to be : plywood siding, plywood structural sheathing, and foam insulation sheathing on the framing exterior, batt insulation, wood framing, and 1/2" gypsum on the interior. The entire wall is assumed to be covered at the specified R-value.										

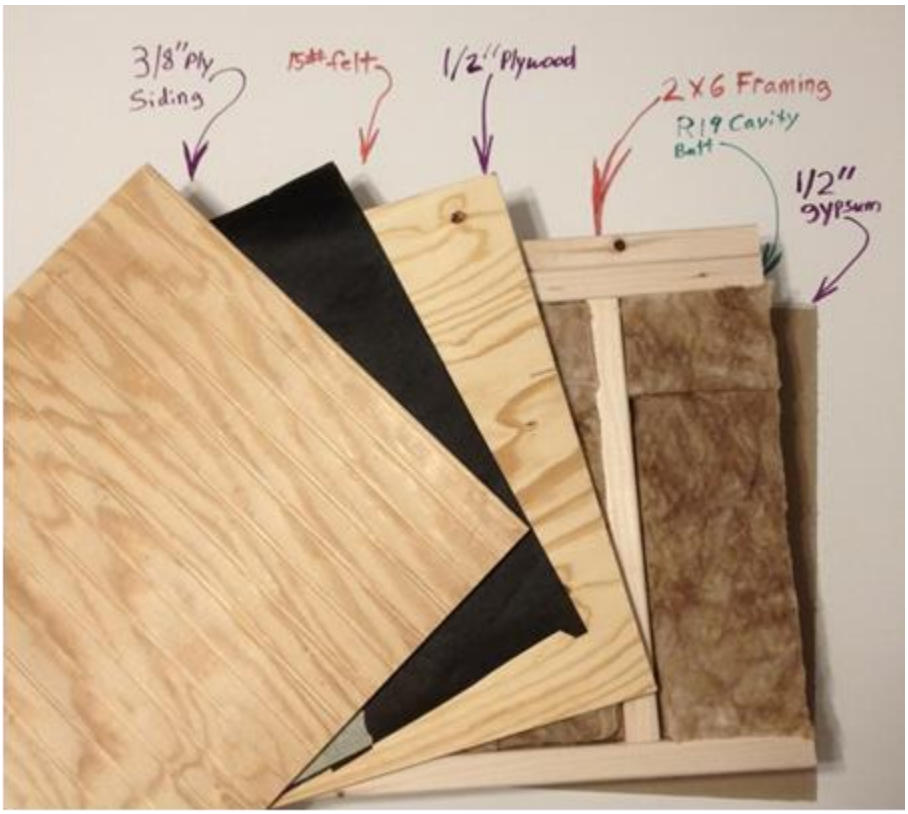

Figure 5: Sample Wall - Zone 5

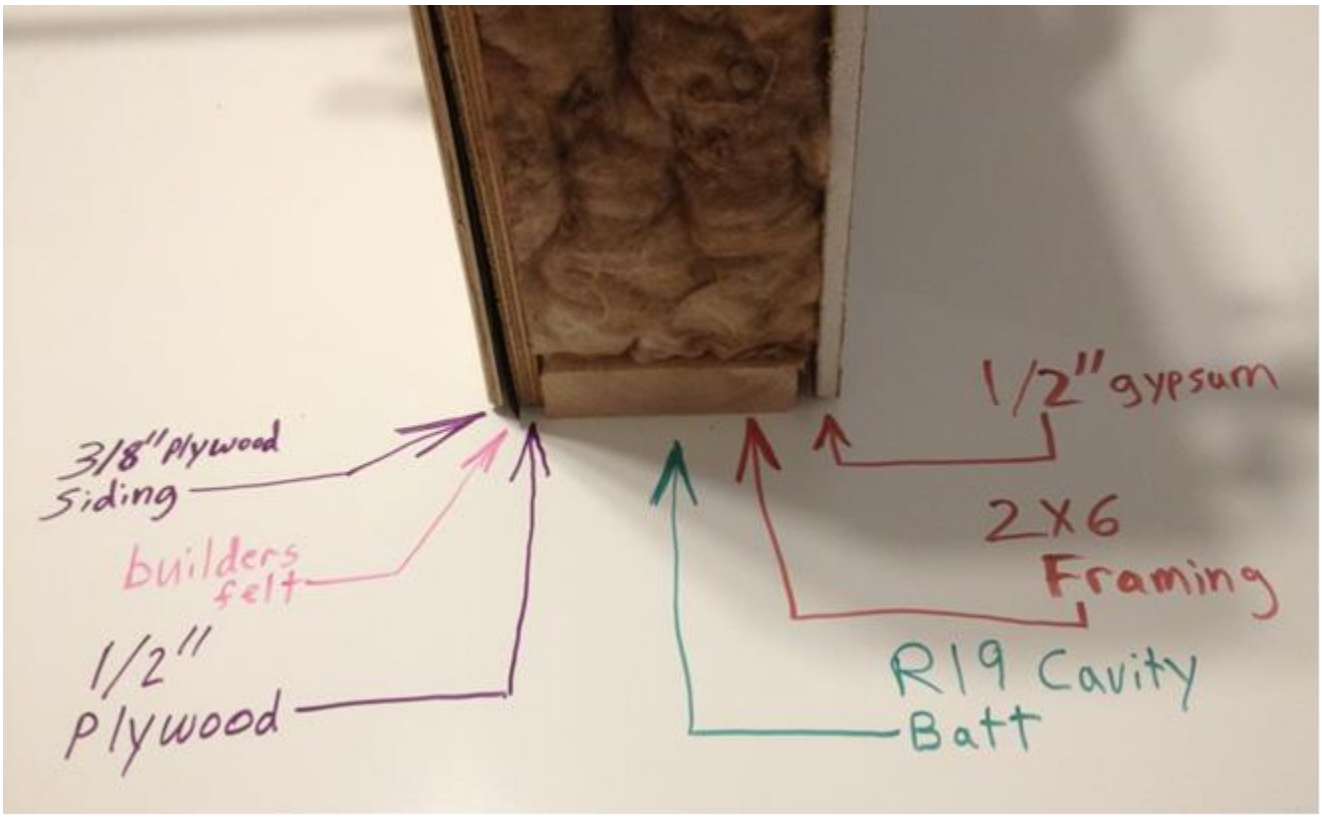

Figure 6: Sample Wall - Zone 5 Cross Section

Follow-up question#1
Can the parallel heat flow equation shown in Equation 1 be rewritten and solved using the layout in Equation 2?

Equation 1[iii]
Uo = a / (R1 + R2 + … + Rn) + b / (R1 + R2 + …+ Rn)

Equation 2
Uo = 1 / [a * R1 + a * R2+..+ a * Rn + b * R1 + b * R2 ..+b * Rn]
Where the "*" is a multiplication symbol?

Where a and b for both equations are respective fractions of a typical basic area composed of several different heat flow paths, and Uo is the overall heat transmittance for the basic area being analyzed.

Answer #1:
No. This is mathematically incorrect. You cannot algebraically rewrite Equation 1 so that it equals Equation 2. It is a violation of the order of operations required for mathematical equation solving. It will give incorrect results, and will almost always overstate the actual insulative qualities of the assembly being analyzed. There have been several examples of this being submitted to this office as being correct, but they are not. In a spreadsheet, it is difficult to tell what the actual formula being used is without the electronic version to trouble shoot the formula.

If you were to substitute values in for the variables and solve each equation, you will see that they are not equivalent. The values within parenthesis need to be done before the operations outside of the parenthesis, which in this case is division. See the following rules, reprinted from basic-mathematics website[iv]:

Rule #1:
1. If grouping symbols are used **such as parentheses**, **perform the operations inside the grouping symbols first**.
2. Evaluate any expressions with exponent
3. Multiply and Divide from left to right
4. Add and Subtract from left to right

Search Words:
Thermal envelope, British Thermal Units

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[i] ResCheck technical support document. https://www.energycodes.gov/rescheck-technical-support-document

[ii] http://ncdoi.com/OSFM/Engineering_and_Codes/Default.aspx?field1=Code_Enforcement_-_Design_Tools&user=Code_Enforcement_Resources

[iii] Refer to Equation 1,2,3, and 5 in ASHRAE Handbook of Fundamentals, 1993, chapter 20.
[iv] https://www.basic-mathematics.com/order-of-operations.html [www.basic-mathematics.com, July, 2019]