Air Space R-Value

Design Guide
Revised August 31, 2018

ABTG

Applied Building Technology Group (ABTG) is committed to using sound science and generally accepted engineering practice to develop research supporting the reliable design and installation of foam sheathing. ABTG's educational program work with respect to foam sheathing is provided through a grant by the Foam Sheathing Committee (FSC) of the American Chemistry Council.

ABTG is a professional engineering firm, an approved source as defined in Chapter 2 and independent as defined in Chapter 17 of the IBC.

Foam sheathing research reports, code compliance documents, educational programs and best practices can be found at www.continuousinsulation.org.

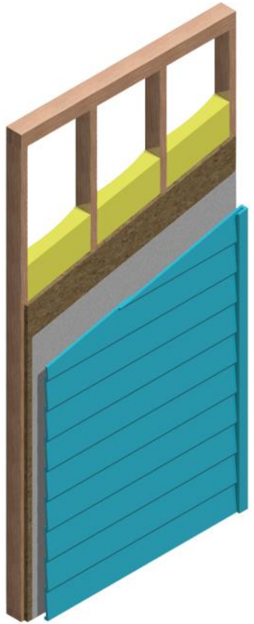
ci | Foam Plastic Applications for Better Building

Introduction

- Airspaces in building envelope assemblies are known to affect thermal performance.
- The exact R-value of an airspace can vary significantly depending on factors such as air-tightness or the type of surrounding materials.
- While conventional “mass” insulation materials also have variable thermal performance depending on conditions of use, the degree of variability is generally much smaller.

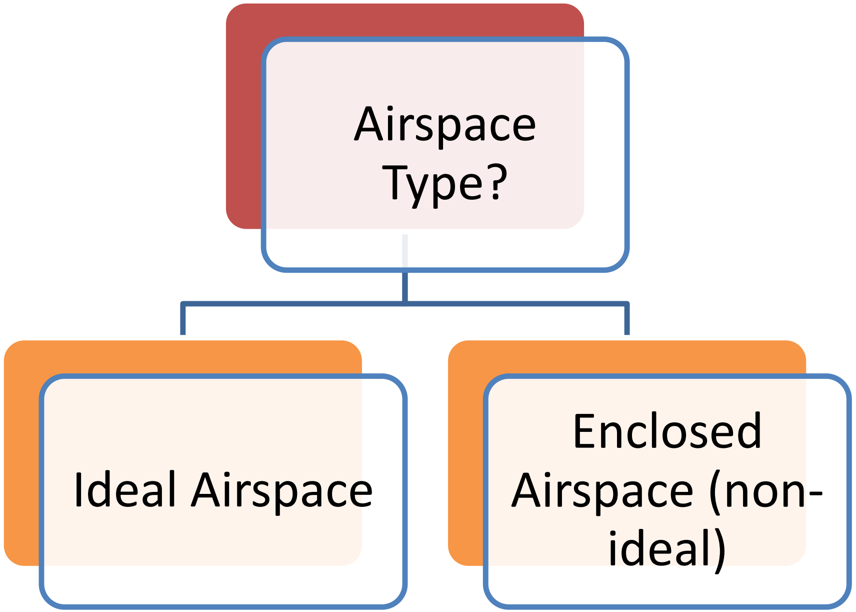
Introduction

- This guide will detail the two main steps to evaluating the air space R-value:
  - How to determine the type of airspace in the wall assembly
  - How to determine the R-value for each type of airspace



Step 1: Determine Airspace Type

- First, determine whether the airspace is Ideal or Enclosed.



Step 1: Determine Airspace Type

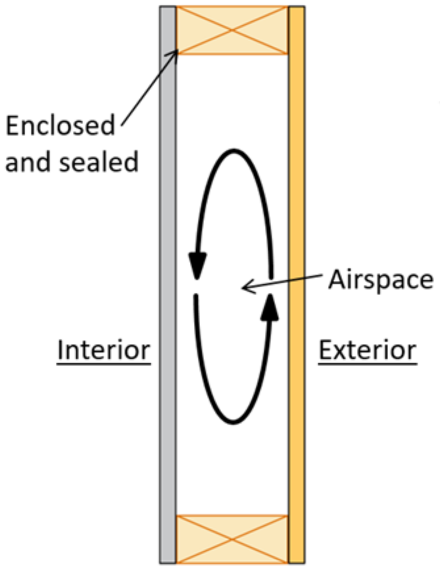
- Per ASHRAE Handbook of Fundamentals (HOF) Chapter 26 Table 3, footnote 'b', an Ideal airspace has:
  - Uniform thickness
  - Bounded by plane, smooth, parallel surfaces
  - No air leakage to or from the space ('sealed')

Table 3 Thermal Resistances of Plane Air Spaces,[a,b,c] $h \cdot ft^2 \cdot °F/Btu$

[b]Values based on data presented by Robinson et al. (1954). (Also see Chapter 4, Tables 5 and 6, and Chapter 33). Values apply for ideal conditions (i.e., air spaces of uniform thickness bounded by plane, smooth, parallel surfaces with no air leakage to or from the space). For greater accuracy, use overall U-factors determined through calibrated hot box (ASTM *Standard* C976) or guarded hot box (ASTM *Standard* C236) testing. Thermal resistance values for multiple air spaces must be based on careful estimates of mean temperature differences for each air space.

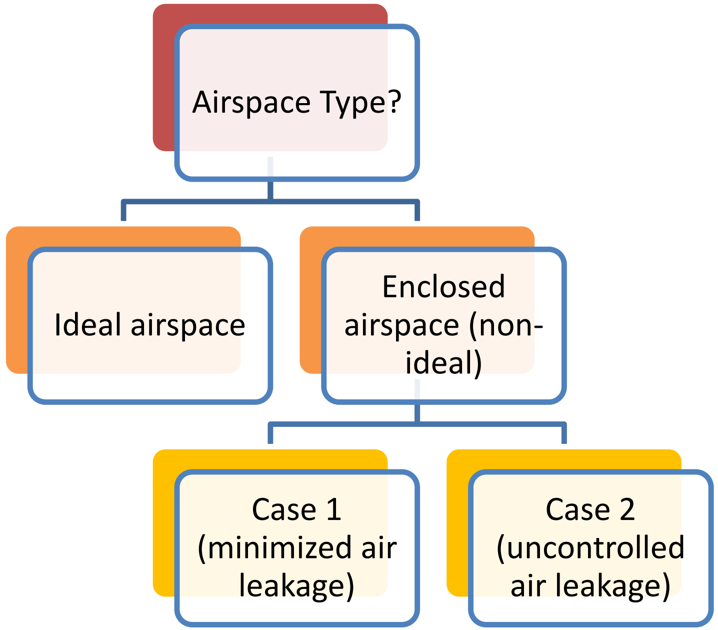
Step 1: Determine Airspace Type

- Ideal airspace examples:
  - Enclosed and sealed airspace inside a stud cavity



Step 1: Determine Airspace Type

- The space is considered enclosed (non-ideal) if it does not meet the criteria for an ideal airspace.
- Determine whether the enclosed airspace is Case 1 or Case 2



Step 1: Determine Airspace Type

- A Enclosed Case 1 (minimized air leakage) airspace is, per ASHRAE 90.1-2013 with Addendum ac or ASHRAE 90.1-2016 Section A9.4.2:
  - Enclosed in an unventilated cavity
  - Located on the interior side of the continuous air barrier
  - Bounded on all six sides by building components to minimize airflow into and out of the space

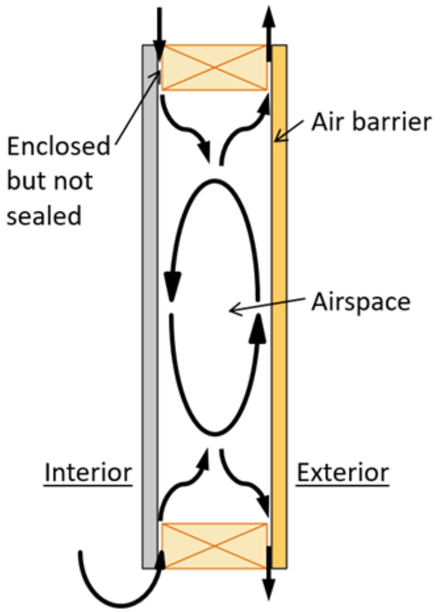
A9.4.2 Airspaces. The R-value for airspaces shall be taken from Table A9.4.2-1 based on the effective emittance of the surfaces facing the airspace from Table A9.4.2-2 provided the following criteria are satisfied:

a. The airspace shall be an enclosed and unventilated cavity designed to minimize airflow into and out of the enclosed air space. Airflow shall be deemed minimized when the enclosed airspace is located on the interior of the continuous air barrier and bounded on all sides by building components.

ABTG

Step 1: Determine Airspace Type

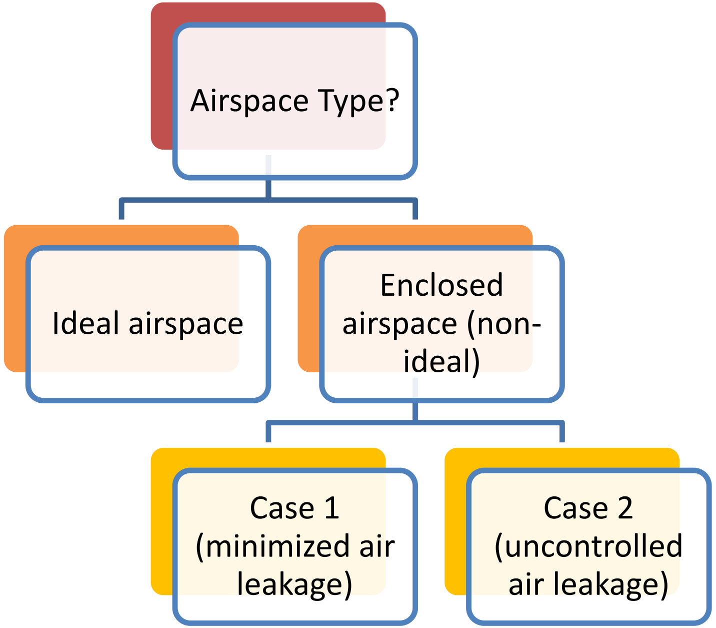
- Enclosed Case 1 example:
  - An enclosed but not sealed airspace inside a stud cavity
- For airspaces with non-uniform thickness, use the average distance between bounding surfaces as the thickness.



ABTG

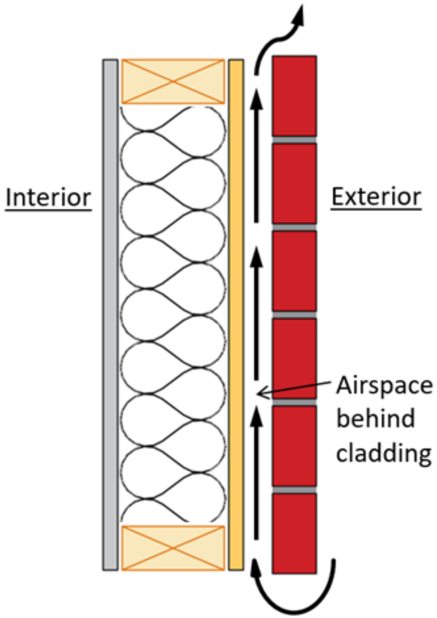
Step 1: Determine Airspace Type

- Airspaces which do not qualify as ideal airspaces or which do not minimize air leakage (Case 1) are Case 2 airspaces.



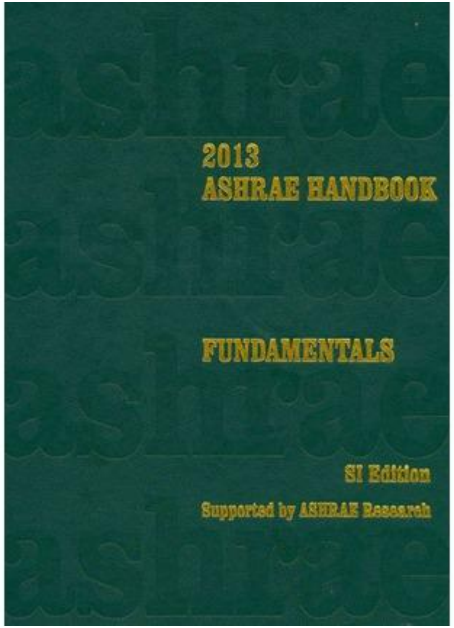
Step 1: Determine Airspace Type

- Enclosed Case 2 example:
  - An airspace located behind or underneath cladding materials, which is subject to airflow



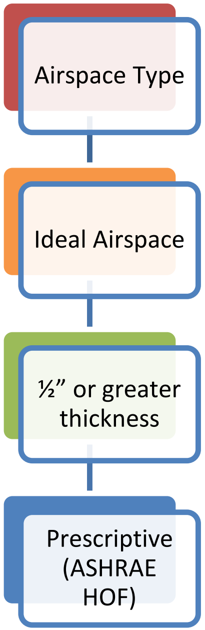
Step 2: Determine Airspace R-Value

- Once the airspace type is determined, the airspace R-value can be evaluated.
- Different evaluation methods are permitted for each airspace type per the ASHRAE HOF.



Step 2: Determine Airspace R-Value

- For Ideal airspaces ½" thick or greater:
  - Determine the R-value for the airspace (including R-values for different directions of heat flow as applicable to horizontal airspaces) in accordance with ASHRAE Handbook of Fundamentals (Chapter 26), Tables 2 and 3.



Step 2: Determine Airspace R-Value

- Use Chapter 26 Table 2 to determine the emittance of the airspace surfaces
    - For example, a 0.75” airspace bounded on all sides by building materials has an emittance of 0.82
- Then use Chapter 26 Table 3 to determine the R-value

Table 2 Emittance Values of Various Surfaces and Effective Emittances of Air Spaces[a]

Surface	Average Emittance ε	Effective Emittance ε_{eff} of Air Space: One Surface Emittance ε; Other, 0.9	Effective Emittance ε_{eff} of Air Space: Both Surfaces Emittance ε
Aluminum foil, bright	0.05	0.05	0.03
Aluminum foil, with condensate just visible (>0.7 g/ft^2)	0.30[b]	0.29	—
Aluminum foil, with condensate clearly visible(>2.9 g/ft^2)	0.70[b]	0.65	—
Aluminum sheet	0.12	0.12	0.06
Aluminum coated paper, polished	0.20	0.20	0.11
Steel, galvanized, bright	0.25	0.24	0.15
Aluminum paint	0.50	0.47	0.35
Building materials: wood, paper, masonry, nonmetallic paints	0.90	0.82	0.82
Regular glass	0.84	0.77	0.72

[a]Values apply in 4 to 40 μm range of electromagnetic spectrum.
[b]Values based on data in Bassett and Trethowen (1984).

Step 2: Determine Airspace R-Value

- Unless use conditions dictate otherwise, the R-values shall be based on:
  - Mean temperature of 50oF
  - Temperature difference of 30oF.

Table 3 Effective Thermal Resistance of Plane Air Spaces,[a,b,c] h·ft²·°F/Btu

Position of Air Space	Direction of Heat Flow	Air Space Mean Temp.[d], °F	Air Space Temp. Diff.,[d] °F	0.5 in. Air Space[c] 0.03	0.05	0.2	0.5	0.82	0.75 in. Air Space[c] 0.03	0.05	0.2	0.5	0.82
…													
Vertical	Horiz. →	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		–50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		–50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
…													
		Air Space		1.5 in. Air Space[c]					3.5 in. Air Space[c]				
Vertical	Horiz. →	90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
		0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
		0	10	3.51	3.35	2.51	1.67	1.23	3.49	3.33	2.50	1.67	1.23
		–50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		–50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50

Effective Emittance ε_{eff}[d,e]

ABTG

Step 2: Determine Airspace R-Value

- In our example, the ½" airspace bounded on all sides by building materials has an R-value of 0.90.

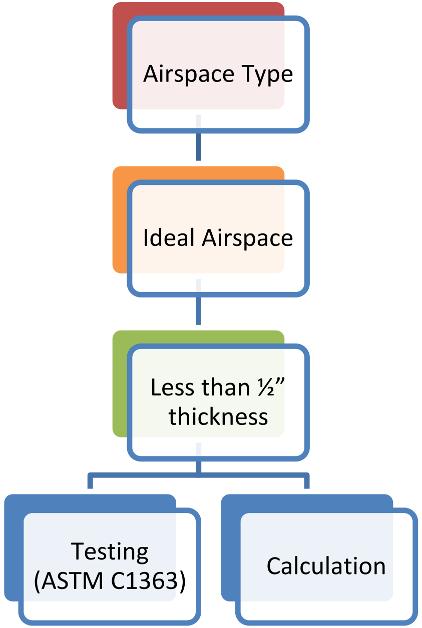
Table 3 Effective Thermal Resistance of Plane Air Spaces,[a,b,c] h·ft²·°F/Btu

Position of Air Space	Direction of Heat Flow	Air Space: Mean Temp.[d], °F	Air Space: Temp. Diff.,[d] °F	0.5 in. Air Space[c]: 0.03	0.05	0.2	0.5	0.82	0.75 in. Air Space[c]: 0.03	0.05	0.2	0.5	0.82
…													
Vertical	Horiz. →	90	10	2.47	2.34	1.67	1.06	0.77	3.50	3.24	2.08	1.22	0.84
		50	30	2.57	2.46	1.84	1.23	0.90	2.91	2.77	2.01	1.30	0.94
		50	10	2.66	2.54	1.88	1.24	0.91	3.70	3.46	2.35	1.43	1.01
		0	20	2.82	2.72	2.14	1.50	1.13	3.14	3.02	2.32	1.58	1.18
		0	10	2.93	2.82	2.20	1.53	1.15	3.77	3.59	2.64	1.73	1.26
		–50	20	2.90	2.82	2.35	1.76	1.39	2.90	2.83	2.36	1.77	1.39
		–50	10	3.20	3.10	2.54	1.87	1.46	3.72	3.60	2.87	2.04	1.56
…													

Position of Air Space	Direction of Heat Flow	Air Space: Mean Temp.	Air Space: Temp. Diff.	1.5 in. Air Space[c]: 0.03	0.05	0.2	0.5	0.82	3.5 in. Air Space[c]: 0.03	0.05	0.2	0.5	0.82
Vertical	Horiz. →	90	10	3.99	3.66	2.25	1.27	0.87	3.69	3.40	2.15	1.24	0.85
		50	30	2.58	2.46	1.84	1.23	0.90	2.67	2.55	1.89	1.25	0.91
		50	10	3.79	3.55	2.39	1.45	1.02	3.63	3.40	2.32	1.42	1.01
		0	20	2.76	2.66	2.10	1.48	1.12	2.88	2.78	2.17	1.51	1.14
		0	10	3.51	3.35	2.51	1.67	1.23	3.49	3.33	2.50	1.67	1.23
		–50	20	2.64	2.58	2.18	1.66	1.33	2.82	2.75	2.30	1.73	1.37
		–50	10	3.31	3.21	2.62	1.91	1.48	3.40	3.30	2.67	1.94	1.50

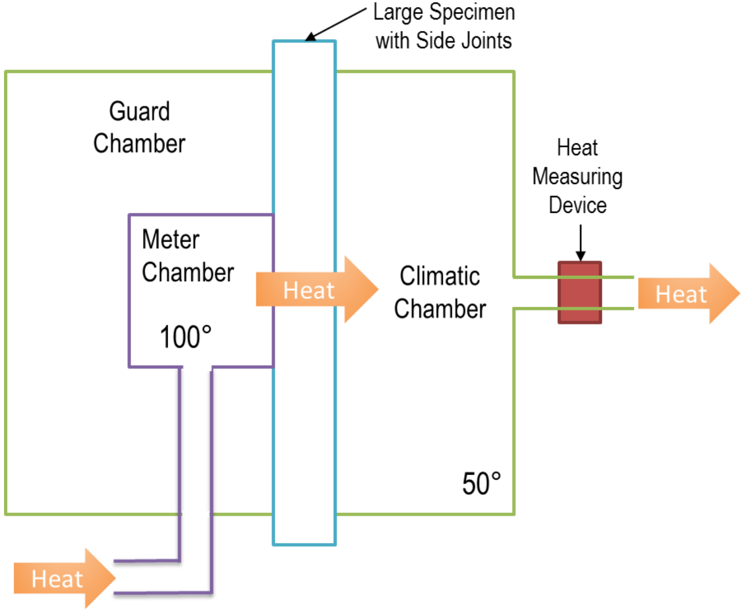
Step 2: Determine Airspace R-Value

- For ideal airspaces of less than ½-inch thickness, or otherwise not complying with ideal airspace conditions, there are two options to determine airspace R-value.



Step 2: Determine Airspace R-Value

- Ideal airspace <½" testing [ASTM C 1363:]()
  - For reflective ideal airspaces, the application of the ASTM C 1363 test method shall comply with conditions and formula specified in ASTM C 1224 (e.g., 75°F mean temperature and 30°F temperature difference).
  - For horizontal airspaces, testing shall include upward and downward heat flow directions to determine R-values accordingly.



Step 2: Determine Airspace R-Value

- Ideal airspace <½" calculation:
  - The ideal airspace R-value shall be calculated in accordance with equations in Chapter 4 of the ASHRAE Handbook of Fundamentals for combined radiation and convection for heat flow directions and temperature conditions applicable to the end use conditions.

Combined Radiation and Convection

When $t_{surr} = t_\infty$ in Equation (4), the total heat transfer from a surface by convection and radiation combined is then

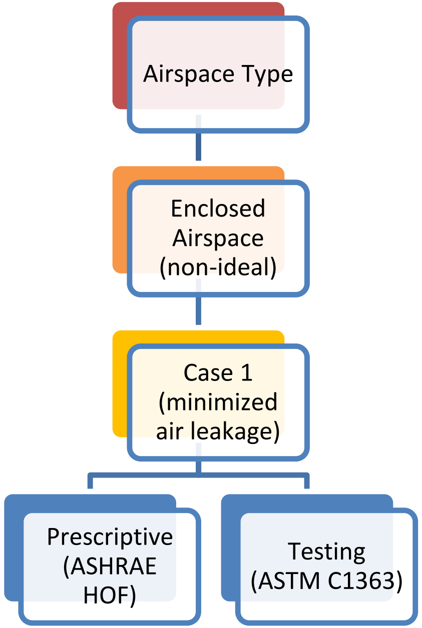
$$q = q_{rad} + q_{conv} = (t_s - t_\infty)A_s(h_r + h_c)$$

The temperature difference $t_s - t_\infty$ is in either °R or °F; the difference is the same. Either can be used; however, absolute temperatures *must* be used to calculate h_r. (Absolute temperatures are °R = °F + 459.67.) Note that h_c and h_r are always positive, and that the direction of q is determined by the sign of $(t_s - t_\infty)$.

ABTG

Step 2: Determine Airspace R-Value

- For an Enclosed airspace R-value, Case 1 (minimized air leakage) two methods are permitted.



Step 2: Determine Airspace R-Value

- Enclosed airspace, Case 1 prescriptive:
  - Determine the R-value in accordance with ASHRAE Standard 90.1-2013 (with Addendum ac) or ASHRAE 90.1-2016 Section A9.4.2.
  - Airspaces less than ½" thick shall have no R-value.
  - The R-value for 3.5-inch thick airspaces shall be used for airspaces of greater thickness provided the airspace thickness does not exceed 12".

A9.4.2 Airspaces. The R-value for airspaces shall be taken from Table A9.4.2-1 based on the effective emittance of the surfaces facing the airspace from Table A9.4.2-2 provided the following criteria are satisfied:

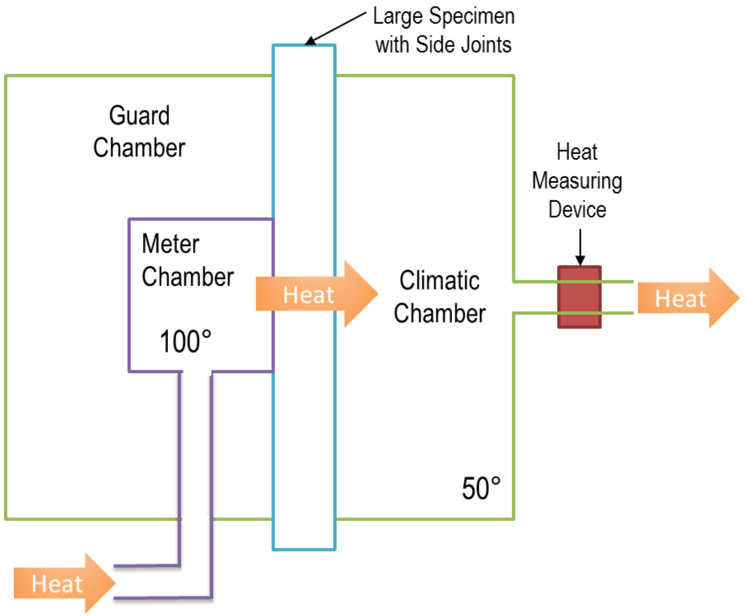
d. Airspaces less than 0.5 in. (13 mm) thickness shall have no R-value.

e. The R-value for 3.5 in. (89 mm) airspaces shall be used for airspaces of that thickness or greater provided that airspace does not exceed 12 in. (300 mm) between the surfaces at any point.

ABTG

Step 2: Determine Airspace R-Value

- Enclosed airspace, Case 1 testing (ASTM C 1363):
  - For reflective airspaces, the application of the ASTM C 1363 test method shall comply with conditions and formula specified in ASTM C 1224 (e.g., 75oF mean temperature and 30oF temperature difference).
  - For horizontal or sloped airspaces (reflective or non-reflective), testing shall include upward and downward heat flow directions to determine R-values accordingly.



Step 2: Determine Airspace R-Value

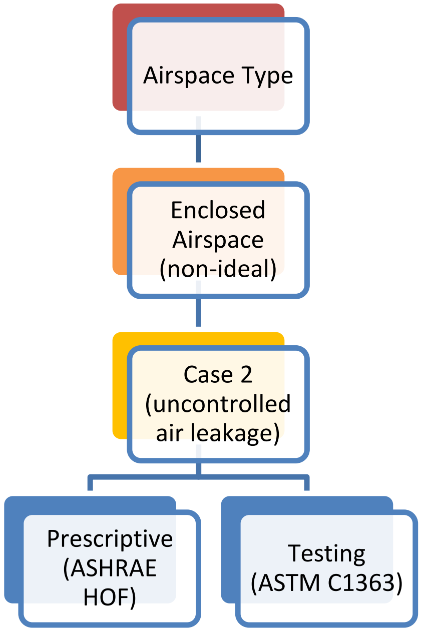
- A single "effective" R-value for energy code compliance purposes shall be permitted to be derived based on weighting of the R-values for different heat flow directions by the relative magnitude of heating and cooling degree days within each climate zone of ASHRAE 90.1
  - Refer to Table A9.4.2-1 for benchmark example of this weighting procedure resulting in different airspace R-values for horizontal airspaces in different climate zones

Climate Zone 6 Effective Emittance			
0.05	0.20	0.50	0.82
1.8	1.4	1.0	0.8
2.1	1.6	1.1	0.8
2.8	1.9	1.2	0.9
3.6	2.2	1.3	0.9
2.5	1.8	1.2	0.9
2.8	2.0	1.3	0.9
2.5	1.8	1.2	0.9
2.6	1.9	1.3	0.9
2.3	1.7	1.2	0.9
3.1	2.1	1.3	1.0
4.7	2.7	1.5	1.1
6.6	3.3	1.7	1.1

ABTG

Step 2: Determine Airspace R-Value

- For an Enclosed airspace R-value, Case 2 (uncontrolled air leakage), both prescriptive and testing methods are also permitted.



Step 2: Determine Airspace R-Value

- Enclosed airspace, Case 2 prescriptive:
  - The airspace R-value and R-value of any material to the exterior side of the airspace shall be taken as zero (0).
  - An exterior air-film R-value shall be permitted to be applied. (Table 1)

Table 1 Surface Conductances and Resistances for Air

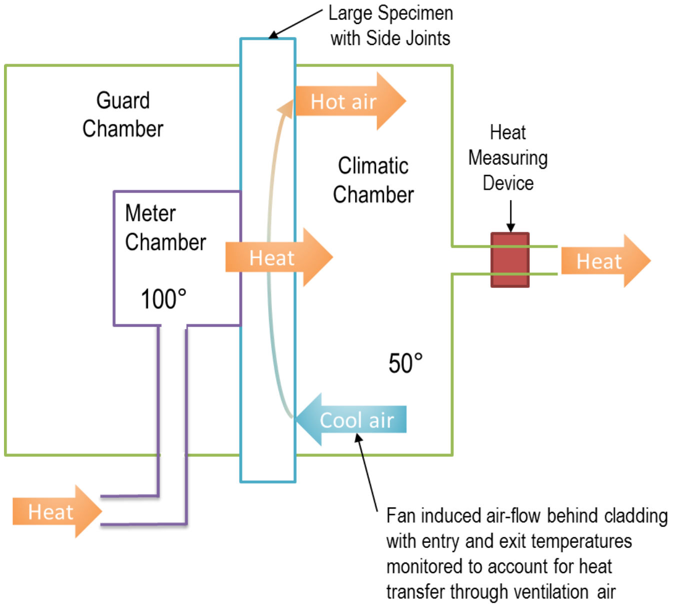
Position of Surface	Direction of Heat Flow	Surface Emittance, ε: Nonreflective ε = 0.90 h_i	R	Reflective ε = 0.20 h_i	R	Reflective ε = 0.05 h_i	R
Still Air							
Horizontal	Upward	1.63	0.61	0.91	1.10	0.76	1.32
Sloping at 45°	Upward	1.60	0.62	0.88	1.14	0.73	1.37
Vertical	Horizontal	1.46	0.68	0.74	1.35	0.59	1.70
Sloping at 45°	Downward	1.32	0.76	0.60	1.67	0.45	2.22
Horizontal	Downward	1.08	0.92	0.37	2.70	0.22	4.55
Moving Air (any position)		h_o	R				
15 mph wind (for winter)	Any	6.00	0.17	—	—	—	—
7.5 mph wind (for summer)	Any	4.00	0.25	—	—	—	—

Notes:
1. Surface conductance h_i and h_o measured in Btu/h·ft^2·°F; resistance R in h·ft^2·°F/Btu.
2. No surface has both an air space resistance value and a surface resistance value.
3. Conductances are for surfaces of the stated emittance facing virtual black-body surroundings at same temperature as ambient air. Values based on surface/air temperature difference of 10°F and surface temperatures of 70°F.
4. See Chapter 4 for more detailed information.
5. Condensate can have significant effect on surface emittance (see Table 2).

ABTG

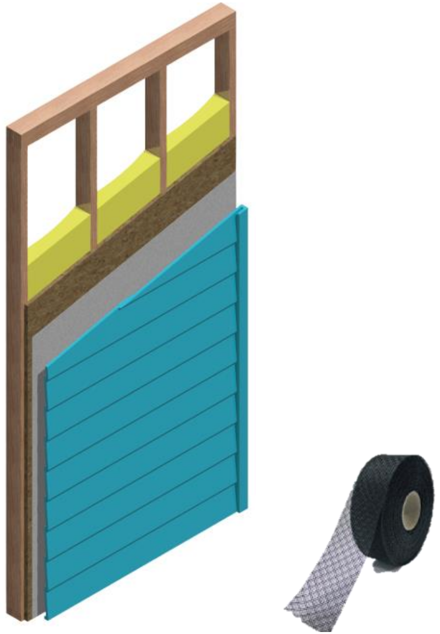
Step 2: Determine Airspace R-Value

- Enclosed airspace, Case 2 testing – [ASTM C 1363](modified):
  - The airspace R-value shall be determined in accordance with ASTM C 1363 modified with an air-flow entering the bottom and exiting the top of the airspace.



Step 2: Determine Airspace R-Value

- The minimum air-movement rate for testing shall be:
  - 3 cm/s for claddings installed in end use with bottom vents only including bug screens or other obstructions in the vent openings;
  - 7 cm/s for claddings with intermittent top and bottom vents including bug screens or other similar obstructions in the vent openings or in the airspace;
  - 15 cm/s for all claddings having continuous top and bottom vents or claddings that are air-permeable (e.g., distributed ventilation through ports or unsealed seams).



Step 2: Determine Airspace R-Value

- The air flow rate and temperature shall be monitored during testing and the enthalpy change of the ventilation air shall be incorporated in the analysis of the R-value of the overall assembly.
- To determine the R-value of the airspace alone, an additional test shall be conducted on an assembly without the airspace, and the difference between the two may be taken as the R-value of the airspace (by itself or in combination with a specific cladding)

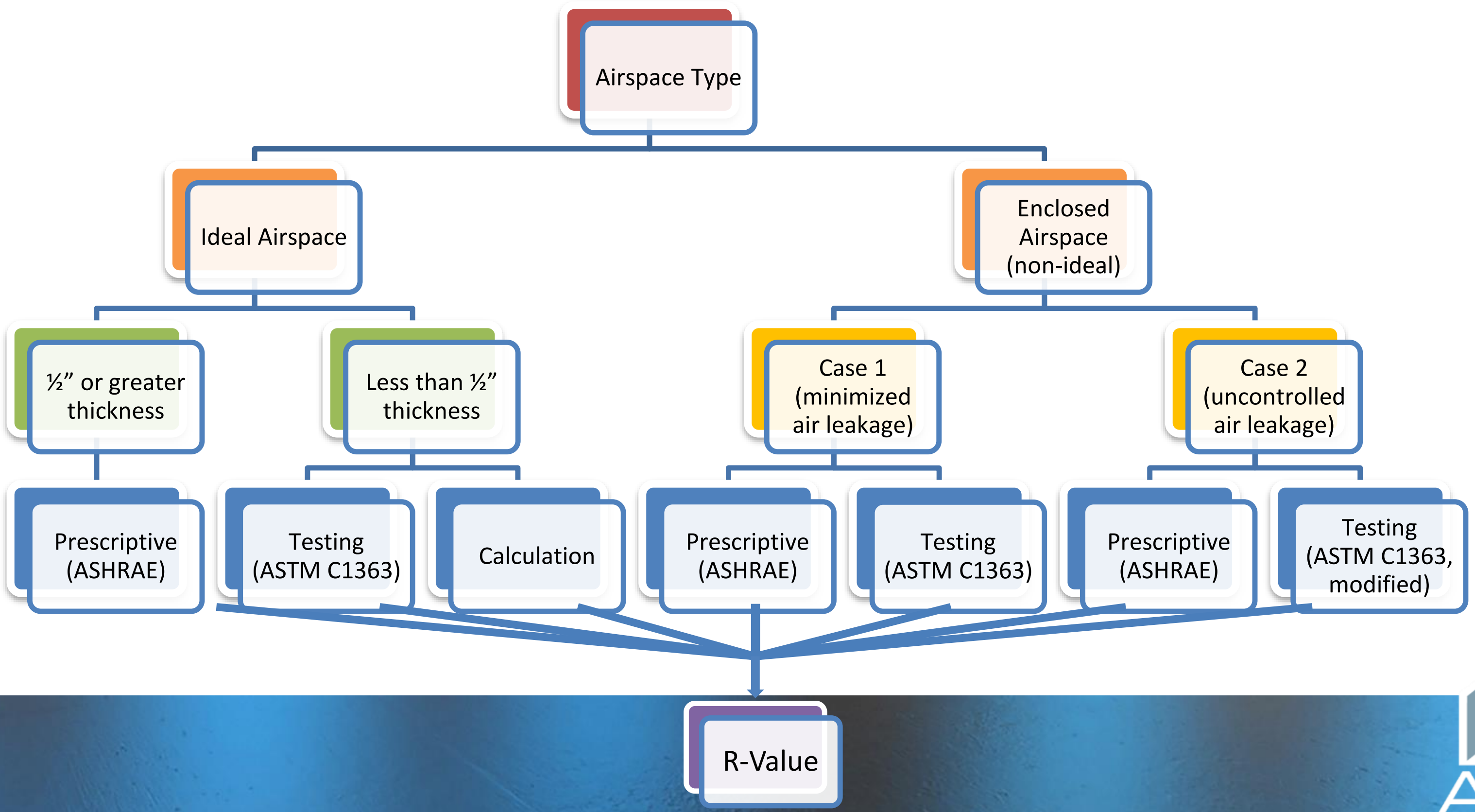
Step 2: Determine Airspace R-Value

- An ASHRAE research project is under development to provide a recommended testing approach and criteria for airspaces with uncontrolled air leakage.

Conclusion

- Many variables and conditions affect the R-value of airspaces.
- Airspace R-values can vary substantially from those published in ASHRAE Handbook of Fundamentals, which are based on idealized conditions of uniform air space thickness, smooth surfaces, and no air leakage to or from the airspace.
- Using technical data and regulatory requirements, one can categorize airspace types and determine appropriate R-values for each type of airspace, particularly in relation to air leakage

Flowchart


Airspace Type
Ideal Airspace
Enclosed Airspace (non-ideal)
½” or greater thickness
Less than ½” thickness
Case 1 (minimized air leakage)
Case 2 (uncontrolled air leakage)
Prescriptive (ASHRAE)
Testing (ASTM C1363)
Calculation
Prescriptive (ASHRAE)
Testing (ASTM C1363)
Prescriptive (ASHRAE)
Testing (ASTM C1363, modified)
R-Value

Suggested Resources

- [Air Space R-Value - ContinuousInsulation.org]
- [Thermal Insulation - ContinuousInsulation.org]