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Standard Guide for Evaluating the Relative Effectiveness of Building Systems to Resist the Passage of Products of Combustion Based on the Aggregation of Leakage Rates[1]

This standard is issued under the fixed designation E3021/E3021M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide provides a method of evaluating the relative effectiveness of building systems to resist the passage of smoke.

1.2 The method of evaluating the relative effectiveness of a building system is based on the aggregation of leakage rates of openings, penetrations, joints and interfaces of the construction elements forming the building system.

1.3 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in non-conformance with the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

E176 Terminology of Fire Standards

E283 Test Method for Determining Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen

E1424 Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure and Temperature Differences Across the Specimen

2.2 *Underwriters Laboratories Standards:*[3]

UL 555S Standard for Smoke Dampers

UL 1479 Fire Tests of Through-Penetration Firestops

UL 1784 Standard for Air Leakage Tests of Door Assemblies

UL 2079 Tests for Fire Resistance of Building Joint Systems

3. Terminology

3.1 For definitions of terms other than those contained in this guide, refer to Terminology E176.

3.2 *Definitions:*

3.2.1 *building system, n—for the purpose of this guide*, a building system is defined as any assembly of wall, floor, or combination floor and ceiling elements, as applicable, including any penetrating items, intended to function as a barrier to resist the passage of products of combustion through the barrier.

NOTE 1—See commentary for examples of building systems.

4. Summary of Guide

4.1 Using current air leakage rate tests and test results, this guide provides a method of aggregating the air leakage rates for the various components, interfaces and penetrations in a building system.

4.2 The determination of the total air leakage rates of building systems provides a direct comparative tool for the relative ranking of such building systems.

5. Significance and Use

5.1 Use of this guide can be beneficial in determining the relative effectiveness of building systems as it relates to potential protection from passage of products of combustion between building spaces under both ambient and elevated temperatures.

5.2 Determining the relative effectiveness of a building system to limit the total air leakage between building spaces is

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Underwriters Laboratories (UL), 2600 N.W. Lake Rd., Camas, WA 98607-8542, http://www.ul.com.

important in the evaluation and selection of potential construction components to meet desired performance requirements for a building.

5.3 To properly assess the relative effectiveness of a building system's total air leakage rate, a guide as to how to aggregate the individual component air leakage rates into a total air leakage rate for the building system is needed.

5.4 It is the intent of this guide to provide a methodology for the conversion of individual component air leakage rates into common values that can be aggregated into a total air leakage rate for a building system, thus providing a means for establishing the relative effectiveness of various building systems to resist the passage of products of combustion.

6. Procedure

6.1 The effectiveness of building systems to resist the passage of products of combustion is dependent upon the ability of such building systems to limit the total amount of air leakage.

6.2 Building systems may consist of a wide variety of one or more components including but not limited to walls, floors and ceilings. In some cases, such as but not limited to, pipes, wiring, doors, windows and ducts, the penetration of components may provide a path for air leakage.

6.3 In order to calculate the total amount of air leakage through a building system, the air leakage for all the individual components must be known, including all penetration and component interfaces.

6.4 Currently, there are a number of air leakage test standards being utilized for the testing of various components of what may potentially be a part of a building system. While each of these standards may vary in some of the test requirements of how the test is conducted, there are a number of commonalities that should be noted when attempting to aggregate the amount of total air leakage through a building system. Table 1 provides a listing of important test requirements and conditions for each of the currently used test standards.

6.5 Each of the current test standards uses a somewhat different nomenclature for the computation of the component leakage rate. In order to establish a common nomenclature for this guide, the component leakage rate is computed based on the total metered air flow out of the chamber minus the extraneous chamber leakage loss in accordance with the following:

TABLE 1 Test Standard Comparison

Test Standard and Subject Matter	Rating	Air Leakage	Sealed Chamber	Temperature	Pressure Differential	Leakage Determination
UL 555S-1999						
UL 1479-2003	*L* rating based on amount of air leakage through the test sample.	Leakage differential between inside and outside chamber (cfm/ft^2)	Yes	Ambient 75 ± 20°F [24 ± 11°C] Elevated 400 ± 10°F [204 ± 5°C]	0.3 ± 0.005 in. of water pressure	Q(air leakage) = Q_m (total metered air flow) – Q_L (extraneous chamber leakage)
UL 2079-2004	No ratings. Optional part of test standard.	Leakage differential between inside and outside chamber at ambient and elevated temperature (cfm/linear ft)	Yes	Ambient 75 ± 20°F [24 ± 11°C] Elevated 400 ± 10°F [204 ± 5°C]	0.3 ± 0.005 in. of water pressure	Q(air leakage) = Q_t (total metered air flow) – Q_e (extraneous chamber leakage) q(air leakage rate through joint system) = Q / L(overall length of joint system-39 in. minimum)
UL 1784-2001	No ratings. Report results.	Leakage rating at specified pressure and temperature conditions (cfm/ft^2)	Yes	Ambient 75 ± 20°F [24 ± 11°C] Elevated 400 ± 10°F [204 ± 5°C]	Testing required at 0.1, 0.2 and 0.3 in. [25, 50 and 75 Pa respectively].	Q(air leakage) = Q_m (total metered air flow) times W_m/W_w (Air Density Adjustment) – Q_L (extraneous chamber leakage)
E283-04	No ratings. Test method for determining rate of air leakage through exterior windows, curtain walls, and doors under specified pressure differences across the specimen.	Test method for testing without any specific metrics as far as leakage rate limitations, temperature or differential pressures.	Yes	Assumed to be ambient since no requirement contained in standard.	As required but if not specified, the minimum is 75 Pa.	Leakage calculations similar to other standards except calculated leakage rates expressed in terms of unit area and unit length. Formulas for adjustments due to air temperature and density.
E1424-91(00)	No ratings. Test method for Determining rate of air leakage through exterior windows, curtain walls, and doors under specified pressure differences across the specimen.	Test method for testing without any specific metrics as far as leakage rate limitations, temperature or differential pressures.	Yes	Assumed to be ambient since no requirement contained in standard.	As required but if not specified, the minimum is 75 Pa.	Leakage calculations similar to other standards except calculated leakage rates expressed in terms of unit area and unit length. Formulas for adjustments due to air temperature and density.

$$Q_C = Q_T - Q_L \quad (1)$$

where:

Q_C = component leakage rate (ft³/min-ft²) [m³/s-m²],
Q_T = total meter air flow out of the chamber (ft³/min-ft²) [m³/s-m²], and
Q_L = extraneous chamber leakage loss (ft³/min-ft²) [m³/s-m²].

6.6 In order to aggregate the total air leakage rates of all components in a building system, some of the test conditions used in the currently available test standards must be converted to a common set of test conditions, that is, sealed chamber, temperature, pressure differential.

6.7 The air leakage for individual components should be determined based on testing using a sealed chamber apparatus.

6.8 While the influence of pressure differentials within and over the height of the compartment due to fire within the compartment is not included as a part of this guide, it is appropriate whenever possible to consider air leakage rates for various components under both ambient, 75 ± 20°F [24 ± 11°C] and elevated temperatures, 400 ± 10°F [204 ± 5°C].

6.9 Current test standards vary regarding the test pressure differential requirements between the inside and outside of the test chamber. There is a reasonable range of differential test pressures which can be established and conversion of the air leakage rates to a common value for aggregation is possible. The reasonable range of differential test pressures is 0.1 to 1.0 ± 0.005 in. of water pressure [25 to 75 Pa]. Tests results for various components at different differential test pressures can be converted using the relationship:

$$Q_c / Q_t = \sqrt{P_c} / \sqrt{P_t} \quad (2)$$

where:

Q_c = converted value of air leakage rate,
Q_t = reported air leakage at test pressure,
p_t = pressure differential used in test, and
p_c = pressure differential for aggregation of air leakage rates.

NOTE 2—Given that flow properties of air and smoke at a given temperature and pressure are sufficiently close for engineering purposes, the measurement of air leakage by this method is considered to provide a reasonable estimate of the measurement of smoke leakage.

7. Aggregation of Test Results

7.1 In order to establish a total value of leakage for a building enclosure system, it is necessary to aggregate the results of the various components of the building system as well as any penetrations of the wall, floor and ceiling components. To facilitate the aggregation of results, the leakage rate of the individual components and penetrating elements shall when necessary be converted to leakage rates with common units of measure. In addition, whenever possible, leakage rates shall be aggregated for both the ambient and elevated temperature test conditions. In some cases, test methods such as Test Methods E283 and E1424 do not provided test results for elevated temperature test conditions and therefore, aggregation of leakage values is only possible for ambient temperature test conditions. Table 1 provides a comparison of the various leakage rate test methods and the manner in which the results are reported.

7.2 The total aggregation of leakage rates for a building system can be determined through a process of summing the individual leakage rates of all components of the building system including their associated penetrations and interfaces.

7.3 The calculating of the total aggregation of leakage rates can be accomplished using the following general aggregation formula:

$$\text{Total Leakage Rate} = \{\Sigma\,(R_{door}) + \Sigma(R_{damper}) + \Sigma(R_{penetration}) + \Sigma(R_{joint})\} \quad (3)$$

where:

R = the leakage rate of the item, with units as specified in 7.4, and
Σ = the summation of the leakage contributed by each individual item, 1 through *n*.

NOTE 3—The aggregation of leakage rates using the formula must be done in a manner to ensure aggregation using common units.

7.4 In order to use the general aggregation formula of 7.3, it is important to consider the differences in the way various leakage rates are reported and the pressure differential use in the test method. The general aggregation formula for a common pressure differential of 0.1 in. of water column would take on the following form:

$$\text{Total Leakage Rate} = \{\Sigma\,(R_{door} \times A_{door}) + \Sigma\,(R_{damper} \times A_{damper} \times 0.32) + \Sigma\,(R_{penetration(1)} \times A_{penetration} \times 0.58) + \Sigma\,(R_{penetration(2)} \times 0.58) + \Sigma\,(R_{joints} \times L_{joints} \times 0.58)\} \quad (4)$$

where:

R_{door} = the leakage rate of the door in cfm per ft² @ 0.1 in. water column,
R_{damper} = the leakage rate of the damper in cfm per ft² @ 1 in. water column,
$R_{penetration(1)}$ = the leakage rate of the Type 1 penetration in cfm per ft² @ 0.3 in. water column,
$R_{penetration(2)}$ = the leakage rate of the Type 2 penetration in cfm per device @ 0.3 in. water column,
R_{joint} = the leakage rate of the joint in cfm per linear ft @ 0.3 in. water column,
A = the cross-sectional area of the individual item as identified, ft²,
L = the length of the joint, ft, and
Σ = the summation of the leakage contributed by each individual item, 1 through *n*.

7.5 While any form of calculation of the total leakage rates into common units of measure is acceptable, a tabulation of the leakage rate values is preferred. A tabulation will ensure that all components of the building system and penetrations have been accounted for in the evaluation.

$$\text{Total Leakage Rate} = \{\Sigma\,(R_{doors} \times A_{doors}) + \Sigma\,(R_{dampers} \times A_{dampers} \times 0.32) + \Sigma\,(R_{penetrations} \times A_{penetrations} \times 0.58) + \Sigma\,(R_{joints} \times L_{joints} \times 0.58)\} \quad (5)$$

where:

R = the leakage rate of the item, with units as specified in 7.4,

A = the cross-sectional area of the individual item as identified, ft^2,

L = the length of the joint, ft, and

Σ = the summation of the smoke leakage contributed by each individual item, 1 through n.

8. Keywords

8.1 air leakage; smoke; smoke barrier; smoke partition

APPENDIX

(Nonmandatory Information)

X1. COMMENTARY

X1.1 For many decades, it has been recognized that products of combustion (smoke) produced by fires within occupied buildings can potentially provide a significant risk to occupants of the building as well as result in an increase in the economic impact attributed to the impact on building contents losses. Construction regulations (codes) for several decades have contained provisions intended in some manner to provide for a level of life safety protection to the occupants of buildings from exposure to the accumulation or migration of smoke. Large spaces, such as shopping malls and buildings with multi-level atriums where the accumulation of smoke may represent a potential hazard to occupants, are currently mandated to provide building systems, sometimes mechanically driven, to control or manage the movement of smoke within the open areas. In addition, requirements for "smoke barriers" and "smoke partitions" have also become a mandatory part of the code requirements, although the specific details of the performance of such "smoke barriers" and "smoke partitions" have yet to be defined in those codes. Absent some definitive code mandated performance levels, this has resulted in what might be termed as subjective judgment decisions with a wide variation of opinions both on the part of the code official and the designer.

X1.2 This guide is provided not for the purpose of defining the required levels of performance but rather as one method by which the relative effectiveness of building systems to resist the passage of products of combustion such as smoke might be evaluated. Thus, this guide provides a tool that can be used as a basis for an improvement in the judgment applied by the code official and designer.

X1.3 The development of this guide was fundamentally driven by the examination of whether existing test methods and data could be used in establishing a method of evaluating building systems. Several existing standards (Test Methods E283 and E1424, UL 1479, UL 1784, UL 2079 and UL 555S) were determined to have direct applicability and would provide meaningful test data which could be used by designers. Although several of the standards were established for the primary purpose of evaluating building components and systems for air leakage related to energy conservation issues, the air leakage test standards were judged to provide data that was deemed satisfactory for the evaluation of building systems intended to resist the passage of products of combustion.

X1.4 A definition for "building system" is provided to make it clear that when the evaluation of the overall leakage rate from one area of a building to another is desired, a varied number of components might need to be considered. The walls, floor/ceiling assemblies, the penetrations for items such as doors, windows, grills and other similar items as well as the intersection of building elements composing the separation should be part of the evaluation.

X1.5 The following diagrams may help in understanding the basics for which components and perimeter joints to include in a specific building system.

X1.5.1 Fig. X1.1 is an example of a one story building wherein one portion is desired to be separated from the remaining parts of the building. As can be seen in the diagram, the primary element for the separation is the wall. There are, however, three principle perimeter joints that should be included in the overall leakage rate evaluation. These three perimeter joints are those where the separating wall joins the exterior walls of the building along two lines and the third being the intersection of the wall with the solid roof elements.

X1.5.2 Fig. X1.2 is an example of a two-story building wherein one portion of the first story is desired to be separated from the remaining parts of the first story as well as the entire second story. In this example, there is both a wall and a floor/ceiling component that are necessary to provide the separation. In this case, six perimeter joints rather than just three should be evaluated. There are now three rather than two wall intersections and an additional three perimeter joint where the floor/ceiling component over the separated area intersect the exterior walls as shown on the diagram.

X1.5.3 Fig. X1.3 is an example of a three-story building wherein one portion of the second story is desired to be separated from the remaining parts of the second story as well as both the entire first and third stories. In this example, there is still only one wall but now there are two floor/ceiling components that form the separation. In this case, the number of perimeter joints to be evaluated expands to eleven as shown on the diagram.

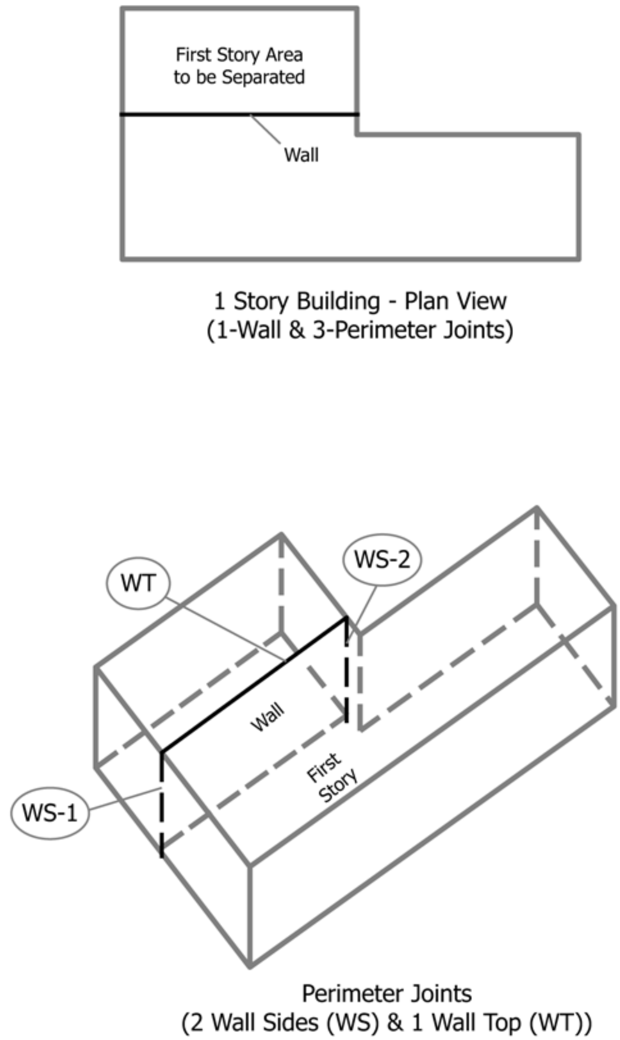

FIG. X1.1 Example of One-Story Building with Smoke-Resisting Separation Wall

X1.5.4 While an unlimited number of additional examples could be provided, the application of the fundamental considerations contained in the above three examples should provide the basis for establishing the number of components and perimeter joints that need to be evaluated for most if not all other building configurations.

X1.5.5 In addition to the evaluation of the components and perimeter joints, penetrations through components such as walls and floor/ceiling assemblies must be included. Penetrations such as but not limited to doors, windows, outlets, grills, pipes, ducts and cables as shown in Fig. X1.4 need to be included in the determination of the overall leakage rate for a building system functioning as a barrier to the passage of products of combustion.

X1.6 In the development of this guide, a wide variety and number of existing test standards were considered. The guide now only covers the use of data resulting from the six referenced tests in Section 2. The intent is not to exclude additional test methods that may not have been considered or test methods which may be developed in the future. The use of other test data from additional tests is considered not to be a problem provided the test results are able to be converted to comparable pressures, temperature conditions and leakage rate measurement units.

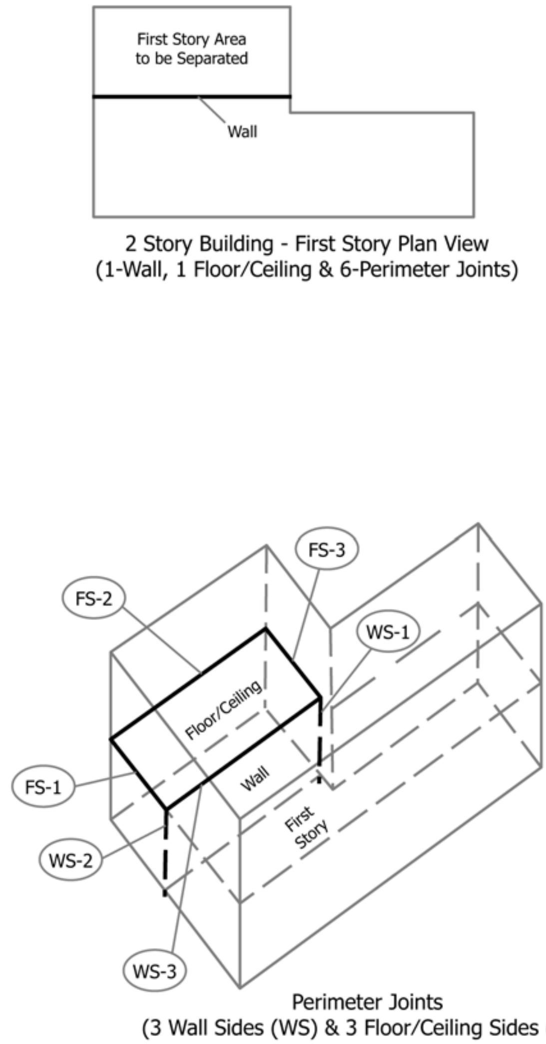

FIG. X1.2 Example of a Two-Story Building with Part of First Story Separated from Remainder of Building by Smoke Resisting Assemblies

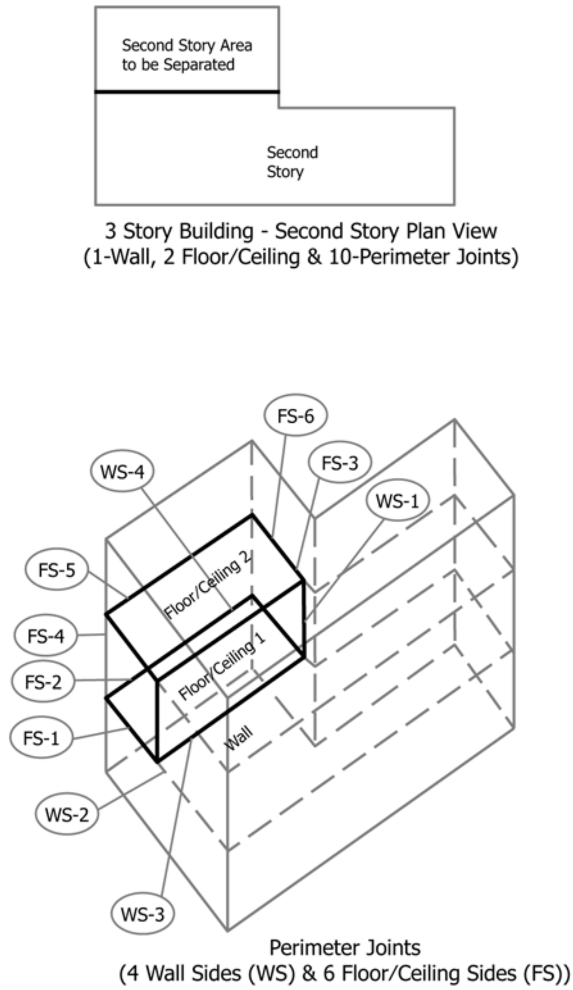

FIG. X1.3 Example of Multi-Story Building with Second Story Volume Protected by Smoke-Resisting Assemblies

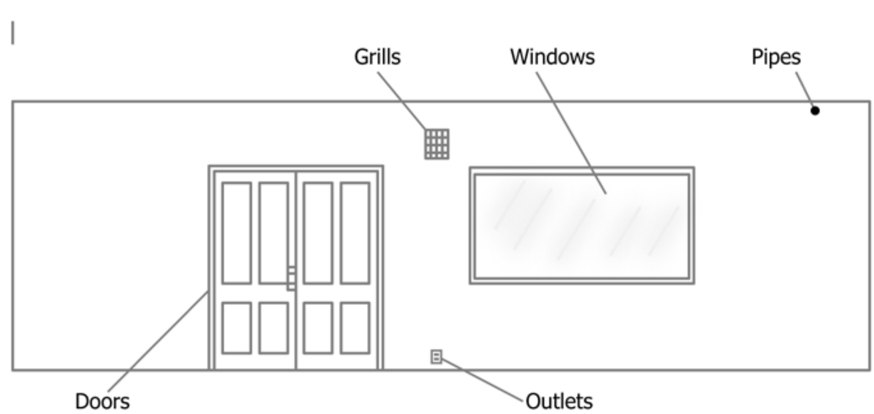

FIG. X1.4 Examples of Wall Penetrations