Eight-Inch Thick Masonry Chimney Test Report

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Table of Contents

Introduction 3
- Background 3
- Objective 4
- Success Criteria 4
- Validation Approach 4

Experimental 4
- Test Engineer 4
- Procedures 5
- Construction 5

Results & Discussion 6
- Experimental Results 6
  - Phase 1 Testing 7
  - Phase 2 Testing 8
  - Assumptions Implicit within Testing Procedure 9
  - Additional Testing 9
- Calculation Results 9

Conclusions 12

References 12

Appendix A – Tabular Heat Flow Calculation Results A-1

List of Tables

Table 1 – Stages within UL 1777 Chimney Test Standard 5
Table 2 – Results of Experimental Chimney Testing per UL 1777 Acceptance Criteria 6
Table 3 – Temperature Reading Results (in °F) from the First Phase of Testing 7
Table 4 – Temperature Reading Results (in °F) from the Second Phase of Testing 8
Table 5 – Material Parameters for the Heat Flow Calculations 10

List of Figures

Figure 1 – Cross-sectional Diagram of (a) a Code-Compliant Chimney and (b) the Proposed Allowable Configuration 4
Figure 2 – (a) Diagram of the Chimney Test Configuration, (b) Photograph of the Test Chimney to Show the Masonry Configuration and (c) a Photograph Showing the Final Appearance after a Plywood Enclosure was Installed 6
Figure 3 – Temperature Profiles for the Inside of the Plywood 11

Introduction

The current building code requires that masonry chimney walls be 12" thick or greater in order for baseboards, flooring, or combustible ceilings to directly contact them. This requirement is overly restrictive and makes it difficult to build chimneys to code, as few outside chimney walls are 12" or greater from the inside of the flue.

Background

Older fireplaces and chimneys were usually built in contact with combustibles. If they were massive enough or part of a masonry wall, 4" thick chimney walls were considered safe. If the chimney had only one or two flues and was built in a wood frame house, the chimney walls were built 8" thick as they passed through the roof.

In 1998, the IRC development committee accepted a proposal to allow combustible materials to be in contact with masonry fireplaces if the fireplace walls were at least 12" thick. The same 12" rule was conservatively applied to chimneys despite the fact that the required minimum thickness of chimney walls with an airspace is 4" thick – half the thickness of the minimum required thickness of firebox walls with an airspace.

Builders now have a problem building a masonry fireplace or a masonry chimney when it comes to clearances to combustibles. If the 12" distance between the masonry wall and the inside of the flue cannot be met, then the current I-codes require a 4" masonry chimney surrounded by a 2" airspace clearance to combustibles. The airspace can be filled only with fireblocking and flashing. No builder wants to leave 2" of airspace around the chimney, through the roof, blocked off with only fire stopping and roof flashing. They want to seal off and insulate that space, and many custom builders want to trim the masonry chimney with wood.

A strict interpretation of the current code is essentially unbuildable and discourages architects from specifying and builders from building masonry chimneys. It is therefore necessary to allow an alternate, equally-safe chimney design consisting of 8" of solid masonry in contact with combustibles.

The purpose of this report and the testing described herein is to revisit that excessively conservative decision to require 12" thick masonry walls when in direct contact with combustibles in light of historical precedent and actual building practice. It will be shown that 8" solid masonry walls are equally safe (Figure 1 b) if not safer than 4" masonry walls plus a 2" airspace (Figure 1 a), and it will be proposed that chimneys with walls at least 8" thick be permitted to abut combustible materials.

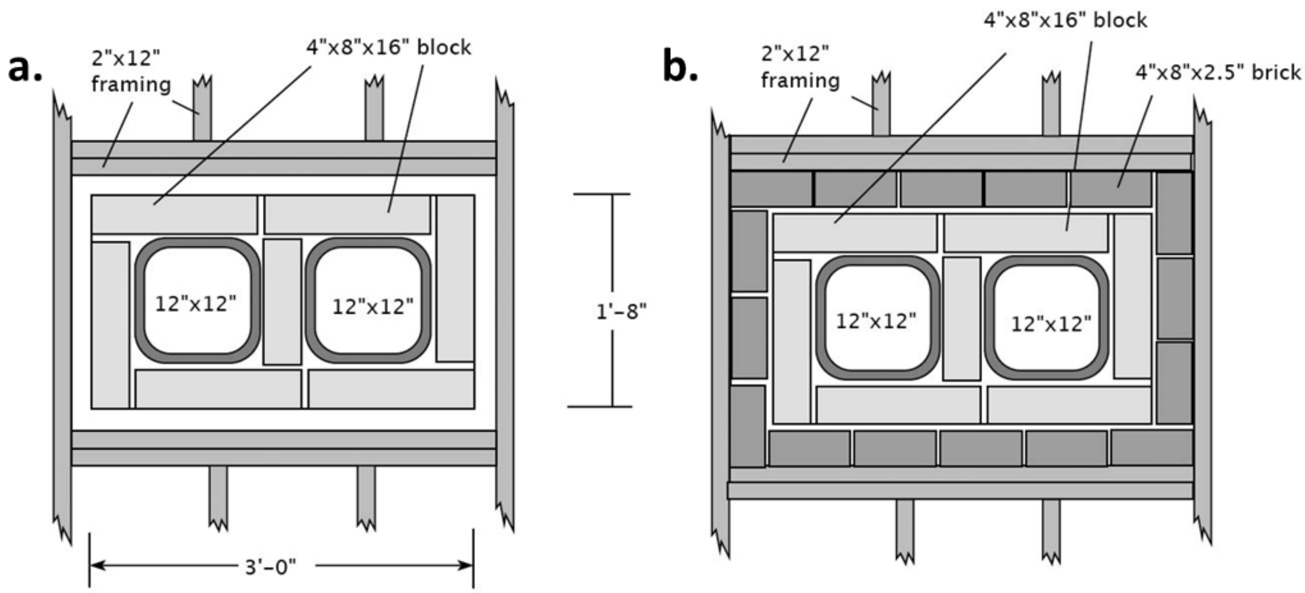

Figure 1 – Cross-sectional Diagram of (a) a Code-Compliant Chimney and (b) the Proposed Allowable Configuration

Objective

The test objective was to determine that a chimney built so that the clay flue liner is enclosed with 8" of solid masonry in contact with combustible materials is at least as safe as the current code requirement that the clay flue liner be enclosed with 4" of solid masonry plus 2" of airspace to combustible materials.

Success Criteria

The objective will be considered met if the temperature profiles of the combustibles in contact with the 8" thick masonry were below the temperature profiles of combustibles 2" clear of a 4" thick masonry chimney wall (the code compliant condition).

Validation Approach

Validation of the test results was performed by comparing test data with calculated values from transient heat transfer calculations.

Experimental

The experiment was performed by building a masonry chimney where one side was built to code - 4" thick masonry wall plus a 2" airspace to combustibles - and the opposite side was built with 8" thick masonry in direct contact with combustibles. The chimney was then subjected to flue gas temperatures representing an over fire or chimney fire condition.

Test Engineer

Testing was performed by Ralph Ruark, who has worked in the ceramic industry for forty years and is a licensed Professional Engineer in Pennsylvania and Florida. He holds dual degrees in Ceramic Engineering and Business Administration from Rutgers University.

Prior to forming his own company, Ralph worked at Director and Vice President level positions with Lenox China, Bickley/Riedhammer and Freeport Brick and Refractories Company. He currently serves as Senior Technical Editor of “Ceramic Industry” magazine.

Procedures

Test procedures were based on the testing protocol proscribed by UL 1777 - the Standard for Chimney Liners. UL 1777 requires a flue gas temperature of 1000 °F until equilibrium is reached or for eight hours, whichever comes first. The max allowable temperature of any combustible material during this phase is 90 °F above ambient temperature. The test then requires a 1400 °F flue gas temperature for one hour where combustibles are allowed to reach up to 140 °F above ambient temperature. Finally, there are three ten-minute spikes to a 2100 °F flue gas temperature with an hour cool time in between each spike. The allowable temperature of the combustibles during this final stage of testing is up to 175 °F above ambient. The UL 1777 test standard is summarized in Table 1.

Table 1 – Stages within UL 1777 Chimney Test Standard

	Stage 1	Stage 2	Stage 3
Flue Gas Temperature	1000 °F	1400 °F	2100 °F spikes
Length of Stage	The shorter of 8 hours or until equilibrium is reached	1 hour	3 ten-minute spikes with one-hour cool time in between spikes
Acceptance Criteria for the Temperature of the Inner Side of Combustibles	90 °F	140 °F	175 °F

Construction

A test chimney was built at Superior Clay Corp. using a 12"x12" clay flue lining. One side of the clay flue was built to code, enclosed with 4" of brick and two inches of airspace. The other side of the chimney wall was composed of 8" thick masonry by adding 4" blocks. See Figure 2 a for a diagram and Figure 2 b for a photograph of the test configuration.

The entire configuration was then enclosed in plywood, as depicted in Figure 2 c. The exposed side in Figure 2 b had a four-inch space between the flue and the plywood that was filled with insulation. Ceramic fiber insulation was used for the first 4 feet where the anticipated temperatures would be elevated, and then fiberglass insulation was used against the flue the rest of the way up the chimney.

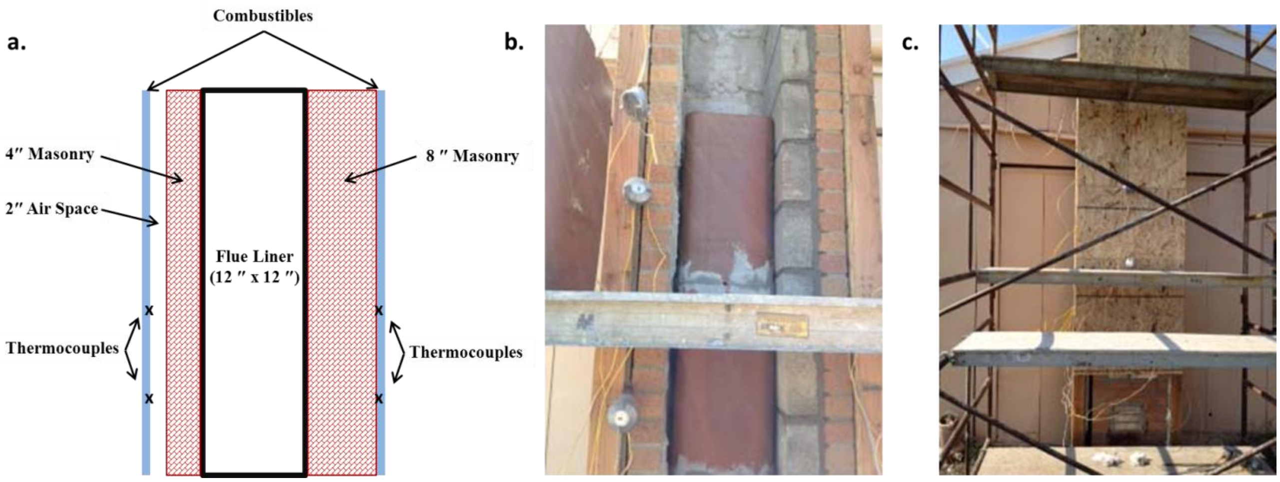

Figure 2 – (a) Diagram of the Chimney Test Configuration, (b) Photograph of the Test Chimney to Show the Masonry Configuration and (c) a Photograph Showing the Final Appearance after a Plywood Enclosure was Installed

Results & Discussion

Results and discussion of experimental testing as well as backup calculations performed to validate the experimental results are described in the following subsections.

Experimental Results

The chimney testing was performed in two phases. The first phase was performed on September 14, 2012, and consisted of eight hours at a flue gas temperature of 1000 °F. The second phase was performed on September 20, 2012. The ending temperatures from the first phase on the code-compliant side were duplicated with a flue gas temperature of 1400 °F, and the chimney was subjected to the last stage of the UL 1777 test - three spikes to 2100 °F for ten minutes with an hour cooling time between each spike. Table 2 displays a summary of the results from the test.

Table 2 – Results of Experimental Chimney Testing per UL 1777 Acceptance Criteria

		Stage 1	Stage 2	Stage 3
Flue Gas Temperature		1000 °F	1400 °F	2100 °F spikes
Length of Stage		The shorter of 8 hours or until equilibrium is reached	1 hour[1]	3 ten-minute spikes with one-hour cool time in between spikes
Acceptance Criteria for the temperature of the inner side of combustibles		90 °F above Ambient	140 °F above Ambient	175 °F Above Ambient
Code Compliant Side	**Time to Failure**	4 hours	Failed before Test Began	Failed before temperature spikes began
	Max Temp	240 °F	243 °F	288 °F
8″ Masonry Side	**Time to Failure**	6 hours	No Failure	No failure
	Max Temp	205 °F	127 °F	180 °F

1. **The UL test performs each stage in series. The tests described in this report were performed on two separate occasions. The chimneys therefore had an opportunity to cool between stages 1 & 2. Stage 3 was begun as soon as the interior of the plywood on the code compliant side reached the ending temperatures from Stage 1. Data reported for Stage 2 correspond to the 4-hour duration that the flue gas temperature was 1400 °F in order to bring the code-compliant side of the chimney up to temperature.**

In all three stages of the test, the 8" masonry side outperformed the code-compliant side of the chimney.

Phase 1 Testing

The first phase of testing was performed on September 14, 2012 and consisted of Stage 1 in Table 1. Results are shown below, in Table 3. The two columns labeled "Flue" are the temperature readings from the thermocouples located inside the flue liner measuring the flue gas temp. They are 2 feet apart vertically – the lower one being the hottest during firing.

The three columns labeled "8″ M" (8″ Masonry) are the temperature readings from the thermocouples at the three hottest recorded spots on the inside surface of the combustibles on the 8″ thick masonry side. There was zero clearance between the 8″ thick masonry and the combustibles.

The three columns labeled "CC" (Code Compliant) are the temperature readings from the thermocouples at the three hottest recorded spots on the inside surface of the combustibles on the 4″ masonry plus 2″ airspace clearance side.

The column labeled "Ambient" shows the temperature readings from the thermocouple set up to measure the ambient outside temperature. The last two columns show the difference between the highest recorded temperature on each side of the chimney and the ambient temperature.

Table 3 – Temperature Reading Results (in °F) from the First Phase of Testing

Time	Flue 1	Flue 2	CC 1	CC 2	CC 3	8" M 1	8" M 2	8" M 3	Ambient	CC Above Ambient	8" M Above Ambient
Start	71	71	66	66	66	66	66	66	56	10	10
1 hr	1000	1008	66	71	74	66	66	66	56	18	10
2 hr	1000	1005	94	102	111	85	78	79	56	55	29
3 hr	1001	992	127	132	137	111	102	104	58	79	53
4 hr	1001	993	168	165	175	147	142	142	57	**118** [a]	90
5 hr	1002	995	200	201	197	144	160	168	74	**127** [a]	90
6 hr	1000	992	220	226	227	167	170	170	78	**149** [a]	**92** [a]
7 hr	1000	992	230	232	236	191	194	197	83	**153** [a]	**114** [a]
8 hr	1002	995	231	231	240	203	202	205	83	**157** [a]	**122** [a]
After 1 hr Cooling	387	423	211	215	214	217	220	220	85	**130** [a]	**135** [a]

a. Data values failed the UL 1777 acceptance criteria.

Per UL 1777, the maximum allowable temperature rise of any combustible material during the 1000 °F stage is 90 °F above ambient. The code compliant side (4" masonry plus 2" airspace) failed in four hours. The 8" masonry side in contact with combustibles made it to six hours before the failure criterion of 90 °F above ambient was reached.

The airspace on the 4" thick side of the test chimney was confined both at the top and bottom. It was noted that the combustibles on the inside of that airspace were hotter near the top of the chimney where the flue gasses were cooler, indicating that convection in the airspace allowed the hot air to rise.

Phase 2 Testing

As stated in the Objective, the purpose of this test was to compare the code-compliant configuration with the proposed allowable configuration. Therefore, the 1400 °F and 2100 °F stages (Stages 2 & 3 in Table 1) of the UL 1777 test were still performed even though the chimney failed the UL test acceptance criterion during Stage 1, the eight-hour 1000 °F stage.

On September 20, 2012, the temperature of the combustibles on the code-compliant side of the chimney was brought up to about the same temperature (~230 °F) as they were at the end of the first phase testing. This was accomplished by firing the chimney at 1400 °F for four hours. The results of the second phase testing are displayed in Table 4.

Table 4 – Temperature Reading Results (in °F) from the Second Phase of Testing

Time	Flue 1	Flue 2	CC 1	CC 2	CC 3	8" M 1	8" M 2	8" M 3	Ambient	CC Above Ambient	8" M Above Ambient
Start	47	49	51	52	49	52	49	51	47	5	5
1 hr	1400	1338	71	71	76	52	53	53	52	24	1
2 hr	1403	1358	137	142	143	61	62	65	55	88	10
3 hr	1403	1355	208	215	218	87	94	101	61	**157** [a]	40
4 hr	1401	1357	243	236	222	127	125	119	60	**183** [a]	67
10 min hold @2100	2100	1911	236	242	221	107	113	114	61	**181** [a]	53
after 1 hr of cooling	702	693	235	241	248	136	143	147	64	**184** [a]	83
10 minute hold @ 2100	2100	1928	239	241	248	131	135	137	62	**186** [a]	75
after 1 hr cooling	637	714	229	268	270	135	138	143	64	**206** [a]	79
10 min hold @ 2100	2073	1962	218	257	255	127	127	136	64	**193** [a]	72
Peak Temp During 2 ½ hr Cooling	329	406	206	287	288	139	139	180	63	**225** [a]	117

a. Data values failed the UL 1777 acceptance criteria.

Note that the temperatures on the 8" thick side did not rise above the 90 °F above ambient limit after the four-hour preheating, emphasizing the effect of thermal mass.

The UL 1777 test acceptance criteria allow a 140 °F rise above ambient in the 1400 °F stage and a 175 °F rise above ambient in the 2100 °F spikes stage. Note that even the code-compliant side didn't fail by much, and the 8" masonry side in contact with combustibles didn't come close to failing. The chimney just had too much mass.

Assumptions Implicit within Testing Procedure

During the second phase of the test, the 8" masonry side of the chimney did not fail the UL 1777 test acceptance criteria for allowable temperature rise of the combustibles. This should bring into question the assumptions behind the test. UL 1777 is designed for metal chimneys which achieve equilibrium with 1000 °F flue gas temperatures in about 20 minutes. Masonry chimneys may take hours to achieve equilibrium. The eight-hour specification during the first phase is too short to estimate an equilibrium temperature when such significant thermal mass is present, as with this test. It became apparent that UL 1777 is written for low-mass chimneys and is not an entirely appropriate test for a masonry chimney with high thermal mass, but little insulation.

Furthermore, a 1000 °F flue gas temperature is arbitrarily high. Wood-burning fireplaces only have flue gas temperatures of 300-400 °F under normal conditions. Wood-fired stoves and furnaces may reach as high as 500 °F. Chimney fires, though rare now with more efficient appliances, usually last no more than half an hour. It's difficult to imagine such an over fire condition lasting four hours let alone eight hours.

These test results showed clearly that masonry chimneys are very good at protecting against over fire conditions lasting up to four hours and also against extreme, but quick-burning chimney fires.

Additional Testing

During the Phase 2 tests, the masonry chimneys performed very well, with the temperature of the combustibles rising no more than 50 °F above their starting temperatures. A modified test run was therefore performed at a 1400 °F flue gas temperatures for one hour immediately followed by an increased flue gas temperature of 2100 °F for thirty minutes. This is the equivalent of running the three 2100 °F spikes together to create a more extreme chimney fire test condition.

Even during this more stringently modified test, both the code-compliant side and the 8" masonry side passed with ease. At the end of the 1400 °F and 2100 °F phases of the test, the 8" masonry side in contact with combustibles was a full 71 °F cooler than the code-compliant side, again indicating that building chimney walls 8" thick in contact with combustible materials is at least as safe as building chimneys with 4" thick walls 2" clear of combustible materials, as the current code requires.

Calculation Results

Transient heat transfer calculations were performed in Microsoft Excel 2010 for the conditions present during the first phase testing to compare the experimental results with calculated values. The one-dimensional heat transfer model equations used are Equations 1, 2, and 3, below.

$$\frac{dT}{dt} = \frac{q_{in} - q_{out}}{c_P \cdot \rho \cdot D} \qquad \textbf{(Equation 1)}$$

$$q = h \cdot dT \qquad \textbf{(Equation 2)}$$

or

$$q = k \cdot D \cdot dT \qquad \textbf{(Equation 3)}$$

Where:

T = Temperature, ℃
t = Time, s
q = Heat Flow, $\frac{W}{m^2}$
ρ = Density, $\frac{kg}{m^3}$
D = Depth of Material, m
c_P= Specific Heat Capacity of Material, $\frac{J}{kg \cdot ℃}$
h = Convective Heat Transfer Coefficient, $\frac{W}{m^2 \cdot ℃}$
k = Thermal Conductivity, $\frac{W}{m \cdot ℃}$

Equation 1 was integrated stepwise for each material in series with known boundary conditions. The step size was one second, and the calculation was performed for a total of 36 hours at a constant flue gas temperature of 1000 °F. This yielded close to 13,000 data points for each parameter calculated: the temperature on the inside face of each material, the temperature on the outside face of each material, and the heat transfer through each individual material.

The heat transfer through convection—when a material is bordered by air—is performed with Equation 2, and the heat transfer calculation through a solid material, conduction, is performed with Equation 3.

The parameter values utilized for each material are listed in Table 5, and the units of each parameter are consistent with those described above, after Equation 3. Values were gathered from *www.engineeringtoolbox.com*, and the convective heat transfer coefficients were chosen from within accepted ranges to most closely match the results of the experimental data.

Table 5 – Material Parameters for the Heat Flow Calculations

Material	c_P	ρ	D	k	h	$T_{initial}$
Flue Gas Air	-	-	-	-	5.5	537.8
Clay Liner	900	1920	0.0254	1.4	-	21.1
8" Brick Masonry	900	1920	0.2032	0.89	-	21.1
4" Brick Masonry	900	1920	0.1060	0.89	-	21.1
Air in Airspace (Conduction)	1012	1.204	0.0508	0.025	-	21.1
Air in Airspace (Convection)	-	-	-	-	20	21.1
Plywood	1210	540	0.0127	0.12	-	21.1
Mineral Wool Insulation	840	100	0.0508	0.04	-	21.1

Four temperature profile calculations were performed on the chimney. The first was for the code-compliant configuration assuming that no convection took place inside the 2" airspace—only conduction. This is an ideal calculation where the air acts as a layer of very efficient insulation. The next calculation was for the same physical, code-compliant configuration, however significant convection was assumed to occur in the 2" airspace. This approach is more consistent with the testing results, as the data shows, and assumes that the air in the 2" airspace is well mixed with minimal to no temperature gradients. The third calculation was to investigate the effect of filling the 2" space with mineral wool insulation. The fourth calculation was for the proposed, 8" thick masonry wall configuration.

In total, there were close to 700,000 individual data points calculated during the four chimney temperature-profile calculations.

Figure 3 shows a graph of the four calculated temperature profiles as well as the experimental temperature readings from the Phase 1 Chimney Test.

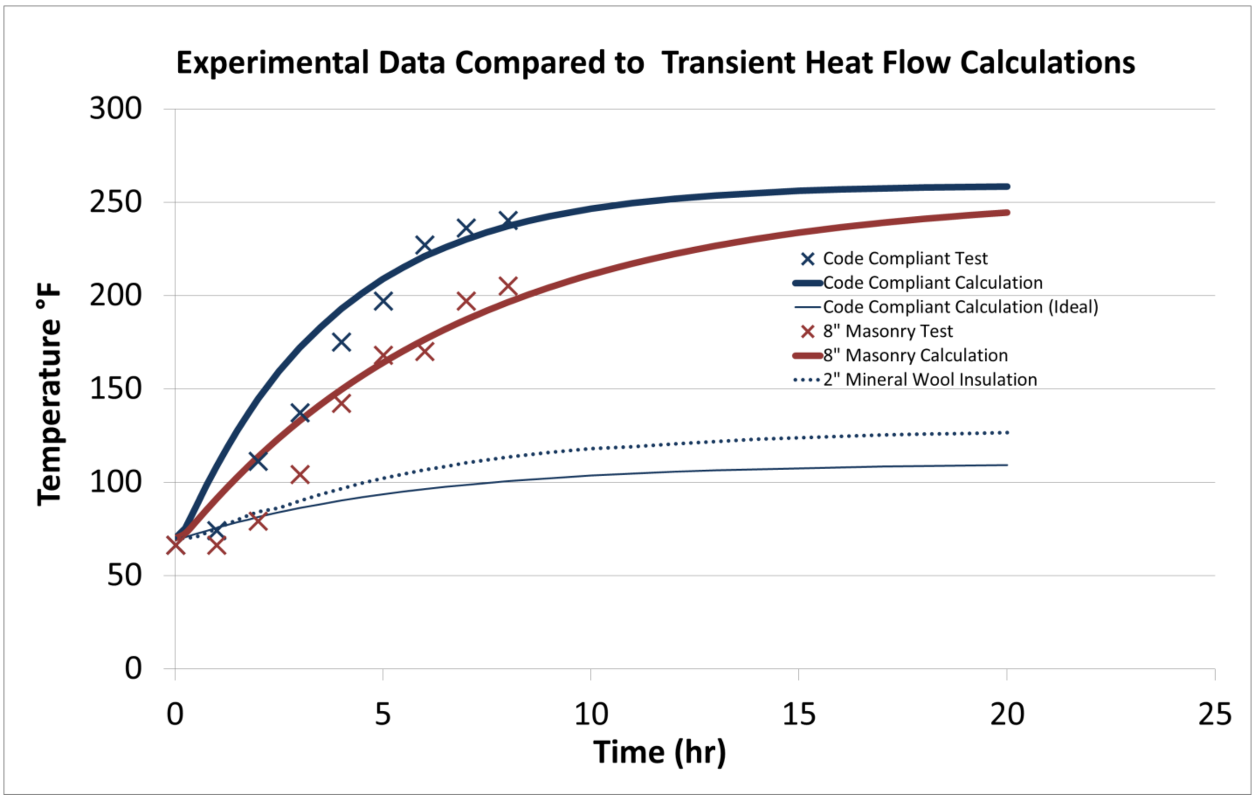

Figure 3 – Temperature Profiles for the Inside of the Plywood

It is clear from the results of testing that as heating progressed, the temperature profile of the inside of the plywood on the code-compliant side more closely matches the heat flow calculation where the convective heat transfer mechanism is assumed in the 2" airspace. The convective mode of heat transfer, which is the reality of what was observed, is over 15,000 times more efficient than the conductive mode of heat transfer through the 2" airspace, which is the intent of the airspace. Being free of insulation to prohibit air movement, the insulative purpose of the airspace (the “Ideal” line) is not being accomplished. Filling the airspace with insulation would bring the temperature profile of the inside of the plywood down closer to the “Ideal” line, as the dotted line displays.

An 8" thick masonry chimney wall is at least as safe as the actual performance of the wall configuration that the code currently permits because of the convective modes of heat transfer that occur. Tabular results from the heat transfer calculations are included in Appendix A.

Conclusions

The 8' thick chimney walls in contact with combustibles outperformed the code compliant configuration of 4" thick chimney walls plus a 2" airspace in each stage of the test.

The combustibles on the code compliant side reached 90 °F above ambient temperature within four hours at a flue gas temperature of 1000 °F, whereas it took the combustibles in contact with the 8" masonry side six hours to reach 90 °F above ambient. After eight hours at a flue gas temperature of 1000 °F, the temperature of the combustibles on the code-compliant side was 35 °F above the temperature of the combustibles on the 8" masonry side. The difference is even more profound during the 2100 °F flue gas temperature spike portion of the test, where the temperature of combustibles on the code-compliant side peaked at over 100 °F above the temperature of combustibles on the 8" masonry side.

As further shown by the heat transfer calculations, because of the convective heat transfer mechanism occurring within the 2" airspace, the insulative purpose of the airspace is not being accomplished. The space is instead acting as a pretty efficient conductor of heat—more so than solid brick.

It can be concluded that building chimney walls with 8" thick masonry in contact with combustible materials is at least as safe as building chimneys with 4" thick masonry walls 2" clear of combustible materials, which is current code.

References

2012 International Building Code, International Code Council, 2011.

2012 International Residential Code for One- and Two- Family Dwellings, International Code Council, 2011.

http://www.engineeringtoolbox.com/density-solids-d_1265.html

http://www.engineeringtoolbox.com/specific-heat-solids-d_154.html

http://www.engineeringtoolbox.com/thermal-conductivity-d_429.html

Appendix A – Tabular Heat Flow Calculation Results

Tabular Results from the heat flow calculation for the proposed allowable 8" thick masonry chimney wall configuration. Temperature values are in degrees Feirenheight.

Time (Hr)	**T Flue Gas**	**T Inside Flue**	**T Outside Flue**	**T Inside Masonry**	**T Outside Masonry**	**T Inside plywood**	**T Outside Plywood**
Start	1000	70	70	70	70	70	70
0.01	1000	78	70	70	70	70	70
0.25	1000	154	84	84	73	73	70
0.5	1000	178	104	104	79	79	70
0.75	1000	196	124	124	85	85	70
1	1000	214	143	143	91	91	70
1.25	1000	231	162	162	97	97	70
1.5	1000	247	179	179	103	103	70
1.75	1000	263	197	197	108	108	70
2	1000	279	213	213	114	114	70
2.5	1000	307	244	244	124	124	70
3	1000	334	274	274	133	133	70
3.5	1000	359	301	301	142	142	70
4	1000	382	326	326	150	150	70
4.5	1000	404	349	349	157	157	70
5	1000	424	370	370	164	164	70
5.5	1000	442	391	391	170	170	70
6	1000	459	409	409	176	176	70
6.5	1000	475	426	427	182	182	70
7	1000	490	443	443	187	187	70
7.5	1000	504	457	458	192	192	70
8	1000	517	471	471	196	196	70
8.5	1000	529	484	484	201	201	70
9	1000	540	496	496	204	204	70
9.5	1000	550	507	507	208	208	70
10	1000	560	518	518	211	211	70
11	1000	577	536	536	217	217	70
12	1000	591	552	552	222	222	70
13	1000	604	566	566	227	227	70
14	1000	615	578	578	230	230	70
15	1000	624	588	588	234	234	70
16	1000	632	597	597	237	237	70
17	1000	639	604	604	239	239	70
18	1000	646	611	611	241	241	70
19	1000	651	616	616	243	243	70
20	1000	655	621	621	244	244	70
21	1000	659	625	625	246	246	70

Time (Hr)	T Flue Gas	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Inside plywood	T Outside Plywood
22	1000	662	629	629	247	247	70
23	1000	665	632	632	248	248	70
24	1000	668	635	635	249	249	70
25	1000	670	637	637	250	250	70
26	1000	672	639	639	250	250	70
27	1000	673	641	641	251	251	70
28	1000	675	642	642	251	251	70
29	1000	676	644	644	252	252	70
30	1000	677	645	645	252	252	70
31	1000	678	646	646	252	252	70
32	1000	679	647	647	253	253	70
33	1000	679	647	647	253	253	70
34	1000	680	648	648	253	253	70
35	1000	680	649	649	253	253	70
36	1000	681	649	649	253	253	70

Tabular Results from the heat flow calculation for the code-compliant chimney wall configuration with 4" of masonry and a 2" airspace. Temperature values are in degrees Feirenheight. The flue gas temperature is constant at 1000 °F throughout the calculation.

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Air Space	T Inside plywood	T Outside Plywood
Start	70	70	70	70	70	70	70
0.01	78	70	70	70	70	70	70
0.25	161	96	96	85	80	75	70
0.5	197	132	132	108	97	87	70
0.75	229	165	165	129	114	98	70
1	258	197	197	150	129	109	70
1.25	286	226	226	169	144	119	70
1.5	312	254	254	187	157	128	70
1.75	336	280	280	203	170	137	70
2	358	304	304	219	182	145	70
2.5	399	347	347	247	203	159	70
3	434	385	385	271	222	172	70
3.5	465	418	418	293	238	183	70
4	492	446	446	311	252	193	70
4.5	515	471	471	327	264	201	70
5	535	493	493	342	275	209	70
5.5	553	512	512	354	285	215	70
6	569	529	529	365	293	221	70
6.5	582	543	543	374	300	226	70
7	594	556	556	382	306	230	70
7.5	604	567	567	389	312	234	70
8	613	577	577	396	316	237	70
8.5	621	585	585	401	321	240	70
9	628	592	592	406	324	242	70
9.5	634	599	599	410	327	245	70
10	639	604	604	414	330	246	70
11	648	613	613	419	335	250	70
12	654	620	620	424	338	252	70
13	659	626	626	427	340	254	70
14	663	630	630	430	342	255	70
15	666	633	633	432	344	256	70
16	668	635	635	433	345	257	70
17	670	637	637	435	346	257	70
18	671	638	638	435	347	258	70
19	672	639	639	436	347	258	70
20	672	640	640	437	348	258	70

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Air Space	T Inside plywood	T Outside Plywood
21	673	640	640	437	348	259	70
22	673	641	641	437	348	259	70
23	674	641	641	437	348	259	70
24	674	642	642	438	348	259	70
25	674	642	642	438	348	259	70
26	674	642	642	438	348	259	70
27	674	642	642	438	349	259	70
28	675	642	642	438	349	259	70
29	675	642	642	438	349	259	70
30	675	642	642	438	349	259	70
31	675	642	642	438	349	259	70
32	675	642	642	438	349	259	70
33	675	642	642	438	349	259	70
34	675	642	642	438	349	259	70
35	675	642	642	438	349	259	70
36	675	642	642	438	349	259	70

Tabular Results from the heat flow calculation for the code-compliant chimney wall configuration with 4" of masonry and a 2" airspace if the heat transfer mechanism through the airspace were limited by conduction. Temperature values are in degrees Feirenheight. The flue gas temperature is constant at 1000 °F throughout the calculation.

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Inside Air	T Outside Air	T Inside plywood	T Outside Plywood
Start	70	70	70	70	70	70	70	70
0.01	78	70	70	70	70	70	70	70
0.25	161	96	96	95	95	71	71	70
0.5	198	133	133	130	130	72	72	70
0.75	231	169	169	164	164	74	74	70
1	263	203	203	196	196	75	75	70
1.25	293	235	235	227	227	77	77	70
1.5	322	266	266	256	256	79	79	70
1.75	349	296	296	284	284	80	80	70
2	375	324	324	311	311	81	81	70
2.5	424	377	377	361	361	84	84	70
3	469	425	425	407	407	86	86	70
3.5	510	469	469	449	449	88	88	70
4	547	509	509	487	487	90	90	70
4.5	581	546	546	522	522	92	92	70
5	611	579	579	553	553	94	94	70
5.5	640	610	610	582	582	95	95	70
6	665	637	637	608	608	96	96	70
6.5	689	663	663	632	632	98	98	70
7	710	686	686	654	654	99	99	70
7.5	729	707	707	674	674	100	100	70
8	747	726	726	692	692	101	101	70
8.5	763	743	743	709	709	101	101	70
9	778	759	759	724	724	102	102	70
9.5	792	774	774	738	738	103	103	70
10	804	787	787	751	751	104	104	70
11	825	810	810	773	773	105	105	70
12	843	829	829	791	791	106	106	70
13	858	845	845	806	806	106	106	70
14	870	859	859	819	819	107	107	70
15	880	870	870	829	829	108	108	70
16	889	879	879	838	838	108	108	70
17	896	886	886	845	845	108	108	70
18	902	893	893	851	851	109	109	70
19	907	898	898	856	856	109	109	70

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Inside Air	T Outside Air	T Inside plywood	T Outside Plywood
20	911	902	902	860	860	109	109	70
21	914	906	906	864	864	109	109	70
22	917	909	909	867	867	109	109	70
23	919	912	912	869	869	110	110	70
24	921	914	914	871	871	110	110	70
25	923	916	916	873	873	110	110	70
26	924	917	917	874	874	110	110	70
27	926	918	918	875	875	110	110	70
28	926	919	919	876	876	110	110	70
29	927	920	920	877	877	110	110	70
30	928	921	921	878	878	110	110	70
31	928	921	921	878	878	110	110	70
32	929	922	922	879	879	110	110	70
33	929	922	922	879	879	110	110	70
34	930	923	923	879	879	110	110	70
35	930	923	923	880	880	110	110	70
36	930	923	923	880	880	110	110	70

Tabular Results from the heat flow calculation for the chimney wall configuration with 4" of masonry surrounded by a 2" thickness of mineral wool insulation before the plywood. Temperature values are in degrees Feirenheight. The flue gas temperature is constant at 1000 °F throughout the calculation.

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Inside Air	T Outside Air	T Inside plywood	T Outside Plywood
Start	70	70	70	70	70	70	70	70
0.01	78	70	70	70	70	70	70	70
0.25	161	96	96	87	87	71	71	70
0.5	197	132	132	119	119	73	73	70
0.75	230	167	167	152	152	75	75	70
1	261	200	200	183	183	78	78	70
1.25	290	232	232	212	212	80	80	70
1.5	318	262	262	241	241	82	82	70
1.75	345	291	291	268	268	84	84	70
2	371	319	319	294	294	86	86	70
2.5	418	370	370	342	342	90	90	70
3	462	417	417	385	385	94	94	70
3.5	501	460	460	425	425	97	97	70
4	537	499	499	461	461	99	99	70
4.5	570	534	534	494	494	102	102	70
5	600	566	566	524	524	104	104	70
5.5	627	595	595	552	552	107	107	70
6	651	622	622	576	576	109	109	70
6.5	674	646	646	599	599	110	110	70
7	694	668	668	620	620	112	112	70
7.5	713	688	688	638	638	113	113	70
8	730	706	706	655	655	115	115	70
8.5	745	723	723	671	671	116	116	70
9	759	738	738	685	685	117	117	70
9.5	772	751	751	698	698	118	118	70
10	783	764	764	709	709	119	119	70
11	803	786	786	730	730	121	121	70
12	820	804	804	746	746	122	122	70
13	834	818	818	760	760	123	123	70
14	845	831	831	772	772	124	124	70
15	854	841	841	781	781	125	125	70
16	862	849	849	789	789	125	125	70
17	869	856	856	796	796	126	126	70
18	874	862	862	801	801	126	126	70
19	879	867	867	806	806	127	127	70

Time (Hr)	T Inside Flue	T Outside Flue	T Inside Masonry	T Outside Masonry	T Inside Air	T Outside Air	T Inside plywood	T Outside Plywood
20	882	871	871	809	809	127	127	70
21	885	874	874	812	812	127	127	70
22	888	877	877	815	815	127	127	70
23	890	879	879	817	817	127	127	70
24	892	881	881	819	819	128	128	70
25	893	883	883	820	820	128	128	70
26	894	884	884	821	821	128	128	70
27	895	885	885	822	822	128	128	70
28	896	886	886	823	823	128	128	70
29	897	886	886	824	824	128	128	70
30	897	887	887	824	824	128	128	70
31	898	888	888	825	825	128	128	70
32	898	888	888	825	825	128	128	70
33	898	888	888	826	826	128	128	70
34	899	889	889	826	826	128	128	70
35	899	889	889	826	826	128	128	70
36	899	889	889	826	826	128	128	70