ASHRAE 1478: Measuring Airtightness of Mid- and High-Rise Non-Residential Buildings

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ABSTRACT

ASHRAE 1478 is a research project designed to measure enclosure airtightness of mid- and high-rise buildings in the United States. Data were collected from 16 non-residential buildings in climate zones 2–7 constructed since the year 2000. The dataset includes buildings with no particular attention to making the building airtight, buildings where some attention was given to airtightness, and buildings where extensive attention was paid to airtightness. Some of the buildings were designed to be sustainable (e.g., receiving LEED status). Buildings ranged from four to fourteen stories. A fan pressure testing protocol based on ASTM E779 was developed by the project team. A number of issues in using E779 to test large building were identified, discussed, and addressed. Building airtightness was reported in CFM per square foot of above grade enclosure at a 75 pascal induced shell pressure difference and CFM per square foot of complete enclosure (including slab and below grade conditioned space walls). The results range from 0.06 cfm 75/ft^2 to 0.75 cfm 75/ft^2 of complete enclosure (1.10 m^3/h/m^2 to 13.7 m^3/h/m^2). Major air leakage sites were identified in the course of testing. Air leakage through HVAC related penetrations was measured in a subset of the buildings. Factors that are associated with the most airtight enclosures include air-barrier continuity detailed in construction documents and precast concrete panel construction. Damper air leakage turned out to be a significant portion of the total enclosure air leakage in some of the buildings. The significance of air leakage by HVAC systems is reviewed in relation to building air tightness.

INTRODUCTION

The air leakage characteristics of commercial and institutional building enclosures is important to design engineers, IAQ consultants, researchers, and forensic investigators. Unintentional air leakage through the building enclosure may result in indoor air quality issues, condensation problems in the enclosure, excessive energy consumption, and, in snow country, ice dams (Brennan 1997; Anis 2001; Brennan 2002; Ask 2003; Fennel and Haehnel 2005). Emmerich and Persily (2005) reported fan pressure test results of over 200 US non-residential buildings, only 11 of which were for buildings greater than 3 stories. ASHRAE 1478 “Measuring Airtightness of Mid- and High-Rise Non-residential Buildings” is a research project intended to provide airtightness data for buildings greater than 3 stories, that were designed and constructed during or after the year 2000. This project conducted fan pressurization testing on 16 buildings located in Climate Zones 2–7 as defined by the IECC Climate Zone map (IECC 2012).

METHODS

Test Procedure

Tests were conducted in accordance with ASTM E779-2010 *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. A test protocol based on E779 that addresses issues specific to testing large buildings was developed for the project.

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The test protocol first required selecting a date when the fewest occupants would occupy the building. It was vital to address security issues and arrange for building personnel authorized to place HVAC in the desired test mode, provide interior access, and to reset circuit breakers. Emergency contacts were also collected.

Portable test fans to test the buildings were used unless compelling reasons stipulated the use of the HVAC system. Pressure taps were placed on all four sides of the buildings as shown in Figure 1 of E779. The measurements of these taps were averaged. Interior pressure differences between the test control location and locations in the building that were most likely to have reduced distribution of interior pressure (e.g., between bottom floor lobby and top floor of building or lobby and the end of a wing. In accordance with E779, single zone condition was achieved if the difference between the highest and lowest interior pressure was less than 10% of the pressure difference induced across the enclosure (taken to be the numerical average of all four ground floor enclosure taps).The interior measurements were monitored so single zone conditions could be maintained and documented. Doors could remain closed if a single zone condition was achieved. If portions of the building had an ambiguous air barrier, the decision made regarding these spaces was documented. Finally, HVAC penetrations were identified and either closed, sealed, or left open, depending on their typical state and other stipulations of the test method.

The test itself involved:

- Collecting baseline and induced envelope pressure and test fan flow data using a central computer
- Analyzing data using the methods in E779 while still in the test building with the test equipment still installed; identifying problems with test data, correcting problems in the building test conditions (e.g. doors blowing open) and collecting additional data to correct the problem.
- Reporting the data in terms of:
    - CFM (m^3/h) at 50 and 75 pascals induced envelope pressure
    - CFM/ft^2 (m^3/h per m^2) above grade enclosure at 50 and 75 pascals, and
    - CFM/ft^2 (m^3/h per m^2) of total enclosure at 50 and 75 pascals.

Identifying the largest air leakage sites in the building and details that contributed to the air leaks was completed during the testing.

Air leakage through HVAC related penetrations was estimated during the test, as well. The building was initially tested with all HVAC related penetrations sealed with masking and any associated dampers closed. After those tests were completed, the test equipment was set to automatically induce 75 pascals indoor-outdoor pressure. The masking was removed from the HVAC penetrations one at a time and the airflow required to maintain the pressure difference at 75 pascals was recorded. Increases in airflow are attributed to air leakage through the unmasked penetration.

Buildings Tested

Table 1 summarizes the properties of the buildings tested. The buildings in the data set are all owner-occupied buildings. Many of them were designed for the owner by the design team. Buildings 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, and 15 are green labeled buildings. Buildings 4, 5, 6, 10, 13, and 14 included an envelope consultant on the design team and had air barriers specified in the construction documents.

Leakage data for all HVAC related openings was collected in 11 of the test buildings. It was collected for smoke evacuators only in Building 1 and kitchen exhaust only in Building 3 and 4.

RESULTS

Table 1 summarizes average air leakage results of the 16 buildings tested. The test results for the buildings with all HVAC penetrations in dampers closed, openings sealed mode are listed in Table 2. Figure 1 plots the results of depressurization and pressurization tests and the average of the two for each building. The mean of the averaged test results is 0.29 cfm 75/ft^2 with a standard deviation of 0.20 cfm 75/ft^2 (5.3 $m^3/h/m^2$ with a standard deviation of 3.6 $m^3/h/m^2$).

The air leakage rate of buildings designated a green building is 0.32 cfm75/ft^2 (5.8 $m^3/h/m^2$). The average leakage rate of all other buildings in the data set is 0.22 cfm 75/ft^2 (4.2 $m^3/h/m^2$).

The air leakage rates for buildings with an air barrier specified and an envelope expert consulted average 0.13 cfm 75/ft^2 total enclosure (2.4 $m^3/h/m^2$). If buildings with air barriers and air barrier consultants included in the design of the buildings are removed from the data set, the mean of the remaining buildings is 0.39 cfm75/ft^2 total enclosure (7.1 $m^3/h/m^2$).

The major air leakage sites were identified at each building. The most frequently encountered large leakage sites were:

- The intersection of roofs and walls
- Soffits and overhangs
- Through portions of buildings that join either non-conditioned or semi-conditioned space (e.g., mechanical rooms, garages, basements, loading docks).
- Coiling doors, primarily at the top of the door.

HVAC related penetration leakage was assessed in 14 of the test buildings. In some of the buildings, the total HVAC related leakage was minimal, while in others it was significant. The average increase in HVAC related CFM 75 airflow across the fourteen buildings was 27% and ranged from 2% to 51%.

DISCUSSION

Biases due to diversity and size limited the analysis of the results. It proved difficult to find owners of commercial rental

Table 1. Properties and Air Leakage of the Building Data Set

Building	Function	Height, number of stories	Floor Area, ft^2 (m^2)	Total Building Enclosure Area, ft^2 (m^2)	CFM 75/ft^2 total enclosure area ($m^3/h/m^2$)
1	Institutional	4	129441 (12025)	135501 (12588)	0.36 (6.63)
2	Institutional	1–5	152333 (14152)	197999 (18394)	0.59 (10.81)
3	Corporate	5	166636 (15480)	193918 (18015)	0.14 (2.47)
4	Institutional	4	330000 (30657)	260800 (24228)	0.13 (2.44)
5	Mixed-use	6	180000 (16722)	147690 (13720)	0.22 (4.01)
6	Corporate	4	109933 (10213)	108751 (10103)	0.06 (1.04)
7	Corporate	14	476162 (44235)	169876 (15781)	0.31 (5.60)
8	Institutional	5	51563 (4790)	78457 (7289)	0.30 (5.48)
9	Corporate	4	85004 (7897)	87428 (8122)	0.57 (10.35)
10	Corporate	4	121825 (11318)	109691 (10190)	0.10 (1.79)
11	Institutional	5	123314 (11456)	126955 (11794)	0.43 (7.86)
12	Institutional	4	141472 (13143)	122269 (11359)	0.15 (2.80)
13	Mixed-use	4	54540 (5067)	77952 (7242)	0.10 (1.87)
14	Institutional	6	214656 (19942)	193824 (18006)	0.18 (3.24)
15	Institutional	4	57286 (5322)	80685 (7496)	0.75 (13.69)
16	Institutional	9	362201 (33648)	210184 (19526)	0.27 (4.99)

properties who were willing to allow the testing to occur. It is suspected that the data set is biased towards tighter buildings. The small dataset may not be representative of the entire set of mid- and high-rise buildings constructed since 2000. However, there are some conclusions that can be made. First, as seen in Figure 1, most of the results are within one standard deviation. However, there is still a large range in air leakage. In addition, pressurization air leakage is always slightly greater than depressurization results. It is believed this is because some air leakage sites are leakier when the building is pressurized (e.g., entry doors that open outward are drawn against weatherstripping in depressurization mode and are pressed to the limits of the latch during pressurization mode. Essentially the same test result was found whether using induced enclosure pressures at the top of the building or on the ground floor.

The eight tightest buildings tested meet the Army Corps of Engineers air leakage requirement of 0.25 cfm 75/ft^2 (4.6 $m^3/h/m^2$). Six of these, Buildings 4, 5, 6, 10, 13 and 14 had special attention to airtightness during design and construction.

The difference in airtightness for green buildings implies that a green building designation is counter-productive to achieving high airtightness. However, there are many other goals when working towards a green label. In addition, only four of the buildings in the data set are not considered environmentally friendly. Results may not be statistically significant.

The air leakage sites identified during the building test are almost all due to detailing at corners, penetrations, and joints. These problems can be addressed by design and installation and are much more difficult to locate and repair at a later time. It is clear that addressing airtightness early is important.

There is a large amount of air leakage associated with HVAC related penetrations. The largest air leaks were through undampered exhaust fans serving kitchens, toilets, elevator shafts, and dampers that did not cycle to the closed position when instructed to do so by the control system. These problems can be fixed, but must be located first. Leakage through fans that operate continuously (e.g., electrical room exhaust) has little effect on energy use. Leakage through fans that almost never run (e.g., smoke evacuation fans) behave as any other enclosure leakage site.

SUMMARY

There is a large range in building air tightness. However, with appropriate detailing and HVAC control, a tighter building can be achieved. This knowledge must be incorporated into all of our buildings to ensure energy efficiency and human comfort.

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Table 2. Results of Fan Pressure Tests

HVAC penetration unmasking results. The columns from left to right are: Building ID number, IECC 2012 climate zone, fan pressure test mode (depressurization, pressurization, or the average of the depressurization and pressurization results), airflow in CFM required to induce a 75 pascal envelope pressure difference, the 95% confidence interval, test result in CFM 75 per square foot of above grade enclosure area, CFM 75 per square foot of total enclosure area (all six sides of the enclosure), airflow in cubic meters per hour required to induce a 75 pascal envelope pressure difference, test result in m^3/h 75 per square meter of above grade enclosure area, in m^3/h 75 per square meter of total enclosure area (all six sides of the enclosure), the air exchange rate needed to induce a 50 pascal pressure difference between inside and outside, flow coefficient, the flow exponent, and r squared.

Building ID	Climate	Test Mode	CFM75	95% CI (±%)	CFM75/ft² above grade encl	CFM75/ft² total encl	m³/h	m³/h/m² above grade encl	m³/h/m² total encl	ACH50	C	n	r²
1	2B	2-dep	49121	0.6	0.48	0.36	81983	8.7	6.6	1.24	4479	0.56	0.9996
2	5A	1-dep	112195	0.2	0.76	0.57	187253	13.8	10.4	2.01	6501	0.66	1.0000
2	5A	2-Press	121958	6.9	0.82	0.62	203548	15.0	11.3	2.16	6405	0.68	0.9966
2	5A	ave 1-2	117077	3.5	0.79	0.59	195401	14.4	10.8	2.08	6453	0.67	0.9983
3	6A	1-dep	25537	1.4	0.18	0.13	42621	3.2	2.4	0.43	1807	0.61	0.9983
3	6A	2-Press	26893	2.6	0.19	0.14	44884	3.4	2.5	0.46	2346	0.57	0.9878
3	6A	ave 1-2	26215	1.5	0.18	0.14	43753	3.3	2.5	0.45	2076	0.59	0.9980
4	6A	1-dep	33301	2.8	0.19	0.13	55579	3.5	2.3	0.36	3157	0.55	0.9967
4	6A	2-Press	36183	1.6	0.21	0.14	60389	3.8	2.5	0.40	3582	0.54	0.9981
4	6A	ave 1-2	34742	1.6	0.20	0.13	57984	3.7	2.4	0.38	3370	0.54	0.9974
5	4C	1-dep	31286	1.4	0.27	0.21	52216	4.9	3.9	0.61	2151	0.62	0.9980
5	4C	2-Press	33552	1.4	0.29	0.23	55998	5.2	4.2	0.66	2510	0.60	0.9985
5	4C	ave 1-2	32419	1.0	0.28	0.22	54107	5.0	4.0	0.63	2330	0.61	0.9982
6	3A	1-Press	6440	2.1	0.08	0.06	10748	1.5	1.1	0.21	601	0.55	0.9938
6	3A	2-Dep	5889	3.0	0.07	0.05	9829	1.3	1.0	0.19	453	0.59	0.9932
6	3A	ave 1-2	6165	1.8	0.08	0.06	10289	1.4	1.0	0.20	527	0.57	0.9935
7	5A	1-Press	52604	1.0	0.40	0.31	87796	7.3	5.7	0.26	3462	0.63	0.9946
7	5A	2-Dep	51442	3.4	0.39	0.30	85857	7.1	5.5	0.26	3565	0.62	0.9905
7	5A	ave 1-2	52023	1.8	0.39	0.31	86826	7.2	5.6	0.26	3513	0.62	0.9926
8	4A	1-Press	25330	2.7	0.36	0.32	42276	6.6	5.9	1.14	1347	0.68	0.9766
8	4A	2-Dep	21649	1.6	0.31	0.28	36132	5.7	5.0	1.00	1457	0.63	0.9964
8	4A	ave 1-2	23490	1.6	0.34	0.30	39204	6.1	5.5	1.07	1402	0.65	0.9865
9	4A	1-dep	48605	4.2	0.77	0.56	81122	14.0	10.2	1.97	3920	0.58	0.9922
9	4A	2-Press	50384	2.1	0.79	0.58	84091	14.5	10.5	2.03	3968	0.59	0.9920
9	4A	ave 1-2	49495	2.3	0.78	0.57	82606	14.3	10.4	2.00	3944	0.59	0.9921
10	6A	1-dep	9840	1.6	0.12	0.09	16423	2.2	1.6	0.24	692	0.62	0.9978
10	6A	2- Press	11609	1.5	0.14	0.11	19375	2.5	1.9	0.28	699	0.65	0.9979
10	6A	ave 1-2	10725	1.1	0.13	0.10	17899	2.3	1.8	0.27	696	0.63	0.9979
11	4A	1-dep	53350	1.3	0.53	0.42	89041	9.7	7.7	1.34	4653	0.57	0.9967
11	4A	2-Press	55729	1.4	0.55	0.44	93012	10.1	8.0	1.38	4237	0.60	0.9960

Table 2. *(continued)* Results of Fan Pressure Tests

Building ID	Climate	Test Mode	CFM75	95% CI (±%)	CFM75/ft^2 above grade encl	CFM75/ft^2 total encl	m^3/h	m^3/h/m^2 above grade encl	m^3/h/m^2 total encl	ACH50	C	n	r^2
11	4A	ave 1-2	54540	1.0	0.54	0.43	91026	9.9	7.9	1.36	4445	0.58	0.9964
12	7A	1-dep	18640	1.0	0.25	0.15	31110	4.5	2.8	0.49	1290	0.62	0.9993
12	7A	2-Press	18818	0.5	0.25	0.15	31407	4.5	2.8	0.51	1597	0.57	0.9998
12	7A	ave 1-2	18729	0.6	0.25	0.15	31259	4.5	2.8	0.50	1443	0.60	0.9995
13	5A	1-Press	8361	1.1	0.16	0.11	13955	2.9	2.0	0.55	616	0.60	0.9996
13	5A	2-Dep	7568	0.6	0.14	0.10	12631	2.6	1.8	0.50	543	0.61	0.9999
13	5A	ave 1-2	7965	0.6	0.15	0.10	13293	2.7	1.9	0.52	579	0.61	0.9998
14	5A	1-dep	32870	1.7	0.21	0.17	54860	3.9	3.1	0.49	2385	0.61	0.9984
14	5A	2-Press	35839	0.9	0.23	0.18	59815	4.3	3.4	0.53	2316	0.63	0.9998
14	5A	ave 1-2	34355	1.0	0.22	0.18	57338	4.1	3.2	0.51	2350	0.62	0.9991
15	5A	1-dep	58233	1.1	1.08	0.72	97191	19.7	13.2	3.58	5505	0.55	0.9982
15	5A	2-Press	62536	2.1	1.16	0.78	104373	21.2	14.2	3.77	4773	0.60	0.9969
15	5A	ave 1-2	60385	1.2	1.12	0.75	100782	20.5	13.7	3.68	5139	0.57	0.9976
16	5A	1-Press	62088	1.6	0.39	0.30	103625	7.1	5.4	0.61	3724	0.65	0.9966
16	5A	2-Dep	52563	1.8	0.33	0.25	87728	6.0	4.6	0.52	3791	0.61	0.9947
16	5A	ave 1-2	57326	1.2	0.36	0.27	95676	6.6	5.0	0.56	3757	0.63	0.9957
Mean						0.29			5.32				

Table 2. *(continued)* **Results of Fan Pressure Tests**

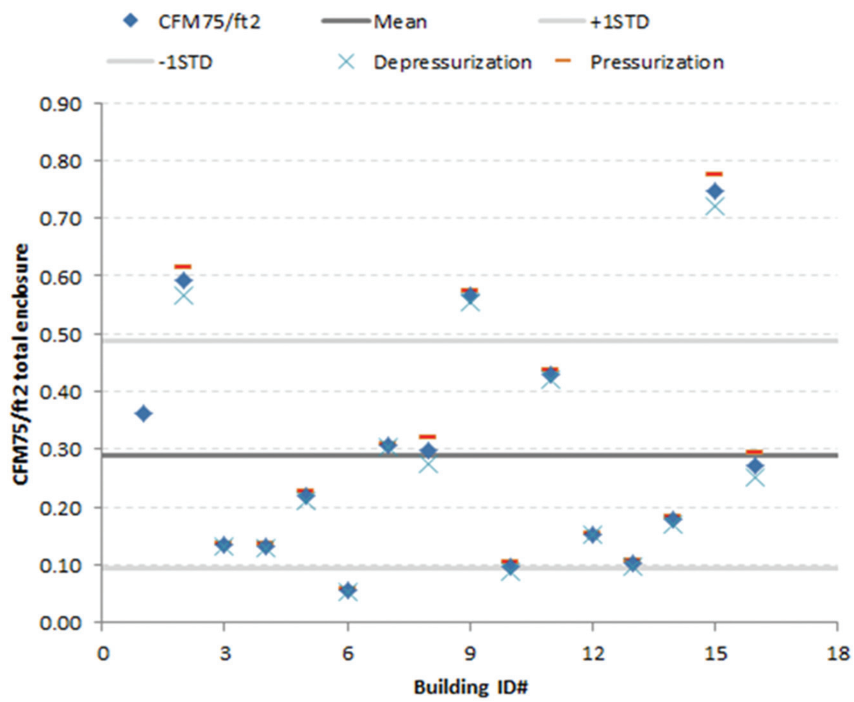

Figure 1 *The depressurization, pressurization, and average of the two test results is plotted for each building.*

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