Impacts of Airtightness on Energy Use

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INTRODUCTION

The energy use in commercial buildings due to infiltration has received little attention in the United States. However, as improvements have been made in insulation, windows, etc., the relative importance of these airflows has increased. Despite common assumptions that envelope air leakage is not significant in office and other commercial buildings, measurements have shown that these buildings are fairly leaky. Infiltration in commercial buildings can have many negative consequences, including reduced thermal comfort, interference with the proper operation of mechanical ventilation systems, degraded indoor air quality (IAQ), moisture damage of building envelope components and increased energy consumption.

Since 1997, the Building Environment and Thermal Envelope Council of the National Institute of Building Sciences has sponsored several symposia in the U.S. on the topic of air barriers for buildings in North American climates. Others have also published articles on the importance of air leakage in commercial buildings (Anis 2001, Ask 2003, Fennell and Haehnel 2005). However, the focus of these conferences and publications has largely been air barrier technology and the non-energy impacts of air leakage in buildings.

Over the last 20 years, engineers in the Building and Fire Research Laboratory at the National Institute of Standards and Technology (NIST) have studied the issue of airtightness of commercial buildings including development of airtightness measurement methods, compilation of a database airtightness measurements, and analysis of the energy impacts of infiltration in commercial buildings. This article presents the most complete set of measured U.S. commercial building airtightness data and describes two simulation studies on the impact of airtightness on building energy use.

AIRTIGHTNESS DATA

In 1998, Persily published a review of commercial and institutional building airtightness data that found significant levels of air leakage and debunked the "myth" of the airtight commercial building. In 2005, Emmerich and Persily updated the earlier analysis for the U.S. by including data from over 100 additional buildings. The 2005 update reports on measured envelope airtightness data from over 200 U.S. commercial and institutional buildings assembled from both published literature and previously unpublished data. The buildings include office buildings, schools, retail buildings, industrial buildings and other building types.

The airtightness of building envelopes is measured using a fan pressurization test in which a fan is used to create a series of pressure differences across the building envelope between the building interior and the outdoors. The airflow rates through the fan that are required to maintain these induced pressured differences are then measured. Elevated pressure differences of up to 75 Pa (0.3 in H20) are used to override weather-induced pressures such that the test results are independent of weather conditions and provide a measure of the physical airtightness of the exterior envelope of the building. ASTM Standard E779 (ASTM 2003) describes the fan pressurization test procedure in detail. In conducting a fan pressurization test in a large building, the building's own air-handling equipment sometimes can be employed to induce the test pressures.

The airtightness data presented here are collected from a number of different studies that use different units and reference pressure differences (see Emmerich and Persily 2005 for sources of data). Air leakage data were available for 201 U.S. commercial and institutional buildings that were tested for a variety of purposes but were not randomly selected to constitute a representative sample of U.S. commercial buildings. None of the buildings are known to have been constructed to meet a specified air leakage criterion, which has been identified as a key to achieving tight building envelopes in practice. The results are presented here as airflow rates at an indoor-outdoor pressure difference of 75 Pa normalized by the above-grade surface area of the building envelope. When necessary, this conversion was based on an assumed value of the flow exponent of 0.65. The values of envelope airtightness are given in units of $m^3/h \bullet m^2$, which can be converted to cfm/ft^2 by multiplying by 0.055.

The average air leakage at 75 Pa for the 201 buildings is 28.4 $m^3/h \bullet m^2$, which is essentially the same as the average for U.S. buildings included in the earlier analysis by Persily. This average airtightness is tighter than the average of all U.S. houses but leakier than conventional new houses based on a large database of residential building airtightness (Sherman and Matson 2002). The average of the U.S. commercial buildings is also similar to averages reported by Potter (2001) of 21 $m^3/h \bullet m^2$ for offices, 32 $m^3/h \bullet m^2$ for factories and warehouses, and 26.5 $m^3/h \bullet m^2$ for superstores built in the United Kingdom prior to new building regulations that took effect in 2002.

The airtightness data were also analyzed to assess the impact of a number of factors on envelope airtightness including number of stories, year of construction, and climate. It is important to note that the lack of random sampling and the sample size limits the strength of any conclusions concerning the impacts of these factors. Also, not all of these parameters were available for all buildings in the database. **Figure 1** **(Page 23)** is a plot of the air leakage at

75 Pa vs. the number of stories of the building and shows a tendency toward more consistent tightness for taller buildings. The shorter buildings display a wide range of building leakage. This result is consistent with the earlier analysis by Persily (1998).

Figure 2 (Page 23) is a plot of the air leakage at 75 Pa vs. the year of construction of the building for buildings built more recently than 1955. While common expectation is that newer commercial buildings must be tighter than older ones, the data gives no indication that this is true. This result is also consistent with the earlier analysis by Persily (1998), despite the addition of numerous newer buildings in this dataset. However no attempt has yet been made to specifically study the achieved airtightness in U.S. commercial buildings constructed with a continuous air barrier such as currently required in Massachusetts.

Figure 3 (Page 23) is a plot of the air leakage at 75 Pa vs. the climate where the building is located as measured by annual heating degree-days base 18C for buildings of 3 stories or fewer (189 of the buildings). The data indicate a general trend toward tighter construction in the colder climates. Although there are data from numerous locations, there is little data from the northern U.S. and even less from the western U.S. If possible, future efforts should focus on collecting data in those regions.

ENERGY IMPACT STUDIES

Recently, NIST has published the results of two simulation studies of the energy impact of airtightness in U.S. commercial buildings. Emmerich et al. (2005b) reported on an estimate of the national energy liability of infiltration in U.S. office buildings by performing simulations for 25 prototype buildings using a coupled building thermal and multizone airflow analysis tool. Using the same simulation technique, Emmerich et al. (2005a) conducted a simulation study to provide input to the consideration of an air barrier requirement by the American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) SSPC 90.1 committee.

Continued on Page 20

TABLE 1: SUMMARY OF MODELED OFFICE BUILDING CHARACTERISTICS

No.	Floor Area (m^2)	Floors	Year	Location	Lighting Load (W/m^2)	Receptacle Load (W/m^2)	Weekly Operating Hours (h)	Effective Leakage Area at 10 Pa (cm^2/m^2)
1	576	1	1939	Indianapolis, IN	22.2	7.1	83	15
2	604	3	1920	Toledo, OH	18.0	6.2	83	15
3	743	1	1954	El Paso, TX	22.5	6.9	83	10
4	929	2	1970	Washington, DC	25.4	7.5	83	7.5
5	1486	2	1969	Madison, WI	28.2	7.5	83	5
6	2044	2	1953	Lake Charles, LA	20.3	6.7	77	10
7	2601	4	1925	Des Moines, IA	18.0	6.2	77	10
8	3716	5	1908	St. Louis, MO	21.1	7.2	77	10
9	3902	2	1967	Las Vegas, NV	23.5	5.5	84	7.5
10	4274	3	1967	Salt Lake City, UT	28.0	7.6	86	5
11	13 935	6	1968	Cheyenne, WY	23.6	6.7	84	5
12	16 723	6	1918	Portland, OR	19.1	5.0	105	10
13	26 942	11	1929	Pittsburgh, PA	18.0	7.1	168	10
14	26 942	6	1948	Amarillo, TX	19.7	6.5	77	10
15	27 871	12	1966	Raleigh, NC	21.8	7.3	168	5
16	28 800	10	1964	Fort Worth, TX	23.1	6.6	105	5
17	53 884	19	1965	Minneapolis, MN	24.8	6.8	105	3.33
18	67 819	10	1957	Boston, MA	29.7	9.6	86	5
19	68 748	28	1967	New York, NY	26.5	8.1	102	3.33
20	230 399	45	1971	Los Angeles, CA	25.5	8.4	102	3.33
21	1022	2	1986	Greensboro, NC	18.5	7.5	77	5
22	1208	2	1986	Tucson, AZ	18.5	6.2	84	5
23	1579	2	1986	Scranton, PA	18.5	7.5	77	5
24	38 090	9	1986	Pittsburgh, PA	16.1	8.3	102	3.33
25	46 452	14	1986	Savannah, GA	16.1	5.8	102	3.33

TABLE 2: SUMMARY OF ANNUAL INFILTRATION RESULTS (H-1)

Building No.	Average when system is off	Average during system operation			Average for all hours		
		Negative	Neutral	Positive	Negative	Neutral	Positive
1	0.27	0.54	0.31	0.15	0.40	0.29	0.21
2	0.57	0.91	0.70	0.52	0.74	0.64	0.55
3	0.14	0.56	0.16	0.026	0.35	0.15	0.086
4	0.14	0.45	0.12	0.013	0.29	0.13	0.076
5	0.12	0.45	0.13	0.015	0.28	0.12	0.066
6	0.16	0.48	0.20	0.066	0.31	0.18	0.12
7	0.29	0.64	0.40	0.23	0.45	0.34	0.26
8	0.22	0.47	0.22	0.085	0.34	0.22	0.16
9	0.12	0.42	0.12	0.026	0.27	0.12	0.070
10	0.10	0.40	0.10	0.015	0.25	0.10	0.057
11	0.13	0.41	0.15	0.044	0.27	0.14	0.088
12	0.25	0.62	0.26	0.089	0.48	0.26	0.15
13	NA	0.40	0.20	0.087	0.40	0.20	0.087
14	0.28	0.58	0.35	0.19	0.42	0.31	0.24
15	NA	0.61	0.19	0.031	0.61	0.19	0.031
16	0.2	0.56	0.22	0.05	0.42	0.21	0.11
17	0.14	0.37	0.13	0.023	0.28	0.13	0.067
18	0.12	0.39	0.12	0.071	0.26	0.12	0.095
19	0.19	0.44	0.19	0.057	0.34	0.19	0.11
20	0.13	0.40	0.12	0.006	0.29	0.12	0.056
21	0.11	0.42	0.14	0.027	0.25	0.12	0.074
22	0.10	0.26	0.10	0.033	0.18	0.10	0.067
23	0.12	0.41	0.14	0.025	0.25	0.13	0.076
24	0.063	0.40	0.058	0	0.27	0.061	0.025
25	0.075	0.40	0.081	0.003	0.27	0.079	0.031

Continued from Page 17

SIMULATION TOOL

McDowell et al. (2003) describes the details of the coupling of the CONTAM and TRNSYS simulation tools used for the two studies. CONTAM is a multi-zone airflow and contaminant dispersal program with a graphical interface for data input and display (Walton and Dols 2005). The multi-zone approach is implemented by constructing a network of elements describing the flow paths (ducts, doors, windows, cracks, etc.) connecting the zones of a building. The network nodes represent the zones, each of which are modeled at a uniform temperature. The pressures vary hydrostatically, so the zone pressure values are a function of the elevation within the zone. The network of equations is then solved at each time step of the simulation.

TRNSYS (Klein 2000) is a transient system simulation program with a modular structure that is a collection of energy system component models grouped around a simulation engine. The simulation engine provides the capability of interconnecting system components in any desired manner, solving the resulting equations, and facilitating inputs and outputs. The TRNSYS multi-zone building thermal model includes heat transfer by conduction, convection and radiation, heat gains due to the presence of occupants and equipment, and the storage of heat in the room air and building mass.

U.S. OFFICE BUILDING STUDY

To study the national impacts of infiltration and ventilation rates on the energy usage of buildings, it was necessary to conduct simulations of airflow and energy usage for a set of different building types and locations. The source for the building set was a statistical analysis completed by the Pacific Northwest Laboratory (PNL) which defined 25 buildings to represent the commercial office building stock of the United States (Briggs et al. 1987, Briggs et al. 1992 and Crawley et al. 1992). A summary of the buildings with some key modeling parameters is shown in **Table 1** including airtightness values based on the Persily (1998) dataset and engineering judgment. Other simulation details are discussed in McDowell et al. (2003).

Annual energy simulations and cost estimates were prepared for a two-story office building, a one-story retail building, and a four-story apartment building. Each building was modeled with both frame and masonry construction. The apartment building and masonry construction results are not included in this article due to space limitations but can be found in Emmerich et al. (2005a). The combined airflow-building energy modeling tool (McDowell et al. 2003) was used to estimate the energy impact of envelope airtightness for five U.S. cities representing different climate zones (Miami, Phoenix, St. Louis, Bismarck and Minneapolis). Building model parameters were chosen such that the buildings would be considered typical of new construction and meet current ASHRAE Standard 90.1 requirements.

The two story office building has a total floor area of 2250 m^2 (24,200 ft^2), a window-to-wall ratio of 0.2 and a floor-to-floor height of 3.66 m (12 ft) including a 0.92 m (3 ft) plenum per floor. The internal gains for the occupied spaces include lighting, receptacle loads, and occupants. These gains are all applied using a peak value and fraction of peak schedule. The lighting peak is 10.8 W/m^2 (1.0 W/ft^2), the peak receptacle load is 6.8 W/m^2 (0.63 W/ft^2), and the peak occupancy density is 53 persons/1000 m^2 (5 persons/1000 ft^2).

TABLE 3: SUMMARY OF HEATING AND COOLING LOAD RESULTS

	Annual Loads with No Infiltration (MJ/m^2)		Annual Loads with Infiltration (MJ/m^2)	
No.	Heating	Net Cooling	Heating	Net Cooling
1	398	186	530	202
2	593	134	922	146
3	80	226	100	228
4	150	311	173	301
5	112	167	135	163
6	39	353	62	377
7	236	178	388	175
8	183	213	266	221
9	25	190	34	200
10	27	283	34	264
11	24	26	45	25
12	138	30	236	29
13	179	246	229	234
14	49	205	158	160
15	33	617	32	599
16	16	431	18	417
17	33	286	67	257
18	8.8	117	15	116
19	63	311	91	284
20	1.3	110	2.2	107
21	21	278	36	263
22	12	394	16	378
23	40	109	64	106
24	3.4	141	6.0	139
25	8.9	305	8.8	299

RESULTS

Table 2 summarizes the calculated annual average infiltration rates for all 25 buildings, including all three pressurization cases and the averages when the systems are on and off. The overall annual average infiltration for positive pressurization cases ranges from 0.025 h^{-1} to 0.55 h^{-1} with an average of 0.12 h^{-1}. For negative pressurization cases, the average infiltration rates increase and range from 0.18 h^{-1} to 0.74 h^{-1} with an average of 0.35 h^{-1}. The neutral pressure cases fall in between.

Table 3 summarizes the predicted annual heating and cooling loads per unit floor area for all 25 buildings including both the zero infiltration case and one of the three infiltration conditions. For buildings 1, 2, 3, 6, 7, 8, 9, and 12, the infiltration case included in Table 3 is the neutral pressure case, since the systems for those buildings in the PNL set were such that pressurization of the building would not be expected. For the remaining buildings, the case shown is the positive pressurization case. Additionally, the cooling loads presented for buildings 1, 2, 3, 5, 8, 9, 11, 12, 18, 20, 23, 24, and 25 are net cooling loads obtained by subtracting the portion of the cooling that may be met by an "ideal" economizer (either mechanical or operable windows) from the total cooling load.

Figure 4 (Page 23) shows the impact of infiltration on individual building space loads as a percent of total load relative to the no infiltration case. Weighted by the floor area represented by the buildings, infiltration is responsible for an average of 33 per cent of the heating load in U.S. office buildings. For cooling, infiltration can either increase or decrease the load depending on the climate, presence of economizer capability and other building factors. On average, infiltration was responsible for a 3.3 per cent decrease in cooling load, but resulted in a significant increase in cooling load in several cases.

U.S AIR BARRIER REQUIREMENT STUDY

Emmerich et al. (2005a) reported on a simulation study of the energy impact and cost effectiveness of improving envelope airtightness in low-rise U.S. commercial buildings to provide input to the ASHRAE SSPC 90.1 committee in its consideration of adding a continuous air barrier system requirement to the standard. Such an air barrier system is the combination of interconnected materials, flexible joint systems, and components of the building envelope that provide the airtightness of the building. The current standard includes detailed quantitative limits for air leakage through fenestration and doors but only very general qualitative guidance for the opaque portion of the building envelope (ASHRAE 2001). For example, the Standard requires sealing, caulking, gasketing, or weather-stripping such locations as joints around fenestration and doors, junctions between floors, walls and roofs, etc. However, there is no quantitative air leakage limit specified for either the wall and other envelope components or the building as a whole. This might be considered analogous to requiring that care be taken when installing insulation without requiring any minimum R-value.

Annual energy simulations and cost estimates were prepared for a two story office building, a one-story retail building, and a four-story apartment including a 3ft (0.92m) plenum per floor. The internal gains for the occupied spaces include lighting, receptacle loads, and occupants. These gains are all applied using a peak value and fraction of peak schedule. The lighting peak is 1.0 W/ft^2 (10.8 W/m^2), the peak receptacle load is 0.63 W/ft^2 (6.8 W/m^2), and the peak occupancy density is 5 persons/1000 ft^2 (53 persons/1000 m^2).

TABLE 4: INFILTRATION AND HVAC ENERGY COST SAVINGS FOR TARGET OFFICE BUILDING

City	Annual Average Infiltration (h^{-1}) Baseline	Target	Gas Savings		Electrical Savings		Total Savings
Bismarck	0.22	0.05	$1,854	42%	$1,340	26%	$3,195
Minneapolis	0.23	0.05	$1,872	43%	$1,811	33%	$3,683
St. Louis	0.26	0.04	$1,460	57%	$1,555	28%	$3,016
Phoenix	0.17	0.02	$124	77%	$620	9%	$745
Miami	0.26	0.03	$0	0%	$769	10%	$769

TABLE 5: INFILTRATION AND HVAC ENERGY COST SAVINGS FOR TARGET RETAIL BUILDING

City	Annual Average Infiltration (h^{-1}) Baseline	Target	Gas Savings		Electrical Savings		Total Savings
Bismarck	0.20	0.02	$1,835	26 %	$33	2 %	$1,869
Minneapolis	0.22	0.02	$1,908	28 %	$364	18 %	$2,272
St. Louis	0.24	0.01	$1,450	38 %	$298	9 %	$1,748
Phoenix	0.13	0.00	$176	64 %	$992	14 %	$1,169
Miami	0.21	0.01	$6	98 %	$1,224	14 %	$1,231

TABLE 6: SUMMARY OF CALCULATED SCALAR RATIOS

Two Story Office Building	Bismarck	Minneapolis	St. Louis	Phoenix	Miami
Masonry Backup Wall					
First cost	$12,054	$12,054	$12,054	$12,054	$12,054
Scalar	3.8	3.8	4.0	16.2	15.7
Steel Frame Building - Taped sheathing (Option l)					
First cost	$4,612	$4,612	$4,612	$4,612	$4,612
Scalar	1.4	1.4	1.5	6.2	6.0
Steel Frame Building - Commercial Wrap (Option 2)					
First cost	$325	$325	$325	$325	$325
Scalar	0.1	0.1	0.1	0.4	0.4
One Story Retail Building	**Bismarck**	**Minneapolis**	**St. Louis**	**Phoenix**	**Miami**
Masonry Backup Wall					
First cost	$7,287	$7,287	$7,287	$7,287	$7,287
Scalar	3.9	3.2	4.2	6.2	5.9
Steel Frame Building - Taped sheathing (Option l)					
First cost	$2,604	$2,604	$2,604	$2,604	$2,604
Scalar	1.4	1.1	1.5	2.2	2.1
Steel Frame Building - Commercial Wrap (Option 2)					
First cost	$176	$176	$176	$176	$176
Scalar	0.1	0.1	0.1	0.2	0.1

The retail building is a one-story building with a total floor area of 12,100 ft² (1125 m²), a window-to-wall ratio of 0.1 and a floor-to-floor height of 13ft (3.9m) including a 3ft (0.9m) plenum. The lighting peak is 1.5 W/ft² (16.2 W/m²), the peak receptacle load is 0.24 W/ft² (2.6 W/m²), and the peak occupancy density is 15 persons/1000 ft² (162 persons/1000 m²).

The HVAC system modeled for the office building included water-source heat pumps (WSHPs) with a cooling tower and a boiler serving the common loop. Each zone had its own WSHP rejecting/extracting heat from the common loop. The HVAC system modeled for the retail building was a packaged rooftop unit including a DX cooling coil and a gas furnace, with a separate system for each individual zone. The St. Louis, Bismarck and Phoenix buildings included economizers. The heating setpoint is 70F (21.1C) with a setback temperature of 55F (12.8C) and the cooling setpoint is 75F (23.9C) with a setup temperature of 90F (32.2C).

Three different airtightness levels (no air barrier, target, and best achievable) were modeled in each building. The values for the no air barrier level varied for each location, while the target and best achievable construction cases were the same for all locations.

The values for the no air barrier (i.e., baseline) case were established through an analysis of the airtightness data available at the time of the study. First, the dataset was adjusted by excluding buildings older than 1960 (even though examination of the data by U.S., Canadian and U.K. authors have found no trends toward increased airtightness in more recent buildings), all industrial buildings, and one extremely leaky building. The data were then divided into north (Standard 90.1 climate zones 5 and above) and south (Standard 90.1 climate zones 4 and below) subsets for the North American buildings only. Unfortunately, the available data are inadequate to support a breakdown by the individual climate zones. Finally, within those North and South subsets, average airtightness was calculated for short buildings (three stories and less) and tall buildings (four stories and up) as the data demonstrate that the tall buildings are tighter on average. The average measured value from the short buildings in the south was used as the baseline value in the warmest climate (Miami) and the average measured value from the short buildings in the north was used as the baseline value in the coldest climate (Bismarck). The values for the remaining locations were assigned by linearly interpolating between these values using the number of heating degree days (HDD) for the location. As a result, the baseline whole building air leakage values with no air barrier are as follows, in units of L/s-m² at 75 Pa (cfm/ft² at 0.3 in H_2O):

- Miami: 2.3 cfm/ft² (11.8 L/s-m²)
- Phoenix: 2.2 cfm/ft² (11.1 L/s-m²)
- St. Louis: 1.8 cfm/ft² (9.1 L/s-m²)
- Minneapolis: 1.4 cfm/ft² (7.2 L/s-m²)
- Bismarck: 1.3 cfm/ft² (6.6 L/s-m²)

In addition to the baseline level, all buildings were modeled at two levels of increased airtightness. Both published building airtightness data and current commercial buildings airtightness standards were considered in selecting these levels. The "target" level was selected to represent a level of airtightness that can be achieved through good construction practice, while the 'best achievable' level is based on the tightest levels reported for nonresidential buildings. About 6 per cent of the buildings listed in the database would meet the selected target airtightness level (0.24 cfm/ft² (1.2 L/s-m²)). Achieving the tightest level (0.04 cfm/ft² (0.2 L/s-m²)) would require an aggressive program of quality control during construction and airtightness testing, combined with efforts to identify and repair any leaks.

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RESULTS

As shown in Tables 4 and 5, the annual average infiltration for the office and retail buildings with the baseline air leakage rate ranges from 0.13 h^{-1} to 0.26 h^{-1} depending on the climate. Reducing the air leakage rate to the target level reduces the annual average infiltration rates by an average of 83 per cent for the office building and 94 per cent for the retail building (note that outdoor air ventilation requirements are met for these buildings through operation of the mechanical ventilation systems).

Tables 4 and 5 also summarize the annual predicted heating and cooling energy cost savings for the office and retail buildings at the target air leakage level relative to the baseline level. The annual cost savings are largest in the heating dominated climates.

COST EFFECTIVENESS

As described in Emmerich et al. (2005a), a cost effectiveness analysis of the air barrier energy savings was conducted using the scalar ratio methodology (McBride 1995) employed by ASHRAE SSPC 90.1. This cost analysis was performed to put the calculated energy savings in context using estimated values of the costs associated with the air barrier measures. As seen in Table 6, the majority of cases with two exceptions (the office building with masonry backup in climate zones 1 and 2) have a Scalar Ratio less than 8 for the Target case.

SUMMARY

Despite common assumptions about "sealed" commercial buildings, the available U.S. building airtightness data indicate that commercial buildings are similar to typical U.S. houses and, significantly, the data shows no trend toward improved airtightness for newer buildings. Although this airtightness database includes over 200 buildings, any general conclusions from this analysis are still limited by the lack of random sampling.

Two recent simulation studies using a coupled multi-zone airflow and building thermal modeling tool demonstrate that the energy impact of infiltration in U.S. commercial buildings is substantial—up to one third of HVAC energy use—and that cost effective measures are available to save much of this energy for many buildings in most U.S. climates.

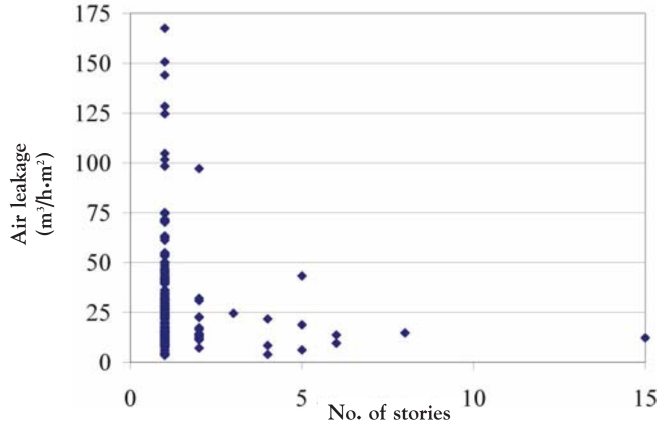

Figure 1 - Normalized building air leakage vs. height of building (in stories).

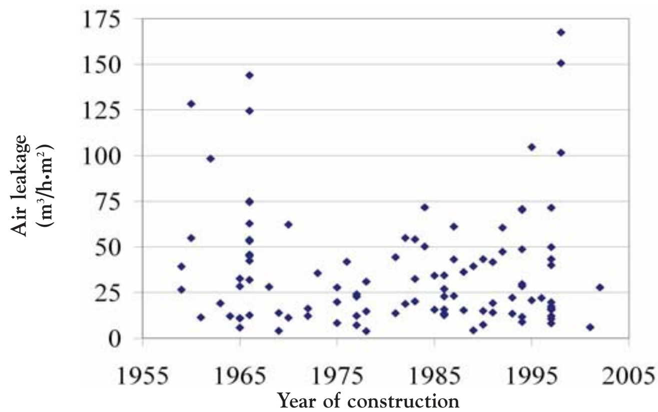

Figure 2 - Normalized building air leakage vs. year of construction.

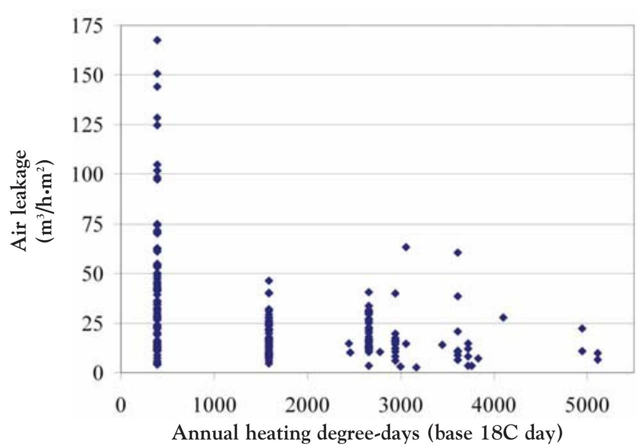

Figure 3 - Normalized building air leakage vs. climate (in heating degree-days base 18C).

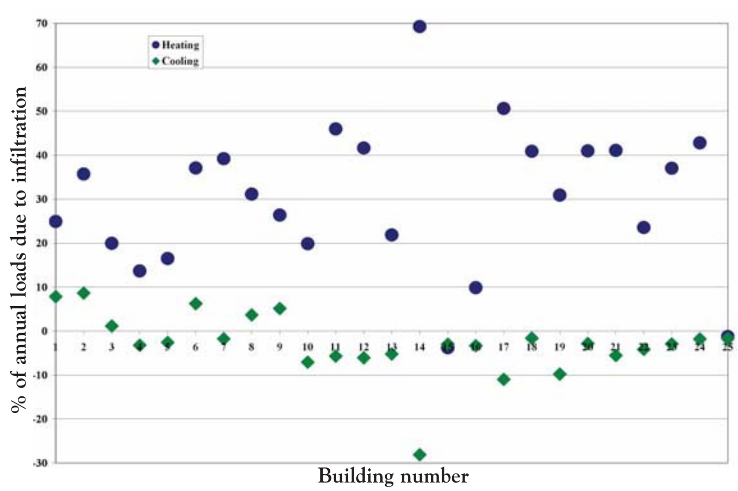

Figure 4 - Per cent of space loads due to infiltration.

Further study is needed to boost the knowledge of energy impacts of commercial building airtightness. Additional measured airtightness data should be collected including for new buildings constructed with continuous air barriers and in under-represented regions such as the Northern and Western U.S. Additionally, field studies documenting energy savings would be helpful. Finally, the potential for tightening and saving energy in the vast stock of existing buildings should be demonstrated in sound field studies.

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