ACHIEVING GOOD AIR TIGHTNESS IN NEW AND RETROFITTED US ARMY BUILDINGS

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ABSTRACT

All Army facilities have been required to increasingly reduce site and source energy use. Along with improvements in energy consumption, building performance in hot humid climates has been a major concern of the Army. Barracks facilities in these environments often experience significant problems with interior mold and mildew as a result of the inability to control relative humidity within the buildings. The major problem is created by a combination of leaky buildings and air-conditioning systems operating at supply air temperatures below the dew point temperature. The Army has been investing large sums of money to remediate mold and mildew damage and maintain these facilities in a healthful and comfortable state.

During the past several years ERDC CERL has been conducting investigations to develop design/construction strategies for improving the energy efficiency, preventing mold, and improving indoor air quality in newly constructed buildings and buildings undergoing major renovations. An important part of these studies was building envelope leakage tests on some existing facilities to gain a better understanding of the general leakiness of Army buildings and the effect of increased air tightness on the building energy consumption. Based on the results of these studies, air tightness criteria and performance requirements to new construction and major renovation projects have been developed and included in the Army design/construction strategies.

Since 2009, the US Army Corps of Engineers (USACE) implemented a requirement for air tightness in all new construction and building enclosure renovation projects. This requirement set levels of air tightness for the building enclosure at the material, assembly, and system level. Additionally, it requires that a whole building air leakage test be completed at completion of construction to verify performance of the constructed air barrier system. This paper presents results of air tightness tests for more than 250 newly constructed and renovated large buildings from before and after new requirements were set, and analyzes the design and construction process, air barrier materials, building use, and construction types. The paper also shows simulation results that illustrate the effects of air tightness on the building energy use for two types of buildings in 15 representative US and 16 Canadian and European climate conditions. The data presented may support future decisions regarding air tightness levels to be adopted for commercial buildings.

KEYWORDS
Air tightness, air barrier testing protocol, energy conservation

INTRODUCTION

All Army facilities have been required to increasingly reduce site energy consumption in response to EPACT 2005, ECB 2010-14, and also the Army Sustainable Design and Development Policy Update (Environmental and Energy Performance, October 27, 2010).

EPACT 2005 required new facilities to reduce site energy consumption, not including plug and process loads, by 30% compared to a baseline facility designed in accordance with the minimum requirements of ASHRAE 90.1-2004, if life cycle cost effective. The Army Sustainable Design and Development Policy Update (Environmental and Energy Performance, October 27, 2010) requires new facilities to achieve reduced energy consumption at or below the levels specified in ASHRAE 189.1 Section 7.

To comply with the requirements of EISA 2007 to eventually eliminate fossil fuel use, new Army buildings and buildings undergoing major renovations shall be designed so that consumption of energy generated by fossil fuels (including electricity generated by fossil fuels) is reduced, as compared to energy consumption by a similar building in Fiscal Year 2003 (FY03) (as measured by the Commercial Buildings Energy Consumption Survey or Residential Energy Consumption Survey data from the Energy Information Agency), by 55% starting 2010, 65% - 2015, 80% - 2020, 90% -2025, and by 100% starting 2030. Meeting FY10 EISA 2007 fossil fuel-based energy use reduction will, in most cases, automatically result in compliance with the building site energy use reduction.

Along with improvements in energy consumption, building performance in hot humid climates has been a major concern of the Army. Barracks facilities in these environments often experience significant problems with interior mold and mildew as a result of the inability to control relative humidity within the buildings. The major problem is created by a combination of leaky buildings and air-conditioning systems operating at supply air temperatures below the dew point temperature. The Army has been investing large sums of money to remediate mold and mildew damage and maintain these facilities in a healthful and comfortable state.

PRELIMINARY ERDC STUDIES

Field Tests. During the past several years ERDC CERL has been conducting investigations to develop design/construction strategies for improving the energy efficiency, and for preventing mold and improving indoor air quality in newly constructed buildings and buildings undergoing major renovations. In the course of these studies, it became clear that building envelope air leakage needs to be addressed. To this end, ERDC-CERL has conducted building envelope leakage tests on some existing facilities to gain a better understanding of the general leakiness of Army buildings, to analyze the effect of increased air tightness on the building energy consumption, and to develop air tightness criteria and performance requirements to be included into the design/construction strategies.

Table 1 lists results of a sample of tested buildings, including four barracks buildings with interior entry ways (older buildings A, B, and C, and a newly constructed building D), a modular barracks building (building G), newly constructed dining facility (building E), and a two storey classroom training facility constructed in 1997 (Building F).

	Envelope Surface Area		Envelope Volume		Envelope Air Leakage
Bldg	sq ft	(m^2)	cu ft	(m^3)	@ 75 Pa (cu ft/min-sq ft)
A	23,300	(2,167)	137,300	(3,844)	0.57
B	37,200	(3,460)	269,100	(7,535)	0.56
C	33,600	(3,125)	230,200	(6,446)	0.77
D	55,000	(5,115)	590,200	(16,526)	0.65
E	80,700	(7,5050	690,000	(19,320)	0.63
F	43,000	(3,999)	345,000	(9,660)	0.28
G	9,700	(902)	**		0.38

Table 1. Test results for selected Army buildings.

Envelope surface area is defined as the sum of the areas of walls, lowest floor slab, and roof or ceiling. Data shows that the envelope leakage in Bldgs A, B, C, and D was in the range 0.56-0.77 cfm/sq ft (@ 0.3 in. of water (75 PA) pressure difference. The envelope of the modular barracks (Bldg G) had an air leakage of 0.38 cfm/sq ft. The newly constructed barracks (Bldg D) was no tighter than the other barracks that were constructed 30 years earlier. When examining the data for two buildings of like construction and configuration (Bldgs B and C), the renovated Bldg C is more than a third leakier than the unrenovated Bldg B due to poor sealing of penetrations through building structure elements. An analysis of data from 139 commercial and institutional buildings in the United States (Persily) revealed that the mean value of their envelope air leakage was 1.48 cfm/sq ft. These buildings ranged in age from 4 years to several decades. The seven Army buildings that were tested were all below this value indicating that typical Army construction is certainly no less airtight than other US buildings. However, only two of the tested Army buildings meet 0.40 cfm/sq ft requirement of recently adopted ASHRAE Standard 189.1 for Design of High Performance Green Buildings and the International Energy Conservation Code (IECC) 2012.

Computer Simulation Analysis. To estimate the achievable savings from reduced air leakage in newly constructed and retrofitted buildings, ERDC and National Renewable Energy Laboratory (NREL) researchers conducted simulation studies using the EnergyPlus 3.0 building energy simulation software. The baseline building was assumed to be an existing barracks, dormitory or multi-family building built to meet the minimum requirements of ASHRAE Standard 90.1-1989 (ASHRAE 1989) by climate zone. The barracks are three stories high with an area of 30,465 sq ft (2,691 m^2) and include 40 two-bedroom apartment units, a lobby on the main floor, and laundry rooms on each floor. Benne (2009) includes further details on the barracks and the baseline heating, ventilation, and air-conditioning (HVAC) systems used. Note that energy costs used in this study are based on Energy Information Administration (EIA) 2007 average data for commercial rates in each state and may not reflect the utility rates at a specific location (EIA 2008).

Four representative air tightness levels were modeled: 1.0, 0.5, 0.25 and 0.15 cu ft/m-sq ft (@ 75 PA pressure difference). The first value is used as the baseline and comes from expert opinion of existing buildings based on pressurization tests. The other three values are considered to represent reasonable performance improvements achievable with a low, medium, and a best effort for sealing existing buildings.

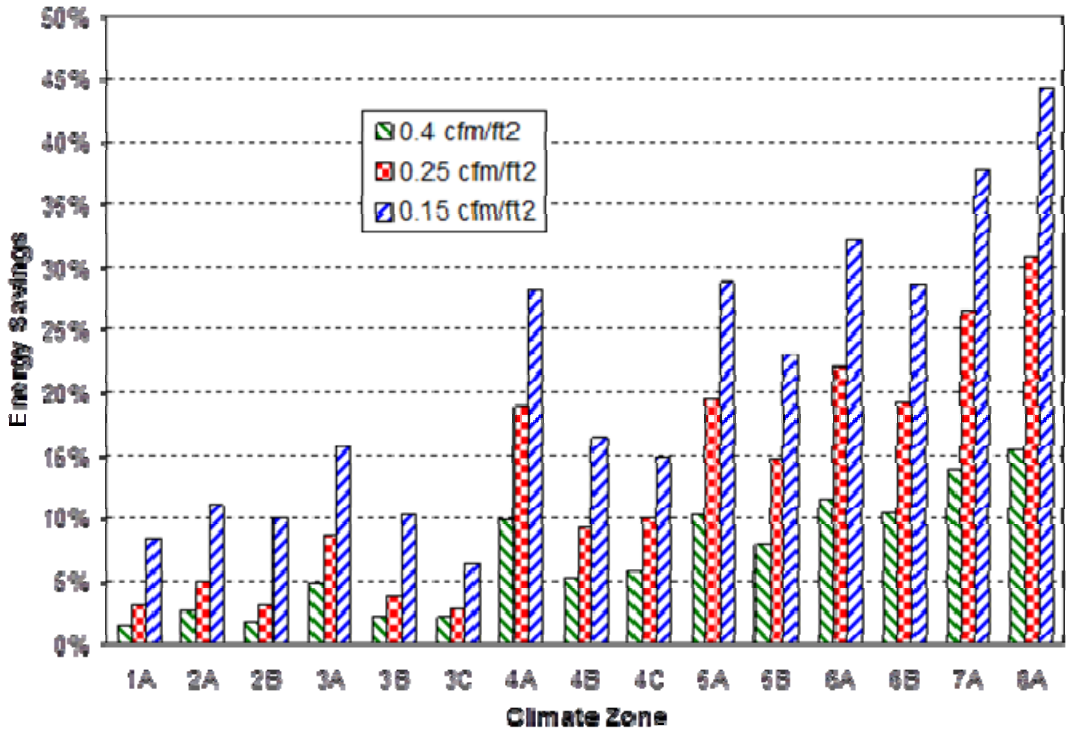

Figure 1. Percent annual energy savings in a barracks building due to air tightness improvement for US climate zones.

Figure 1 shows the results of analysis for improving the building air tightness for each climate zone. The energy savings are based on total building site energy consumption. Energy savings of range between 2% and 16% with the air tightness improvement to 0.4 cfm/sq ft at 75 PA, between 3% and 31% (0.25 cfm/sq ft) and between 8% and 44% with the air tightness at 0.15 cfm/sq ft. The highest results are achieved in the coldest climates and decrease in warmer climates. These savings translate to roughly $0.10-0.50 per sq ft. The results can vary with the change of baseline building air tightness, types of HVAC systems used, and energy rates.

For the economic analysis of air tightness improvement in buildings undergoing renovation, it was assumed that the air leakage rate of the modeled building can be reduced to 0.40 cfm/sq ft at a cost of $15,700 which includes attic sealing ($8,200) and a top floor sealing ($7,500). To reduce air leakage rate to 0.25 cfm/sq ft, additional weatherization of the two bottom floors and sealing doorways would be required and will add approximately $18,440, with a total retrofit cost of $34,140. These costs will be significantly lower if tightening of the building envelope will be a part of a more comprehensive retrofit project, which includes other measures (e.g., building envelope insulation, replacement of window, etc.). Figure 2 shows that improving building air tightness with building retrofits has a reasonable payback (<10 years) in all climate zones.

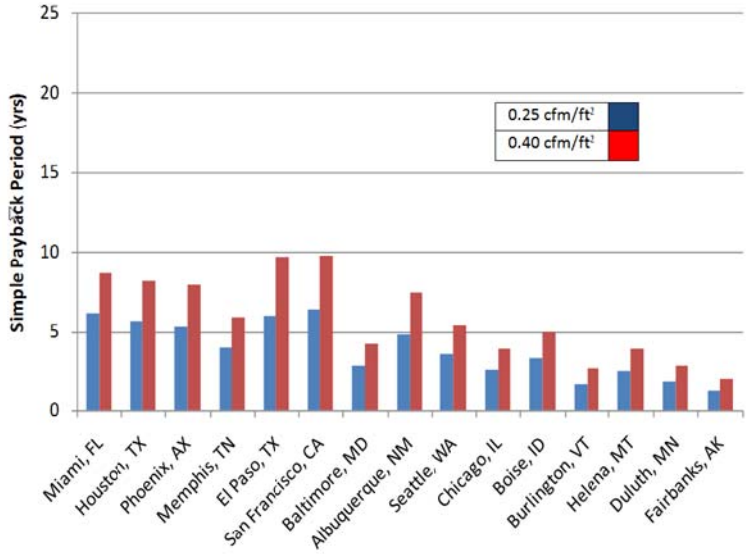

Figure 2. Average simple payback period in a barracks building due to air tightness improvement for US climate zones.

USACE REQUIREMENT FOR AIR BARRIERS AND WHOLE BUILDING TESTING

Based on the results of these studies, the US Army Corps of Engineers set a requirement (ECB 29-2009) that all new buildings and buildings undergoing major renovation shall pass an air leakage test where the results are less than or equal to 0.25 cfm per square foot of exterior envelope at 0.3 in. of water gage (75 Pa) pressure difference. If a building is found to leak more air than this rate, it is considered a "failed" test and the contractor must find and fix air leaks until the building reaches the "passing" level. The test is to be performed according to the protocol developed by USACE ERDC together with Air Barrier Association of America (ABAA) and industry partners. For comparison, Table 2 lists this requirement with other national and international standards.

ECB 29-2009 also requires a thermographic survey of the completed building in accordance with ASTM E 1186 using infrared cameras with a resolution of 0.1 °C or better. IR testing is required to determine the major remaining air leakage pathways and perform corrective work as necessary to achieve the whole building air leakage rate specified in above.

Country	Source	Requirement*	cfm/sq ft @75Pa
USA	ASHRAE 189.1-2009/IECC 2012		0.40
UK	TS-1 Commercial Best Practice	5 $m^3/h/m^2$ at 50 Pa	0.36
USA	LEED	1.25 sq in EqLA @ 4 Pa / 100 sq ft	0.30
Germany	DIN 4108-2	1.5 1/h at 50 Pa	0.28
UK	TS-1Commercial Tight	2 $m^3/h/m^2$ at 50 Pa	0.14
CAN	R-2000	1 sq in EqLA @10 Pa /100 sq ft	0.13
Germany	Passive House Std	0.6 1/h at 50 Pa	0.11
*USACE Requirement is 0.25 cfm/sq ft at 75 Pa			

Table 2. Air Tightness Standards Comparison (For a four-story building, 120 x 110 ft, n=0.65).

Other major requirements to the air barrier established by ABAA include:

- Air barrier must be continuous, with all joints sealed.
- The materials shall have an air permeability not to exceed 0.004 cfm/sq ft under a pressure differential of 0.3 in. of water. (Or 0.02 L/s/m^2 @ 75 Pa)
- It shall be capable of withstanding positive and negative combined design, wind, fan and stack pressures on the envelope without damage or displacement, and shall transfer the load to the structure. It shall not displace adjacent materials under full load.
- It shall be durable and maintainable.
- The air barrier shall be joined in an airtight and flexible manner to the air barrier of adjacent systems, allowing for the relative movement of systems due to thermal and moisture variations and creep. Connections shall be made between: foundations and walls, walls and windows or doors, different wall systems, wall and roof, wall and roof over conditioned space, walls to floor and roof across construction, control and expansion joints, walls floor and roof to utility pipe and penetrations.

Since introduction of the requirements to air barrier and a maximum allowable air leakage rate in 2009, more than 250 newly constructed and renovated buildings have been tested to meet or significantly exceed these requirements. Most of them were proven to have an air leakage rate between 0.05 and 0.25 cfm/sq ft at a pressure difference of 75Pa during the first test (see Table 3). Few buildings, usually those where there was insufficient consideration for the air barrier in design and construction, have to be sealed and re-tested to meet these requirements.

ANALYSIS OF THE SAMPLE OF 200 LARGE BUILDINGS AIR LEAKAGE TESTING RESULTS

The following discussion is based on results of tests performed by BCRA Inc. and Pie Consulting & Engineering on 200 buildings built and retrofitted to meet the USACE requirement. Some of these buildings were among the first to include the Building Air Tightness requirement in the RFP while others represent projects with design-build teams that had already learned lessons on buildings with the requirement. The subject buildings represent projects that completed final testing over a range of 29 months and represent buildings from 34 DoD installations and different US climate zones. Although all buildings or air barrier zones reported on qualify as commercial construction, buildings included in this study ranged from one to eight stories and building envelope areas ranging from 1,000 to 370,000 sq ft.

Location	Building Type	Air Barrier Envelope Size		Result		% Better than 0.25 CFM/sq ft (0.132 (m^3/min/m^2)
		sq ft	(m^2)	CFM/sq ft	(m^3/min/m^2)	
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.05	(0.026)	81%
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.06	(0.032)	76%
Ft. Sam Houston, TX	Medical Education and Training, Dorm	371,099	(34,512)	0.07	(0.037)	73%
Ft. Bliss, TX	Barracks	71,312	(6,632)	0.07	(0.037)	72%
Ft. Bliss, TX	Barracks	72,573	(6,749)	0.10	(0.053)	62%
Ft. Polk, LA	Barracks (Renovation)	52,476	(4,880)	0.10	(0.053)	60%
Ft. Sam Houston, TX	Medical Education and Training, Dorm	141,893	(13,196)	0.10	(0.053)	60%
Ft. Bliss, TX	Maintenance Facility	24,632	(2,290)	0.13	(0.068)	48%
Ft. Riley, KS	Company Operations	43,115	(4,010)	0.14	(0.074)	44%
Ft. Leonard Wood, MO	Battalion HQ	63,276	(5,885)	0.14	(0.074)	44%

Table 3. Sample of test results.

In addition to simply reporting the results of the testing, information was gathered regarding how the air barrier requirement was addressed in the design-build delivery process. Information was gathered on construction type, building use, as well as what air barrier materials, assemblies, and systems were utilized. Variables recorded for each building include:

- Date Tested
- Location
- Gross Floor Area
- Number of Floor Levels
- Area of Building Envelope (Pressure Boundary)
- Building Use
- Construction Type
- Envelope Consultant Incorporated Holistically (DD, DQC, CQC, Cx)
- Envelope Consultant Incorporated to perform Independent Technical Review of
- Envelope Design Documents (DQC)
- Envelope Consultant Incorporated to perform Construction Quality Control Site Visits (CQC)
- Typical Wall Air Barrier System Type
- Typical Roof/Lid Air Barrier System Type.

Major trends realized from the data set are:

1. **Achievable.** The first major trend is the fact that, of the 200 building tests performed and analyzed, all but a few were able to meet the USACE air leakage requirement of 0.25cfm/sq ft @75Pa. Three years ago, most design and construction professionals had little idea of what a continuous air barrier was, how to implement it, or even what a good air leakage rate would be. ASHRAE has struggled for years to put an appropriate number on envelope air tightness levels. The industry simply knew that air leakage had serious negative impacts on building durability and energy use and that it should be limited. So when USACE set forward the air leakage requirement in 2009, it was met with some resistance. Additionally, the learning curve for design-build teams to successfully implement air barrier strategies proved to be quite small. Average results of the first 200 buildings tested for the USACE proved to be 0.17cfm/sq ft @75Pa.

2. **Applicable.** The industry also called into question that the same allowable leakage rate was applied to buildings of all types and uses, over differing climate zones, and varying building sizes (gross floor area and height). Test results indicate that all buildings were able to meet the requirement regardless of size, location, construction type, and most importantly, building use. Figures 3 to 10 show examples of diverse building types that met the USACE air leakage requirement. On each building, whole building air leakage testing was performed in accordance with the USACE Protocol for Large Building Air Leakage Testing.

Figure 3. USACE Admin Bldg 270, Detroit Arsenal, MI - 0.17 cfm/sq ft @ 75Pa

Figure 4. 5-5 ADA COF, Joint Base Lewis McChord, WA - Admin- 0.06 cfm/sq ft @ 75Pa Mezzanine Office- 0.19 cfm/sq ft @ 75Pa

Figure 5. Brigade Complex HQ, Joint Base Lewis McChord, WA - 0.05 cfm/sq ft @ 75Pa

Figure 6. School Age Services Center, Ft. Wainwright, AK - 0.16 cfm/sq ft @ 75Pa

Figure 7. Range Control Tower, Ft. Dix, NJ – 0.22 cfm/sq ft @ 75Pa

Figure 8. IBCT UEPH Barracks, Ft. Bliss, TX – 0.07 cfm/sq ft @ 75Pa

Figure 9. SOF Barracks, Ft. Bragg, NC – 0.12 cfm/sq ft @ 75Pa

Figure 10. VOLAR Barracks Renovation, Ft. Polk, LA – 0.14 cfm/sq ft @ 75Pa

3. **Construction and Materials**. The industry was concerned that the new requirement would dictate the use of certain construction types or materials and assemblies, which would close the market to others. While certain materials have become more heavily used due to this requirement, the study shows that there were a number of successful solutions that incorporated combinations of wall and roof air barrier materials. Analysis of specific construction and material types is ongoing and will be presented in a subsequent paper. Table 4 lists the wall and roof/lid materials reported to be used in the study.

Construction Types	Wall Air Barrier Types	Roof/Lid Air Barrier Types
Wood or metal framed	Liquid applied	Self-adhered roof underlayment
PEMB	Building wrap	Single-ply, fully adhered
Concrete tilt, panels, cast	Concrete tilt, panels, cast	Polyethylene sheet
Concrete masonry unit	Interior drywall	Blanket insulation w/scrim sheet
	Spray polyurethane foam	Single-ply, mechanically attached
	XPS board system	Spray polyurethane foam
	Self-adhered membrane	Built-up roof
	Polyethylene sheet	Interior drywall
		Concrete panel, tee, or poured deck

Table 4. Construction and material types use for building envelope sealing .

4. **Holistic Envelope Consulting**. Beyond any other variable that affected the final outcome of the testing was the level of involvement of an envelope or air barrier consultant on the project. A significant difference was noted when an envelope consultant was brought on early in the project and provided consultation in design phase, construction phase, and testing phase as opposed to just testing phase. Figure 11 shows a comparison by building type of buildings that incorporated holistic envelope consulting and projects that did not. Only building types that had at least 10 samples were included in the graph. Buildings compared are Barracks (B), Company Operations Facilities (C), Mezzanine Offices in high bays (MEZ), Tactical Equipment Maintenance Facilities (T), Headquarter Buildings (HQ), Army Reserve Training Centers (RTC), and Other (O), which includes Fitness Centers, Firing Ranges, etc. Data shown in Figure 11 indicate that the use of an envelope consultant improves the performance of the building in all cases.

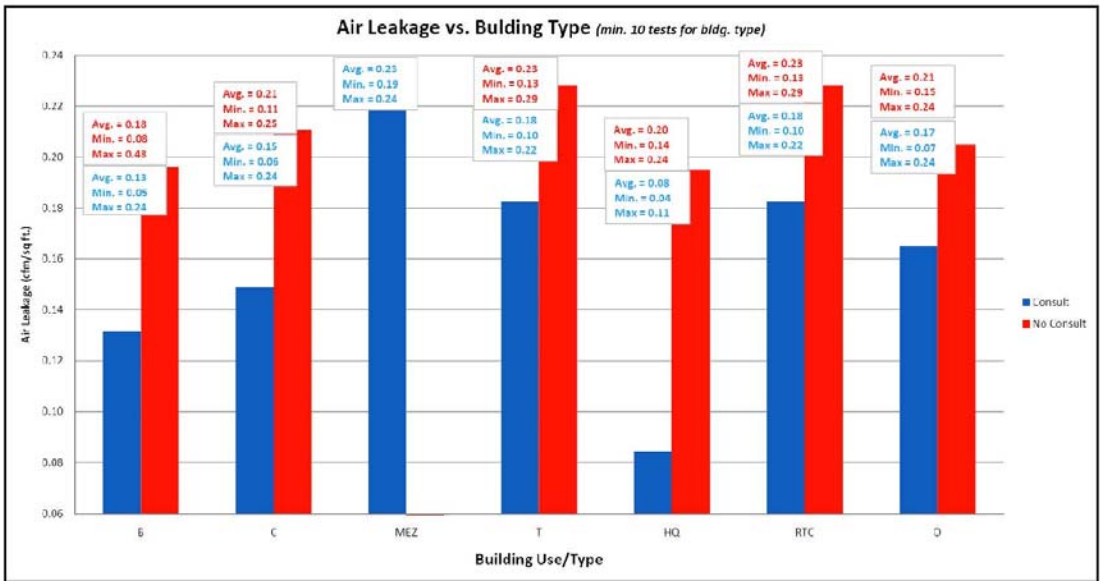

Figure 11. Summary of air leakage test results of 200 buildings by a building type.

SUMMARY

Air barriers play an important role in building durability and energy use and to date have been poorly integrated in the design and construction industry in the United States. With the implementation of the USACE air leakage requirement that include whole building performance verification testing, the industry answered the call. Given the results to date, USACE will be tightening the air leakage rate allowed on DoD projects.

Already several Requests for Proposal (RFPs) have been issued with the new requirement of 0.15 cfm/sq ft @ 75Pa. However, it is recommended that envelopes under 15,000 sq ft remain at the 0.25 cfm/sq ft level. This is due to the fact that when an envelope is this small much of the air leakage that will occur will be in doors and windows that make up a large portion of the smaller envelope. This new requirement will call for a careful design and diligence in the results of the first 200 tests show an average of 0.17 cfm/sq ft @ 75Pa, which is not a significant change from what is already occurring. The data also shows the importance of including an experienced building envelope consultant on the project and RFPs and project specifications have already begun including requirements for a independent envelope consultant to review drawings and perform site visits for quality control review.

The USACE requirement for air tightness already significantly contributes to more durable buildings that consume less energy to operate. The requirement has proven to be both achievable and applicable to all building types and locations. Furthermore, it does not limit the design and construction process to any one set of materials or systems. The move toward tighter buildings will continue, beginning with the USACE tightening the requirement to 0.15 cfm/sq ft @ 75Pa. Based on the data presented in this paper, these results are clearly already achievable.

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Tables 5 and 6 summarize of concerns and lessons learnt regarding reliable airtightness testing and reporting in the United States, and the potential for improving airtightness through QM approaches.

SUMMARY TABLE FOR RELIABLE TESTING AND REPORTING - PREPARED BY THE AIR BARRIER ASSOCIATION OF AMERICA (ABAA)

Questions	Answer
Is there a quality framework for airtightness testers in your country?	The Air Barrier Association of America (ABAA) (http://www.airbarrier.org/)is in the process of developing a certification program for people who will be conducting whole building air tightness testing. As part of this effort ABAA organized a committee for whole building testing and a tester certification program committee in 2010. The committees include testing agencies, air barrier manufacturers, enclosure consultants, all three North American fan test equipment manufacturers and building researchers. At the request of the Army Corps of Engineers the ABAA test committee has revised the US Army Corps of Engineers (ACE) Air Leakage Test Protocol for Building Envelopes http://www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf. Initially the ACE protocol forms the basis of testing. The ACE protocol references ASTM E779 as the basis for testing but has incorporated additional requirements to address issues that arise while testing larger, more complex buildings. Currently the ABAA committee is developing a standard method for testing building enclosures of all sizes and uses to determine whether they have met specified air tightness requirements. The ABAA certification program for building enclosure fan pressurization testing is being developed to train, test and monitor testing competency based on the standard test methods developed by the test committee.
If yes,	There are multiple reasons for developing the certification program and associated test standards: As airtightness requirements become more frequent in the design and renovation of non-residential buildings qualified testing agencies will be needed to reliably and defensibly conduct building enclosure pressure tests. A number of issues are either not covered by current US test standards or must be further clarified in order to reliably pressure test buildings that are large, complex, extremely leaky or extremely airtight. When pressure testing to determine whether or not a building meets an air tightness requirement these issues become paramount. The ACE test protocol and the new standard test method under development by ABAA elaborate on these issues.
What were the reasons behind the development of these frameworks?	The reason for developing a certification program is to develop a standard set of knowledge, skills and abilities (KSAs) base that all people conducting these tests shall possess in order to assure accuracy, repeatability and reproducibility of the testing. The certification program is planned to include training and written examinations. Certification will follow the completion of the training course and successful completion of test requirements.
What is (are) the body(ies) that issue the certification or qualification?	Building Professionals Quality Institute (BPQI) will be the body that issues the certification.

Questions	Answer
Are there specific guidelines for performing or reporting the airtightness test beyond the requirements of EN 13829 or ISO 9972?	Yes. The details depends on whether one is comparing the ACE protocol to ISO 9972 - 2006 (A2009) or whether one is comparing the test method under development by the ABAA test committee to the proposed ISO 9972. Some of the issues being addressed in the proposed ISO 9972 have been addressed in the ACE protocol and most are being addressed in the standard test method being developed by the ABAA test committee. These issues include: Target airtightness requirements Location and dimensions of the test enclosure boundaries The purpose of the test Logistics for planning and executing a test in buildings occupied by multiple, independent tenants, none of whom may manage or own the building; some of whom may have security requirements that prohibit open, single zones to be established. Test status of HVAC and combustion equipment related penetrations (e.g. motorized dampers closed or closed and air sealed; gravity dampers closed-but-operational, closed and wedged or air sealed; unvented vents or chimneys open or air sealed) Treatment of ancillary spaces (e.g. vented crawlspaces, attached garages, mechanical rooms) Treatment of spaces with interior doors that must remained closed for security purposes Apparatus requirements Data analysis
Are there specific guidelines for the airtightness equipment and software beyond the EN or ISO standards requirements?	Yes. From the currently applicable standard (ACE protocol): Manometer requirements: Digital required Resolution – 0.1 pascal Accuracy - ± 1% or ± 0.25 pascals (whichever is greater) Range -250 to +250 pascals Adjustable averaging of intervals required Calibrated within 2 years or manufacturers recommendations (whichever is the shorter time period). Calibration performed against NIST traceable standards over at least 16 pressures from -250 to +250 pascals Certificates required. Test Fan Measurement requirements: Fans must be calibrated at least every four years in compliance with ASTM E1258 – 88(2008). Calibrated over a range of flows and back pressures including at least the maximum and minimum flows allowed by fan manufacturer plus one intermediate flow and back pressures of 25, 50 and 75 pascals for each back pressure. Calibration certificates must show all data. Accuracy – calibration curve must be within ±5% of each actual test flow Digital manometers and fans may be calibrated separately and used interchangeably
What are the steps for a tester to be qualified/certified?	Obtain the required knowledge, skills and abilities as identified by a job task analysis Meet the pre-qualifications established by the certification scheme Successfully complete the test instruments Complete the required documentation A Certification Scheme Committee (CSC) has been established in accordance with ISO 17024. The CSC is in the process of established the details for the above listed steps.
How many testers are qualified according to this framework?	No testers are currently qualified by the ABAA certification program as the training and testing requirements have not been developed.
Is/are there a specific scheme(s) for airtightness test reporting?	Yes. The ACE protocol (the currently applicable standard) clearly requires specific information in a format included as part of the protocol. The standard test method being developed by the ABAA test committee will also include reporting requirements.

Questions	Answer
If yes,	
What were the reasons behind the development of these schemes?	The specific format is to document competent conduct of the test and accuracy of the final test result including: • all factors relevant to interpreting the test result (e.g. weather conditions, status of HVAC and combustion equipment, single zone condition), • the test data, • analysis of results (e.g. pass/fail, reduction of air leakage rate, acceptable confidence intervals)
Does it include specific measures to guarantee the accuracy of the airtightness inputs in the EP calculation?	The main purpose of the ACE protocol is to determine whether or not a building enclosure is equal to or less than 0.25 cfm/sq ft of enclosure at an induced pressure difference of 75 pascals. It is not intended to produce data that will serve as inputs to energy use models. The standard test method being developed by the ABAA test committee is being developed for the same quality assurance purposes. The intentions are to eliminate building enclosure failures related to infiltrating or exfiltrating air and to reduce fuel and electric power used to condition the buildings. These goals are best achieved using a test that has the smallest confidence intervals at the reference test pressure. While data from the test can be used to provide air leakage inputs for energy models it will not have been collected to reduce uncertainty at fairly small indoor-outdoor pressure differences. More importantly, a single zone condition pressure test provides an unrealistic data set for modeling the energy use of a complex, multizone building in which a network of air pressure relationships are intentionally and accidentally induced by the mechanical system, air density differentials and wind.
Does it include the collection of test reports by a central body?	Currently test results are reported to the Army Corps of Engineers. Data collection programs for tests conducted outside the ACE program is being considered by ABAA.
Is there a monitoring scheme?	As part of the certification scheme, there will be monitoring / surveillance

Questions	Answer
List information and references (preferably in English) on this subject in your country	There are many references. The following are mostly institutional sources. ASHRAE (2009) Handbook of Fundamentals, American Society of Heating, Refrigerating and Air-Conditioning, Inc ASTM. (2010). E779-10. Standard Test Method for Determining Air Leakage Rate by Fan Pressurization. American Society for Testing and Materials. ASTM E 2178 (2003) Standard Test Method for Air Permeance of Building Materials ASTM E 1827 (2011) Standard Test Methods for Determining Air tightness of Buildings Using an Orifice Blower Door ASTM E 1186 (2003; R2009) Standard Practices for Air Leakage Site Detection in Building Envelopes and Air Barrier Systems CGSB. (1986). CAN/CGSB-149.10-86. Determination of the Overall Envelope Air tightness of Buildings by the Fan Depressurization Method. Canadian General Standards Board. CGSB. (1996). CAN/CGSB-149.15-96. Determination of the Overall Envelope Air tightness of Buildings by the Fan Depressurization Method Using the Building's Air Handling Systems. Canadian General Standards Board. ECB. Building Air Tightness Requirements. Engineering and Construction Bulletin. ECB 29-2009. US Army Corps of Engineers. 30 October 2009. http://www.wbdg.org/ccb/ARMYCOE/COEECB/ARCHIVES/ecb_2009_29.pdf ISO. (1996). Standard 9972. Thermal Insulation – Determination of Building Airtightness – Fan Pressurization Method. International Standards Organization. Persily, A. K. (1998). Airtightness of Commercial and Institutional Buildings, Proceedings of ASHRAE Thermal Envelopes VII Conference. US Army Corps of Engineers Air Leakage Test Protocol for Building Envelopes. USACE-ABAA. V.3.0 www.wbdg.org/pdfs/usace_airleakagetestprotocol.pdf Zhivov Alexander, David Bailey, Dale Herron, Don Dittus, Michael Deru, and Colin Genge. (2009) Testing and Analyzing US Army Buildings Air Leakage. Proceedings of the 30th AIVC Conference , Trends in High Performance Buildings and the role of Ventilation" and the 4th International Symposium on Building and Ductwork Air Tightness (BUILDAIR). Berlin, Germany. October 1-2, 2009.

Table 5. Summary of concerns and lessons learnt regarding reliable airtightness testing and reporting in the USA.

SUMMARY TABLE FOR QM APPROACHES

Questions	Answer
What are the benefits for builders or owners for implementing QM approaches?	To ensure that the building enclosure does not fail as a result of air flow through assemblies that results in: • condensation, freeze-thaw, ice dams, efflorescence and sub-fluorescence, corrosion, colonization by pest species (mold, decay fungi, rodents, bats, insects • thermal comfort problems for occupants • excessive energy use for conditioning the interior space.
Are there in your country companies involved in QM approaches for airtightness in the construction process?	Yes. The Air Barrier Association of America has a certification program for contractors that requires implementation of the ABAA Quality Assurance Program. In addition many ABAA members provide services that include: • enclosure design • design review • field inspections • qualitative and quantitative testing during construction • final enclosure testing • forensic investigation of failed enclosures

Questions	Answer
Are there incentives for these QM approaches?	Yes. One accrues to all buildings constructed with QM procedures: reduced building enclosure problems. Others are related to specific programs (E.g. Army Corps of Engineers ECB 2012, GSA P100, EPA EnergyStar, US Green Building Council LEED for Homes, passiv haus, 1000 Home Challenge…)
If yes,	
Are there restrictions?	Yes. The building type must be within the scope of the program (e.g. EnergyStar is limited to singles and multifamily residential buildings).
How are they approved?	The approval process varies from group to group. Most require whole building testing by independent test agencies. In the residential programs testing must be conducted by third parties certified by RESNET or BPI. Some programs allow sampling a fraction of completed projects.
How are they controlled?	
Do you think such approaches have great/moderate/little potential for improving airtightness in practice?	Great potential. I have witnessed a large, general improvement in airtightness and consequent reduction of enclosure problems in residential construction over the past 30 years. Over the same time period the improvement in commercial buildings I have witnessed has been limited to those designed or built by interested, pioneering firms and owners. The Army Corps of Engineers program has resulted in astonishing improvements in building airtightness over the last 3 years. I believe that this improvement would not have occurred without programs that require design review, field inspection and intermediate testing and final testing of building enclosures.
Do you think such approaches give greater confidence in the final airtightness? Has this been evaluated?	Yes. The improvement has been very well documented by the Army Corps of Engineers program.
To your opinion, what are the pitfalls to avoid?	The main pitfall is depending on a final test rather than a process. The details must be in the design and specifications, daily inspections during construction are critical, intermediate third party inspection testing catches many potential errors, final testing provides motivation.
What is your general feeling about these approaches?	I feel good about them. They are already making a difference in the quality and durability of the buildings I see.
List information and references (preferably in English) on this subject in your country	

Table 6. Summary of potential for improving airtightness through QM approaches.