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Conserving Energy, Conserving Buildings: Airtightness Testing in Historic New England Homes

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ABSTRACT

As a location of early European settlement, New England enjoys a wealth of historic buildings, which represent a rich cultural heritage and insight into New England life. Their longevity also offers the opportunity to identify the characteristics of long-lasting buildings, and to guide design for the historic buildings of the future. Old buildings are inherently *sustainable*; both because of abstract ideas like “embodied energy” but also by sustaining history and culture over time. This study combines field methods from *vernacular architecture* (a branch of material culture studies) and *building science* (which exists between architecture and engineering) to conduct detailed investigations buildings representing four centuries of New England residential construction. Methods include detailed physical measurements of each building, interior and exterior photography, as well as air leakage measurement with a blower door. Buildings are contextualized from the historical literature, and scientific measurements are compared to the literature of both contemporary and other past buildings. Applying these methods to everyday buildings reconnects the study of building performance to its material, technical and cultural context, as well as the behavior of the occupants whose shelter and comfort it is meant to provide. At the same time, the information about the environment created by the building adds depth and nuance to the understanding of the cultural attitudes and activities of generations of occupants and supports the continued stewardship of these shared cultural resources. This research enriches the narrative of historic human and building interaction: infusing scientific questions of *how* buildings work with the cultural context and human intentions that dictate *why*. Understanding and preserving old buildings includes environmental as well as cultural conservation, prompts us to think of reversible interventions, and militates against the hubris of present thinking that assumes current knowledge and approaches are optimal, and therefore eternal.

KEYWORDS

Blower Door; Vernacular; Historic Buildings; New England; Building Conservation

INTRODUCTION

Pressurization testing using blower doors is a direct, and relatively inexpensive method for quantifying the airtightness of buildings (ASHRAE, 2013). Sherman concisely recounts the history, principles, and applications of blower door pressurization in buildings (1995). For detached homes—which tend to rely on uncontrolled infiltration through the envelope for ventilation—airtightness has important influence on energy conservation, indoor air quality, and identifying deficiencies for repair (Chan, Joh, & Sherman, 2013). These concerns are perhaps even more critical in historic structures, particularly those being maintained by non-profit stewardship organizations as house museums, given the tangle of preservation, maintenance, repair, alteration, cultural and economic considerations. In this context, airtightness testing may be a valuable tool. Beyond the benefit to individual buildings,

“understanding the magnitude of leakage in the building stock is important for prioritizing both research efforts and conservation measures” (M. Sherman, 2007). It is clear from the context that he means *energy* conservation, however, the same statement could equally apply to the practice of *building* conservation, particularly of vernacular buildings, both as a pragmatic measure, and as a tool for historical analysis. It may be surprising then how little data are available regarding the airtightness of historic—or even particularly old—buildings.

Sherman and Dickerhoff compiled the results of 1,492 residential airtightness tests from across the United States. to characterize the existing building stock. The data was used to investigate five building criteria that could impact leakage, including year of construction. While acknowledging the potential selection bias (much of the data came from weatherization programs) the authors found a positive relationship between leakiness and age for buildings prior to 1980 (M. H. Sherman & Dickerhoff, 1998). To address the overrepresentation of older buildings in previous data—the feature of greatest value for the present study—a subsequent database compiled blower door results from some 73,000 buildings, many shortly after construction, to yield a set only slightly older than the American Housing Survey dataset (M. H. Sherman & Matson, 2002). Using that data, an exhaustive 2003 study found that older homes are generally leakier than newer homes and described a roughly lognormal distribution. However, the authors went on to identify complex interactions among year built, floor area, and occupant income, with older, smaller and lower-income homes showing higher leakage rates (Chan, Price, Sohn, & Gadgil, 2003). It is difficult to apply these findings directly to the historic homes considered here, but these results do illustrate a similar situation in which building science is complicated by—while simultaneously offering insight about—social, cultural and economic issues. Finally, a 2013 study expanded that database to include results from blower door testing some 134,000 detached homes, and conducted regression analysis to explain the substantial variation among buildings. Limitations in the available data required the authors to categorize year of construction, with the oldest grouping including all buildings built before 1960. However age was identified as one of the most influential parameters, increasing Normalized Leakage by a factor of 2.2 (Chan et al., 2013).

METHODS

This study conducted air pressurization tests with a blower door in historic New England homes following ASTM-E1827-11 (2017) and ASTM-E779-10 (2010). Ten properties were tested in June and July 2015. Multi-point tests, typically at intervals of 10 Pa, were used in all buildings. Additional points (smaller pressure intervals) were used when building size, leakiness, or equipment limitations made it impossible to achieve a 50 Pa pressure difference. Except where curatorial concerns (e.g. intrusion of chimney soot) dictated otherwise, the results of pressurization or depressurization tests were combined to calculate results. Mechanical and plumbing systems were sealed prior to testing to ensure air leakage across the exterior envelope.

Equipment

Tests were conducted using a Retrotec Model 1000 calibrated fan, with accuracy of $\pm 3\%$ of flow. For larger and leaker properties requiring a two-fan setup, a model 3 fan from The Energy Conservancy (TEC) with accuracy of $\pm 3\%$ of flow when used with the corresponding gauge. Measurements were taken using a Retrotec Model DM32 5A WiFi gauge, running then-current firmware version 2.3.62, accurate to $\pm 1\%$ of pressure reading or ± 0.50 Pa (whichever is greater). When needed, the second fan was paired with a TEC model DG-700 gauge, with a stated accuracy of 1% of the reading, or ± 0.15 Pa, whichever is greater.

External pressure taps were split with a tee and located a minimum of 5m from the testing door, near the midpoints of two walls to balance local pressure differentials. Internal readings were taken at the gauge. All tubes were checked for leaks with the manometer, and manufacturer-recommended field calibrations conducted at the start of each test. Baseline pressure corrections were taken for a minimum of 60 seconds, and retaken whenever testing was interrupted. After stabilization, pressure and flow measurements were recorded with time-averaging of at least 5 seconds, and up to 60 seconds on windy days. A Kestrel 3500 pocket weather station, with a 0.1°C resolution, and $\pm 0.5^\circ\text{C}$ accuracy, was used to record indoor and outdoor temperatures.



Figure 1: Test Locations

Sample Buildings

The historic buildings presented in this report are managed by Historic New England, generally as house museums, and represent a broad range of sizes, ages, locations, construction types, and levels of restoration (Historic New England, 2017). Table 1 summarizes key attributes about the sample buildings, including the year of construction (although many were later modified) and primary structural material drawn from HNE records.

Table 1: Attributes of the Sample Buildings

Name	Construction Type	Year	Floors	Envl. Area (m ²)	Vol. (m ³)
Pierce House	Timber Frame	1683	3	438	585
SPL Stone House	Stone & Brick	c.1690	2	1463	2,745
Arnold House	Stone, Heavy timber	1693	2.5	404	503
Cogswell's Grant	Wood Frame	1728	2	850	1,597
Casey Farm	Timber Frame	c.1750	2	720	1,183
Langdon House	Wood Frame	1784	3	910	1,614
Lyman Carriage House	Heavy Timber	c.1793	2	823	1,309
Phillips House	Wood Frame	1820	3	1126	2,355
SPL Carriage Barn	Heavy Timber	c.1850	2	453	526
Gropius House	Wood Frame	1938	2	533	632

Buildings are located throughout New England, as shown in Figure 1. In addition to the blower door testing, each building was documented through field measurement and photography to confirm existing drawings and/or develop drawings for the area, volume and surface-area.

RESULTS

Summary results for each historic property are presented in Table 2 using several metrics. Air Changes Per Hour at 50 Pa pressure difference (ACH50), is a popular, single parameter based on the airflow measurements and building volume. Alternatively, dividing the volumetric flow by the surface area of the enclosure yields envelope flow; which is useful for envelope studies, particularly on geometrically-complex buildings like some in the sample. Effective Leakage Area (ELA) is sometimes characterized for lay readers as the size of the hole if all the leaks were combined and offers a seemingly direct metric that belies the complexity of measurement.

Table 2: Summary results from air-tightness testing sample buildings

Name	ACH50	Envelope Flow (L/s·m ²)	ELA (m ²)	NL
Pierce House	17.9	6.60	0.278	2.42
SPL Stone House	11.6	6.05	0.576	1.92
Arnold House	30.4	10.52	0.348	1.99
Cogswell's Grant	10.4	5.45	0.321	1.10
Casey Farm	14.4	6.55	0.415	1.58
Langdon House	10.9	5.38	0.453	0.82
Lyman Carriage House	13.5	5.96	0.376	1.14
Phillips House	10.8	6.29	0.479	0.95
SPL Carriage Barn	33.9	2.84	0.136	1.18
Gropius House	9.1	2.99	0.122	0.85

For context, the testing results are also presented in terms of Normalized Leakage (NL)—a metric commonly used by ASHRAE—and plotted in Figure 2 along with airtightness data for a sample of U.S. homes drawn from the literature (M. H. Sherman & Dickerhoff, 1998).

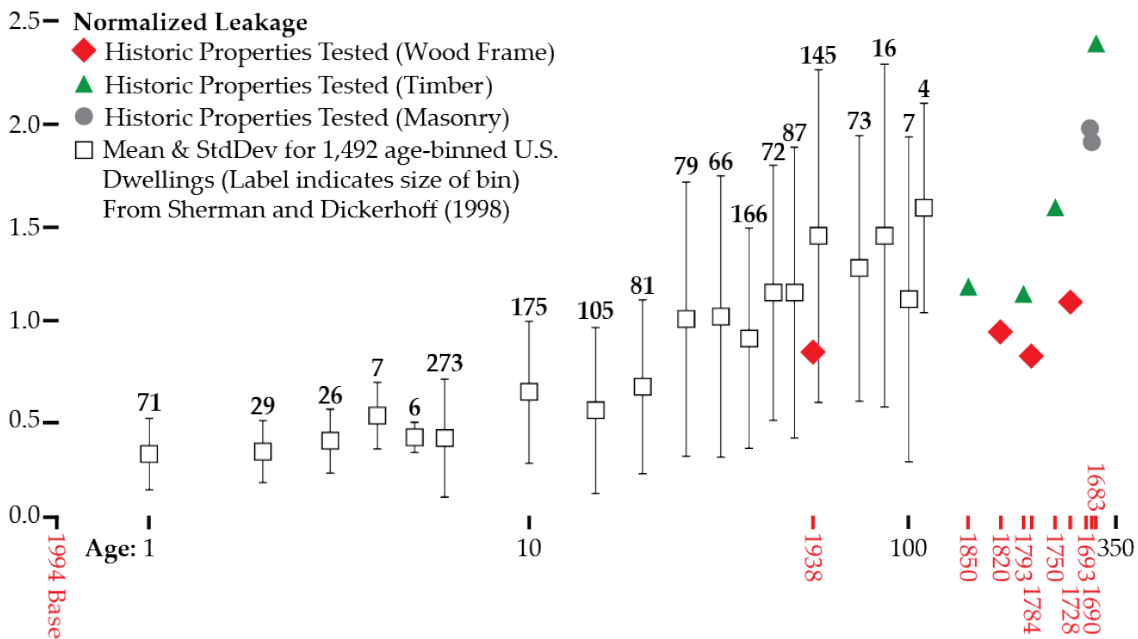


Figure 2. Plot of normalized air leakage as a function of age¹. Historic buildings from this study are noted with color-filled shapes based on primary structural material: diamonds (wood) circles (masonry) and triangles (timber). Hollow squares indicate reference averages and standard deviations for irregular age-based bins drawn from Sherman & Dickerhoff (1998).

DISCUSSION

As shown in Figure 2, older buildings are generally less air-tight than newer buildings, but even the oldest properties tested exhibit leakage rates broadly aligned with those in the pre-1980 historic record. While only a small sample, extending the historical record by approximately

¹ The testing for this study took place over 2 months; however not all houses in the reference set were tested at the same time, so as in the reference, “Age” is calculated with a base year of 1994. It is important to note that “age” cannot distinguish the effect of improvements in construction from the effect of deterioration over time.

two centuries suggests that the positive relationship identified in the literature (M. H. Sherman & Dickerhoff, 1998; Chan et al., 2003) continues, but the nature of the relationship may be complex. Naturally, the scarcity of U.S. buildings from this time, and each building's unique circumstances and history of change, necessarily complicate any generalization. While the collective results offer some general insight, these data also afford only a limited view of each unique home. Understanding the interaction of airtightness with complexities of changes over time are a bridge to a deeper and richer understanding of each building's performance, from the thermal comfort of the occupants to the labour and economic costs of fuel. These curatorial and historical interpretations require a case-study approach and are not presented here; however, they do point to a didactic function of performance testing old buildings. It is tempting to seek lessons in resilience from the sample buildings as among the most durable buildings of their era (the others having not survived), for example based on the suggestive link between leakage and construction material. Yet even putting aside the countless other factors that affect building durability, the sample buildings' status as house-museums complicates any suggestion that these structures offer direct strategies for long-term durability and performance in the New England climate. Belonging to an organization focused on the stewardship of historic buildings and landscapes, these homes are more carefully maintained and more thoughtfully modified than other buildings. Likely their longevity is both a product of care and the impetus for it, so better understanding how to care for them, and how they work demands humility and nuance.

The homes in the sample tend toward vernacular rather than monumental architecture; built for living and having endured long histories of occupation and adaptation prior to becoming museums. Now that they are owned by Historic New England, and preserved as significant examples of historic building, each has undergone various degrees of restoration, both to ensure the physical persistence of the structure into the future, as well as to represent—or interpret—cultural history as an artifact of a time and place. The homes in the sample exhibit a range of curatorial approaches. At one extreme, repairing leaks and openings in the enclosure with period-appropriate materials and techniques restores the performance of the envelope as well as the appearance, with all the associated advantages and liabilities. On the other extreme, modern interventions—albeit usually invisible—may be desirable or essential, particularly to control moisture in liquid and vapor form. For example, one of the projects in this sample required substantial envelope renovations to correct deficiencies in the roof-edge detail and to install flashing under the windows. These details intentionally altered the performance of the original design, although the appearance is all but indistinguishable (Bronski & Gabby, 2013). In another example, bronze weather stripping at windows is an essentially invisible modern intervention when the windows are closed yet provides a seal against air and moisture necessary for the economical operation of modern environmental controls quite unlike the original construction. This reality also reflects a significant challenge for house museums: the buildings in the sample must persist and ensure suitable interior environments for the artifacts inside, such as furniture and decorative arts, without continuous occupancy or the original environmental technologies. The homes in the sample are no longer heated primarily by wood burning fireplaces, and so a common intervention consists of removeable, plastic-wrapped foam plugs to seal the unused chimney flues, thereby dramatically reducing what would have been a major path for air movement out of these buildings. Since none of these buildings are “original” it is fair to wonder whether modern testing reveals anything about the historical reality, however, regardless of changes, to the extent these old buildings are “really” old, the results describe “real” old buildings. As with all history, the measurements of airtightness presented here incorporate both historical facts, and our modern reinterpretation of them.

CONCLUSIONS

As expected from the literature, blower-door testing a sample of historic, primarily vernacular New England homes built between 1683 and 1938 revealed increased leakage with increased age. Although a numerically small sample, the buildings in this group extend the record of airtightness data in U.S. homes by nearly two centuries, to a period from which there are relatively few existent structures to test. The variation in the data demonstrate that buildings particularly very old buildings, exhibit a range of performance, and militate for specific and nuanced investigations to the history of change over time. Such investigations—while perhaps prompted by and valuable for preservation and curatorial activities—also illuminate the homes performance as shelter: adding a directly human dimension to the study of vernacular history. The persistence and resilience of these vernacular buildings offer buildings scientists examples to study and from which to learn the behavior of structures which have endured—or more precisely, have been *made* to endure—in a specific climate for a long time.

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