PHRC Research Series Report No. **106**

The Pennsylvania Housing Research Center

Energy Code Enforcement and Compliance in Pennsylvania: Lessons from the Field

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Preface

This report was prepared by the Pennsylvania Housing Research Center (PHRC) to describe its energy code technical assistance pilot program and communicate the findings of an energy code enforcement and compliance study.

This project received financial and other support from the following organizations:

- The U.S. Department of Energy – primary funding organization
- The Pennsylvania Department of Environmental Protection
- The Commonwealth of Pennsylvania through the Department of Community and Economic Development
- The Pennsylvania State University

The following organizations provided help advertising to potential participants in this project:

- Pennsylvania Construction Codes Academy
- Pennsylvania Association of Building Code Officials
- Pennsylvania Building Code Officials Conference
- Pennsylvania Association of Code Officials
- Lancaster Association of Code Officials

This report was researched and written by Mike Turns, Housing Program Development Specialist at the PHRC, with input from Mark Fortney, Director of the PHRC.

Many thanks go to Bob Buddenbohn and Dave Buskirk for their help and expertise during site visits and their assistance in writing the technical assistance reports. Their help was invaluable to the success of this project. Thanks also to EIC, Inc. & Comfort Home Corporation for assistance regarding diagnostic procedures.

Executive Summary

This project consisted of an energy code technical assistance program for municipalities across Pennsylvania, and an assessment of common energy code enforcement and building practices. An additional function was to estimate the energy performance of typical new homes in Pennsylvania through field testing and computer modeling. The PHRC worked with twelve municipalities, COGs and third-party agencies, over a wide geographic range across the Commonwealth, who volunteered to participate in the technical assistance program and enforcement assessment.

The PHRC paid visits to each of the participating code offices and met with plan reviewers, inspectors and building code officials. Prior to these meetings the PHRC reviewed a set of plans that were previously approved by the code office. Findings from these pre-meeting plan reviews were discussed with plan reviewers and additional information about their plan review process was gathered. Following the discussion and review of plans, inspectors were interviewed in the field during rough framing, insulation and final inspections. At the locations of the final inspections, envelope and duct leakage tests, as well as infrared scans were performed.

The findings from code official interviews, visual inspections and field tests resulted in the 27 recommendations to code officials found in this report. These recommendations are also indications to builders of opportunities for improving energy efficiency and energy code compliance. There were several noteworthy trends among many code offices and homes observed in this study.

In many cases, plan submittals documentation was insufficient to determine whether the proposed home would be fully compliant with the energy code. In addition, plan reviews were frequently limited in scope, placing more of the enforcement burden on inspectors. Plan review or inspection checklists and other quality assurance methods were not commonly used.

One general problem was a lack of attention to the location and continuity of the thermal envelope, particularly in regard to basements. There was frequently confusion as to whether a basement, or a portion of a basement, was considered conditioned or unconditioned space. This resulted in missing basement wall insulation, or slab insulation in the case of walk-out basements. Interviews with inspectors also indicate that slab insulation is frequently not installed such that the insulation creates a thermal break between the slab and the foundation wall as is required by code. In addition, stairwell walls and ceilings in stairways leading to unconditioned basement were frequently not insulated despite comprising a portion of the thermal envelope.

Generally, inspectors were thorough with regard to air sealing of electrical, plumbing and other penetrations. Inspectors were less thorough about air sealing of exterior sheathing. Many inspectors considered housewrap to an acceptable air sealing method, despite the fact that most brands of housewrap are not considered air barriers. In addition, special installation of housewrap is required for designation as an air barrier. There was no evidence of housewrap being installed in this manner. Thus, sealing of sheathing seams should be required.

Air barriers on the attic sides of kneewalls and interior sides of tubs and showers were not observed during this study, leaving these areas exposed to windwashing of insulation and reduced R-values. The code makes reference to air sealing these locations, but is not clear about the location of the air barrier. Thus it is open to the interpretation of code officials as to whether there should be an air barrier on both exterior and interior sides of these locations. Additional clarification of this issue in the code would be useful.

Despite a somewhat superficial attention to air sealing details on the part of code officials, the majority of homes tested for thermal envelope air leakage exhibited relatively low infiltration rates during blower door tests. Some builders appear to be taking responsibility for air sealing requirements upon themselves by purchasing air sealing packages. Interpretation of the blower door results is somewhat of an issue as standards for infiltration have changed over the years. Many homes in this study significantly exceeded the baseline set by the performance path in the code, and would be considered tight. However, the latest version of ACCA Manual J interprets the same homes as average.

Duct leakage testing results yielded two major groupings of duct leakage rates: one group with relatively low leakage rates, and a second, larger group with excessive leakage. Homes containing mostly flexible ducts with good connections, or metal ducts thoroughly sealed with mastic performed well. Homes with unsealed and improperly fastened duct connections, and homes using building cavities as returns had high rates of duct leakage. Air handlers and filter boxes were also not sealed in these homes.

Inspectors typically did not pay much attention to duct sealing. Despite difficulties in finding leaks via visual inspections, many duct construction defects were obvious. This indicates an increase in visual inspections could help reduce duct leakage. A more reliable way to reduce duct leakage would be through field testing.

The relatively small sample size of code offices and homes makes it difficult to make sweeping generalizations about the findings of this study with regard to the entire state of Pennsylvania. In addition, the voluntary nature of participation on the part of code offices makes the findings subject to bias. Nevertheless, the report provides a starting point for further study, and enhancements or additions to current training programs for builders, code officials and subcontractors.

Additional studies would improve our understanding of the energy performance of typical new homes in Pennsylvania. To make accurate generalizations, field testing similar to that which was performed in this study on a much larger number of homes would be necessary. In addition, a more in depth look at thermal distribution system performance would help answer the “so what?” questions frequently asked by builders and code officials as to the significance of duct design, leakage and airflow restrictions.

The information contained in this report will help enhance existing training programs and guide the development of new programs. Enhancements in training programs targeted at builders and code officials on the concept of a continuous thermal envelope are recommended. New training programs for builders, code officials, and HVAC contractors on proper duct installation are also recommended. These training programs will help reduce the gap between energy code requirements and typical practice. Better compliance with the energy code will result in increased energy independence, reduced emissions, lower utility bills and improved occupant comfort for decades to come.

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1. INTRODUCTION

1.1 Purpose

The purpose of this project was to develop a better understanding of residential energy code enforcement and compliance in Pennsylvania. Many aspects of this report will apply to other states that have similar energy codes and building practices.

1.2 Objectives

The objectives of this report are to:

- Provide technical assistance to municipalities and third-party agencies in order to improve their effectiveness in energy code enforcement
- To provide a limited assessment of the effectiveness of energy code enforcement in Pennsylvania as well as the rate of energy code compliance in Pennsylvania
- Estimate the baseline level of energy consumption of typical new homes in Pennsylvania
- Inform policymakers in Pennsylvania and other states that have adopted, or are considering adopting, a similar energy code as to what challenges and opportunities exist in energy code enforcement
- Identify educational and training needs for code officials and homebuilders in Pennsylvania

1.3 Approach

A team made up of PHRC technical staff and senior building code officials (hereafter referred to as the PHRC team) made ten site visits to municipal and third-party code offices over a wide geographic range in Pennsylvania. PHRC site visits provided technical assistance to participating code officials and also served as platforms for data collection regarding energy code enforcement practices and compliance, as well as home energy performance. Data on code enforcement practices were collected through interviews with plan reviewers, inspectors and administrators as the PHRC team followed them through plan reviews and various inspections. Home performance data were collected through visual inspections, blower door and duct blaster tests and infrared scans. A more detailed discussion of how this program/study was executed is located in the Methods (Chapter 2) below.

Participants were selected on a volunteer basis. A call for volunteers was sent out to code offices throughout the state via the newsletters and email distribution lists of several code official organizations in Pennsylvania. Volunteers contacted the PHRC to enroll in the program. To increase participation, and ensure openness and honesty, the PHRC agreed not to publicly identify participating individuals and organizations.

1.4 Background

To fully understand the challenges that Pennsylvania faces with regard to energy code enforcement, it is necessary to have a basic knowledge of the history of energy codes in the Commonwealth. Pennsylvania's first energy code went into effect in 1980 under the Building Energy Conservation Act (Act 222). The provisions of Act 222 were based on ASHRAE's Residential Standards. However, for the vast majority of municipalities and third-party agencies, energy code enforcement is a relatively new responsibility.

Enforcement of Act 222 was extremely minimal, as builders self-certified their compliance with the Act. The Pennsylvania Department of Community Affairs (DCA) reserved the right to inspect post-construction, but these inspections were only performed upon homeowner complaints. Municipalities could also choose to administer Act 222 instead of DCA. Only 136 of Pennsylvania's 2,564 municipalities[1] opted to self-administer Act 222. Municipal enforcement of Act 222 generally consisted only of filing the builder's signed warranty of compliance. In general, inspections were only performed at the request of the homeowner, and homeowner requests were also rare. Of the limited inspections that did take place, the PHRC is not aware of a single home that passed.

Pennsylvania updated its energy code when the Uniform Construction Code (UCC) went into effect in April of 2004. Following the adoption of the UCC, 92% of Pennsylvania municipalities opted to take on the responsibility of enforcing the provisions of the UCC[2], which include the energy code. Thus, the majority of municipalities have only begun enforcing an energy code since April 2004. Pennsylvania's energy code options include the latest versions (not including supplements) of Chapter 11 of the International Residential Code (IRC), the International Energy Conservation Code (IECC) and Pennsylvania's Alternative Residential Energy Provisions (PA-Alt).

"Opt-in" municipalities are also responsible for enforcing the International Code Council's (ICC) Residential, Mechanical, Plumbing, Electrical, Fuel Gas, Fire, Existing Building and Wildland-Urban interface codes. Municipalities were also given the option to opt out of enforcing the UCC, in which case code enforcement is delegated to third-party agencies under contract with the municipality or permit applicant.

Since few municipalities enforced Act 222 or local energy ordinances prior to 2004, energy code enforcement is a relatively new responsibility for municipalities and third-party agencies. In addition, under the UCC, Pennsylvania has mandated that its building codes be updated every three years, as the latest versions of the ICC family of codes. This places an additional strain on code offices as they struggle to keep up-to-date with a frequently changing code. Thus, the recentness and frequently changing nature of code requirements result in an educational and training challenge for code offices in Pennsylvania.

[1] Pennsylvania Department of Community Affairs, *Residential Builder's Guide to Act 222*, 1996.
[2] Pennsylvania Department of Labor & Industry, Building Codes Web Site (http://www.dli.state.pa.us/landi/lib/landi/bois/asb_lead_ucc_updates/uccmun.htm), October 22, 2007.

Currently, Pennsylvania is one of 14 states in the U.S. whose energy code meets or exceeds the 2006 IECC or equivalent. Eleven states have energy codes that meet the 2003 IECC or equivalent, nine states' energy codes meet a 1998-2001 IECC or equivalent and five states' energy code precedes the 1998 IECC. The remaining ten states have no statewide energy code.[3]

[3] Building Codes Assistance Project (BCAP), http://www.bcap-energy.org, October 22, 2007

2. METHODS

2.1 Recruiting Participants

This project combined an energy code technical assistance program with an energy code compliance evaluation. The PHRC recruited participants in the technical assistance program by advertising through the email lists and newsletters of several code organizations. These organizations included the Governor's Center for Local Government Services, Pennsylvania Construction Codes Academy (PCCA), Pennsylvania Association of Building Code Officials (PABCO), Pennsylvania Building Code Officials Conference (PENNBOC), Pennsylvania Association of Code Officials (PACO) and the Lancaster Association of Code Officials (LanCode). Interested code offices then contacted the PHRC for information on how to participate. None of the interested groups were denied participation.

In all, twelve groups, ranging from small to very large, including eight municipalities, three third-party agencies and one council of governments (COG) participated in the program. Forty-one individuals participated in the technical assistance program. The PHRC team charged participating code offices with the task of identifying homes in that office's service territory that were at or near rough framing, insulation (if typically performed) and final inspections. The PHRC team visited a total of 29 homes: nine in the rough framing phase, eight with insulation installed, and twelve at or near the final inspection.

Participating organizations came from a wide geographic range across Pennsylvania. Figure 1.1 shows the general locations of the participants. In western Pennsylvania there were no volunteers in central or southern latitudes. This is the only major housing markets that are not represented in this study.

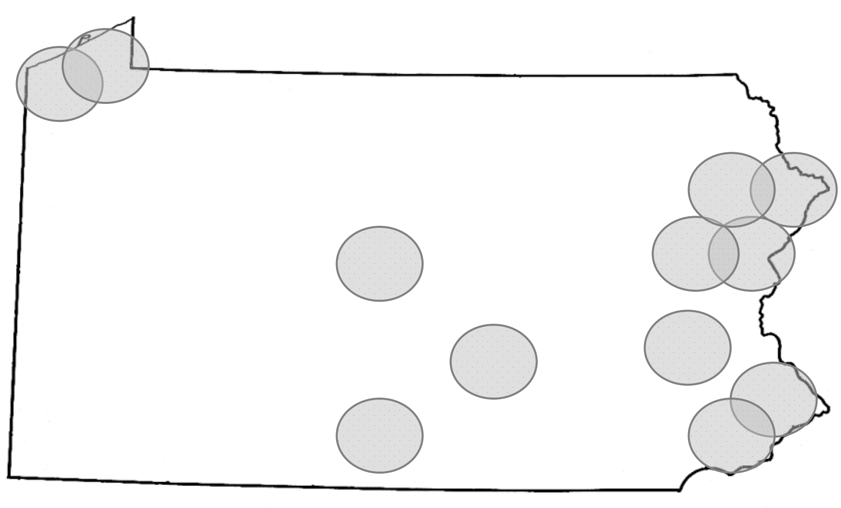


Figure 1.1: The general location of the twelve code offices that participated in this study

To increase participation in the program, the PHRC granted anonymity to all individuals and organizations participating in the study. As such the PHRC will not identify the names of participating individuals, municipalities, third-party agencies or COGs in this report.

2.2 Technical Assistance and Evaluation

2.2.1 Pre-Meeting Plan Reviews

Prior to meeting with each code office, the PHRC team performed a review of any plan submittal forms and checklists used by the code office. Plan review checklists were also reviewed when applicable. In addition, a detailed energy review of a set of building plans that had been previously approved by that office was performed. The code office supplied the PHRC team with these plans. Over the course of the program the PHRC team performed twelve pre-meeting document reviews.

Plan submittal document reviews consisted of evaluating the accuracy, level of detail and presence of energy-related items. It was noted whether the required documentation would enable the code office to perform a thorough energy review if that documentation was submitted by a permit applicant.

PHRC plan reviews consisted of the identification of various items that would be necessary or beneficial to determine whether the proposed home is in compliance with Pennsylvania's energy code. The first item identified was whether or not a compliance path was specified by the builder. Builders, not code officials, are responsible for selecting a compliance path. It is essential for code officials to work within the framework of a compliance path because specific requirements vary based on the compliance path chosen. For example, in Climate Zone 5 (Central) an R-13 wall between a garage and conditioned space is permissible when using a trade-off in the PA-Alt, and potentially when using RES*check*, while R-19 walls would be required in IRC/IECC prescriptive paths. Without knowing the compliance path chosen, the plan reviewer has no way of knowing whether an R-13 garage wall is permissible.

The PHRC also identified the presence of the code year on the plans and other documentation and whether that code year was correct for the time of application. Energy code and other requirements change with each new version of the code. This transition occurs every three years. Pennsylvania has already seen significant changes in energy code requirements when it transitioned from the 2003 versions of the IRC/IECC and PA-Alt to the 2006 versions. Therefore, plan reviewers must be very cognizant of the code year that a permit applicant is required to build under and whether the code year on the application matches. This is especially true in transitional periods when plan reviewers are very likely to be concurrently reviewing applications that fall under different code years.

Consistency between plans and other forms of documentation in a permit application is also important. The most common form of energy code documentation, other than building plans, is a RES*check* Compliance Certificate. The PHRC team reviewed submitted RES*check* compliance documentation and compared the inputs to the plans for accuracy. This included checking that all building envelope requirements (e.g. ceiling, walls, floors) were listed on the RES*check* form, that component areas were reasonably accurate, and that insulation values listed matched what was specified on the plans.

The PHRC team also checked to see if the plans had sufficient detail to determine if the home would be in compliance when built. This included checking for building component R-values and fenestration U-values specified on plans, and if it was possible to identify the location and continuity of the thermal envelope. Duct insulation specifications and proposed grading around conditioned basements were also checked on the plans.

Proper sizing of HVAC equipment is important for occupant comfort and efficient operation. The IRC, IECC and PA-Alt require that equipment be sized in accordance with the Air Conditioning Contractors of America (ACCA) Manual J. The PHRC team noted whether code offices collected equipment sizing documentation and the extent of their review of that information.

It was also noted whether or not code offices used checklists. One way of increasing the likelihood of obtaining sufficient details on plans is to issue plans submittal checklists detailing all of the required documentation. Also, a code office can increase consistency and thoroughness if plan reviewers use a plan review checklist. This will increase the chances that important energy (or other) code requirements are reviewed.

2.2.2 Plan Reviewer and Inspector Interviews

To begin each of the PHRC team's site visits, the PHRC met with building code officials, plan reviewers, and inspectors to discuss their overall energy code enforcement process from permit application submittal to issuance of a certificate of occupancy. The PHRC team assessed the size and level of sophistication of the code office. This consisted of obtaining estimates of the number of single-family, new residential permits issued per year, the geographic area of the service territory, and the number of people employed at that office. The PHRC team also assessed the experience and qualifications of the participating code officials including years experience, certifications, and educational or construction experience.

The team proceeded with the interview identifying the energy-related items plan reviewers typically check for when performing a plan review. Plan reviewers were asked to review and discuss a typical plan review. Code officials also estimated the frequency with which each of the energy code compliance paths were chosen by permit applicants.

Following the meeting at the code office, the PHRC team accompanied inspectors on inspections in the field. Inspectors took the PHRC team through their typical inspection process. Feedback was provided to inspectors based on its observations. In most cases, inspections were performed on one house at the rough framing phase, one with insulation installed, and one at final inspection. Various items were photographed for incorporation into future training programs.

2.2.3 Rough Framing Inspections

During rough framing inspections, the PHRC team noted what items inspectors were looking at. This was done by asking inspectors to walk through the home as if they were doing an actual insulation inspection (in some cases they were doing an actual inspection) and "think out loud" about what they are inspecting.

The PHRC team focused on a few specific items. One of these items was whether or not plans were required on site, if that requirement was enforced, and if inspectors used those plans. The IRC requires that a set of approved plans be kept at the site of work. Generally, inspectors would need to use those plans to adequately evaluate certain energy (and structural) issues.

The 2003 IRC/IECC and PA-Alt state that, "all joints, seams, penetrations, openings between window and door assemblies and their respective jambs and framing, and other sources of air leakage through the building envelope shall be caulked, gasketed, weatherstripped, wrapped or otherwise sealed to limit uncontrolled air movement." For this reason, the PHRC noted the degree of attention to which inspectors paid air sealing details.

Inspection of window and door U-factors was another focus of the PHRC team. It is not necessary that verification of window and door U-factors occurs at the rough framing inspection. However, it makes sense to inspect this item as early as possible in case NFRC labels are removed prior to the next inspection.

The PHRC team also noted the degree to which inspectors looked at duct sealing and duct construction. This included whether inspectors were looking for properly sealed ducts, air handlers and filter boxes, proper duct connections, and limited duct constrictions or turn radii.

2.2.4 Insulation Inspections

The PHRC team followed the same procedure used for rough framing inspections. The PHRC team focused on whether or not inspectors identified if thermal envelope was continuous and contained the required R-values. The degree of attention given by inspectors to proper insulation installation was also noted. The PHRC team also noted whether inspectors require air barrier on the backs of kneewalls, and behind tubs and fireplaces. Code language on these items is vague. This will be discussed further in later sections.

2.2.5 Final Inspections

Once again inspectors walked the PHRC team through their inspection procedure at a home that was at, or close to, final inspection. The PHRC team focused on inspectors' practices regarding inspection of attic insulation and attic access insulation and air sealing. Other items that the PHRC team noted included presence of pipe insulation (where required), sealing of exterior penetrations, HVAC efficiency verification, weatherstripping and final checks on duct/air handler sealing and connections.

2.2.6 Building Performance Tests

Following the PHRC team's evaluation of code officials' final inspection procedures, the team performed several building diagnostic procedures. These procedures were used to estimate the future energy performance of the home and conceptualize construction imperfections or defects. Data from these tests were used to estimate annual energy consumption and compare the home's performance to a code-equivalent reference home.

Blower Door Test

The PHRC team performed a blower door test on twelve homes over the course of the study. A blower door consists of an adjustable aluminum frame with canvas cover that is installed in an exterior door frame. A large fan (blower) is installed in an opening in the canvas. When the fan is turned on the home is either depressurized or pressurized (depending on the direction of the fan). A digital gauge measures the pressure difference between the interior and exterior of the home, and the volume of air moving through a sensor located on the fan. This information is used to estimate the air infiltration rate of the building envelope.

In this study the PHRC team used a Minneapolis Blower Door manufactured by the Energy Conservancy along with a DG-700 digital manometer. For each tested home, a multipoint depressurization test was performed per the Canadian standard *Determination of the Airtightness of Building Envelopes by the Fan Depressurization Method* (CAN/CSGB-149.10-M86) as permitted by ASHRAE Standard 119-1988 (RA 2004), *Air Leakage Performance for Detached Single-Family Residential Buildings*. Tests were performed with the basement door closed for homes with unconditioned basements and the basement door open for homes with conditioned basements (as determined by the presence or absence of supply registers).

Data were analyzed using the Energy Conservatory's TECHTITE 3.1 software. Air infiltration results that will be presented in this report include: cubic feet per minute at 50 Pascals (CFM_{50}), air changes per hour at 50 Pascals (ACH_{50}), CFM_{50}/square foot of conditioned floor area, the Canadian National Research Council's Equivalent Leakage Area (EqLA), Lawrence Berkley Lab's Effective Leakage Area (ELA), natural air changes per hour, and specific leakage area. An explanation of these terms is located in the Glossary on **pages 64 & 65** of this report.

Duct Blaster Test

The PHRC team performed ten duct leakage tests in this study using a duct blaster. A duct blaster is essentially a small blower door used for estimating duct leakage. All supply registers and return grilles are sealed off and a small fan is attached to either the blower cabinet of the air handler or to a central return grille. The fan is turned on to depressurize or pressurize the ducts while a gauge measures the duct pressure and air flow. This information is used to estimate the relative air leakage in a duct system.

A Minneapolis Duct Blaster system was used to conduct depressurization tests, including total duct leakage and duct leakage to outside the thermal envelope. For total duct leakage, a multipoint test was performed when high enough pressures could be reached. A minimum duct pressure of -25 Pa was attempted. Leakage to outside was measured using a single point depressurization test at -25 Pa. The blower door was also used for this test. For duct leakage to outside tests performed in an unconditioned basement, a door or window was opened in the basement to ensure that the basement was fully isolated from the conditioned space (from the standpoint of building pressure).

The Duct Blaster fan was usually installed at the air handler with duct pressure measured in the main supply trunk. If possible, the fan was installed at central return grille and duct pressure measured at a supply register located near the middle of the duct system.

Infrared Scans

Infrared scans were performed with a Monroe Heat-Find IR-HR infrared camera. These scans were performed to check for indications of thermal bridging and air infiltration. A scan of the interior of each house was made without the blower door on to inspect insulation integrity and again with the blower door on to visualize air leakage. This was done primarily as an educational tool for code officials so they could gain a new perspective on why many of the code requirements exist.

2.2.7 Reports to Technical Assistance Program Participants

Following each site visit to a municipality, COG, or third-party agency, the PHRC team produced a written report reviewing the site visit and offering recommendations. These individualized reports were mailed to the relevant code office for their review.

2.2.8 Comparison's with the 2003 IECC Performance Path Reference Home

For each home that was tested at final inspection a REM/Rate v 12.42 software simulation was performed to compare the home's likely performance with the 2003 IECC Standard Design as defined in section 402.2.1 in the code. The 2003 Standard Design was used because all of the homes tested in the study were built under the 2003 energy code.

Whole house infiltration inputs were based on the blower door tests described above. Duct leakage inputs were based on the duct blaster tests described above. In a few cases, default values in the software were used because the test pressure could not be reached or testing was technically infeasible. This will be discussed further in the Results section.

Other building characteristics input into REM/Rate such as conditioned floor area, volume of conditioned space, and floor, wall, ceiling and window areas were taken from building plans. Characteristics such as R- and U-values were taken from building plans, REM/Rate Compliance Certificates or other documentation provided by the builder. The PHRC team did not follow these homes throughout their construction so items like wall R-values and window and door U-factors could not be verified in the field. Since there is no specific window solar heat gain coefficient (SHGC) requirement for homes in Pennsylvania, there was no documentation of this value on any of the plans or other documentation. For this reason, the same value as the 2003 IECC Standard Design was used (0.68).

HVAC capacity and efficiency were determined by searching by model number in online databases. For air conditioning equipment, the Air-Conditioning and Refrigeration Institute's *ARI Unitary Directory of Certified Product Performance* was used. For gas appliances, the Gas Appliance Manufacturers Association (GAMA) *Consumers' Directory of Certified Equipment Ratings* was used. In rare instances, the model number could not be found and equipment capacities were estimated. In these cases, efficiencies were obtained from the equipment's EnergyGuide label or RES*check* Compliance Certificate.

Using REM/Rate software, a 2003 IECC Performance Report was created to compare the tested home with the Standard Design. A Building File Report was used to compare specific components of the tested home with the reference home.

3. Code Enforcement Findings

3.1 Study Bias

Before presenting the results of this study, it is important to discuss its inherent bias. Due to the voluntary nature of participant recruitment, there is a participation bias. Code offices motivated enough to respond to the PHRC's technical assistance program advertisements, and follow through with scheduling homes for site visits are more likely to care about energy code enforcement. Enforcement practices in these code offices are likely to be better than the average code office in Pennsylvania. Similarly, code offices with little interest in enforcing the energy code are not likely to participate in the technical assistance program. Therefore, it is quite possible that areas with lax energy code enforcement were not represented at all in this study.

The PHRC envisions three main groupings of code offices in Pennsylvania. One group is ill-informed of energy code requirements and/or takes little to no interest in enforcing provisions of the energy code. Another group is aware of the energy code requirements and does a fair job of energy code enforcement, but lacks the resources, knowledge, time or motivation to enforce the code to the fullest. The third group is highly knowledgeable about energy code requirements and does a thorough job of enforcement. The PHRC estimates that only code offices falling in the latter two groups participated in this study. Therefore, the level of energy code enforcement observed in this study may not be representative of the Commonwealth as a whole.

3.2 Participant Characteristics

The size and complexity of participating code offices varied widely. Code offices ranged from a one-person operation to major cities and third-party agencies with more than 15 employees in multiple divisions. General characteristics of code offices are listed in Table 3.1. All numbers are approximate.

Table 3.1: Participating code office characteristics

Code Office	Type	Approximate new, single family residential permits per year	Number of employees for residential	Average experience in code enforcement (years)	Number of code officials not ICC certified for energy	Plan Submittal Checklists		Plan Review Checklists		Inspection Checklists	
						General	Energy	General	Energy	General	Energy
1 [a]	City	60	6	8.5	0	Yes	No	NA	NA	No	No
2	City	60	2	10	0	No	No	No	No	No	No
3	3rd Party	300	>15	5	0	No	No	No	Yes	No	No
4	Township	250	2	11	0	Yes	No	No	No	No	RES
5	Township	250	2	1	0	No	No	No	No	No	No
6	3rd Party	300	8	6	1	Yes	No	No	No	No	No
7 [a]	City	20	2	5.5	2	NA	NA	NA	NA	No	No
8	3rd Party	200	2	2	0	No	No	Yes	No	Yes	Yes
9	Township	90	4	9	1	Yes	No	No	No	No	No
10	Township	40	3	2	1	Yes	No	No	No	No	No
11	City	>500	>15	<3	0	Yes	No	No	No	No	No
12	COG	200	4	5	0	Yes	Yes	No	Yes	No	No

a. All plan reviews performed by a third party agency

3.3 Plan Review

3.3.1 Plan Submittal Requirements

The first step toward ensuring energy code compliance is getting all of the necessary information from applicants prior to plan review. Under the UCC, a code official can require any information that s/he deems necessary to determine if a proposed home is in compliance. The 2006 IECC specifically outlines a few energy-related items that should be required on construction documents. IECC section 104.2 states, "Details shall include, but are not limited to, insulation materials and their R-values; fenestration U-factors and SHGCs; system and equipment efficiencies, types, sizes and controls; duct sealing, insulation and location; and air sealing details."

Most code offices had some type of plan submittal requirements. These requirements had varying levels of detail, but for the most part were quite general with minimal, if any, energy-specific items.

Code offices should work to create or improve plan submittal checklists or forms to be filled out by permit applicants. Permit application materials provide the first opportunity to communicate code requirements to builders. Given a frequent lack of understanding of code requirements by builders, it is typically up to the code officials to educate them about the code. A thorough list of document submittal requirements (including both energy-related and non-energy items) will save plan reviewers time if the submittal requirements are enforced. Applicants should be required to submit or identify the following energy-related items in application materials:

- Code year (and verification of signed contract if not using the latest code year)
- Energy code compliance path (IRC chapter 11 prescriptive, IECC prescriptive, PA Alternative, RES*check*, other)
- Trade-off taken (PA-Alt only: A, B, C)
- Conditioned floor area (square feet)
- Will basement be conditioned? (yes/no)
- Full cross-sectional drawings of each different area to be constructed (showing insulation placement and R-values)
- Wall sections
- Side, front, and rear elevations with proposed finished grading
- Slab details (showing thermal break for slabs associated with conditioned spaces that have a floor surface < 12″ below grade)
- Door and window schedules (U-factors, SHGCs, size - including rough opening dimensions)
- Stairwell insulation details (stairs to/from unconditioned basements only)
- Duct location and R-value (including panned returns)
- Recessed lighting fixture type (ASTM E 283 or other)
- HVAC type and fuel
- HVAC equipment efficiency of each unit to be installed (PA-Alt and RES*check* only)
- Heating and cooling load calculations

Recommendation 1: Code office administrators should create a plan submittal requirement checklist containing the above energy-related items (in addition to other non-energy items) and enforce the submission of these items.

3.3.2 Compliance Paths

There are various ways a builder can meet the energy code. These different methods are known as compliance paths. The main compliance paths are IRC chapter 11 (prescriptive), IECC (prescriptive), UA Alternative/limited-scope performance (RES*check*), Simulated Performance Alternative, and the Pennsylvania Alternative Energy Provisions (PA-Alt). Knowing the compliance path is important for a plan reviewer to determine if insulation and window specifications, as well as proposed equipment efficiencies, are acceptable. This will also save plan reviewers time, as they will not have to spend time trying to "fit" application to one compliance path or another.

Most code offices required builders to specify a compliance path, but this information was frequently not shown on the plans. In most cases this was not a highly important issue, because RES*check* was used by almost every applicant. With RES*check*, a RES*check* Compliance Certificate is submitted and the compliance path is self-evident. However, RES*check* was not the chosen compliance path in all cases.

In some cases, code offices routinely accepted applications that did not specify an energy code compliance path. When a compliance path was not submitted, code offices typically assigned the applicant a prescriptive path. In 2003 and earlier versions of the code the window-to-wall ratio determined which prescriptive insulation package should be used. Code offices that assigned prescriptive packages did so without regard for the proposed window-to-wall ratio of homes for which applicants sought approval. In some cases this would have led to overly restrictive insulation packages, and in other cases non-compliance. In 2006, window-to-wall ratios do not affect which prescriptive insulation package is chosen, since there is only one prescriptive package for all homes regardless of window area.

Regardless of the compliance path chosen, the plan review process can be made more efficient if the compliance path is specified on the plans every time. This way fewer applications will need to be returned, and/or fewer change notices issued, if prescriptive values are not met. In addition, the plan reviewer will know whether to look for prescriptive R-values on the plans, or if reduced R-values are acceptable per the PA-Alt, RES*check*, or other documentation.

3.3.3 Equipment Sizing

Proper equipment sizing is important for providing occupant comfort and efficient operation of HVAC equipment. In 2003, proper HVAC system sizing was required by the 2003 IECC section 503.3 and IRC chapter 14, section M1401.3. The same requirements exist in the 2006 IECC and IRC in IECC section 403.6 and IRC section M1401.3.

Only a few code offices required any type of equipment sizing documentation. None of the code offices requiring equipment sizing documentation appeared to do a meaningful review of that documentation. When code officials did receive equipment sizing documentation, they were typically only concerned with under-sizing of equipment, not over-sizing. In fact, one group estimated that about 40% of the Manual J calculations they receive included an unconditioned basement as conditioned space. In addition, none of the offices verified equipment sizes in the field.

Due to the importance of equipment sizing for efficient HVAC equipment operation and occupant comfort, code officials should consider requiring and learning to perform a quick, but meaningful review of load calculations. This can be accomplished by verifying the correct design temperatures for the climate are used (found in Manual J) and that the R-values and U-factors match those specified on the plans. Checking to make sure a conditioned basement is not included in the calculations, when an unconditioned basement is specified on the plans, will help prevent over-sizing.

3.3.4 Code Year

With code requirements in Pennsylvania changing every three years, it is important that permit applicants and plan reviewers are operating under the correct code year. The majority of the code officials interviewed, appeared to be checking for the code year on the plans and/or RES*check* documentation. However, several code offices did not appear to routinely check that the code is correct. There was also some confusion about which code year is applicable in which circumstances. Approval of plans based on an outdated code was observed more than once during this study. Plan reviewers did not always verify that the code year used in RES*check* was the same as on the plans.

Recommendation 2: Plan reviewers should verify that the code year is the most recent code year. If it is not, they should look for verification that the builder had a contract in place prior the adoption of the latest code version.

3.3.5 Identifying the thermal envelope

The 2006 IRC and IECC define the "building thermal envelope" as "The basement walls, exterior walls, floor, roof, and any other building elements that enclose the conditioned space. This boundary also includes the boundary between conditioned space and any exempt or unconditioned space." Generally, this means that the thermal envelope is the boundary between areas that are heated and/or cooled and the outside, an unconditioned basement, or attic space. The components that make up the thermal envelope should create a continuous boundary of insulation and air barrier materials. This continuous boundary will eliminate thermal bridges that result in heat loss during the winter and heat gain during the summer.

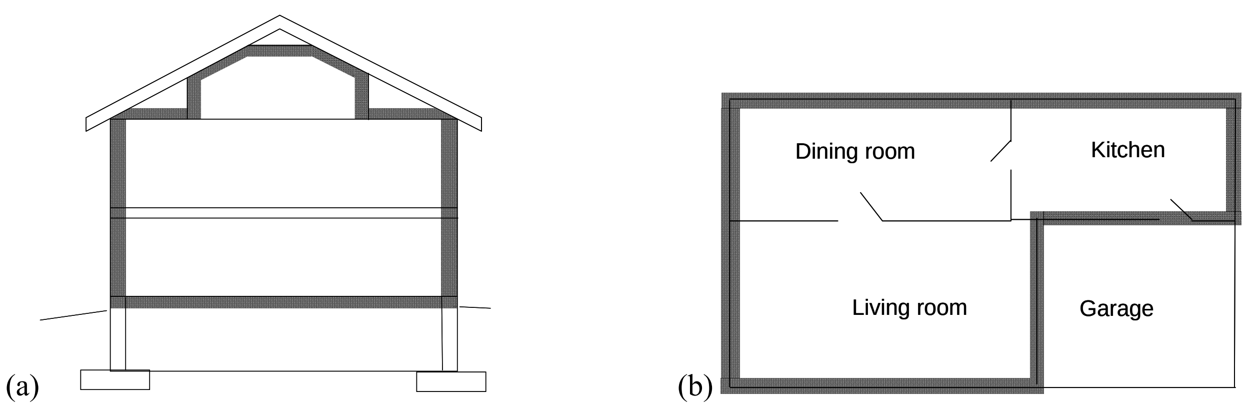


Figure 3.1: Building plans with the thermal envelope highlighted in gray for cross section and floor plan views.

Plan reviewers should identify and mark the thermal envelope to ensure all insulation requirements are met, and to guide inspectors.

It is important for plan reviewers to identify the thermal envelope to make sure that it is continuous and insulation (with the required R-values) is specified in all of the required components. This will reduce the potential for the omission or discontinuity of the thermal envelope upon construction. If the thermal envelope is identified on the plans by the plan reviewer, inspectors will have a guide to follow as they perform their insulation inspections.

Plan reviewers in this study typically did not identify the thermal envelope on the plans. Typical cross-sections or REScheck Compliance Certificates were usually considered to be sufficient documentation of thermal envelope characteristics. Identifying the thermal envelope would consist of identifying (and perhaps highlighting) all building components that separate conditioned spaces from unconditioned spaces or the outside. It is important to ensure that these components create a continuous boundary. Figure 3.1 above shows a cross-section and plan view of a home with the thermal envelope identified.

One issue relating to identifying the thermal envelope is determining whether the basement will be conditioned or unconditioned space. Plan reviewers typically did not make an effort to determine if the proposed home's basement was conditioned or unconditioned. In the 2006 IECC, the presence of a heating or cooling supply, uninsulated ducts or fixed opening to an unconditioned space defines a basement conditioned. This information is necessary for a plan reviewer to assess whether REScheck inputs are correct and whether insulation specifications on the plans are acceptable. When a basement is conditioned, the proposed grading level of the soil determines the required R-value of the basement wall. For these applications plan reviewers did not typically look at grading.

Boundaries between conditioned and unconditioned portions of basements were commonly not identified. Problems with thermal envelope continuity in basement were seen in the field. (This is discussed further in the Insulation Inspection section of this report.) It also appears to be fairly common for plan reviewers to fail to identify the need to insulate above-grade portions of slabs associated with conditioned "walk-out" basements.

In addition to these big picture issues, there are details relating to thermal envelope continuity that can have a large impact on home energy performance. For example, when the issue of slab insulation came up during this project, most code officials were unaware of the proper way(s) to install slab insulation. The biggest misunderstanding lies in the fact that slab insulation must provide a thermal break between the slab and the footer. Without this thermal break there is an uninsulated pathway for heat to travel from the slab to the outside. This will result in a cold slab, increased energy consumption and reduced occupant comfort.

Section 502.2.1.4 of the 2003 IECC and section 402.2.7 of the 2006 IECC both state that slab insulation must extend downward from the top of the slab, thus achieving a thermal break. The PA-Alt also has this requirement, but a ½″ thermal break is acceptable rather than the two inches that would be required to achieve the full required R-value. This detail is not usually shown on plans thus leaving the plan reviewer no way to help ensure that the slab insulation will be installed properly.

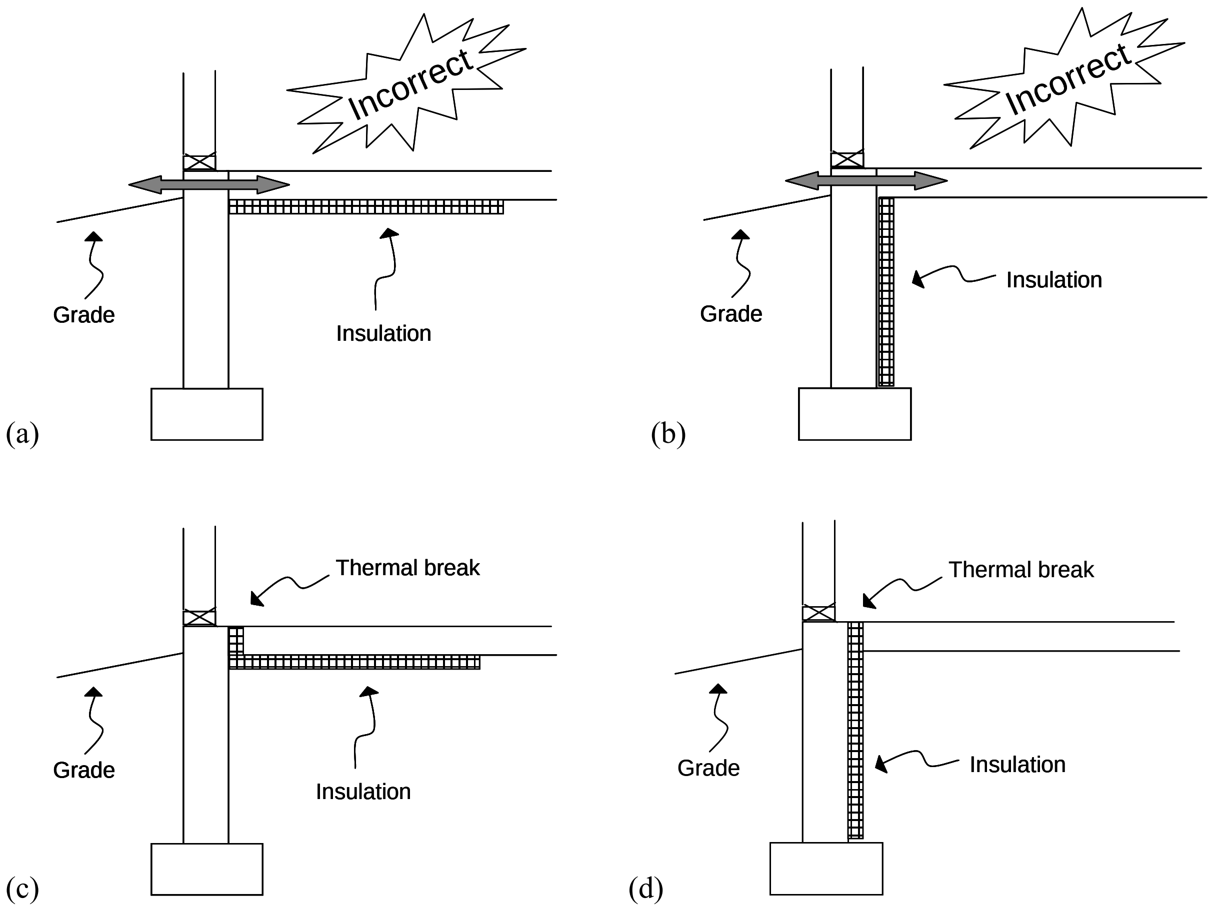


Figure 3.2: Slab insulation details

Drawings (a) and (b) depict improper installation of slab installation. These details do not contain a thermal break between the slab and the footer leading to energy loss and a cold slab (in winter). Drawings (c) and (d) depict proper installation of slab insulation as the insulation extends downward from the top of the slab creating a thermal break. To reduce problems with flooring installation, the IRC and IECC allow the top of the insulation to be cut at a 45° angle away from the wall. The PA-Alt allows for a ½″ thermal break instead of the full required R-value. Insulation may also be placed on the exterior of the foundation, but must still extend from the top of the slab. Slab insulation is not required in jurisdictions designated by the code official as having heavy termite infestation.

Another issue that came up during discussions with code officials was whether or not it is acceptable to insulate a foundation wall on the inside for the above-grade portion of the wall and on the exterior of the wall for below-grade portions. While the PHRC team did not witness this during this project, discussions with code officials indicate that the practice is common in some areas of the Commonwealth. Discontinuous foundation wall insulation leads to a direct conductive pathway from the inside to the outside resulting in significant heat loss during the heating season.

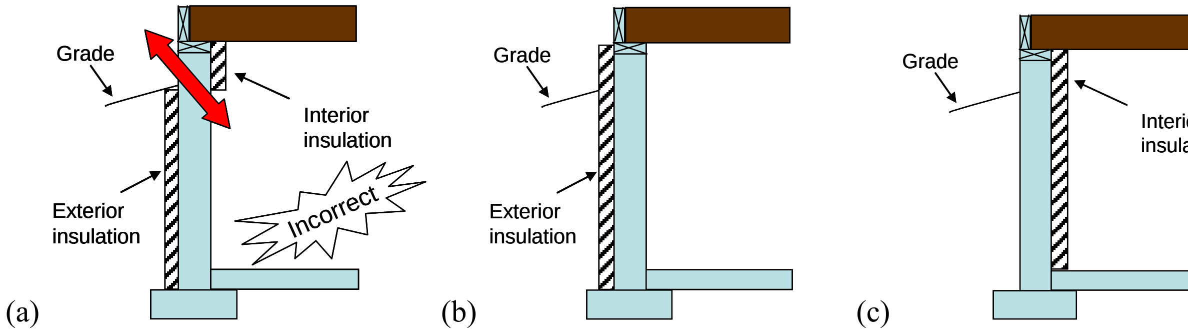


Figure 3.3: Thermal bridging due to improper installation of basement wall insulation and two methods of proper installation.

One of the first things a plan reviewer should do from an energy standpoint is to identify the thermal envelope of the building. In doing this, the plan reviewer will identify all of the building components (floors, ceilings/roofs, above-grade walls, basement walls, windows, and doors) and verify that specified insulation values are adequate and match other submitted documentation (e.g. RES*check*). If adequate detail is provided, the plan reviewer should also check for slab thermal breaks, basement wall insulation on the exterior *or* interior (not a discontinuous combination of both), and other architectural details such as eaves that commonly interrupt insulation continuity.

> **Recommendation 3:** Plan reviewers should identify and mark the building thermal envelope on the plans for each area to be constructed ensuring that it is continuous. Also, check for continuity of insulation in slabs, foundation walls, stairwells and other architectural details where applicable.

3.3.6 HVAC Equipment Efficiencies

HVAC equipment efficiencies are regulated by the federal National Appliance Energy Conservation Act (NAECA). Thus, except for in limited circumstances, HVAC equipment efficiency is not a concern for code officials. However, code officials should be aware of the circumstances in which HVAC efficiency is a regulatory issue under their jurisdiction.

When RES*check*, the Simulated Performance Alternative, or a PA Alternative tradeoff is used as a compliance method, HVAC equipment efficiencies are a matter of concern for code officials. RES*check* and Simulated Performance Alternative applications should come with compliance certificates that indicate the required HVAC efficiencies (unless a home passes even when using the federal minimum efficiency). However, if a builder is using PA-Alt equipment efficiency tradeoffs, there is no compliance certificate and the plan reviewer should look for documentation that the proposed equipment efficiency meets the required minimum efficiency, and/or note to inspectors what minimum efficiency is required.

In addition, the presence of multiple HVAC systems has ramifications for energy code compliance when RES*check* or PA-Alt equipment efficiency trade-offs are used. In 2003 versions of RES*check*, the least efficient equipment entered into the software would be used to determine compliance. This could result in problems if a plan reviewer failed to identify the presence of a second HVAC system. For example, conscious or unconscious cheating could occur if a builder proposed to use a 92 AFUE furnace in the basement and an 80 AFUE in the attic and only the 92 AFUE furnace was entered into RES*check*. Therefore, if a plan reviewer did not notice the less efficient furnace s/he would approve an application that would likely fail REScheck if proper inputs were made.

In addition, 2006 versions of RES*check* do not allow for multiple HVAC systems to be used (unless the home passes based on proposed R-values and U-factors (UA calculation) instead of the new "limited scope performance calculation"). A limitation of the RES*check* performance calculation restricts the software from being able to model multiple heating/cooling zones

In both 2003 and 2006 versions of the PA-Alt, a capacity-weighted average calculation is necessary if an applicant chooses one of the equipment efficiency trade-offs. A capacity-weighted average can be calculated using the following equation:

$$\text{Capacity-weighted average} = \frac{(\text{Efficiency}_1 \text{ x Capacity}_1) + (\text{Efficiency}_2 \text{ x Capacity}_2)}{(\text{Capacity}_1 + \text{Capacity}_2)}$$

Plan reviewers involved in this study generally did not appear to routinely identify secondary HVAC systems. They were also generally unaware of how RES*check* dealt/deals with multiple HVAC systems.

If two or more HVAC systems are specified, the home must either pass RES*check* based on the UA calculation (no HVAC equipment inputs), or use a different compliance path. Because of the reduced benefit to builders from low window areas and high HVAC efficiencies when using a post-2006 version of RES*check*, it is likely that many builders will turn to alternate compliance paths. It is also likely that builders in Climate Zone 5 (most of Pennsylvania) will not be able to reduce wall insulation below R-19 (or R-13 +5) through RES*check*. The reductions in ceiling R-values and increases in window U-factors that appear to have been common in Pennsylvania in 2003 will also be more difficult to achieve through RES*check*.

Thus, code officials should review plans with an eye for multiple HVAC systems. In addition, they should begin to familiarize themselves with compliance paths that can give builders more flexibility than prescriptive paths or the latest version of RES*check*. These paths include the PA-Alt with equipment efficiency trade-offs and the Simulated Performance Alternative (performance path) described in section 404 of the IECC.

Code officials should also familiarize themselves with which software tools are acceptable. The IRC and IECC leave it up to code officials to decide which software tools are acceptable. However, the non-profit Residential Energy Services Network (RESNET) tests software tools that are submitted and has compiled a National Registry of Accredited IECC Performance Verification Software Tools. As of this writing, EnergyGuage USA Version 2.6 and REM/Rate REM/Design v12.4 are the only two software programs listed in this registry. The most current list of accredited software programs can be found at:

http://www.resnet.us/programs/iecc_software/directory.aspx.

Recommendation 4: Plan reviewers should identify the presence of multiple HVAC systems and be aware of the ramifications for the use of RES*check* and PA-Alt tradeoffs.

3.3.7 RES*check*

Most code offices did very little with respect to reviewing RES*check* submissions for accuracy. The PHRC team identified several problems resulting from improper inputs into RES*check* software. Most of the approved RES*check* applications had missing components, inaccurate areas, or other discrepancies.

In a few instances, it did not appear that plan reviewers ensured that applicants were using the correct code year or latest version of RES*check* as is required by the code. Since RES*check* allows for the user to select the code year, it is especially important to verify that the correct code year is being used. At the same time, plan reviewers should check to see if the software version is the latest available. These two items (code year especially) can have a profound impact on the energy code compliance of a home.

Recommendation 5: Plan reviewers should review RES*check* Compliance Certificates by starting at the top and verifying that the location, code year, and software version are correct.

One major problem with RES*check* Compliance Certificates was missing building components (eg. floors, ceilings, walls). Omitting an entire building component can have large impacts on whether a proposed design will actually be compliant with the energy code. Doors and floors were the most commonly omitted items. Doors leading from conditioned space to unconditioned basement stairwells and doors from conditioned space to garages were frequently missed.

Floor components that were frequently not listed on RES*check* compliance documentation were floors over outside air (bump-outs and cantilevers) and floors over garages. Several approved RES*check* applications were missing one or more floor components. One of these also did not list a ceiling of any kind. These components affect a home's energy performance, and depending on the insulation values that are intended to be installed, they could affect whether a proposed home passes or fails RES*check*. In addition, items not listed on a RES*check* Compliance Certificate will not appear on the inspection checklist that is automatically generated by the software.

The latest version of RES*check* helps prevent missing components by refusing to calculate compliance when a ceiling/roof assembly is not specified, or if no floor or basement wall is specified. The report will note a missing component instead of whether the home passes or fails. However, it is still possible that not all doors, floors, roofs/ceilings, or basement walls specified on the plans are input into RES*check*. Plan reviewers should pay special attention to identifying the number of doors that are in the thermal envelope, the presence of cantilevered floors and floors over garages, and roof/ceiling and basement assemblies that differ from the main portions of these assemblies.

Recommendation 6: When identifying the thermal envelope, plan reviewers should note each different component in the thermal envelope and verify that all of those components are present on the RES*check* Compliance Certificate. Particular attention should be paid to floors over garages, cantilevered floors and doors to unconditioned spaces.

Inaccurate area inputs into RES*check* were also found to be problematic. Half of the approved RES*check* applications had areas that were inaccurate by greater than 20%. Several of these underrepresented window area by one-third to two-thirds. Window areas were very important under the 2003 IECC as insulation R-value stringency was based on the window-to-wall ratio. Underrepresentation of window areas would artificially decrease insulation requirements in RES*check* software. Window areas are probably less important with the 2006 energy code, however they are still important. Windows are one of the largest areas of heat loss in a home, and the latest version of RES*check* software does a home performance calculation that accounts this fact.

Plan reviewers should do quick reviews of RES*check* Compliance Certificates to make sure that listed component areas seem reasonable. A few quick initial checks could determine whether a more detailed review is warranted. One quick check could be verifying that insulated floor and ceiling areas are similar (ceiling area slightly larger for vaulted ceilings). In addition, a very low glazing area percentage (below 10%) is reason for a more thorough review. After reviewing the areas of several RES*check* certificates, a plan reviewer should get an idea of what areas are reasonable given a certain square footage of conditioned floor area. Performing take-offs from plans and calculating component areas several times would help plan reviewers more accurately “eyeball” RES*check* certificates in the future.

Recommendation 7: Plan reviewers should perform a few quick checks of component areas to determine if they seem reasonable, or if a more detailed review is warranted. Typically, floor and ceiling areas should be roughly the same and glazing percentages above 10%.

3.4 Inspections

Inspections are necessary to verify that homes are built to the specifications of the approved plans. It is fairly easy to include energy-related inspection items along with other regularly scheduled inspections. The only inspection that requires an additional trip, is an insulation inspection (which is not a required inspection).

Observations during this study revealed a general disconnect between plan reviews and inspections. None of the inspectors appeared to routinely use building plans while performing an inspection. In most cases plans were not located on site despite the requirement in the code and of most code offices. Thus, it appears that the requirement to have plans on site is frequently not enforced.

A minority of code offices appeared to use the RES*check* Inspection Checklist, or other checklist. Many inspectors had some kind of strategy for maintaining consistency such as starting in the basement and working their way up, or walking in a counter-clockwise of clockwise direction during inspections. Some inspectors said that they see little variation from home to home so they did not feel the use of a checklist is necessary. Others appeared to inspect for IRC prescriptive values regardless of the compliance path chosen.

3.4.1 Slab Inspections

The PHRC team did not accompany any code officials on slab or foundation inspections. However, discussions with code officials indicated that even when there is a slab inspection, there is typically no inspection of slab insulation. Inspectors and plan reviewers do not appear to be looking for a thermal break between the slab and the footer. It appears to be common construction practice to pour a slab such that it rests directly on the footer. Heat loss issues aside, most slabs are designed to be floating slabs. Contact between the slab and the footer could lead to cracking of the slab.

A thermal break between the slab and the footer is required by the energy code to eliminate a thermal bypass from the slab to the outside. Inspectors should look for insulation extending downward from the top of the slab for the depth of the slab and then continue downward or extend horizontally to achieve a cumulative distance of 2′ in climate zones 4 (south) and 5 (central) and 4′ in zone 6 (north). The top of the insulation should be visible around the perimeter of the slab after it has been poured.

Recommendation 8: Code offices should consider inspecting for properly installed slab insulation. Slab insulation should be required to extend downward from the top of the slab. Builders should be made aware of this requirement at plan review.

3.4.2 Rough Framing Inspections

While there are several energy-related items that could be inspected at rough framing inspections, most code officials interviewed informed the PHRC team that they look for few, if any, energy-related items at rough framing.

Comparison with Plans

One of the most basic items that inspectors could perform is a comparison of the home with the approved plans. None of the inspectors verified that the home matched the plans. To verify that a home matches the plans an inspector can make a comparison of a home's actual elevations with elevations on the plans. Windows and grading are two potentially important items.

In two instances there were windows on the actual home that were not present on the plans. Increased window area could cause a home that previously passed RES*check* to fail when the additional window area is input. From an energy code compliance perspective this issue is not important when using the PA-Alt, as long as the NFRC labels are checked for the required U-factor. However, there may be structural considerations resulting from adding windows that should be identified during the inspection process.

Few inspectors appeared to routinely pay attention to grading. From an energy perspective, grading is only an important consideration when dealing with conditioned basements. In one instance grading was such that two walls insulated as basement walls should actually have been classified as above-grade walls. This also had ramifications for where slab insulation was required. The rear elevation, as well as portions of the left and right elevations, required slab insulation because they were less than 12″ below grade as they approached the walk-out portion of the basement on the rear elevation. It is unknown whether or where slab installation was installed. There was no slab insulation specified on the plans.

Recommendation 9: Inspectors should compare elevations on the approved building plans with the actual home at rough framing. Particular attention should be paid to unspecified fenestration and grading that influences whether a wall will be above or below grade.

Air Sealing

Air leakage accounts for 20-50% of the energy usage of a typically new home. Air sealing of the thermal envelope is an important energy item that should be inspected. This is most easily done during rough framing inspections. According to a few builders (who went along on inspections), and several code officials, it is fairly common for builders to purchase an air sealing package from an insulation contractor. In this case the air sealing would not be done until after the rough framing inspection, and air sealing details would need to be inspected at another time.

There were a few air sealing locations that most inspectors required. While sealing of all seams in sheathing was generally not required, many inspectors did require the sealing of large, easily visible gaps. It appears that most inspectors view housewraps as acceptable with regard to sealing the building shell. Indeed, the popular DuPont™ Tyvek® Homewrap® is considered an air infiltration barrier in the ICC ES Legacy Report 98-46. However, this air infiltration barrier designation depends on the product being installed as an air barrier according to manufacturer's instructions.

The installation guidelines for Tyvek Water-Resistive Barriers state that:

For maximum air leakage reduction (when installing as an air barrier), seal wrap at the bottom of the wall with caulk, DuPont Tyvek Wrap Caps (nails, screws, staples). Wide staples with a 1.0 inch maximum crown can also be used… All vertical seams shall be taped with DuPont Tyvek Tape – For maximum air penetration resistance (when installing as an air barrier) all horizontal seams shall also be taped.

House wrap was typically not an inspection item for code officials, and none of the inspectors checked for the details necessary to qualify the house wrap as an air infiltration barrier.

Nearly all homes visited during this project had some type of house wrap installed. However, based on visual inspections, the guidelines for installation as an air barrier described above were not followed. House wrap was often affixed with ordinary staples, all seams were not taped, and in some cases there was incomplete coverage of the sheathing. The ICC ES Legacy Reports for two other brands of house wrap observed in this study (Typar® and Barricade®) do not list these products as air infiltration barriers.

> **Recommendation 10:** Inspectors should check for the sealing of seams in sheathing, or for house wrap installed to the manufacturer's instructions for installation as an air barrier.

Inspectors typically did a fairly thorough job checking for sealing of penetrations to the exterior. Other air sealing details such as plumbing and electrical penetrations in the interior were also inspected, primarily for fireblocking reasons. Many inspectors also looked for sill sealing, usually in the form of a foam gasket, where the sill plate meets the foundation. Also, nearly all outlets on exterior walls had observable air leakage (via infrared thermography). Inspectors should consider checking for outlet gaskets at final inspection, or foaming of the back side of the outlet box during rough framing.

Only one townhouse was visited during the rough framing phase. This home was found to have a major air sealing deficiency. This problem was located along the shaft wall between two units, where there was an approximately one inch gap running the entire length of the shaft wall at all locations where floors/ceilings abutted the shaft wall. From an energy efficiency perspective this is a very significant source of heat loss via warm air rising through the house and into the attic. This could also create building durability problems as warm, moist air condenses on cold surfaces in the attic. In addition, this is a required fire blocking area as a significant fire hazard is created with an open conduit for fire to move between all floors of the structure.

None of the inspectors observed in this project required caulking where the parallel sides of 2x4s or 2x6s abut in areas like top plates, bottom plates, corners, and jack studs. Sealing between studs and sheathing was also not required. Only one house contained thorough air sealing details such as these.

It is recommended that inspectors discuss with builders or superintendents about sealing these areas as well as other places in the thermal envelope where 2x4s or 2x6s abut. Builders enrolled in energy efficiency programs typically perform this type of air sealing. This may be beyond what should be required under a code that sets minimum requirements. In addition, builders should take care that mechanical ventilation is provided to avoid moisture build-up in very tight homes.

Cracks around window frames were typically stuffed with fiberglass insulation as an air sealing method. While this is considered an acceptable method of sealing in ASTM E 2112, it is frequently difficult to achieve an effective air seal without resulting in with operability problems. In fact, some window manufacturers' installation instructions require the use of a low expansion foam sealant to better control air infiltration. Several code officials and superintendents expressed concern about impeding window operability with foam sealants. Proper installation of windows and use of low expansion spray foams according to manufacturers' instructions will eliminate this problem.

The IRC requires window manufacturers to provide installation instructions along with each window. Typically these instructions are adhered directly to the window. The manufacturer's installation instructions, and/or ASTM E 2221-07 guidelines, should be followed carefully by the installer, and proper installation should be verified by inspectors.

Recommendation 11: Inspectors should review window manufacturers' installation instructions to ensure proper installation, as well as proper air sealing of the gap between the window and the rough opening on the interior side of the home. They should then verify that it is done properly, which may require the use of a low expansion spray foam sealant.

Another important source of air leakage can occur when unsealed recessed lights penetrate the thermal envelope. The vast majority of inspectors made it a point to check for the ASTM E 283 label for airtightness on recessed light housings. The PHRC team did not find any recessed light housings that did not possess the ASTM E 283 label.

The energy code requires sealing, with air barrier materials, of several specific areas including knee walls, and behind tubs and showers on exterior walls. In the code it is not clear whether this means there should be an air barrier on the *exterior* side of knee walls or the *interior* side of walls behind tubs and showers. From a building science standpoint, insulation in these locations (and in bump-out fireplaces) should be encapsulated on all six sides. Code officials do not appear to be requiring air barriers in these locations, and typically builders do not appear to be installing them in the field.

Air barriers were not typically installed such that fireplace, tub/shower, and knee wall insulation was encapsulated on all six sides. Code language is somewhat ambiguous on this subject. Building science research has demonstrated that leaving one or more sides of vertical insulation exposed to free airflow significantly reduces its R-value[4]. This process is sometimes referred to as "wind washing" of insulation. For knee walls associated with rooms over unconditioned spaces, (e.g. bonus room over garage), the exterior air barrier should extend downward to the bottom of the floor joists to prevent wind washing of the floor insulation.

Recommendation 12: Code officials should discuss with builders the issue of insulation wind washing and encourage them to install some form of air barrier on the backs of knee walls, and interior portions of fireplaces and tubs/showers where insulation is left exposed. Plan reviewers should discuss these issues with builders at plan review.

There was one instance in which there was not adequate stud bay depth to accommodate the required level of insulation. This occurred in an attic knee wall. Code offices that do not perform separate insulation inspections could quickly check stud bay depths as a technique to gauge whether the proper R-value will be installed. This is particularly important for walls between conditioned space and garages and knee walls because 2x4 studs are commonly used in those areas. In most of Pennsylvania R-19 is required in above-grade exterior walls under prescriptive paths. Inspectors could check for 2x6 walls or foam sheathing on the backs of 2x4 walls to help ensure the required R-value is installed.

Recommendation 13: In code offices where stand-alone, pre-drywall insulation inspections are not performed, inspector should make sure that stud bay depths are adequate to accommodate the require insulation R-value or that foam sheathing is present. Particular attention should be paid to knee walls.

A final air sealing detail that is very important is peculiar to townhouses. As mentioned earlier, one shaft wall inspected by the PHRC team did not contain any type of blocking between floors to prevent conditioned air (and fire) from moving from floor to floor and into the attic. Discussions with code officials indicate that this is likely common across Pennsylvania. Inspectors should look for blocking along shaft walls between all floors and between the top floor and the attic. This is a very important inspection item for energy, building durability and fire safety reasons.

Recommendation 14: Inspectors should check for blocking along shaft walls in townhouses in every location where these walls intersect with floors and ceilings.

NFRC Labels

Another important inspection item is the window U-factor. NFRC labels were usually checked by inspectors, but not always. Some inspectors said that they never check NFRC labels and others paid only cursory attention to them. Since inspectors rarely used the RES*check* inspection checklist they usually looked for the IRC prescriptive U-factor on the NFRC labels. As a result it is possible that windows that sometimes, or even frequently, do not meet what is required to pass RES*check*. NFRC labels were not present in two homes visited by the PHRC team.

NFRC labels are the only reliable way for inspectors to verify window U-factors in the field. Inspectors should check for these labels in all cases and verify that U-factors match what was specified on the

[4] Powell, F., M. Krarti, and A. Tuluca. 1989. Air movement influence on the effective thermal resistance of porous insulations: A literature survey. *Journal of Thermal Insulation* 12:239-251.

approved plans. Inspecting for prescriptive values will not be effective because higher or lower U-factors may be used if RES*check* was used as the compliance method. If window U-factors are not regularly verified, an unscrupulous builder could input window U-factors into RES*check* that are lower than what s/he intends to install. This could bring a home into noncompliance with the energy code.

For homes that comply with the energy code via 2006 versions of RES*check*, inspectors would also have to verify the window SHGC. RES*check* now requires SHGCs since it contains a performance approach.

Ducts

Despite being responsible for an estimated 25% of the total energy consumption for heating in the sample homes, code officials appeared to pay minimal attention to duct sealing, connections or air flow restrictions. Most code officials do not appear to be aware of the negative impacts of leaky duct systems. They also do not appear to be well-versed in the proper installation techniques for the various duct systems used.

The PHRC team did not accompany any inspectors on mechanical inspections. However, some inspection of duct work can be performed at rough framing inspections. Key items to inspect include duct insulation, connections, sealing, support and sizing.

The 2006 energy code states that, “All ducts, air handlers, filter boxes, and building cavities used as return ducts shall be sealed.” The duct systems section in IRC Chapter 16, also states that “Joints of duct systems shall be made substantially airtight.” While these requirements are somewhat subjective, it does not appear that it is common to attempt to enforce them.

Inspectors did look for UL 181 rated tape on some lateral seams, but did not appear to be very thorough. Connections between duct runs and trunk lines or plenums were typically not sealed.

The PHRC team did not comprehensively inspect for proper duct connections for connections that were covered with insulation and a vapor retarder. However, in some cases vapor retarders on flexible duct were observed to be attached improperly without the use of tape or clamps. This can result in condensation and water-logging of insulation during the cooling season. Also, in some cases, connections of ducts to fiberglass plenums were observed not to be mechanically fastened. Improperly installed and/or unsealed duct connections can constitute a major home performance deficiency.

The use of tapes was found to be far more common than mastic, a resin-based sealant. The shape of many joints and connections are such that achieving a good seal with tape is extremely difficult. In addition, there is no UL rating for tape used on sheet metal ducts. The closest rating is UL 181B for attaching flex duct to a metal collar.[5] The code (IRC section M1601.3.1) only mentions air sealing (closure systems) for rigid fibrous glass ducts and flexible ducts, and does not explicitly approve or disapprove of any tape for use on sheet metal ducts. The only Air-Conditioning Contractors of America (ACCA)-approved method for duct sealing is with mastic.

[5] Energy Design Update, Volume 23, No. 4, Aspen Publishers, Inc., April 2003

In addition, metal ducts ideally should be cleaned with soap and water to remove fabrication oils prior to application of tapes (and mastics). This is not typical practice among HVAC contractors, and it is suspected that it is rarely, if ever, performed.

Potential Consequences of Duct Leakage

There are a variety of potential consequences of duct leakage including the loss of heated or cooled air to the outside, increased building infiltration, decreased HVAC equipment efficiencies, impaired indoor air quality, building damage, and compromised occupant safety. The presence and severity of these problems will vary from house to house. They will also vary based on differing conditions at different times in the same house. The common practice in Pennsylvania of having a return in each room increases the duct length and area. This probably results in significantly more duct leakage than in homes with one or two central returns.

Several studies have concluded that duct systems are typically responsible for a significant amount of energy loss. The results of two studies on a large number of homes in the Pacific Northwest suggest that electrically heated homes with forced-air distribution systems consume 13-40% more energy for space heating than their counterparts with electric resistance heating.[6,7] These and other studies also estimate that annual building envelope infiltration is increased 22-70% as a result of duct leakage.[6,7,8]

The most important duct leakage is leakage to, or from, outside of the thermal envelope. Leakage to the outside can be broken up into supply leakage and return leakage. There are two main consequences of supply leaks to an unconditioned space such as an attic, vented crawl space or unconditioned basement. The most obvious consequence is the loss of heated or cooled air to the outside, resulting in direct energy loss. A less obvious consequence is a result of unbalanced air flows. If less air is being delivered to the conditioned space, as a result of supply leakage, than is leaving via returns, the conditioned space is depressurized. This leads to increased building infiltration and results in energy loss and possibly comfort problems.

Return leaks in unconditioned spaces also have potentially serious consequences. First, excessive return leaks in an unconditioned space cause the conditioned space to be pressurized, thereby increasing air exfiltration in the building envelope. A second result of leaky return ducts in unconditioned spaces is that they draw unconditioned air into the distribution system putting an increased load on HVAC equipment. This increased load can significantly reduce equipment efficiency.

Also, as return leaks draw air in from unconditioned basements, they depressurize that space drawing more air in from the outside and potentially backdrafting open combustion appliances located in the basement. This can be extremely hazardous to building occupants as they are exposed to poisonous carbon monoxide fumes. In addition, there is the potential for indoor air quality problems as radon, moisture, mildew, dust and other potential air contaminates are sucked into the return ducts and

[6] Parker, D.S., Evidence of Increased Levels of Space Heat Consumption and Air Leakage Associated with Forced Air Heating Systems in Houses in the Pacific Northwest, *ASHRAE Transactions* 95, 1989 (2).
[7] Lambert, L.A., Robison, P.E., Effects of ducted forced-air heating systems on residential air leakage and heating energy use, *ASHRAE Transactions*, 1989.
[8] Modera, M.P., Residential duct system leakage: magnitude, impacts, and potential reduction, *ASHRAE Transactions*, 1989.

distributed throughout the house by the air handler. A typical air filter is capable of filtering out only a portion of these contaminants (or none in the case of radon and moisture).

From an energy standpoint, duct leakage to unconditioned spaces is much more serious in attics and vented crawl spaces than in unconditioned basements. Air temperatures are much more extreme in attics and vented crawl spaces (especially attics) than unconditioned basements. Unconditioned basement temperatures remain much closer to the desired temperature inside the conditioned space.

Thus, duct leakage in unconditioned basements may not have a large energy penalty. In fact, studies have found evidence that 60-100% of the energy lost to unconditioned basements as a result of duct leakage is recovered to the conditioned space.[9,10] However, one of these studies estimates that sealing 80% of leaks, and insulating to R-5, previously unsealed and uninsulated ducts located in basements will reduce space conditioning use by 9%[10]**.** Since the code requires R-8 duct insulation, the amount of savings to be had from duct sealing in basements of new homes in Pennsylvania is probably somewhat less. On the other hand, the studies discussed above were performed on homes where there was no insulation between the basement and the conditioned space above. With the prescriptive requirement of R-30 insulation in floors above unconditioned basements, the basement is much more isolated from the conditioned space, and it is likely that significantly less energy from duct leakage will be recovered to the conditioned space.

Duct leakage to and from conditioned spaces are less important than leakage to outside, but it can still have negative impacts. Generally, if air movement is unrestricted between the rooms of a house, duct leakage in conditioned spaces does not affect the energy efficiency of the distribution system. However, if a room becomes isolated due to the closing of interior doors, and there is an imbalance of airflow to that room (i.e. more supply air than return air, or vice versa) then that room can become pressurized or depressurized resulting in increased exfiltration or infiltration. This creates an additional load on HVAC equipment resulting in increased energy consumption and potentially reducing equipment efficiency.

Another potential impact of duct leakage (and duct constrictions and design) is inadequate airflow resulting in rooms that are cold in the winter and hot in the summer. This creates the potential for occupant discomfort and comfort complaints. It may also indirectly affect energy efficiency as occupants may adjust the thermostat to compensate for a cold/hot room.

Recommendation 15: During mechanical inspections inspectors should make an attempt to follow duct runs from the trunk or plenum to the register or grille to ensure that all ducts are properly connected and sealed. Inspectors should also become more aware of code requirements for mechanical attachment of duct connections as well as manufacturer's installation instructions for connections between a few common duct types. In addition, inspectors should be aware of the compatibility of sealants with different duct materials.

Most of the homes visited during this project used building cavities as return ducts. Panned return ducts were not required to be sealed by inspectors. In a few cases panning material was sealed with tape or caulk, but in most case only staples were applied (although it is possible that caulk was applied to the panning material prior to stapling). Joist bays were not visible since the panning material had already

[9] Francisco, F., Siegel J., Palmiter, L., and Davis, B., Measuring residential duct efficiency with the short-term coheat test methodology, *Energy and Buildings*, Vol. 38, Issue 9, 2006.
[10] Treidler, B., Modera, M.P., Thermal Performance of Residential Duct Systems in Basements, *ASHRAE Transactions,* 1996.

been applied, so it was impossible tell if the joist bay had been sealed as required by code. According to discussions with code officials is highly unlikely that these bays were sealed. In addition to a general lack of sealing, large holes were found in panned returns due to popped staples, unsealed electrical penetrations and other holes.

The use of building cavities as return ducts was found in each of the homes with high rates of duct leakage. It is also widely recognized that this practice is frequently problematic. The NAHB Research Center's, *A Builder's Guide to Residential HVAC Systems* states several disadvantages of panning:

- Air leakage from panned and building cavity returns is comparatively high.
- Air leakage from cavities increases building infiltration rates, decreases overall energy efficiency, and may depressurize rooms or basement spaces, potentially resulting in health- or safety-related problems.
- Sources of cavity leakage air often are unknown and may carry pollutants from utility rooms or garage rooms.
- Sealing of building cavities is difficult, time-consuming, and largely ineffective.
- Sealing must be coordinated during framing, mechanical installation, and finishing.

The final point above underscores the need for inspectors to pay attention to duct sealing over the course of multiple inspections.

ACCA Manual J also discusses drawbacks of using building cavities as ducts:

> …this approach to solving duct routing problems produces airways that are very leaky. (A leakage path can be established between the conditioned space and the attic, basement, crawl space or the outdoors.) Therefore, stud spaces and panned joist spaces should not be used as part of the air distribution system unless the airway can be completely sealed. This means sealing all of the cracks, joints and penetrations that are associated with the structural surfaces and sealing the joints and seams that are associated with the panning material.

Code officials should begin to inspect panned returns for some type of sealing such as caulk (that is rated for smoke developed and flame spread requirements for duct materials as specified by the IRC). Requiring the sealing of the inside of building cavities that are to be used as return ducts should be required at rough framing. In addition, these ducts should be thoroughly checked for unsealed penetrations.

Another issue relating to panned return ducts is the insulation requirement for all ducts in unconditioned spaces. Code officials should begin to inspect for insulation of panned returns to minimize energy loss to unconditioned spaces. Since panned returns are currently almost never insulated, or sealed on the interior, this will be a challenge for builders who wish to continue using panned returns. One manufacturer states that its popular panning material achieves an R-8 when doubled.

Only one air handler/filter box was found to be sealed during this project. This is the most important location for air sealing because pressures are highest closest to the air handler. Code officials should become more aware of the code requirement to seal all air handlers and filter boxes, as well as the implications of the large amount of leakage that occurs at these sites.

Recommendation 16: In addition to sealing of ducts, mechanical or rough framing inspections should include the verification of sealing of air handlers, filter boxes, and building cavities used as

The PHRC team witnessed numerous duct constrictions and tight turn radii. Plumbing and electrical installations running perpendicular to ducts were the most common form of duct constriction. Some inspectors told the PHRC team that they would call out a severe duct constriction, or a constriction of a duct that supplies a large room. Duct constrictions are a major cause of poor home performance as inadequate air flow can lead to cold rooms and increase infiltration and exfiltration due to room pressure imbalances. Generally, duct constrictions were not considered violations.

While it is difficult to visually inspect for air leakage, inspectors should begin to check for obvious cases of poorly installed and/or poorly sealed duct connections. Adding performance-based requirements to the energy and/or mechanical code would also improve the quality of duct installation and relieve some of the pressure from frequently over-burdened inspectors. There is some precedent for performance testing in the IRC. For example, IRC chapter 25 contains requirements for testing drain, waste and vent (DWV) piping systems for leakage, as well as testing water-supply systems and backflow prevention devices. Precedent for performance testing has also been set in the California energy code as it has more stringent thermal envelope requirements in homes that do not undergo duct testing.

Inspectors generally checked for duct insulation but did not pay attention to the R-value. In some cases, R-6 duct insulation was observed where R-8 was required. However, the presence of insulation is more important than the R-value. Most of the under-insulated ducts were in unconditioned basements where the difference in performance is negligible. In fact, the PA-Alt recognizes that R-6 ducts in unconditioned basements perform better than R-8 ducts in attics and allows R-6 ducts in unconditioned basements.

Recommendation 17: Inspectors should verify that the required R-value for duct insulation is installed and that there are no excessive constrictions created by tight turn radii, plumbing, wiring etc.

3.4.3 Insulation Inspections

Insulation inspections are not required inspections under the UCC. Nevertheless, all but one of the code offices participating in this study performed a stand-alone, pre-drywall insulation inspection. Inspectors participating in this study generally appeared to check for the presence of insulation in all required building components. Although, in several cases, the PHRC team arrived at final inspections to find an incomplete thermal envelope with insulation missing in whole or in part from basement components. In one case, the RES*check* Compliance Certificate specified foundation wall insulation and neither foundation insulation nor floor insulation was installed. This was caught by an inspector at final inspection.

In another case, a change from an unconditioned basement to a conditioned basement occurred after the insulation inspection. At final inspection, the inspector noted the problems of backward installation of fiberglass batts (vapor retarders on warm-in-summer side) and an uninsulated wall in the furnace room (which had a fixed opening to the rest of the basement). There was also a closet space with a fixed opening that was not insulated.

In another case it was found that a large, uninsulated furnace/storage room was being supplied with conditioned air. The plans specified floor insulation (which was not present) indicating that space would not be conditioned. Either the supply duct and register would need to be removed and the floor above insulated, or the walls would need to be insulated in order for the basement to be in compliance. This was not picked up by the inspector.

Recommendation 18: Inspectors should be aware of the location of the thermal envelope as specified by the approved plans and verify that insulation is properly located and forms a continuous boundary.

In general, inspectors did not pay much attention to the installed R-values of insulation. One inspector in an area where R-19 is required said he looks for at least R-13. A minority of code offices used RES*check* checklists to ensure that R-values were in compliance with what was specified in RES*check* documentation. In one area, pre-cast foundation wall systems were common for conditioned basements. RES*check* documentation supplied to code officials specified R-10 basement walls. The product that was used was only an R-5. Inspectors were not aware of this discrepancy.

Using checklists or approved plans to verify R-values does not appear to be common. Similar to window U-factors, R-values can vary from home to home when RES*check*, PA-Alt trade-offs, or performance compliance paths are used. Thus, using approved plans or a checklist may be necessary to verify that the installed R-values are adequate. Inspectors should consider using a checklist to verify R-values meet the individual requirements for each home. This may not be necessary for developments in which the specifications for all homes are the same.

Recommendation 19: Inspectors should use the RES*check* Inspection Checklist to ensure that installed R-values are adequate given what was specified in RES*check*. Prescriptive IRC and IECC R-values may not apply.

In terms of installation integrity most inspectors made sure there were no major voids in insulation. Many required insulation to be cut around electrical outlets to avoid compression, but few appeared to be scrupulous about this. Inspectors did not require that insulation be split around wiring to avoid compression. Some instances of plumbing getting in the way of a good insulation installation were observed without comment from inspectors. In cavities of non-standard sizes, insulation was frequently not cut to fit, resulting in some compression.

The biggest problem with insulation integrity that was observed was with floor insulation. The 2006 IECC, IRC and PA-Alt all state that, “Floor insulation shall be installed to maintain permanent contact with the underside of the subfloor decking.” There were no instances where fiberglass batts were installed to meet this requirement, and inspectors did not require any changes except in one instance where a batt was hanging vertically. Support pins were observed to be absent, spaced too far apart, or upside down. One instance of blown fiberglass may have achieved permanent contact with the subfloor.

The insulating capacity of floor insulation is greatly decreased when it is sagging down from the subfloor. Inspectors should identify hanging or sagging floor insulation and require it to be properly supported. They should also consider using a ladder to feel for gaps between the insulation and the subfloor. Alternatively, knowing the depth of the installed insulation and the depth of the floor joist, an inspector could tell if the insulation is properly installed by measuring the distance between the bottom of the insulation and the bottom of the floor joist.

Recommendation 20: Inspectors should verify that floor insulation is adequately supported such that in maintains permanent contact with the underside of the subfloor decking.

In addition, the ceilings of stairwells leading to unconditioned basements are frequently not insulated. Basement stairwells constitute a fairly significant portion of a homes thermal envelope. Inspectors generally did not require stairwells to be full insulated.

Recommendation 21: Inspectors should check for insulation on both walls and the ceiling of stairwells to unconditioned basements.

3.4.4 Final Inspections

There are a few energy-related items that typically cannot be inspected prior to the final inspection. These items include mechanical systems, final air sealing details, and attic insulation. Inspectors observed in this study typically spent little time on energy-related inspection items.

HVAC Equipment Efficiency

There are no specific requirements for the energy efficiency of HVAC equipment in Pennsylvania's energy code because federal minimum efficiencies are set by the National Appliance Energy Conservation Act (NAECA). However, equipment efficiencies do come into play for energy code enforcement if a builder is using RES*check,* or an efficiency trade-off under the PA-Alt. It is common in Pennsylvania for builders to use high-efficiency heating equipment as a means to pass a RES*check* compliance analysis. Thus, it is important to verify that high efficiency equipment is actually installed. An inspector should know whether a high-efficiency unit was specified by the builder going into a final inspection.

Builders of homes visited during this study commonly used high efficiency HVAC equipment in order to take advantage of trade-offs available through RES*check*. HVAC efficiency is an item that does not appear to be checked frequently by inspectors. The PHRC team also found that HVAC equipment manufacturers' labels were typically difficult to access and did not contain an efficiency rating. Equipment did typically have a yellow Energy Guide label containing the efficiency rating affixed to the air handler.

Due to difficulties in finding and accessing manufacturers' labels, inspectors could use the yellow Energy Guide label, if present, to verify the efficiency. Also, because small differences in efficiency are not extremely important, inspectors could quickly determine if a gas furnace is a high-efficiency unit (≥90 AFUE) by looking for the two PVC pipes characteristic of a direct-vent system versus a less efficient non-direct-vent system.

Recommendation 22: Inspectors should know when high efficiency HVAC equipment was specified by the builder to pass RES*check* or take PA-Alt tradeoffs. In these cases inspectors should verify that high efficiency HVAC equipment has been installed. High efficiency gas furnaces can easily be identified by the presence of two PVC pipes.

Pipe Insulation

Circulating hot water systems may be becoming fairly common in Pennsylvania. The energy code requires that circulating service hot water system piping is insulated to at least an R-2. Inspectors do not appear to recognize when pipe insulation is required as two instances of uninsulated circulating service hot water piping were observed during this study. Inspectors should identify the presence of a circulating system by checking for the presence of a pump on hot water pipes near the water heater.

Recommendation 23: Inspectors should identify the presence of a circulating hot water system by checking for the presence of a pump on hot water pipes near the water heater. These pipes should be insulated to R-2.

Weather Stripping

Since doors leading to unconditioned basements comprise a portion of the building thermal envelope, the energy code requires that they are sealed. Only a few inspectors observed during this study checked for weather stripping on exterior doors. Only one inspector required weather stripping on doors leading to unconditioned basements. An unsealed basement door could be a significant contributor to heating and cooling loads as a result of the stack effect drawing unconditioned air up from the basement. In addition, leaky return ducts will cause the basement to depressurize, thus drawing conditioned air from the upper floors into the uninsulated basement.

Recessed lights can also be a significant source of air leakage from conditioned space into the attic. As discussed in the rough framing section of this report, all of the recessed light housings observed by the PHRC team were labeled in accordance with the ASTM E 283 airtightness standard. However, the installation of a sealed trim kit is also necessary to create an airtight fixture. Only one inspector observed in this study routinely checked for sealed trim kits. Infrared scans of recessed light fixtures during this study indicated that there may be an issue with unsealed or improperly installed trim kits.

Weather stripping of attic access hatches appears to be a rare practice. Weather stripping was only present in one home visited during this study, and inspectors did not require it. Generally the greatest potential for air leakage occurs between the top floor of a home and the attic. This is because the buoyancy of warm air creates pressure on the upper portions of the building envelope. The pressure forces conditioned air through any leaks to the attic. This results in wasted energy and can create building durability problems as moisture contained in indoor air condenses on cold surfaces in the attic. This can lead to mold growth and an increased rate of decay. Inspectors should begin requiring air sealing of attic hatches due to the potentially significant energy and durability impacts of air leakage into attics.

Recommendation 24: Inspectors should check for weather stripping or gaskets on doors to unconditioned basements, and around attic access hatches. Recessed lights may also require gasketed trim kits to achieve airtightness.

Attic Insulation

The PHRC team also found that several code offices did not perform any inspection of attic insulation. One barrier to inspecting attic insulation was the lack of a ladder on site at final inspection. Inadequate or no access to attics was also observed on two occasions. Most inspectors that performed attic insulation inspections looked for insulation depth markers and verified that the depth of insulation was correct. They also checked for installers' certificates, but did not necessarily verify that the correct number of bags of insulation was installed for the area covered.

The installation quality of blown-in insulation was frequently less than perfect. Substantial peaks and valleys in blown-in insulation were observed on several occasions leading to thermal weaknesses in the ceiling. A proper installation should result in insulation with a level surface. In some cases builders may install their own blown-in insulation instead of a well-qualified insulation contractor. Inspectors should talk to builders about blown-in insulation installation to improve the quality of future jobs. Also, trey ceilings did not have dams or other methods to prevent insulation from falling which led to reduced insulation depth around the edges. Areas with reduced insulation depth are potentially significant sources of heat transfer.

Attic access hatches were frequently not insulated, or were poorly insulated. Only a few inspectors inspected for attic hatch insulation and only a few attic hatches contained insulation. Where insulation was installed it typically consisted of a loose piece of fiberglass insulation that did not easily fit back into place after an individual accessed the attic. In addition, dams to prevent blown-in insulation from spilling into the living space were not typically installed.

Loose rectangles of fiberglass batts are probably not an effective and durable solution to insulating attic access hatches. It is likely that after a homeowner (or someone else) accesses the attic for the first time, the hatch insulation will not remain in place. It is especially difficult to insulate pull-down attic stairs. However, there are solutions to these problems, such as insulating with foam sheathing or using an insulated dome over pull-down stairs. Inspectors should require more adequately insulated attic hatches. Also, dams should be required around attic hatches and trey ceilings to keep blown-in insulation in place.

While inspectors often checked for attic insulation installer's certificates, they did not appear to verify that the information met the requirements of the installation. The number of bags for the given area should be verified. Some certificates have charts that give this information while others may require simple arithmetic by the inspector.

Recommendation 25: Inspectors should visually inspect attics for overall thermal integrity by checking for evenness of blown-in insulation and permanently affixed attic access hatch insulation.

Certificate

Electrical panel certificates containing a list of R- and U-values of building components were not a requirement when this study was performed. Because this is a new requirement, it is likely that many inspectors are not currently checking for these certificates. Code officials should be informed of this requirement so that certificates are installed and future homebuyers can be fully informed about their prospective purchase.

> **Recommendation 26:** The installation of permanent certificate listing the predominant R-values of building components on the electrical distribution panel should be verified by inspectors.

3.4.5 Recommended Tools for Inspections

There are a number of tools that are helpful to conduct a thorough inspection. Below is a list of recommended tools and a description of their use. This is not an exhaustive list and there are likely to be additional uses of the tools listed.

Step Ladder: One barrier to inspecting duct connections and attic insulation is the lack of a ladder available to inspectors. Code officials should either carry a 6- or 8-foot step ladder or require one to be on site for rough mechanical, rough framing and final inspections.

Tape Measure: A 25-foot long, 1-inch wide tape measure will assist in assessing cavity depth and insulation depth in areas where markings are not visible (e.g. floor insulation).

Screw Driver: A screw driver may be necessary to access HVAC equipment labels found inside of air handlers.

Flashlight: A flashlight is helpful when inspecting duct connections, HVAC labels and other items.

Mirror: A small mirror may also be useful to inspect duct connections and other items where there is limited visual access.

Binoculars: A set of inexpensive binoculars may be useful for inspecting for IC and ASTM E 283 labels in recessed lights located in great room ceilings. Binoculars also may aid in inspecting other items such as stamps on lumber, truss bracing details, flashing details and other inspection items that are beyond the reach of the naked eye.

3.4.6 Using Checklists

Very few code offices appear to be using any type of plan review or inspection checklists. The plan review checklists that were used were very generic, containing broad categories, but few, if any, specific energy items. Also, despite frequently being supplied with automatically generated RES*check* inspection checklists, very few code offices used any type of inspection checklist.

Given the multitude of items that plan reviewers and inspectors must look for, it is easy to miss something when working without any written cues. This is true for both inexperienced and experienced code officials. There are large numbers of inexperienced code officials because the UCC only went into effect in 2004. These new code officials would benefit from the guidance provided a checklist. Experienced code officials will also benefit from checklists as complacency may come with experience.

A lack of consistency may lead to problems in the field and builder confusion as enforcement may appear somewhat random. Plan review checklists can help reduce problems in the field and minimize time-consuming re-inspections and costly modifications.

Since RES*check* results in the greatest variation of requirements from home to home this checklist, or the approved plans should be used to verify R- and U-values. The prescriptive requirements from this checklist could also be incorporated into another more comprehensive checklist for use with all homes. The PHRC also offers an adaptable plan review/inspection checklist in Microsoft Word format at:

http://www.engr.psu.edu/phrc/Building_Code_Forms.htm

Code offices should also consider developing plan review and inspection checklists or integrating energy items into existing checklists. Since there is no single inspection that covers all of the energy code requirements, it is recommended that energy items be integrated into a more comprehensive checklist. Checklists would be particularly important to ensure thoroughness and consistency in larger, more complex code offices. They could also serve as important quality control tools.

Recommendation 27: Code offices should consider developing and using plan review and inspection checklists, or integrating energy items into existing checklists to ensure consistency and thoroughness.

4. Home Performance

In addition to assessing common code enforcement practices, this study endeavors to provide a rough estimate the actual energy performance of a typical new home in Pennsylvania. The most common method of estimating home energy performance is through the use of energy modeling software with inputs of home size, component areas, component R- and U-values, and data from performance testing. Performance tests consist of a blower door test to estimate air infiltration levels in thermal envelope, and a duct blaster test to estimate duct leakage. Energy modeling results from tested homes are compared with a standard (code-equivalent) reference home. The results from using these methods are discussed below.

Financial and temporal constraints limited this study to a small sample of code offices and homes. Due to this small sample size this study is not able to yield statistically significant results. A sample size of more than 400 randomly selected houses would be necessary to achieve statistical significance. Therefore, the homes inspected and/or test during site visits were not necessarily representative of homes in the local area or the entire state. Envelope tightness, duct tightness and other construction characteristics may depend more on the builder than the local code enforcement practice. Sample homes were also not necessarily representative of the level of energy code enforcement at that location. Further study would be necessary to get a comprehensive picture of code enforcement and construction practices across Pennsylvania. However, the study does offer a glimpse of common energy code enforcement and building practices.

4.1 Sample Home Characteristics

The average conditioned floor area (CFA) of the twelve sample homes was 3,388 sq ft. On average the window area of these homes comprised 15% of the gross wall area. Half of the homes tested had conditioned basements. Ten out of the twelve sample homes had high efficiency heating equipment (≥90 AFUE, 8.7 HSPF). Table 4.1 shows features relevant to the energy performance of the sample homes.

Table 4.1: Features relevant to the energy performance of the sample homes

No.	Conditioned floor area (ft²)	Window-to-wall ratio	Conditioned Basement	Duct Location			HVAC type	Heating efficiency	Cooling efficiency
				Conditioned space	Unconditioned basement	Attic			
1	2,723	14%	Yes	33%	33%	33%	Gas furnace	95 AFUE	13 SEER
2	2,835	16%	No	33%	33%	33%	Gas furnace	92 AFUE	13 SEER
3	2,567	14%	No	33%	33%	33%	Heat pump (2)	8.7, 8.7 HSPF	14, 14 SEER
4	2,883	21%	No	10%	45%	45%	Gas furnace (2)	92, 80 AFUE	13, 13 SEER
5	3,036	14%	Yes	100%	0	0	Gas furnace	92 AFUE	13 SEER
6	2,364	14%	Yes	90%[11]	0	0	Gas furnace	92 AFUE	None
7	4,595	10%	Yes[12]	100%	0	0	Gas furnace	80 AFUE	13 SEER
8	4,475	11%	Yes	95%[13]	0	0	Gas furnace	92 AFUE	13 SEER
9	2,823	9%	No	0	75%	25%	Gas furnace	92 AFUE	13.5 SEER
10[14]	3,687	19%	NA	100%	0	0	Water heater w/coil (2)	76, 76 effective AFUE	13, 13 SEER
11	5,698	17%	Yes	25%	25%	50%	Gas furnace (2)	92, 80 AFUE	13, 13 SEER
12	2,973	22%	No	33%	33%	33%	Gas furnace	92.5 AFUE	13 SEER
Mean	3,266	15%	--	--	--	--	--	--	--

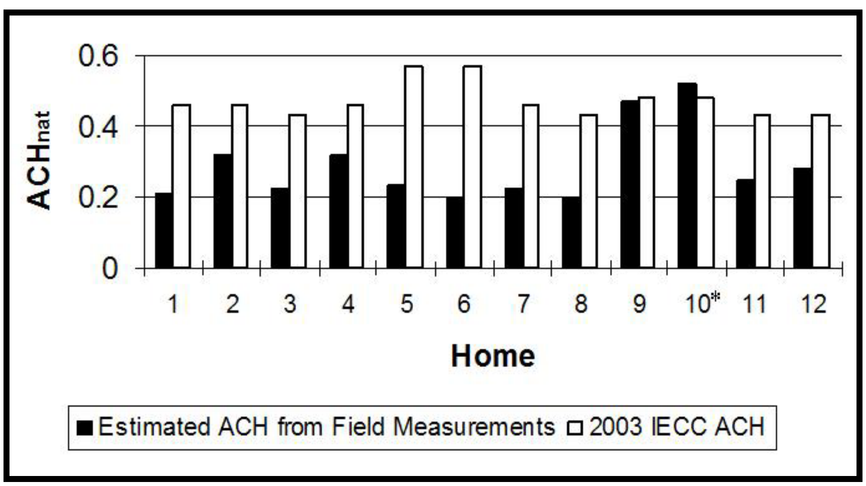
[11] Ten percent of ducts were located in and exterior wall.
[12] Contained a supply register and return grille, but insulation was located in the ceiling above, not the foundation walls
[13] Five percent of ducts were located in and exterior wall.
[14] Four-story townhouse

4.2 Infiltration

Blower door tests indicated a trend of lower than expected levels of infiltration in tested homes. Since the blower door test measures the rate of air flow under exaggerated pressures, air changes per hour under natural conditions (ACH_{nat}) were estimated using TECHTITE software which calculates ACH_{nat} in accordance with ASHRAE Standard 136-1993, *A method of Determining Air Change Rates in Detached Dwellings*. The mean infiltration rate for the twelve homes in this sample was 0.29 estimated ACH_{nat}. The median ACH_{nat} was 0.25. Various air infiltration measures of the sample homes are presented in Table A1 in Appendix 1.

To interpret these results it is helpful to compare these infiltration rates with those set forth in the "standard design" and "standard reference design" of the performance paths in the 2003 and 2006 IECC respectively. The standard design and standard reference design, hereafter referred to as the 2003 or 2006 reference home, are intended to detail the characteristics of a home that meets, but does not exceed, the requirements set forth by the energy code. The infiltration rate of the 2003 reference home varies by geographic location and ranges from 0.43 to 0.57 ACH_{nat}. The 2006 reference home specifies an SLA (Effective Leakage Area/Conditioned Floor Area) of 0.00036 regardless of location or climate.

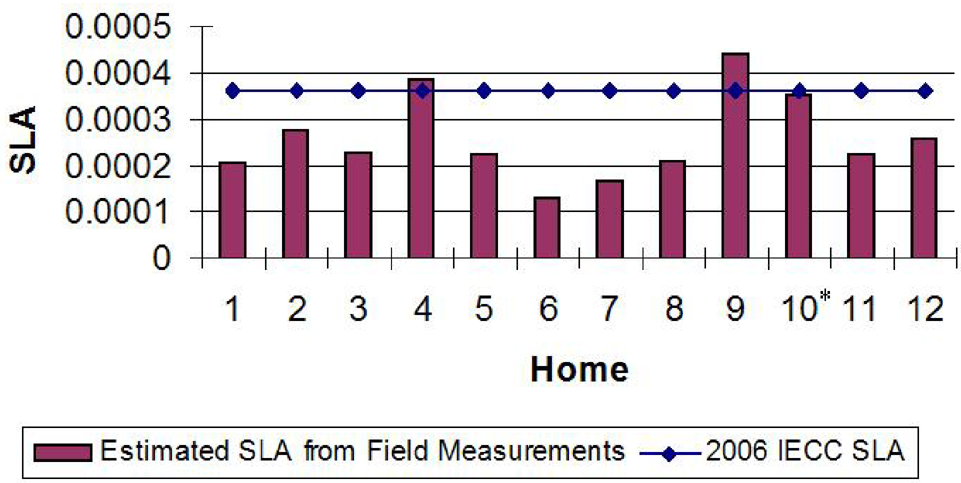
The average infiltration rate of sample homes was significantly lower than either of these standards (However, as a target for infiltration rates the IECC does set forth a very lofty goal.) Infiltration rates of sample homes are shown in Figures 4.1 and 4.2 along with the rates of the 2003 and 2006 reference homes. It should be noted that home #10 officially fell under the commercial energy code because it was a four-story townhouse. This is somewhat of a technicality. So, in this report, this home is not treated differently than the other homes in this study and is compared with the residential reference homes.



*Four-story townhouse built to the commercial provisions of the IECC 2003

Figure 4.1: Sample home infiltration rates compared to 2003 IECC Reference Home

Figure 4.1 shows estimated infiltration rates, based on blower door tests, of twelve homes compared with the infiltration rates used in the standard design in the 2003 IECC systems analysis path (Chapter 4). The black bars represent the estimated ACH of the twelve homes in this sample and the white bars represent the ACH of the 2003 IECC reference home (which varies by climate).



* Four-story townhouse built to the commercial provisions of the IECC 2003

Figure 4.2: Sample home infiltration compared to 2006 IECC Reference Home

Figure 4.2 shows estimated infiltration rates, based on blower door tests, of twelve homes compared with the infiltration rates used in the standard reference design in the 2006 IECC Simulated Performance Alternative path (Chapter 4, Section 404). The bars on the graph represent the estimated SLA of the twelve homes in the sample. The line represents the SLA (0.00036) used in the 2006 IECC Standard Reference Design (reference home).

4.2.1 Outliers

Two homes stand out from the rest in Figure 4.1 and three homes stand out in Figure 4.2. One home (#10) that tested fairly poorly was a four-story townhouse in which there was no blocking along the tops of shaft walls to prevent air infiltration and exfiltration from/to the attic. In addition, the home was constructed with open web floor trusses, which allows air to flow more readily from exterior leaks throughout the whole floor assembly.

Home (#9) had mediocre performance in comparison with the rest of the sample homes. On this home a blower door test was performed with and without duct registers and grilles sealed off. The difference between these two tests indicated that a large amount of the overall air infiltration was occurring through leaky ducts into unconditioned space.

Home (#4) stands out when compared with the 2006 reference home, but not when compared to the 2003 reference home. This is mainly because it had a higher ratio of volume to conditioned floor area than most other homes. The ACH_{nat} used in the 2003 reference home is dependent on building volume (floor area and average height above grade), whereas the SLA used in the 2006 reference home is dependent only on floor area. This put Home (#4) at an advantage in 2006 as compared to the 2003 reference home infiltration standard. Home (#4) also stands out partly because the reference home infiltration rate went from being more lenient for harsher climates in 2003 to being climate/location neutral in 2006.

4.2.2 Interpretation of Blower Door Test Results

There are a few possible reasons for the lower than expected infiltration rates found in the majority of the sample homes. First, builders are tightening their houses in response to market pressures, or to meet the intent of the code. Based on conversations with builders, superintendents, and code officials during this study, it appears to be fairly common for builders to purchase air sealing packages from their insulation contractors. This is occurring in spite of somewhat inconsistent enforcement of air sealing details and somewhat subjective and ambiguous code requirements.

Another possible reason that building envelopes were tighter than expected is because there appears to be heightened enforcement of fireblocking requirements. While few code officials are highly motivated when it comes to energy efficiency, most are highly motivated by health and safety issues. Fireblocking is one of the most important elements when it comes to fire safety. Proper fireblocking, especially around penetrations to the attic, addresses many aspects of air sealing.

Finally, the homes tested in this study were fairly large. The larger a home is, the lower its surface to volume ratio. This means that in large homes the impact on air changes per hour of leakage in the surface of the home is less than in smaller homes with similar attention to air sealing details. In other words, the large volume of large homes somewhat overwhelms the impact of leakage in the thermal envelope. However, localized leaks could still lead to comfort, moisture, and durability problems, as well as increased energy bills.

4.3 Duct Leakage

Once again, the 2006 energy code states that, "All ducts, air handlers, filter boxes, and building cavities used as return ducts shall be sealed." The duct systems section in the IRC (Chapter 16), also states that "Joints of duct systems shall be made substantially airtight." While distribution systems are required to be sealed, leakage testing is not required by code, and there is no performance requirement set forth in the code.

Duct leakage test results indicated a wide range of duct tightness among homes tested in this study. Total duct leakage ranged from as low as 105 cubic feet per minute at a pressure of -25 Pa (CFM_{25}) to so high that significant pressure could not be achieved during the test.

Results from duct blaster testing are most meaningful when standardized for duct area. Since duct area is difficult to measure, duct leakage results are commonly standardized by conditioned floor area (CFA). The federal ENERGY STAR Qualified Homes program's maximum duct leakage rate is six CFM_{25} per 100 sq ft CFA.

Ducts tested in this study can be grouped roughly into three groups for total duct leakage. One duct system was fairly tight with a leakage rate of less than 10 CFM per 100 sq ft CFA. Five systems had moderate duct leakage with between 10 and 30 CFM per 100 sq ft CFA. Four systems had severe leakage with greater than 50 CFM per 100 sq ft CFA, or a significant pressure could not be achieved.

Duct leakage to outside of the building thermal envelope also varied widely. Six homes had duct leakage to outside at levels close to, or lower than, required by the federal ENERGY STAR Qualified Homes program. It should be noted that two of these duct systems (homes 5 and 7) had leaky ducts, but all ducts were located entirely within the building thermal envelope. Four duct systems had large amounts of duct leakage to the outside with greater than 20 CFM per 100 sq ft CFA. One of these four systems was so leaky that adequate pressure could not be achieved for testing.

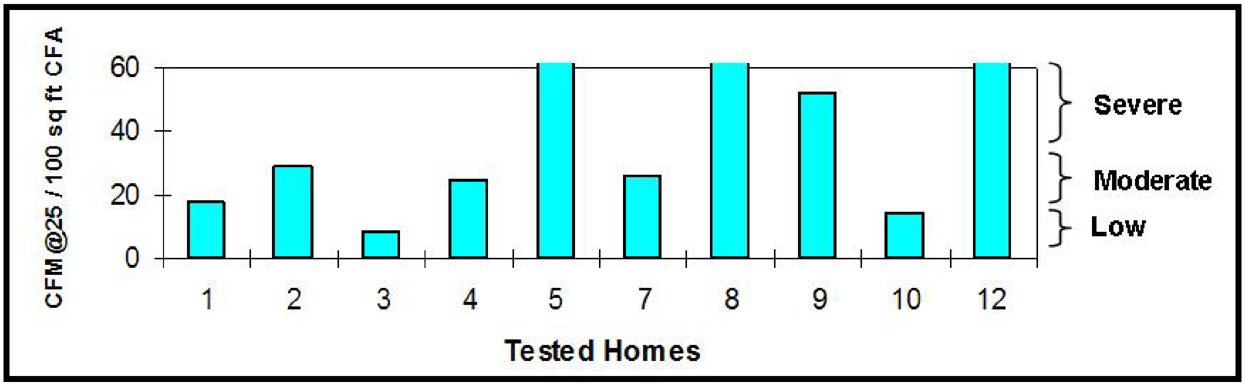


Figure 4.3: Total duct leakage in CFM as a proportion of conditioned floor area

Figure 4.3 shows total duct leakage in cubic feet per minute (CFM) when tested with a duct blaster at a pressure of -25 Pa. This measure is standardized by the conditioned floor area of the home in which the ducts were located. Bars that extend past the border of the graph indicate that duct leakage was so extensive that a useful test pressure could not be reached. Homes 6 and 11 are not shown because no duct testing was performed due to technical infeasibility.

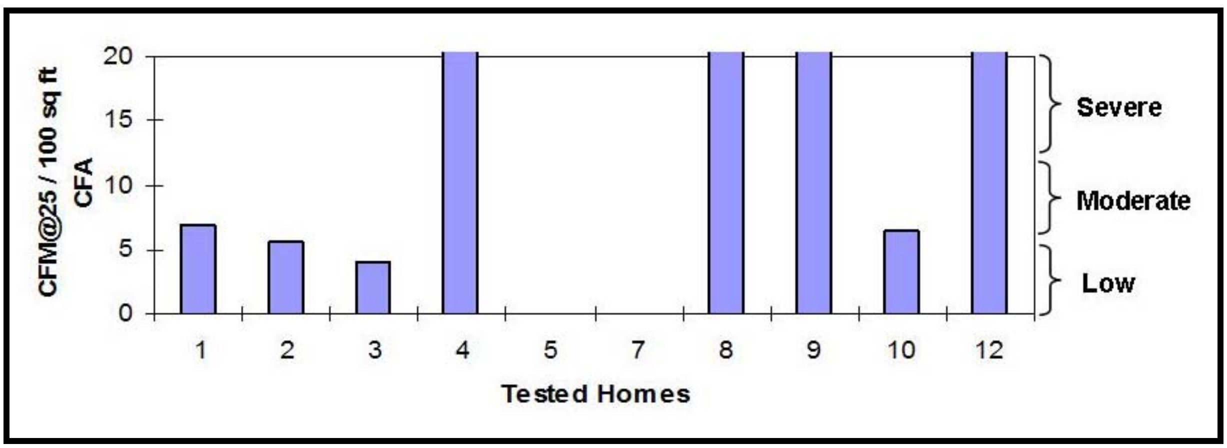


Figure 4.4: Duct leakage to outside as a proportion of conditioned floor area

Figure 4.4 shows duct leakage to outside the building thermal envelope in cubic feet per minute (CFM) when tested with a duct blaster at a pressure of -25 Pa. The conditioned space was also depressurized to -25 Pa to isolate duct leakage to the outside. This measure is standardized by the conditioned floor area of the home in which the ducts were located. Bars that extend past the border of the graph indicate duct leakage greater than 20 CFM/100 sq ft CFA or that the test pressure could not be achieved. Homes 6 and 11 are not shown because no duct testing was performed due to technical infeasibility.

4.3.1 Interpretation of Duct Blaster Test Results

Results of duct test were mixed, but most duct systems were estimated to have moderate to severe leakage. Poorly performing ducts commonly had improperly made and/or unsealed duct connections. Metal collars were not properly fitted into duct board trunk lines and flex duct connections were not always taped or fastened with draw bands. All of the poorly performing duct systems used panned returns in the basement.

The use of building cavities as return ducts is likely responsible for huge amounts of duct leakage across Pennsylvania. The one saving grace, from an energy standpoint, is that panned return ducts are located in basements where temperatures are typically not as severe as attics or exterior walls. However, depressurization of the basement that results from leaky return ducts can result in sucking of conditioned air from the above floors into the uninsulated basement. Also, indoor air quality and safety issues can arise from leaky return ducts in basements. Air from the basement, possibly containing radon, dust, and/or mold is sucked into the duct system and distributed throughout the house resulting in reduced indoor air quality. In addition, the risk of backdrafting of dangerous carbon-monoxide containing combustion gases into the space is increased.

Tight duct systems either consisted primarily of rigid fiberglass trunks with flex duct branches that were connected properly, or metal trunks and branches thoroughly sealed with mastic. Flex ducts are continuous, so the only chance for leakage occurs at the connections (unless the duct is torn). While air leakage is relatively low with flex duct, air flow restrictions are a potential problem as it is easy for duct runs to contain overly tight turn radii or be constricted by plumbing and electrical work.

Metal ducts are advantageous because they have the lowest resistance to airflow due to friction of any type of duct, and they are not prone to airflow restrictions from plumbing and electrical work. However, they are rather prone to air leakage and are required to be thoroughly sealed. Mastic is messy and avoided by many HVAC contractors, but many duct experts feel that mastic is the only way to adequately and durably seal metal ducts.

Based on visual inspections alone, it was clear that many of the duct systems observed in this study were not sealed adequately. Poor workmanship appears to be common among HVAC contractors as unconnected or poorly connected ducts and completely unsealed returns were encountered frequently in this study. Much of this indicates inadequate mechanical inspections. The performance of many duct systems could be significantly improved with more thorough mechanical inspections paying attention to sealing and proper connections.

Another issue affecting thermal distribution (duct) system efficiency that was not addressed in this study is duct sizing. Using building cavities as returns frequently results in undersized returns, starving the system for return air. Notching of top plates in partition walls to allow for return air to pass through frequently result in an inadequate area for sufficient return air flow. In addition, HVAC subcontractors frequently compete with plumbing and electrical subcontractors for space within building cavities. This frequently results in obstructions or constrictions of ductwork. Competition for existing space is a design and sequencing challenge for builders and subcontractors that should be addressed as early in the construction process as possible.

4.4 Thermal Integrity

During this project infrared scans were performed mainly as an educational tool for code officials. Due to varying indoor and outdoor temperatures, and varying degrees of incident solar radiation, it is difficult to quantify and compare building performance using the infrared scans performed in this study. Therefore, only general observations are discussed here.

The PHRC team did not find any instances of missing insulation. Minor defects such as compressed batts at the bottoms of study bays, around electrical outlets, or in narrow stud bays were detected. Attic hatches typically showed large temperature differences as compared to the surrounding ceiling. Corners were nearly always cold. This is a result of the typical three-stud corner construction which makes for significant areas with no insulation. The same is true with structural elements used as support around windows. These items are sources of energy loss, but are not energy code violations.

Infrared scans performed while the blower door was running revealed a few common air leakage sites. Top and bottom plates usually had visible air leakage. In a few cases air leakage was visible around the outside of window and door frames. Recessed lights did not typically appear to have significant air leakage. In a few cases one or more recessed lights demonstrated more leakage than others in the same house. This is likely due to improper installation of gasketed trim kits, which are required to form a seal between the drywall and the fixture. Other penetrations such as electrical outlets, light switches, light fixtures and smoke detectors also typically demonstrated visible leakage. Attic hatches were the most visible sources of air leakage. In a few cases air leakage from the attic or basement was visible in partition walls and plumbing chases. This indicates poor fireblocking and air sealing.

Overall the PHRC team did not find the appearance of any glaring defects resulting in large voids or air leakage through the thermal envelope.

4.5 Estimated Home Energy Performance

Building performance modeling is not an exact science as the actual performance of a home may differ significantly from the modeled home. In general, it could be said that a 5% margin of error is quite good for this type of modeling. In addition, occupant behavior can cause the actual home performance to vary dramatically from what a model predicts.

Energy performance simulations performed with REM/Rate software predict that the homes tested in this study will generally perform close to the standard set by the 2003 reference home. Data from blower door tests and duct blaster tests were used as inputs in these simulations along with inputs of building component areas and other information as described in the Methods section of this report.

All, but four of the sample homes were estimated to use ±5% of the amount of energy used by the 2003 reference home. Only one home passed the 2003 IECC performance simulation by more than 5%. This home used 8.9% less energy than the reference home. Three homes used more than 5% more energy than the reference home, exceeding the 2003 reference home by 5.2%, 14% and 20%. The energy performance of a home typically varies based on which direction the home faces. Best-case orientations are presented here. Worst-case orientations generally decreased home energy performance by 2% as compared to the reference home.

The energy performance of the sample homes in this study was generally within 5% of the reference home. Factors that increased energy consumption as compared to the reference home included: higher window U-factors, lower wall R-values and leaky duct systems. These detriments were typically countered by high efficiency HVAC equipment and lower infiltration rates than used in the reference home. Leaky ducts and basements with missing or inadequate wall or slab insulation were major deficiencies in homes that performed significantly below code.

These estimates of energy consumption relative to a code baseline differ greatly from comparisons to code using RES*check*. Homes averaged 3.2% below code with performance modeling. On the other hand, RES*check* Compliance Certificates submitted by builders claimed an average of 19% above code. Given this disparity it is likely that builders and code officials have a perception that typical homes have better energy performance than they actually do.

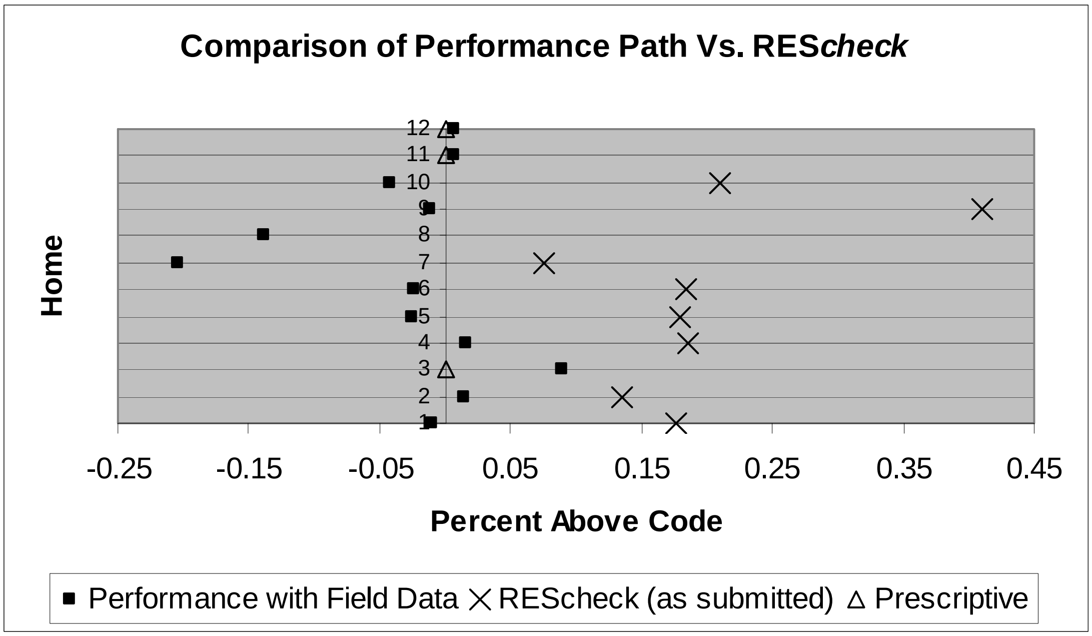


Figure 4.5: Comparison of performance path vs. RES*check*

Figure 4.5 shows the difference between the percent above code claimed by builders using RES*check* with the percent above or below code when using a computer simulation with field data. Home 10 is a comparison of the commercial energy code software COM*check* results with the residential performance path because COM*check* was (correctly) used instead of RES*check*. Given the same inputs RES*check* results would not have been as favorable and the discrepancy reduced.

Table 4.2: Qualitative Comparison of Installed Energy-Related Components with the 2003 IECC Reference Home

	House											
Feature	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10[a]**	**11**	**12**
Foundation wall	-	NA	NA	NA	-	O	--	+	NA	NA	-	O
Slab	NA	NA	NA	NA	NA	NA	NA	O	O	+	O	NA
Floor	+	O	O	O	NA	NA	NA	NA	O	-	O	O
Above-grade wall	-	-	O	O	--	-	-	O	O	O	O	O
Windows	-	-	O	-	-	--	--	-	--	-	-	-
WWR diff	-4%	-2%	-4%	+3%	-4%	-4%	-8%	-7%	-9%	+1	-1%	+4%
Ceiling	-	O	O	O	O	O	O	O	O	O	O	O
Heating efficiency	++	++	++	+	++	++	O	++	++	-	+	++
Cooling efficiency	O	O	+	O	NA	NA	O	O	O	O	O	O
Water heating			+	+	O	+	+	+	+	-	?	?
Infiltration	++	++	++	++	++	++	++	++	+	+	++	++
Overall	O	O	+	O	-	O	--	-	O	-	O	O

Compared to reference home:
- slightly worse -- moderately worse O about the same + slightly better ++ moderately better

[a] This home was a four-story townhouse, so it was built to commercial energy code requirements, which are less stringent than residential energy code requirements.

There a few reasons for the disparities between the results of performance modeling and submitted RES*check* documentation. One reason is that inputs into RES*check* are frequently incorrect, which can lead to an artificial increase in the percent above code shown in the output. Another reason is that RES*check* uses prescriptive U-factor tables as a baseline that, in 2003, became less stringent as the window-to-wall ratio decreased. The performance path baseline did not vary with window-to-wall ratio. Therefore, homes with low window-to-wall ratios would receive a substantial advantage compared to the RES*check* baseline, whereas the same home would not receive that advantage with the performance path. Finally, the way that RES*check* (operating under the 2003 IECC) treated HVAC equipment efficiency tradeoffs appears to have exaggerated the energy benefits of high efficiency HVAC equipment giving a disproportionate lift to homes with high efficiency equipment.

The overly positive perception of energy performance given by older versions of RES*check* is probably decreasing as a result of changes in 2006 versions of RES*check*. New versions of RES*check* no longer give an advantage to builders using low window areas because the 2006 energy code is window area neutral. In addition, the new “limited scope” performance calculation performed by new versions of RES*check* has substantially reduced the benefits previously obtained from inputting high efficiency equipment. Therefore, it is likely that versions of RES*check* using the 2006 IECC as a baseline present builders and code officials with a more accurate picture of a home’s energy performance in relation to the code minimum.

4.6 Trends

There were a few trends among the sample homes that reduced their projected energy consumption as compared with the 2003 reference home. First, all but two of the sample homes had window-to-wall ratios lower than the reference home's 0.18 WWR. Since windows have a high conductivity relative to insulated walls, a lower WWR means lower energy consumption. (Passive solar techniques may be an exception to this rule.)

Another feature that benefited nearly all of the sample homes was high efficiency heating equipment. In most cases this was a 90 AFUE or higher gas furnace. The 2003 (and 2006) reference home uses the federal National Appliance Energy Conservation Act (NAECA) minimum efficiencies. Currently the minimum gas furnace efficiency is 78 AFUE. This means that a direct-vent furnace will reduce the energy consumption for heating, the largest end use, by at least 12% over the reference home. Most of the homes also had water heaters that were significantly more efficient than the federal minimum.

Low infiltration rates also reduced the projected energy consumption of sample homes compared to the reference home. On average the infiltration rate of the sample homes was 38% less than the 2003 reference home. However, for performance simulations under the 2003 (and 2006) IECC, homes cannot benefit from infiltration rates below 0.35 ACH_{nat} unless mechanical ventilation is installed. This reduced the fairly large benefit from low infiltration rates in simulations of the sample homes.

There were also trends among the sample homes that increased their projected energy consumption compared to the 2003 reference home. A few homes with conditioned basements did not have insulation in locations where the reference home did and/or had lower R-values than the reference home. Sample homes typically had lower above-grade wall R-values than specified in the reference home. Similarly, nearly all of the sample homes had windows with higher U-factors (lower R-values) than the reference home. This was accomplished within the bounds of the energy code by using RES*check* and installing high efficiency equipment.

Duct leakage is difficult to directly compare with the reference home because it uses distribution system efficiency rather than measured duct leakage. An idiosyncrasy in how REM/Rate software accounts for duct leakage also makes a direct comparison difficult. About half of the sample homes benefited from tight ducts, or ducts located in conditioned space, and the other half was penalized for leaky ducts. REM/Rate simulations did show that ducts are very important contributors to energy consumption as the software estimated they would be responsible, on average, for 24% of the total energy consumption for heating. The range was from 11 to 38 percent.

Overall, the homes simulated in this study came out about even with the energy performance of the 2003 reference home. The one home that was projected to perform significantly worse than the reference home had an uninsulated conditioned basement, above-grade wall R-values lower than the reference home, and window U-factors significantly higher than the reference home. Very little ground was made up with HVAC efficiency in this home because an 80 AFUE furnace was installed.

5. Conclusions

5.1 General Observations

The PHRC energy code enforcement assessment included a wide variety of code offices in terms of size, complexity and experience. Techniques for enforcing any portion of the code will vary based on differences in the size and organizational structure of code offices. Local building practices and code officials' relationships with builders and superintendents will also influence which aspects of code enforcement will be emphasized or deemphasized. The PHRC recognizes that there is no single correct way to enforce a code. Therefore, not all of the recommendations in this report will necessarily make sense for all code offices. Code offices are encouraged to consider the intent of these recommendations and decide for themselves how best to implement changes (if necessary).

The number of homes and code offices included in this study is too small to make sweeping conclusions about the status of code enforcement and home performance across Pennsylvania. In addition, the voluntary nature of participation in this study creates an inherent bias as regulatory laggards are not likely to participate in a program such as this. With that in mind this study provides a glimpse into code enforcement and construction practices in Pennsylvania that can inform future education and training efforts and provide a starting point for further study.

5.2 Code Office Administration

During this study it was sometimes difficult to tell if a participant's responses during interviews about their typical practices were representative of all of the code officials on staff in that code office, or merely a reflection of one individual. Several code office administrators appeared to be uncertain as well. This underscores the need for quality assurance practices to ensure thorough and consistent enforcement of the building code. Most code offices observed in this study had few, if any, quality assurance measures in place. The same level of quality assurance is not necessary for all code offices as large code offices will probably find quality assurance measures more useful than very small offices.

One potentially useful and important quality assurance measure that has been discussed in this report is the use of checklists. Given the 500+ pages of code requirements contained in the IRC, there is a plethora of information that each code official must know, or be able to quickly reference. A comprehensive checklist covering plan review and each inspection can serve as a quick reference, and help an individual code official, and a code office as a whole, to be more thorough and consistent. A stand-alone energy checklist may not be the most effective guide as energy items are inspected throughout the course of many inspections. Therefore, it is recommended that energy items be integrated into a comprehensive checklist in places that mesh well with the existing inspection schedule.

5.3 Plan Submittals and Plan Reviews

Observations during this study indicate that typically little attention is paid to energy-related issues at plan review. Nevertheless, plan review is often the best and most efficient time to address many energy items.

There are at least three main roles of the plan review. One role is to educate the builder about the requirements of the energy code and to establish what will be expected throughout the construction process. A second role of the plan review is to ensure that all the information necessary to perform a thorough inspection can be found on the plans or other documentation. This is particularly important when RES*check* is used because R-values, U-factors and required HVAC efficiencies will vary from home to home leaving an inspector with little idea of what R-and U-values are acceptable.

A third role of the plan review is to reduce conflicts and confusion in the field. If a detail does not appear on the plans it is less likely to be installed in the field. In addition, if code requirements are not understood following the approval of plans it is likely that there will be problems in the field. For code offices this often means increased time spent on re-inspections. For builders it can mean costly changes in the field and construction delays. In some cases, code violations may be very difficult, if not impossible, to correct and may lead to noncompliance.

One reason for insufficient plan reviews is inadequate detail on plans and other documentation. This frequently results from inadequate plan submittal requirements or inadequate enforcement of those requirements. Many problems seen in the field could be avoided with more aggressive plan submittal requirements (and enforcement) and a brief, but thorough review of energy-related items at plan review.

Some apparently common energy deficiencies are related to insulation requirements for conditioned basements. Many of these issues can be linked to limited attention to energy issues during plan reviews. Problems such as missing or improperly installed slab insulation, missing or improperly installed basement wall insulation (or the presence of conditioned air supply in an ostensibly unconditioned basement), inadequate basement wall insulation, and discontinuous thermal envelope insulation could be addressed at plan review. Specification on the plans, and review of, conditioned versus unconditioned basements, proposed grading, and basement wall and slab cross-section details showing insulation placement and R-value would go a long way toward increasing energy code compliance and decreasing costly and time-consuming field changes.

A brief review of RES*check* documentation by plan reviewers would also improve energy code compliance. As discussed above, plan reviewers should do a top-to-bottom review of the RES*check* Compliance Certificate including verification of location, code year, and software version, as well as verification that all building envelope components are listed and component areas seem reasonably accurate.

Energy code training and education should stress the usefulness and importance of a quick, but thorough plan review with energy efficiency in mind. This will result in more efficient energy code enforcement as extra time spent during plan reviews frequently results in less time spent overall, because the rate of re-inspection is reduced. In addition, energy code compliance will be improved as cases where field changes are difficult or impossible will be reduced.

5.4 Mechanical Inspections/Duct Leakage

It is likely that typical residential mechanical inspections in Pennsylvania are not adequate to enforce energy and duct requirements in the code. There appears to be a significant training need on the subject of mechanical inspections. Evidence for this was found in the field in the form of unconnected or improperly connected ducts, unsealed ducts, air handlers and filter boxes, and various airflow restrictions. These visual observations were supported by field testing that indicated that most distribution systems had substantial leakage. Unsealed and improperly connected distribution systems are out of compliance with the energy and building codes and can result in a significant reduction in thermal distribution system efficiency and occupant comfort. Existing training programs for code officials, builders and HVAC subcontractors should be enhanced to focus more on preventing duct leakage and improving airflow. Alternatively, an entirely new training program focusing specifically on mechanical inspections should be developed.

5.5 Rough Framing Inspections, Air Sealing and Infiltration

Rough framing inspections were, for the most part, a missed opportunity to address important energy issues. Training programs should emphasize the importance of using the rough framing inspection to address those issues. One issue is comparing the actual building to the approved plans. Energy-related and structural differences from the approved plans may arise if there are changes in details like window size and number and soil grading. In addition, many air sealing details are most easily addressed before insulation is installed. While most fireblocking issues, such as sealing of penetrations, were addressed fairly well, other leakage sites were not. These included sheathing seams, top and bottom plates, the exterior sides of knee walls and the interior sides of showers and tubs (on exterior walls) and fireplaces.

It was also found that common walls between dwelling units may frequently be left open between floors and to the attic, resulting in a significant fireblocking violation and energy deficiency. Finally, house wrap was commonly perceived by inspectors as forming a complete air barrier. However, only one brand of house wrap has been tested and rated as an air barrier, and this product has specific instructions for installation as an air barrier. This type of installation was not observed in the field. Thus, inspecting for proper and thorough air sealing of homes should continue to be emphasized in training programs for builders and code officials.

Despite limited enforcement of air sealing details infiltration rates were relatively low (based on blower door test results). It was expected that most of the homes tested would have substantially higher air leakage rates than the rates that were found. This means that there may be less of an opportunity for energy savings from more aggressive code enforcement than was originally anticipated. Many builders may be staying ahead of code enforcement on air sealing issues by purchasing air sealing packages from insulation contractors as they respond independently to code requirements and market pressures. Builders should be aware that as they tighten up there homes mechanical ventilation may be necessary to prevent excessive moisture build-up and maintain adequate indoor air quality.

On the other hand, as discussed in the Results section of this report, the low infiltration rates may have more to do with the large building volumes than the quality and thoroughness of the air sealing. In addition, modern standards for what constitutes a “loose” versus “tight” new home have changed significantly over the years. Homes that were once considered fairly tight may be considered average today. This issue is discussed in more detail in Appendix X. Finally, the small sample size of tested homes, and participation bias in this study means that the results presented may not be a representative sample of homes or code enforcement practices. Significant variation across Pennsylvania is likely.

5.6 Needed Policy Clarifications

Because of the ambiguity of the air sealing requirements in the energy code, it is difficult to recommend how thorough an inspector should be in requiring air sealing details. The complexity of air sealing a home makes it unlikely that a consistent level of air sealing will occur based on the current code language. For example, IECC 402.3.1 lists "All joints, seams and penetrations" as locations that are required to be sealed. Does this mean that all top and bottom plates and double jack studs should be caulked? The same section lists knee walls and behind tubs and showers on exterior walls. There is debate over the intent of these items because of the failure to specify the location of the air barrier.

Some have interpreted these requirements to mean that there only needs to be an air barrier on the interior side of knee walls, and on the exterior side of tubs and showers. Others note that there would be no reason to mention knee walls, tubs and showers specifically unless the intent is to require an air barrier on the exterior side of knee wall, and on the interior sides of tubs and showers. If the latter is the case, the code language should be clarified to indicate the location(s) of the air barrier. A more detailed checklist of air sealing/air barrier locations would help clarify requirements and improve the enforcement of air sealing in general. Another way to address ambiguity in the code language pertaining to air sealing would be to create performance-based energy code requirements.

Another issue that could use clarification is which methods are acceptable for sealing the gaps at the intersections of floor and ceilings with common walls in multi-unit dwellings. Many builders and code officials are reluctant to put any material against the common wall for fear of disqualifying the fire rating of that assembly. Additional guidance on acceptable materials and methods to deal with this important fire and energy issue would improve the prevalence and efficacy of fireblocking and air sealing at common walls.

Yet another issue that could use clarification is what, if any, tapes are acceptable for use on sheet metal ducts. None of the current ratings address acceptable sealants for metal ducts. A new rating for closure systems for metal ducts along with a statement in the Duct Systems section of the IRC would help eliminate confusion.

5.7 Home Energy Performance

As estimated through computer modeling, most of the homes in this study will likely perform close to the baseline home energy performance established in the 2003 IECC Residential Building Design Systems Analysis approach. High efficiency HVAC equipment and low levels of infiltration relative to the reference home were typical and this commonly made up for common deficiencies, such as improperly installed or missing basement/slab insulation and leaky ducts.

5.8 Future Research and Final Thoughts

Based on the findings in this study increased attention should be paid to a variety of areas including mechanical systems (duct sealing and connections), conditioning status of basements (when, where and how much insulation is required), thermal envelope continuity (focusing on slabs and architectural features), attic access insulation and weather stripping, proper floor insulation installation, and blocking of townhouse common walls. The use of plan submittal, plan review and inspection checklists, or other means of improving accuracy, consistency and thoroughness are also worth serious consideration.

The findings of this study point to at least two follow-up studies, and two areas to focus future training efforts. First, a more extensive study would have to be performed to make accurate generalizations about new home performance and code enforcement practices across Pennsylvania. For the diagnostic testing, a much larger sample size of randomly selected homes would be necessary to yield statistically significant results. (A statistically significant sample size would be in the range of 400 to 500 homes.) This would require a large fiscal commitment on the part of legislators.

It would also be helpful to eliminate the participation bias inherent in this study. This would be difficult since a truly random sample could not be achieved without some type of mandatory audit system. Alternatively, testing could be arranged through new home owners. This would eliminate the bias present in this study, but introduce other biases. Logistics of the testing procedures would also be more difficult in occupied houses. In addition, it would be useful to correlate air sealing measures with building performance by documenting air sealing measures installed during construction of sample homes. (This was not possible in this study because homes were not followed longitudinally through the construction process.)

A second follow-up study would entail a more thorough investigation of duct performance in a typical new home. The present study yielded a strong indication that many new duct systems are not performing well. However, the measurements taken in this study comprise only one aspect of duct performance: duct leakage. A more detailed study could investigate other performance questions such as: 1) Have ducts been sized properly?; 2) Is each room getting sufficient airflow to maintain a comfortable temperature?; 3) Is there a sufficient return air pathway?; and 4) Are there pressure imbalances resulting in increased thermal envelope infiltration?

A study addressing these issues would yield a more comprehensive understanding of the performance of typical duct systems, and would point more directly to the consequences of poor duct design and installation than was possible in this study. In addition to performance testing, a more systematic visual inspection of duct connections would be helpful to gauge the pervasiveness of unconnected or improperly connected ducts, as well as un-sized or improperly sized ducts. It would also be interesting to see how builders and code officials deal with the requirement for R-8 insulation on all ducts when panned returns are used.

In addition to a need for future study, there are also additional training needs for builders, subcontractors and code officials. One major training need has to do with educating builders and code officials on the concept of a continuous thermal envelope. Existing training providers should enhance their programs, or create new ones that focus on thermal envelope continuity, air sealing and identifying conditioned versus unconditioned spaces. Specific target areas include, but are not limited to, basements, slab insulation, attic access hatches, common walls, kneewalls, bathtubs and fireplaces.

Another major training need relates to duct design and performance. Training is needed for code officials, builders and HVAC contractors. The present study suggests that in many cases little attention is being paid to design, installation or inspection of duct systems in Pennsylvania. Training should provide an overview of relevant duct design and construction standards and provide information about duct design, sizing, installation and air sealing. HVAC contractors will require greater detail than builders and code officials. Thus, training programs are likely to be most effective if they are tailored to a specific audience.

The studies proposed above would give policymakers a better understanding of the gap between conditions in the field and code requirements. If implemented successfully, the proposed additions and enhancements to training efforts will help reduce that gap, and move Pennsylvania and other states toward the construction of more energy efficient, durable and comfortable new homes. These benefits will be reaped for decades to come.

Appendix 1: Sample Home Characteristics and Air Infiltration Estimates

Table A1: Characteristics and air infiltration estimates of sample homes

House	Exposures	Stories	CFA (ft^2)	CFM_{50}	ACH_{50}	CFM_{50}/sq ft	ACH_{nat}	EqLA (in^2)	ELA (in^2)	SLA
1	4	2.4	2,723	1457	3.83	0.53	0.21	154	81	0.000206
2	3	3.4	2,835	2689	6.84	0.95	0.32	235	113	0.000278
3	4	2.3	2,567	1486	4.09	0.56	0.22	157	85	0.000229
4	4	2.2	2,883	2556	5.79	0.89	0.32	253	131	**0.000385**
5	4	1.3	3,036	1814	3.98	0.60	0.23	178	92	0.000222
6	4	2	2,364	1118	3.55	0.47	0.20	108	55	0.000127
7	4	2.3	4,595	2115	4.99	0.68	0.22	212	110	0.000166
8	4	2.3	4,447	2568	3.87	0.57	0.20	257	135	0.000209
9	4	2.2	2,823	2334	5.78	0.82	0.47	298	179	**0.000441**
10[15]	2	4.75	3,687	4290	8.24	1.26	0.52	382	187	0.000352
11[16]	4	2.3	5,698	2873	3.56	0.56	0.27	328	184	0.000225
12	4	2.3	2,973	2147	4.86	0.72	0.28	212	110	0.000257
Mean	---	---	3,388	2287	4.92	0.71	0.29	231	122	0.000258
Median	---	---	2,928	2241	4.48	0.64	0.24	223	112	0.000229

See the Glossary of Terms in Appendix 2 for explanations of column headings.

Glossary of Terms

CFA: Conditioned Floor Area – the floor area of a building being heated or cooled, containing uninsulated ducts, or with a fixed opening directly into an adjacent conditioned space.

CFM_{25}: Cubic Feet per minute at 25 Pascals of pressure. A standard measure of duct leakage when using a duct blaster.

CFM_{50}: The airflow (in Cubic Feet per Minute) needed to create a change in building pressure of 50 Pascals.

CFM_{50}/sq ft: CFM_{50} divided by the floor area of the building.

ACH_{50}: ACH at 50 Pa is the number of complete air changes that will occur in one hour with a 50 Pascal pressure being applied uniformly across the building envelope.

EqLA: Equivalent Leakage Area - defined by Canadian researchers at the Canadian National Research Council as the area of a sharp edged orifice (a sharp round hole cut in a thin plate) that would leak the same amount of air as the building does at a pressure of 10 Pascals.

[15] Four-story townhouse
[16] The correlation coefficient of the data collected on this home was 0.977, not meeting the standard of 0.99.

ELA: Developed by Lawrence Berkeley Laboratory (LBL) and is used in their infiltration model. The Effective Leakage Area is defined as the area of a special nozzle-shaped hole that would leak the same amount of air as the building does at a pressure of 4 Pascals.

ACH_{nat}: Estimated annual air changes per hour for a building under natural conditions. This value is calculated from the Effective Leakage Area using the procedure in ASHRAE 136-1993.

SLA: Specific Leakage Area – the Effective Leakage Area divide by the Conditioned Floor Area.

Appendix 2: Changing Definitions of Airtightness

As houses have gotten tighter over the years, the interpretations of infiltration rates using subjective terminology (loose, average, tight, etc.) have changed. What was once considered "unusually tight" for a new home is now the standard, and would be considered average. For the purposes of combustion air requirements, all houses built to the 1980 Act 222 standard are considered "unusually tight construction." A similar increase in expectations of house tightness is apparent in the terminology used for estimating infiltration loads via the ACH method in ACCA Manual J.

The ACH method in Manual J consists of a table of default design infiltration values in air changes per hour. These default infiltration values are grouped into categories based on the tightness of construction. In the latest version of Manual J (8th Edition, 2nd Version), these categories are: Tight, Semi-Tight, Average, Semi-Loose and Loose. Manual J has verbal descriptions of the air sealing details and quality of workmanship that would place a home into one of the above categories. A Manual J practitioner would choose the category that best describes the construction details to be used in the proposed home, and select the appropriate design infiltration value from the table. (These values vary by home size: decreasing as homes size increases.)

Table A2: Estimated design infiltration rates of sample homes and designations of construction tightness from default infiltration rate tables in Manual J.

House	Estimated Design ACH (winter)	Closest Manual J designation (7th Edition)	Closest Manual J designation (8th Edition)
1	0.39	Best	Average
2	0.62	Average	Semi-Loose
3	0.42	Best	Average
4	0.54	Average	Semi-Loose
5	0.27	Best	Average
6	0.30	Best	Semi-Tight
7	0.43	Best	Average
8	0.37	Best	Average
9	0.74	Average	Semi-Loose to Loose
10	0.62	Average	Loose
11	0.36	Best	Average
12	0.43	Best	Average

The Seventh Edition of Manual J, released in 1986, has similar tables of design infiltration values with those values grouped into the categories: Best, Average and Poor. The infiltration values in this table are roughly double the values in the comparable table in the Eighth Edition. In other words, a home with construction classified as "Best" in the Seventh Edition has a default design infiltration rate that is roughly twice the rate of a home of the same size that is classified as "Tight" in the Eighth Edition. The same is true when comparing "Average" with Average" and "Poor" with "Loose." Thus, a home that ACCA considered to be average in 1986 would be considered loose today.

This change in subjective terminology can influence the interpretation of the infiltration rates found in homes tested for this study. By older standards the homes tested in this study would be considered tight homes. Indeed, the infiltration rates of the sample homes were significantly lower than would be expected in older homes. However, by some modern standards for infiltration rates for new construction, the same homes are interpreted, in most cases, as slightly looser than average. Figure A1 below shows a comparison of the estimated design infiltration rates for the sample homes in this study with default rates found in the latest version of Manual J. Estimated design infiltration rates for sample homes were calculated by TECHTITE software using blower door test data and the calculation procedure found in the ASHRAE Handbook of Fundamentals Chapter 27 (Ventilation and Infiltration) and Manual J.

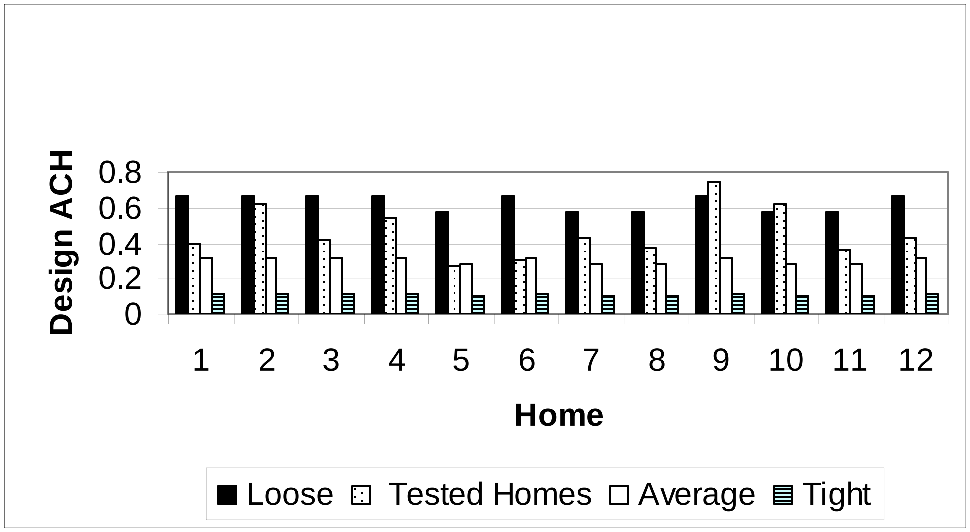


Figure A1: Sample Home Calculated Estimated Design Heating Infiltration Rates vs. Manual J Default Infiltration Rates

Figure A1 shows comparison of the estimated design infiltration rates for the sample homes in this study with default rates found in Manual J. Estimated design infiltration rates for sample homes were calculated by TECHTITE software using blower door test data and the calculation procedure found in the ASHRAE Handbook of Fundamentals Chapter 27 (Ventilation and Infiltration) and Manual J. Using this interpretation, all of the homes tested in this study would be consider Average to Loose, with most being closest to Average.