Supplemental Data #2

A Review of Programs and Standards Relative to Whole-House/Systems Design and Construction: Energy and Environmental Systems

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Abstract:

This report contains an industry overview of home performance as defined in the residential construction market and describes how performance is impacted at various stages of the home building process. Part 1 discusses a variety of programs mainly from an energy and environmental perspective. Part 2 addresses interactions of various systems in homes. Part 3 summarizes two case studies that show how systems approaches have been applied to home building. Part 4 contains a breakdown of the costs and data for the case study homes.

Background

In the residential construction industry, the processes for determining the fundamental level of actual home performance compared to the intended performance are not especially clear. Many builder programs establish performance standards and guidelines, some manufacturers provide training for the installation of their products, and compliance is generally determined by a software evaluation tool or on-site inspection of the final product. The performance of a home relative to standards is only as good as the installation and the process for verifying compliance. However, there is an inherent disconnect between defining performance standards and guidelines and verifying compliance and the appropriate integration of systems throughout the construction process.

This disconnect in the process is especially true for systems that are hidden by other incrementally installed systems. The compliance process still fundamentally relies on the traditional approaches of building code inspections and home warranties. For example, poorly installed house wrap and flashing details are not likely to be evaluated by typical compliance inspections, and performance will only be evaluated by failure and warranty claims. For this reason, this report places an emphasis on key points in the construction process that require inspection and communication guidelines and standards.

Equally important to establishing construction standards is the availability of tools and procedures for designing to and evaluating compliance, as well as strategies for homebuilders to remain competitive while meeting the standards. Applying the concept of system thinking to the entire design and construction process, including components such as site development, construction practices, transportation, and waste management, inherently links the elements of the whole process to an end result that may improve the overall performance of the housing industry. Performance standards and integration strategies applied to the whole process can be effective in enabling and encouraging higher performing homes and communities, reducing environmental impact, and improving marketability.

Introduction

The performance of a home is dependent not only on the performance of the individual systems, but more importantly, the interaction of the systems as a whole. Traditionally, these systems are those that fall under the categories of energy, envelope, and mechanical. Extrapolating this concept beyond the enclosure of the home links the performance of the building to its interaction with the local and regional climate, the community, and the housing market. Standards and measures are established to define the performance of individual systems, the interaction of systems within the building, and the interaction with those things outside the home.

This report is an industry overview of how home performance is defined in the residential construction market and how performance is impacted at various stages of the home building process. This is the first of several deliverables that outline home performance standards and measures, as well as case studies demonstrating the positive and negative consequences of system interactions. While performance standards typically describe characteristics of building components and systems, the processes involved in achieving the standards are also discussed. This report investigates the definition of home performance in several representative builder programs, system integration strategies and related design criteria, and other opportunities for defining performance.

As several of the programs and standards identified in this report define performance criteria relative to benchmark characteristics, an overview of performance measures used in design and evaluation software is also discussed. Finally, as standards drive innovation, and innovation drives standards, out-of-the-box concepts for system and process integration and consolidation are introduced in this report. These concepts, even those that are decades old, may hold solutions to meeting today's system integration and performance challenges, provide insight into tomorrow's housing industry, and identify criteria for integration performance.

A high-level discussion of accessibility, interpretation, and viability of standards is also included throughout this document. The ability to effectively interpret and apply standards is important not only to the performance of the home, but also to the long-term viability of the program. Standards define the intended performance of the home, but the interpretation of standards by designers, architects, and engineers has a significant impact on the actual performance of the home. As with codes, there is likely a workbook or checklist that defines criteria, and there are those who design the home and systems, install the systems, and evaluate compliance with the criteria. However, it is not always clear who dictates the interpretation of standards or who ensures systems are installed to desired standards and properly integrated during construction. Standards define a level of desired performance and a mechanism to evaluate compliance, but give little direction or guidance for actually delivering a high performance home. While codes are fundamental measures of performance, and certainly subject to interpretation, they are not discussed in detail in this report.

Whole House, Community, and Site

This section outlines several builder programs that utilize a whole systems approach to defining home performance through several different approaches. This overview provides a description of system and component classification strategies, program or project standards, and processes for determining and measuring compliance. While this is certainly not an exhaustive overview of existing programs, it serves to demonstrate how performance standards and systems integration are considered in some relatively progressive builder-oriented programs. As the performance of the home is impacted by the entire design and construction process, examples of standards and guidelines related to community, site, and construction planning are also outlined below.

DOE Building America Performance Standards

The Building America program defines the Building America Benchmark through residential system performance as a whole. Through pilot research and delivery projects, compliance goals are based on a performance approach to account for individual site or design variations. The following outlines the classification of systems under the Building America Research and Benchmark Definition:

- Building Envelope
- Space Conditioning/Air Distribution Equipment
- Domestic Hot Water
- Air Infiltration and Ventilation
- Lighting Equipment and Usage
- Appliances and Other loads
- Occupant Loads
- Operating Conditions
- Site Generation

The benchmark is used to track and manage progress towards long-term building energy reduction and for comparison to current regional and builder standards practice. The version of the benchmark definition used for this document is the Building America Benchmark Definition Version 3.1(NREL 2003). It is generally consistent with the 1999 HERS Reference Home as defined by NASEO/RESNET, with additional consideration for loads not included in HERS specification. These include systems other than space conditioning and hot water, such as lighting and appliances. Additional information can be found at the following website:
http://www.eere.energy.gov/buildings/building_america/benchmark.shtml

Accessibility and Interpretation

Building America is an example of a program with limited accessibility, but a high level of defined interpretability. The performance standards are applied by a limited number of specialized Building America partner organizations to pilot homes built by specific builders that have developed research partnerships with each Building America partner. This approach allows a high level of control over how performance standards are achieved from a systems design and integration perspective, in addition to how they are installed and evaluated. This eliminates much of the potential for variability in interpretation through a process of a specialized builder support and collaboration.

Performance Specification and Assessment

The Building America Benchmark provides a point of reference for comparing Building America Prototype design strategies, as well as for comparison to regional and builder standards practice. IBACOS uses this benchmark to develop strategies for meeting pilot home energy performance goals, but also includes strategies for ensuring performance of non-energy related matters as well. Specific case studies will be described in detail in following deliverables (see attachments), but the following outlines general performance standards and measures related to the benchmarking approach.

In order to communicate a strategy to the builder, IBACOS outlines the performance requirements and specifications through nine primary systems. This allows the builder to meet not only energy performance criteria, but also high performance design strategies for less quantifiable aspects, such as durability and indoor air quality. The following is a breakdown of the systems and the general performance requirements. Specifications are not included, as they are detailed and house-specific in most cases. This level of detail will be included in future deliverables outlining case studies.

System #1. Foundation System

There are three general items pertaining to items in this category: Footing, Foundation Wall, and Foundation Seal. The performance requirements include a capillary break between the footing and foundation wall to prevent moisture movement from the ground to the foundation wall, wall insulation and permeability levels, drainage details, and an airtight construction detail between the foundation and wood frame construction.

System #2. Exterior Cladding & Drainage Plane

The Exterior Cladding and Drainage Plane section is also broken down into three main components: Wall Cladding, Drainage Plane/Secondary Weather Barrier, and Flashing. The performance requirements for this section are weather resistance and aesthetic value, water repellency, surface control of water, and control of water behind exterior cladding (protection against moisture penetration and proper exit paths for water).

System #3. Insulation System

The Insulation System comprises of exterior wall cavities, interior foundation walls, attics and vaulted ceilings, ductwork in unconditioned spaces, exterior doors, and vapor retarders. Performance criteria are primarily for reducing conductive heat transfer, but vapor retarders will have installation location and permeability requirements.

System #4. Air Leakage System

This section is divided into sections outlining primary strategies for reducing uncontrolled air infiltration – main air barrier, draftstopping, foaming and sealing, weather-stripping, and the sill plate treatment. With the approach specific to each home outlined, the overall air leakage is measured and defined by the number of air changes per hour (ACH) at 50 Pa as tested by a blower door.

System #5. Framing System

Optimum Value Engineering (OVE) framing techniques are specified to allow for complete insulating of the exterior walls and employs strategies such as ladder framing for interior wall junctions with exterior walls and two stud corner framing. Under the framing system, a requirement for designing and adjusting the framing layout to facilitate the placement of ductwork influences the efficacy of the forced air system.

System #6. Glazing System

While there is a significant energy-related impact associated with the area of the glazing system, the performance requirements in this section are specific to material and window type, along with National Fenestration Rating Council (NFRC) rating criteria. These requirements are generally resistance to conductive heat transfer (U-value), Solar Heat

Gain Coefficient (SHGC), and gas-fill type, but can also include Visible Transmittance, Air Leakage (AL), and Condensation Resistance (CR).

System #7. Space Conditioning System

The performance of space conditioning equipment is defined through specifications for the furnace, evaporator coil, condensing unit, water heater, mechanical air filter, and the thermostat. The gas furnace criteria involve the combustion venting strategy, Annual Fuel Utilization Efficiency (AFUE), design temperature and load, and a target total airflow through the unit. The air conditioner specifications are the Seasonal Energy Efficiency Rating (SEER), sensible heat ratio, total and nominal capacity, pressure drop across the evaporator coil, as well as entering and operating temperatures. Other rating and performance criteria may exist in this section when different equipment is used, such as Coefficient of Performance (COP) for when central heat pump systems are used.

The water heater performance related criteria are the combustion venting strategy, energy factor (EF), recovery efficiency, and capacity. Heat Pump water heater efficiency may be expressed in EF or COP.

The mechanical air filter ratings are given in efficiency using the ASHRAE method, or in Minimum Efficiency Reporting Values (MERVs).

Thermostats are generally programmable and specifications will change depending on the systems installed. Factors to consider are number of programmable days, stages of heating and cooling, and capability to add and control other systems, ventilation and humidity control for example.

System #8. Duct System

The duct system will be designed in coordination with the forced air equipment, and engineered in accordance with ACCA Manual J and D. Material specifications and installation methods are generally provided, including duct tightness minimums. Examples of these considerations are eliminating the use of building cavities as ductwork, pressure balanced return strategies, minimizing ducts in unconditioned spaces, and when needed, duct insulation levels. Air tightness is generally given in terms of percent of system airflow rate as measured by a duct pressurization test unit (such as the Duct Blaster™) at 25 Pa.

System #9. Ventilation System

The ASHRAE 62.2 Standard governs ventilation requirements, but additional performance criteria can be considered when specifying ventilation equipment. While ASHRAE 62.2 specifies whole house and source ventilation for kitchens and bathrooms, requirements, controls, and control strategies to meet the requirements must be considered. The noise rating for ventilation fans, given in units of sones, and whether the unit is rated for continuous duty are other factors in selecting ventilation fans.

Built Green® Colorado Performance Measures and Standards

Built Green® Colorado is one of the largest green building programs in the country, with over 100 builder members in Colorado, in addition to sponsor and industry leader members. The program involves voluntary participation with the intention of encouraging builders to use products and practices that provide greater energy efficiency and reduce pollution, provide healthier indoor air, reduce water usage, preserve natural resources, improve the durability, and reduce maintenance. Builders enroll in the program, and register homes built to program standards.

Every home registered with the Built Green® program must meet the program criteria, through complying with minimum standards and choosing a set of additional measures that provide a point total qualifying the home as Built Green®. Certified E-Star raters determine compliance. E-star Colorado is an independent, non-profit agency that certifies home energy raters.

Tier I compliance is divided in twenty-three sections, beginning with the minimum energy efficiency requirement and ending with water conservation. Many of the features go beyond the conventional definition of system performance to include interaction with the environment and even material transport issues. Tier II and Tier III compliance requires more systems-based diagnostics and incorporates a whole house systems based approach. This section of the report outlines the twenty-three categories for Tier I, followed by a description of Tier II and Tier III standards and guidelines.

Accessibility and Interpretation

The Built Green® Colorado program standards are very accessible through the website, or a published document, which outlines standards for compliance. However, unlike the specialized entity in the Building America program, the interpretation of the standards is dependant on someone in the builders' network of designers. HERS raters will certify compliance, but do not provide assistance during the design and implementation stages. Tier II and Tier III begin to address this through integrating more specialized mechanical system design compliance, for example, but there is still a significant amount of potential variability in how standards are interpreted. The person(s) responsible for interpreting and applying the standards should be well versed in whole house design and systems integration in order to effectively produce high performance results. Currently, there are no provisions that define the desired capabilities of this person or persons, to impact how well standards are applied.

Tier I Compliance and System Categorization

Builders must meet minimum energy standards through one of three prescribed methods: E-Star rating of 82 points, chapter 5 of the IECC, or Chapter 11 of the IRC 2000. Then, in order to complete the certification, they must choose other compliance items that give a point total of 70 or more. Some items require independent verification or other form of verification that the measure actually meets the standard. See www.builtgreen.org for complete details.

I. Energy Efficiency: Minimum Requirement

II. Energy Efficiency: Envelope
III. Energy Efficiency: Mechanical Systems
IV. Energy Efficiency: Water Heating
V. Energy Efficiency: Appliances
VI. Energy Efficiency: Lighting
VII. Materials: Foundation
VIII. Materials: Structural Frame
IX. Materials: Sub-floor
X. Materials: Windows
XI. Materials: Doors
XII. Materials: Insulation
XIII. Materials: Exterior Wall Finishes
XIV. Materials: Roof
XV. Materials: Finish Floor
XVI. Materials: Cabinetry and Trim
XVII. Heath and Safety: Indoor Air Quality
XVIII. Health and Safety: Moisture Management
XIX. Resource Conservation: Land Use
XX. Resource Conservation: Materials Reduction
XXI. Resource Conservation: Materials Re-Use
XXII. Resource Conservation: Waste Reduction and Recycling
XXIII. Resource Conservation: Water

Tier II and Tier III Compliance and System Categorization

Tier II and Tier III incorporate a whole house approach and increased consideration for the house as a system of interacting components. The general goals of Tiers II and III are outlined below, with letter reference to compliance description in the table in Appendix A. The tables in Appendix A are directly from the Built Green® website and outline Tier II and Tier III requirements and commissioning/verification. The categories used for the Tier II and III are listed below with a summarized description of the standards addressed in each.

General Goals of Tier II and III:

A. **Health/Safety** – combustion safety, ventilation, pressure differentials, house/garage boundary, performance testing, minimizing indoor pollutants with material choices
B. **Comfort** – minimizing temperature differentials in conditioned space, indoor relative humidity, "inherently comfortable" design using ACCA RS, performance testing to verify design specifications
C. **Durability** – moisture management strategies, select materials to increase building life, minimize replacement costs and impact on landfill.

D. **Energy Efficiency** – System analysis of HVAC design/installation, increase standards for building envelope, performance testing, reduce operating costs

E. **Environmental Impact** – efficient use of natural resources, green products, minimize environmental "footprint," water conservation, construction waste recycling and diversion from landfill.

Categories for Tier II and Tier III: The list below is a summarized version of the requirements for compliance, highlighting key standards or methods. The full text and commissioning and verification process is provided in Appendix A.

- HERS Score – Tier II: 86 minimum, Tier III: 88 minimum
- Ventilation – Controlled mechanical ventilation system meeting ASHRAE 62.2, make-up air for range hoods over 200 cfm, HRV for Tier III.
- HVAC equipment sizing – ACCA Manual J specifications
- HVAC equipment products/efficiency – power or direct vent, or sealed combustion
- HVAC Ductwork – maximum 10% leakage of rated system flow, no building cavities, etc.
- House Tightness – house-to garage tested for IAQ purposes
- Envelope – Low-e in all above-grade windows
- Indoor Air Quality – power vented water heater, sealed gas fireplace, garage air sealing
- Lighting and Appliances – see 2004 Checklist
- Moisture Management Strategies – foundation perimeter drains, flashing details, etc.
- Water Conservation – see 2004 Checklist
- Lumber Reduction/Responsible Wood Use – see 2004 checklist
- Material Resource Efficiency (non-wood) – see 2004 checklist
- Waste Reduction and Recycling – see 2004 Checklist
- % Builder Commissioning – 25% of homes tested for Tier II, 100% for Tier III

EarthCraft Home – Southface

The EarthCraft House™ program is a voluntary green building program that was first developed for new construction in 1999 and was modified in 2001 for use in renovation. The program uses a point system to score, or rate, the home's compliance to program specifications, including energy consumption, the use of "green" construction materials, site water management, combustion safety, ventilation, etc. when generating the home's score. They have expanded the certification program to include renovations, including a breakdown of required certification points by the scope of the retrofit: renovations that do not add conditioned space, renovations that add conditioned space without changing the exterior shell of building, renovations that change exterior shell of building but use the existing foundation, and renovations that add a foundation.

Accessibility and Interpretation

Like the Built Green® Colorado program, the EarthCraft Home™ program standards are very accessible to builders in the form of a workbook and checklist, but the actual interpretation and application is left to an individual in the builder's design team. In order to become an EarthCraft Builder, the builder must join the local HBA, join the Earthcraft Home™ program, and attend a one-day training session. A design review and pre-drywall walk-through by Southface Institute is required for every certified home. In addition, there are training events sponsored by the local HBA in improved practices. However, this still leaves interpretation to the builder's team initially, which is the most critical point during the design process for effective implementation. Standardization in the processes for designing to and determining compliance early in the design stage, by individuals trained in the concepts of high performance homes and whole house solutions, may help to facilitate the adoption of whole house and site performance standards with a greater level of quality.

Categorization of Systems

Each primary category has a pre-requisite minimum standard with points to be gained for additional measures. An EarthCraft House™ certification requires 150 points. A quick 90 points can be earned with an Energy Star® certification. The following is a description of the new construction guidelines for Earthcraft Home certification, starting with the system classification strategy.

<u>Site Planning</u>

Prerequisite: Comply with all federal, state, and local government erosion control and tree protection measures
Example upgrade: tree preservation plan, erosion control plan

<u>Energy Efficient Building Envelope and Systems</u>

Prerequisite: Must meet or exceed Georgia Energy Code (MEC 1995 with Georgia Amendments)
Example upgrade: Certify home as Energy Star® or earn points through improvement in sub-categories of air leakage, insulation, windows, heating and cooling equipment, and duct work/air handler.

<u>Energy Efficient Lighting and Appliances</u>

Prerequisite: None
Example upgrade: automatic outdoor controls, fluorescent lighting, energy efficient refrigerator

<u>Resource Efficient Design</u>

Prerequisite: None
Example upgrade: home smaller than 2100 sq.ft., wall studs at 24 in. centers, drywall clips

<u>Resource Efficient Building Materials</u>

Prerequisite: None
Example upgrade: recycled and natural content materials, advanced and engineered materials, durability

Waste Management

Prerequisite: No construction materials burned or buried on job site or anywhere but in a state-approved landfill.

Example upgrade: a number of measures under sub-categories of Waste Management Practices and Recycle Construction Waste.

Indoor Air Quality

Prerequisite: No unvented combustion fireplaces or space heaters are permitted

Example upgrade: several options in areas of Combustion Safety, Moisture Control, Ventilation, Materials

Water – Indoors

Prerequisite: All fixtures must meet low flow standards from the National Energy Policy Act

Example upgrade: high efficiency clothes washer, solar domestic water heating, water filter

Water – Outdoors

Prerequisite: None

Example upgrade: xeriscape, drip irrigation, timer on irrigation system

Homebuyer Education

Prerequisite: None

Example upgrade: guaranteed energy bills, built-in recycling center, review energy options with homeowner

Builder Operations

Prerequisite: None

Example upgrade: warranty standards from HBA Homeowner Handbook, Certified Professional Homebuilder

Bonus Points

Prerequisite: None

Example upgrade: site located ¼ mile from mass transit, solar electric system, American Lung Association Health House

More details are available at the EarthCraft Home website.

Environments for Living® – Masco Contractor Services, Inc

Environments for Living® (EFL) is a new home certification program that is performance based, and provides limited guaranteed performance related to heating and cooling energy use and comfort. According to the program description, homes that meet program requirements have increased durability, enhanced indoor air quality, and manage indoor moisture better than homes that do not meet program criteria. Seven reasons for using this program are listed on the organizations website:

- Tight Construction
- Fresh Air Ventilation
- Improved Thermal Systems
- Correctly-Sized HVAC Equipment
- Pressure Balancing
- Interior Moisture Management
- Combustion Safety

Accessibility and Interpretation

A builder who submits a home for certification under the EFL program requiring a plan review and post-construction inspection, is responsible for interpreting the program standards to his or her best ability. Despite the guidance of performance standards, there is still plenty of room for variability in interpretation and may require a higher level of specialization to effectively achieve the desired end result. This is another example of a program that dictates performance standards and evaluates compliance, but does not provide a significant amount of direction or assistance in actually delivering a high performance home.

<u>Program Requirements and Performance Criteria:</u>

The EFL performance criteria are divided into nine sections beginning with the Builder's Responsibilities. Builder responsibility to comply with program criteria and local building codes is not discussed in this section. Climate zones are defined in the February 2002 ASHRAE Journal. The following is a summary of performance criteria:

<u>Framing</u>

The framing criteria section states that a continuous air barrier will be established throughout the structure enclosing the conditioned space. In this program, air barriers define the location of the pressure boundary, which is defined as that location where 50 percent or more of the air pressure drop across an assembly occurs. While it is not explicitly stated in the listed criteria, it is assumed that this is determined using a blower door test.

The conditioned space definition references the International Residential Building Code for One and Two-Family Dwellings (2000), and defines that any area within a building with a heating/cooling system capable of maintaining a minimum of 50°F during the heating season and 85° during the cooling season, or that directly communicates with the conditioned space, as a conditioned space. Defining a conditioned space by its connection to a conditioned space is a little misleading, but this approach appears to attempt to bring some clarity to how areas like basements and garages should be considered in the context of the whole house.

Thermal Envelope

Insulation will be installed to manufacturer's specifications with special attention to avoiding gaps, voids, compression, and wind intrusion. The insulation and air barrier must be installed in physical connection with each other. Insulation levels are defined by local building code or IECC, where applicable.

Gold and Platinum level homes have particular window specifications to meet program criteria:

- Solar Heat Gain Coefficients (SHGC) – cold climate specifications are 0.53 or lower, while all other climates must utilize units with am SHGC of 0.40 or lower.
- U-values – cold climate specifications are 0.35 or lower, while other climate zones are 0.75 or lower.

Air Sealing

The performance criterion for the air tightness of the home is defined for each level of program compliance and uses a blower door test to determine compliance. The performance criterion is outline as follows:

Silver: 0.50 cfm or less per square foot of envelope area at 50 Pa
Gold: 0.35 cfm or less per square foot of envelope area at 50 Pa
Platinum: 0.25 cfm or less per square foot of envelope area at 50 Pa

Mechanical Systems

Heating and Cooling System Design and Performance

The Environments for Living program requires a submittal demonstrating that each heating and cooling system is sized according to ACCA Manual J room-by-room load calculations. Airflow to each room from the forced air system must be within 10 percent of the average requirement, based on ACCA Manual J and the average of four orientations of the home.

Furnaces, water heaters and boilers in conditioned spaces (including basements) are to be sealed combustion units, and vent-less fireplaces and space heaters are not permitted. All other combustion appliances must be vented to the outside.

This program also addresses refrigerant charge of the air conditioner, through requiring charging to manufacture's specifications, and any brazing/soldering of the refrigerant lines must be done with and inert gas. Indoor and outdoor HVAC equipment must be matched according to the ARI directory.

Ductwork

Ductwork criteria are based on insulation values and air tightness requirements, with differential requirements for each compliance level. Duct tightness is measured at 25 Pa using a duct pressurization test. The following outlines duct performance criteria, and assumes this is total system leakage:

- All ductwork in unconditioned spaces are to be insulated to R-6, and sealed with a UL listed mastic.
- Duct tightness is defined for each certification level:
    - Silver: Maximum leakage of five percent of the conditioned floor area in cfm at 25 Pa or seven percent of system airflow at high speed.
    - Gold: Maximum leakage of three percent of the conditioned floor area in cfm at 25 Pa or five percent of system airflow at high speed.
    - Platinum: Maximum leakage of three percent of the conditioned floor area in cfm at 25 Pa or five percent of system airflow at high speed. For a duct system that is completely in the conditioned space, the criterion increases to seven percent of the conditioned floor area or ten percent of the high-speed fan flow.

Ventilation

The criteria in this section are for whole house ventilation needs, as well as spot ventilation for kitchens and bathrooms. Outside air supplied by supply-only or balanced ventilation systems must be filtered and have a means of control. The following describes ventilation requirements under this program:

- Whole House Ventilation: Minimum ventilation is defined by 0.75 cfm per person plus 0.01 cfm per square foot of conditioned floor area. The number of bedrooms plus 1 defines the number of people per home. Any ventilation requirements that exceed the minimum requirements by 10 percent must be accounted for in the load calculations.
- Kitchen ventilation at the cooking station must be capable of exhausting 100 cfm to the outside.
- Bathroom ventilation must be capable of exhausting 20 cfm continuous of 50 cfm intermittent to the outside.

<u>Pressure Balancing</u>

Pressure balancing criteria defines the pressurization of individual rooms with respect to outside when all interior doors are closed and the forced air system is operating. This defines the effectiveness of the return side of the forced air system. Each room is not to be over- or under-pressurized by 3 Pa outside, with the exception of bathrooms and laundry rooms.

<u>Carbon Monoxide Detectors</u>

Hardwired carbon monoxide detectors are to be installed in all homes with attached garages, fireplaces, wood stoves, or other combustion appliances. A minimum of one per story or house level, placed near or outside sleeping areas. For homes with more than one sleeping area, a detector must be placed near each one. Any bedroom with a fireplace must have a detector in the room in addition to the one outside the room. Homes that have elevators that open to a garage must have a detector installed near each elevator door opening to the interior.

Moisture Management

The Energy and Environmental Building Association (EEBA), with other additional specifications, specifies water management in this program. Moisture that enters any building assembly must be able to dry to the interior or exterior of the home. In hot-humid, mixed-humid, cold, and hot-dry/mixed-dry climates, as defined by the February 2002 ASHRAE Journal, the following materials are not to be used on the interior of walls and ceilings:

- Low perm paints (less than 1 perm, ASTM E96)
- Vinyl wall paper
- Sheet polyethylene
- Any low perm material (less than 1 perm, ASTM E96)

Energy and Environmental Building Association (EEBA) Criteria

EEBA publishes criteria on their website for recommended practice for the design and construction of energy and resource efficient buildings. The segmentation of the criteria is as follows: Component Criteria, Indoor Environment Criteria, and Environmental Impact Criteria. Each primary section is broken down into subcategories of Building Structure, Mechanical Systems, and Occupant Considerations. As air leakage and duct leakage require further explanation, a special section discussing these issues is also included. These sections of EEBA's criteria, discussed in this report, are the more quantitative criteria, while other sections discuss more qualitative goals and objectives. The following is a summary of how criteria are addressed in each category.

Accessibility and Interpretation

The EEBA criteria are reasonably accessible to any builder, but they do not apply to a specific builder program. Due to this generalization, there is little guidance for climate variability. These guidelines may define criteria related to characteristics of a high performance home, but it will also require a high level of specialization by the individual responsible for interpreting and applying the standards to their house type(s), climate, and desired end result. This is especially important in understanding how the criteria will impact the other systems and the house as a whole.

Component Criteria

There are too many to include in the following lists. See Appendix B or the EEBA website for a complete list.

A. Building Structure –

1. Energy Star compliance (30 percent better than 1993 Model Energy Code) determined by accredited HERS procedure
2. Infiltration less than 2.5 in2/100 ft2 leakage ratio (CGSB, calculated at 10 Pa differential pressure), 1.25 in2/100 ft2 leakage ratio (ASTM, at a 4 Pa pressure differential), 0.25 cfm/ft2 of building envelope surface area at 50 Pa pressure differential

B. Mechanical Systems –
1. Controlled mechanical ventilation for minimum 20 cfm per master bedroom, 10 cfm for each additional bedroom when house is occupied
2. Exterior duct leakage limited to 5.0 percent of the total air handling system rated air flow at high speed (as measured by pressurization)
3. Lighting power density not to exceed 1.0 Watts per square foot

C. Occupant Considerations –
1. Controls for space conditioning, hot water, and lighting must be clearly marked, and any information on the operation and maintenance must be provided to the homeowner.
2. Designer and general contractor should provide information on safe, healthy, comfortable operation of the building and the mechanical systems

Indoor Environment Criteria – ASHRAE Standard 55-1989 (Addendum 55a-1994) defines comfortable indoor conditions for energy and resource efficient construction.

A. Building Structure –
a. Utilize radon resistant construction practices as referenced in ASTM Standard E-1465-90, “Radon Resistant Design and Construction of New Low Rise Residential Buildings”
b. Building assemblies should be designed and constructed to allow drying of interstitial spaces

B. Mechanical Systems –
a. Design forced air systems to provide balanced airflow to all conditioned spaces, with no more than 3 Pa inter-zonal pressure difference
b. Indoor humidity controlled to a range of 25 – 60 percent, and air filtration with a minimum atmospheric dust spot efficiency of 30 percent (from ASHRAE Standard 52.1-1992)

C. Occupant Considerations –
a. Operators manual with instructions on maintaining a healthy indoor environment
b. Control systems should include an alert for “trouble” or “failure” modes

Environmental Impact Criteria

This section states that energy and resource efficient construction should be designed, constructed, and operated to reduce overall life-cycle impact on the environment. Considerations for energy use, resources use and labor inputs should be included for fabrication, erection, modernization, operation and disassembly of the building, components, and systems. Use of recycled materials and content, and minimization of scrap, and designing for disassembly should also be considered.

American Lung Association Health House®

The American Lung Association developed builder guidelines to improve the indoor air quality in newly constructed homes, and labeled the program Health House®. This program focuses on defining home performance through indoor air quality. This program provides Builder Guidelines (with climate appropriate guidelines coming soon), a builder-training curriculum, and each home built to program standards will have home analysis report-on-site inspection and assessment of the home's performance. This program explicitly includes commissioning in the builder guidelines.

The program defines standards and guidelines with the following categorization. Each section listed below includes a summary of the task under each category.

SITE

1.1 Assess the site – review ambient air quality records, current and planned use of the adjacent property, water and soil sampling
1.2 Orient the building – climate tempering and use of daylight
1.3 Prepare the site – manage on-site water and landscaping design (non-allergenic and pest resistant)
1.4 Use Integrated Pest Management (IPM) – building and site inhospitable for pest animals and plants

BUILDING ENVELOPE

2.1 Building envelope design to manage moisture migration – allow walls to dry to interior or exterior or both as dictated by climate
2.2 Provide proper foundations
2.3 Wall requirements – water drainage, permeability, pest control, insulation
2.4 Doors and Windows – window selection and proper installation
2.5 Entryway – storage, track-off system
2.6 Review attic – conditioned or unconditioned attic
2.7 Review roof – roof pitch, overhang, gutters and drains, flashings, IPM
2.8 Garage – slope, airflow control

FINISHES AND FURNISHINGS

3.1 General guidelines – follow manufacturer's directions, durability and cleaning, "age" products before installing, porous materials, ventilation
3.2 Flooring systems and floor coverings – concrete sub-floor, hard-surfaced flooring, carpet products
3.3 Paints and Varnishes – low VOC products, varnishes, MSDS sheets, ventilation guidance
3.5 Composite materials – when to avoid composites and what to do if they must be used
3.6 Caulks and adhesives – alternative to caulk and low VOC products
3.7 Planters – avoid indoor planters or proper drainage system

MECHANICAL EQUIPMENT

4.1 General Guidelines – easy to use equipment, easy to access, easy to understand

4.2 Ventilation – adequate ventilation, filters, and air distribution

4.3 Humidity control – maintain humidity below 60 percent year round, proper sizing of air conditioning, and control of central dehumidification

4.4 Lighting Guidelines – recessed lights in insulated ceilings must be airtight and IC-rated

4.5 Water treatment – remove chlorine compounds, storage of water treatment chemicals

COMMISSIONING

5.1 HVAC System – measure airflows, inspect equipment – debris and cleanliness

5.2 Seal ducts – seal ducts to avoid contamination during construction

5.3 Ventilate before occupancy – highest rate ventilation between finishing and occupancy by the ventilation system

5.4 Provide owner's manual – operating and maintenance instructions, equipment specifications, load assumptions, product information an all adhesives, cabinets, finishes, etc.

5.5 Provide "As-Builts"

CONSTRUCTION HYGENE, SAFETY, AND HEALTH

6.1 Keep the site clean – wall cavities, ducts, and mechanical equipment

Solar Access in Community and Site Planning

When considering solar design strategies, whether active or passive, site exposure to solar access is critical. When considering whole house design strategies that utilize solar systems or strategies to offset water heating, space heating, or other electrical loads, integrating the site plan with other design components in the home will help to optimize the overall house performance. Properly designed window shading strategies, for example, can reduce cooling loads during the summer and heating loads during the winter, but the orientation of the home with respect to the sun's path and the site characteristics must be an integral component of the design approach. Other buildings in close proximity can interfere with a site's access to adequate insulation. Several communities, including the City of Boulder, Colorado, the City of Portland, Oregon, and Berkeley, California, adopted standards governing a site's right to solar access and defining structure orientation standards. The following example is from the City of Boulder, Colorado Solar Access Guide.

City of Boulder, Colorado

Boulder, Colorado enforces a city ordinance guaranteeing access to sunlight for homeowners and renters in the city. Based on providing a four-hour period of sunlight on December 21 (the shortest period of daylight in any given year), the protective ordinance is defined by a 12 or 25-foot hypothetical "solar fence" depending on the Solar Access Area in which the property is located. The process involves developing a "shadow analysis" to ensure that all shadows that are cast by a proposed building or addition fall only within the property lines.

Boulder, Colorado goes beyond just defining a site's right to solar access to setting standards for solar siting in new construction developments. The orientation of the structure on the site is critical in optimizing the impact of solar gain on heating and cooling loads. All units in new developments in the City of Boulder, which do not specifically incorporate solar features, must include the following items to the maximum extent possible:

- Long axis of the home within 30 degrees of east-west;
- Roofs which are physically and structurally capable of supporting at least 75 square feet of solar collectors per dwelling unit; and
- Unimpeded solar access through provisions of this ordinance or through private covenants.

There are exceptions to this requirement that would allow this siting requirement to be waived, including the incorporation of solar energy systems or other renewable energy sources.

More information on Community Solar Access concepts, such as solar site design, solar landscaping, and solar building design, as well as resources for specific approaches to this concept can be found at the flowing website: http://www.eere.energy.gov/consumerinfo/refbriefs/ja1.html

Integrated Systems - Heat Pumps and Municipal Water Supply

The primary function of infrastructure in a municipality is for providing services related to electricity, water supply, and wastewater removal, and transportation. Short of ensuring service is adequate, little consideration is placed on how these systems affect the performance of a home. Site and community management of rainwater is important for maintaining dry foundations and streets, circulation and control of transportation impacts traffic noise and community safety, and municipal water supplies and sewage treatment offset costs, maintenance, and health and safety issues associated with wells and on-site waste treatment.

This section describes a concept gaining residential industry interest that directly integrates the characteristics of a municipal water supply system to a home's comfort and energy efficiency. Waterfurnace International, Inc. and Hardin Geotechnologies have introduced a concept called Water+, which utilizes the municipal water supply as a heat source and heat sink for geothermal heating and cooling units. Municipal water supply water is piped to the house, through water-to-air heat pump units, then back to the water supply at a slightly different temperature, depending on whether the unit is in the heating or cooling mode. According to the joint effort by these two companies, this system provides benefits to users, utilities, and developers, in addition to the potential large-scale reduction in carbon emissions. The benefits listed below are directly from the Water Plus website.

Benefits to Users

- Heating and cooling savings up to 70%
- Reduces equipment installation cost

Benefits to Utilities

- Increases utility revenue
- Maintains and often improves the integrity of the water supply

Benefits to Developers

- Reduces installation costs of HVAC systems
- Reduces maintenance costs

- Lower maintenance costs
- Reduces or eliminates need for internal pumping
- Less space required for mechanical room
- No roof penetrations or outdoor units
- No flames, fumes or combustion
- Longer life of HVAC equipment

- Balances water use throughout the year
- Positions the utility as an ally for new homes and businesses
- Keeps energy dollars in the local economy
- Reduces total water consumption
- Positions the utility and municipality as environmentally friendly

- Provides additional source of revenue
- Flexible and easily expandable
- Can use geothermal technology in areas that might be impractical for closed loop systems

This type of system introduces performance standards and measures not commonly applicable to residential heating and cooling systems. Such as standards to protect against backflow, significant temperature changes in the water supply, and potentially water quality. When designing these systems, the location of treatment plants, direction of flow, size of water mains, and the design of the system grid must be carefully considered.

Minimizing construction waste and maximizing material savings

Deliberate strategies for reducing residential construction waste can save money for builders, reduce impact on landfills, and in the end result in a higher performing home for the homeowner. Efficient design, framing, construction practices can reduce material use and cost, and reduce the amount of material that goes to the dumpster. Recycling of construction waste reduces disposal costs and diverts material from landfills. The management of construction waste is linked to the entire construction process and standards may have a significant impact on the resulting home. Savings from material and disposal costs can be used for other systems performance improvements, and techniques like efficient framing (discussed in greater detail in the Building America section of this report) can actually improve the thermal performance of the home.

According to the Southface Journal of Sustainable Building, sixty to eighty percent of construction waste is wood, drywall, and cardboard. This article reviews several case studies performed by the National Association of Home Builders (NAHB), citing waste as a potential resource with economic and environmental benefits. The case studies demonstrated that advanced framing techniques resulted in approximately a 65 percent reduction in wood waste generation, translating to a savings of $100 in disposal costs.

According to a separate NAHB article, there are several key reasons to improve management of the material stream in residential construction. A typical builder pays about $511 per house for construction waste disposal, and costs may only increase as old landfills close. The article states that materials wasted on site are paid for twice – once at the initial purchase and again for disposal. In addition, improved management strategies will protect the builder against unauthorized or unregulated disposal of hazardous materials. In the end, the builder's commitment to efforts for protecting the environment may be a marketing tool.

Standards and guidelines can be beneficial in reducing construction waste from both ends of the construction process. Designing for and incorporating efficient construction practices and waste minimization strategies can help reduce the amount of waste generated on site. Specifying recycled materials and developing program guidelines to include recycled materials can increase market demand for recycled products. The Built Green Colorado ™ program is an example of this approach. Points are awarded for the use of materials containing recycled content, but also for reduced framing material packages, for example. See program details in Appendix A and the Built Green website for more information and specific requirements.

Individual System Performance

Whole house and program standards are comprised of many subsets of individual standards and guidelines, but many systems and performance criteria can be ignored, left to chance, or just have yet to be incorporated. This section of the report provides an overview of industry activity not normally included in most production builder programs, or that is related to emerging technology and systems. While the building industry begins to focus on improving the overall performance of production homes, greater emphasis on the operating performance and integration of sub-categories of systems may prove to be incrementally effective in meeting overall objectives.

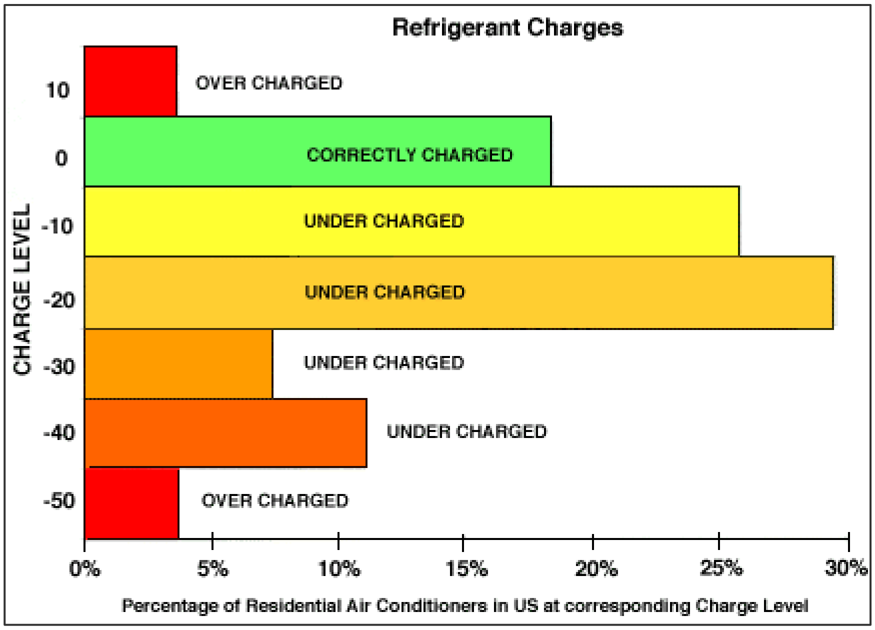
The following sections provide examples of industry activity related to the operating performance of central air conditioning, lighting, ventilation, acoustics, and on site power and hot water generation. These systems and associated performance standards are critical paths in whole house performance and demonstrate the importance of intermittent compliance inspections. For example, a program may specify a 12 SEER air conditioner, but the efficiency is only as good as the level of refrigerant charge and airflow across the coil.

Air conditioner performance measures and standards

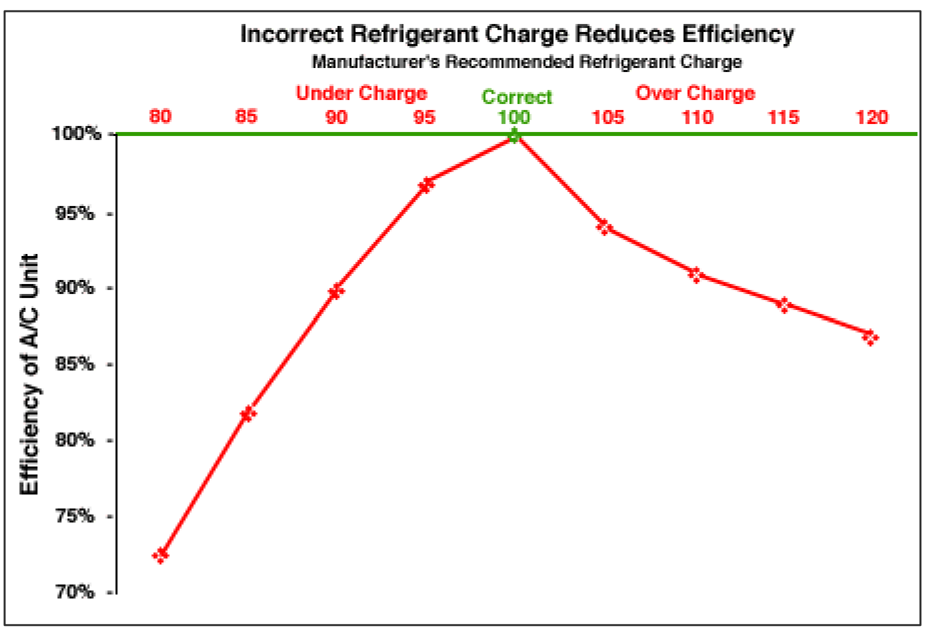
Air conditioner performance standards, related to the impact on the house as a whole, focus on sizing and efficiency, but rarely on refrigerant charge and airflow. Proctor Engineering Group developed the CheckMe!™ evaluation to precisely check for problems with refrigerant charge and airflow. While it was originally developed for existing systems, a version called CheckMe! Install© was developed for new central air conditioners.

According to Proctor Engineering Group, problems with refrigerant charge in older air conditioning units is likely due to problems during the original installation or during a servicing that used more traditional methods of approximating refrigerant charge. As most air conditioners provide enough refrigerant from the factory for twenty-five feet of tubing, adjustments to the refrigerant charge must be made if the line-set is more or less than twenty-five feet. Problems can occur if this is not properly done.

In a recent study for Arizona Public Service, reported by Proctor Engineering Group, only eighteen per cent of all units were properly charged. Seventy-eight percent were undercharged, while only four percent were overcharged. A ten percent undercharge can reduce the air conditioners capacity by ten percent.



Source: Proctor Engineering Group



Source: Proctor Engineering Group

Airflow rates are critical to proper air conditioner operation as well. According to Proctor Engineering Group, twelve different studies found that seventy percent of all home air conditioners have inadequate airflow, with an average of twenty percent below manufacturer's recommendations. The combined performance of refrigerant charge and airflow in air conditioners, and an accurate method to measure the performance, are important components in indoor air quality (through humidity control), comfort, operating costs, and durability.

Acoustic Performance Measures and Standards

Residential acoustic considerations may include reducing sound transmission between interior rooms, through transfer grilles, between inside and outside, and from noises generated by mechanical equipment. However, as new materials and systems are introduced in production building, an increased consideration for noise exposure may serve to define a component the overall performance of a home. Noises produced by air-conditioning compressors, airplane and car traffic, poorly designed and installed HVAC systems, and ventilation fans may interfere with daily life, reducing the perceived quality of the home. The excessive noise may generate homeowner complaints or limit the use of noise producing equipment. This can be problematic if homeowners are deterred from using the ventilation fans because of noise. An example of acoustic performance of ductwork, from ACCA Manual D duct system design guide, is outlined below.

Duct System Velocity

If velocity gets too high in duct runs or at the register grille face, the associated turbulence can create a level of noise that some occupants may find objectionable. Considering this potential, ACCA Manual D explicitly defines airflow velocity limits when designing residential duct systems. These values are listed in Table 3-1 of ACCA Residential Duct Systems Manual D, which is the source for the data in Table 1 below.

Table 1. Recommended and Maximum Velocity in Duct Systems – Manual D

	Supply				Return			
	Recommended		Maximum		Recommended		Maximum	
	Rigid	Flex	Rigid	Flex	Rigid	Flex	Rigid	Flex
Trunk Ducts	700	600	900	700	600	600	700	700
Branch Ducts	600	600	900	700	400	400	700	700
Supply Outlet Face Velocity	-		700		-		-	
Return Grille Face Velocity	-		-		-		500	
Filter Grille Face Velocity	-		-		-		300	

Lighting and Daylighting Performance and Standards

High performance residential lighting systems can enhance the visual quality of interior spaces, improve the ability to perform specific tasks, and improve the overall energy efficiency, but it requires a high level of integration between the parties involved. Designing and installing residential lighting systems consists of a complex set of variables, including aesthetic, technical, and control criteria. Performance standards exist for lamp and luminaire characteristics, surface illuminance, contrast, architectural enhancement, etc., but it is critical that the installation is performed properly to ensure design goals are met. In addition, lighting systems can increase the cooling load of a home through introducing a heat source, and increase the air infiltration through equipment such as non-IC rated recessed downlights.

It is useful to discuss residential lighting in the context of High Performance Lighting (HPL) systems as they encompass many of the criteria that define quantitative and qualitative performance. Typically, residential lighting is based on the use of inefficient incandescent lamp sources, but utilizing an HPL approach can improve the quality of lighting and reduce whole house energy use. This section discusses criteria used in defining lighting system performance, the impact on whole house energy use, and the incorporation of daylighting in residential applications.

Lighting Design Criteria

When discussing high performance lighting, there are three primary categories of lighting levels: ambient, task, and accent. Ambient provides general illumination and provides light for navigation. Task lighting provides illumination for specific activities, such as reading, writing, and computer use. Accent lighting adds sparkle and liveliness to the visual scene (Holton, 2003). Primary considerations when using a HPL approach to design residential lighting are:

- Relationship to the architectural character of the home
- Observance of Illumination Energy Society (IES) light level guidelines
- Relationship to room functions
- The use of concealed source lighting
- Room surface reflectance
- Perception of room form
- Lamp characteristics
- Fixture technology

Lighting design requires much aesthetic consideration, but there are fundamental technology based criteria that must be understood to produce a functional and aesthetically pleasing design. Many of these characteristics must be considered throughout the design phase, but the most quantitative performance standard is defined by IES guidelines. These criteria are related to tasks and a consideration for the average age of the people performing the task. The following table lists the foot-candle requirements for specific tasks. The source of this specific table is from an Expert Meeting Summary Report (IBACOS 2003) held at IBACOS in May 2003.

Table 2. Horizontal I luminance goals

Task	IES Guideline (fc)	40 to 55 years of age (fc)	55 years and older (fc)
A	3	4.5	6
B	5	7.5	10
C	10	15	20
D	30	45	50
E	50	75	100
F	100	150	200

Tasks are defined by IES in the flowing categories (IES 2000):

Orientation and simple visual tasks

Task A – Public Spaces
Task B – Simple orientation for short visits
Task C – Working spaces where simple visual tasks are performed

Common visual tasks

Task D – Performance of visual tasks of high contrast and large size
Task E – Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size
Task F – Performance of visual tasks of low contrast and small size

The IES Lighting Handbook also defines design issues and rates the importance of each issue for specific tasks. For example, when reading in a chair, color appearance and color contrast of the lighting system is not as importance as when applying makeup or shaving in the bathroom. The following list is from the IESNA 9th edition Lighting Handbook (Rea 2000) outlining design issues:

- Appearance of Space and Luminaires
- Color Appearance an Color Contrast
- Daylighting Integration and Control
- Direct Glare
- Flicker and Strobe
- Light Distribution on Surfaces
- Light Distribution on Task Plane or Uniformity
- Luminances of Room Surfaces
- Modeling of Faces or Objects
- Points of Interest
- Reflected Glare

- Shadows
- Source/Task/Eye Geometry
- Sparkle/Desirable Reflected Highlights
- Surface Characteristics
- System Control and Flexibility
- Horizontal and Vertical Illuminace per Task

Lamp and Luminaire Specifications

Primary lamp characteristics include color rendering index (CRI), Correlated Color Temperature (CCT), Lumens per Watt (lpw), total watts, type of base, voltage, lamp life (in hours), etc. Luminaire characteristics are more related to the efficiency and spectral distribution of the luminaire when used with specific lamps.

Lighting Energy Performance

As new homes are being constructed with more airtight envelopes, improved windows, and more efficient space conditioning and water heating equipment, the impact of lighting on whole house energy use is becoming more of a factor in pursuing overall energy efficiency. The energy use of the lighting system is highly dependant on occupant use and schedules, and can be very difficult in predicting energy use. This is also the case when attempting to predict the contribution of the lighting system to cooling and heating loads. Energy savings related to lighting systems can come from lamps and luminaires with higher efficiencies and efficacies, reduced run time, and reduced space cooling loads.

Lighting and Daylighting Integration and Control

The use of daylighting to reduce lighting energy use is gaining wide acceptance in the commercial applications because the significant dependence on artificial lighting can become costly. However, due to limited lighting loads in residential applications, the argument for daylighting from an energy savings perspective is difficult to justify. Depending on the method and process for implementation, increased daylighting in homes may even increase energy use due to the increase glazing area.

Integrating daylighting and artificial lighting can pose a significant control challenge, especially when balancing cost and energy savings. Continuous and step dimming controls respond to changing outdoor light to adjust interior lighting to achieve predetermined illuminance levels on specified surfaces inside the building. The cost of these controls can be quite significant, requiring a substantial energy savings to justify the initial cost. There are other options for controlling interior light levels, such as a whole house network and automatically adjustable window shades, but in order to ensure that the end result is achieved, it is essential that the system are designed, installed, and operated as intended.

Appliances

As the envelope and space conditioning systems in the home are becoming increasingly energy efficient, the energy use by appliances and plug loads is becoming an increasing percentage of the whole house energy use. While Energy Star® provides a rating criteria for appliances, the consumer also has the EnergyGuide label to rate the energy consumption of the appliance. However, the EnergyGuide labeling system only compares the energy use of a particular model to similar types of equipment. It does not demonstrate how the equipment performs relative to different types of equipment. For example, gas water heaters are only compared to that particular type of water heater, and not compared across the board to electric or tankless models. In addition, these listings are highly dependant on the occupant use patterns.

Solar Hot Water

Solar hot water systems are normally used for supplementing domestic hot water and space heating in addition to traditional systems. As sizing strategies vary and are traditionally based on average water use and schedules, the resulting performance can also vary significantly. Predicting the performance of these systems in coordination with other systems can be complicated and actually integrating a control strategy can be costly and potentially unreliable. Standards and compliance review can be effective in optimizing the performance and value of solar hot water systems.

The Florida Solar Energy Center has been active in developing standards and performance criteria for solar hot water systems for a number of years. Additional information can be found at the following web address: http://www.fsec.ucf.edu/solar/testcert/testcert.htm. In addition to the development of the Florida Energy Factor (FEF) for describing the performance of solar hot water system, FSEC has developed simplified sizing procedures, standard practice for the design and installation of solar domestic water and pool heating systems, and several other performance related documents. The following discussion is specific to the use of the FEF as a performance criterion. More specific system component criterion and integration consideration can be found at the flowing web address: http://www.fsec.ucf.edu/solar/testcert/systems/systems.htm

The FEF is used for determining compliance with the 1993 Florida Energy Efficiency Code for Building Construction, but can also be used to compare the efficiency of conventional water heaters that use the Energy Factor (EF) as a rating measure. The FEF is a dimensionless ratio describing the hot water energy available from each approved system divided by the electrical energy used by the system. Collector type and area, tank volume, collector tilt and location are primary components that affect the system efficiency.

For purposes of approval, FSEC has defined a system by the following identification strategy:

1. Manufacturer's model name or number for the system
2. Collector system performance rating – cumulative for all collectors in the system, or performance rating per square foot of collector for pool heating systems.
3. Storage tank volumetric capacity
4. Method of heat transfer to tank – direct or heat exchanger

5. System diagram showing components and their interconnection
6. Controller type: differential temperature, timer, absolute temperature, photovoltaic, etc.

Based on the review of solar hot water systems, there are several key considerations that affect the performance. There are individual system component ratings and control strategies, tank and other system component sizes, overall system performance, and performance when integrated with other systems to consider. Location also plays a key role in the amount of available energy and may dramatically affect system sizing and performance.

Onsite Power Generation

The incorporation of onsite power generation systems is gaining more acceptance and system interaction and performance standards must be addressed to ensure desired operation. These systems may include photovoltaics, solar thermal, micro-turbine, or fuel cell applications and, in most situations, the design and installation requires integration with the other systems of the house. Optimizing these systems means incorporating load reduction strategies, proper design and equipment sizing, and effective integration. As the use of these systems is almost always in addition to traditional systems, performance measures and standards can assist in optimizing the integration of systems. The following section outlines some onsite power generation systems and considerations for integration and potential opportunities for performance specifications.

Fuel Cell Study

IBACOS monitored the performance of a fuel cell installed on a single-family residence in New York State beginning in May 2002, and reported on measured system performance, an evaluation of system reliability, possible avenues for system integration and re-engineering, and barriers to broader market penetration of fuel cell technologies. The following is a summary of findings from IBACOS' Onsite Power Generation: Advanced System Performance Report (2002a), but additional information and details can be found through IBACOS or the DOE Building America database. The market barriers and integration opportunities present concerns that may benefit from the development of integration and performance standards.

Measured System Performance

The fuel cell is a grid parallel unit set up to operate at a nominal 2.5 kW continuous output, without waste heat recovery. In this configuration, the unit will use grid power to meet peak load conditions when needed. The average daily output of the fuel cell averaged about 50 kWh, satisfying 100 percent of the house electrical needs. However, there is data showing 1-second peak loads recorded over a 15-minute period that required grid supplement. Under other operating configurations, the unit would be able to meet the typical measured peak demand.

<u>Primary Market Barriers and Integration Opportunities</u>

This research report presents cost and availability as the primary market barriers to widespread application of fuels cells in the residential market, as most manufacturers are still in the beta test stage. An identified opportunity for exploration on the manufacturing side of the fuel cell market is to integrate their systems with the central load distribution center and metering for the house, producing a "plug and play" device. This approach incorporates the fuel cell, related components, meter socket, and electric circuit breakers for the house. This integration may simplify installation, and potentially reduce field labor and additional components associated with stand-alone units.

While net metering laws exist for residential scale power generation, there are currently no programs allowing for an individual residential consumer to be compensated for the real time price of electricity in the wholesale market. A related market barrier to integration of the fuel cell with the electricity grid is related to the current net metering laws, which do not account for time of use load control and do not account for demand reduction. Energy efficiency and demand reduction strategies on the residential scale may be more readily employed if net metering laws provide for compensation for distributed generation contribution to the electric grid, and if technology is developed further to encourage the integration of the load, fuel cell operation, and the electric grid.

Market demand may be encouraged through an integration of the functions within the house to the fuel cell and integrating the fuel cell to the electricity grid. Components for integrating distributed generation, real time metering, and control of residential loads are available in the market place, but there is little market force to integrate and adopt these strategies. There are a variety of residential gateway products, home automation and load control systems, and metering systems on the market, but IBACOS has not found a single company that integrates these and offers them in the marketplace.

A potential strategy to overcome barriers to adoption would be the development and integration of residential control and metering capabilities in the fuel cell units themselves. The unit would act as a central control system that monitors and prioritizes the home electric loads, and provides power to the grid to economically optimize the system. This approach could be adopted on a single home or community scale utilizing wireless networks.

An additional opportunity for integration of fuel cell technology is waste heat recovery. IBACOS is refining work on this model through system modeling to look closer at potential benefits in utilizing waste heat from the fuel cell system for space heating and domestic hot water. A cogeneration approach will add other performance criteria when designing and implementing such a strategy. This approach could also be implemented on a single house scale or on a community scale.

Further research is needed to document the potential benefits of a coordinated strategy in varied climate zones and how building energy efficiency, demand response controls, and distributed generation systems could be integrated to provide maximum benefit to the electric system, society, and consumers.

Software Evaluation Tools

Many software programs were developed for evaluating compliance with standards and the energy performance of new construction, while other software is used for system design. The inherent discontinuity between programs can make the design and evaluation difficult and error prone. This section of the report describes compliance standards evaluated in several of the industry leading software programs and efforts for integrating the design and evaluation process. While performance standards and system integration are essential in improving the energy efficiency, durability, and health and safety of new residential construction, the process for design and evaluation is critical in ensuring the whole house solution meets applicable standards. While it is not discussed in this section, standardized processes for inputting data may alleviate some of the potential for error.

Building Energy Simulation TEST (BESTEST)

While several of the tools outlined in this section are used to determine a home's compliance to specific standards, the BESTEST serves as a performance standard for energy modeling tools. The process evaluates design and analysis tools relative to their ability to adequately model the envelope dynamics of buildings. It is used especially for certifying tools used in the Home Energy Rating Systems programs. The validation consists of three parts – analytical verification, empirical validation, and a comparative validation. Validation is measured in two specific Tiers:

Tier 1: Specific cases are designed to test the modeling software with respect to infiltration, wall and ceiling R-values, glazing properties and orientation, south overhangs, internal loads, exterior surface color, crawlspace, slabs, basements

Tier 2: Additional validation elements include direct gain passive solar, variation in mass, glazing orientation, east and west shading, glazing area, and south overhang.

REM/Rate and REM/Design

The REM/Rate and REM/Design programs are industry standards for determining energy consumption and compliance with energy standards. The primary standards evaluated with this program are specific to each tool individually.

REM/Rate was developed specifically for HERS providers, and calculates heating, cooling, hot water, lighting, and appliance energy loads, consumption, and costs. It also serves to size mechanical equipment and evaluate compliance with CABO Model Energy Code, ASHRAE 90.2 and the IECC. It is in compliance with the National Home Energy Rating Technical Guidelines for performing energy ratings. In addition, the performance of the home is reported through the following standards:

- Energy efficient mortgage report
- Energy appraisal addendum
- Energy code compliance (MEC, ASHRAE, IECC)
- Improvements analysis for existing homes

- Design optimization for new homes
- Utility DSM compliance
- Solar tax credit analysis
- US EPA Energy Star Home analysis

REM/Design is a more comprehensive program that performs design optimization, improvement analysis, compliance analysis, and equipment sizing. It is approved for use in the DOE Weatherization Assistance Program which fundamentally incorporates both performance and economic criteria. It provides similar compliance reports to REM/Rate, but with less focus on HERS scores and more focus on economic criteria, and the incorporation of less conventional systems.

Targeted Residential Energy Analysis Tool (TREAT)

TREAT was developed by Taitem Engineering and Performance Systems Development with sponsorship from the New York State Energy Research and Development Authority (NYSERDA) in coordination with the National Renewable Energy Laboratory (NREL). TREAT integrates room-by-room heat loss with an hourly energy modeling simulation and utility bill analysis. The program is approved for use in the DOE Weatherization Program, and is being integrated as the required tool for the Home Performance with Energy Star® and New York Energy Star® Labeled Homes program.

EnergyPlus

Energy Plus is a building performance program developed from the best capabilities of BLAST and DOE-2, and is primarily a simulation engine only. Currently, there are approximately 11 front-end interfaces being developed by separate organizations. The flexibility of EnergyPlus allows links to other programs, such as WINDOW5, COMIS, TRNSYS, and SPARK. However, perhaps the most promising capability is the interoperability with CAD tools. Through data manipulation, output files from CAD tools containing the geometry of walls, floors, windows, etc. can generate EnergyPlus input files. While it is still undergoing significant development to expand the capability and make it user-friendly, the concept may eliminate the potential for error in the time-consuming translation of building plans and layouts into software energy evaluation/modeling tools.

Perhaps this approach is the future for energy modeling and standard compliance software tools, allowing a full visual rendering of the building and building systems to be evaluated in regard to performance without the inherent discontinuity between different programs.

System Integration and Consolidation of the Construction Process

While the performance of housing systems relative to other systems is the focus of many standards and measures, standards for integration of systems can encourage strategies to combine systems that are not traditionally integrated. For example, the result of extrapolating the concept of system performance to integrating structural systems with electrical, communications, and mechanical systems can reduce construction costs, improve quality and maintainability, enable future expansion, and facilitate compliance verification. The intention is to look beyond traditional site built construction process and beyond the house itself. This may include partial industrialization of the production process, through modularity and transportation of materials, or perhaps an improved vision of site and infrastructure coordination.

The development and application of performance standards to this process is imperative to facilitate market adoption. These standards might apply to portions of the construction process, such as factory processes, transportation requirements, varying building and energy codes, modular construction strategies. The following section includes a discussion of two resources that address whole process concepts that look for performance and integration of systems beyond the whole house. The first topic is a summary of HUD's Operation Breakthrough from the late 1960s, and the second topic is a discussion of concepts developed out of the Department of Energy Solar Decathlon student competition.

Operation Breakthrough

Project Introduction

In the mid-1960s, the United States faced a number of severe social issues. It was believed that one of the generators of these problems was the lack of affordable housing. In response, Congress mandated the "construction and rehabilitation of 26 million housing units…in the decade 1968 – 1978." The 1960s was also the decade of spectacular US achievement in the space programs and in the development of electronics. Thus was born Operation Breakthrough.

Operation Breakthrough was formally announced on May 8, 1969, by George Romney, Secretary of Housing and Urban Development, as a residential development program designed to resolve a multitude of problems to make quality housing available in large quantities. The approach was to use modern design, technology, financing, marketing, land use, and management. A significant emphasis was placed on utilizing prefabrication and factory construction of major components.

A primary objective of the program was to establish a large continuous market, such as those associated with other manufacturers of consumer products. This would enable the producers of high volume housing components to recover their investment in research and development, in improvements to methods and processes, and in factories required for high volume production.

Local governments, private citizens, and organizations were invited to respond to the program's objectives in the areas of prototype sites, site planners, site developers, and housing system producers. Requests were made for advanced housing concepts located on suitable sites that meet requirements for improved planning concepts. In addition, an emphasis was placed on management of the evolution of site communities as prototypes for marketing and subsequently integral components in their localities. Responders were encouraged to submit concepts with levels of quality above minimum compliance to encourage competition.

There were three primary parts in this program. The first (Phase I: Design and Development) involved private enterprise competition for contracts to design the industrialized housing systems. Second (Phase II: Prototype Construction), prototype sites would be constructed across the country. Finally (Phase III: Production), the successful systems would go into volume production.

Phase I awarded twenty contracts resulting in 3,000 prototypes constructed in Phase II on new sites that represent different climate and market conditions. After Phase II, the National Bureau of Standards, the Academy of Sciences, and the National Academy of Engineering provided program laboratory testing to evaluate and certify acceptability. In Phase III, the awarded private enterprise would assume leadership from HUD.

Operation Breakthrough was terminated in the early 1970s and the dream of the predominance of factory fabricated housing in the marketplace was, seemingly, never realized. Yet, today, the legacy of Operation Breakthrough may be seen throughout the homebuilding industry; modular housing represents a significant segment of the low- and middle-income market. Many major builders employ panelized construction. Structural Insulated Panels (SIPs) are direct descendants of the stressed skin panel systems of Operation Breakthrough. Utility cores are often employed in high-rise hotel construction.

Production integration and standardization

A re-examination of the OBT systems, with a clear understanding of how today's builders conditions vary from the 1970s, may still provide fruitful insight for innovation in residential construction and the interaction between systems. In the following section, OBT construction systems will be reviewed specifically for aspects that provide insight into innovative systems and their interactive characteristics. These observations will go beyond the whole house concept to also include consideration for whole system interaction of details such as site planning and factory delivery considerations.

Twenty-two industrialized housing systems were brought to production status and provided the housing units constructed in Phase II on nine OBT demonstration sites. Eight of these were for high-rise construction and generally offer a limited number of technologies appropriate for single-family residential construction (for example, most were based on the use of concrete or steel structures). Of the fourteen systems for single family or low-rise construction, many were modular housing concepts and are the forerunners of today's well-developed modular housing industry.

Several systems, however, had unique characteristics that offer examples of very creative design innovation. These are summarized in the following paragraphs.

Grade Beam Concepts

Multipurpose Grade Beam - A multi-purpose grade beam concept was developed to address foundation and structural support, HVAC zoning, distribution, and maintenance, in addition to low- and line-voltage electrical distribution. The grade beam concept limited floor plan configuration and was not suited to multi-story application.

Pre-stressed Concrete Grade Beam – This concept was developed for year round construction, even in cold climates, to avoid time constraints of site built foundation systems during poor weather conditions. This system can also satisfy tolerances required for industrialized housing.

Panel Cast Plaster Walls and Ceilings

Through OBT, a company developed a factory cast wall panel consisting of plaster and steel studs to reduce field time associated with gypsum board installation and finishing. This factory product panel is constructed with a continuous bed of plaster with steel studs connected with embedded "punched shear keys."

Interior Heat Registers

A company developed an approach that reduced long duct runs through the use of high interior wall supply registers with high face velocities. This strategy discharged high velocity air through a slot diffuser towards the exterior wall. This approach minimizes material and labor during construction, and can be more easily integrated with the framing system.

Single Stack Plumbing System

The same company that designed the interior heat register approach also developed a single stack plumbing system to reduce material and labor time during installation, and takes up less space. The single stack system uses the same pipe to relieve pneumatic pressure and carry waste. When using a modular construction approach, this will also reduce the number of connections required between modules. This approach is also a potentially conducive strategy when integrating framing design and plumbing system design.

Mechanical Core Module

In order to package the high value and high complexity systems of a home, an organization in OBT developed a stackable mechanical core module that includes a kitchen, bathroom(s), laundry facilities, the stairway, and primary elements of the heating, ventilating, air conditioning, and electrical services. The units are factory built, transported to the site, and put in place on the site. The remainder of the home is then built around the core module using panelized construction. A special joist layout is used in the ceiling structure to facilitate the distribution of mechanical, electrical, and plumbing systems. The module is left with exterior framing exposed to enable easier coordination of services and finishes in the field. This approach combines factory assembly with flexibility of site construction.

Baseboard Electrical Raceway

The baseboard compartmented raceway strategy is useful in wall construction techniques, such as pre-cast concrete panels, which inhibit system distribution. The design concept for OBT was a metal raceway configuration with separate channels for high and low voltage wiring. This approach was designed to incorporate electrical distribution, television, telephone, and other communications signal distribution. This approach may be beneficial in making changes and updating systems in retrofit situations.

Surface Mounted Wiring

This design concept was developed to integrate the electrical wiring with a honeycomb panelized construction process. As the electrical system could not easily be run in the wall interior, this approach was integrated with the multi-functional grade beam concept. The electrical wiring was run in the grade beam with switch loops installed in a recessed channel between panels. When finished, a plastic cover is installed over the channel.

Wiring Harness

A wiring harness concept was developed for integration in high volume factory assembly lines, and to be installed by unskilled labor. The pre-assembled electrical harness is laid out in an “octopus” arrangement to be dropped into the module during the factory process. Each system consists of a central junction box and a network of predetermined legs. Precut holes are provided to attach the factory cut lines to conventional switches and outlets.

Department of Energy Solar Decathlon 2002

The Department of Energy held its first Solar Decathlon student competition in 2002 to design and operate the most attractive and effective solar-powered house. This was not a typical design competition, which in turn produced some fundamentally valuable concepts that may not typically be investigated in industry. The homes were first designed and constructed at each university and then transported in pieces to the National Mall in Washington, DC, where they were re-assembled temporarily for participation in the competition.

The participating teams devised creative solutions to not only address competition guidelines, but also innovative ideas that may impact sustainability and energy efficiency in production housing. These concepts perhaps provide a basis for standardizing the performance of modularized components and the integration of components in a partially or fully industrialized housing market. Some of the highlights are outlined below, and more information is available through each team. Each team website is accessible through the main Solar Decathlon website:
http://www.eere.energy.gov/solar_decathlon/follow.html

Accessibility and Interpretation

The competition is not necessarily representative of the current housing market, but it does demonstrate the impact of how performance criteria are subject to interpretation. While the competition was open to all Universities, only those who provided a comprehensive and realistic approach to accomplishing the goals set by the competition criteria were selected. The interpretation of the competition guidelines resulted in a multitude of potential solutions. All teams received the same contest guidelines, but all teams interpreted the guidelines differently in the interest of achieving the same end result. However, the team that performed consistently well in all areas of the competition - Design and Livability, Design Presentation and Simulation, Graphics and Communication, The Comfort Zone, Refrigeration, Hot Water, Energy Balance, Lighting, Home Business, and Getting Around – would win the overall competition.

University of Colorado BASE+ Concept

The 2002 University of Colorado Solar Decathlon team developed a fundamental concept that blends an approach to mass-market home design and production with energy efficiency and high-quality, low-impact construction practices. The *BASE+* (Building a Sustainable Environment) concept was developed around a framework for an adaptable construction methodology for repeatable, site-specific housing suitable for production in a factory setting. Utilizing a customizable modular approach, each home can be upgraded or scaled to meet climate, budget, and homeowner needs. While this strategy was devised as the backbone to the design strategy, the concept is one that could be adapted toward improving the quality and customization not typically available in today's industrialized home building industry. This approach attempts to take advantage of the benefits of factory produced housing while allowing flexibility and customization to increase consumer interest. This approach is formed around three basic building modules: Basic, Spec, and Utility.

The ***Basic*** module is the fundamental building block to the fabrication process. Constructed of Structural Insulated Panels (SIP) these modules are used for areas that require little construction customization, such as bedrooms and living spaces.

The *Spec* module is for areas where architectural customization is the intent and is the cohesive module between the *Basic* modules. The *Spec* module can be used for areas such as the kitchen, where homeowner input can create a design that reflects their lifestyle.

The ***Utility*** module is the module that houses the primary utility systems of the home. It is described as "the energy and equipment module that organizes, distributes, and collects the technological systems, the home's energy center for monitoring and controlling thermal and systems performance, whose size, configuration, and form is derived from the technical needs of each project.

While the *BASE+* approach was used as the fundamental approach to the University of Colorado's design, it is a "larger picture" concept that was not fully investigated for feasibility beyond the design of the home for the actual competition. The home was not produced in a factory setting, repeatability was not confirmed, and customization went beyond the normal construction project to meet criteria specific to the competition. However, this team did accomplish a unique vision of an approach for creating affordable and energy efficient factory-produced housing with an expressed interest in increasing the appeal to the production-housing consumer. More information about the house and the BASE+ concept can be found on the team website.

Other Notable System Performance and Integration Concepts

University of Texas-Austin – Primary features:

- Low impact reusable foundation and anchorage system,
- A column and beam structure that permits accessible utilities through the building,
- Floors, walls and roof which are interchangeable structural panels,
- Carbon balanced components such that the upstream C02 emissions the steel is balanced by the net carbon content of infill materials.
- Ice storage system for space cooling

University of Puerto Rico – Desiccant cooling with solar regeneration, converted dryer for use with solar hot water system

Virginia Polytechnic Institute and State University – Integration of building envelope and daylighting through the use of Aerogel.

University of Maryland – Photovoltaic powered solar domestic hot water pumps with evacuated collectors

Auburn University – Incorporation of thermal mass space tempering strategy using water tubes

University of Virginia – Fiber optic daylighting system and a chiller based cooling system

Implementation and Quality Control

While performance standards and integration strategies guide the design specifications of the home, the actual operating performance of the home is measured as a function of implementation, quality assurance, quality acceptance, and ultimately, the satisfaction of homeowner expectations. There is a gap between design intent and the actual implementation that involves a significant amount of communication between the builder and trades, and between the trades themselves. Quality assurance goes beyond site inspections to include contractor training and/or certification, construction management, and field diagnostic testing. Quality acceptance and homeowner satisfaction is dependant on establishing appropriate expectations and demonstrating that the final product meets or exceeds the expectations.

This section discusses less quantifiable performance issues that exist throughout the home building and occupancy process. The balance between productivity, profitability, and quality presents opportunities and challenges that directly affect how well the home measures up to performance standards and homeowner expectations. As the program criteria outlined in previous sections extrapolates systems-based home performance to include interaction with the site and community, this section builds upon the home performance concept to include the sales process, customer service, training and certification, productivity, and quality control.

Financing Options

Home financing for purchasing and building homes may provide another avenue for defining performance standards. The funding available for designing, building, and purchasing a home can shape how potential homeowners and builders respond to performance standards. It is in the interest of the financing institution and potential homeowner that the home meets quality expectations, and is durable and low cost to operate.

Energy Efficient Mortgage

Fannie Mae's Energy Efficient Mortgage program demonstrates how a financing programs impact the performance of a home. The Energy Efficient Mortgage for new homes allows the present value of energy savings to be added to the appraisal value. The loan to value calculation is then based on the lower of the purchase price of the adjusted value. The measure of the energy savings present value is calculated by a HERS rater using a set mortgage rate as determined annually by Fannie Mae. This program also allows manufacturer rebates and tax incentives to be used towards the closing costs or borrower's income.

Construction Loan Performance Based Inspections

While there is no documentation to support is argument, there may be an opportunity for a lending institution to further define performance through strategic inspections during the construction process. The lending institution has an interest in the homeowner's ability to repay construction and home loans. Energy efficient, durable, and low maintenance homes cost less to own and operate, which increases the homeowner's ability to repay loans.

Basing the release of construction loan funds on performance inspections may provide an avenue to define performance standards in a manner that benefits all parties involved. Inspections at predetermined stopping points would utilize standards that not only ensured that the installed systems were implemented appropriately, but also to ensure that they are properly integrated with the systems installed before and after. Lending institutions may even be able to specify appropriately certified companies to do the work. This approach builds on the mortgage industry's support of energy efficiency, and would include the adoption of performance standards related to durability and maintenance. In order to address the required overlapping of trades to ensure proper integration of systems during installation, strategies for scheduling, communication, and project oversight may have to be based on a whole house approach.

Productivity and Training

The performance of any home or any design criteria is dependent on how well the systems are installed and the skill of those overseeing work completed. It is also in the best interest of a builder that subcontractor remain in business and be able to attract new talent. Recognizing these needs, several organizations have developed training and certification programs that emphasize the demonstration of fundamental skills and knowledge, the importance of continuing education, and technical and business support. The following examples demonstrate several leading training and certification programs in the residential home performance industry, and their approach to defining performance.

North American Technician Excellence, Inc. (NATE)

NATE is a leading certification program for technicians in the heating, ventilation, air conditioning, and refrigeration industry, with an emphasis on those who work on residential and light commercial systems. This certification program identifies those technicians who have achieved a mastery of an industry-approved level of knowledge. This measure of performance translates to more trust in the ability and skill of certified individuals, and potentially a better performing system. NATE also serves as uniform standard of knowledge, resulting in better training and education programs. (http://www.natex.com/)

Building Performance Institute, Inc. (BPI)

BPI's mission statement is to "enhance the health, safety, comfort, durability, and the energy efficiency of residential buildings by providing skills verification and promoting best-practices by building trades." (www.bpi.org). The approach to achieving these goals sets out to define performance standards in construction and construction practices, and the minimum level of expertise that should be demonstrated in order to meet or exceed these standards. The importance of optimizing business relations with consumers through brand recognition is demonstrated through providing certification exams and marketing materials.

As of May 2003, the four primary categories for knowledge and skill related to building performance are Health and Safety, Advanced Building Science, Inspection and Diagnostic Skills, and Installation Skills. As of January 2003, the four primary tiers for certification included Technician, Analyst I, Specialist, and Master Building Analyst. The following is a summary of the certification levels from BPI's Certification Roadmap – January 2003.

1. Technician: field technicians with experience in a specific trade, or building technician, installer level.
2. Analyst I: sales staff and auditors, this certification is required for Specialist level certification, provides the foundation for "house as a system" approach.
3. Specialist: crew supervisors and inspectors, systems approach and whole house diagnostics related to chosen trade. Examples: Shell, Heating, Cooling.
4. Master Building Analyst: "doctorate" level based on peer review process.

Residential Energy Services Network (RESNET)

RESNET standards and guidelines emphasize energy use as a primary indicator of home performance, with a basis in the Home Energy Rating System (HERS). The HERS performance measure, previously discussed in several builder programs, is used extensively to determine compliance to program standards and goals for energy efficiency. The following quote from the RESNET website (www.natresnet.org) describes the organizations intent to define the energy efficiency standard for the mortgage industry.

> “In 1995 the Residential Energy Services Network (RESNET) was formed as a partnership between the national mortgage industry, Energy Rated Homes of America, and the National Association of State Energy Officials. RESNET's mission is to qualify more families for home ownership and improve the energy efficiency of the nation's housing stock by expanding the national availability of mortgage financing options and home energy ratings. RESNET is guided by a National Mortgage Industry Steering Committee.”

RESNET adopted the RESNET Building Option Package Providers Accreditation Standard for providers in the Energy Star Homes programs. The standard is recognized by the Environmental Protection Agency, as well. Through this standard and the Mortgage Industry National Home Energy Rating Standards, RESNET is defining home performance in the context of home financing. This demonstrates how a lending institution, in the interest of the homeowner and the institution itself, may dictate the performance standards of a home.

Construction Management and Communication

Implementing standards and practices for home performance is dependant on skilled and well-trained trade contractors, but it also relies on good communication and scheduling between the builder, trades, manufacturers, and perhaps the lending institution. Coordination of trade contractors and ensuring equipment and materials are installed to manufacturer’s recommendations are essential to providing an end result that meets performance criteria. A standardized process that enables communication between trades, site supervisors, and project managers may assist in ensuring that materials and equipment is installed to manufacturer’s guidelines, that they are integrated appropriately with other systems in the home, and that the home as a whole meets expectations.

Manufacturer’s Recommended Practice

While the best and most efficient product can be specified for a job, the quality of the end result is dependant on the quality of the installation and the integration with other systems. The initial factor that influences this is the designer and installer’s knowledge of the product and the manufacturers recommended practices. Lutron® is a leader in the lighting controls industry, and demonstrates well the concept of supporting its industry through innovation, training, certification, design assistance, and commitment to servicing customers. The performance of their systems is not limited to product specifications, but also its support network.

Lutron® uses the phrase “lighting controls” to communicate the concept of a “total lighting environment – controlling the amount and appearance of both electrical lighting and natural daylight.” Their approach is either on a single circuit basis, an entire room, or even a whole-house networked lighting system. Products range from single dimmer controls to controllable window treatments and total home controls. The perceived quality and performance of the lighting system is determined not only by the performance of the product, but also by the quality of the design and installation. In order to ensure that the performance of their systems meet the design intention, Lutron® provides extensive support, training, and certification.

Lutron® provides training and certification through their Lighting Control Institute (LCI) in the areas of Fundamentals Natural Light Control, Advanced Residential, and Advanced Natural Lighting and Controls. The training courses are intended to keep industry professionals up to date on the newest lighting control technology, processes for selecting equipment, and information to ensure customer satisfaction. Lutron® establishes standards of performance for lighting control and implementation of their products through training seminars, contractor field training, product videos, and on site training.

Integration of Structural and Mechanical Systems

Traditionally, the mechanical systems receive little attention during the design stage in residential construction, leaving design and installation to the sub-contractor who installs the systems. As a result, plumbers and HVAC contractors must install the system around, and sometimes through, the framing system. This can reduce the performance of forced air systems, and undermine the structural integrity of the home. Without an integrated approach to the design of these systems, and a coordinated effort in the field, systems can be damaged by other trades, and the overall performance can be jeopardized.

As documented in a research project by IBACOS, even when mechanical systems are explicitly laid out on house plans, the coordination still may not occur. A plumber, who was not used to reading plans as part of his normal job, installed a drainpipe where he thought it should be installed. However, it interfered with the duct layout and had to be removed and reconfigured. Had this not been a research project, this may not have been corrected, and the mechanical installer would have had to work around the drainpipe, potentially reducing airflow.

An uncoordinated effort can have significant impact on the performance of the home as a whole. Cutting framing for plumbing or ductwork undermines structural integrity. Running pipes and wiring through ductwork presents locations for duct leaks. Installing convoluted duct runs to avoid cutting through framing can increase the total equivalent length of duct runs, jeopardizing the airflow delivered by the duct branch. These are examples of the type of performance reducing impact of an uncoordinated approach to design and installing structural and mechanical systems.

A solution to the integration problem is one that involves several components. A residential home design should always include all systems, developed out of a coordinated effort between the architect, structural engineers, and mechanical engineers. There also needs to be project management in place to provide a feedback mechanism when installing the systems in the field. Feedback loops should be implemented to allow communication of concerns between field personnel and designers, and between trades.

Consumer Satisfaction and Quality Acceptance

Customer Satisfaction

The underlying measure of whole house performance is the homeowner’s perception of the quality of the home. While the basis for quality acceptance by both the builder and the homeowner is the warranty, J.D. Power and Associates measured New-Home Builder Customer Satisfaction in a 2002 study in nine related key areas. The following is a table of nine factors that drive overall satisfaction with a homebuilder, with the respective contribution to the overall satisfaction.

Table 3. Nine Customer Satisfaction Driving Factors

1	Builder's Customer Service	23%
2	Home Readiness	19%
3	Builder's Sales Staff	16%
4	Quality of Workmanship/Materials	14%
5	Price/Value	10%
6	Physical Design Elements	7%
7	Design Center	5%
8	Recreation Facilities	4%
9	Location	3%

Over seventy percent of the overall satisfaction score is the result of the home meeting consumer expectations or the ability to effectively communicate the performance of the home to potential homebuyers. These factors represent the targets for performance standards, whether they are currently represented in the industry or not. An interesting note is that aesthetics (Physical Design Elements) ranks low in importance when compared to value, quality, completeness, and the builder's support of his product. While Table 3 demonstrates consumer expectations, the home warranty fundamentally defines the mutually agreed upon standards and measures of quality acceptance by the homeowner and builder.

Home Warranty

The fundamental acceptance level of quality by both parties (the homeowner and builder) can be defined by the home warranty performance criteria. The warranty generally describes the expectation for home performance and the extent of responsibility of both parties. Performance standards help minimize warranty claims and ensure that the expectations of the homeowner are met. The following is an example of how the performance of a home is measured in the context of a home warranty program. Pulte Homes HOMEOWNER for life ™ Home Protection Plan has helped Pulte Homes achieve the status of one of the top builders in the country for customer service. Environments for Living goes a step further by virtually warranting energy and comfort performance trough a guarantee program.

Pulte Home Protection Plan

The premise of the performance approach to home design and construction is reflected in "The Spirit of the Warranty" section by the simple statement, "Things should work." The introduction to the warranty explains what the homeowner can expect from the home, and what the home expects from the homeowner. The warranty almost defines standards for homeowners, who play a primary role in how the home functions.

While there are variations by State, the warranty coverage is broken into one, two, five, and ten-year periods. The one-year coverage states that the home will conform to tolerances for materials and workmanship, as defined in the Performance Standards, while the two-year covers workability of the plumbing, electrical, heating, ventilating, air conditioning, and other mechanical systems. The five-year coverage protects against water infiltration and internal leaks, and the ten-year primarily emphasizes structural integrity. Other details are outlined in the performance standards, and are summarized below.

Interior Concrete and Foundation – standards address evenness, cracks, finishes, and efflorescence in walls and floors, in addition to water and leaks in crawlspaces and basements.

Framing – defines straightness of walls, columns, and posts; acceptable splitting and twisting of wood beams.

Roof – addresses deflection, shingle and tile issues, leaks, color variance, damage from ice-damming, roof tile efflorescence, and mildew, algae, and moss.

Exterior and Siding Trim – defines the expected performance of siding and trim under normal exposure, and what is defined as negligence or defect.

Stucco Cemetitious Finish, Above Grade Block and Concrete Walls – this section describes normal behavior and defects of these components in terms of cracks, finish loss and appearance, straightness, and interaction with moisture.

Exterior Paint and Finishes – deterioration, fading, and mildew and fungus associated with paint, staining, and clear finishes, and the extent of after-repair painting

Wood Decks – the performance of wood decks is described by levelness and imperfections in materials.

Site Drainage – defines improper drainage and expectations of both parties for repair, maintenance, and extent of responsibilities.

Doors – describes the performance of doors in terms of splitting, warping, and operation for all doors in the home, including garage doors.

Windows – expectations are outlined for operability, water leaks, condensation, imperfections and defects, and air infiltration. This section includes a discussion about the responsibility of the homeowner to control indoor humidity levels.

Electrical – this section performance issues related to the normal and abnormal operation of fuses, circuit breakers, and GFCIs. It also addresses low-voltage wiring systems, ceiling fan operation, and communication wiring.

Comfort Control – the operation of the heating and cooling system is defined by ASHRAE standards that relate house air temperature to the thermostat temperature and variation of indoor setting to outdoor temperature. Thermal insulation levels are defined by local code of state energy guidelines, and ductwork noise and vibration thresholds are established.

Plumbing – discusses freezing, drainage problems, pipe noise, wells, septic, and sump pumps.

Interior Trim and Moldings – defines blemishes, including nail pops, cracking, and blistering in finished walls and ceilings, and nail sets and gaps in trim.

Flooring – defines actionable defects in flooring material and workmanship, including floor nail pops, fading and staining of floor materials, evenness, gaps, and broken tiles.

Cabinets and Countertops – performance related to materials and workmanship, and describes maintenance expectations.

Fireplace and Chimney – section addresses fireplaces, pre-fabricated gas fireplaces, and chimney cracks and separation. Builder will repair situations when smoke from the fireplace enters the living space if due to improper installation. However, it notes that high winds and external factors, such as trees, can cause negative draft situations.

Landscape – No warranty due to regional variances in temperature and terrain.

Driveways and Exterior Concrete Surfaces – defines normal cracking, settling, shifting, color variation, pop-outs, paver surfaces, and water ponding.

Outdoor/Indoor Pools – The builder does not warrant Pools, but the builder will repair cracks in the decking that are larger than normal.

Appliances – Finishes on laundry, kitchen, or bar appliances are not covered by the warranty. Functionality is defined by manufacturer's specifications and only covered by the manufacturer's warranty.

The warranty is the fundamental basis by which home performance, builder performance, and occupant performance is defined and accepted. It describes maintenance expectations, the expected and normal performance of materials and workmanship, and the line between normal wear and tear and malfunction. The Environments for Living program extends the definition of performance to include energy use and comfort of the home.

Environments for Living ®

The program requirements and performance criteria are discussed in the Whole House, Community, and Site section of this report, but the following describes how this program defines quality by guaranteed performance. This program guarantees performance through a limited Heating and Cooling Energy Use Guarantee and a limited Heating and Cooling Energy and Comfort Guarantee. All levels of program certification receive the energy use guarantee, while only Gold and Platinum levels add the comfort guarantee.

Energy Use Guarantee – the actual energy use of the home (as calculated by an internal account analysis) will not exceed the guaranteed energy use (as calculated by an internal computer simulation program).

Comfort Guarantee – the temperature in the center of the home will not vary by more than three degrees from the temperature at the thermostat. Note: It is noted that fixing this problem may involve the addition of screens or protective window coatings to decrease the effect of sunlight.

Home Value Appraisals

The appraisal of home value is perhaps the most indicative standards in the residential housing market reflecting consumer expectations and market conditions. These standards impact when and where homes are built, financing options, and how the home will perform in the market. The value of performance measures like energy efficiency is not commonly included in the appraisal, but recent trends, as reported by Energy Rated Homes of America™ (ERHA), show this maybe changing. Federally sponsored secondary mortgage markets, FHA, Fanny Mae, and Freddy Mac, allow the capitalization of energy savings to be added to the market value of the home for appraisal purposes.

The ERHA website states that 78 percent of real estate appraisers believe that energy efficient homes are worth more, by about 5 percent. Potential homebuyers ask more questions about the cost of maintaining the home than anything else, and energy features ranked above features like wall-to-wall carpeting, dishwashers, and fireplaces in importance. 94 percent of new homebuyers believe that energy features were important in their decision.

Field Diagnostic Evaluation Tools

While many performance standards can be evaluated using modeling and compliance software, others must be determined in the field. Systems can be designed to meet performance criteria, but the true performance is only as good as the installation. In order to measure the status of the existing system and account for interaction, field diagnostic verification techniques are used. This approach is particularly useful for non-visual compliance, such as air infiltration, duct leakage, airflow rates and distribution, and pressure imbalances. Due to the prevalence of the specific equipment and techniques, many performance standards and measures are developed around these testing methods.

The methods of testing home performance can provide insight into standards that are not typically incorporated in larger home performance programs. Prevalent testing methods, less common techniques, and the results of using a similar approach in developing best practices for retrofits is included in Appendix C. The best practices are based on a report generated by Lawrence Berkeley National Laboratory and the Department of Energy for evaluating existing homes. While the document focuses on existing homes, many of the standards and diagnostic practices can be applied to new construction as well. The best practices document is included to outline field diagnostic testing, but also to demonstrate the importance of performance standards for appropriately carrying out the test procedures to ensure accuracy in compliance verification.

Conclusion

This report outlines performance standards used in several builder programs, methods for designing to and evaluating compliance, and integration strategies. While it is not a comprehensive list of all programs and evaluation methodologies, the report serves to identify system categorization, and provide examples of performance standards and opportunities for system integration standards. While standards define the intended performance of a home, the actual performance is dependant on how well systems are installed, integrated, and evaluated.

Standards and measures impact the performance of the home from the very beginning at the construction planning and development stage, and compliance verification standards can be utilized throughout the entire process, including occupancy of the home, to ensure that the desired performance is achieved. While compliance can be estimated by well-planned program standards, simulated results, and a final inspection, the intermittent steps are generally left to code inspections. As codes dictate the minimum level of acceptable quality, the desired performance may not be well represented by this approach.

Standards that provide more than a basis for developing specifications can help in achieving a higher performance home. This approach may include standards for sub-trade communication and integration through developing processes for trade overlap and installation quality compliance. For example, a multi-purpose grade beam, as demonstrated in Operation Breakthrough, that incorporates foundation and structural support, HVAC zoning, distribution, maintenance, and low- and line-voltage electrical distribution requires a high level of management and communication between designers, fabricators, installers, and evaluators to ensure the intended result. Additionally, standards for contractor certification indirectly define the acceptance of industry quality and performance. Finally, the operation of the home and homeowner perception is critical in fundamentally defining home performance. Standards for homeowner expectations and operation of the home are important for long-term satisfaction and a continued high level of home performance.

Codes and performance standards are subject to interpretation, and a higher level of specialization by the team or teams of individuals who interpret and apply standards in the design process may help to ensure performance goals are achieved. Improving the process for interpreting standards and delivering results may be effective in not only meeting the intended results of a specific program, but with a high level of quality and durability. Whole house solutions depend on well-developed standards and validation processes, but also on well-trained individuals. An approach that enables the effective interpretation of program intentions to actual design strategies may have a trickle down effect, providing specifications and guidance to appropriately and effectively install and integrate systems that affect the performance of a home, including energy, envelope, and mechanical systems.

In conclusion, the systematic integration of the processes for actually delivering a high performance home will assist in facilitating the adoption of performance standards and result in a higher quality product.

This report was intended to introduce challenges in the construction process for defining and implementing performance standards, and will be followed up by future deliverables and phone conversations.

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Appendix A

(Source: www.builtgreen.org)

Requirements of Tiers II and III of Built Green Colorado™		
	TIER II	**TIER III**
HERS score	86 minimum	88 minimum
Ventilation	(A, C) A controlled mechanical ventilation system (one of: HVAC blower w/ air-cycler; HRV; minimum 44000-hr rated exhaust fan) meeting the requirements of ASHRAE 62.2. Range hoods are vented to exterior, and those over 200 cfm require make-up air.	Heat Recovery Ventilation required. Requirement for range hoods is same as Tier II.
HVAC equipment sizing	(B, C, D) Equipment sized to ACCA Manual J specs, using proper building shell components and using proper indoor and outdoor design temperatures.	Same as Tier II
HVAC equipment products/efficiency	(A, D) Appliances either power- or direct-vented, or sealed combustion	#21 (90% AFUE), #25 (12 SEER min.)
HVAC ductwork	(A, B, C, D) #26 (no building cavities) #32 (sized according to Manual D, using proper design conditions) #41 (exterior ducts R-8) (maximum 10% leakage of rated system flow)	#26, 28 (modified commissioning), #29 (good sealing), #27 (max 10% leakage), #32 (room-by-room load calcs), #34, #38 (pressure relief), #41 (Ducts with R-8 and buried in attic insulation are acceptable in attic.)
House tightness	(A, B, D) #13 (advanced sealing); house-to-garage connection is tested for IAQ purposes	# 15 (blower door 0.35 min.) (It is acknowledged that most homes will need to be much tighter in order to consistently score an 88)
Envelope	(B, C, D) #108 (Low-E) in all above-grade windows	(Note that higher HERS requirement my necessitate including some Low-E windows in basements as well)
Indoor air quality	(A) #152 (power-vented water heater), #157 (sealed gas fireplace or wood stove with outside air); #168 (extensive garage air sealing)	Same as Tier II
Lighting and Appliances	5 pts from 2004 Checklist categories V and VI as they will appear in the 2004 checklist (can lights will be moved to envelope and additional items may be available)	8 pts from 2004 checklist categories V and VI as they will appear in the 2004 checklist (can lights will be moved to envelope and additional items may be available)

Moisture Management Strategies	Foundation Perimeter Drains – meet criteria in Built Green Moisture Management reference packet. Excavation and Backfill – meet at least first two criteria of reference packet. Wetting of Soils below Basement Floor during Construction – meet all four criteria of reference packet Clearance Below Floor Systems and Plumbing – meet criteria of	Same as Tier II.

	packet. Ground Preparation and Cover for below-grade under-floor spaces – meet requirements of checklist item #177, with the option of employing alternative systems based upon engineered design. Downspouts – comply with item #176 on checklist Insulation in below-grade under-floor spaces – see guidelines in reference packet. Ventilation of below-grade under-floor spaces – follow guidelines in reference packet. Building envelope flashing – comply with checklist item #175	

Water conservation	6 pts from water conservation category on Built Green 2004 Checklist	8 pts from water conservation category on checklist, with items #207 and #208 from the water category (provide landscaping sketch plans and incorporate water-wise landscaping on model home) mandatory while also being counted toward point total.
Lumber Reduction, Responsible Wood Use	20 pts from 2004 checklist categories VIII and IX.	30 pts from 2004 checklist categories VIII and IX.
Material Resource Efficiency (non-wood)	10 pts from 2004 checklist remaining materials and resource conservation categories (VII, X-XVI, IXX-XXI) and any material-related items from XVII.	15 pts from 2004 checklist remaining materials and resource conservation categories (VII, X-XVI, IXX-XXI) and any material-related items from XVII.
Waste Reduction and Recycling	None required.	Comply with credit #188 (minimize job site waste by using materials wisely and prohibit constructions waste; recycle job site waste >50%), or otherwise document the diversion of >50% job site waste from landfill to other uses by grinding, re-using, etc.

% Builder Commissioning (please see Appendix A for an overview of the process)	25 % of homes tested (15% if HVAC plan is supplied for every model of home built)	100 % of homes tested

5% testing performed for Built Green™ through third party	
Tier II	**Tier III**
Energy Score – 86 minimum	Energy Score – 88 minimum
Duct Blast/Flow Test	Duct Blast/Flow Test
Test Furnace Heat Rise (vs. spec)	Furnace Heat Rise (vs. spec)
Pressure Testing: garage/bsmt/bdrm	Pressure Testing: garage/bsmt/bdrm
Verify completed Manual J, on whole system and room-by-room	Verify completed Manual J, on whole system and room-by-room
Confirm ducted returns	Confirm ducted returns
Test HVAC flow at handler	Test HVAC flow at handler and registers
Confirm Low-E	Confirm Low-E
Verify completion of AC subcooling document	Verify completion of AC subcooling document
Confirm closed-combustion DMHW, sealed fireplace	Confirm AFUE, SEER, closed-combustion DMHW, sealed fireplace
Test Ventilation flow	Test Ventilation Flow
Confirm measured flows within 20% of Manual J room-by-room calcs.	Confirm measured flows within 20% of Manual J room-by-room calcs.
Confirm duct insulation	Confirm duct insulation Field inspect sizing on furnace
	Combustion Safety Inspection
	CAZ pressure test

Builder	
Tier II	**Tier III**
25% testing required (15% if HVAC plans for each house are supplied)	**100% testing required**
Test ventilation to prescribed standards of ASHRAE 62.2	Test ventilation to prescribed standards of ASHRAE 62.2
Provide system-wide and room-by-room Manual J	Provide system-wide and room-by-room Manual J
Demonstrate measured flows within 20% of Manual J room-by-room calcs.	Demonstrate measured flows within 20% of Manual J room-by-room calcs.
Perform HVAC flow test at handler	Perform HVAC flow test at registers/handler
Calculate Furnace Heat Rise	Calculate Furnace Heat Rise
Perform Pressure test garage/bsmt/bdrm	Perform Pressure test garage/bsmt/bdrm
Verify correct AC charge via subcooling method	Verify correct AC charge via subcooling method

Appendix B

(Source: www.eeba.org)

Criteria for Energy and Resource Efficient Building

The following criteria are recommended for the design and construction of energy and resource efficient buildings.

Component Criteria

A. Building Structure

Overall energy consumption for heating, cooling and water heating should meet Energy Star requirements (30% improvement over a standard reference home based on the envelope and equipment requirements of the 1993 Model Energy Code) as determined by an accredited home energy rating system procedure.

Air leakage of buildings (determined by pressurization testing) should be less than 2.5 square inches/100 square feet leakage ratio (CGSB, calculated at a 10 Pa pressure differential); or, 1.25 square inches/100 square feet leakage ratio (ASTM, calculated at a 4 Pa pressure differential); or, 0.25 cfm/square foot of building envelope surface area @ 50 Pa.

B. Mechanical Systems

Controlled mechanical ventilation at a minimum base rate of 20 cfm per master bedroom and 10 cfm for each additional bedroom will be provided when the building is occupied.

A capability to increase the base rate ventilation on an intermittent basis to 0.05 cfm per square foot of conditioned areas will also be provided.

Intermittent spot ventilation of 100 cfm will be provided for each kitchen. Intermittent spot ventilation of 50 cfm or continuous ventilation of 20 cfm when the building is occupied will be provided for each washroom/bathroom.

Positive indication of shut-down or improper system operation for the base rate ventilation will be provided to occupants.

Mechanical ventilation shall use less than 0.5 watt/cfm for ventilation systems without heat recovery or less than 1.0 watt/cfm for ventilation systems with heat recovery.

Mechanical ventilation system airflow should be tested during commissioning of the building.

Heat recovery on controlled mechanical ventilation is recommended in severe heating climate zones. Heat recovery rates of heat recovery ventilators should be greater than 65 percent, including effectiveness of distribution.

Total ductwork leakage for ducts distributing conditioned air should be limited to 10.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.

Ductwork leakage to the exterior for ducts distributing conditioned air should be limited to 5.0 percent of the total air handling system rated air flow at high speed determined by pressurization testing at 25 Pa.

Only sealed combustion or power vented direct combustion appliances should be installed in occupied spaces. These appliances must be rated to vent properly at largest expected negative pressure. Gas cooktops and gas ovens should only be installed in conjunction with exhaust fans.

Major appliances should meet high energy efficiency standards using current appliance ratings. Select only those appliances in the top one-third of the DOE Energy Guide rating scale.

Lighting power density should not exceed 1.0 Watts per square foot.

C. Occupant Considerations

Systems that provide control over space conditioning, hot water or lighting energy use should be clearly marked. Information relating to the operation and maintenance of such systems should be provided to occupants.

The designer and general contractor should provide comprehensive information to occupants relating to the safe, healthy, comfortable operation of the building and mechanical systems.

Indoor Environment Criteria

Energy efficient and resource efficient construction should provide comfortable indoor conditions as defined by ASHRAE Standard 55-1989 (Addendum 55a-1994).

A. Building Structure

The building and site should provide effective drainage measures to control rainfall runoff and to prevent entry into the building.

The building foundation should be designed and constructed to prevent the entry of moisture and other soil gases.

Building assemblies should be designed and constructed to permit drying of interstitial spaces.

Building assemblies should be designed and constructed to prevent airflow into insulation systems from both the interior and exterior.

Radon resistant construction practices as referenced in the ASTM Standard E-1465-90 "Radon Resistant Design and Construction of New Low Rise Residential Buildings" should be utilized.

Materials, adhesives and finishes with tested low emission rates should be selected.

B. Mechanical Systems

Controlled mechanical ventilation systems shall be installed.

Where combustion appliances are used, only sealed direct combustion or power vented systems should be installed in habitable spaces. Gas cooktops and gas ovens should only be installed in conjunction with exhaust fans.

Forced air systems should be designed to provide balanced airflow to all conditioned spaces and zones. Interzonal air pressure differences should be limited to 3 Pa.

Filtration systems should be provided for forced air systems, which provide a minimum atmospheric dust spot efficiency of 30 percent (derived from ASHRAE Standard 52.1-1992).

Indoor humidity should be maintained in the range of 25 to 60 percent by controlled mechanical ventilation, mechanical cooling or dehumidification.

C. Occupant Considerations

Occupants should be provided with an operator's manual containing specific operating instructions on how to maintain a healthy indoor environment.

Control systems should include advisory display or indicative modes to alert occupants to "trouble" or "failure" conditions.

Environmental Impact Criteria

Energy efficient and resource efficient construction should be designed, constructed and operated to reduce overall life-cycle impact on the environment considering energy consumption, resource use and labor inputs in the fabrication, erection, modernization, operation and disassembly of the building, components and systems.

The design and construction of buildings should use recycled materials, or new materials with a high recycled content. Minimization of scrap on site and design for disassembly should be provided.

Discussion Relating to Criteria

The Criteria are for the most part self-explanatory. However, two concepts require explanation: air leakage coefficients and ductwork leakage. The following discussion relates to these two concepts.

In selecting the approach to measure/evaluate energy use the following factors were considered:

- A single airtightness value was selected as it has become clear that it is as important to build a tight building envelope in the hot, humid south as in the cold north. Similarly, mixed, humid climates and hot, dry climates also require tight building envelopes. The importance of tight construction goes far beyond energy conservation. Health and durability are the principle concerns with respect to this issue.

- The airtightness value is based on the surface area of the building envelope not the volume. Air change per hour at 50 Pa was rejected as a basis for measurement because it confuses the issue. We are dealing with leakage through the building envelope. Holes, holes, holes. Of course, ach @ 50 Pa is a popular, albeit misguided, criteria. The requirements have been translated for information purposes only. Based on ach @ 50 Pa, values are between 3.2 and 2.8 for 1,500 to 2,500 square foot houses with basements (not including the basements in these square footage determinations). The airtightness value is roughly double the Canadian R-2000 tightness requirement of 1.5 ach @ 50 Pa although it is roughly twice as tight as conventional construction.

Air Leakage -- Determining Leakage Ratios and Coefficients

Using a blower door, measure the flow rate necessary to depressurize the building 50 Pa. This flow rate is defined as CFM50. Alternatively, determine the Equivalent Leakage Area (EqLA) in square inches at 10 Pa using the procedure outlined by the Canadian General Standards Board (or alternatively, determine the ELA using the ASTM procedure calculated at 4 Pa). When determining these values, intentional openings (design openings) should be closed or blocked. These openings include fireplace dampers and fireplace glass doors, dryer vents, bathroom fans, exhaust fans, HRVs, wood stove flues, water heat flues, furnace flues and combustion air openings.

Calculate the leakage ratio or the leakage coefficient using the entire surface area of the building envelope. When determining the surface area of the building envelope, below grade surface areas such a basement perimeter walls and basement floor slabs are included.

For example, a 2,550 square foot house constructed in Grayslake, IL has a building envelope surface area of 6,732 square feet and a conditioned space volume of 33,750 cubic feet (including the basement). The measured Equivalent Leakage Area (EqLA) using a blower door is 128 square inches. This also corresponds to a blower door measured CFM50 value of 1,320 cfm and a blower door measured 2.3 air changes per hour at 50 Pa.

Surface Area	EqLA	CFM50	ach @ 50 Pa	Volume
6,723 ft2	128in^2	1,320 cfm	2.3	33,750 ft3

To determine the Leakage Ratio, divide the surface area of the building envelope by 100 square feet and take this interim value and divide it into the EqLA.

6,732 ft^2 » 100 ft^2 = 67.32

128 in^2 » 67.32 = 1.9 in^2/100 ft^2
(Leakage Ratio)

To determine the Leakage Coefficient, divide the CFM50 value by the surface area of the building envelope.

1,320 CFM50 » 6,732 ft^2 = 0.20 cfm/ft^2
(Leakage Coefficient)

Many airtightness measurements are recorded as air changes per hour at a pressure differential of 50 Pa (ach @ 50 Pa). To convert ach @ 50 Pa to CFM50 multiply the volume of the building envelope (including the basement) by the ach @ 50 Pa and divide by 60 min/hour.

For example, 2.3 ach @ 50 Pa across a building envelope of volume 33,750 ft3 is equivalent to a CFM50 value of 1,320 cfm.

33,750 ft^3 x 2.3 ach @ 50 Pa » 60 min/hr = 1,320 CFM50

Ductwork Leakage

To determine the allowable limit for ductwork leakage, determine the rated air flow rate of the air handler, furnace, air conditioner, etc. at high speed from the manufacturer’s literature. For example, a typical heat pump system may have a high speed flow rate of 1,200 cfm across the blower according to literature supplied with the unit. Ten percent of this value is 120 cfm. This 10 percent value becomes the total ductwork leakage limit when the total air handling system is depressurized to 25 Pa with a pressurization test of the distribution system

Appendix C

(Source: http://ducts.lbl.gov/HVACRetrofitguide.html)

Measurement/Observation	Potential Target value	Potential Retrofit Action
Duct leakage	<10% of air handler flow	Seal ducts: aeroseal/tape/mastic
Duct insulation	R6 (RSI 1) to R8 (RSI 1.4) for all ducts outside conditioned space	Add insulation to ducts
Air flows at registers	Compare to ACCA manual J	Replace registers, open/close dampers, reduce system flow resistance by straightening existing ducts or replacing them with straight runs of new ducts.
Air handler flow	Cooling: >400 cfm/ton in dry climate, or >350 cfm/ton in humid climate Heating: 12.5 cfm/kBtu/h	Replace filters, fix duct restrictions, change fan speed, replace fan with high efficient unit, add extra returns in return restricted systems
Filter Condition	Clean and at least MERV 6[1][1]	Replace with MERV 6 or better. Use 2 or 4 inch filters if possible
Thermostat Setting	Heating: 68°F (20°C) Cooling: 78°F (25°C)	Thermostat raised in summer and lowered in winter to account for better distribution, mixing and envelope improvements.
Spot ventilation	50 cfm each bathroom 100 cfm each kitchen	Replace fans, fix restrictive ducting
Spot Ventilation fan power consumption	2.5 cfm/W (1.2 L/s/W). A good source for these ratings is the HVI directory (www.hvi.org)	Replace with higher efficiency unit, remove/reduce duct flow restrictions, clean fan and ducting
Equipment capacity	Manual S	Replace with correct size
Refrigerant charge	Use superheat or subcooling tests	Add/subtract refrigerant
Age and Condition of HVAC system	Clean and undamaged. Determine system age.	Clean the system and repair damage or Replace the system if > 15 years old
Location of HVAC system equipment and ducts	Inside conditioned space	Seal and insulates duct locations to make them more like conditioned space, or move system location.
Window A/C units	EnergyStar compliant	Replace with central unit or improved distribution
Multiple systems/zoning	System and controls in good working order and providing good comfort for occupants	Ensure correct damper operation, check capacity of each system/zone matches a Manual J (or equivalent) load calculation
Envelope leakage	Normalized Leakage Area reduction of 0.35	Insulate envelope, seal windows/doors/other openings
Moisture testing	No moisture problems	Source control – better kitchen and bath venting, fix flashing/detailing, seal and condition crawlspaces in high humidity climates, replace windows, add insulation to walls, floors and ceiling

House insulation	Ceiling: R-30 (RSI 5.3) minimum, R-49 (RSI 8.6) in cold/severe cold climate. Floor over crawlspace: R-25 (RSI 4.4). Basement walls: R10 (RSI 1.8), Basement Floor or slab usually depends on local codes. Walls: Cavity should be completely filled with insulation.	Add insulation to fill cavity. Add semi-permeable rigid exterior insulation in cold/severe cold climates if the wall is 2×4 construction.
Windows	Double-glazed, low-e. Shaded in cooling dominant climates	Replace windows. Add shading.
Window shading	Located on south and/or west facing windows	Add shading to reduce solar loads
Solar radiation control	Radiant barrier in attic, low absorbtivity roof coatings	Add radiant barrier in attic, or low absorbtivity roof coatings
Wall, floor and ceiling construction	Space for ducts/vents	
Evaluate house energy bills (if available)		
Occupant survey Ask occupants to report problems	No problems	Moisture removal strategies, new windows (for condensation resistance), change register type, airflow and location to improve mixing/remove drafts, add envelope insulation, etc.

PART 2 - Systems Interactions

Background

When discussing the systems in residential construction and home operation, it is useful to identify the performance reducing influence of system interaction in order to generate processes and standards that overcome these issues. This report connects the operating performance of energy, envelope, and mechanical systems to energy, envelope, and mechanical performance measures. In this context the performance reducing influence of other systems (such as structural, electrical, plumbing, and communication characteristics and performance) on energy, envelope, and mechanical systems is included in the discussion.

The performance of a home is based on the combined interaction of systems internal to the home, but also on the interaction with the local climate and community. For the purposes of this report, the focus is limited to systems that comprise the home and how these systems respond to each other and the immediate local climate. While systems of construction practices and quality control procedures have significant performance reducing impact, only the symptoms of poor implementation of these practices will be discussed.

Introduction

This report serves to connect residential system integration characteristics to measures of performance through a discussion of performance reducing influence of other systems on energy, envelope, and mechanical systems. The structural, electrical, plumbing, and communication systems characteristics and performance impact the energy, envelope, and mechanical systems of a home, both negatively and positively. For the purposes of this report, the scope of energy systems includes energy efficiency and energy generation.

This report attempts to segregate individual system performance measures and the performance reducing influence of other systems in the home, but there is also a critical human element involved. The performance reducing influence can be the result of inadequate system compatibility, design integration, poor construction or installation practices, insufficient quality control, or occupant operation. For this reason, each section not only outlines how materials, operation, and performance specifications create the negative influence, but also how the installation can cause performance-reducing impacts.

In addition, there is also a brief discussion on potential performance reducing impacts of builder programs and defining performance through a multi-tiered trade-off strategy. This is a follow up discussion to the previous report (Task 6) that relates well with issues presented in this report. As with any discussion involving relative standards, there is no baseline reference defining a consistent level of performance through this document.

Defining Systems and Performance

Energy, envelope, and mechanical systems and related performance measures are broad categories when discussed in the context of residential construction and home operation. For the purposes of this report, we set out to define what is included in the discussion of each category and how performance is measured. The relative performance-reducing impact on each system will then be discussion based on this initial description.

Energy Systems

This is perhaps the least defined category in this report, as it can apply to energy generation, distribution, and consumption. For the purposes of this report, we limited our approach to include how energy consumption is negatively influenced by system interaction, and to applications involving onsite energy generation. Lighting, electrical, appliances, and plug loads may also be included in this category, where applicable.

The energy generation component is limited to market-ready systems for photovoltaic electricity generation and solar thermal systems for space and water heating. As there is a growing interest in utility inter-tie of photovoltaic systems and an increased use of fluorescent lighting in residential applications, there is also a brief discussion on power quality and concerns for negative interaction with utility generation and distribution. Photovoltaic and solar thermal can add a significant amount of complexity to residential systems in terms of control optimization, but for the purposes of this report that level of detail will not be discussed.

Performance of systems in this category is generally measured by energy conversion and energy transfer efficiency, work produced per unit of energy input, and percentage of load offset by onsite generation. Onsite electrical generation performance is also measured by these general criteria, but in the case of utility integration it can also be measured by power quality, including power factor and total harmonic distortion.

Envelope Systems

Envelope systems are more straightforward in definition, in that they include any system that buffers external climate conditions from interior conditions. This category may be further reduced to sub-categories of pressure boundaries, thermal boundaries, and water/water vapor management boundaries. For the purposes of this report, the building envelope will include two primary categories: the foundation system(s) and the non-foundation system(s).

The performance of the building envelope can be measured in the context of pressure, thermal, and water/water vapor boundaries. This can include thermal resistance (conductive, convective, and radiant), the ability to manage exterior bulk water, the ability to manage interior and exterior water vapor, and structural integrity (live and dead loads, snow and wind loads, for example).

Much of the performance reducing influence of residential systems on other residential systems is related to how the building envelope is defined and consideration for the definition during design and construction. The building envelope serves to thermally isolate the interior of the home from the exterior conditions and manage bulk water from the exterior. From this perspective, it is critical to define the thermal and pressure boundaries, in addition to the exterior drainage plane. In addition to defining these boundaries, it is important to maintain continuity of these boundaries throughout construction, and provide an appropriate path allowing the wall assembly to dry.

When penetrations in the thermal, pressure, and moisture management boundaries are made, it is important to justify the penetration, understand the impact on the performance of the home, and ensure it does not compromise the performance of the home. This may also include the size and location of thermal “holes”, such as windows and skylights. Basing design and installation strategies on fundamental energy, pressure, and moisture balance principles can help optimize the performance of the home and avoid performance-reducing interaction of residential systems on energy, envelope, and mechanical systems.

Mechanical Systems

The mechanical systems discussed in this report include space conditioning equipment and distribution, hot water equipment and distribution, and ventilation equipment and distribution. There is some overlap with systems defined under energy and envelope systems, but this is to be expected when the performance of a home is viewed as a whole system of interacting components. Throughout this report, an effort will be made to explicitly differentiate these systems from those listed in the Energy and Envelope categories, where needed.

The performance of mechanical systems can be measured in the context of equipment energy conversion efficiency, distribution efficiency, adequacy of distribution (flow and delivery), and appropriateness of equipment size. Ventilation can be measured in the context of whole house air change rates and spot elimination of source contaminants. As with any system or system interaction in a home, performance can also be measured by occupant comfort and satisfaction.

Performance Reducing Interaction

The performance reducing influence of residential systems is outlined in this section through subsets of the energy, envelope, and mechanical systems. These subcategories include characteristics and performance of structural, electrical, plumbing, space conditioning, and onsite generation. For the purpose of this report, plumbing includes distribution, wastewater removal, and non-solar hot water production. Electrical systems include electrical distribution, lighting, appliances, communication, and plug loads. Each section includes system descriptions, potential performance reducing influence on other systems, and how installation practices can negatively influence the performance of other systems.

Structural Systems

The structural systems can have a significant impact on the energy consumption of a home and the performance of the envelope and mechanical systems. The influence of the structural system is divided into two primary sections, foundation and non-foundation, to discuss the influence on other systems. As the building envelop is the primary buffer between the interior and exterior of the home, the performance reducing influence is discussed in terms of interaction with exterior conditions as well as with the internal systems and conditions.

Foundation Systems

Foundation systems affect the performance of the energy, envelope, and mechanical systems through influence on space conditioning loads, moisture management, and structural integrity. While structural integrity is, of course, critical to the overall performance in the home, it will not be discussed in any great detail in this section. The system interaction will be discussed in the context of three generic foundation systems: full basements, vented crawlspaces, and slab-on grade.

Full Basements

Basements can negatively impact the space conditioning load, indoor air quality, and durability of a home if exterior bulk water is not managed properly, and the thermal boundary is not effectively applied. Surface water runoff can penetrate the basement if the site is not graded properly, groundwater can penetrate the foundation if drainage is not appropriately applied, and moisture can move by capillary action from the footer to the foundation wall if a capillary break is not incorporated into the foundation design. In addition, moisture can move through the basement floor if an appropriate strategy is not applied.

In addition to increasing the humidity levels in the home and potentially damaging items in the basement, the high moisture levels can instigate mold growth. When finishing or insulating foundation walls, any moisture behind the surfaces can also instigate mold growth and rot, especially if the wall assembly does not allow the moisture to escape. Even when the foundation remains dry, applying a finished wall assembly or insulation reduces the surface temperature of the interior surface of the foundation. If any conditioned air makes its way to this surface during the heating season, it may condense and, again, instigate mold or rot problems.

Vented Crawlspaces

While there is movement to build crawlspaces as an integral part of the conditioned space, many are still constructed using the conventional vented approach. Venting the crawlspace defines the crawlspace as outside the thermal and pressure boundaries, which introduces a new set of concerns regarding the mechanical systems. The moisture management component is similar to that of the basements described above (Full Basements), but there is an additional concern due to the exposure of the earth floor in many cases.

Venting the crawlspace isolates the crawlspace outside the building envelope, requiring attention to penetrations through the envelope and energy loss from mechanical systems in the crawlspace. Ductwork and water pipes are typically installed in the crawlspace, and sometimes even the space conditioning equipment, which requires insulation, additional air sealing, and extensive condensation control. In addition, duct leakage in vented crawlspaces can contribute to problems that are described in the forced air section of this report (Forced Air Distribution).

Many conventionally built crawlspaces do not finish the floor, and may not even at the very minimum use a plastic sheeting cover. Exposed earth, or a non-continuous ground cover, can introduce problems associated with moisture. High humidity levels in crawlspaces may contribute to mold and rot of framing members or floor decking, as well as floor swelling and increased indoor humidity levels.

Slab-on-grade

Slab-on-grade foundation strategies introduce several performance-reducing impacts associated with energy, envelope, and mechanical systems. In addition to heat transfer through the perimeter of the slab, moisture can migrate through the slab from the ground beneath if not constructed with adequate protection (drainage and capillary control). Eliminating the basement or crawlspace forces mechanical systems and distribution to be located in attic spaces, which can be exposed to greater temperature and climatic variations.

Interface between Foundation and Framing

The interface between the foundation wall, in any foundation system, and the framed wall is a point at which moisture can migrate and air can infiltrate. The moisture movement can degrade the wood wall components, and uncontrolled air infiltration reduces the energy efficiency of the home in an unpredictable manner. The direct connection between the concrete foundation wall and the wood sill plate can allow moisture to move from the concrete to wood if not properly controlled. This can lead to some of the moisture related problems discussed in the paragraphs above. Due to the irregular top surface of the foundation wall the sill plate may not be able to sit flush with the foundation wall, creating a long linear crack allowing unconditioned air to infiltrate the home. Stepped foundation walls on sloped sites are particularly hard to seal.

Framing Systems

The discussion of performance reducing influence of above grade residential construction methods will be limited to wood stud framing, as this is the predominant technique used in production housing. The discussion is in the context of defining thermal and pressure boundaries, as well as the management of bulk water and water vapor as outlined in the previous section on the building envelope (Building Envelope). Negative interaction results in problems related to indoor air quality, energy performance, comfort, and durability. As there are many techniques for finishing the interior and exterior of the building envelope, for the purposes of this report a generic approach to the building envelope will be utilized in this section.

Utilizing an Optimum Value Engineering (OVE) approach to framing the building envelope helps avoid many of the performance reducing impacts on energy and mechanical systems associated with conventional approaches. This approach reduces the amount of material needed to construct the walls, reducing material costs and material waste in addition to increasing the overall R-value. The amount of framing in a wall can impact the thermal resistance of a wall, which in turn impacts the space conditioning loads. Excess use of framing associated with conventional strategies creates more thermal bridges in the wall and, if not accounted for in load calculations may cause a mismatch between equipment size and actual loads. Conventional framing impacts not only the quantity of insulation, but the quality as well, since more custom cuts are needed to fit smaller spaces.

The framing layout also includes the window layout, which can have a significant impact on comfort, space conditioning loads, and moisture management. As a significant component of occupant comfort is associated with the mean radiant temperature of the surrounding surfaces, the location and type of window plays an important role in occupant comfort.

Selecting windows with a relatively high resistance to heat transfer, both conductive and radiant can improve the thermal comfort of the occupant and reduce the space-conditioning load. Climate and site characteristics, as well as visible transmission, are critical considerations when choosing window types and shading options through a system integrated approach. As with the wall framing, the actual thermal performance of the windows and shading devices must be well represented in load calculations to ensure that comfort can be maintained by the space conditioning systems.

The finish material of exterior framed walls is almost never a primary barrier to bulk water or water vapor intrusion, and should be designed as a system of interacting components in itself. The exterior finish must be designed and installed with a well-defined and continuous drainage plane underneath with an exit point for the water at the bottom of the wall. A water vapor barrier is sometimes also used in the wall assembly, with the location dependant on climate, to avoid condensation within the walls. With this said, it is likely that water will enter the wall at some point during the life of the wall, and must be allowed a drying path. A strategy that sheds water, reduces migration of water vapor, and allows the wall to dry to one side or the other will reduce problems associated with moisture intrusion that does occur.

Corner framing can pose a particularly difficult situation in ensuring that a continuous barrier to moisture and water intrusion is installed over the framing. The corner of the home experiences some of the greatest wind-induced pressures, driving rain behind the corner finish board. If an effective strategy is not used to stop water intrusion and provide drainage, significant moisture related problems can result. There are many points on the exterior finish that require a significant amount of attention in order to avoid water-related problems. Flashing details, gutter layout strategies, drainage plane integration with flashing, windows, and doors, all significantly impact the long-term performance of the envelope if not installed or designed properly.

Electrical Systems

The performance reducing influence of electrical systems on energy, envelope, and mechanical systems is divided in to four sections: Lighting, Appliances, Plug Load, Electrical Distribution, and Communication. These systems are integral in the energy consumption of the home, and have characteristics that may minimize the effectiveness or interfere with the operation of other equipment and systems. The section on communication primarily discusses communication between the house systems and the internal and external conditions.

Lighting

As practices involving the building envelope and mechanical systems become more energy efficient, the energy use associated with lighting, appliances and plug loads becomes a greater percentage of overall household energy use. The system interaction impact of the lighting system is three-fold. There is an aesthetic and usability component, a direct energy consumption component, and an impact on the space-conditioning load.

The first component involves the interaction with the occupant, related to task and ambient lighting, in addition to lighting controls. There are minimum lighting system design requirements set by building codes and many homes will provide advanced lighting to accentuate architectural elements and to improve usability of spaces in the home. The variability in occupant use patterns and lighting system design presents a challenge when estimating whole house energy savings when compared to an assumed base energy use pattern.

Utilizing natural daylight to offset lighting needs can help to reduce energy use, but presents a design challenge in the impact on space conditioning loads. Conventional lighting systems, utilizing primarily incandescent lighting, contribute to meeting the heating load of a home, but also increase the cooling load on the space. Utilizing lighting systems that reduce the amount of energy required to produce the same lighting levels, such as with fluorescents, can reduce the energy consumption associated with providing lighting, and reduce the cooling load of the structure, but the contribution to the heating load is also reduced. This is also an issue with incorporating daylighting in residential structures. Increasing the amount of usable daylight, in the context of residential lighting, generally requires significant attention to design to ensure that energy use associated with an increased window area does not offset energy savings associated with reducing lighting energy use.

Incorporating daylight to offset lighting energy consumption also presents a challenge from the control perspective. As daylight can vary throughout the day, an appropriate lighting control strategy is generally needed to ensure adequate lighting levels are maintained. The initial cost is significantly greater than conventional controls and the placement of the controls is a critical component. The placement of light level controls must represent the location where lighting levels are defined for their specific purpose. There may even be opportunities and challenges in integrating automatic variable shading devices.

Lighting controls are also used in conventional lighting systems that sense occupancy, turning lights on or off depending on occupancy. Coordinating the location of the lights and the controls is important to ensure that detection is appropriate for the use of the space. For example, many closets may have the manual switch on the exterior of the closet. In order to effectively implement an occupancy sensor strategy, it would need to be placed on the interior to avoid unnecessary energizing of the circuit when someone walks by the closet. This can also be explained in the context of exterior lighting, when the placement of motion sensors may cause the circuit to be unnecessarily energized by tree branches blowing in the wind.

Appliances

It can be difficult to quantify the impact of appliances on energy, envelope, and mechanical systems as they have many different operating cycles and use varies from household to household, but the performance reducing influence is nevertheless apparent. Clothes dryers, clothes washers, refrigerators, dishwashers, ovens, ranges, and even aquariums, among others, can impact the space conditioning load and humidity levels of the home in several ways.

Clothes dryers

Clothes dryers are perhaps the most influential appliances in terms of system interaction, as there is little choice in available energy efficient models. There are several different types in the market today, including electric resistance, gas fired, and condensing ventless models. Each has a relatively high-energy demand, and each has a wasteful energy component. There is an innovative heat pump clothes dryer technology gaining some attention, but many are in the prototype stage and others (not available in the US market) are cost prohibitive. While this technology will not be discussed in this section, it is worth mentioning, as perhaps it will be able to combine space dehumidification and clothes drying duties in the future.

Regardless of fuel sources, vented clothes dryers consume a significant amount of energy in producing heat for drying clothes, but they also exhaust a significant amount of conditioned air from the space. The vent is also yet another penetration in the building envelope and must be handled accordingly. Many installations can increase drying time (and therefore energy consumption) due to poor venting strategies or a blocked vent. In addition, when coupled with a relatively airtight building envelope, the dryer may cause ambient draft combustion appliances to backdraft. This becomes even more realistic when other vent fans (kitchen, bath, etc.) are operated at the same time as the dryer. As with all ventilation strategies, it is important that the location of the vent termination allows the air to be exhausted outside, and not to the crawlspace or attic.

Ventless clothes dryers avoid the pressure imbalance issues associated with vented dryers, but at the same time, consume a significant amount of water in the condensing process. The heat extracted through condensing the moisture laden dryer air is dumped down the drain.

Others

The performance reducing influence of the following appliances are more related to energy use and indoor air quality. Refrigerators, ovens, and ranges can add heat to the living space, increasing the cooling load, but also contributing to meeting the heating load. Dishwashers add humidity to the space and, like clothes washers and condensing dryers, waste energy through dumping hot water down the drain. Gas fired ranges and ovens can produce deadly levels of carbon monoxide in certain cases, which can be exhausted directly to the interior space. Aquariums can also be a silent contributor to these loads on the building. Occupant use and cycle selection is one of the greatest impacts that determine the magnitude of the reduced performance of the home.

Plug Loads

The impact of plug loads is also difficult to quantify, but it could be argued that, as building envelopes and space-conditioning equipment become more energy efficient, they are an increasing portion of the overall energy use in a home.   Many plug loads also have standby power draws when not in use. These are unpredictable loads in a home, which can make energy savings estimates difficult.

Electrical Distribution

The current practice for residential line voltage electrical distribution can be prohibitive when energy management practices are considered, such as load prioritization and demand reduction. Mixed-use circuits complicate the opportunity when control over specific loads is desired. In addition, along with the increased presence of low-voltage wiring associated with security systems and other control strategies, wiring strategies can increase air infiltration through the building envelope and interfere with continuity of insulation in the building envelope.

While demand management and load prioritization are not critical in today's residential energy service structure, the current method of electrical distribution may prohibit the adoption of such strategies in the future. For example, as lighting circuits may also include plug and appliance loads, it would be difficult to reduce the standby power draw of plug loads without affecting the lighting. This may also be a factor when attempting to coordinate coincident solar-induced loads and solar energy generation.

In addition to operational impact, there is also a physical interference impact associated with line voltage distribution and the increase of low-voltage and home networking wiring. These wiring strategies generally penetrate the building envelope through the attic or through switch and outlet boxes, for example, and increase the air infiltration into the home. These penetrations may also provide a path for moisture laden indoor air to migrate to colder surfaces where condensation can occur.

Low voltage wiring styles impact insulation installation and frequently impact bath fan ventilation performance. As these wires can be collectively installed side-by-side in some cases, it may interfere with the ability to insulate continuously. Tangled and abundant wiring can run along the bottom chord of roof trusses, blocking the cavity that is to be insulated. This interference can also occur with ventilation fan ducting, significantly reducing the ability to correctly install the ductwork, decreasing the effectiveness of the ventilation strategy.

Communication

Communication in the context of the electrical systems is related to how systems communicate with each other, with the occupants, and with the interior and exterior environments. This was already discussed in relation to the lighting systems in a previous section (Lighting), but there is also a significant impact of communication on the performance of energy, envelope, and mechanical systems. The following section outlines a general approach to integrating and optimizing the communication between the space conditioning systems and the indoor and outdoor environments.

Temperature Variation

An example included in the related Task 8 deliverable describes a case study where a significant temperature difference occurs between the first and second floors of a small townhouse. While the problem is directly related to poor mechanical system design and performance, it addresses the issue of a single thermostat control representing the current status of the entire indoor environment. In the case study, the second floor is significantly overheated because the thermostat is located on the first floor, in addition to other factors.

In order to optimize system performance and energy efficiency, improvement in how the space conditioning systems communicate with the indoor and exterior environments may be effective. This is also directly relates to the envelope characteristics and overall home design, because the different locations in a home will behave differently throughout the day depending on solar exposure, wind direction and magnitude, occupant behavior, etc. Controlling the interior environment as a single zone with a single thermostat may not be the most effective strategy in all cases in the context of performance and energy efficiency.

The location of the thermostat relative to the location of windows has a performance reducing potential that will also influence the comfort and energy consumption of the home. The thermostat may be located on a wall that experiences solar gain at times during the day, causing the thermostat to inaccurately determine the space temperature. This may cause the space to be over conditioned during the cooling season, and under conditioned during the heating season.

Control Integration

A control strategy based on sensing the interior dry-bulb temperature alone may not be an effective strategy in optimizing the comfort and performance of the interior environment, especially in homes with improved building envelopes. The indoor relative humidity is also an important component from a comfort and indoor air quality perspective, and carbon dioxide levels may also be an indicator of indoor air quality. An effective strategy for integrating indoor environment indicators to communicate needs to space conditioning equipment may help to improve the overall performance of the home.

A strategy for communication between the indoor and outdoor environment may also be useful in optimizing the performance of the home through adjusting how the space conditioning system responds to indoor needs based on outside conditions. An advanced control system that evaluates indoor needs and outside conditions may optimize system performance through a residential economizer strategy, and optimized ventilation strategy, or through adjusting the thermal output of heating systems. For example, many advanced boiler control systems will sense the outdoor temperature and adjust the boiler water temperature accordingly. An advanced control and communication system may enable the space conditioning systems (heating, cooling, ventilation, humidity, etc.) to work together in a strategy that responds to and takes advantage of exterior conditions to optimize performance.

Plumbing Systems

The scope of plumbing systems is fairly limited, and for this report will only include distribution on the house side of the meter and wastewater drainage systems. While the water heater will not necessarily be a focus of this section, a discussion about the performance reducing influence of the hot water supply as a whole will be included. This section is divided into Distribution and Wastewater, and Hot Water Supply for the purposes of this report.

Distribution and Wastewater

The plumbing for domestic supply and wastewater management impacts the performance of energy, envelope, and mechanical systems related to installation and occupant use. A coordinated design and installation practice can help avoid entanglement issues with the ductwork and electrical layout. There is an energy loss component associated with hot water distribution and with the wastewater energy content. A potentially large portion of losses occur as the occupant waits for hot water to reach the fixture and adjusts the outlet temperature at the fixture.

In order to avoid the issue of wasting water while waiting for hot water to reach the fixture, some homes use a hot water re-circulation device. However, some units use timer controls rather than demand controls, which can substantially increase heat loss associated with distribution. IBACOS has experienced scenarios where the occupant has extended the re-circulation time to many hours, with a very significant impact on energy used for hot water. A related problem associated with the re-circulation system is the location of water distribution pipes. While the heat loss associated with pipes in unconditioned spaces is evident, there can also be a significant amount associated with pipes buried under concrete slabs. This strategy can rob heat from the pipes, reducing the delivery temperature.

Hot Water

The use of hot water and hot water generation presents several performance reducing components associated with energy, envelope, and mechanical systems, but is dependant on the type of system used. In this section, the discussion will be limited to gas and electric storage tank, tankless, and hot water heat pump systems. Solar hot water generation is discussed in a later section (Solar Hot Water).

Storage tank systems present several potential performance reducing impacts related to standby losses and combustion by-products. Standby losses associated with both electric and gas storage tank units can impact the heating and cooling loads of a home, and become a greater impact when high performance building envelopes are utilized. During the heating season, the standby losses contribute to meeting the space-conditioning load, but during the cooling season the standby losses are a component of the space-conditioning load.

Ambient draft gas hot water generating units also have the potential to backdraft if the venting strategy is not sufficient or if the unit is installed in a zone that can be depressurized by leaks in the return side of the forced air system, or by exhaust-only ventilation associated with kitchen, bath, and clothes dryer fans. This potential for backdrafting is increased with tighter building envelopes. The interaction that can occur in these situations can compromise the indoor air quality and potentially cause carbon monoxide poisoning of occupants.

Tankless hot water systems eliminate the energy loss associated with storage tank systems, but backdrafting can still occur if a direct or power vent strategy is not used. The gas tankless units also required a substantially larger gas line to be installed, as the input capacity is significantly larger than that of a storage tank system. It is also important that the sizing is correct to meet the demand for the household. As there is not a volume of hot water to draw on, it is important that the unit is large enough to handle several hot water needs at once.

Heat pump water heaters are gaining greater market presence, and generate hot water at higher efficiencies, but the impact on space conditioning must be considered. These units extract heat from the surrounding air, so if installed in a conditioned space, it could have a significant impact on the energy use used in space conditioning. The impact on space conditioning is inverse to the storage tank system, contributing to meeting the space cooling load, but detrimental during the heating season. The unit will be utilizing energy input to the space by the heating system.

Communication

As implied in the section above, occupant use can have a significant impact on hot water energy consumption through waiting for hot water to reach the fixture and through adjusting the outlet temperature at the fixture. A communication strategy that allows the user to call for hot water and set the outlet temperature may help reduce these energy losses. Technologies exist for these purposes, but have yet to be perfected and implemented on a significant scale.

Space Conditioning Systems

The discussion about performance reducing influence of space conditioning systems will be limited to forced air heating and cooling systems and ventilation strategies. Pressure imbalances, leakage, and indoor air quality will be the focus of this discussion. This section will not address issues inherent to combined systems integrating hot water, ventilation, and space heating. Instead, it will treat the performance reducing impact of systems individually on energy, envelope, and mechanical systems.

Forced Air Distribution

Forced air distribution systems can be one of the greatest culprits in reducing the performance of other systems in the home, especially if not engineered or installed correctly. These systems operate with relatively large pressures and flows, which can negatively influence comfort, energy efficiency, indoor air quality, and durability. This section will discuss the interaction with the energy and envelope systems, but there is also a component related to communication between the conditioned space and equipment discussed in the electrical system section of this report (Communication).

If systems are not design and installed with adequate return air pathways, pressure imbalances can increase heat loss, decrease comfort, and can potentially backdraft ambient draft combustion appliances. For example, if a duct system is not designed with return air pathways that account for operation when interior doors are closed, those rooms can be over supplied and over pressurized. This can increase ex-filtration of conditioned air through leaks in the building envelope of the over-pressurized room. If these rooms are over-pressurized then it is likely the return system will depressurize other zones. This may increase the infiltration of outdoor air in the depressurized zones, and potentially backdraft any ambient draft appliances.

Duct systems with a significant amount of duct leakage can impact the energy consumption of the home, reduce comfort, cause pressure imbalances like the details in the previous paragraph, and cause moisture related problems. The performance reducing influence of duct leakage is significantly greater when they occur outside the thermal and pressure boundaries of the home. A disproportionate amount of supply-side duct leakage outside the pressure boundary can cause the house to operate under a negative pressure, while the opposite is true for a disproportionate amount of return leakage. In addition, return leaks can draw unconditioned air from crawlspaces, garages, and attics, which not only affect the energy efficiency of the system, but also may compromise indoor air quality. Supply side leakage in attic spaces may also contribute a significant amount of moisture-laden interior air to the attic space, increasing the potential for damage from condensation in colder weather.

Whole House Ventilation

Unbalanced whole house ventilation can create pressure imbalance issues like those presented in the previous section (Forced Air Systems), and can also add a significant space conditioning load to the home. There is also a climatic consideration for exhaust or supply type whole house ventilation in terms of introducing moisture, and variations in performance-reducing influences will depend on which approach is utilized.

Spot Ventilation

Spot ventilation can introduce the same performance reducing problems as the whole house ventilation in terms of pressure imbalances and increased load. With this said, it is also important to mention that the location of the termination of the ventilation system is critical to performance. The vent must be installed with a practice that does not significantly increase the operating static pressure on the fan, and it must be vented outside the home. Ventilation systems that exhaust to the attic or crawlspaces introduce a high humidity source to these spaces, increasing the potential for moisture related problems.

Onsite Renewable Energy Systems

This section focuses on photovoltaic and solar thermal residential systems and several performance reducing influences associated with the installation and operation of these systems. Power quality issues associated with utility inter-tie photovoltaic systems are discussed in the following section (Power Quality). There are a variety of control and component optimization strategies, but this will not be an exhaustive overview of performance reducing impacts on solar related systems by any means. Some of the more typical, well-documented concerns may be related to the following:

- Site orientation and interference with solar access
- Climatic variations - freeze protection and collector angle
- Storage capacity, collector size, and load optimization

Less typical performance reducing influences may include architectural integration, mounting strategies, serviceability and maintainability, pipe and line losses, collector and storage losses, and space requirements. These will be discussed in general terms as applicable to both photovoltaic and solar thermal systems, with differentiation where necessary. There may also be references to passive solar strategies where they apply.

When designing and installing both photovoltaic and solar thermal collectors, there can be concern over the impact on the architectural aesthetics of the home and concern for the impact of the mounting strategy on the performance of the roof. If the collectors are mounted after the fact and not integrated into the architectural design, there may be objection to the appearance of the collectors. This has even led to some homeowner organizations outlawing solar panels in their community. Mounting strategies, if not installed correctly, can create the potential for the roof to leak in mounting locations.

Serviceability and maintainability are critical considerations in photovoltaic, solar thermal, and passive solar strategies. Collectors need to be serviced and cleaned periodically to maintain performance, and providing easy and safe access will facilitate a regular schedule. Passive solar design, involving direct gain strategies in particular, must not only incorporate location appropriate shading devices, but also be designed for easy maintenance. The homeowner, or service personnel, must be able to easily access all flashing and caulking. In addition, they must be able to reach all areas of the window for cleaning. For example, in many two-story window strategies used for passive solar design, only the top and bottom can be easily accessed by a ladder. Due to the angle of the ladder, the middle sections of the window may be out of reach.

The distance between the collectors and the storage medium in both photovoltaic and solar thermal is an important consideration. In long solar hot water piping systems there can be significant pipe losses, especially when installed in unconditioned spaces. With DC electricity generation, a long distance between the collector and battery storage can result in either significant power loss or increased cost associated with larger wires.

The storage required for solar hot water systems and photovoltaic systems using a battery bank can require a substantial amount of space. If not integrated into the design of homes, limited space can prohibit the use of these systems, or add an additional cost for increasing space availability. There are also standby heat losses from solar water storage that impact space conditioning loads, and a need to address hydrogen production from battery storage banks with photovoltaic systems.

Recent observation of a system comprising of a passive (pump-less) solar hot water system, a storage type water heater, and a timer controlled hot water re-circulation device (used to circulate hot water to fixtures), demonstrates a significant reduction in performance due to poor integration. The original solar system generates hot water passively without the use of pumps, for storage in a tank style hot water system. Homeowners subsequently had re-circulation devices installed to bring hot water to fixtures to eliminate the wasted water and time associated with waiting for hot water to arrive at the fixture. However, the device was installed without consideration for the impact on the solar system. Due to the design and installation of the systems, the re-circulation pump actually forced hot water out through the collector on the roof, and as a timer controls the pump, it can be left to run for hours at a time. One homeowner even had it set to run 24 hours a day, 7 days a week. While the final analysis is not yet complete, the estimated impact on energy use shows that the worst system in this case uses about 15 times more energy than the best measured system in this case (without a re-circulation device), and 6 times more than a conventional system.

Power Quality

While power quality is not necessarily a concern when discussing performance reduction of system interaction, it should be noted that inverters and fluorescent lamps can create power quality concerns for utilities. Both items are gaining greater acceptance in residences, and both can exhibit harmonic distortion in the current and voltage waveform that can impact the electricity network. While this is not necessarily a critical matter in this discussion, it is worth mentioning as a potential performance reducing influence of homes on the utility grid.

Integration of Trades and Installation Practices

Much of the performance reducing interaction of residential systems is related to communication between the designers, builders and the sub-trades and oversight of the integration of trade practices. Specifications and standards provide a guide for producing a high performance product, but the implementation is critical in ensuring performance levels are met and that performance is not compromised. While post-construction quality control can be effective in quantifying and comparing the intended results to actual results, making changes at this point can be challenging and costly. A solution to this integration problem is to develop a capacity, based on a whole house system integration strategy, for pre-job coordination, training and certification of trades, and the capability to make system design and material changes to overcome challenges to implementation. A case study demonstrating these challenges and resolution of the challenges is provided in Task 8.

Trade-off Approach to Performance Standards

While the development of green building and performance standards have facilitated an industry wide change in the specifications of new homes, many fall short when addressing performance-reducing interaction. There also seems to be lack of clarity in what fundamentally defines a high performance or “green” home, which is typically based on a relative energy performance standard. The intention of this section of the report is not to criticize the current status of builder programs, but rather to address opportunities for improving the implementation of home performance based programs.

Many certifications are based on minimum compliance with a standard based on a home energy rating score. This standard defines a level of relative energy efficiency, not absolute energy efficiency. For this reason, it is quite possible that a 5000 square foot home can achieve the same “green” or energy efficient rating as a 2000 square foot home, despite the fact that the larger home will use more energy, materials, and resources. This approach ensures that participating homes will likely be built to more energy and resource efficient standards, it does not address the total energy and resource impact of the housing stock as a whole.

A trade-off, point based certification process allows flexibility in how homeowners and builders choose to meet certification standards, but does not provide guidance on implementing the selected package to ensure performance reducing interaction. This becomes of greater importance when progressive standards like building envelope air tightness and ventilation are applied. The performance reducing impact of poorly implemented systems in this environment may likely be exaggerated compared to conventional practices. An approach that provides process guidance to improve the delivery and implementation of high performance and green building standards may be beneficial in avoiding the performance reducing impact of system interaction in participating homes.

Conclusion

As building standards and program criteria demand more stringent adherence to energy and resource efficient guidelines, the importance of developing processes for implementation and quality control is becoming more apparent. While the impact of performance reducing system interaction influences existing homes, it is potentially easier and cheaper to proactively address system interaction before the home is designed and constructed. The designer, builder, and trades obviously play critical roles in determining the performance of the final product. A deliberate design and construction strategy that enables the integration of not only the building systems, but also the construction processes can be effective in avoiding the performance reducing impacts described in this report. An integrated approach can also be effective in meeting program certification criteria, and in delivering a product that performs well to the expectations of homeowners participating in these programs.

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Part 3 - Case Studies of Whole-House Design

Background

This report is part of a series of deliverables that outline and discuss residential performance standards and measures, and the influence of system interaction on the performance of homes. Describing home performance as the result of a complex system of interacting components provides a basis for evaluating individual system performance, system interaction, and overall performance. This report describes case studies where system interaction potentially compromises home performance, and suggests revisions to enhance the overall performance of the home.

Introduction

This report describes case studies where interaction between systems compromise home performance through system design, installation, or both. In addition, suggested revisions are presented for design and installation practices. These case studies are based on experiences at IBACOS research homes, so a significant amount of the information presented will describe advanced performance standards, challenges to implementation, and the resolution of these challenges. IBACOS works closely with builders throughout the construction process, so many potential performance-reducing issues were caught before they actually compromised performance. For this reason, documentation of the actual problem is not available for each case study, but rather a description of the potential problem.

It may be argued that a case study of almost any existing home will demonstrate performance-reducing impacts of system interaction. With this said, the focus of this report is on challenges to implementation of advanced strategies. While specifications and post-installation inspection are important in minimizing negative system influence, the installation is where critical mistakes or challenges can occur. Where available, quantitative descriptions of reduced performance will be included. To protect reputations, anecdotal descriptions of several of the challenges will be provided, leaving out names of builders and contractors. However, it should be noted that the companies in this report are making an effort to improve their practices through their involvement with the Building America program.

The second case study is provided to emphasize the performance-reducing influence of system interaction and the difficulty in retrofitting a poor performing system after-the-fact. This second case study describes comfort and efficiency problems in recently constructed town homes that result from an inadequate design, poor translation of the design to installation, limited quality control, and poor integration between the structural system and mechanical controls. This second case study outlines a recommended retrofit strategy, but also acknowledges that unless a complete overhaul is done, the performance is likely to fall short of an integrated approach from the initial design stage.

A qualitative description of the performance-reducing system interaction, challenges to implementation, and suggested revisions is provided in this report on a case study basis. Quantitative impacts and results are discussed in the Task 9 deliverable.

Case Study: 40% Better than BA Benchmark

This case study describes a Building America pilot research home completed in 2003 that represents strategies to avoid performance reducing system interaction. IBACOS has worked with this builder in the past, so the builder is reasonably well experienced with integrating system performance specifications. However, as the building industry and processes are fragmented, there is still a significant amount of concern for negative system interaction when implementing high performance strategies.

Pilot Home Project Description

Overview

The home is located in western Pennsylvania, which is a heating dominated climate, and is located in a new home development. The home described in this case study is a three-story end unit of a town home building. It has three bedrooms, 2.5 bathrooms, and a third floor loft space, with a total of 3,550 square feet of conditioned floor area. The home is built on a crawlspace foundation and has a garage.

The production builder was interested in offering a high performance home upgrade package to prospective buyers, and intended to utilize this home for demonstration purposes. In order to maintain a desired profit margin, a financial constraint was placed on the cost of the high performance package. IBACOS worked against this figure to minimize costs while maximizing performance benefits. The energy efficiency target for this home was a minimum of 40% better than the Building America Benchmark Version 3.1 (NREL).

The final analysis of the pilot project shows a simulated energy savings of 52% with respect to the Building America benchmark, and 42% compared to the Builder Standard Home for end-use source energy for space heating, space cooling, domestic hot water production, and lighting. When considering an estimate of equipment energy use (appliances and plug loads), the total savings are 40% with respect to the Building America Benchmark, and 31% with respect to the Builder Standard Home.

Improvement Package

The builder partner for this project was already familiar with and utilized relatively advanced construction practices due to past partnerships with IBACOS. The improvement package included the use of an Insulated Concrete Form (ICF) foundation system, improved thermal envelope and building airtightness, improved mechanical ventilation, high performance HVAC and air distribution, DHW improvements, and energy efficient lighting and appliances. The total improvement package cost to the builder was estimated to be approximately $9,600, which is well within their predetermined limit. The specifics of the improvement package follow:

- ICF foundation system
- Advanced framing techniques
- Sustainable framing lumber

- Open-cell, expanding spray foam insulation
- Optimized space conditioning system
- Energy Recovery Ventilator ventilation system
- Improved air distribution
- Direct vent, tankless water heater
- Manifold distribution plumbing system
- Advanced lighting design
- Energy Star® appliances

Performance Impact and Challenges to Implementation

This section outlines the benefits of the items listed in the improvement package above, establishing the context for discussing the performance reducing potential of other systems. While this is not an exhaustive overview of all possibilities, the key components are addressed. One of the primary factors in negative system interactions is the actual implementation of advanced strategies. This is discussed in each section, as applicable, as challenges to implementation.

ICF Foundation System

This home design has an unvented, conditioned crawlspace that is conventionally built utilizing concrete masonry units with a TUFF-N-DRI® exterior. The intended benefits of the ICF system compared to the Builder Standard Home are improved R-value, moisture control, structural integrity, and speed of installation, in addition to ease of creating finished basements. In this case, the ICF foundation provided an opportunity to incorporate fly-ash, a recycled industrial waste product, into the concrete mix.

From a system interaction standpoint, this approach improves upon the thermal performance of the home, through reducing the thermal load of the crawlspace with a greater total R-value. The two-inch thick expanded polystyrene insulation and a capillary break between the footer and the foundation wall provide improved resistance to moisture intrusion as well. Expanding the width of the sill gasket between the foundation wall and sill plate also controls capillary movement of moisture. Reduced installation time translates to reduced cycle time in the construction practice. Concerns for utilizing this foundation technique were alleviated through training provided by the manufacturer's field representative.

Advanced Framing System

Utilizing an advanced framing system reduces the amount of framing material in the exterior walls improving the overall R-value, reducing material cost and construction waste, and enables better integration with other systems. The advanced framing is accomplished through stack framing, aligned roof trusses, open-web floor trusses, and wall framing to carry the structural load straight down to the foundation. In addition, ladder framing for attaching interior walls, and two-stud corners are utilized. Open-web trusses provide a much-improved system for installing ductwork, plumbing, and electrical systems without interference or compromising structural integrity.

However, there were challenges in the builder's ability to effectively communicate design changes to trades and building officials, which required a significant amount of IBACOS assistance. In this case, the builder did not have the capabilities to develop in-house structural changes on construction drawings to communicate to the trade workers the advanced framing techniques or the HVAC coordination with the framing. This presented a challenge in effectively communicating details of advanced practices, resulting in the need for more oversight by IBACOS representatives to ensure the practices were effectively implemented.

The inability to communicate advanced construction techniques on paper to building officials also slowed down the approval process. Despite the acceptance of advanced framing techniques in many areas, the design, review, and permitting process was quite lengthy and involved. IBACOS facilitated the resolution of these challenges by assisting in generating new construction drawings and providing technical support. Strategies for pre-job coordination and capabilities to make design changes can be effective in resolving performance reducing system interaction, and provide an improved mechanism for adopting advanced construction practices.

Sustainable Framing Lumber

The use of sustainable produced framing lumber reduces the impact of construction practices on natural resources, but cost and availability present a challenge to implementation. The first step was to identify engineered wood products for the roof and floor structure, followed by a value decision for wall studs. Finger-joint studs were the economic choice between engineered wood studs, finger-joint studs, and Forest Stewardship Council certified lumber. The greatest challenge was locating an affordable source and distribution channel. The lack of local sources is a major barrier to improving the interaction between the housing industry and the environment.

Improved Cavity Insulation System

In an effort to improve the thermal performance of the home through reducing conductive and convective heat transfer, an open-cell expanding spray foam was used in the exterior walls and roof cavities. The installation of the foam was coordinated with mechanical system installation and air sealing activities to simplify the construction process by eliminating the need for a separate airtightness contractor. The expanding foam creates a more complete insulation layer and a much better air barrier than fiberglass in this case because it expands into all gaps and cracks in the framing. Coordinating the foam installation after all the mechanical systems were installed ensured that all envelope penetrations were sealed.

Two of the greatest challenges to implementation, which can also be considered a performance reducing influence, are the local availability of a provider for an environmentally-sound expanding foam product, and demonstrating value despite a significant cost increase for the insulation. After a lengthy search, IBACOS located a supplier and installer for the project. However, the initial cost was first determined to be cost-prohibitive. Evaluating the economic benefits through a system interaction process alleviated this concern. The improved insulation reduced the HVAC initial cost and operating cost. The increase in monthly mortgage cost to the homeowner was $17 per month, but the overall system improvements show an energy savings estimate of $39 per month. The increased value of the improved systems is attractive to both the builder and homeowner.

Optimized Space Conditioning and Ventilation Systems

The greatest challenge to implementation of the optimized space conditioning and ventilation systems was coordination between the framing and the location of the air handler/furnace. The design and installation of these systems demonstrate an integrated strategy to control ventilation and infiltration, improve comfort, and reduce space conditioning loads, environmental impact, and initial cost. This was accomplished through the use of several strategies to reduce space-conditioning loads, which in turn reduced the typical use of two HVAC systems for such a home to one system.

Originally, the Energy Recovery Ventilator (ERV), air handler, and furnace were located in a conditioned attic location to reduce the length of duct runs, which decreases initial cost and makes it easier to provide adequate delivery of conditioned air. However, it was later determined that this location would not work due to interference with the roof trusses. The equipment was moved to a second floor closet location, which created a situation where duct runs could be shortened further.

The ERV system provides a balanced ventilation strategy to avoid pressure imbalances that may increase uncontrolled exfiltration or infiltration. The energy recovery feature reduces the space-conditioning load, and provides a source of controlled ventilation. With this unit in place, ASHRAE 62.2 ventilation rates can be achieved without concern for making the home too airtight through air sealing.

High Performance Air Distribution/Systems Integration Design

In order to design and install a high performance air distribution system, a significant amount of system design and trade integration must be employed to avoid performance-reducing impacts on other systems and by other systems. Many of the design decisions must be made early in the design process and have consideration for other systems in the home including the roof, plumbing, floor trusses, and electrical systems. The goal of the high performance air distribution system is to minimize thermal losses and maximize comfort without compromising the integrity of other systems or becoming cost prohibitive.

Two primary strategies are utilized in the approach to delivering high performance air distribution systems: locate all ductwork within the conditioned space and maximize flexibility in design options. This was accomplished in two ways for this case study:

- The thermal and pressure boundary was moved to the roof plane to bring the attic space within the conditioned space. This allowed the attic space to be used for duct distribution.

- All floor framing systems utilized open-web floor trusses to allow more flexibility in duct locations without interfering with structural integrity or other mechanical systems.

In order to improve airflow and distribution, duct fittings were selected and designed to reduce pressure drop in accordance with Manual D (reference). A variable speed furnace fan was selected that allows the system to operate more quietly using less energy. In addition, duct leakage targets were set at 10% of the total system airflow, and 3% air leakage to the outside. In this case, all ducts were intended to be in the conditioned space, so exterior leakage should not be an issue. Duct sealing with a UL-181 approved duct mastic can ensure all airflow reaches the intended locations.

The return system was designed to minimize duct material, but also to ensure that pressure imbalances do not occur in rooms with doors that remain closed for significant amounts of time. Common areas on the first and third floor utilize a central return strategy, while the bedrooms on the second floor each have a dedicated return. This design strategy will ensure that zones in the home will not be over- or under-pressurized, which can emphasize the impact of envelope leakage and create comfort problems. In cases where ambient draft equipment is used (such as gas log fireplaces and gas water heaters), pressure imbalances can cause the equipment to backdraft.

The supply side of the duct system takes advantage of the improved thermal envelope, by locating supply diffusers in the interior walls or ceiling 10 to 12 feet from the perimeter. The warmer surfaces created by advanced framing, sheathing strategies, and high performance windows eliminate much of the need to locate the supply registers at the perimeter. This approach allows shorter runs, which results in decreased cost and increased performance. Diffuser selection is also a critical component to provide sufficient distribution of conditioned air throughout the room.

While one of the challenges to providing good airflow is the availability of engineered fittings, the coordination of trades and adjusting to field changes proved to be most challenging. After lengthy design and planning, including discussions with the trade contractors, the HVAC contractors followed the engineered system very closely, but other contractors simply did not follow the drawings. For example, the plumbing contractor was not accustomed to using drawings showing integrated system design, so he installed a wastewater drain line in the floor joist cavity intended for the central return. As this is a research pilot home, the mistake was caught before walls were closed in and the problem was alleviated. However, in a production environment, this level of quality control for ensuring appropriate system integration may not exist.

Domestic Hot Water and Plumbing Systems

Two advanced approaches were incorporated in this case study home with the intention of improving the integration of hot water generation and distribution, but as with most systems there are several challenges to implementation. The approach in this case study was to utilize a tankless, direct vent, gas-fired water heater with an EF of 0.82, combined with a manifold plumbing system with half-inch cross-linked polyethylene (PEX) piping. This example also emphasizes a less quantitative impact on aesthetics that must also be integrated in any system design and installation.

The intention of this approach to the hot water and plumbing system is to improve integration with other systems in the house, as well as to facilitate the installation process. Using a tankless water heater improves the efficiency of providing hot water, as standby losses associated with a storage tank system are eliminated. While this approach reduces the impact of the standby losses on the cooling load of the home, it also removes the contribution of the standby losses to the heating load of the home. Utilizing a direct vent hot water unit allows the unit to be installed within the living space with little concern for backdrafting of combustion by-products caused by pressure imbalances in the home. This approach also eliminates the need for an ambient supply of combustion air, which can significantly contribute to infiltration rates in the home.

While this tankless hot water unit provides several advantages over a storage type unit, careful consideration for sizing must be taken to ensure that hot water needs are met. The system in this case study is sized to meet the demand of two major hot water uses, based on a fixed temperature rise through the unit. Because water main temperatures vary with location, it is important to consider the main temperature to ensure the unit is capable of meeting demand. This approach also requires a significantly larger gas supply to meet the capacity of the burners in this unit, which may cause problems in some circumstances. The burner capacity of these units can be over four times larger than a standard tank unit, which in some cases will require a larger gas main. In this case, the capacity did not require a larger main to be installed.

The water distribution system used in this home is intended to provide flexibility and ease of installation, as well as to reduce distribution losses and water consumption. The manifold system utilizing half-inch PEX piping allows flexibility in where the pipe is installed, which facilitates integration with the location of other systems. This system reduces the surface area of the overall piping, which in turn reduces the heat loss associated with distribution. This impacts the heating and cooling load on the home. The other advantage to this approach is the reduced volume of hot water left in the system when it is not being used. This reduces the amount of water that runs down the drain while the occupant waits for hot water to reach the fixture.

Despite the significantly reduced size of the tankless unit and flexibility in installation location, the primary challenge in this case study was where to locate the unit without impacting the aesthetics of the home. The architect and developer objected to the original proposed location because the vent pipe would be visible from the front of the home. The solution was to move it to a walk-in closet in a secondary bedroom.

Energy Efficient Lighting Design

In a high performance home, the lighting energy is a greater percentage of overall energy use, as the energy use associated with heating, cooling, and water heating is significantly reduced compared to a typical home. A typical approach to lighting can also impact the cooling load associated with internal gains, as a greater percentage of the energy conversion produces heat rather than light. The approach in this case was to provide an energy efficient lighting strategy, utilizing 50% fluorescent fixtures, with a consideration for the cooling load, function of the space, and architectural characteristics.

Other factors to consider in the integration of an advanced and energy efficient lighting system are color temperature, color rendering, and the capability of fixtures to efficiently and effectively distribute the light produced. In addition, recessed fixtures typically used in production homes are not airtight. Since they are typically installed across boundaries between conditioned and unconditioned space, these units can significantly contribute to the air infiltration rate of the home. However, high quality fixtures can be very expensive and cost-prohibitive in many cases. In this case study, a significant amount of effort was applied to finding the balance between a high quality, energy efficient lighting design and installed costs. This is primarily due to the lack of product availability in the residential market.

While advanced controls are a critical consideration in lighting design and energy efficiency, they were deemed to be cost prohibitive in this case. Occupancy sensors and daylighting integration controls can help reduce the energy use associated with lighting, but are not necessarily cost-effective in most residential applications.

Energy Star® Appliances

Energy efficient appliances are perhaps one of the most easily implemented measures to reduce energy and water consumption associated with typical operation of a home. As with lighting, appliance and plug loads are a greater percentage of overall energy use in high performance homes. Field installation techniques are not very different, if at all, from conventional equipment, so implementation is not a primary concern. In this case study, Energy Star® appliances are specified for dishwashing, clothes washing, clothes drying, refrigeration, and other households tasks.

While system interaction associated with appliances and plug loads are not explicitly addressed in this case study, there are several implications that should be noted. While the energy and water use of items that fall under this category is reduced, there is still opportunity to improve on how these items influence the performance of the home. There is still wasted energy associated with appliances that send warm water down the drain after use, such as dish and clothes washers. These units also contribute to the sensible and latent cooling loads of the home, and add moisture to the indoor environment. Using Energy Star® appliances reduces this impact, but does not eliminate it. There is still an opportunity to recover this waste heat, or at least improve the control over the impact on the rest of the house.

More subtle energy and indoor air quality issues that have yet to be directly addressed in most high performance homes are also listed in this category for future consideration. Clothes dryers are still a major energy consuming device that not only use energy for the specific purpose of drying clothes, but they also exhaust a significant amount of conditioned air out of the home. Ventless condensing clothes dryers may use more water than the clothes washer cycle, with the warm water dumped down the drain. Refrigerators, ovens, and ranges also contribute heat, and in the case of gas appliances, combustion by-products add moisture to the indoor environment.

Case Study: Mechanical System Performance Evaluation

This case study is the result of a request by a builder partner in the Building America Program to investigate comfort complaints in several townhouses in the same community. The reported problems include high energy bills and a significant temperature difference between the first and second floor. It was reported that during the heating season the second floor is significantly warmer than the first floor. While the focus of the investigation was on the mechanical system, it is apparent that the poor performance is a function of system integration, implementation, consistency, and quality control. The following describes the results of the initial investigation and recommendations for retrofitting the existing systems to improve performance as a whole.

This case study describes system interaction problems that result from not applying an upfront system engineering strategy, poor communication of the design to the installers, and inadequate post-installation commissioning. This study also demonstrates how addressing performance reducing interaction during the design phase and maintaining a quality control strategy throughout installation can reduce the substantial effort required for after-the-fact system reconfiguration. The retroactive approach also limits the options for maximizing performance as the homes are finished and much of the system is located behind finished surfaces. Opportunities for integrating structural, mechanical, and plumbing systems are no longer available at this point, or are very limited.

Project Description

This project involved a thorough inspection of two town homes and a walkthrough of several others to determine the cause and extent of comfort problems. The air-handling unit in each home is located on the second floor in a small closet, with most of the ductwork located in the attic and partially covered with blown insulation. Each home has return air grilles on the first and second floor, and the thermostat is located on the first floor. Each home also has a first floor room with a two-story high ceiling that is open to a loft area on the second floor. The first floor return duct in each unit is installed through the garage due to limited available space in the framing layout.

In this case, construction drawings were developed for each town home unit showing the mechanical system layout, but were not followed very well. Several attempts to improve the system were attempted before IBACOS' involvement with little success. There was an attempt to balance the system to deliver more conditioned air to the first floor, and unspecified duct changes were made. The changes were evidenced by a large quantity of insulation present in the supply duct registers. The homeowner attempted to resolve to comfort issue by sealing off all second floor supply registers with duct tape.

Problem Description

The investigation process involved an initial construction drawing review, followed by a visual inspection, and a series of pressure and flow diagnostic procedures, which all pointed to several performance reducing problems. The primary problems appeared to be related to the sizing of the space conditioning system, the layout and sizing of the supply and return duct system, and communication between the individual spaces and the space conditioning system. The following section describes the observed issues and how they combine to reduce the overall performance of the home.

Design Review and Site Investigation

The initial design review was completed before the site visit to develop a preliminary hypothesis and develop a strategy for following through with the site investigation. This review led to an expectation that the space conditioning equipment was undersized and that the duct sizes and positioning were inadequate. While it was expected that the equipment would be 2-tons in size, they were actually 2.5 or 3.0 tons, without a corresponding increase in duct size. It was also noted that the execution of the design was poor.

Diagnostic testing of two homes showed similar airflow and distribution problems in both homes. The results showed that approximately one third of the supply air flow did not reach the termination and approximately two thirds of the return air flow actually comes from the attic instead of the intended interior space. This is primarily due to excessive leakage throughout the duct system, with a total leakage rate of 875 cubic feet per minute (cfm) at 25 Pascals (Pa) pressure difference. All the existing supply duct sizes are too small to allow adequate airflow, and both intentional returns, first and second floor, are insufficient in size for the return air required.

Evaluation

The performance reducing impact of system interaction is well documented in this case, with an emphasis on comfort and energy consumption as the primary indicators of poor performance. The floor layout and framing system does not encourage an efficient duct layout, forcing a majority of the ductwork to be located in the unconditioned attic. The attic ductwork was installed on the floor of the attic, which reduces the overall R-value of the ceiling. In addition, a large portion of the return system for the first floor penetrates the plane between the house and the unconditioned garage, and along the ceiling of the garage. While the ductwork is framed in, there is still the potential for return leaks to draw air from the garage into the living space.

The poor translation of design intent to field implementation resulted in inconsistency between installations, also demonstrating poor oversight and quality control. In the first house, a main return component for the first floor was a seven-inch flexible duct, in the second house it was an eight-inch, and a walkthrough of a third home showed a nine-inch duct in this location. In addition, most attic ducts installed using flexible ducting were strained, which encourages them to pull away from mechanical connections and does not allow gentle bends. Additionally, most of the return system was constructed using panned floor joists at some point in each run.

The lack of engineered design in this case resulted in poor performance, as undersized duct work was incapable of ensuring even temperature distribution throughout the structure. There is a high delivery and return rate for the second floor and poor delivery and return on the first floor. The two-story living room open to the second floor loft encourages any heat delivered to the first floor to rise to the second floor by buoyancy. As the thermostat is located on the first floor, the system significantly overshoots the second-floor heating load before the thermostat is satisfied.

Finally, as the system was not installed with an airtight strategy, large holes and gaps allow a significant amount of conditioned air to escape to the unconditioned attic. This was confirmed from an observation by an on-site collaborator, who mentioned that the snow melts very quickly on these roofs. This is a concern not only from an energy efficiency standpoint. This can cause ice damming, and moisture laden interior air leaking to the attic space can result in condensation on the roof deck. This can lead to mold growth and/or roof deck degradation.

Recommended Actions

The poor performance of the systems in this case study can be avoided through an integrated strategy including design, implementation, and quality control. As the homes are finished, it is less likely that the remodeled system will reach performance levels available when an integrated approach is utilized from the initial design stages. With that said, the following strategy is recommended to improve the performance of the system, the comfort and durability of the home, and the energy efficiency of the home.

The retrofit strategy is quite extensive and involves replacing or repositioning the system ductwork. Through reconfiguring the system to account for the interactions described above (Problem Description section), a comprehensive solution can be achieved. The proposed solution essentially involves re-engineering the duct system with a second supply trunk, balancing dampers, increased return air size, and the addition of new return ducts. All of the ductwork in the attic should be replaced with adequate lengths so it can be installed above the insulation. In this case, additional insulation must be installed to account for voids left after moving the ductwork. In addition, the ductwork should be insulated to R-6 with sealed vapor barrier facings to prevent damaging condensation during the cooling season.

The second supply trunk with a balancing damper is added to the system to provide more control over the airflow to the first and second floor. Even with the performance-based retrofit, the envelope design and floor plan is vulnerable to seasonal differences in comfort between the first and second floors. As little can be done to change the characteristics of the structure itself, the occupant will have to change the damper position on the supply duct according to season to give preferential balancing. Where accessible, panned return ducts should be replaced, and all duct connections sealed and connected with mechanical strain relief.

Conclusion

The performance reducing influence of systems in a home can be the result of an approach to home design and construction that does not take into consideration the potential impact the structural, electrical, plumbing, and communication systems can have on the energy, mechanical and envelope systems (and vice versa). The system by which the home is designed and constructed, including the initial design, design translation, construction communication, and quality control, can influence the end result as well. Even with advanced strategies and experienced builders, the segmented building industry is still prone to constructing homes with reduced performance due to system interaction.

The case studies described in this report do not encompass all possibilities for negative system interaction, but they do outline many of the symptoms, causes, and challenges to implementing improved strategies. Framing systems must allow flexibility in the location of plumbing, electrical, and mechanical systems so they do not interfere with each other, or compromise structural integrity. With improved envelope systems, the mechanical system design must be carefully considered and effective communication between the space conditioning system and the house must be established to ensure even temperature distribution.

Comfort, indoor air quality, durability, and energy efficiency can be significantly compromised by the performance-reducing influence of residential systems on each other. In many cases, it is difficult and/or expensive to retrofit these systems, and it is less likely that the same level of performance can be achieved as compared to an integrated approach beginning at the initial design phase. Pre-job coordination, contractor and labor training, a capability to make alternate material selection and system designs to overcome challenges, and a comprehensive quality control strategy that targets performance reducing influence throughout the design and construction process can be effective in delivering a well performing home.

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Personal correspondence with Brad Oberg, Anthony Grisolia, Bruce Dickson, and Eric Newhouse of IBACOS.

Part 4 - Case Study Data

Background

This report is part of a series of deliverables that outline and discuss residential performance standards and measures, and the influence of system interaction on the performance of homes. Describing home performance as the result of a complex system if interacting components provides a basis for evaluating individual system performance, system interaction, and overall performance. This report serves to assess and analyze the performance reducing influence of other systems on the energy, envelope, and mechanical systems, with quantitative support for improving current system performance.

Introduction

This report provides an assessment of the performance reducing influence of system interaction in homes in the context of quantitative support for capacity to improve current system performance. Quantitative support for improving current system performance is described through actual field measurements and validation of improved performance, simulated energy efficiency comparison, and long term data analysis. In addition, the impact of improving system performance can be discussed in terms of labor and material costs as well.

As performance-reducing interaction is not always apparent during standard construction practices and inspections, the costly symptoms can show up well after construction is complete. Callbacks, warranty and insurance claims, and other customer service costs can provide quantitative support for making small upfront investments in quality and performance verification during the construction to avoid larger costs after the home is complete. It is almost always cheaper to fix a problem before or during construction rather than after the home is complete.

This report presents quantitative support for the construction industry's capacity to improve the current system performance levels, based on the two case studies described in part 3. Where information is not available to discuss all of the quantitative aspects of improving system performance, it will be described qualitatively.

Improving Performance in New Construction

This section of the report describes quantitative results from the first case study discussed in part 3, with performance and cost considerations presented. It describes simulated energy performance expectations compared to the Building America Benchmark 3.1and the builder standard home. The approach to incorporating the cost of advanced home performance into the process, and an estimate of the potential for implementation, is also introduced.

Project Summary

Overview

The home is located in western Pennsylvania, which is a heating dominated climate, and is located in a new home development. The home described in this case study is a three-story end unit of a town home building. It has three bedrooms, 2.5 bathrooms, and a third floor loft space, with a total of 3,550 square feet of conditioned floor area. The home is built on a crawlspace foundation and has a garage.

The production builder was interested in offering a high performance home upgrade package to prospective buyers, and intended to utilize this home for demonstration purposes. In order to maintain a desired profit margin, a financial constraint was placed on the cost of the high performance package. IBACOS worked against this figure to minimize costs while maximizing performance benefits. The energy efficiency target for this home was a minimum of 40% better than the Building America Benchmark Version 3.1 (NREL).

The final analysis of the pilot project shows a simulated energy savings of 52% with respect to the Building America benchmark, and 42% compared to the Builder Standard Home for end-use source energy for space heating, space cooling, domestic hot water production, and lighting. When considering an estimate of equipment energy use (appliances and plug loads), the total savings are 40% with respect to the Building America Benchmark, and 31% with respect to the Builder Standard Home.

Improvement Package

The builder partner for this project was already familiar with and utilized relatively advanced construction practices due to past partnership with IBACOS. The improvement package included the use of an Insulated Concrete Form (ICF) foundation system, improved thermal envelope and building air tightness, improved mechanical ventilation, high performance HVAC and air distribution, DHW improvements, and energy efficient lighting and appliances. The total improvement package cost to the builder was estimated to be approximately $9,600, which is well within their predetermined limit. The specifics of the improvement package follow:

- ICF foundation system
- Advanced framing techniques
- Sustainable framing lumber
- Open-cell, expanding spray foam insulation
- Optimized space conditioning system
- Energy Recovery Ventilator ventilation system
- Improved air distribution
- Direct vent, tankless water heater
- Manifold distribution plumbing system
- Advanced lighting design
- Energy Star® appliances

Energy Performance

A case study discussion of performance reducing system interaction, challenges to implementing advanced strategies, and suggested resolution to the challenges is included in part 3. This section reports on the simulated energy performance of the case study home compared to the builder’s standard construction practice and relative to the

Building America Standard. In conjunction with the qualitative discussion in part 3, this section is intended to provide insight into the industry's capacity to effectively adopt advanced methods for increased energy savings.

The table below (Table 1) shows the predicted end-use site energy for the case study, with a comparison of the pilot home to the Building America Benchmark 3.1 and the Builder Standard Home. The Builder Standard represents the materials and practices currently used by the builder. Table 1 lists the energy use by major category as calculated with EnergyGauge USA 2.1 energy simulation software. The analysis is done in accordance with Building America House Performance Analysis Procedures (Hendron 2001).

Table 1. Predicted end-use site energy for pilot home.

Annual End-Use Site Energy						
	BA Benchmark 3.1 Home		Builder Standard Home		Pilot Home As-Built	
End-Use	kWh	therm	kWh	therm	kWh	therm
Space Heating	1,361	1,755	1,281	1,376	1,034	732
Space Cooling	2,023		1,548		1,081	
DHW		221		203		118
Lighting	3,647		3,647		2,188	
Subtotal	7,031	1,976	6,476	1,579	4,303	850
Appliances & Plug Loads	7,749	78	7,749	78	7,509	78
Total	14,780	2,054	14,225	1,657	11,812	928

The predicted annual energy cost savings for the pilot home is approximately $1,209 or about 32 percent compared to the Builder Standard materials and processes. The energy costs are based on an average electricity rate of $0.1184/kWh, and an average natural gas rate of $1.265/therm. When implemented as described in part 3, an average monthly energy savings of approximately $100 can be provided to the consumer. At an interest rate of 7.0 percent, the energy cost savings could be used to increase buying power by $15,000 in the context of a 30-year mortgage. The incremental savings associated with each upgrade measure is outlined in Table 2 below.

Table 2. Incremental savings for upgrade measures.

	Site Energy		Energy Cost		Energy Savings	
	kWh	therms	Energy Cost ($/yr)	Savings (%)	Incremental Savings ($/yr)	Total Savings ($/yr)
BA Definition	14,780	2,054	$4,349			
Builder Standard	14,225	1,657	$3,782			
(1) = Base + ICF Foundation	14,210	1,652	$3,774	0.20	$8	$8
(2) = (1) + Improved Thermal Envelope & air tightness	13,820	1,367	$3,366	11.0	$407	$415
(3) = (2) + Improved Mechanical Ventilation	14,018	1,112	$3,068	18.9	$298	$713
(4) = (3) + High Performance	13,543	983	$2,848	24.7	$221	$934

HVAC & Distribution						
(5) = (4) + DHW Improvements	13,543	898	$2,739	27.6	$109	$1,043
Total = (5) + Energy Efficient Lighting & Appliances	11,812	928	$2,573	32.0	$166	$1,209

While the energy savings and performance upgrades have an obvious benefit for the homeowner, they cannot be implemented without being profitable to the builder and affordable for the buyer. A successful adoption of high performance practices is dependant on the builder to implement a system that integrates the design and construction processes to ensure that the performance meets the marketed expectations for improved performance. The following section describes the costs and benefits to the homeowner and builder.

Advanced System Costs and Benefits

This section discusses costs, savings, and benefits in terms of the builder and homeowner interests. This includes a comparison of the cost to the builder for this pilot project, and an estimate of the cost to the builder if the same approach were implemented in all homes built by the company. A projected estimate of savings to the homeowner over the life of the mortgage is also included.

The total cost for the upgrade package to the homeowner is estimated to be approximately $9,000, based on a projected builder cost of about $6,650 at full scale purchasing quantities. A categorized breakdown of these costs is included in Table 3 below. Assuming a 30 year mortgage with a 7.0 percent interest rate, a $9,000 upgrade package would cost the homeowner $60 per month. With an estimated average monthly energy savings of $100 due to the upgrade package, the homeowner will net a $40 savings per month. The homeowner could spend up to $15,000 on this upgrade and break even on a monthly cost/savings basis. Plus, the homeowner gets the added benefit of comfort, improved indoor air quality, and durability in construction.

Table 3. Cost Estimate for upgrade package

Improvement Measure	Cost Estimate
ICF foundation system	$1,500
Advanced framing techniques	- $200
Sustainable framing lumber	$0
Open-cell, expanding spray foam insulation	$4,300
Optimized space conditioning system	- $1,300
Energy Recovery Ventilator ventilation system	$700
Improved air distribution	$0
Direct vent, tankless water heater	$250
Manifold distribution plumbing system	$50
Advanced lighting design	$1,000
Energy Star appliances	$350

Total	$ 6,650

While this is a projected estimate of builder costs with improved supply sources, it shows the potential for a builder to provide a better product to the consumer and improve the profitability of the organization. However, the performance of the upgrade package is dependant on an integration of the design and implementation processes with a high level of quality control throughout. For a description of this case study and information on process improvements and challenges to implementing the upgrade package described in this section, see part 3.

The time and processes involved in implementing these changes is dependant on the availability of materials, the learning curve for the designers, builder, and contractors, and developing an appropriate communication and tracking process. The following section describes the potential for the builder in this case study for implementing the measures described in this case study (Improvement Package). The ratings for implementation are based on market conditions and builder/contractor skill at the time of the construction of the home (Summer 2003).

Potential for Implementation

Based on an evaluation of the case study, IBACOS developed an estimate of the potential for implementing the strategies outlined in the project summary section above (Project Summary). The following table (Table 4) attempts to quantify this potential through assigning a value of High, Medium, and Low to reflect cost and implementation barriers to utilizing these strategies in the current market. Justification for these assignments is also discussed after the table.

Table 4. Implementation Potential for Pilot Home Improvements

Improvement Activity	Implementation Potential
ICF Foundation	Medium
Advanced Framing Techniques	High
FSC Certified Framing Lumber	High
Open cell, expanding spray foam insulation	Medium
Optimized Space Conditioning System	High
Energy Recovery Ventilation System	High
Improved Air Distribution System	High
Direct Vent, Tankless water heater	High
Manifold distribution plumbing system	High
Advanced lighting design	Low
Energy Star Appliances	Medium

ICF Foundation

This system improvement was given a Medium priority rating, basically because the initial cost compared to energy savings cannot be justified at this point. This is not to say that it should not be considered, because this rating does not include the potential for volume purchasing rates or construction cycle time reductions. This evaluation is also based on a crawlspace foundation, where the application in a basement scenario may demonstrate better energy improvements.

The installed costs for the ICF system was about $3000 greater than the builder standard practice, which includes R-10 exterior insulation above and below grade. Estimates show that the installed increase in cost could be reduced to about $1500 with volume purchasing. At this point, incorporating ICF foundations into the standard practice should not be abandoned by the builder, but should be evaluated including reduced cycle time and potentially reduced labor costs as crews become more familiar with the practice.

Advanced Framing Techniques

This case study provided an opportunity for the structural engineer and the primary framing contractor to become familiar with advanced framing strategies. This practice saves the builder and framing contractor money and improves the performance of the home. This measure was labeled as a high priority item with a high potential for implementation in their every day practices.

FSC Certified Framing Lumber

This strategy was given a high potential for implementation despite the high initial cost associated with this case study. The certified lumber in this case was higher quality, which reduced the amount of unused lumber due to imperfections. The only additional cost was associated with shipping fees, as a local source was not readily available. With volume orders, it is anticipated that the costs can be comparable to conventional lumber. The lumber can also be marketed as an environmentally friendly product.

Open Cell Expanding Spray Foam Insulation

While this strategy has benefits of a simplified approach through combining air sealing and insulation, the high initial cost makes this approach less desirable and cannot be completely justified at this time. As the product gains wider market presence, and a new version that is manufactured from soybeans is perfected, costs may drop, giving this strategy more potential.

Optimized Space Conditioning System

This strategy received a label of High potential, as the builder and contractor are quickly understanding the interaction of the building systems and the impact that a quality building envelop has on the size and performance of the space conditioning system. It is estimated that the cost of an optimized space conditioning system to the builder will be less than the conventional approach. The decreased cost and the value of communicating the benefits to the homeowner justify the High potential rating.

ERV System

The implementation of ERV systems as a standard practice is contingent on the ability to effectively market the value of increased energy savings, comfort, indoor air quality, and improved humidity levels to the potential home buyer. The energy savings alone cannot justify the initial cost of the equipment and the increased installation costs compared to the standard practice. Despite the cost increase, this measure still receives a High rating for implementation, as it is believed that the consumer will respond well to the benefits.

Improved Air Distribution

This measure is labeled as having High potential as the builder and contractors are beginning to see the benefits of a systems integration approach. In addition, it should be utilized to ensure that a home that is marketed as high performance is capable of meeting the homebuyers' expectation for comfort. This approach simplifies and standardizes the construction process, and helps to avoid conflicts between system installations in the field. It is estimated that there will be no additional cost to the builder compared to the standard practice.

Direct Vent Tankless Water Heater

This type of system has a High potential for implementation due to the reduced space requirements for installation, the reduced energy costs, and a comparable initial cost to other direct vent storage tank water heaters. This rating is based on the already recognized benefits of direct vent combustion appliances on indoor air quality concerns. The builder standard in this case is already a direct vent storage tank unit.

Manifold Distribution Plumbing System

The cost for the learning curve of the plumber increased the installed cost of the system in the case study home, but after the contractor becomes familiar with the manifold system and PEX piping the increased cost should be eliminated. Due to the benefits of minimized water waste and distribution losses, and the flexibility to avoid entanglement with other systems during installation, this system also receives a High rating for potential for implementation.

Advanced Lighting Design

The advantages of a high quality lighting design include reducing the energy consumption associated with residential lighting, improving the ambiance of the home, and providing greater ability for homeowners to perform tasks requiring certain light levels. However, advanced lighting fixtures are more costly than standard fixtures, and the professional design support required is not conducive to standardization in the builder's design process yet. As lighting fixture costs come down, and the builder improves upon their design capabilities to integrate high quality lighting designs, this measure receives a low potential for implementation at this time.

Energy Star® Appliances

Energy Star® appliances receive a medium potential for implementation as the installation is unchanged compared to conventional practices. While the purchasing costs can be slightly higher, the overall energy savings can be significant.

The Cost of Retroactive Performance Improvements

When discussing performance-reducing influence of system interaction in a home, it may be said that in general it requires less effort and cost to proactively address performance and system integration rather than try to fix the problem after the home is complete. This is true for the second case study described in part 3, which involves townhomes in a cold climate with complaints of high energy bills and poor comfort. The primary issues are identified as restricted supply and return ductwork, excessive duct leakage to the interior and exterior, and poor distribution of conditioned air.

As the house is finished and the home is occupied, the cost and effort for correcting the problems will likely be significantly more than installing it correctly the first time. The following section of this report describes retroactive efforts to make performance improvements, with test results and cost considerations. Test results for post-retrofit performance were not available at the time of this report, so performance will be discussed in the results of target performance levels. Post-retrofit results can be provided as an addendum to this report.

Problem Summary

Detailed measurements of one of the homes represent the observed performance of both homes. The airflow rate of the furnace was measured to be 993 cubic feet per minute (cfm), which is higher than the specified 800 cfm. The total of the supply flow rates, as measured with a balometer, is 661 cfm. The total return airflow rate for the system was 393 cfm. Based on these measurements, it is estimated that about 1/3 of the supply airflow is lost to the attic and wall cavities, and 2/3 of the return air coming from the attic.

The static pressure in the supply plenum was 44 Pascal (Pa) and the return was 75 Pa, compared to a target value of 50 Pa to 75 Pa for the total of the two. In order to test the air tightness of the ductwork, a duct pressurization test was performed at a test pressure of 25 Pa. The total system leakage was measured to be 875 cfm, evenly split between the supply and return. This indicates an airflow restricted and excessively leaky duct system.

Temperature stratification in this townhouse requires that a method be installed for changing the distribution depending on season. Due to the two story open floor plan, seasonal comfort problems may occur due to the buoyancy of conditioned air and the location of the single system thermostat on the first floor. During the winter months, the heated air will rise and overheat the open second floor loft before the thermostat is satisfied. In the summer months, the opposite will occur and under-cool the second floor. This problem is aggravated by the poor performance of the forced air system.

The ductwork in the attic was installed on the attic floor with blown insulation installed around it. While this may improve the insulation of the ductwork, it minimizes the overall insulating value of the attic floor. The ductwork is also installed with minimal lengths, stretched tight between connections. This does not allow for installing gentle bends and may promote premature failure.

Retrofit Solution

The retrofit solution involves reconfiguring the ductwork to reducing the system operating pressure to a normal operating range, but also to improve the distribution. The attic ductwork needs to be replaced with adequate lengths, and be suspended properly from the trusses. In addition, a comprehensive duct sealing should be completed to a target minimum near 50 cfm total leakage at 25 Pa. However, an optimal solution may not be cost effective because much of the system is behind finished walls.

A second main supply trunk must be added to the system, along with a balancing damper for changing seasonal distribution. All of the ductwork in the attic must be replaced and installed properly, and the total return system must be upsized, especially to the first floor. The duct system must be sealed as much as possible, but target values will be difficult to achieve with much of the duct system behind finished walls. Reconfiguring and sealing the ductwork, and providing improved control, will make the townhome more comfortable and energy efficient year round.

At the time of the writing of this report, the post retrofit cost and performance data was not yet collected. However, initial reports say that the retrofit is taking the contractor crews three days as compared to the initial installation, which took one day. It is not clear at this point whether this retrofit time includes repairs to drywall and post retrofit balancing. In addition to increased labor, the retrofit calls for more duct materials and additional insulation. While the exact costs are not yet available, it is very likely that retrofit costs will be significantly greater than the installation costs for a more optimized system design and installation. There will be energy savings from this retrofit, but will be difficult to quantify because the erratic system would be difficult to model.

Conclusion

The more quantitative results from the case studies described in part 3 demonstrate that the performance reducing influence of system interaction in a home can be avoided in a profitable and effective manner if addressed during design and construction. The performance can actually be optimized more cheaply and effectively in new construction when addressed during the initial planning stages. The builder can improve the quality, marketability, and profitability of the business, while improving the performance of the home, including comfort, indoor air quality, energy efficiency, and durability.

While duct sealing can be cost effective in many cases where the duct leakage occurs outside the thermal and pressure boundaries of the home, reconfiguration cannot easily be justified by energy savings alone. The retrofit of recently installed systems in several town homes demonstrates the significant amount of effort and cost that can be applied to correcting a system after the home is complete. Had the townhomes been designed from the beginning to avoid performance reducing interaction through minimizing temperature stratification, engineering the duct design, and installing the system as designed and to a high standard, they would have avoided the significant call-back effort required in this case.

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