U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Quality Assurance Strategy for Existing Homes:

Final Quality Management Primer for High Performing Homes

J. Taggart, J. Sikora, A. Wood
NAHB Research Center

December 2012

Building America
U.S. Department of Energy

NOTICE

Available electronically at www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Quality Assurance Strategy for Existing Homes:

Final Quality Management Primer for High Performing Homes

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

Prepared by:

J. Taggart, J. Sikora, A. Wood

The NAHB Research Center Industry Partnership

400 Prince George's Boulevard

Upper Marlboro, MD 20774

NREL Technical Monitor: Stacey Rothgeb

Prepared under Subcontract No. KNDJ-0-40335-00

December 2012

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by the NAHB Research Center Industry Partnership.

List of Tables

Unless otherwise noted, all tables were created by the NAHB Research Center Industry Partnership.

Definitions

BA	Building America
COQ	Cost of quality
DOE	U.S. Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
FMEA	Failure mode effects analysis
HPH	High performing home
IAQ	Indoor air quality
NHQ(A)	National Housing Quality (Award)
QA	Quality assurance
QC	Quality control
QI	Quality improvement
QMS	Quality management system
TQM	Total quality management

Executive Summary

Building high performing homes (HPH) that are energy efficient, durable, comfortable, and safe to live in does not simply require knowledge of building science principles. It also requires the ability to properly design, specify, and install new technologies and systems. Quality management systems (QMS) provide the infrastructure necessary to ensure repeatability as well as manage continual improvement to increase first time quality, reduce warranty, and increase customer satisfaction. As a result, QMS is needed as the industry shifts from building conventional to HPH and ultimately state-of-the-art homes such those meeting the DOE's Challenge Home.

This guide is designed to help a builder understand quality management and its role in transitioning from conventional to HPH building and remodeling. It addresses the typical quality management systems for new home construction, and also provides context for the use of quality management in existing homes. It explains what quality means, the value of QMS, the unique need for QMS when building HPH, and the first steps to a implementing a comprehensive QMS.

1 Introduction

Quality has been an industry buzzword for decades. Yet, quality management is not a fuzzy concept. Instead, it is a tried-and-true framework for delivering high quality products, on time and within budget. Companies who implement comprehensive quality management systems (QMS) and obtain quality certification enjoy tangible, reproducible benefits such as increased profitability and higher customer satisfaction. Within a QMS, companies define standards of quality and create designs and procedures to meet those standards. Through the QMS process, companies focus on proactively preventing problems rather than reacting to crises.[1] Furthermore, although this report primarily addresses quality processes in new home construction, the goal is to address quality in existing homes using these same techniques to increase first time quality, reduce warranty, and increase customer satisfaction.

Although it was developed for the manufacturing sector, the QMS approach is not limited to industrial facilities. In fact, the approach can be broadly applied to any company that provides a product or service. Residential construction, however, presents unique challenges that increase the difficulty of ensuring a high-quality finished product. Unlike the typical factory setting—in which many identical products are assembled by employees working in a controlled environment—most homes are built on a jobsite in varying weather and site conditions, with trade contracted labor, and with very few identical products. This lack of repeatability and control over the production environment and training of workers confounds quality assurance. The interdependence of one trade contractor's work on the success of another trade contractor can also stymie the process. Further, the inspection process can create production delays and, thus, be viewed negatively.

Despite the challenges, builders and remodelers stand to benefit greatly from implementing QMS—in large part because of the disproportional cost of correcting defects in a finished product. Industry-specific programs such as the National Housing Quality program are helping residential construction companies successfully implement sweeping QMS programs, which have been credited with dramatically improving product quality and economic indicators of success.

Recent advances in building science, shifting consumer demands, and more stringent building codes are compelling more remodelers and builders to switch to constructing high performing homes (HPH). Impending code-mandated performance testing, as well as the prevalence of testing in energy and green building programs, is placing myriad demands on remodelers, builders, suppliers, design professionals, and trade contractors to meet tough performance specifications and lofty performance goals. These demands, in turn, are sparking renewed interest in QMS for the construction industry. As builders and remodelers strive to build HPH, QMS is emerging as a critical need for implementing complex, whole-house changes to the conventional design and construction processes.

Although many companies have informal quality control mechanisms, a systematic and formal approach to quality is increasingly important for ensuring that HPH systems are designed and installed to meet strict tolerances and rigorous standards. A comprehensive QMS can address the

[1] See www.toolbase.org/Best-Practices/Quality-Management/quality-management-high-performance-homes for more information.

proper implementation of new products, materials, and construction techniques, and can ensure repeatability throughout a subdivision or region.

This document is intended as a primer for implementing quality management systems during the construction and remodeling of HPH. The key areas covered include the following:

- **Quality basics.** This section defines quality and its commonly confused terms and explains the components of a formal quality management system (QMS).
- **Need for quality in HPH.** The need for comprehensive QMS as the industry shifts toward HPH construction is established.
- **Value of quality management—economics of quality.** This section demonstrates that delivering a poor quality product is much more expensive than delivering a high quality product.
- **First steps**—where to start with quality. Because the process, at first, can seem overwhelming, this section describes how to get started with quality management.

2 Background

DOE's Building America (BA) program fosters research and development into improving the energy performance, durability, quality, affordability, and comfort of new and existing homes. The ultimate goal of the program is to develop practical examples of cost-effective, energy efficient home building and remodeling solutions that increase comfort, safety, and durability across all U.S. climate zones. BA goals are being met by implementing a whole-house systems engineering approach and by uniting segments of the industry that traditionally work independently—such as architects, engineers, builders, remodelers, trade contractors, manufacturers, material suppliers, community planners, and mortgage lenders.

2.1 History of Quality Management Systems

Quality has evolved from informal inspections of finished products to the process-oriented, proactive, and formal method of continuous improvement that represents a QMS for today's businesses.

In the 19th century, the primary approach to quality was the inspection of a finished product. Quality activities started expanding in the early 20th century when, to reduce the cost of inspections, a scientist at Bell Laboratories began applying statistical methods to improve product quality and the efficiency of the manufacturing process. During World War II, the military's demand for products meeting exacting specifications brought a rise in popularity to statistical quality control methods. When government contracts ended after the war, however, quality control measures were frequently abandoned.[2]

After World War II, Japanese corporations—seeking to quash their reputations for producing poor quality products—enlisted the help of American quality experts W. Edwards Deming and Joseph M. Juran. As these Japanese companies successfully improved quality and began to gain market share in the United States, American corporations responded by adopting quality improvement methods. During this time, firms adopted the statistical quality control methods developed at Bell Labs, but went further to implement total quality management (TQM) across the entire organization. The quality movement continued with the publishing of international quality standards (ISO 9000 series), the establishment of the Baldrige National Quality Program, and the launch of the Malcolm Baldrige National Quality Award. Since the end of the 1990s, TQM has faded in name, but quality initiatives have continued to proliferate and mature with the expansion of ISO 9000 standards and the Baldrige award, and the development of alternative quality management systems such as Motorola's Six Sigma.[3]

2.2 Quality Management Systems in the Residential Construction Industry

The typical residential construction process is substantially different from other types of manufacturing in that no two products are identical, conditions during assembly vary, and trade contractors (rather than manufacturer's employees) usually perform most of the production work. The changing conditions during assembly can include variability in the topography, weather (which can affect both the assembly process and the performance of installers), and significant

[2] See www.asq.org for more information.
[3] See http://www.motorola.com/Business/US-EN/Training+Home/North+America+Training/North+America+Certifications/Lean+Six+Sigma+Certifications

variability in material properties of construction materials used (e.g., wood, concrete, fill). Because of these unique challenges, there was historically no "one-size-fits-all" QMS for the industry, and quality programs were rare. Some early adopters, however, did embrace TQM, Six Sigma, and ISO 9000.

In 2004, recognizing the need for an industry-specific quality program, the NAHB Research Center established the National Housing Quality (NHQ) program which targets builders, trade contractors, and remodelers. In addition, the National Housing Quality Award (NHQA)[4] was established to recognize residential construction companies that had successfully integrated QMS. In recent years, the increasing prevalence of these and other quality programs has contributed to the industry's increased adoption of quality principles.

2.3 Quality Management Systems in High Performing Homes

Residential construction, in general, presents challenges to implementing quality management methods, but the construction of HPH confounds those challenges with more rigid specifications and increasingly critical construction details. When switching from conventional home construction to HPH, companies don't simply need to develop new designs, specifications, and installation methods—they also need to ensure these specifications are implemented correctly by multiple trade contractors. Further, many trade contractors' success depends on other trade contractors work to ensure the success of the house and ensure repeatability.

Recognizing that QMS are key to implementing change in any industry, the BA program established a quality assurance research and outreach program to support the home building and remodeling industry's transition to HPH. Although BA team members have demonstrated that prototypes or even a few HPH can be built or remodeled using only quality control without a comprehensive QMS, the industry needs systematic QMS to adopt HPH methods on a larger scale to ensure repeatability. In addition, as houses are higher performing it is also important to address system interactions to ensure not only the energy performance, but also the durability, health, safety, comfort, and affordability of the house.

Quality activities under the BA program began with the development of high performance scopes of work for components of a HPH. This seminal work weaves HPH building specifications and procedures into the active management and implementation strategies of a comprehensive QMS. In addition, it addresses trade partnering and more continual monitoring, feedback, and control.

With the HPH scopes of work as the first step, the need for more HPH-specific quality management research became apparent. The BA program responded by establishing the Quality Working Group (QWG, now the Standing Technical Committee for Implementation Tools [STC-IT]), to provide leadership, structure, and support for BA quality research. These Building America Resources are available on the Building America web site,[5] Office of Energy Efficiency and Renewable Energy (EERE) publications[6] site, and ToolBase.[7] Appendix A lists and describes specific resources.

---

[4] See www.housingzone.com/professionalbuilder/nhqa and www.nahbrc.com/technical/awards/nhqa.aspx for more information.
[5] See www.eere.energy.gov/buildings/building_america for more information.
[6] See www.eere.energy.gov/library/default.aspx for more information.
[7] See www.toolbase.org/quality for more information.

3 Quality Basics

Quality management is often misunderstood to refer simply to the inspection process. Yet, a QMS is much more involved. It encompasses the entire framework to define what should be built, designing to achieve these goals, and then constructing what is designed. In addition, it also addresses repeatability to ensure that the same house is constructed the same way every time. Defining the mechanisms and formalizing them into a comprehensive QMS helps businesses operate more efficiently. (Refer to Appendix B for a set of common construction quality terms and definitions). Builders transforming their practices from conventional to HPH construction can increase their chances of success by applying QMS principles to new techniques and technologies.

3.1 Quality Assurance and Quality Control

Quality terms are often misused, which can lead to confusion. The two terms most often confused are quality assurance (QA) and quality control (QC).

QA is a systematic process to improve business operations and increase customer satisfaction. It addresses both the quality of a finished product or service (the effectiveness of the operation) and the efficiency (costs and resources) of producing it. It is important to note that, in order for a business to be categorized as a high-quality operation, it must operate both effectively and efficiently. For example, a highly efficient construction operation that results in a home with numerous defects at closing, or a process that results in zero defects at closing, but which proceeds at an excessively slow rate or at a tremendous cost, is not considered a high quality operation. Examples of QA include developing construction documentation (e.g., drawings, specifications, scopes of work) with input from all relevant parties, training workers on proper installation techniques, and keeping the construction schedule on track.

QA addresses overall improvement of business operations in the prevention of defects, and QC, a subset of QA, focuses on detecting and correcting product variance. Examples of QC include completing a job-ready checklist and performing inspections of installed work.

Ultimately, the goal is to create a formal system that documents the structure, responsibilities, and procedures required to achieve effective quality management.[8] QMS is a process-based approach to optimizing effectiveness, efficiency, and variance prevention. A QMS establishes the expectations of quality and the QA and QC processes to achieve those desired results. A company with an integrated QMS emphasizes creating highly satisfied customers and continually improving products.

[8] Adapted from the definition provided by the American Society for Quality, www.asq.org.

Table 1 presents an example of how issues are addressed by a company without formalized QMS compared to a company with a comprehensive QMS.

Table 1. How Issues Are Addressed in Residential Construction Based on Company Level of Quality Management

No Formal Quality Management System (Typical Construction)	Greater Quality Management (Comprehensive QMS)
Corporate Culture of Quality	
Finishing the job quickly is most important. Senior management does not create accountability to quality; there is no overall culture of quality.	Senior management values QA and is committed to its QMS, communicates this commitment, and holds all workers accountable in a corporate culture of quality.
Statistical Measurement of Performance Including Customer Satisfaction	
Minimal tracking of statistics and minimal feedback for continuous improvement. Customer satisfaction is not a primary driver for improvement.	Comprehensive feedback loops using statistics and lessons learned are consistently evaluated resulting in continuous improvement. Customer satisfaction is a primary driver for quality improvement.
Company Quality and Financial Performance Results	
Company financial (such as gross/net profits) and quality performance (such as callback ratios) are average.	Company financial (i.e., gross and net profits) are above industry average and quality performance (i.e., callback ratios) are below industry average.
Company Operational Policies and Procedures	
Few policies and procedures are documented, they are not effectively communicated or monitored, and they are often not understood or followed.	Many policies and procedures are written, effectively communicated, and monitored to ensure that they are followed; procedures are typically followed.
Installation Process and Performance Standards and Tolerances	
Inconsistent installation and no agreement for installation process and tolerances.	Consistent application and common agreement for installation process and tolerances.
Inspection Process and Feedback Loops	
Ineffective, unstructured, or undocumented inspection process with minimal or ineffective feedback loops.	Effective, structured, and documented inspection process with effective feedback loops for continuous improvement.
Design Process	
Design planning process is minimal or ineffective with minimal feedback loops.	Comprehensive design and planning process with feedback loops from all relevant parties.
Specifications	
Specifications are minimal, incorrect, or unclear and often undocumented.	A detailed process is used to develop and document clear and detailed specifications.
Application of Building Science	
Understanding of local, state, and federal energy codes.	Thorough understanding of building science applied to design and construction process.
Material Selection and Approval	
There is no clear material approval process, and no or ineffective material inspection.	There is a detailed material selection and approval process and material inspection.
Installer Skills and Training	
Unskilled and/or untrained labor with little accountability for results.	Labor is trained and held accountable to performance standards.

3.2 Comprehensive Quality Management System

Quality management has the most effect when strategically coordinated, driven, and aligned throughout the organization. A QMS starts with a corporate vision and strategy for quality. It proceeds with the development of a framework for delivering the QMS, which includes operational tools to use in the process. A comprehensive QMS has, at its foundation, the specifications and standards to which product quality must adhere. Having a QMS is essential to the industry's ability to correctly and cost effectively implement advanced building science principles.

The conceptual model of a comprehensive QMS for HPH is presented in Figure 1.

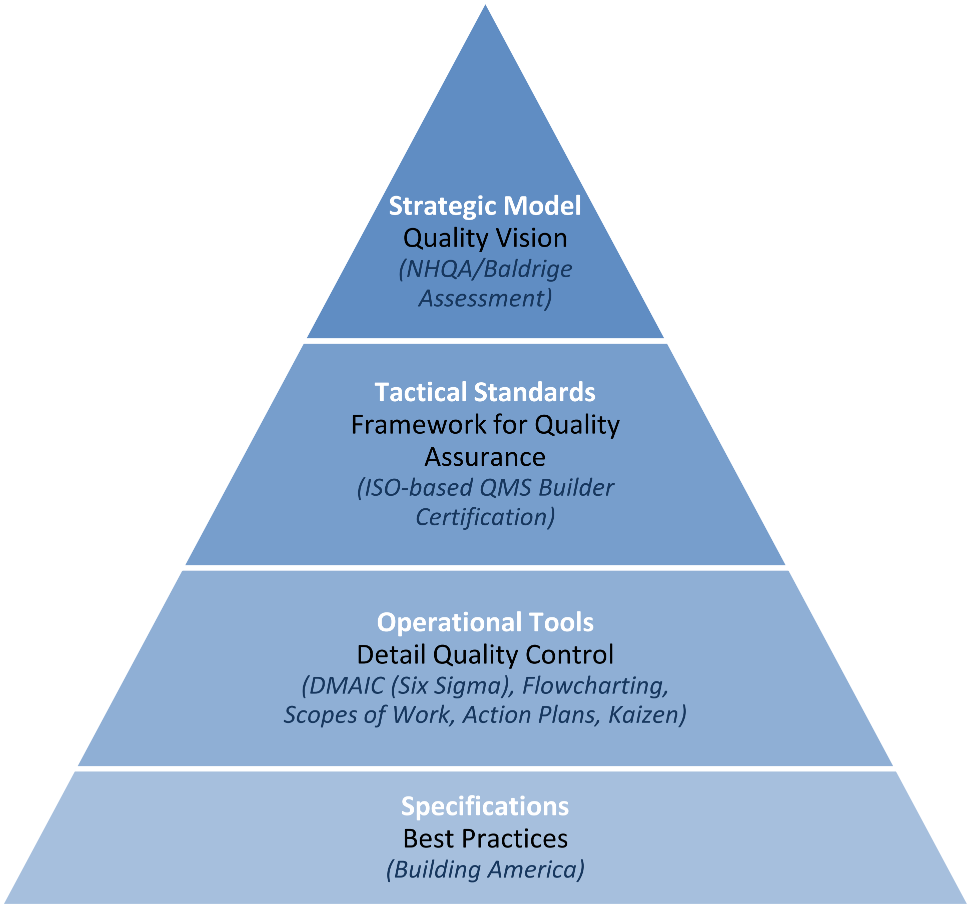


Figure 1. Strategic, tactical, and operational layering of a QMS for an HPH

In simple terms, the strategic model is the overall QMS for a company. Tactical standards represent the framework for meeting quality standards. Operational tools refer to the documentation for ensuring quality control, and specifications are the requirements that must be met in order for the final product to meet quality standards. Following is a description of each of these key areas of a comprehensive QMS.

3.3 Strategic Models

At the top of the pyramid is the quality vision for the company. Typically defined by senior management, the quality vision serves as the driving force for the company's QMS. This corporate vision for a quality program is essential to the success of any QMS because commitment from top executives compels a corporate culture of valuing quality.

At this strategic level, companies begin by self-assessing current QA and QC practices to identify gaps and define strategies for eliminating those gaps (refer to Section 6 for more details on this process). Leaders identify longer-term goals and allocate resources for the quality improvement process. Self-assessment is the springboard for companies to decide how to focus resources toward the successful implementation of a QMS.

3.4 Tactical Standards

Tactical standards are the actions and the documentation that serve the strategic purpose of the QMS; they provide the framework for implementing a QMS. Programs such as the NAHB Research Center's NHQ Certified Builder, NHQ Certified Trade Contractor, and NHQ Certified Supplier programs[9] (based on ISO 9000, ISO 14000, and OSHA 18000) and other residential quality programs and consultants such as BuildIQ,[10] Business Excellence Consulting,[11] First Time Quality,[12] and Quality Built[13] help the home building industry create this framework by setting industry-tailored criteria for quality, safety, and environmental management. The more generic ISO 9000 certifications can also be adapted by construction firms, suppliers, and product managers.

At the tactical level, builders, remodelers, and trade contractors usually start by developing a quality manual that describes the organization's policies, procedures, and documents necessary for implementing a comprehensive QMS. Where applicable, a quality manual references supporting documents such as codes and standards, HPH criteria (e.g., Builder's Challenge Quality Criteria), specifications, scopes of work, and installation instructions.

The development of a quality manual can be facilitated by a certification process or through a quality consultant. During this process, companies must demonstrate a QMS that affects the entire company—from scheduling and billing to jobsite inspection and trade contractor partnering, using sample documents to guide the process. A sample quality manual is available online.[14]

3.5 Operational Tools

Operational tools facilitate the quality process. They are the tools used by the company and others, in the office and at the jobsite, to ensure that quality standards are met. The NAHB Research Center and other BA teams have developed many tools, specific to the home building industry, to support quality improvement while transitioning from conventional to HPH construction techniques.

Some operational tools are process-oriented, such as:

- **6-Sigma process.** A process designed to eliminate defects (i.e., any process output that does not meet customer specifications)
- **Process mapping.** An activity to define what a business entity does, who is responsible, to what standard a process should be completed, and how to determine the success of the process
- **Value stream mapping.** A technique used to analyze and design the flow of materials and information required to bring a product or service to a consumer

---

[9] See www.nahbrc.com/builder/quality/index.aspx for more information.
[10] See www.buildiq.com/ for more information.
[11] See www.businessexcellenceconsulting.net/ for more information.
[12] See www.firsttimequality.com/ for more information.
[13] See www.qualitybuilt.com/ for more information.
[14] See www.toolbase.org/Best-Practices/Quality-Management/sample-builder-quality-assurance-manual for more information.

- **Failure mode effects analysis (FMEA).** A procedure to determine the potential failure modes within a system for classification by the severity and likelihood of the failures
- **Design FMEA, the application of FMEA to the design**
- **Process FMEA, the application of FMEA to the construction process to consider process-induced failures**
- **Fishbone chart.** A diagram used in defect prevention to identify potential factors causing a specific event
- **80/20 rule.** A principle stating that, for many events, roughly 80% of the effects come from 20% of the causes
- **Brainstorming.** A technique to find a conclusion for a specific problem by gathering a list of ideas spontaneously contributed
- **Error proofing ("poka yoke").** A mechanism to eliminate product defects by preventing, correcting, or drawing attention to human errors as they occur.

Others are tools for inspection and documentation of quality, such as:

- Comprehensive design documentation (construction drawings, specifications, etc.)[15]
- Scopes of work (detailing trade work and specifications)
- Procedure documents ("how to" manufacturer installation instructions, etc.)
- Hotspot training (address recurring issues)
- Satisfaction surveys (determine customer satisfaction).

Many sample operational tools for building HPH can be found at www.toolbase.org/quality.

3.6 Specifications

At the foundation of the quality pyramid lies specifications—the exact requirements that need to be met during construction. Just as a QMS can support the construction of a conventional home based on conventional specifications, the strategic, tactical, and operational levels of QMS support the effective design and implementation of HPH specifications. It is these HPH specifications and the enhanced performance goals for the final product that set an HPH QMS apart from a standard QMS for a code minimum home.

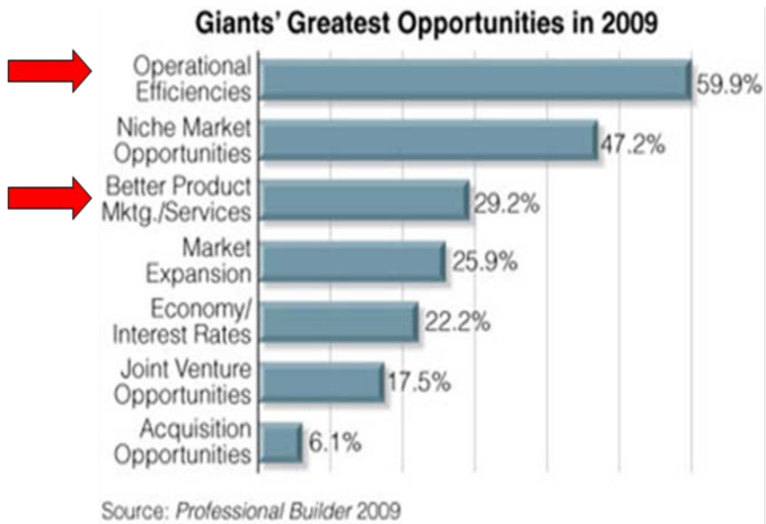
When selecting climate-appropriate specifications for HPH, the BA *Best Practices* series provides an excellent starting point[16]. Other resources include energy and green building program criteria, building codes, industry trade association best practices, and green building consultants.

[15] See http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/strat_guide_constr_doc.pdf for more information.
[16] See http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/36960.pdf

4 Quality in Residential Construction

The benefits of QMS—such as measured higher customer satisfaction, lower defect costs, reduced warranty costs, fewer employee injuries, and higher profitability—have been well documented in the manufacturing sector. The residential construction industry, despite being presented with unique challenges when implementing QMS, has also documented beneficial impacts (e.g., Rosenfeld, 2009; McIntyre and Kirshenman, 2000).

The need for quality improvement is recognized in the industry. In a survey of the biggest opportunities facing the largest companies in home building, *Professional Builder* magazine ranked operational efficiency at the top of the list and better product marketing and services at third as shown in Figure 2.



Professional Builder. Reprinted with permission.

Figure 2. Greatest opportunities for builders

4.1 Need for Quality in High Performing Homes

As the home building industry shifts its methods, either by choice or by increasingly stringent code requirements, toward high performance standards, there is a tremendous need for systems that can help successfully implement those changes. The industry has, historically, experienced difficulty with the effective and efficient construction and renovation of code-minimum homes. Therefore, it is not surprising that there will be even greater challenges as the industry strives to meet the higher standards for energy efficiency, durability, indoor air quality (IAQ), and comfort of HPHs.

When implementing any product change, it is imperative to do so in a highly efficient and effective manner such that changes are implemented properly and delays are avoided while profitability is maintained. QMS provide the necessary framework for effecting product improvements with minimal disruption.

HPH construction involves upgrading specifications and installation methods and often introducing new products, trade contractors, or inspections. Often, HPHs have a much greater reliance on interdependent and interrelated systems; for example, the thermal enclosure performance affects the effectiveness of a minimized space conditioning system to deliver comfort to the occupant.

These changes are the type of product improvements that a QMS is geared for accommodating. For small companies, a formal QMS system has historically been unnecessary because the hands-on approach of the construction company owner grants a high level of control over the construction process. Yet, applying HPH to typical construction standards, quality assurance systems can assist with progressive change even in small-scale production. Table 2 outlines some examples of the challenges inherent in designing and constructing HPH.

Table 2. Example Comparison of Standard Construction to HPH Construction

Standard Construction	HPH Construction
Design Phase	
Simple design process to meet code minimums; standard for contractors.	Integrated design process involving numerous trade contractors for improving energy efficiency and performance with regard to moisture, durability, and IAQ.
Building envelope air sealing meets code minimum.	Building envelope is designed to reduce air infiltration as much as possible.
No whole-house ventilation needed because there is significant air infiltration and exfiltration.	Because of tight construction, whole-house ventilation needed to enhance indoor air quality.
Designs are done by specifying and purchasing products without emphasis on how the house functions as a system.	A whole-house design process is needed to integrate and coordinate highly interdependent systems.
Single or small design team with minimal input from trade contractors.	Design process must involve consideration of multiple trades, best done with direct input and review by key trade contractors.
Construction Phase	
Installers adopt new products, materials, and technologies more slowly.	Installers must learn to install new products, materials and technologies quickly.
Installers require no change in mindset; installation continues as before.	Installers must install products properly and must modify and adapt installation per new products and installation procedures.
Inspection, Verification, and Performance	
Must meet code minimums.	Must meet code and high performance specifications.
Usually no performance/diagnostic testing.	Often tested for air infiltration, duct leakage, and insulation installation.
Visual inspection by code official, and contractor and homeowner.	Same as typical construction, but also often more involved third-party energy efficiency or green certification inspection.

4.2 New Trade Contractors

An HPH may require additional trade contractors to design the ventilation system or to install a PV system or air sealing measures. Adding trade contractors, and associated inspections, can create a domino effect with other trades or the construction schedule. A QMS can ease the transition by setting expectations, identifying installation procedures and scopes of work for new contractors, and creating a system for including the new contractor without disrupting the construction schedule and other trade contractors' work.

4.3 More Frequent and Involved Inspections

In addition to code inspections, HPH are subject to performance testing and inspection by third-party energy efficiency or green certification personnel. These inspections typically verify installation details with rigorous standards, specifications, and other criteria. During these inspections, the home is often subject to performance testing (such as infrared thermography, pressure imbalances, infiltration, and duct leakage tests) that can verify that performance standards are met more accurately than a visual inspection.

Not only is the home required to perform better than code minimum in these inspections, but also the builder must build additional inspection time (and resources) into the HPH construction process. The transition to HPH may represent a significant update for design and construction specifications. Because third-party testing happens after the installation, it can be used as a additional feedback mechanism in the hotspot process whereby defects are identified, brought to light, and corrected.

4.4 New Materials and Methods

To improve performance, remodelers and builders often use new products and materials that require new installation or application techniques. Contractors must be trained on these techniques, and be informed about how new procedures affect other design and construction activities. For example, installing rigid pipe versus semi-rigid pipe (e.g., crosslinked polyethylene) requires different tools, connection techniques, layout, and allowances for clearances because of thermal expansion and contraction. QMS systems put the processes in place for contractors and installers to learn how to properly install myriad new products to achieve the desired results. One method of ensuring that a new product or process is used correctly is through a production pilot program to identify any required changes to the process to maintain the desired quality control. In addition, the pilot program process should encompass the entire construction process from design through control.

4.5 Tight Tolerances

When builders and remodelers transition to high performing designs, they must meet increasing performance goals and customer expectations for energy efficiency, durability, IAQ, and comfort. To achieve this, houses must be designed and constructed using a systems approach in which the components of a home interact and function together as a system. Failure to carefully consider and calculate these interactions results at best in an underperforming house and at worst in expensive lawsuits, damaged reputations, and ruined businesses.

The combination of increased performance specifications, enhanced performance evaluation tools and testing, and the resulting tighter building envelopes and potential negative effects of systems interactions make designing and constructing HPH much more challenging than conventional code minimum home building. For example, building a tight duct system that achieves the proper airflow for comfort in each room requires careful duct design and installation. Therefore, extra steps such as air balancing and duct leakage testing ensure that installation was accomplished according to design in the HPH. In conventional practice, deficiencies in the installation result in a costly service call that could have been avoided.

To ensure that an HPH performs as expected, extra steps are needed, like procedures and measures of a quality manufacturing and construction process, during the design phase and throughout construction to meet the performance goals and customer expectations. By providing the procedures, scopes, and tolerances for any job, and the tools for overseeing the successful completion of that job, a QMS can greatly increase the likelihood of a high performance finished product and greatly diminish the chance for defects and performance issues.

5 Value of Quality Management

Although there are costs associated with implementing a quality management system, the cost of producing a poor quality home—with associated callbacks, warranty claims, and lack of customer confidence—is often far greater than the cost of producing a high quality home using a QMS.

A large body of research gives ample evidence of the positive effect that quality programs have on businesses, as summarized in a previous NAHB Research Center report (NAHB Research Center, 2010). The most tangible effect of implementing a QMS, however, may be a lower total cost of quality—with several organizations reporting significant savings after implementing QMS (NAHB Research Center, 2010).

5.1 Total Cost of Quality

The classical cost of quality (COQ) states that the cost of producing a high-quality product or service is the sum of the costs of prevention (P), appraisal (A), and internal failure (IF) and external failure (EF).

$$\text{Total COQ} = P + A + IF + EF$$

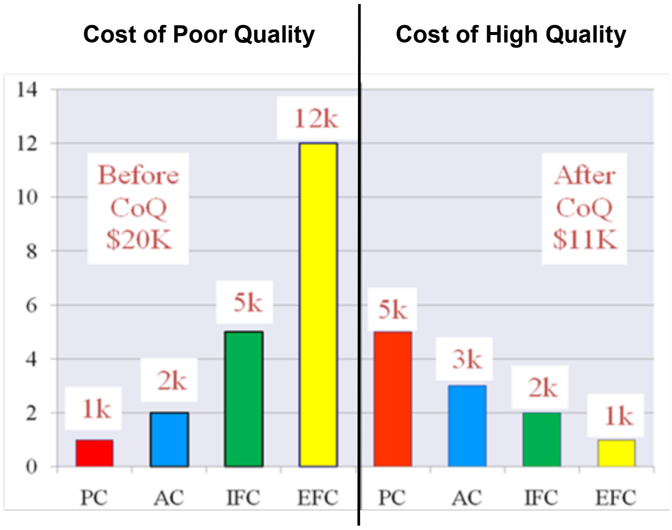
Prevention refers to activities that prevent poor quality (e.g., scopes of work, specifications, standard procedures, job ready forms); appraisal is the verification and evaluation process (e.g., inspections, checklists); internal failure refers to a defect during the construction process (e.g., resulting in rework) prior to homeowner occupancy; and external failure is a defect after the product is complete and has been received by the customer (e.g., warranty callbacks).

A study based on a survey of 208 construction firms, including home builders, in the Midwest, concluded that substantial economic benefits can be attained by implementing a QMS. The findings suggest a correlation between the amount of total annual expenses dedicated to QMS and construction quality. Overall, contractors who reported spending the most resources on quality management reported a significant increase in product quality and customer satisfaction after implementing a QMS program (McIntyre and Kirschenman, 2000).

There can, however, be a point of diminishing returns in which one more dollar spent on prevention and appraisal will not result in bottom line savings. Although there is some uncertainty, one construction industry report found an optimal level of investment in preventing defects of between 2% and 4% of revenue (Rosenfeld, 2009).

5.2 Total Cost of Quality—Example

Figure 3 compares the COQ at a hypothetical company before and after implementing a QMS (Cokins, 2006). The left-hand side shows the typical quality management process in which errors are corrected after they have occurred. The right side shows the COQ after the company has implemented a QMS. In both cases, the company invests in prevention and appraisal and incurs costs because of internal and external failure. For this sample business, however, after implementing a QMS (which nearly triples the prevention and appraisal costs), the total COQ is cut nearly in half—a value that is echoed by other real-world case studies showing a 25% to 65% reduction in total COQ (Cokins, 2006).



PC = prevention cost;
AC = appraisal cost;
IFC = internal failure cost;
EFC = external failure cost

Figure 3. Example COQ for a company before and after implementing a comprehensive QMS

As Figure 3 illustrates, companies without effective QMS spend the bulk of their quality budget on correcting defects after the product is complete—a practice that can be detrimental to a company's reputation and, hence, negatively affect sales. After implementing a comprehensive QMS, the same example company, by investing in defect prevention and inspections (bringing the cost of prevention and appraisal to $8,000 from $3,000), is rewarded with fewer defects and substantially lower costs for correcting failures.

5.3 Value of Defect Prevention

Another way to examine the importance of prevention and appraisal is to consider the cost to correct defects—which, according to a study of 63 manufacturers, makes up 70–80% of

Veridian Homes Quality Management Business Results

One of the best ways to fully appreciate the potential for successfully implementing QMS in the production of high performing homes is to examine Veridian Homes, a Madison, Wisconsin-based production builder. In large part due to its comprehensive QMS, the company is an NHQ Certified Builder, has participated and won NHQA and EVHA awards, and has supported the NHQ certification of many of its trades. The high performing home builder boasts the following statistics (NAHB Research Center, 2010):

- Profits above average of 20 similar companies in its "Builder 20" club
- Construction budget versus actual construction costs -/+1%
- Over 95% customer satisfaction rating
- 90% zero defects at buyer orientation (walk-through).
- HERS Index of 58-61
- All homes ENERGY STAR and Green Built Home certified
- EnergyValue Housing Award gold winner
- 3-time US EPA ENERGY STAR Leadership in Housing award winner

the total cost of quality (Rodchua, 2009). As Figure 4 illustrates, the cost to fix a defect varies greatly according to when the defect is identified and corrected. The example, from the American Construction Insurance Group, is based on an 18-year average construction defects claim of $124,000 and the generally accepted rule of thumb that a $1 investment in preventative quality management yields somewhere between a $10 to $100 return. Using this example and tracing the cost of addressing defects from least cost (i.e., prevention in the design stage) to highest cost (i.e., paying a construction defect litigation claim), the financial advantage of investing in prevention and appraisal becomes apparent (American Construction Insurance Group, 2009).

There are other advantages to early prevention and correction. Workers can feel more satisfied when quality issues are approached proactively rather than reactively as crises. Further, because customers see fewer defects in the final product, customer satisfaction is higher, the builder's reputation is improved, and referral rates are likely to perk up.

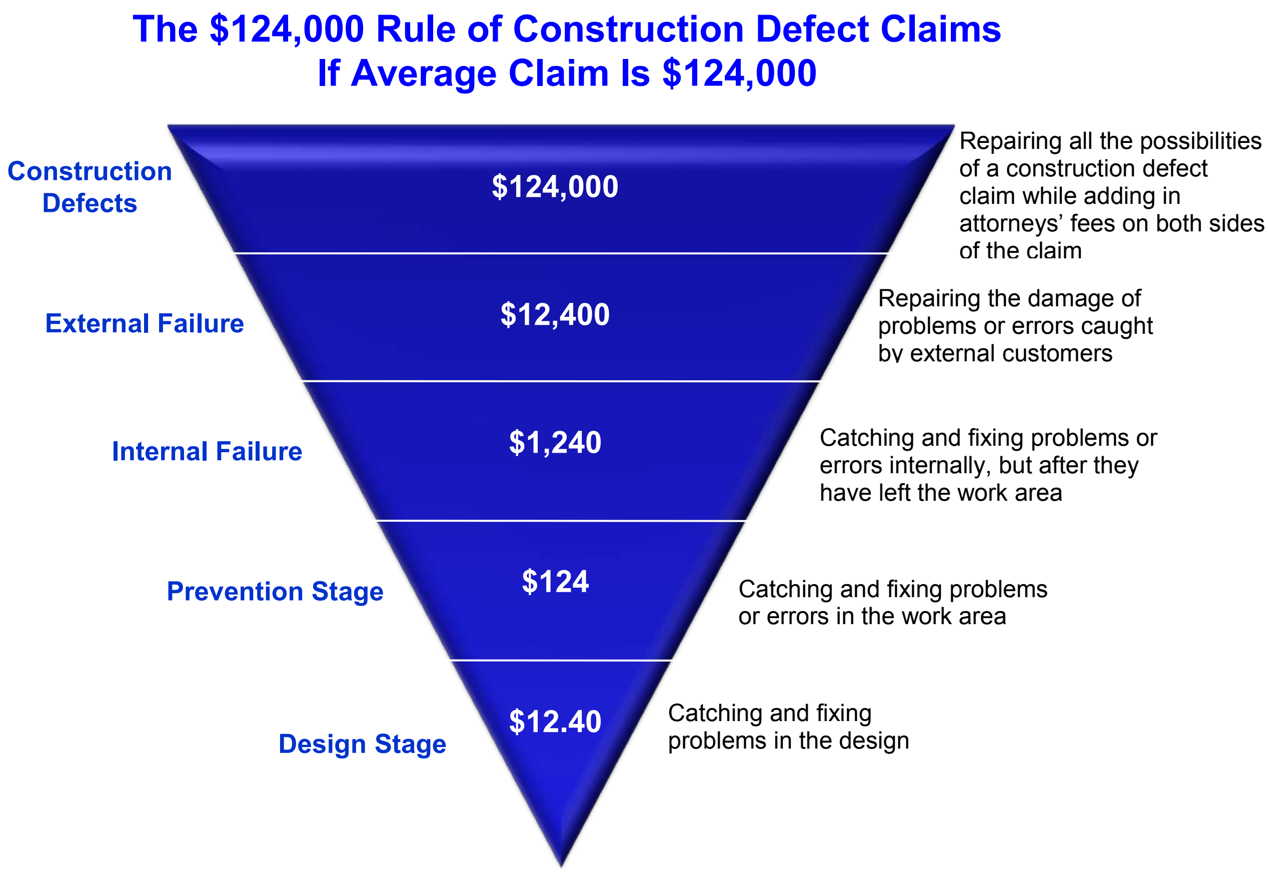


Figure 4. The construction defect cost triangle

The example is supported by several studies investigating the cost of defects in residential construction.[17] In a study of 32,000 residential construction projects, Australian researchers found the cost of defects to be 4.1% of contract value (Mills et al., 2009), which aligns well with other construction industry cost analyses of 2 to 6% (Josephson and Hammarlund, 1999. A 2006 study of nearly 32,000 homes supports these data, revealing the average cost to correct defects in new single-family homes to be $5,400 (Quality Built, 2006).

When analyzing data by type of builder, Mills et al. (2009) found that defect costs for the top 20 builders (by volume) were about half those of the industry mean. The researchers conclude that, "the top 20 firms appear to be significantly better than those constructed by other builders…because they are better organized, and have a more professional approach to quality management."

5.4 Financial Impacts of Quality

There is a compelling relationship between implementing a comprehensive QMS and a company's bottom line. The NAHB Research Center's NHQ program has recorded remarkable results from home building companies that have implemented quality management systems. A survey of the NHQ program[18] revealed that, after achieving NHQ certification:

- 80% of trade contractors reported a reduction in callbacks
- 88% achieved an increase in employee accountability
- 79% improved relationships with builders
- 65% overall improved their bottom line
- 70% of builders improved their bottom line
- 75% reported a reduction in callbacks and improved relationships with trades
- Trade contractors reported up to 25% reduction in cycle time.

Further, NHQA winning builders have noted tremendous effects from implementing QMS. A sampling of results includes:

- 98% homes zero defects at closing, net profit increased 9% (Grayson Homes, Maryland)
- Reduced cycle time by 15% (Pringle Homes, Florida)
- 95% of trades list builder as the best to work for (Estes Homes, Washington)
- 33% of homeowner recommendations resulting in sale (TS Lewis, Arizona). [NAHBRC, 2010]

Finally, a 1997 NAHB study reported the average builders' net income before taxes was 5.1% and gross margin was 18.5%; NHQA builders, on the other hand, achieved an average net income of 11.2% and gross margin of 25.5%.[19]

[17] Although the stage of defect correction (e.g., internal or external failure) is not known from these studies, it is assumed that a combination of external and internal failure contributes to the reported costs.
[18] http://gbgreview.nahbrc.net/news/pressreleases/rc_20070207b.aspx
[19] See http://www.toolbase.org/Best-Practices/Business-Management/Bottom-Line-Quality

6 First Steps—Where To Start With Quality

For a company switching from conventional to HPH construction, introducing a new QMS can seem overwhelming. Yet, a QMS is precisely the mechanism needed to effect change within an organization and to ensure that new HPH specifications are done right.

This section details the first steps for implementing a comprehensive QMS. These steps have been effective for many residential construction companies and trade contractors. Note that not all steps must be followed in order; the sequence can be modified to fit a company's needs. In addition, many companies also use a quality consultant to assist in this process.

Some of the key steps to implementing an effective quality management system include the following:

1. **Assess and prioritize company needs.** Assess where the company is on the quality path. Prioritize quality improvement activities.
2. **Develop a strategic plan.** Appreciate the value proposition of quality management and understand the basic quality concepts. Give longer-term direction to the quality program and identify resources to be allocated in pursuit of the strategy.
3. **Create a corporate culture of quality.** Starting with top management, become committed to quality management; foster a culture of quality throughout the company.
4. **Implement quality improvements.** Adopt quality management tools and techniques from an assessment of current designs and processes.
5. **Expand to comprehensive QMS.** Develop and implement a company-wide QMS.
6. **Become third-party certified.** Achieve third-party quality certification.
7. **Apply for quality award.** Be recognized; use awards as a marketing tool.

The success of these steps is measured by increasing first time quality, reducing warranty callbacks, and increasing customer satisfaction. The intent of these steps is to show that there are multiple starting points for implementing quality management depending on the company. Out of these steps, step 1 is most often the best place to start because it helps create a plan for quality. In addition, while it is not necessary to have third-party certification (step 6) or to apply for an award (step 7), some companies have found the structure of a program or award to be an easy start for quality.

6.1 Step 1: Assess and Prioritize Company Needs

As with any big task, QMS is easier to tackle when it is divided into a set of smaller, accomplishable tasks. To determine what these smaller tasks will be, companies must honestly assess the degree to which quality management is implemented throughout the organization. This process, called "gap analysis" by quality experts, identifies needs for quality improvement throughout the organization.

Self-assessment can be a daunting process, and companies without a formal QMS process vary greatly in their level of existing quality processes. A widely accepted approach to this assessment is to do a formal, written gap analysis of current business practices. The gap analysis can be accomplished internally, but often a company adopting quality management will use a consultant to facilitate the process. Regardless of who conducts the analysis, input is needed from all relevant personnel to obtain the greatest accuracy and comprehensiveness. Because this process involves everyone in the organization, this first step can help cultivate a culture of quality.

Two resources available at www.toolbase.org/quality, the NHQ Certified Builder Program Gap Analysis and the Gap Analysis for In-house Design, Design Centers, Escrow Departments, Land Development Operations, and In-house Mortgage Financing, can help a builder assess the degree to which company operations adhere to quality standards outlined in the NHQ builder certification requirements. Though developed for new home builders, these gap analysis tools can be modified slightly by remodelers and trade contractors to assess opportunities for quality improvement across the major functional areas of a company's operations.[20]

Another useful resource is the NHQA application and self-assessment tool.[21] The NHQA application is, essentially, a self-assessment tool. It can be used to help align resources, improve communication, increase productivity, boost effectiveness, and achieve strategic goals. The eight categories for the NHQA and the questions that can guide the process of self-assessment are as follows:

1. **Leadership.** How do company leaders guide the organization toward a common purpose of quality based on shared values and priorities? Do leaders' actions reflect the vision for quality? How do leaders communicate the vision throughout the organization?
2. **Strategic planning.** How does the company create and implement a strategic plan to achieve a vision for the future, enhance competitive position, and improve overall performance?
3. **Performance management.** How does the company develop, manage, measure, and improve processes to achieve performance excellence?
4. **Customer satisfaction.** How does the company manage the design and delivery of products and services that promise a high level of customer satisfaction?
5. **Human resources.** How do employee selection and development practices, as well as staff performance management, well-being, motivation, satisfaction, and compensation, contribute to the growth of the organization?
6. **Construction quality.** What methods does the company use to drive quality in the home construction process and ensure high performing, trouble free products and services?
7. **Trade partnerships.** How does the company create high performance relationships with its independent trade partners?
8. **Business results.** What are the tangible business benefits resulting from high performance practices in the financial, operational, customer satisfaction, and product and service quality areas?

---

[20] See gap analysis links at www.toolbase.org/Best-Practices/Quality-Management/nhq-gap-analysis and www.toolbase.org/Best-Practices/Quality-Management/example-requirements-gap-analysis for more information.

[21] See NHQA application at www.housingzone.com/sites/default/files/2011%20NHQ%20Awards%20Application%20.pdf for more information.

After an initial gap analysis is complete, a company prioritizes opportunities for improvement. Prioritizing is crucial, because one of the most common barriers to starting an effective QMS is trying to implement too many new improvements at once. Although larger companies might be able to initiate multiple improvements simultaneously, smaller companies most likely will need to start with only one improvement and undertake others incrementally. In addition, there are numerous other quality management resources available from industry-recognized programs and experts.[22]

6.2 Step 2: Develop a Strategic Plan

A quality oriented company must have a strategic plan representing the leadership's vision for quality. This process addresses questions such as: "What is the longer-term vision for the company?" and "Where does the company want to be in five years?" After long-term vision and goals are established, company leadership develops a strategy for implementation.

The strategic plan might include using NHQ certification requirements or ISO 9001 requirements to develop a comprehensive QMS. Another approach might be to implement some key elements of a QMS for rapid impact, and over time complete the development and implementation of a comprehensive QMS.

6.3 Step 3: Create a Corporate Culture of Quality

The creation of a culture of quality begins with a commitment from company executives and flows to everyone who works for the company, including trade partners. It is essential that each person has a thorough understanding of the expectations of quality and a commitment to adhering to standards and procedures in order to produce quality products. For a culture of quality to exist at a company, quality must be reinforced at every opportunity. Once a culture of quality is successfully established, developing and implementing quality management processes and tools is made simpler. Having a corporate commitment to quality is considered an essential factor for the successful implementation of quality management strategies.

6.4 Step 4: Implement Key Quality Management Elements

Every aspect of a QMS is important, but certain elements stand out as essential and highly impactful. Sometimes, early implementation of key quality strategies can yield immediate results and help a business owner build momentum and support for the quality management concept from employees and trade contractors. Key elements of a QMS that can affect a company quickly include the following.

6.4.1 Effective Inspections Processes

A remodeler or builder with a fully implemented QMS has well-defined inspection processes, internal audits, performance metrics, satisfaction surveys and other tools that ensure multiple feedback loops. The common purpose of these tools is to continually improve the production process, reduce errors, and increase efficiency (produce higher profits).

The inspection process needs to be well defined and documented, with critical inspection criteria selected with input both from installers and inspectors. Inspection checklists should be well laid out and easy to use, and should not be too long. Some good examples of inspection checklists

[22] For example, ASQ, TQM, Six Sigma, Lean Construction, and ISO 9000.

can be found in the high performance scopes of work located under Best Practices→Scopes of Work on www.toolbase.org[23]

6.4.2 Hotspot Implementation (Inspection Feedback)

A hotspot is a recurring issue that is identified by reviewing inspection checklists. By systematically reviewing inspection documentation, hotspots can be identified. This feedback is a major benefit of the inspection process.

After hotspots are found, root causes can be identified and adjustments made to prevent recurrence. The NAHB Research Center's *Hotspot Implementation Guide and Tools* aids the process of assessing, identifying, and preventing recurring hotspots.[24]

6.4.3 Effective Communication of Standards and Processes

Effective communication is fundamental to ensuring quality outcomes—it is essential for all to know what the expectations of quality are and how to implement the processes in place for quality assurance. In the shift to HPH, in which the house works as a system, the work of one trade contractor tends to be intertwined with, and have substantive impacts on, that of another. As a company moves to high performance construction, effective communication is paramount.

Effective communication can take the form of weekly meetings, on-site training sessions, detailed and well-documented specifications in a scope of work, job ready checklists, and other methods. High performance scopes of work can offer an effective means of communicating expectations for installation procedures, specifications, and tolerances for builders and remodelers (see footnote 19). These documents can affect employees in the field and in the office; it is critical to elucidate all new processes, procedures, and specifications for all company operations to the appropriate staff and trade partners.

6.4.4 Achieve Outstanding Results Using Quality Performance Metrics

Quality performance metrics—such as defect rate, cycle time, revenue, and customer satisfaction—allow builders, remodelers, and contractors to track a quality program's success. Yet, many builders and remodelers do not track metrics, do not define which metrics indicate high performance, or do not monitor metrics to guide quality improvement strategies. When implementing quality programs, it is essential to track metrics in order to analyze performance and define areas needing improvement. Performance metrics can be measured against predefined goals or against past performance.

Common performance metrics for HPH include:

- Short-term metrics
- Home Energy Rating System (HERS) Index25

[23] These high performance scopes of work inspection checklists for different construction activities, though designed for new home construction, provide a good basis for what to include in an effective inspection checklist for builders or remodelers. See www.toolbase.org/ToolbaseResources/level3.aspx?BucketID=5&CategoryID=62 for more information.

[24] See www.toolbase.org/ToolbaseResources/level4BP.aspx?ContentDetailID=4171&BucketID=5&CategoryID=25 for more information.

[25] See http://www.resnet.us/hers-index for a complete explanation of the RESNET HERS Index

- Air infiltration results
- Duct leakage results
- Pressure differentials across doorways
- Room-by-room airflow rates (relative to design)
- Affordability
- Long-term metrics
- Whole-house energy use
- End-use energy use
- Energy production
- Moisture performance
- Durability
- Affordability
- Quality metrics
- Customer satisfaction ratings
- Profitability
- Number of days to complete a job (cycle time)
- Number of punch items at final inspection
- Number of production callbacks per job
- Number of warranty callbacks per job
- Service call or warranty rate
- No fault service call rate
- First time quality rate
- Scrap (pounds).

Beyond the common performance metrics, it is also helpful to track the cost of each element of quality—prevention, appraisal, and internal and external failures. Ideally, performance metrics should be tracked, tabulated, and reviewed on a monthly or quarterly basis to reveal areas of success and areas needing improvement.

6.4.5 Effective Continuous Improvement Process

Quality oriented companies are never satisfied with current performance and are always seeking to improve. Although many companies may want to improve, quality-oriented companies distinguish themselves by applying a strict process approach to continuous improvement that follows the general principles of plan, do, check, and act or define, measure, analyze, improve, and control. The feedback loops inherent in the continuous improvement process result in the constant monitoring, measurement, and tabulation of company performance to understand what is not effective and to develop new implementation strategies.

6.5 Step 5: Expand to Comprehensive Quality Management System

A truly high performing home cannot be built by the piecemeal upgrade of a few elements such as ENERGY STAR appliances or windows—instead, it requires a whole-house approach to design and construction. Likewise, the successful implementation of a QMS requires a comprehensive approach to quality that impacts the entire corporation.

Although it is acceptable to start by introducing a few quality management tools and techniques, the most successful companies are those that realize the need for and implement a comprehensive QMS. Quality management activities, just like the various elements of an HPH, function best when designed and implemented together as a system.

For a residential construction company looking to expand quality activities into a comprehensive QMS, there are a few essential resources. Companies can use any of a number of comprehensive QMS available, including ISO 9001 (a generic system for any type of business), and the NHQ Builder and NHQ Trade Contractor certification programs.[26] These programs provide support and guidance for developing a comprehensive QMS.

6.6 Step 6: Become Third-Party Certified

Many companies that seriously embrace formal QMS recognize the importance of becoming third-party certified through the NHQ certification programs or through ISO 9001. Although companies often emphasize third-party recognition for the credibility it lends in the eyes of the customer, it also provides tremendous value beyond marketing. Third-party quality certification can increase accountability, pride, and unity as well as knowledge and understanding of quality management principles.

6.7 Step 7: Apply for Quality Awards

Applying for a quality award is not necessary; however, many builders, remodelers, and contractors have found this a structured way to begin working toward a formal QMS. Applicants can apply to a few different quality award programs, including the NHQA and Malcolm Baldrige National Quality Award, to evaluate how their business measures up to high quality standards. As with quality certification, applying for and winning quality awards can bring much more to a company than simply a marketing edge. Simply going through the application process enables a company to analyze its quality performance according to a strict rating system.

Each NHQA applicant is given written feedback from expert judges, including representatives of past NHQA-winning companies. Further, award finalists receive site visits from a team of judges. Both the feedback reports and the site visits are invaluable learning opportunities from quality experts within the residential construction industry.

7 Conclusion

This report primarily describes quality processes in new home construction, and the goal is to enhance quality in existing homes using these same techniques to increase - post construction quality, reduce warranty, and increase customer satisfaction.[27] Effective quality management is challenging for any company to implement, and is particularly challenging given the unique conditions in which site-built homes are constructed. As builders, remodelers, and trade contractors shift operations from conventional to HPH construction, having an effective QMS is

[26] See http://toolbase.org/ToolbaseResources/level3.aspx?BucketID=5&CategoryID=25

[27] The first step of this work included developing a draft existing home scope of work from a new home statement for crawlspaces (NAHB Research Center, 2012).

essential for a smooth transition. A QMS is the framework for the proper implementation of the strict tolerances and stringent specifications inherent in an HPH.

Not only can a QMS help to get the job done right, but also it has been repeatedly demonstrated to improve a company's success—as measured by profitability, customer satisfaction, or other key indicators. Moreover, a QMS actually reduces the total cost of quality, when factoring the increased cost of prevention and defects with the decreased cost of correcting defects.

Starting the QMS process begins with the intentional creation of a corporate culture of quality. Effective quality management is a continuous process in which a company constantly monitors its performance and its business environment with the goal of continuous improvement. Within the QMS, a company is always seeking ways to achieve higher efficiency and effectiveness in delivering the service and finished product. A quality-oriented company, no matter how successful, is never satisfied with the status quo. QMS is vital as the industry shifts from building conventional to high performing homes and ultimately state-of-the-art homes.

References

American Society for Quality (ASQ), The History of Quality Overview, http://asq.org/learn-about-quality/history-of-quality/overview/overview.html.

American Construction Insurance Group. (2009). Quality News Network newsletter. October. www.acig.com/services/quality/2009-10.pdf.

Cokins, G. (2006). "Measuring the Cost of Quality for Management." *Quality Progress* September, 2006, pp. 45-51. http://www.platinumregistration.com/kbfiles/qp0906cokins.pdf

Josephson, P.E.; Hammarlund, Y. (1999). "The Causes and Costs of Defects in Construction. A Study of Seven Building Projects." *Automated . Construction* (8:6); pp. 681–642.

Lukachko, A.; Gates, C.; Straube J. (2011). *Strategy Guideline: Advanced Construction Documentation Recommendations for High Performance Homes*. Building Science Corporation. December 2011.

Mills, A.; Love, P.E.D.; Williams, P. (2009). "Defect Costs in Residential Construction." *Journal of Construction Engineering and Management* (Volume 189:1); January 2009. pp. 12-16.

NAHB Research Center. (2012). NAHBRC-IP Building America Deliverable Number 11.4.2.1. *Quality Assurance Strategy for Existing Homes, Draft Energy Efficiency Crawlspace Foundation Retrofit—Mixed Humid Climate*. Subcontract Number: AXL-9-99208-02.

NAHB Research Center. (2010). NAHBRC-IP Building America Deliverable Number 4.5.2. *Final Report of Quality Assurance Activities for New Homes (Interim Project Report), Economics of Quality: The Implementation & Economic Impact of Quality Management in the Homebuilding Industry*. Subcontract Number: AXL-9-99208-01. http://toolbase.org/PDF/BestPractices/AppendixAEconomicsofQuality.pdf

McIntyre, C. and Kirschenman, M (2000). "Survey of TQM in Construction Industry in Upper Midwest." *Journal of Management in Engineering* (Volume16:5); September/October, 2000, pp. 67-70.

Rosenfeld, Y. (2009). "Cost of Quality versus Cost of Non-Quality in Construction." *Construction Management and Economics* (27); pp. 107–117.

Quality Built. (2006). "Nation's Leading Risk Management Company Releases Top Builder Defect Data for Construction Industry: Quality Built Data Shows Builder Top Risk Issues Are Preventable." Media Kit, International Builders' Show, Orlando, FL, January 11, 2006.

Rodchua, S. (2009). "Comparative Analysis of Quality Costs and Organization Size in the Manufacturing Environment." *Quality Management Journal* (16:2); pp. 34–43.

Appendix A: Predesign Assessment

Table 3 lists the key quality management tools and resources that have been developed as part of the Building America program and provides of brief description of each resource. These tools are available on www.ToolBase.org.[28]

Table 3. Key Quality Management Tools

BA Quality Management Tool/Resource	Description
High Performance Scopes of Work Framing HVAC Excavation, Backfill, Grading Vinyl Siding Rigid Insulating Sheathing Weather Resistant Barrier Vented/Unvented Crawlspace	HPH Scopes of Work provide design and installation specifications and tolerances, as well as QA tools and techniques to facilitate the successful design and construction to meet those specifications.
Draft HPH Quality Management Requirements and NHQ Requirements	Provide industry leaders a framework around which to design a HPH quality management system.
Hotspot Implementation Guide and Tools	Provide a training approach and tool for effective targeted training.
Economics of Quality Research Paper	Provides the research-based justification to demonstrate the economic benefits of quality management on the bottom line.
Veridian Homes HPH Quality Management Case Study	Provides a real example of a HPH builder with a fully-developed quality management system with excellent results and explanations of many quality management approaches that this company is implementing.
Guidelines on Quality Management and HPH Remodels	Provides remodelers guidance for integrating quality into their business operations.
NHQ Award for Remodelers, Builders and Trade Contractors	Provides contractors a process to evaluate their company practices against a rating system in eight key quality categories. Each award applicant receives a valuable feedback report, and finalists get a site visit by judges
Remodeler, builder and trade contractor certifications ISO, NHQ etc.	Provide contractors with a third-party auditor visit their offices and jobsites to evaluate their QMS manual and implementation.
Primer	Orientation to learn about quality management to design and construct existing and new homes.
Prioritized Gap Analysis (currently under development)	Tool for contractors to assess current quality practices and identify practices they should add to their quality management activities
Scopes of Work for Existing Homes (currently under development)	Defines elements in a Scope of Work for existing homes and the process to develop the scope.

[28] See www.toolbase.org/ToolbaseResources/level3.aspx?BucketID=5&CategoryID=25 for more information.

Appendix B: Definitions of Common Quality Terms

A major challenge to bringing quality management systems to the residential construction industry is confusion over the often similar sounding terms used to discuss quality. To address this, common words and phrases related to quality are defined here in simple language rather than the formal, technical verbiage often used by quality management experts.

Appraisal Cost: Costs of measuring, evaluating, or auditing products and services to ensure conformance to standards of quality.

Continuous Improvement: The ongoing and structured efforts to evaluate and improve business operations' efficiency and to improve the quality of the finished product or service.

Culture of Quality (Quality Culture): Collective mindset of all employees emphasizing and valuing high caliber performance, products, and continual improvement including internal operations and worker satisfaction.

Economics of Quality: The total cost of quality, which is the cost of conformance (meeting quality standards) minus the cost of nonconformance (producing a poor quality product), as described by the following equations:

Economics of Quality (total cost) = Cost of Conformance—Cost of Nonconformance
Cost of Conformance (good quality) = Prevention Costs + Appraisal Costs
Cost of Nonconformance (poor quality) = Internal Failure Costs + External Failure Costs

External Failure Costs: Costs incurred as a result of delivering a defective product or service to the customer.

High Performance Home Quality Management System: A method for managing the process of building homes according to high performance specifications.

Internal Failure Costs: Costs incurred as a result of correcting defects during the production process.

Plan, Do, Check, and Act: Four steps in a continuous improvement process: develop a plan, implement the plan, check for desired results, and act to correct and improve the plan.

Prevention Cost: Cost of all activities designed to prevent poor quality in products and services.

Quality Assurance (QA): A systematic process to improve both the finished quality of products and services and the efficiency (costs) required to produce them. QA addresses overall improvement of business operations to prevent defects from occurring in the first place. Examples of QA include developing detailed scopes of work with input from all relevant parties and training workers on proper installation (prevention).

Quality Control (QC): A subset of QA, QC focuses on detecting and correcting errors and defects. Steps taken to ensure that products and services adhere to specifications and are free from defects; QC most often takes the form of some kind of assessment or inspection process used to detect and correct errors. An example of QC is the final inspection of a product installation.

Quality Management System (QMS): A formalized system that documents the structure, responsibilities, and procedures required to achieve effective quality management.[29]

[29] Definition from the American Society for Quality, www.asq.org

buildingamerica.gov

DOE/GO-102012-3591 ▪December 2012

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.