A METHODOLOGY FOR IDENTIFYING, DISCUSSING, AND ANALYZING THE COSTS AND BENEFITS OF CODE CHANGES THAT IMPACT HOUSING

Prepared For

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A METHODOLOGY FOR IDENTIFYING, DISCUSSING, AND ANALYZING THE COSTS AND BENEFITS OF CODE CHANGES THAT IMPACT HOUSING

Executive Summary

Changes to model building codes are proposed for a variety of reasons. Some are proposed to support public policy initiatives such as energy conservation, accessibility, and natural disaster mitigation. Some are proposed following a disaster. Others are proposed to enhance the market opportunities for specific materials and products or to place barriers on the market opportunities of other materials and products. Yet others are proposed to incorporate new developments in science and engineering into the regulation of building design and construction. Finally, some changes are proposed to reconcile perceived or real contradictions within the code, reduce redundancy, and improve clarity.

The adoption and enforcement of each proposed code change might impose costs on different stakeholders in the building process and on society as a whole. The adoption and enforcement of each proposed code change may accrue benefits, to its proponents, to other stakeholders in the building process, and to society as a whole. There is a need to determine whether or not a proposed code change will provide a net benefit after all benefits and costs are reasonably considered.

Each code change cycle of the International Code Council includes hundreds of proposed code changes. While proponents of code changes are required to submit a justification statement in support of their proposal, the statements rarely include detailed cost analysis or benefit analysis. The process of advocacy in support or opposition to any particular proposed code change is extremely time-constrained, and precludes, in most cases, the presentation of these analyses and of cost-benefit analysis for use in adjudicating the proposal.

The methodology presented in this report is based on the premise that it is possible to perform cost analysis and benefit analysis of proposed code changes that affect housing when the stakeholders involved are prepared to apply rigor to the process of acquiring information and the analytical tools for applying it. Use of this methodology will facilitate the review and rational discussion of the pros and cons of proposed coded changes. If a required piece of information or analytical tool is not available, this missing information will be identified and localized, suggesting the need for specific targeted research.

The methodology consists of six steps:
- Step 1: Develop a Description of the Code Change
- Step 2: Describe Design and Construction Implications of the Code Change
- Step 3: Perform a Cost Analysis
- Step 4: Identify Benefit Distribution and Metrics
- Step 5: Identify Benefit Measurement Models and Their Characteristics
- Step 6: Perform a Benefit Analysis and Integrate it into a Cost-Benefit Analysis

A seventh step, Conduct an Economic Analysis of Housing Impacts, is mentioned and discussed briefly, but it is outside the scope of this methodology.

A METHODOLOGY FOR IDENTIFYING, DISCUSSING, AND ANALYZING THE COSTS AND BENEFITS OF CODE CHANGES THAT IMPACT HOUSING

Introduction

Intent

This “methodology for identifying, discussing, and analyzing the costs and benefits of code changes that impact housing” is intended for use by both proponents and opponents of any given code change. It is intended to structure and rationalize the arguments for and against a code change, allowing, hopefully, fuller understanding and better decision making by all parties.

The development of this methodology was undertaken based on the observation that the cost impact statements required to accompany building code change proposals are often not adequately explained and estimated, and that the benefits attributed to code change proposals are rarely estimated at all. It is the intent of the methodology to provide a basis for estimating these costs and benefits.

Steps in the Methodology

This methodology consists of six steps:

- Step 1: Develop a Description of the Code Change
- Step 2: Describe Design and Construction Implications of the Code Change
- Step 3: Perform a Cost Analysis
- Step 4: Identify Benefit Distribution and Metrics
- Step 5: Identify Benefit Measurement Models (as needed)
- Step 6: Perform Benefit Analysis and Integrate it into a Cost-Benefit Analysis

Each step is described in a separate chapter of this document. Each chapter includes discussion of one or more examples of the application of the respective step to a specific code change, and each of these code changes is discussed in at least two of the steps, so that the reader may track a specific code change through two or more chapters.

A seventh step, Conduct an Economic Analysis of Housing Impacts, is mentioned and discussed briefly, but it outside the scope of this methodology. Step 7 will be done when a more comprehensive economic analysis than applicable to the code change process is required.

In general, Steps 1-4 will be required to some level of sophistication for all proposed code changes. Steps 5 and 6 will be desired for proposed code changes that are either complex or controversial. Most analyses of costs and benefits of code changes for purposes of the code change process will end with Step 6.

In the report, examples are included for the following code changes:

- “Foundation Anchorage” (requirements for lateral support of foundations)
- “Continuous Structural Panel Sheathing” (requirements applicable to one of several methods to brace walls against lateral forces)

- “Sprinklers in the IRC” (IRC Appendix requirements for residential sprinkler systems)
- “7-11 Residential Stairs” (proposed maximum riser and minimum tread requirements for residential stairs).

Appendix A contains an example application of all the Steps 1-6 to a single code change, “Water Heater Pan” (requirements for a drained pan under water heaters).

Other code changes were considered in selecting the code changes to be discussed in the examples, as described in Appendix B. Appendix B discusses the process used by the authors to select the code changes used in the Methodology examples.

All of the examples and Appendices are printed in smaller and different typeface so as to distinguish them from the text of the methodology itself.

Reference Materials

This methodology is derived directly from two sources (HUD reports):

- *A Suggested Methodology for Estimating the Cost Impact of Changes to the Model Building* Codes, HUD, August 1994
- *Housing Impact Analysis*, HUD, January 2006.

The former report is limited to the costs of code changes that impact housing, and does not address the benefits. Thus it is of more limited scope than this methodology, but is similar as regards the cost side (Steps 1-3), and is quoted herein where applicable.

The latter report, while addressing federal regulations rather than building codes, has a much broader scope than this methodology. Of the 14 types of federal regulation discussed in the report that affect the housing market, only two are similar to building code changes:

- Regulations that affect the cost of building materials, supplies or components
- Regulations that affect standards of building design or performance.

This methodology adopts some of the elements of the latter report, quotes from it where applicable, and provides specific references to other parts of it.

The International Code Council has granted its permission to reproduce sections of the International Residential Code and other publications within this report.

1. “Step 1: Develop a Description of the Code Change”

A code change subject to an analysis of costs and benefits can be of limited technical scope, such as “foundation anchorage spacing,” or it can be broad and comprehensive in scope, such as “seismic design, NEHRP provisions in lower and moderate seismic regions” or the “rewrite of the Residential Energy Code.” The methodology offers ways of analyzing code changes at both extremes and in between. Firstly, it is very important to be precise about the description of the code change being analyzed. Code changes subject to analysis may fall into three categories:

- A code change that has been proposed for consideration
- A code change that has been approved for inclusion in the code, following discussion and modification
- A code change that has been rejected.

Secondly, the description of the code change should include the following elements:

- Specific reference to the version of the change to be analyzed
- The full text of the code change, if possible
- A summary of the major provisions of the code change
- A description of the scope of the change, including housing type limitations, geographic or regional limitations, and other limitations on its applicability
- All supporting and opposing statements available in the record of the code change deliberations.

The following two examples, “Foundation Anchorage” and “Continuous Structural Panel Sheathing,” demonstrate the scope and depth of Step 1 development for code changes with differing characteristics. Each example is organized around answering a series of questions about the particular code change:

- What is the status and substance of the code change?
- How does it fit into the big picture?
- What is the proponent’s rationale for the code change?
- Is there any additional information in support or opposition?

Step 1 Example: Foundation Anchorage

There are several questions that must be addressed to adequately describe this code change. These questions include:

- What is the status and substance of the code change?
- What is the context of this code change (i.e., how does it fit into the big picture)?
- What is the proponent’s rationale for the code change?
- Is there any additional information in support or opposition?

Because of the length of the description for this code change item, a summary description is provided after the above questions are answered.

What is the status and substance of the code change?

The subject code change on foundation anchorage was approved and affects one- and two-family dwelling construction in accordance with the 2006 *International Residential Code* (IRC). Therefore, the primary resources necessary for describing and understanding the substance of the code change include the following three documents:

- 2003 International Residential Code (IRC 2003), International Code Council, Inc.—This document establishes the baseline requirements related to foundation wall anchorage (lateral support at top of wall) prior to the introduction and acceptance of the subject code change proposal increasing foundation anchorage requirements.
- 2004/2005 Code Development Cycle – Proposed Changes, International Code Council, Inc.—This document contains the original code proposal and reason statement as provided by the proponent of the code change item. It does not include any revisions or amendments that may subsequently occur in the code development process.
- 2005 Final Action Agenda, 2004/2005 Code Development Cycle, International Code Council, Inc.—This document provides documentation of the final step in the code development process. It includes any public comments that may request revisions to proposed code changes or decisions made earlier in the code development process.
- 2006 International Code Residential Code (IRC 2006), International Code Council, Inc.—This document is the revised residential building code including the effects of the approved code change proposal. It represents the end result of the code change in terms of its inclusion in the model building code.

Additional resources to assist in describing the intended and actual effects of the model code change include:

- Written or video-taped documentation of discussions at the subject code hearings where the code proposal was heard and acted upon.
- Communication with those involved in the code development process (e.g., the proponent(s) and opponents(s)).
- Published errata for any of the above documents (usually provided at the model code organization’s web site, in this case, www.iccsafe.org)

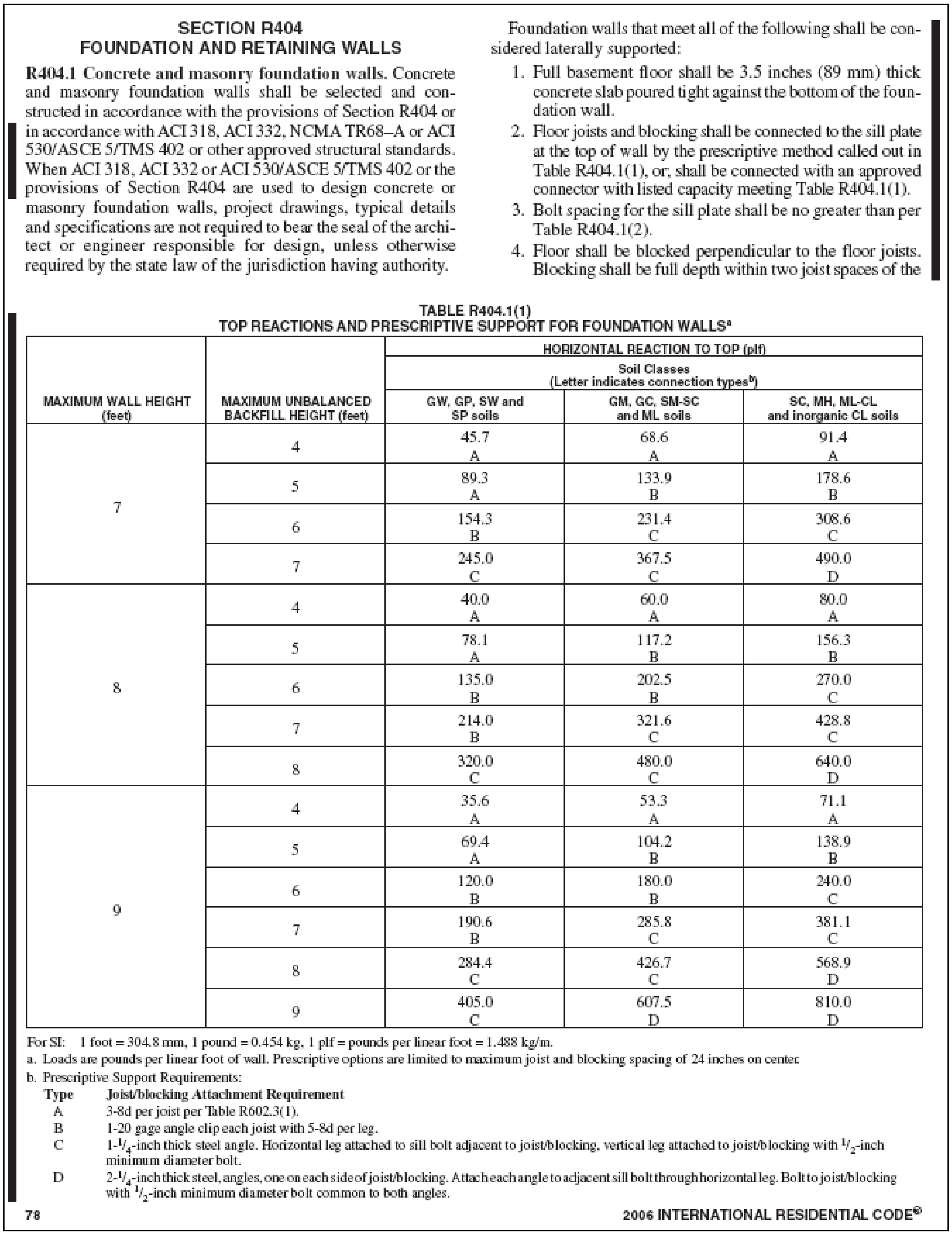
It is very important to be precise when describing the code change being evaluated because the intent in this first step of the Methodology is to determine what was changed. Any lack of precision at this stage will result in errors when implementing later steps of the Methodology. The three primary sources listed above are instrumental for this purpose and all three should be consulted as it is possible for errors to have been made in publishing any new code change. In doing so, a factual and precise representation of the change relative to the prior and current model code language should be constructed. The intent is not to evaluate or interpret the impacts at this stage, but rather to document how the change affected the literal content of the model building code.

For example, a careful review of the three primary resources listed above results in the following literal description of the approved code change in Section R404.1 of the IRC (see “Step1, Foundation Anchorage, Figure 1” below). This representation clearly shows how the original code (the “starting point” or baseline) was changed to result in the later code edition (the “ending point”). Care must be taken to not include other related or unrelated code proposals that affect the subject text of the code unless it is clear that these other changes were intended to be coordinated with the subject code change. If this were the case, the scope of the assessment should be expanded to include additional code changes affecting the same or different portions of the code. This situation does not appear to be the case with this code change item.

Normally, underlined text would be used to represent information added to the baseline code edition and strikeout text used to represent information removed from the baseline code by the approved code change proposal. However, text and tabulated requirements were added with no deletions to the 2003 IRC (baseline code) in this case. Therefore, the added text as a result of

Step 1 Example: “Foundation Anchorage”

Public Comment #3 on code proposal S89-04/05 (2004/2005 Code Development Cycle – Final Action Agenda, http://www.iccsafe.org/cs/codes/2004-05cycle/FAA/IBC-S1.pdf) is shown as highlighted text in the excerpt from the 2006 IRC below. This approach clearly defines the content and extent of the code change as printed in final form in the later code edition (i.e., IRC 2006), including any modifications that may have occurred during the subject code hearing cycle or by code staff (editorial and formatting). Where any discordant text is found in this re-construction of the code change and the final published code, it should be investigated as a potential error in code publication or a missed modification and the code publisher contacted for clarification. This potential problem also does not appear to be a problem in this case because the published 2006 IRC reflects a verbatim transposition of the approved code change proposal (public comment) noted above.



SECTION R404
FOUNDATION AND RETAINING WALLS

R404.1 Concrete and masonry foundation walls. Concrete and masonry foundation walls shall be selected and constructed in accordance with the provisions of Section R404 or in accordance with ACI 318, ACI 332, NCMA TR68–A or ACI 530/ASCE 5/TMS 402 or other approved structural standards. When ACI 318, ACI 332 or ACI 530/ASCE 5/TMS 402 or the provisions of Section R404 are used to design concrete or masonry foundation walls, project drawings, typical details and specifications are not required to bear the seal of the architect or engineer responsible for design, unless otherwise required by the state law of the jurisdiction having authority.

Foundation walls that meet all of the following shall be considered laterally supported:

1. Full basement floor shall be 3.5 inches (89 mm) thick concrete slab poured tight against the bottom of the foundation wall.
2. Floor joists and blocking shall be connected to the sill plate at the top of wall by the prescriptive method called out in Table R404.1(1), or; shall be connected with an approved connector with listed capacity meeting Table R404.1(1).
3. Bolt spacing for the sill plate shall be no greater than per Table R404.1(2).
4. Floor shall be blocked perpendicular to the floor joists. Blocking shall be full depth within two joist spaces of the

TABLE R404.1(1)
TOP REACTIONS AND PRESCRIPTIVE SUPPORT FOR FOUNDATION WALLS[a]

MAXIMUM WALL HEIGHT (feet)	MAXIMUM UNBALANCED BACKFILL HEIGHT (feet)	HORIZONTAL REACTION TO TOP (plf)		
		Soil Classes (Letter indicates connection types[b])		
		GW, GP, SW and SP soils	GM, GC, SM-SC and ML soils	SC, MH, ML-CL and inorganic CL soils
7	4	45.7 A	68.6 A	91.4 A
	5	89.3 A	133.9 B	178.6 B
	6	154.3 B	231.4 C	308.6 C
	7	245.0 C	367.5 C	490.0 D
8	4	40.0 A	60.0 A	80.0 A
	5	78.1 A	117.2 B	156.3 B
	6	135.0 B	202.5 B	270.0 C
	7	214.0 B	321.6 C	428.8 C
	8	320.0 C	480.0 C	640.0 D
9	4	35.6 A	53.3 A	71.1 A
	5	69.4 A	104.2 B	138.9 B
	6	120.0 B	180.0 B	240.0 C
	7	190.6 B	285.8 C	381.1 C
	8	284.4 C	426.7 C	568.9 D
	9	405.0 C	607.5 D	810.0 D

For SI: 1 foot = 304.8 mm, 1 pound = 0.454 kg, 1 plf = pounds per linear foot = 1.488 kg/m.

a. Loads are pounds per linear foot of wall. Prescriptive options are limited to maximum joist and blocking spacing of 24 inches on center.

b. Prescriptive Support Requirements:

Type	Joist/blocking Attachment Requirement
A	3-8d per joist per Table R602.3(1).
B	1-20 gage angle clip each joist with 5-8d per leg.
C	1-$^1/_4$-inch thick steel angle. Horizontal leg attached to sill bolt adjacent to joist/blocking, vertical leg attached to joist/blocking with $^1/_2$-inch minimum diameter bolt.
D	2-$^1/_4$-inch thick steel, angles, one on each side of joist/blocking. Attach each angle to adjacent sill bolt through horizontal leg. Bolt to joist/blocking with $^1/_2$-inch minimum diameter bolt common to both angles.

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Step1, Foundation Anchorage, Figure 1**.** Extent of example code change on foundation anchorage
(Highlighted text is new text added to the 2003 IRC and published in the 2006 IRC;
no deletions were made.)

Step 1 Example: “Foundation Anchorage”

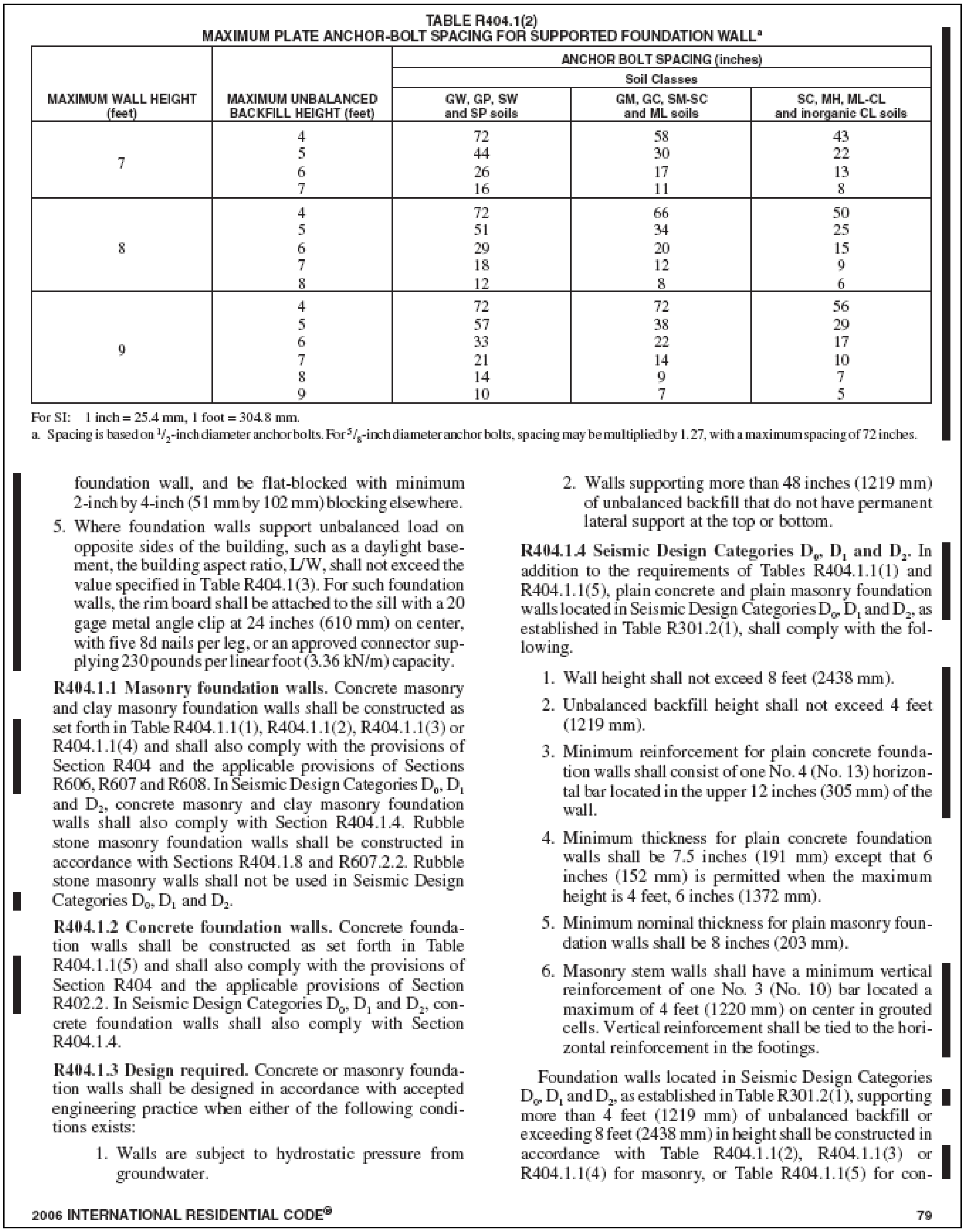

TABLE R404.1(2)
MAXIMUM PLATE ANCHOR-BOLT SPACING FOR SUPPORTED FOUNDATION WALL[a]

MAXIMUM WALL HEIGHT (feet)	MAXIMUM UNBALANCED BACKFILL HEIGHT (feet)	ANCHOR BOLT SPACING (inches)		
		Soil Classes		
		GW, GP, SW and SP soils	GM, GC, SM-SC and ML soils	SC, MH, ML-CL and inorganic CL soils
7	4	72	58	43
	5	44	30	22
	6	26	17	13
	7	16	11	8
8	4	72	66	50
	5	51	34	25
	6	29	20	15
	7	18	12	9
	8	12	8	6
9	4	72	72	56
	5	57	38	29
	6	33	22	17
	7	21	14	10
	8	14	9	7
	9	10	7	5

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

a. Spacing is based on $^1/_2$-inch diameter anchor bolts. For $^5/_8$-inch diameter anchor bolts, spacing may be multiplied by 1.27, with a maximum spacing of 72 inches.

foundation wall, and be flat-blocked with minimum 2-inch by 4-inch (51 mm by 102 mm) blocking elsewhere.

5. Where foundation walls support unbalanced load on opposite sides of the building, such as a daylight basement, the building aspect ratio, L/W, shall not exceed the value specified in Table R404.1(3). For such foundation walls, the rim board shall be attached to the sill with a 20 gage metal angle clip at 24 inches (610 mm) on center, with five 8d nails per leg, or an approved connector supplying 230 pounds per linear foot (3.36 kN/m) capacity.

R404.1.1 Masonry foundation walls. Concrete masonry and clay masonry foundation walls shall be constructed as set forth in Table R404.1.1(1), R404.1.1(2), R404.1.1(3) or R404.1.1(4) and shall also comply with the provisions of Section R404 and the applicable provisions of Sections R606, R607 and R608. In Seismic Design Categories D_0, D_1 and D_2, concrete masonry and clay masonry foundation walls shall also comply with Section R404.1.4. Rubble stone masonry foundation walls shall be constructed in accordance with Sections R404.1.8 and R607.2.2. Rubble stone masonry walls shall not be used in Seismic Design Categories D_0, D_1 and D_2.

R404.1.2 Concrete foundation walls. Concrete foundation walls shall be constructed as set forth in Table R404.1.1(5) and shall also comply with the provisions of Section R404 and the applicable provisions of Section R402.2. In Seismic Design Categories D_0, D_1 and D_2, concrete foundation walls shall also comply with Section R404.1.4.

R404.1.3 Design required. Concrete or masonry foundation walls shall be designed in accordance with accepted engineering practice when either of the following conditions exists:

1. Walls are subject to hydrostatic pressure from groundwater.
2. Walls supporting more than 48 inches (1219 mm) of unbalanced backfill that do not have permanent lateral support at the top or bottom.

R404.1.4 Seismic Design Categories D_0, D_1 and D_2. In addition to the requirements of Tables R404.1.1(1) and R404.1.1(5), plain concrete and plain masonry foundation walls located in Seismic Design Categories D_0, D_1 and D_2, as established in Table R301.2(1), shall comply with the following.

1. Wall height shall not exceed 8 feet (2438 mm).
2. Unbalanced backfill height shall not exceed 4 feet (1219 mm).
3. Minimum reinforcement for plain concrete foundation walls shall consist of one No. 4 (No. 13) horizontal bar located in the upper 12 inches (305 mm) of the wall.
4. Minimum thickness for plain concrete foundation walls shall be 7.5 inches (191 mm) except that 6 inches (152 mm) is permitted when the maximum height is 4 feet, 6 inches (1372 mm).
5. Minimum nominal thickness for plain masonry foundation walls shall be 8 inches (203 mm).
6. Masonry stem walls shall have a minimum vertical reinforcement of one No. 3 (No. 10) bar located a maximum of 4 feet (1220 mm) on center in grouted cells. Vertical reinforcement shall be tied to the horizontal reinforcement in the footings.

Foundation walls located in Seismic Design Categories D_0, D_1 and D_2, as established in Table R301.2(1), supporting more than 4 feet (1219 mm) of unbalanced backfill or exceeding 8 feet (2438 mm) in height shall be constructed in accordance with Table R404.1.1(2), R404.1.1(3) or R404.1.1(4) for masonry, or Table R404.1.1(5) for con-

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Step1, Foundation Anchorage, Figure 1 **(continued)**. Extent of example code change on foundation anchorage (Highlighted text is new text added to the 2003 IRC and published in the 2006 IRC; no deletions were made.)

Step 1 Example: "Foundation Anchorage"

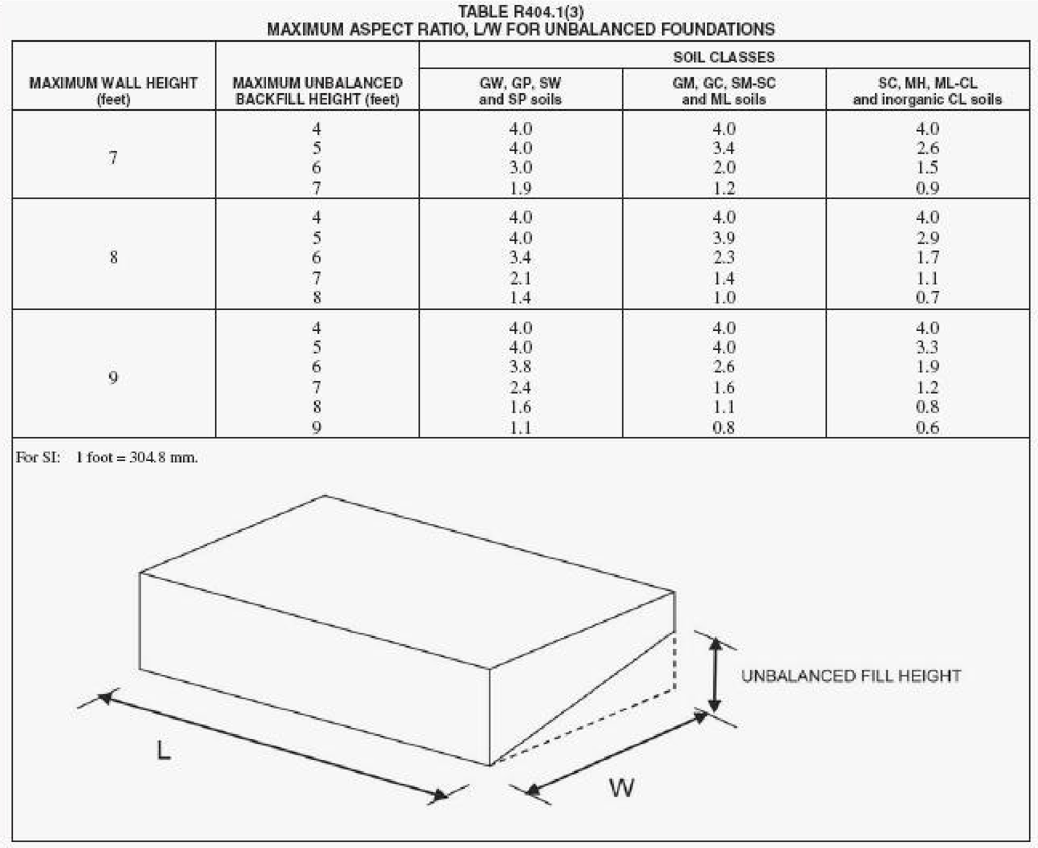

TABLE R404.1(3)
MAXIMUM ASPECT RATIO, L/W FOR UNBALANCED FOUNDATIONS

MAXIMUM WALL HEIGHT (feet)	MAXIMUM UNBALANCED BACKFILL HEIGHT (feet)	SOIL CLASSES		
		GW, GP, SW and SP soils	GM, GC, SM-SC and ML soils	SC, MH, ML-CL and inorganic CL soils
7	4	4.0	4.0	4.0
	5	4.0	3.4	2.6
	6	3.0	2.0	1.5
	7	1.9	1.2	0.9
8	4	4.0	4.0	4.0
	5	4.0	3.9	2.9
	6	3.4	2.3	1.7
	7	2.1	1.4	1.1
	8	1.4	1.0	0.7
9	4	4.0	4.0	4.0
	5	4.0	4.0	3.3
	6	3.8	2.6	1.9
	7	2.4	1.6	1.2
	8	1.6	1.1	0.8
	9	1.1	0.8	0.6

For SI: 1 foot = 304.8 mm.

Step1, Foundation Anchorage, Figure 1 **(continued). Extent of example code change on foundation anchorage**
(Highlighted text is new text added to the 2003 IRC and published in the 2006 IRC; no deletions were made.)
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The code language added to the 2003 IRC and appearing in the 2006 IRC originated with the code change proposal duplicated below, as excerpted from the 2004/2005 Code Development Cycle – Proposed Changes (http://www.iccsafe.org/cs/codes/2004-05cycle/ProposedChanges), in "Step1, Foundation Anchorage, Figure 2. Foundation Anchorage Original Code Change Proposal." This proposal was actually disapproved by the IRC code development committee, but later revised and approved during the final action hearing by way of a public comment. It is noted that this original proposal affected both the International Building Code (covering all types of buildings) as well as one- and two-family dwellings in accordance with the IRC. Only the parts relevant to the IRC and one-and two-family dwellings are considered here. The reason statement provided by the proponent and the proposed code change text clearly indicates that the concern was solely focused on anchorage of foundation walls against lateral soil loads. The reason statement also indicates that the primary justification for the proposal is "current engineering practice" without defining the basis of that practice or justifying its application to replace or modify existing foundation anchorage provisions in the IRC 2003.

S89-04/05
1805.5; IRC R404.1

Proponent: Philip Brazil, P.E., Reid Middleton, Inc., Everett, WA

PART I — IBC
Revise as follows:

1805.5 Foundation walls. Concrete and masonry foundation walls shall be designed in accordance with
Chapter 19 or 21. Foundation walls that are laterally supported at the top and bottom and

within the parameters of Tables 1805.5(1) through 1805.5(4) are permitted to be designed and constructed in accordance with Sections 1805.5.1 through 1805.5.5 for the support of lateral soil loads. The lateral supports at the top and bottom shall be designed so that they are capable of supporting the lateral loads imposed by the foundation wall.

PART II — IRC
Revise as follows:

R404.1 Concrete and masonry foundation walls. Concrete and masonry foundation walls that are laterally supported at the top and bottom shall be selected and constructed in accordance with the provisions of this section or in accordance with ACI 318, NCMA TR68–A or ACI 530/ASCE 5/TMS 402 or other approved structural standards, for the support of lateral soil loads. When ~~ACI318 or ACI 530/ASCE 5/TMS 402 or~~ the provisions of this section are used to ~~design~~ select concrete or masonry foundation walls, project drawings, ~~typica~~l details and specifications are not required to bear the seal of the architect or engineer responsible for design, unless otherwise required by the state law of the jurisdiction having authority. The lateral supports at the top and bottom shall be designed so that they are capable of supporting the lateral loads imposed by the foundation wall.

Reason: The purpose of this proposal is to revise the provisions for foundation walls in IBC Sections 1805.5 and IRC Section R404.1 by bringing them more in line with current structural engineering practice.
The phrase “for the support of lateral soil loads” is added in each Section in order to limit the scope of the provisions to the support of lateral soil loads. Currently, the provisions do not directly take into account the effects of gravity loads on the foundation wall. Inevitably, a point will be reached where an axial load is imposed on a foundation wall constructed in accordance with one of the prescriptive designs contained in IBC Tables 1805.5(1) through 1805.5(4) and IRC Tables R404.1.1(1) through R404.1.1(4) that will render it structurally unsafe and possibly compromise public safety. But limitations on axial loads are not established for use of the tables. The scope of IBC Tables 1805.5(1) through 1805.5(4) and IRC Tables R404.1.1(1) through R404.1.1(4) should be limited to the support of lateral soil loads until such time as technical justification can be provided that establishes safe axial loads in combination with the out-of-plane bending loads that the tables primarily address.

The final sentence of each Section is added to ensure that the lateral supports at the top and bottom of the foundation wall are adequate to safely support design lateral loads. Currently, the provisions do not directly take into account the effects on the lateral supports of the loads imposed by the foundation wall. Inevitably, a point will be reached where the loads imposed by a foundation wall constructed in accordance with one of the prescriptive designs contained in IBC Tables 1805.5(1) through 1805.5(4) and IRC Tables R404.1.1(1) through R404.1.1(4) will render its lateral supports unsafe and possibly compromise public safety. But limitations on the loads from the foundation wall are not established for use of the tables. The scope of IBC Tables 1805.5(1) through 1805.5(4) and IRC Tables R404.1.1(1) through R404.1.1(4) should be limited to the use of lateral supports that have sufficient strength to safely support the loads imposed on them by the foundation wall.

The phrase “that are laterally supported at the top and bottom” is added to IRC Section R404.1 in coordination with the same phrase currently in IBC Section 1805.5. Without the phrase, a code user may conclude that IRC Tables R404.1.1(1) through R404.1.1(4) could be applied to a foundation wall that is supported, for example at the bottom but not at the top. Lateral support of a foundation wall only at the bottom can substantially change the structural demands on the wall, notably the need for negative reinforcement, which is not addressed by Tables 1805.5(2) through 1805.5(4). Use of the Tables for such support conditions could compromise public safety.

The term “design” is changed to “select” in IRC Section R404.1 to further establish that the *provisions of IBC Section 1805.5 and IRC R404.1 are prescriptive and are not intended to be design provisions.*

Reference to ACI 318 and ACI 530/ASCE 5/TMS 402 are deleted because Section R404.1 currently permits their use for the design of foundation walls while also exempting the drawings, details and specifications from the need to bear the seal and signature of the responsible design professional. ACI 318 and ACI 530/ASCE 5/TMS 402 contain provisions for the structural design of concrete and masonry.

Without the change, a code user who is not a registered design professional may conclude that he or she is permitted to design a foundation wall with design conditions beyond the scope of the provisions in IRC Section R404.1 in accordance with ACI 318 and ACI 530/ASCE 5/TMS 402.

Cost Impact: *None*

Step1, Foundation Anchorage, Figure 2. Foundation Anchorage Original Code Change Proposal
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It is interesting to note that the cost impact is indicated as "none" by the proponent. However, the requirement that "lateral supports at the top and bottom shall be designed" clearly has cost implications due to engineering services that would not otherwise be required in the baseline code's (2003 IRC) prescriptive requirements for foundation wall anchorage. It was for this reason (presence of cost impact due to lack of a prescriptive solution in the proposal) that it was denied.

How does it fit into the big picture?

The process followed to this point has focused on tracing the code proposal to it's literal appearance in the newer code but it has not necessarily addressed the provisions which have been changed or affected by the code change proposal. In this case, the previously existing foundation anchorage requirements (top of wall anchor bolt spacing and detailing) are not found in the same section of the code altered by the code change, but rather in Section R403.1.6. While this can be considered poor code writing practice (modifying requirements in one section that effectively replace or alter requirements that remain unchanged in another section of code) and can cause confusion in the use of the code, the analyst must exercise appropriate code interpretation rules where the more stringent requirement over-rules. In this case, the requirements for foundation wall anchorage found in other parts of the code represent the baseline or "starting point" from which to measure the impact of the code change.

The baseline requirements for foundation wall anchorage in R403.1.6 are duplicated below in "Step1, Foundation Anchorage, Figure 3." The highlighted text represents baseline requirements for comparison with the code change that resides in another section of the code. The baseline code text of Figure 3 is based on code text as found in the 2006 IRC. A few additional changes to this section of code have altered some requirements in this section of code compared to the IRC 2003; however, these changes do not affect the issue at hand – anchor bolt spacing and detailing requirements for top of foundation walls. If they were otherwise determined to have an effect on anchor bolt installation requirements and cost, then any compounding effect would need to be considered along with the effect of the subject code change listed in Figure 1 above.

R403.1.6 **Foundation anchorage.** When braced wall panels are supported directly on continuous foundations, the wall wood sill plate or cold-formed steel bottom track shall be anchored to the foundation in accordance with this section. The wood sole plate at exterior walls on monolithic slabs and wood sill plate shall be anchored to the foundation with anchor bolts spaced a maximum of 6 feet (1829 mm) on center. There shall be a minimum of two bolts per plate section with one bolt located not more than 12 inches (305 mm) or less than seven bolt diameters from each end of the plate section. In Seismic Design Categories D0, D1 and D2, anchor bolts shall be spaced at 6 feet (1829 mm) on center and located within 12 inches (305 mm) of the ends of each plate section at interior braced wall lines when required by Section R602.10.9 to be supported on a continuous foundation. Bolts shall be at least 1/2 inch (13 mm) in diameter and shall extend a minimum of 7 inches (178 mm) into masonry or concrete. Interior bearing wall sole plates on monolithic slab foundation shall be positively anchored with approved fasteners. A nut and washer shall be tightened on each bolt of the plate. Sills and sole plates shall be protected against decay and termites where required by Sections R319 and R320. Cold-formed steel framing systems shall be fastened to the wood sill plates or anchored directly to the foundation as required in Section R505.3.1 or R603.1.1.

Exceptions:
1. Foundation anchorage, spaced as required to provide equivalent anchorage to 1/2-inch-diameter (13 mm) anchor bolts.
2. Walls 24 inches (610 mm) total length or shorter connecting offset braced wall panels shall be anchored to the foundation with a minimum of one anchor bolt located in the center third of the plate section and shall be attached to adjacent braced wall panels per Figure R602.10.5 at corners.
3. Walls 12 inches (305 mm) total length or shorter connecting offset braced wall panels shall be permitted to be connected to the foundation without anchor bolts. The wall shall be attached to adjacent braced wall panels per Figure R602.10.5 at corners.

R403.1.6.1 Foundation anchorage in Seismic Design Categories C, D_0, D_1 and D_2. In addition to the requirements of Section R403.1.6, the following requirements shall apply to wood light-frame structures in Seismic Design Categories D_0, D_1 and D_2 and wood light-frame townhouses in Seismic Design Category C.
1. Plate washers conforming to Section R602.11.1 shall be provided for all anchor bolts over the full length of required braced wall lines. Properly sized cut washers shall be permitted for anchor bolts in wall lines not containing braced wall panels.
2. Interior braced wall plates shall have anchor bolts spaced at not more than 6 feet (1829 mm) on center and located within 12 inches (305 mm) of the ends of each plate section when supported on a continuous foundation.
3. Interior bearing wall sole plates shall have anchor bolts spaced at not more than 6 feet (1829 mm) on center and located within 12 inches (305 mm) of the ends of each plate section when supported on a continuous foundation.
4. The maximum anchor bolt spacing shall be 4 feet (1219 mm) for buildings over two stories in height.
5. Stepped cripple walls shall conform to Section R602.11.3.
6. Where continuous wood foundations in accordance with Section R404.2 are used, the force transfer shall have a capacity equal to or greater than the connections required by Section R602.11.1 or the braced wall panel shall be connected to the wood foundations in accordance with the braced wall panel-to-floor fastening requirements of Table R602.3(1).

Step1, Foundation Anchorage, Figure 3. Foundation Wall Anchorage Baseline Requirements
(2006 International Residential Code. Copyright 2006. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved.)

In terms of anchorage requirements for lateral support of the top of foundation walls against lateral soil loads (the subject of the code change), the changed code in Figure 1 not only supersedes the above requirements in most cases, but it also implicates other sections of code that are indirectly affected by the subject code change and must be considered in later steps of the Methodology. It is obvious that the code change affects or supersedes the minimum anchor bolt spacing of 6 feet on center that existed as the prior minimum (and maximum) requirement in the code. For example, a typical basement foundation wall of 8-foot height with 7 feet of unbalanced backfill of common soil materials now requires anchor bolts to be spaced at 16 inches on center, not 6 feet on center as required in the baseline code (per Figure 3). However, it may not be so clear that the new requirements have many direct and indirect effects relative to the baseline code. For example:

- Direct Impacts to Top of Wall Anchorage for Lateral Support
  - As mentioned, it modifies and alters in nearly all cases the anchor bolt spacing in foundation sill plate to masonry or concrete foundation walls found elsewhere in the code (IRC Section R403.1.6 and R403.1.6.1).
  - It also modifies and supersedes wood floor framing connection requirements to foundation sill plates as required elsewhere in the code (Table R602.3(1)) with the addition of three connection details involving additional connection hardware (e.g., light-gage steel clip angles or hot-rolled angles and bolts applied to each floor joist to sill plate connection).
  - It adds requirements for transverse blocking between floor joists that are parallel to a foundation wall.

  - Required wood floor connections to sill plate and sill plate anchor bolt connections to foundation wall vary according to foundation wall height, off-balanced backfill height, and soil class of backfill material whereas the baseline code used an essentially one-size-fits-all solution covering nearly all applications except three-story construction in high seismic hazard regions[1].
  - In addition, the installation of foundation wall anchorage varies with respect to Seismic Design Category and this must be considered in characterizing the impacts and costs associated with the anchorage change which was narrowly focused on the issue of out-of-plane anchorage of foundation walls to resist lateral soil loading. For example, the cost impact will be greater in higher seismic conditions because additional anchorage detailing is required (e.g., 3" x 3" x ¼" plate washers on each anchor bolt) that will accrue with the increased anchorage requirements of the subject code change.
- Direct Impact to Bottom of Wall Anchorage for Lateral Support
  - It requires the use of a "basement floor slab," presumably also required in crawlspace applications, to restrain the bottom of foundation walls from kicking inward.
- Direct Impact to Building Dimensions and Floor Diaphragm Connections to Foundation Walls
  - It limits the newer foundation anchorage provisions to specific building or foundation plan dimensions based on plan aspect ratio (length to width). This limitation did not exist in the baseline code and, for building that exceed this new limit an engineered design will be required.
  - It requires that shear plate connectors be used to transfer floor diaphragm reaction forces from rim (band) joist to foundation sill plates.
- Indirect Impacts to Top of Wall Anchorage for Lateral Support
  - It also affects or potentially negates prescriptive solutions for steel framed floor to foundation wall anchorage found elsewhere in the code because it does not provide a prescriptive solution for this situation.
  - Similarly, it may effect what was previously considered acceptable prescriptive requirements for anchorage of permanent wood foundation walls to wood floor systems.
  - It appears to also effect changes to the use of alternative (proprietary) anchorages that were previously permitted on the basis of equivalence to ½" diameter anchor bolts spaced 6'oc, essentially resulting in an exclusion of previously accepted equivalent anchorages.

The above types of impacts, whether direct or indirect results of the code change, must be noted for subsequent consideration of impacts and cost analyses in later steps of the Methodology.

What is the proponent's rationale for the code change?

As mentioned, the original code proposal was disapproved by the IRC code development committee. However, a public comment was submitted by a different proponent and approved at the 2004/2005 ICC final action hearings, resulting in the added language to R404.1 of the IRC 2006 as indicated in Figure 1. The reason statement provided by the public commenter is duplicated below (excerpted from 2004/2005 Code Development Cycle – Final Action Agenda, http://www.iccsafe.org/cs/codes/2004-05cycle/FAA/IBC-S1.pdf), in "Step1, Foundation Anchorage, Figure 4. Foundation Anchorage Public Comment." It provides insight in regard to the proponent's objective and rationale for offering the approved public comment.

> *Public Comment 3 [on S89-04/05, Part II]:*
> *Scott Beard, City of Tacoma, requests Approval of Part II-IRC as Modified by this comment.*
>
> *Commenter's Reason: The reason for the proposal to require lateral design for the support of basement foundation walls is sound. Failures of inadequately supported basement walls are well documented. The comment from the Hearings Board was that they felt that the IRC should be prescriptively based, and that rather than simply requiring engineering design as the proposal did as originally written, they felt that it should give a prescriptive solution. This modification is such a prescriptive solution.*

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[1] It should be further noted that the IRC prescriptive provisions in general, and foundation anchorage provisions in specific, apply only to wind regions with basic wind speeds of less than 110 mph. Therefore, impacts related to foundation anchorage for high wind loads versus soil lateral loads are not inter-related in terms of the scope of applications addressed by the IRC and this review is limited to the scope of the IRC.

The approach for providing lateral support follows the lead of SSTD-10 and SSTD-13, which contain similar lateral support details, and use the same wall thickness and reinforcement tables as the IRC. (SSTD-10 is already a recognized standard by the IBC/IRC for wind design.) These standards show required floor blocking as described in this modified proposal, and show metal clips bolted to sill and joist for lateral support. Unfortunately the SSTD standards did not take the extra step of actually sizing the required metal angle clip. We have done so for this proposal.

Lateral forces are provided in the table, under the expectation that given the required force, third party vendors will soon provide various connectors that can be used in place of the prescriptive metal clips. (Possibly something like a joist hanger turned sideways.) The capacity of the 3- 8d nail connection was taken from the table in the Wood Framed Construction Manual Commentary, adjusted for non-wind condition. Capacity of the generic 20 ga clip was taken to be the same as a Simpson A35 clip. Capacities for the ¼” steel angle clips were take from the NDS.

Daylight basements create another problem. Rather than the forces directly transferring across the floor through the blocking, the unbalanced portion of the floor must be transferred to the perpendicular walls by shear. The aspect ratio limitation is due to the shear capacity of plywood nailed at 6” o.c. Normal connection of the rim board to plate is not as strong as the allowable plywood shear. In order to get the capacity to a similar magnitude, additional clips are required.

This is a real problem, with documented failures. The modified proposal will allow prescriptive design for most houses.

Step1, Foundation Anchorage, Figure 4. Foundation Anchorage Public Comment

As indicated in the reason statement, the primary reason for this public comment proposal is “failures [of foundation wall anchorage due to lateral soil loads]…are well documented” and that the “reason [for the original disapproved proposal]…is sound.” However, no documentation was provided by the proponent to substantiate these claims beyond the level of personal experience or opinion. In addition, the apparent objection to the original proposal was the need for prescriptive solutions, which this public comment modification to the original proposal provided. However, the IRC code development committee may have had additional reasons for denial that were not documented in the final action agenda. Thus, those few voting members of ICC attending the final action hearing and present when this code item was heard at a late hour, may not have been cognizant of all of the reasons for the initial denial of this code proposal. In this context, the public comment was successful in overturning the IRC code development committee’s earlier decision.

While apparently based on engineering calculations, the engineering analysis was not discussed in sufficient detail in the public hearing proponent’s reason statement to evaluate its suitability to address the intended application (e.g., design lateral pressures for soil classes, soil pressure distribution on the foundation wall, assumptions regarding frictional effects on the foundation wall surface if considered, use of adjustments to account for a system of anchor bolts and connections in lieu of codified single fastener design values, and appropriateness of implied connection deflection [slip] limits for this application were not reported). Important to this concern is the apparently unanswered question of whether or not the alleged “well-documented failures” were related to relevant causes or other causes such as failure to brace the foundation during construction and backfilling, improper compaction procedures for residential foundations, unusual site conditions, excessive equipment loading adjacent to the foundations, and others. These factors need to be considered in later phases of the Methodology (e.g., benefit analysis) when attempting to gather and objectively characterize data on foundation failures in the absence of such information in the proponent’s rationale statement and in relation to the many implications mentioned briefly in the previous section.

Is there any additional information in support or opposition?

There were two key reasons used by the public hearing proponent to substantiate the code proposal: (1) well documented failures and (2) accepted engineering practice. However, these reasons were not substantiated with evidence. Therefore, additional information must be sought by the analyst in regard to these claims and related evidences. This information, if available, will also support later steps in the Methodology, particularly Benefit Measurement Models (Step 5) and Cost-Benefit Analysis (Step 6). However, only Step 5 will be addressed later for this example code change.

Step 1 Example: "Foundation Anchorage"

First, for documentation of failures, a preliminary search for relevant information on the Internet did indicate that residential foundation wall failures do occur which agrees with common experience from other sources (e.g., news reports, code official experience, contractor experience, etc.). However, this preliminary search yielded no information to help discern the frequency of such events relative to the population of residential foundation walls. It also did not provide definitive information to relate the cause of reported foundation wall failures (often a disputed issue due to multiple causes and expert disagreement) to the objectives of the code change. Thus, alternate means of objectively characterizing "well documented failures" must be sought.

Insurance industry data (if available and coded in sufficient detail to assess cause of damage or failure) may provide some indirect indication of the frequency of claims based only on the insured building population. But, at least one court report available on the web indicates that insurance claims may be denied or even unreported due to coverage limitations in insurance policies. Therefore, insurance industry information appears to be of limited value unless the primary beneficiary of concern is the insurance industry and not consumers or builders in general. Thus, without conducting new research (e.g., a survey of home occupants to determine the frequency and cause of foundation wall damage or collapse), it may be very difficult to objectively characterize occurrences of foundation wall collapses or damage in a level of detail suitable for rational analysis of this code change item. However, a thorough literature review effort may yield some useful information.

While the presence of foundation wall collapses may justify the proponent's statement that foundation wall failures are "well documented" (i.e., at least known to occur), it falls well short of justifying a conclusion that the code change is necessary and that it will provide an acceptable net benefit. It also fails to recognize that accepted engineering practice does not imply a zero tolerance for failure. In fact, engineering practice is based on a low probability of failure for practical reasons. This practical reality suggests that some low frequency of foundation wall damage or failure is indeed anticipated and considered acceptable. For example, some small proportion of the total number of residential foundation walls in the population should be expected to experience problems. This issue speaks to the need to establish building practice on the basis of balancing acceptable levels of economic loss (as well as public safety) with costs and benefits of raising or lowering building code requirements, which the proponent does not address. It also indicates that the evaluation of acceptable economic impacts involves a relationship between building code requirements and use of insurance to mitigate potential losses. Thus, this issue involves risk management principles and decisions that are not necessarily coordinated between building code policy and other related policy, such as insurance industry regulation by states[2].

Second, accepted engineering practice was suggested as a primary basis for the code change proposal. Engineering analysis of foundation walls to resist lateral soil forces is governed by building codes, engineering standards, and accepted standards of care. Standards of care for analysis of foundation walls are represented in textbooks, technical literature, and in general practice. Therefore, information in support of or questioning accepted engineering practice should be considered relevant to this proposal. Information in support of accepted engineering practice is, as expected, readily available through building codes, reference design standards, and commonly used foundation design text books. A reputable source of information questioning accepted practice is more difficult to find. One such report was found and relates to soil lateral pressures (loads) on residential foundation walls: *Thin Wall Foundation Testing*, ISBN: 0-88654-378-9, prepared by University of Alberta, Department of Civil Engineering for Alberta Municipal Affairs.

The above report indicates that soil lateral pressures on typical residential foundation walls may be actually half the value currently required by accepted engineering practice as defined by the IBC building code and the ASCE 7 standard for structural design loads. Interestingly, the magnitude of lateral soil pressure found in the report is similar to the design load used in past accepted practice for the design of residential foundation walls (e.g., 30 pcf). This data will be useful in evaluating cost-benefits of the code change using actual soil load conditions in comparison to the loads used as the basis of the code change proposal which evidently relied on "accepted engineering practice". The issue of appropriate design values for soil lateral pressures acting on residential foundation walls has been recently identified as a topic where accepted engineering practice needs improvement[3].
Summary of IRC Foundation Anchorage Code Change

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[2] Crandell, J.H., "Policy development and uncertainty in earthquake risk in the New Madrid Seismic Zone," Continental Intraplate Earthquakes: Science, Hazard, and Policy Issues, GSA Monograph, S. Stein and S. Mazzotti (Eds.), Geologic Society of America (publication pending).

[3] *Residential Building Loads, Review and Roadmap for Future Progress*, J.H. Crandell, T.M. Kenney, and D.V. Rosowsky (Eds), prepared by Special Project Committee on Residential Building Loads of the Structural Engineering Institute, American Society of Civil Engineers, Reston, VA. 2006.

As a final step, the nature and extent of the code change should be condensed into a summary description. An example is shown in Figure 2. Implications are not necessarily discussed or explored in detail in this phase, but would be in Step 2. However, it can be useful to document these implications as well as any relevant information that may be important to consider in later steps of the Methodology. As such, this first step of the Methodology to describe a code change of interest can be view much like a discovery process in a legal case. It is important to provide a preliminary documentation of any "discovery" that may facilitate analyses and help analysts perform their tasks in later steps of the Methodology. Therefore, the person conducting the initial description should have a broad knowledge of the Methodology, the topic of the code change item under consideration, and the informational needs to properly evaluate the issues involved in accordance with the Methodology. Alternatively, this step should be carefully reviewed by the team of analysts to ensure that the proper "starting point" for implementing the Methodology has been thoroughly established.

AUTHOR'S NOTE: This code change has been challenged by a code proposal in the current ICC code development cycle (2006/2007). The proposal to remove this recently added code requirement was disapproved by the IRC code development committee; however, the code development committee's decision was successfully challenged by a floor vote. Therefore, this code change item, in the eyes of those involved in the code development process, is controversial and apparently has uncertain value. The main reason given by the code development committee was that no engineering data was given to support the proposal (however, the same concern should apply to the suitability of the engineering data given by the original proponent of this code item that resulted in its inclusion into the code). In all likelihood, a more careful analysis may identify an appropriate compromise that is technically sound and which maximizes cost-benefits and minimizes negative consequences of this code change as a model for regulatory policy. Furthermore, in local adoption of the IRC 2006 provisions that include this code change item, the tendency has been to amend this new language by removing it in its entirety.

Code Change Item: Foundation wall anchorage (lateral support)
Brief Description: Changes prescriptive and performance requirements for anchorage and detailing of load transfer at top and bottom of concrete and masonry foundation walls to resist out-of-plane lateral soil loads presumed to be acting on residential foundation walls by way of codified engineering analysis and related assumptions.

Baseline Code:	IRC 2003
Code Development Action:	Approved
Current Code:	IRC 2006
Sections of IRC 2003 defining baseline conditions:	R403.1.6, R403.1.6.1*
Changed sections of IRC 2006:	R404.1

* Includes other sections of code as referenced in the listed sections.

Reference Documents:

- 2003 International Residential Code
- 2006 International Residential Code
- 2005 Final Action Agenda, 2004/2005 Code Development Cycle, International Code Council (Public Comment #3 on ICC proposal #S89-04/05, Part II)

Issues Requiring Further Consideration in Methodology:

- Step 2: Additional identification and consideration of direct and indirect impacts of this code change that have been preliminarily identified and discussed in this Step 1 of the Methodology.
- Step 3: Consider first hard cost impact of construction error, delays, failed inspections, etc. as a result of change in practice.
- Step 3: Consider first soft cost impact of potential increased use of design professionals for use of alternative solutions where repetitive use provides economy of scale sufficient to absorb design costs.
- Steps 5 and 6: Relevance of engineering analysis approach used (loads and resistance values and implied deflection or slip limits for connections) to the specific conditions of this application to residential foundation wall anchorage. Any benefit-cost analysis must consider actual loads in residential foundation wall conditions, actual ultimate strength of the implicated connections, variability, and implications of varying degrees of slip in joints as a "true" measure of performance implications.
- Steps 4, 5, and 6: Investigate sources of foundation failure data; de-aggregation of that data to isolate failures that are associated with the premises of the proposed change and not other causes; consider that many older homes may not have had anchorage or that anchorage was not provided in accordance with the code, etc.; compare assumed design load and resistance in engineering standards with actual load and resistance data on residential foundation walls (one known study is mentioned in the discussion on Step 1).

Step1, Foundation Anchorage, Figure 5. Summary description of IRC code change on foundation anchorage

Step 1 Example: "Continuous Structural Panel Sheathing"

Step 1 Example: Continuous Structural Panel Sheathing

There are several questions that must be addressed to adequately describe this code change. These questions include:

- What is the status and substance of the code change?
- What is the context of this code change (i.e., how does it fit into the big picture)?
- What is the proponent's rationale for the code change?
- Is there any additional information in support or opposition?

What is the status and substance of the code change?

The code change in question was an approved change to the IRC 2000 code that resulted in the following text being added (underlined text) to the IRC 2003 code. This language still exists in the IRC 2006 code, pending a recent code action to remove this added language in the future IRC 2009 code edition.

> **R602.10.5 Continuous structural panel sheathing.** When continuous wood structural panel sheathing is provided in accordance with Method 3 of R602.10.3 on all sheathable areas of all exterior walls, and interior braced wall lines, where required, including areas above and below openings, braced wall panel lengths shall be in accordance with Table R602.10.5. Wood structural panel sheathing shall be installed at corners in accordance with Figure R602.10.5. The bracing amounts in Table R602.10.1 for Method 3 shall be permitted to be multiplied by a factor of 0. 9 for walls with a maximum opening height that does not exceed 85 percent of the wall height or a factor of 0.8 for walls with a maximum opening height that does not exceed 67 percent of the wall height. (2006 International Residential Code. Copyright 2006. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved.)

The added code language originated from the following ICC code proposal (excerpted from 2002 Proposed Changes to the International Residential Code, http://www.iccsafe.org/cs/codes/2002cycle/02_irc-be_proposals.pdf):

> RB114-02
> R602.10.5 and Table R602.10.5
> **Proponent:** Randall Shackelford, PE, representing Simpson Strong-Tie Company
> **Revise as follows:** ICC PUBLIC HEARING ::: April 2002 RB 89
> **R602.10.5 Continuous structural panel sheathing.** When continuous wood structural panel sheathing is provided in accordance with Method 3 of R602.10.3 on all areas of all walls, including areas above and below openings, braced wall panel lengths shall be in accordance with Table R602.10.5. Wood structural panel sheathing ~~at corners~~ shall be installed at corners in accordance with Figure R602.10.5. The bracing amounts in Table R602.10.3 for Method 3 shall be permitted to be multiplied by a factor of 0.9 for walls with a maximum opening height that does not exceed 85 percent of the wall height or a factor of 0.8 for walls with a maximum opening height that does not exceed 67 percent of the wall height. (2002 Code Development Cycle Proposed Changes to the 2003 International Codes. Copyright 2002. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved.)

During the code development process, the above proposal was further editorially modified to result in the final code language for the 2003 IRC code as reported above. The committee reason for the modification is as follows (as excerpted from 2002 Code Development Cycle: Report of Hearings, http://www.iccsafe.org/cs/codes/2002cycle/2002roh.html):

> **Committee Reason:** Based on proponent's published reason. The modification was made to clarify the application to exterior and interior sheathed walls.

The proponent's reason for the proposal is discussed later. The modified code proposal was approved in the final action hearing.

How does this code change fit into the big picture?

First, this code change affects structural requirements for light-wood frame dwelling construction in accordance with only the IRC. It relates to one of several prescribed methods to brace building walls against lateral (racking) forces imposed by wind or earthquakes. The subject code section (R602.10.5) further modifies one of the prescribed bracing methods known as "Method 3". Method 3 uses 4'x8' wood structural panels (e.g., plywood or Oriented Strand Board) placed intermittently on building walls to provide adequate bracing. In the continuous structural sheathing application, wood structural panels are applied "continuously" (not as intermittent panels) to each wall line that serves as a braced wall line for a building. For such wall lines, the added sheathing above and below windows contributes to the overall strength of a wall line and thus allows narrower brace panels and less bracing than would otherwise be required for Method 3 or other bracing methods in the IRC to achieve equivalent racking strength. Thus, this bracing method allows greater flexibility in meeting minimum bracing requirements than is afforded by other bracing methods currently recognized in the IRC. It does not result in a stronger braced wall in comparison to other IRC bracing methods at minimum prescribed bracing amounts required in the IRC because the minimum amount of bracing required in the IRC for various bracing methods is intended to result in equivalent bracing performance (i.e., lesser amount of bracing required for stronger bracing methods and vice-versa).

The subject code change deals with how the application of this bracing method is to be interpreted in regard to its use on an entire building structure. The premise of the code change is that the continuous sheathed bracing method must be used on the entire structure (i.e., “all exterior walls”) rather than only on a given wall line that may have limited space for wall bracing which can not be addressed by other prescriptive bracing methods in the IRC. Because many modern house plans have at least one exterior wall line where the continuous sheathed method offers the only prescribed solution that is code compliant, the added text would exclude the use of other bracing methods on other wall lines of the building. Furthermore, the added text seems to imply that interior braced wall lines also will require use of continuous wood structural panel sheathing when this bracing method is used on any exterior wall line. These implications are discussed in greater detail later (see Step 2).

What is the proponent’s rationale for the code change?

The reason submitted with this code change proposal is as follows (excerpted from *2002 Proposed Changes to the International Residential Code*, http://www.iccsafe.org/cs/codes/2002cycle/02_irc-be_proposals.pdf)

> Reason: In providing training on the IRC, there is always some confusion when it comes to this section. The “Continuous structural panel sheathing” method was added during the drafting of the IRC, based on new testing that was done on wall assemblies by NAHB. The concept behind the method is that the sheathing above and below openings (windows and doors) and on adjacent walls at corners prevents rotation (overturning) of braced wall panels under lateral loading. However, the wording of this section does not make it clear that all parts of all walls have to be sheathed for this method to work as intended.
>
> Without these clarifications, it is possible that this method could be used on one wall only, with the rest of the walls using the conventional braced wall panel method. If this were done, there may not be sheathing on adjacent walls to prevent overturning of the braced wall panels in the continuously sheathed wall…

Is there any additional information in support or opposition?

Answering this question requires some additional investigation, much like a literature review for a research report. Therefore, the scope of this inquiry can be extensive, but should be initially focused on identifying and summarizing additional relevant sources of information pertaining to the subject of the code change.

It should be noted that Section R602.10.5 itself appeared in the first edition of the IRC (2000 edition) and is not found in any of the precursor model codes upon which the IRC was based. Because this entire section of code was added during the drafting process for the IRC, it was not documented in a formal manner. Therefore, the model code organization staff and the proponent of this code change item must be consulted to obtain additional historic information and relevant technical data. In this case, the original author of the code section in question is included on the team of analysts. Therefore, the following additional information is based on “first hand” experience of the original author of this section of the 2000 IRC.

The rationale given above by the proponent refers to the intent of the original research (sponsored by HUD and NAHB) to implement a continuous structural sheathing wall bracing approach that (1) allowed the use of narrower than conventional 4-foot wide braced wall panels, (2) relied on building corners to provide adequate overturning restraint at the ends of perforated (continuously sheathed) shear walls, and (3) provided an engineering analysis basis for updating and justifying conventional wall bracing provisions in general. This original research involved a number of studies of wood structural panel sheathed wall systems, including a whole-building test that used multiple bracing methods. Most of these reports can be found on-line at www.huduser.org. Additional reports and relevant data may be identified by contacting the sponsoring agencies for this referenced work (i.e., HUD and NAHB) and the principle investigator(s) for the referenced studies.

Upon consulting the above sources, it appears that the motivation of the subject code change was correct (i.e., it is not clear how continuous braced wall lines are to be terminated at corners of a building). However, the proponent’s reason statement and the IRC code committee’s review of this code change appears to miss a key issue in the relevant research literature as originally implemented in the IRC 2000. The research data clearly shows that the bracing method as described in Section R602.10.5 was based on use of continuous sheathing on individual wall lines that are terminated at corners with only a minimum 2-foot wide corner return panel applied to abutting wall lines. Therefore, the continuous sheathing bracing approach was originally intended to be used on a wall line-by-wall line basis as needed to provide equivalent minimum structural racking resistance in comparison to other IRC bracing methods that require more wall area (or length of bracing) to provide equivalent bracing effect. It also shows that the original intent of Section R602.10.5 was to provide a means of terminating continuous sheathed braced wall lines at building corners such that other approved bracing methods may be used on other wall lines of a given building. Instead, the proponent’s reason statement suggests that the original intent was to require that the entire building be fully sheathed (“all walls”) with continuous wood structural panel sheathing. Thus, a review of additional information provides an opposing view (not documented and possibly not considered in the code development process) and suggests that the added code language creates an arguably exclusionary use of wood structural panels.

AUTHOR’S NOTE: What was originally introduced in the IRC 2000 as a means to address a specific need for specific wall lines was changed to require that the continuous structural sheathing method be used on all braced wall lines of a building, even if it was actually needed on just one wall line due to the architectural configuration of that particular wall line (e.g., no room for conventional 4-foot wide braced wall panels). Because wood structural panels are the only material class in the IRC that have been afforded the benefits of developing and implementing a continuous sheathing approach, this code change effectively became a sole-source specification of wood structural panels on any prescriptively designed home having at least one wall or portion of a wall that required use of narrower than 48-inch wide wall bracing panels.

In recent ICC 2006/2007 code development hearings, an extensive and collaborative effort was made, not without significant controversy, to re-write the IRC wall bracing provisions and to correct a number of problems, including the exclusionary “all walls” language originating from this code change item. At the time of this writing, the IRC code development committee has approved these more recent corrective code proposals. In addition, a number of states have already modified and corrected this code language through an emergency code change process or normal legislative process.

Step 1 Example: “Continuous Structural Panel Sheathing”

2. “Step 2: Describe Design and Construction Implications of the Code Change”

Identify the design and construction implications of the code change in order to develop estimates of their costs. A broad code change such as the “rewrite of the Residential Energy Code” may have multiple design and construction implications that must be identified.

A code change affecting performance requirements may have a multiplicity of possible design and construction implications, all of which comply with the change. For example, the code change “impact protection of glazed openings” in hurricane areas can be met with plywood, shutters, or special glass all of which must be identified. The cost analysis becomes more complicated, because it requires assumptions to be made on the relative frequency of use of the various options.

A code change may entail reduction or modification of the applicability of other code requirements. For example, the “residential sprinklers” option in the IRC may entail reduced exterior wall fire resistance and opening protection requirements that must be identified.

It may be useful, or even necessary, to select representative housing types as example buildings affected by the code change. The representative type is the basis for developing the "before" and "after" designs that illustrate the impact of the code change. *A Suggested Methodology for Estimating the Cost Impact of Changes to the Model Building* Codes, HUD, August 1994, discusses representative types:

> “The impact of many code changes on the construction of residential structures will be most apparent through the modification of existing practices. The modified practices must be isolated before assessing a code change's cost impact. To isolate a change, the new requirements must be applied to the design of some appropriate residential structure(s). These structures are termed ’representative types.’
>
> To allow the accurate portrayal of the impact of a code change, a representative type must:
> - typify the residential units or some subset of those residential units affected by the change; and,
> - characterize the residential construction occurring in the region governed by the code change.
>
> The term "representative type" should not be taken as merely suggesting some common type of construction. The selection process must extend to a careful examination of the description of the code change to identify significant factors for various housing types...
>
> The rationale for the analysis should guide both the consideration of the description and choice of a representative building or unit. If the code change's potential impact on the cost of "affordable", entry-level housing prompted the analysis, it would be inappropriate to select for analysis an upscale, detached, 4,000-square-foot single-family house. This is not to say that all cost-impact analyses must address affordable housing. For example, concerns about the overall impact of a proposed code change would suggest careful selection of the representative type(s) to ensure that the estimate can be generalized. In such cases, the selection of the representative types(s) would depend on the prevalence of each house type affected by the code change. If the assessment is prompted by concerns over a code change's potential impact on a given category of residential units within a code area, the representative type must reflect the characteristics of the affected buildings of that kind within that region.
>
> Although the predominant construction techniques and characteristics of residential units constructed in the different regions of the country may be well-known, the analyst may wish to apply statistical analysis when deciding between candidates for representative types. For example, suppose the rationale for examining the requirement for smoke detectors in all bedrooms is a concern over the cost

> impact on typical new single-family detached residences, the following type of statistical information would aid in defining a representative type.
>
> A recent analysis of data contained in the ***Annual Builder Practices Survey** (ABPS)* database indicates that about 51 percent of single-family detached houses constructed in 1992 with 4,000 or less square feet of living space in states that adopt the ***UBC*** were two-story structures. The average number of bedrooms in these residences was 3.71; the average amount of living space on the second story was 1,043 square feet.
>
> This information indicates that one viable representative type would be a 35-foot by 30-foot, two-story, single-family detached house with four bedrooms. The ***ABPS*** is not the only source of data on housing characteristics. [Other sources include the Bureau of the Census, *American Housing Survey, Housing Characteristics for Selected Metropolitan Areas, New One-Family Houses Sold, Characteristics of New Housing, General Housing Characteristics, and Detailed Housing Characteristics*; F. W. Dodge, *New Construction Report(s)*; and U.S. Department of Energy, *Residential and Commercial Buildings Data Book.*]
>
> If the goal of the analysis is to extend the cost-impact estimates for the representative types into aggregate estimates, then the analyst will require information on either the number or percent of each representative type. In such cases, the data can be developed as part of the identification of representative types. In some instances, detailed statistical data may not be required. For example, it is conceivable that consideration of a code change could indicate that a clearly defined subset of housing would be impacted and the analyst does not intend to develop aggregate estimates. In some cases, reliable relevant statistical data may not be available.
>
> If the analysis calls for multiple representative types, the analyst should organize the information to be developed for each type. For example, [the following table] illustrates the selection of two representative types for analysis of [**seismic design—NEHRP provisions**]. The table provides a numeric designation and a brief description of each representative type."

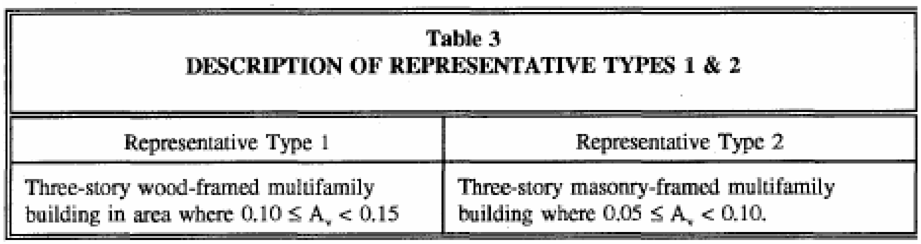


Table 3
DESCRIPTION OF REPRESENTATIVE TYPES 1 & 2

Representative Type 1	Representative Type 2
Three-story wood-framed multifamily building in area where $0.10 \leq A_v < 0.15$	Three-story masonry-framed multifamily building where $0.05 \leq A_v < 0.10$.

Housing Impact Analysis, HUD, January 2006, includes a more recent and comprehensive listing of housing analysis data sources than those included in the above quote. These are listed in Appendix A: Housing Analysis Data Sources and discussed in the following categories:

- General housing surveys
- Housing supply
- Housing demand
- House prices
- Interest rates
- Housing finance
- Regulation measures

Step 2 examples include “Continuous Structural Panel Sheathing” and “Sprinklers in the IRC.” Each example addresses a series of questions related to the particular code change:

- Continuous Structural Panel Sheathing
  - What are the implications of the code change?
  - What, if any, representative housing types are required to facilitate analysis?
- Sprinklers in the IRC
  - What are the direct design implications of the code change?
  - What are the indirect design implications of the code change?
  - What are the implications of the code change at the community level?
  - What, if any, representative housing types are required to facilitate analysis?

Step 2 Example: Continuous Structural Panel Sheathing

This step in the Methodology requires that the implications of the code change be identified and the selection of representative housing types be considered. Therefore, two questions must be addressed:

- What are the implications of the code change?
- What, if any, representative housing types are required to facilitate analysis of the implications?

What are the implications of the code change?

The implications of this code change include direct and indirect impacts to dwelling construction in accordance with the IRC. Direct impacts include those impacts that are associated with the immediate topic or purpose of the code change. In this case, direct impacts are related to compliance with wall bracing provisions in Section R602.10 of the IRC. However, there are also indirect impacts that must be considered because wall bracing methods also affect other wall assembly decisions, such as energy code compliance. Several direct and indirect impacts are discussed below.

- Direct Impacts
  - *Exclusion of Bracing Methods* – The primary impact of this proposal will be the loss of options to use various bracing methods on a building where one braced wall line of the building requires the use of continuous wood structural panel sheathing. This impact will occur regardless of hazard region for any home where the architectural configuration of one or more wall lines of the building do not allow space for conventional 4-foot wide braced wall panels, but for which there is adequate space for narrower brace panels and lesser bracing amounts with the continuous wood structural panel sheathing approach. In the prior code (IRC 2000), such homes may have been required to use the continuous sheathing approach on a particular wall line, but other wall lines of the same building could still use other bracing methods. This code change could even be interpreted to require that interior braced wall lines also be braced with continuous wood structural panels, rather than commonly accepted use of gypsum panels. Finally, there is no impact for homes that have adequate space for conventional wall bracing methods (e.g., traditional 1950s style ranch homes); however, modern housing plans frequently have at least one building side or wall line where the continuous sheathing method provides the only viable prescriptive solution. Therefore, with this code change, the entire building would be required to be fully sheathed with wood structural panels, including interior braced wall lines.
  - *Structural Performance Implications:* As mentioned in Step 1 for this example code change, the primary driver for the code change is not really improved performance, although this was suggested in the proponent's rationale statement. This observation is based on the fact that the minimum bracing amounts required for the continuous sheathed bracing method allow less bracing to be used to give an equivalent level of performance in comparison with other bracing methods where more bracing is required. However, for buildings affected by the newer "all walls" language as described in Step 1 and above, benefits should be expected from some wall lines of a given representative building type that would be strengthened by a greater margin than might otherwise have been experienced using a conventional bracing method on those wall lines.
    - For example, if a street facing wall of a building had a window and door opening configuration that required use of the continuous sheathed bracing approach to obtain minimum required bracing, the "all walls" language added with this code change item would also require building end walls to be continuously sheathed (and everywhere else on all exterior walls, including interior braced wall lines).
    - If the end walls had few or no openings, then bracing amounts for any of the bracing methods would be greater than necessary for minimum performance due to the behavior of the wall as a system of designated bracing elements as well as "non-structural" components that contribute to overall racking strength of a wall line and a light-frame dwelling as a whole. This is demonstrated in the 8.81m and 10.64m end walls of the sample house plan shown in "Step 2, Continuous Structural Panel Sheathing, Figure 2". Requiring these two walls to be fully sheathed with wood structural panels would add some further over-strength to such walls, but the comparative wall in this case is a wall that is also over-designed using any of the other conventional wall bracing methods because of the lack of wall openings. Interior braced wall lines also are affected by this code change.
    - However, the level of cost impact and benefit may vary considerably due to a number of plan-specific considerations. For example, the townhouse plan has fire separation walls between adjacent units that have no openings and that serve as braced wall lines in the transverse plan direction for the townhouse building. In accordance with the code change, these walls could be required to be continuously sheathed with wood structural panel sheathing in addition to gypsum panels used for fire-resistance purposes. This construction impact will depend on the amount of openings in the front and rear wall

    lines of the building that may or may not necessitate use of the continuous sheathing method for these wall lines to comply with the code.
    - If either of the front or rear exterior walls are required to use the continuous sheathing method to accommodate or maximize wall openings amounts in these walls, then the code change would require the interior fire-separation walls also to be continuously sheathed as a result of the added “all walls” language.
    - The net effect of this construction impact, whether or not considered justifiable on the basis of acceptable levels of absolute risk or performance, would tend to produce relative benefits in terms of seismic and wind risk reduction in the transverse loading direction for the townhouse building. This expectation may be especially true for seismic risk because continuous wood structural panel sheathing would be replace a more brittle and less strong gypsum panel bracing method (i.e., Method 5 bracing in the IRC) on the interior fire-separation walls while gypsum panels must still be used for fire resistance purposes. However, this relative benefit would apply conditionally to loads that happen to occur primarily in a direction parallel to the interior wall lines (transverse to the townhouse building).
    - Alternatively, the cost implications of this code change could drive an opposite architectural decision to reduce the amount of openings in the front and rear wall lines to avoid the first cost implications of using the continuous sheathed method on the interior fire-separation walls as described above. In this case, the first cost would be reduced as a result of the code change because windows and doors may be down-sized or eliminated from the front and/or rear walls of the building. Consequently, wind and seismic performance may be improved for loads that are longitudinal (parallel to front and rear wall lines) and a net benefit in performance could be realized along with reductions in first cost. Thus, the analysis of benefits and consequences of this code change are dependent on many factors, creating various conditional probabilities that must be considered for any given building plan.
    - For example, these same considerations would apply to the two-story detached single family home of “Step 2, Continuous Structural Panel Sheathing, Figure 2”. As described above, the continuously sheathed wall system used together with the newer “all walls” language should be expected to provide variable degrees of benefits depending on hazard level, hazard type, and representative building configuration. Building configuration can affect significant differences in conclusions based on seemingly small differences in wall opening amounts or location on a given wall line of a given plan. In summary, the benefits or consequences will be difficult to forecast without conducting a complete analysis of a carefully selected suite of representative building types that reveal the various impacts manifested by this code change in a case-by-case basis.
  - *Regional Hazard Level Implications* – The above implications also need to be considered in terms of geographic or climatic factors that vary regionally, such as wind and seismic hazard. Where these hazards are high, other “drivers” in the code may already be forcing the market to fully-sheathed construction or other forms of construction that over-ride any real impact that this code change would otherwise have in those regions. For example, in high wind zones the IRC refers to construction standards that essentially provide fully-sheathed bracing solutions (usually also with enhanced sheathing nailing and over-turning restraint connections). These conditions exceed the scope limits of the IRC’s bracing provisions in Section R602.10 and, therefore, are not considered to be germane to the analysis of this code proposal. However, the IRC does apply to many regions with higher seismic hazard levels. In this case, much of the housing market may be using fully-sheathed construction for reason of preference, practicality, requirements for engineered construction, excessive amounts of bracing required in code for other bracing methods, and other factors. In conclusion, this code change is likely to have much less of an impact in higher wind and seismic hazard regions because other factors tend to limit bracing method options, even without considering the code change.
- Indirect Impacts
  - *Energy Code Compliance* – Depending on climate region, wall bracing decisions can be affected by energy code requirements and vice versa. For example, in colder climates where increased wall insulation is required, two wall assembly options are typically used for energy code compliance: (1) 2x6 walls with greater amount of cavity insulation or (2) 2x4 walls with standard amount of cavity insulation and exterior rigid foam sheathing insulation. With the subject code change, more walls will be required to be braced with continuous wood structural panel sheathing. While the market must still choose whether to use option 1 or option 2, the economic and design implications are changed. For example, using option 2 will require that the wall assembly have a dual sheathing layer on the exterior and this will impact wall thickness and cost of other wall components (e.g., window and door framing now require extension jambs). Thus, it can be expected that a greater fraction of the market will be driven to use 2x6 wall framing (option 1). Two other options may include seeking energy code compliance following a

performance trade-off route which requires the services of a design professional or using high-density cavity insulation in moderately cold climates where this provides a code-compliant solution. Each of these four options has cost implications and speaks to the need to consider many different representative building types, climate/hazard regions, and wall configurations to properly capture the impact this code change. This also implies the need to determine frequency of market usage of different bracing methods as well as energy code compliance solutions on a regional basis.

- *Competitive Market Implications* – A difficult issue with this code change relates to its potential effect on competitive market conditions. For example, for buildings that require the use of the continuous sheathed method on at least one wall line, the code change will require that all braced wall lines (exterior and interior) be sheathed with wood structural panels. This may displace or exclude various materials that the market would have otherwise been able to choose prior to the code change. Thus, the implications of this code change involve legal considerations (e.g., exclusionary regulation) as well as the related broad consequences on material pricing in the “free market” as affected by changes in regulations that reconfigure the basis of market competition.
- *Other Indirect Impacts* – Additional indirect impacts associated with this code change may include moisture management considerations. For example, the different energy code compliance solutions discussed above may affect the ability of walls to handle moisture vapor loads. More specifically, wood structural panels and foam sheathing have different moisture vapor permeabilities, both on the low end of the scale. However, use of foam sheathing along with less cavity insulation tends to result in a “warm wall” which mitigates moisture condensation potential inside walls. Also, foam sheathing tends to mitigate against thermal bridging through framing members that can result in a “ghosting” effect on interior and exterior walls – a serviceability or esthetic impact. Durability performance of various wall assemblies (as affected by bracing method) also has a long-term impact. Assessing the cost-benefit of these implications involves different analysis methods than would be employed to evaluate structural or energy efficiency implications. Thus, a comprehensive assessment of cost-benefits could become rather complicated if these additional impacts are considered important. Also, the science of moisture management and durability is not nearly as well developed as structural and heat transfer sciences; therefore, any attempt to evaluate moisture management and durability implications is likely to be received with skepticism and controversy due to the uncertainties involved.

The above discussion was not meant to give a full treatment of all of the direct and indirect implications of this code change item. However, it does illustrate the need for a careful consideration of the implications of this seemingly simple code change that effectively added one small, but significant word – “all” – to the original text of the baseline code. These and other implications will affect the selection of representative building types discussed next in this step of the Methodology as well as the analysis of those types in later steps of the Methodology.

<u>What, if any, representative housing types are required to facilitate analysis?</u>

The implications of this code change item involve primarily new housing construction. However, a remodeled home or portion of a home could also experience implications in meeting the “all walls” language added by this code change item. Remodeling implications will be ignored for the sake of this discussion. Therefore, the selection of representative housing types should consider statistical data on new housing starts (e.g., 2000 or newer). This data can be obtained in a generalized fashion from normal sources for statistics on new housing characteristics. Relevant statistics include: house size (number of stories and square footage), bracing or sheathing method usage, window area, etc. Unfortunately, such data will lack specific details regarding the use of bracing materials and the configuration of the building that create “triggers” invoking the consequences (or benefits) of the “all walls” language. Therefore, for the purpose of evaluating this code change item, the normal sources of housing characteristic data may only give a very general guideline for the “size of the box” and any geographic variation in this size as well as basic wall construction material choices.

To properly identify representative housing types in this case, it will probably be necessary to obtain a representative sampling of house plans that are currently being used in the market and which represent the various sectors of the housing market. For example, three sample representative building plans are shown in “Step 2, Continuous Structural Panel Sheathing, Figures 1 through 3”. These plans should be associated with new housing characteristics discussed above such that frequencies of use can be assigned to each in representing some portion of the overall new housing market. In the absence of such information, these homes may be considered as “case studies” with the purpose of revealing implications of the code change through quantitative analysis, but without making conclusions in regard to the broader new housing market.

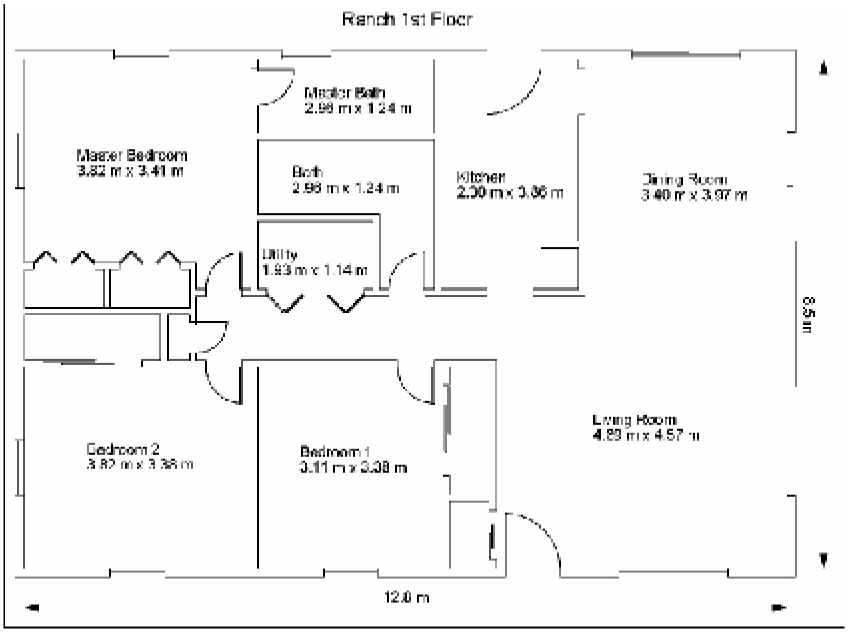
Step 2 Example: "Continuous Structural Panel Sheathing"

"Step 2, Continuous Structural Panel Sheathing, Figure 1" shows a relatively simple single story house floor plan that should experience little or no impact due to the code change. To the extent that this house plan represents a segment of the housing market (affordable single story homes without an attached garage), it will tend to reduce the net impact of the code change on the overall housing market. Conversely, "Step 2, Continuous Structural Panel Sheathing, Figure 2" represents the first story plan of a more complex two-story home with an attached garage. This house plan is likely to represent a larger segment of the overall housing market and will be impacted by the code change because at least one wall line will require use of the continuous sheathing method to comply with the code. Therefore, any impact or benefit of the code change on this typical house plan will tend to have greater ramifications.

"Step 2, Continuous Structural Panel Sheathing, Figure 3" represents a typical town-house plan configuration which would highlight the significance of the code change in terms of its potential impacts to bracing materials used for interior braced wall lines (separation walls between attached dwelling units). However, for the loading direction which would stress these walls, townhouses have generally performed well due to the lack of openings in the interior separation walls, even though they are typically braced with gypsum sheathing panels. For townhouses, racking loads parallel to the front and rear walls (perpendicular to the interior separation walls) are generally most destructive because of the greater amount of wall openings and less space for wall bracing. To avoid speculation, however, these implications must be considered in a detailed structural analysis of benefits and consequences of this code change (see Step 5).

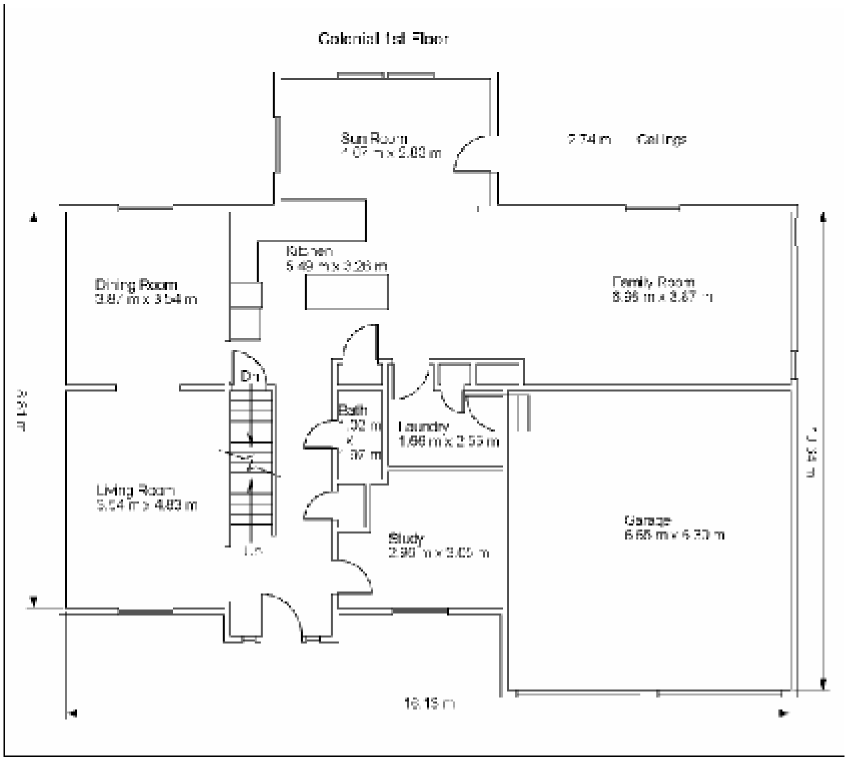
The major concern in selecting representative housing types is to establish the context of subsequent analyses required by the Methodology. This context is extremely important as it will affect the relevance, perception, and interpretation of any analytical result. If the intended context of the study is sufficiently narrow, the selection of "case study" homes as described above may be relevant and adequate to characterize the potential impact of the code change under specific conditions. If the desire is to perform a broader housing impact analysis, then a much more extensive sampling of house plans may be required and these plans must then also be associated with a proportionate share of the overall new housing market. For example, the house plans of Figures 1 through 3 lack any representation of larger, more complex luxury or custom homes.

Ultimately, this step should result in the formation of a study matrix that includes the various representative house plans as well as variations in wall assembly details and regional climate or hazard conditions. The study matrix identifies the conditions that must be subject to cost and benefit analyses conducted in later steps of the Methodology. An example study matrix for this code change item is shown later in Step 3 where it is used to facilitate a cost analysis of the code change.

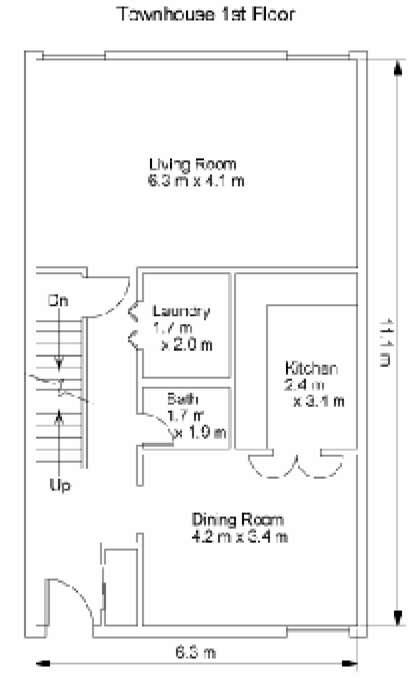


Step 2, Continuous Structural Panel Sheathing, Figure 1. Representative single-story, single-family detached "ranch" house floor plan without an attached garage (simple wall configurations and lay-out).

Step 2 Example: "Continuous Structural Panel Sheathing"



Step 2, Continuous Structural Panel Sheathing, Figure 2. Representative two-story, single-family detached "colonial" house plan with attached garage (1st Floor Plan)



Step 2, Continuous Structural Panel Sheathing, Figure 3. Representative townhouse unit floor plan (single-family attached) showing interior dwelling unit separation walls (at right and left of figure) that also serve as interior braced wall lines.

Step 2 Example: Sprinklers in the IRC

This step in the Methodology requires that the implications of the code change be identified and the selection of representative housing types be considered. Therefore, the following questions must be addressed:

- What are the direct design implications of the code change?
- What are the indirect design implications of the code change?
- What are the implications of the code change at the community level?
- What, if any, representative housing types are required to facilitate analysis of the implications?

What are the direct design implications of the code change?

The code change requires installation of residential sprinklers per the International Building Code (IBC). Although the IBC references three different NFPA sprinkler system standards, the most commonly used standard for system requirements in one- and two-family dwellings will be NFPA 13D, *Standard for the Installation of Sprinkler Systems in One-and Two-Family Dwellings and Manufactured Homes*. Under NFPA 13D there are three possible sprinkler alternatives:

- Multipurpose network
- Stand-alone with backflow preventer
- Stand-alone without backflow preventer

Multipurpose networks are sprinkler systems that use the same piping to supply both domestic and fire protection water needs. Stand-alone systems use piping solely for fire protection purposes. Although not required by NFPA 13D, most plumbing codes and municipal water departments will require a backflow preventer between the sprinkler piping and the domestic piping.

Another direct design implication of the code change is the water supply requirements. In urban and suburban areas, water supplies are usually sufficient for the needs of a residential sprinkler system. Public works connections can usually supply enough volume and pressure for the system. In some instances, the size of the connection to the public water may need to be increased. Where this occurs, there may also be a cost associated with paying “standby fees” that are imposed by the water department for connections above a certain size. In rural areas, however, water supplies may not be sufficient for the fire protection requirements. Water tanks and pumps may be required to be installed to meet the needs of the system.

Construction-wise, consideration must be taken for pipe installation, both above and below ground. Water must be supplied to the house and then the interior pipe system must be protected from things such as freezing and seismic events. In areas subject to freezing this may include additional or modified means of insulating spaces where sprinkler pipe is installed but domestic water pipe is not. In other instances, anti-freeze may be used as a means to prevent the water in the sprinkler pipe from freezing. Another common installation technique is to construct soffits within the conditioned space in which sprinkler pipe is installed.

The availability of products and ongoing research has reduced some of the other design implications. However, the size and geometry of individual rooms will determine the number of sprinklers necessary to protect each space. Sloped ceilings, ceiling pockets (such as skylights), and ceiling fans may require special consideration.

What are the indirect design implications of the code change?

The installation of a residential sprinkler system will have indirect design implications such as the following:

- Exterior wall fire resistance
- Exterior wall opening protection
- Separation of garage spaces
- Escape windows
- Party walls

The International Building Code currently reduces the requirements for openings in exterior walls when a building is protected with an automatic sprinkler system complying with NFPA 13. The International Residential Code does not contain similar provisions for one- and two-family dwellings protected with an automatic sprinkler system. Allowing such openings in an exterior wall where they are not currently permitted makes compliance with light and ventilation requirements easier. In addition, there has been discussion in the past that the separation distance required between a dwelling and the property line could be reduced when automatic sprinkler protection is provided.

Section R309.1 of the IRC currently requires garages to be separated from residences and attic spaces with specific construction. The openings between a garage and a sleeping area also required specific protection. Ducts penetrating a home from a private garage are to be constructed of at least No. 26 gage sheet steel or other approved materials and shall have no openings into the private garage. Code proposals have been made to exempt homes that are sprinkler protected from the opening protection requirements as well as the duct penetration material requirements. However, it should be noted that an NFPA 13D system does not require sprinklers to be installed in garages. Where sprinklers are installed in garages the concerns about protecting the water in the pipe from freezing may be more prevalent.

Similarly, in Section 1026, the IBC grants sprinkler exceptions for the emergency escape window requirements. Currently the exception does not apply for R-3 occupancies. However, there is a potential for a code change proposal to either exempt or reduce the requirements for Group R-3 occupancies when they are protected with an automatic sprinkler system.

Section R317.1 of the IRC requires 1-hour fire-resistance-rated floor-ceiling and wall assemblies between dwelling units in two-family dwellings. However, if the building is protected with a sprinkler system installed in accordance with NFPA 13, the fire-resistance rating is only required to be ½ hour. Unlike 1-hour fire-resistance-rated assemblies, ½-hour fire-resistance-rated assemblies do not require fire dampers for duct penetrations. This rating reduction may be negligible though due to acoustic requirements for the walls.

The indirect design implications mentioned herein are not recognized by the IRC for dwellings protected with an automatic sprinkler system but could be considered as part of a package of changes related to mandating sprinkler protection. The opposition to such changes is typically based on the fact that NFPA 13D does not require protection throughout and is primarily focused on life safety. Although some of the items mentioned above are life safety related, items such as exterior wall and opening protection are typically more of a property protection issue.

What are the implications of the code change at the community level?

While having residential sprinklers means an increase in water service to individual housing units, it results in a decreased fire flow demand for housing community. According to the Scottsdale report (*Saving Lives, Saving Money: Automatic Sprinklers A 10 Year Study: A detailed history of the effects of the automatic sprinkler code in Scottsdale, Arizona*, Jim Ford, 1997), from 1985 to 1996, the estimated residential sprinkler flow for houses in the city was 209 gallons while the average suppression water flow per residential fire incident was 3,290 gallons.

Fire department access requirements and minimum lot sizes may both be reduced. These requirements will vary by local ordinance though and are not something that is typically contained in codes such as the International Fire Code.

What, if any, representative housing types are required to facilitate analysis?

For the purpose of this analysis, three types of housing will be considered: entry level housing, subdivision housing, and custom housing. These housing groups cover a wide variety of homes and each represents unique issues to be addressed when considering residential sprinkler installation. Entry level housing includes homes with a very limited square footage. These houses would be similar to the 1-story ranch home (1171ft^2 (109m^2)) or the 3-story townhouse (2257ft^2 (210m^2)) mentioned in NISTIR 7277, *Economic Analysis of Residential Fire Sprinkler Systems*. Subdivision housing would be homes in a community with a limited number of floor plans. In the NISTIR report, these houses would be similar to the 2-story colonial with a basement (3338 ft^2 (310 m^2)). Floor plans of these houses are included in the Continuous Structural Panel Sheathing example. Custom housing covers homes with unique floor plans. These tend to have greater square footages and be one of a kind housing.

3. “Step 3: Perform a Cost Analysis”

The cost analysis of code changes may require two levels of analysis: costs per housing unit, and aggregated cost over some quantity of units. The cost analysis will always begin with costs per housing unit. Aggregation of costs will not be required if the costs and benefits of the code change accrue exclusively to the building owner or occupant. If, however, costs and/or benefits accrue to third parties or to society (as might be the case code changes addressing natural disaster mitigation, e.g. “seismic design” or “impact protection of glazed openings” and therefore depend on the number of housing units built to the code change, then the costs will have to be aggregated. There may be other analytical reasons to aggregate the costs.

<u>Costs per Housing Unit</u>

The costs of implementing the design and construction implications of the code change, identified in step 2, must be noted. The following cost elements per housing unit (representative type as discussed in step 2) must be considered in the analysis:

- Net hard first costs of construction
- Net soft first costs of design and construction
- Life cycle costs of operation and maintenance.

Net hard first costs of construction: Hard first costs are the expenditures on labor, material, and equipment required for the construction of the unit. Net hard first costs are those hard costs attributable to the added cost of construction of the code change implication minus the cost reductions that may be attributable to implementation of the code change, as described in step 2. These costs should include all builder and subcontractor markups.

A Suggested Methodology for Estimating the Cost Impact of Changes to the Model Building Codes, HUD, August 1994, lists the more common alternatives approaches to deriving estimates of hard first costs:

- Observing the actual construction of buildings
- Using a professional cost estimator
- Using estimation manuals, such as the *MEANS Residential Cost Data* manual.

While some of these costs of labor, material, and equipment may be absorbed by product manufacturers, subcontractors, builders, or others in the supply chain, and not be completely passed on to homebuyers or renters in the form of increased cost of housing, *Housing Impact Analysis*, HUD, January 2006, suggests several key simplifying assumption that can be used in preparing preliminary Housing Impact Analyses (HIA), among which the following are used here:

> “Key simplifying assumptions that can be used in preparing the preliminary HIA are:
>
> - all costs imposed by the regulation on intermediaries (such as product manufacturers, distributors, developers and trade contractors) are marked up and passed through to the ultimate consumer of housing (home buyer, homeowner or renter),
> - for owner-occupied units, regulatory costs financed through a mortgage or other loan are treated as incurring costs in full the year the borrowing takes place, without regard to amortization or tax benefits,

> - for rental units, costs are counted when they are incurred by the building owner, even though they might be passed through to the tenant and recovered over a period of time…
>
> The purpose of these simplifying assumptions is to make the preliminary analysis much more straightforward, and to defer more complex questions about impact to an in-depth HIA…Some of the simplifications, such as immediate 100 percent pass-through, appear to represent a "worst case" approach for impact on housing consumers, although there is no claim that this method will always overstate impact."

Net soft first costs of design and construction: Soft first costs include the cost of design and engineering to develop the method of compliance with the code change, the cost of testing to demonstrate compliance, and the cost of delays for certification, code approval, and inspection. While these costs can be estimated per housing unit, they are likely to be aggregated over a number of housing units, and must therefore be apportioned per housing unit.

Life cycle costs of operation and maintenance: Life cycle costs of operation and maintenance include both costs that occur annually over the life of the building and repair and replacement costs that occur at one or more points in time over the life of the building. "Kitchen ventilation rates" is a code change that may entail annual energy cost and annual, or less frequent, maintenance costs. "Residential sprinklers" is a code change that may entail periodic future maintenance costs. These energy and maintenance costs may be derived from various industry sources. Energy costs may be derived from *Residential Energy Consumption Survey*, U.S. Department of Energy. Maintenance costs for commercial, industrial, public & educational, medical, and residential (apartments and motels) are reported in *The Whitestone Building Maintenance And Repair Cost Reference*, Whitestone Research, which may be used as a starting point for estimating housing maintenance costs.

"Impact protection of glazed openings" is a code change that may entail future replacement costs because some methods of impact protection laminated glass will perform its protective function but will shatter, requiring replacement. The probability that a hurricane of a defined severity will occur in any given year may be derived from hurricane research and from natural disaster models such as FEMA's HAZUS-MH.

These costs should initially be estimated for each future year in which they are expected to occur. When used in the cost analysis in combination with first costs they must be discounted to their present value, using appropriate discount rates. Methodologies for doing this can be found in the following ASTM standard E 917, *Practice for Measuring Life-Cycle Costs of Buildings and Building Systems* and ASTM adjunct *Discount Factor Tables*.

Aggregated Costs

The two main reasons to aggregate the costs of code changes are: and therefore depend on the number of housing units built to the code change:

- When the code change permits various compliance alternatives (e.g., the three alternatives for complying with "impact protection of glazed openings).
- When third party or societal benefits are a function of the quantity of housing units performing in accordance with the code change in question (e.g., the number of lives saved and injuries reduced in an earthquake as the result of "seismic design).

For the first case, information must be provided on the percentage of new houses using each of the compliance alternatives. This can be developed based on observation of construction sites, review of building permit application, industry sources. Absent these sources of information, estimates should be assumed and so stated.

For both cases, the per-unit costs should be expanded into an estimate of the impact on costs for all units of the affected types. This is further discusses in *A Suggested Methodology for Estimating the Cost Impact of Changes to the Model Building* Codes, HUD, August 1994:

> "To accomplish this, the analyst must have access to or develop estimates of the number of each type of units expected to be constructed during the base year. For each representative type, the analyst simply multiplies the number of expected starts by the cost impact…
>
> If the representative type is the sole proxy for some major category of housing, projections on the number of units to be constructed during the coming year may be readily available…
>
> When a representative type is a surrogate for some smaller subset of housing, the analyst will likely need to derive projections for the representative type by using additional information and/or by formulating assumptions.
>
> Suppose that an analyst wants to develop aggregate estimates of the cost-impact of ["seismic design"] on low-rise multifamily housing slated for construction in areas where effective peak velocity-related rate of acceleration is greater than or equal to 0.05 but less than 0.10. In such a case, the analyst would probably select a representative type for low-rise multifamily buildings with a seismic load-resisting system fabricated of wood-frame construction and another based on an entirely masonry constructed system, both to be constructed in an area with the above described seismicity. In the likely event that the analyst does not have access to projections for low-rise multifamily buildings disaggregated by framing type and seismicity, he/she may be able to use statistical analysis to develop such projections by extending more general projections.
>
> …if the analyst has access to, or has developed projections of the number of buildings to be constructed, he/she must derive the percent of low-rise multifamily buildings built in the appropriate seismic regions as well as the percent of those buildings with each type of seismic load-resisting frames noted above. Estimates of these proportions can be derived through statistical analysis of the available historical data on the characteristics of residential construction and from an examination of appropriate maps delineating areas by seismicity… By superimposing results of the statistical analysis on the more general projections, the analyst will be able to derive projections for the number of low-rise multifamily buildings with the two specified framing systems in the affected area. The projected number of each representative type is then multiplied by its per unit cost impact and the results summed to derive an estimate of the potential cost impact on all affected units in the base year… The details of the entire statistical analysis and other procedures used to develop the aggregate-level estimates should be documented.
>
> The credibility of the results depends greatly on the quality and quantity of the statistical data used to produce the aggregate estimates. Nonetheless, budgetary constraints may preclude detailed statistical analysis. Further, data of sufficient quality and quantity may not exist for the building type and geographic region that need to be studied. In such instances, the analyst may be forced to make certain assumptions about the available data. The analyst should be careful to document his/her assumptions. In addition, the analyst should examine the influence of suspect statistics through sensitivity analysis."

The report lists the following sources for housing forecast data:

- *Building & Construction Market Forecast,* Cahners Publishing Company, Division of Reed Publishing Inc.

- *Forecast of Housing Activity,* National Association of Home Builders.
- *U.S. Industrial Outlook,* U.S. Department of Commerce. This document is no longer published by the Department of Commerce, and has been supplanted by the *U.S. Industry & Trade Outlook.*

A more recent source is McGraw-Hill Construction. Sources for historic housing data are listed earlier.

In some cases it may be necessary to further extend the aggregated costs beyond the base year to some specified number of subsequent years.

As previously, Step 3 concludes with examples of the performance of a cost analysis for "Continuous Structural Panel Sheathing" and "Sprinklers in the IRC." Each example addresses a series of questions related to the particular code change:

- Continuous Structural Panel Sheathing
  - What is the matrix of parameters (study matrix) for the evaluation of cost impacts?
  - What percentage of the housing starts is reflected by various combinations of parameters?
  - What are the hard cost impacts and how should they be evaluated?
  - What are the soft first cost impacts related to design and construction?
  - What are the life cycle cost impacts?
- Sprinklers in the IRC
  - What are the net hard first costs of construction for a residential sprinkler system?
  - What are the net soft first costs of construction for a residential sprinkler system?
  - What are the life cycle costs of operation and maintenance of a residential sprinkler system?
  - What are the cost savings of a residential sprinkler system?
  - What are aggregated costs nationally?

Step 3 Example: Continuous Structural Panel Sheathing

In Step 2 of the Methodology, the implications of this code change and representative house types were identified and discussed. In Step 3, information from Step 2 is used to answer the following questions and perform a cost analysis of the impacts of the code change.

- What is the matrix of parameters (study matrix) for the evaluation of cost impacts?
- What percentage of the housing starts is reflected by various combinations of parameters in the study matrix?
- What are the hard cost impacts (differences between baseline vs. new code) and how should they be evaluated?
- What are the soft first cost impacts related to design and construction?
- What are the life cycle cost impacts?

What is the matrix of parameters (study matrix) for the evaluation of cost impacts?

Based on discussions in Step 2 for this code change example, "Step 3, Continuous Structural Panel Sheathing, Table 1" provides a preliminary study matrix for the purpose of guiding the required cost analysis. The table entries (cells) represent combinations of relevant regional conditions (hazard and climate parameters) and representative house plans as identified and discussed in Step 2. Each cell shown with a '$XXX' entry will require an estimate of the difference in hard and soft first costs and life-cycle costs between the "all walls" requirement for continuous sheathing and the prior particular wall requirements, as determined in this step of the Methodology. This study matrix constitutes a template or work plan for evaluating the code change and the cost data from this step will be applied to conduct the cost-benefit analysis in Step 5 following the same format. Table 1 is considered preliminary because it may change as the study progresses to capture conditions that may not have been foreseen in previous steps.

Step 3, Continuous Structural Panel Sheathing, Table 1. Example Study Matrix for Cost Analysis of Continuous Structural Panel Sheathing Code Change

Example Locations	Regional Conditions			House Plan 1	House Plan 2	House Type 3
	Wind Hazard Level	Seismic Hazard Level	Climate (heating) Zone	Typical 1-story affordable	Typical 2-story production	Example Town-house Plan
Typical Conditions (low hazard, excluding special conditions below)						
Southern U.S.	Low	Low	Low	$ XXX	$ XXX	$ XXX
Middle U.S.	Low	Low	Mod	$ XXX	$ XXX	$ XXX
Northern U.S.	Low	Low	High	$ XXX	$ XXX	$ XXX
Special Conditions (moderate to high wind or seismic conditions)						
Charleston, SC Area	Mod to High	Mod to High	Low	$ XXX	$ XXX	$ XXX
New Madrid Seismic Region (Memphis / St. Louis)	Low	Mod to High	Mod	$ XXX	$ XXX	$ XXX
Western U.S.	Low	High	Low to Mod	$ XXX	$ XXX	$ XXX
Gulf / Atlantic Coast	High	Low	Low to Mod	$ XXX	$ XXX	$ XXX

For the purpose of evaluating cost impacts to the selected representative house plans, some added specificity is needed for Table 1. For example, wind hazard levels need to be defined in terms design wind speeds such that the specific code requirements under consideration can be applied (e.g., Low = 90 mph basic wind speed). The representative wind speed categories must also represent the scope limitations of the IRC (i.e., less than 110 mph) and, thus, the applicability limits of the code change under consideration. Similarly seismic hazard levels and climate zones must be related to specific parameters used in the building code to select or determine applicable construction requirements.

Each cell of the table for which a cost impact estimate is needed may be further sub-divided into various options or alternatives that comply with the code. For example, four different means of complying with the energy code may result in different impacts as a consequence of this code change item (see discussion in Step 2). Furthermore, wall constructions meeting the baseline code (prior to the code change) may vary by hazard region or representative house type.

Finally, the selected representative house plans #1 and #2 in Table 1 only address single family detached housing reflective of affordable and starter-level (production home) housing markets. If custom and luxury housing markets are to be captured in the analysis, additional representative house types must be considered. Similarly, representative house plan #3 in Table 1 only represents a sample of one townhouse design. If impacts to townhouse and duplex dwellings are considered to be important, the selection of additional representative attached dwelling types may be necessary. Apartments and other low-rise forms of residential construction are not affected by this code change item and they must be designed in accordance with the International Building Code engineering provisions, which do not include a prescriptive continuous sheathing bracing approach similar to that found in the IRC.

What percentage of the housing starts is reflected by various combinations of parameters?

Each one of the cells in Table 1 must be associated with a frequency of use based on estimated frequency distributions for each of the parameters defining the study matrix. For example, if 50% of housing starts occur in a ‘low-low-low’ (wind-seismic-climate) regional condition and ‘House Plan 2’ represents 50% of the housing starts in that region, then the frequency of use for this cell of the table is 0.5 x 0.5 x 100% = 25% of housing starts. These frequency distributions are necessary to aggregate findings to apply at the level of the housing population and not just the specific house plans analyzed. The credibility of this important step in the analysis will depend on how well the representative types actually represent the housing population and to what degree the frequency distributions for the various study parameters can be justified by data on housing characteristics and housing starts. Thus, it may be necessary to conduct sensitivity studies based on uncertainty in assigned frequencies for each representative plan. The process of assigning frequencies to each condition in the study matrix also will identify which conditions represent the greatest expected impact of the code change in terms of its potential effect on specific categories of housing starts. For example, in Step 2 it was mentioned that the code change is likely to have the greatest impact on houses in low to moderate wind and seismic hazard conditions and these conditions will likely represent the majority of housing starts. Thus, it may be possible to narrow the focus of the study to specific conditions and still gain useful results.

What are the hard cost impacts and how should they be evaluated?

For this code change item, normal procedures for estimating hard first costs of construction may be employed to arrive at a comparative or relative cost impact dollar value for each cell in Table 1. Various construction cost estimation tools are available and appropriate for this task (e.g., Means Residential Construction Cost Data). For special cases, a survey of current material prices and estimator judgment may be required to supplement the analysis.

What are the soft first cost impacts related to design and construction?

This code change item entails soft first costs, which must be considered along with hard first costs discussed above. For any new building plan, the costs of complying with the baseline and changed codes can be considered equivalent. Both will require a similar application of prescriptive bracing provisions found in the building code. However, significant “change-over” costs can be incurred for plans that are used repetitively due to the code change item. For example, any house plan under the prior code that was not continuously sheathed on all walls and which contains at least one wall line that required continuous structural panel sheathing will require a plan re-design.

Large national builders and standard blueprint services utilize “master plans” that serve as models for use in many regional markets. According to an undisclosed source, one large national home builder incurred re-design costs of approximately $250,000 to “change-over” a number of model house plans as a result of this code change item. However, it is possible that other factors will contribute to plan re-design decisions that cannot be attributed simply to the code change under consideration (e.g., material price fluctuations, ability to accommodate owner-specified plan changes or options, impact of local/state amendments related or unrelated to the code change, nature of enforcement of wall bracing provisions in localities where the builder is offering product, etc.).

Data to assess soft first costs must rely on information related to professional service fees and should be supplemented by a survey of current regional fees for relevant design services. The framework for providing such services and the fees may vary widely depending on builder size or regional market factors (e.g., building department plan and permitting requirements). In summary, this code change item has soft first cost implications that require further study for quantification.

What are the life cycle cost impacts?

Step 3 Example: “Continuous Structural Panel Sheathing”

Operation and maintenance life cycle costs are also important to consider. However, little data exists in regard to maintenance costs specifically related to different wall bracing methods that may be internal to the walls and structure of a light-frame wood dwelling. Life cycle costs in this situation may be based on estimates of the service life or useful life of a dwelling and this issue may be very controversial without clear guidelines or data upon which to base life-cycle cost assumptions, especially in regard to differences between one bracing method and another. On the other hand, life cycle costs in regard to the indirect energy efficiency implications of this code change item should be considered. This will require the additional expertise of an energy analyst and related tools for performing such an analysis and is beyond the scope of this discussion.

Known models to estimate operation and maintenance life-cycle costs (aside from seismic or wind damage, of which seismic damage is addressed under step 5) lack the definition necessary to carefully distinguish between residential bracing methods in terms of whole-structure performance, particularly when numerous components (structural and non-structural) interact in a major way. This is an area where significant judgment, without scientifically-based premises, can easily enter into a model and its results and careful documentation and disclosure of modeling assumptions are necessary. Finally, life-cycle costs related to seismic and wind structural system performance differences require a separate analysis addressed later (for seismic performance) in step 5.

Step 3 Example: Sprinklers in the IRC

The cost analysis of the installation of residential sprinklers requires two levels of analysis: costs per housing unit, and aggregated cost over some quantity of units. The cost analysis begins with costs per housing unit. Aggregation of costs will not be required if the costs and benefits accrue exclusively to the building owner or occupant. If, however, costs and/or benefits accrue to third parties or to society and therefore depend on the number of housing units built to the code change, then the costs will have to be aggregated. There may be other analytical reasons to aggregate the costs.

The costs of implementing the design and construction implications of the residential sprinklers per housing unit must be considered. The following cost elements per housing unit must be covered in the analysis:

- What are the net hard first costs of construction for a residential sprinkler system?
- What are the net soft first costs of construction for a residential sprinkler system
- What are the life cycle costs of operation and maintenance of a residential sprinkler system?
- What are the cost savings of a residential sprinkler system?

What are the net hard first costs of construction for a residential sprinkler system?

Hard first costs are the expenditures on labor, material, and equipment required for the construction of the unit. Net hard first costs are those hard costs attributable to the added cost of residential sprinklers and the cost reductions that may be attributable to implementation residential sprinklers.

Specifically for a residential sprinkler system, the net hard first costs include the water supply, pipe installation, and installation inspection and testing. Builder and subcontractor markups must also be considered. The cost of system installation also needs to be considered. The cost of pipe, fittings, and labor all go into the overall cost of sprinkler system installation. Initial testing of the system must be conducted as well. According to the Prince George's County report (*Residential Sprinklers: One Community's Experience Twelve Years After Mandatory Implementation*, Ronald Jon Siarnicki, 2001), in new construction, a residential sprinkler system adds 1-2% of the total cost of construction. The report *Residential Fire Sprinklers for Life Safety: An Economic and Insurance Perspective*, Buddy Dewar, NFSA, 2001 also states that the addition of residential sprinkler systems increases the cost of construction by 1%.

NISTIR 7277, published in December 2005, provides an economic analysis of residential sprinkler systems. Four different sprinkler alternatives designed for each of the representative housing types (colonial, townhouse, ranch) were analyzed in the report. System A was a multipurpose network. These systems are more complicated than stand-alone systems and require specialized training on the part of the designer. System B was one stand-alone network (not included in the following summary). Systems C and D were also stand-alone networks, reviewed both with and without backflow preventers (without backflow preventers not included in the following summary). The systems vary in design approaches. Note that the values in "Step 3, Sprinklers in the IRC, Table 1" include design costs but do not include the cost of markups or inspections.

		Colonial 3,338 sq. ft.	Townhouse 2,257 sq. ft.	Ranch 1,171 sq. ft.
(A) Multipurpose Network	Cost	1,419.78	1,301.38	601.16
	$/sq. ft.	0.43	0.58	0.51
(C) Stand-Alone w/BFP	Cost	1,881.27	1,830.00	1,434.08
	$/sq. ft.	0.56	0.81	1.22
(D) Stand-Alone w/BFP	Cost	2,284.19	1,956.43	1,147.62
	$/sq. ft.	0.68	0.87	0.98
Average Stand-Alone w/BFP	Cost	2,082.73	1,893.22	1,290.85
	$/sq. ft.	0.62	0.84	1.10
Average of three Systems (A) (C) (D)	$/sq. ft.	0.56	0.75	0.90

Step 3, Sprinklers in the IRC, Table 1. Summary of NISTIR 7277 Costs

The NISTIR cost estimates in the table can be summarized as follows:

- Average sprinkler cost for the 3,338 sq. ft. colonial: $0.56/sq. ft.
- Average sprinkler cost for the 2,257 sq. ft. townhouse: $0.75/sq. ft.

- Average sprinkler cost for the 1,171 sq. ft. ranch: $0.90/sq. ft.

According to the National Fire Sprinkler Association's (NFSA) website, "In a 1987 study, the National Association of Home Builders determined that the average cost of a residential sprinkler system was $1.31 per square foot." The National Association of Home Builders also states that the average single family detached home size is 2,330 sq. ft., which is approximately the size of the townhouse from the NISTIR report.

The installation cost will vary based upon regional difference in construction cost and the availability of contractors experienced in installing residential sprinkler systems. The Scottsdale data is based upon having a significant number of contractors experienced in the installation of NFPA 13D sprinkler systems. The report states that over the 10-year period, the cost of installing a residential sprinkler system dropped from $1.14/sq. ft. to $0.59/sq. ft., which is consistent with the NISTIR cost estimates.

The cost estimates given above vary from $0.43/sq. ft. to $1.31/sq. ft. These differences can partially be attributed to the availability of qualified and experienced contractors. It is difficult to determine the actual cost impact of a mandate. In one sense, it should increase the availability of contractors, thereby reducing cost. However, in the short term, the contractors would not be available which would likely lead to higher short term costs. Additionally, if sprinklers are mandated there is less of an incentive for contractors to be cost competitive.

For purposes of this analysis the baseline sprinkler costs per housing unit will be based on $1.31/sq. ft. (NFSA). Lower limit costs will be based the NISTIR costs per sq. ft. The upper limit is beyond the scope of this analysis, but would include systems in extreme climates, custom homes, and homes in rural areas.

In urban or suburban areas, water supply will not likely be a problem for residential sprinkler systems. The water for the sprinkler system can come from the domestic water supply provided to the house. In more rural communities, there may be weaker water supplies or wells may supply the domestic water for the homes. In these cases, a separate water tank may need to be provided to supply water for the sprinkler system, increasing the cost of the system. NBS-GCR-87-533, *Development of Cost Effective Techniques for Alleviating Water Supply Deficiencies in a Residential Sprinkler System*, estimated the cost of water supply tank to cost an additional $210 and a pump to cost $551 in 1987. Given inflation, the tank and pump would cost approximately $816.61 today. (http://inflationdata.com/inflation/Inflation_Rate/InflationCalculator.asp#results)
According to the National Fire Sprinkler Association, a stored water supply increases the cost of the system approximately $2,500. (http://www.nfsa.org/info/fyi/resqck.html) As with the cost of the sprinkler system, the increased demand has resulted in some reduction in the cost due to increased availability of equipment. The current cost for a stored water supply is likely to be bounded by these two figures.

What are the net soft first costs of construction for a residential sprinkler system?

Soft first costs include the cost of design and engineering of the sprinkler system, the cost of testing to demonstrate code compliance, and the cost of delays for certification, code approval, and inspection. While these costs can be estimated per housing unit, they are likely to be aggregated over a number of housing units, and must therefore be apportioned per housing unit.

For a residential sprinkler system, the cost of the system design, AHJ acceptance, permit fees, and additional construction time must be considered.

The cost of the system design will depend on whether a home is a custom design or part of a community with a limited number of floor plans. For custom homes, the cost of a residential sprinkler system design will be significantly higher than that of a community as the design will be unique to the house. For communities of homes with set floor plans, the cost of system design per residence will be lower due to the single system design being applicable to multiple homes. The NISTIR report includes the design costs in the overall cost per square footage estimate. For other than custom housing, design costs reported range from $160 to $400 per system. These costs would be much higher for custom housing designs.

Once the system has been designed, it must be accepted by the authority having jurisdiction (AHJ). A fee may be associated with this approval and an additional permit may be required for the sprinkler system. For example, in the city of Redmond, Washington, the cost for fire protection plan review is $116 for both new home construction and additions. (http://www.ci.redmond.wa.us/insidecityhall/permitting/pdf/feeschedules/resfees2006.pdf) In Prince George's County, Maryland, the minimum permit fee is $75 (http://www.co.pg.md.us/Government/AgencyIndex/DER/PRD/prd-faq.asp?nivel=foldmenu(9)). In Anne Arundel County, Maryland, the cost is $55 for fire suppression system permits. (http://www.co.anne-arundel.md.us/IP/PAC/PermitFees.cfm).

The installation of a residential sprinkler system may also increase the construction time. While the sprinkler system can be installed simultaneously with other construction of the home, it is possible that coordinating the installation, acceptance, and testing of the system could result in additional construction time.

What are the life cycle costs of operation and maintenance of a residential sprinkler system?

Many different costs go into operating and maintaining a residential sprinkler system. Maintenance and repair of the system are two major cost items for the system. Typical costs for maintenance and repair of a system would be related to the backflow preventer. The homeowner can perform the majority of other maintenance. According to the NISTIR report, typical backflow preventer inspection costs range from $100 to $200.

Although rare, there is the potential for the recall of system components. Should this happen, the homeowner would have to pay for replacement system components. In some jurisdictions, they may also have to pay to have the system reevaluated for permitting purposes.

Having a sprinkler system in a home may result in higher taxes as the assessed value of the home increases. The sprinkler system adds to the value of the home by protecting the contents which could mean a greater tax payment for the owner.

It is also possible that the water supply may decrease over time. This change would potentially result in the required addition of a water tank or pump, adding a cost to the system.

What are the cost savings of a residential sprinkler system?

On the cost reduction side, a homeowner may have a reduced insurance premium for installing a sprinkler system. The increased safety of having a residential sprinkler system can lower insurance premium payments. In the Scottsdale Report, it was found that insurance companies offered an average of a 10% discount for having an approved residential sprinkler system.

The cost reduction due to a reduction in dwelling unit separation from 1-hour to ½-hour mentioned in Step 2 would not likely result in a significant cost savings. Current code requirements would require an NFPA 13 system, which are more expensive than NFPA 13D systems. Also, as previously mentioned, acoustic requirements must still be met so the wall construction may not be able to be significantly reduced.

What are aggregated costs nationally?

Sprinkler costs per housing unit are an adequate measure for benefit cost analysis for benefits that accrue to the homeowner, such as reduced possibility of death and injuries and reduced fire damage. Aggregating the annual residential sprinkler costs for all new residential construction may be necessary if some of the benefits of residential sprinklers are accrued nationally. An example of such benefits is a reduction in firefighter deaths and injuries. Applying the average per house cost to the number of new housing units from the American Housing survey can provide a first estimate of aggregated costs. A more refined estimate could be derived from an assumed distribution of different categories of housing, such as the three mentioned in the preceding step and those used in the NISTIR report.

4. “Step 4: Identify Benefit Distribution and Metrics”

Beneficiaries and Metrics

A comprehensive list of beneficiaries of the code change should be developed. These may include:

- Building owner
- Occupant
- Third parties (designers, product manufacturers, code officials, fire departments, health departments, insurers, lenders, and others)
- Society-at-large

It should be noted that the beneficiaries of some types of code changes represent redistribution, or “transfer payments”. For example, a code change that mandated use of plastic in lieu of glass would benefit one industry at the expense of another. From the perspective of an analysis of costs and benefits of code changes, such benefits may not represent net benefits, and need not be considered.

Once the comprehensive list of beneficiaries is developed, it is necessary to identify the metrics for measuring the benefits to each beneficiary. These metrics may in themselves be quite controversial, and the subject of disagreement between code change proponents and opponents. However, by listing the metrics in the most comprehensive way possible, such disagreements might be brought out in the open and become the subject of further discussion and analysis.

Following are four cases of the benefit distribution and metrics for code changes:

- Case #1: Stair geometry

Beneficiaries	Metrics
Occupants	Reduced fall injuries
Third party (visitors)	Reduced fall injuries
Third party (health service providers)	Reduced number of emergency cases of falls
Third party (insurers)	Reduced numbers and $ amounts of claims
Society-at-large	Improved public health

- Case #2: Rewrite of Residential Energy Code

Beneficiaries	Metrics
Owners/occupants	Reduced energy costs (due to more widespread enforcement)
Third party (public utilities)	More stable and predictable energy demand
Society-at-large	Reduced energy use (due to more widespread enforcement)

- Case #3: Residential sprinklers

Beneficiaries	Metrics
Occupants	Reduced fire losses, reduced insurance costs, reduced probability of death or injury in fire
Third party (visitors)	Reduced probability of death or injury in fire
Third party (health service providers)	Reduced number of emergency cases of fire

	injuries
Third party (insurers)	Reduced numbers and amounts of claims
Third party (fire services)	Reduced use of emergency manpower and equipment
Society-at-large	Improved public health

- Case #4: Seismic design—panel sheathing

Beneficiaries	Metrics
Occupants	Reduced seismic losses, reduced insurance costs, reduced probability of death or injury in earthquake
Third party (visitors)	Reduced probability of death or injury in earthquake
Third party (health service providers)	Reduced number of emergency cases of earthquake injuries
Third party (insurers)	Reduced numbers and amounts of claims
Third party (emergency services)	Reduced use of emergency manpower and equipment
Society-at-large	Improved public health

The benefit distribution and metrics of proposed code changes are among the most controversial issues surrounding code changes for some stakeholders. The specific code changes to be used in elaborating and demonstrating this methodology will include changes for which stakeholders strongly agreed as well as changes for which stakeholders strongly disagreed that the respective changes had identifiable benefit impacts and metrics.

Costs of Deaths and Injuries

The economic value of avoiding future deaths and injuries can often make the difference between a risk mitigation measure that is cost effective and one that is not. A congressionally mandated benefit-cost analysis of FEMA hazard mitigation grants published in 2005 by the National Institute of Building Sciences (NIBS) found that the average benefit-cost ratio for grants to mitigate seismic risk was approximately 1.5, but would have been less than 1.0 if it ignored avoided statistically predicted deaths and injuries. The cost-effectiveness of hurricane risk reduction similarly depended on including the benefit of reduced deaths and injuries.

The question of quantification of the costs of deaths and injuries, or the benefits avoidance of deaths and injuries attributable to regulations of various kinds, has been addressed in recent years by several federal agencies responsible for such regulations in specific areas of the national economy, including the Consumer Products Safety Commission (CPSC), the Centers for Disease Control and Prevention (CDC), the Department of Transportation (DOT), the Environmental Protection Agency (EPA), and the Office of Management and Budget (OMB). These and other agencies are required by Executive Order 12866, “Regulatory Planning and Review”, issued by President Clinton in 1993, to perform economic analysis of economically significant regulations. Three categories of death and injury costs have been identified in all of these approaches:

- Lifetime medical costs, which are incurred by the injured (fatal and non-fatal) and by medical insurers

- Lifetime productivity losses, which are incurred by the injured (fatal and non-fatal)
- Quality of life costs (pain and suffering), which are incurred by the injured (fatal and non-fatal).

The relative proportion of each of these categories varies by the cause of injury and by the age distribution of the injured. For example, the CPSC reported an estimate of the national costs of nonfatal stair-related injuries in 1995 (reported in 1997 dollars), as follows:

- Medical costs: $4.7 billion (9.5%)
- Productivity losses: $7.1 billion (14.0%)
- Quality of life costs: $38.1 billion (76.5%).

The first two categories of costs are based on a variety of economic analyses. It should be noted that the CPSC has monetized the third category, quality of life costs, which is reportedly based on analysis of jury awards in damage claims. Monetizing all the benefits enables a simple benefit-cost analysis to be performed. Since 2003 the federal government has argued against the monetization of quality of life costs. The reason is found in the book published recently by the Institute of Medicine, *Valuing Health for Regulatory Cost-Effectiveness Analysis*, Wilhelmine Miller, Lisa A. Robinson, and Robert S. Lawrence, Editors, 2006. The authors argue against monetizing quality of life for use in benefit-cost analyses, and in support of using other metrics in cost-effectiveness analyses that report the ratio of dollars to these other measures of quality of life. Health-adjusted life years (HALYs) are presented as population health measures permitting morbidity and mortality to be simultaneously described within a single number. Several HALY metrics have been used in the United States and internationally to analyze regulations that impact health, including quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). It is beyond the scope of this guide to discuss HALYs in any detail, and the interested reader is referred to the Institute of Medicine publication. At this time it is not known whether HALY metrics have been developed that are applicable to accidental injuries.

For the first two categories (medical costs and productivity losses), the most current source of information on the costs of deaths and injuries in the United States is found in *The Incidence and Economic Burden of Injuries in the United States*, Eric A. Finkelstein, Phaedra S. Corso, Ted R Miller, and Associates, Oxford University Press, 2006. The figures reported are based on CDC injury statistics (rather than the CPSC statistics reported above), and include information on fatalities, hospitalization, and treatment without hospitalization including, but not limited to, emergency room treatment. These figures have all been peer-reviewed and are considered the best available.

The CDC data are for the year 2000. Lifetime medical costs and lifetime productivity losses apply a 3% discount rate to future costs, in accordance with OMB direction. They are presented and analyzed for nine specific categories of injury mechanism, as follows:

- Motor vehicle/other road user
- Falls
- Struck by/against
- Cut/pierce
- Fire/burn
- Poisoning

- Drowning/submersion
- Firearm/gunshot
- Other.

It should be noted that only three, or possibly four of these categories involve injury mechanisms that may be affected by the regulation of housing:

- Falls (through the regulation of stairs, guardrails, and similar hazardous locations)
- Cut/pierce (through the regulation of glazing and similar sharp edges)
- Fire/burn (through the regulation of fire safety)
- Drowning/submersion (possibly, through the regulation of residential swimming pools)

It should be noted that injuries and deaths from natural disaster are not accounted for, if none occurred in 2000, and if they did, they are probably included under the drowning/submersion and other categories.

The CDC data is summarized in the following table:

		All mechanisms	Falls	Cut/pierce	Fire/burn	Drowning/ submersion
Fatal & non-fatal	Incidence	50,127,098	11,566,742	4,124,085	774,376	10,083
	Medical costs ($M)	80,248	26,892	3,662	1,345	95
	Productivity losses ($M)	326,042	54,028	12,664	6,202	5,215
	Total costs ($M)	406,289	80,920	16,326	7,546	5,310
Fatalities	Incidence	149,075	14,052	2,293	3,922	4,168
	Medical costs ($M)	1,113	232	11	66	13
	Productivity losses ($M)	142,042	4,524	2,659	2,985	4,609
	Total costs ($M)	143,154	4,756	2,670	3,051	4,622

It should be noted that the total costs per incident varies dramatically as a function of injury mechanism as illustrated in the following table. Of particular note is that the total cost per fatality, which may be considered the economic value of human life lost, varies from $338,457 to $1,164,413. These variances are attributable to the age distribution of the injured as well as the type of injury.

	All mechanisms	Falls	Cut/pierce	Fire/burn	Drowning/ submersion
Fatal & nonfatal ($)	8,105	6,996	3,959	9,745	526,629
Fatalities ($)	960,282	338,457	1,164,413	777,919	1,108,925

The application of these data to the analysis of the 7-11 stair code change is discussed below.

A congressionally mandated benefit-cost analysis of FEMA hazard mitigation grants published in 2005 by the National Institute of Building Sciences (NIBS) used different sources of information from the US Department of Transportation to estimate the costs of deaths and injuries, and included the monetization of quality of life. The following discussion is based on information from the author of the NIBS report.

DOT assigned dollar values to statistical injuries avoided, based on a 1991 study by the Urban Institute, *The Costs of Highway Crashes, Final Report*. (The phrase "statistical injuries" is used here to indicate that these are not injuries to particular people in an immediate situation, but rather to unknown people at an unknown future date.) These values are used to estimate the benefits of regulatory action and risk remediation, and have been used by the Federal Aviation Administration (FAA 1998) and Federal Highway Administration (FHWA 1994). The Urban Institute figures are comprehensive costs for statistical injuries, reflecting pain and lost quality of life, medical and legal costs, lost earnings, lost household production, etc. The comprehensive cost is dominated by pain and lost quality of life, which represent 60-80% of the total. Lost wages represent 5-18%, while medical costs represent a relatively small portion of the comprehensive cost, typically 5-6%.

The Urban Institute's comprehensive costs were not limited to highway safety. They were averaged from 49 distinct studies of the value of small changes in safety, of which only 11 had to do with automobiles. They included 30 studies of the additional wages that people demand to accept elevated safety risks; five of the market prices for products that provide additional safety (e.g., safer cars, smoke detectors, houses in less polluted areas); six of the cost of safety behavior (e.g., roadway speed choice and decisions about smoking); and eight surveys (e.g., about auto safety and fire safety).

The 49 studies produced fairly consistent values. They ranged from $1.0 M to $3.6 million for the value of a statistical fatality avoided. Their average was $2.2 million; their standard deviation, $0.6 million. The Urban Institute authors addressed the value of nonfatal injuries by multiplying the value of fatal risk reduction by the ratio of the years of lost life in a fatality versus the years of functional capacity at risk (meaning pain or impaired mobility, cognition, self care, and other measure of quality of life).

These values are not arbitrary figures selected by a government agency or contractor. Nor are they values that people would demand to receive a known injury ("how much money would you take to receive a minor scalp laceration right now?"). Rather they are values of such an injury implied by what people have paid or demand to be paid for slight increases or decreases in life safety. For example, if people have been observed to pay $100 to decrease by 1 in 10,000 their chance of death from some particular peril, the implied value of avoiding one statistical fatality would be $100/0.0001, or $1 million.

As noted above, DOT adopted these values; they are shown in "Step 4, Table 1." They are expressed in terms of the Abbreviated Injury Severity (AIS) code, a classification system developed by the Association for the Advancement of Automotive Medicine in 1990 and since updated. The AIS scale, also used in the CDC report discussed above, is an anatomical scoring system, in that it reflects the nature of the injuries and resulting threat to life. It was originally developed for use in quantifying automobile-related injuries, but has been broadened to include other types and causes of injuries. The AIS dictionary currently lists approximately 1,300 injuries, each with a distinct 7-digit numerical injury identifier. The table shows a few example injuries from each AIS level.

AIS level		Sample injuries (drawn from AAAM 2001)	Comprehensive cost (FHWA 1994)
1	Minor	Shoulder sprain, minor scalp laceration, scalp contusion	$5,000
2	Moderate	Knee sprain; scalp laceration > 10 cm long and into subcutaneous tissue; head injury, unconscious < 1 hr	$40,000
3	Serious	Femur fracture, open, displaced, or comminuted; head injury, 1-6 hr unconsciousness; scalp laceration, blood loss > 20% by volume	$150,000
4	Severe	Carotid artery laceration, blood loss > 20% by volume; Lung laceration, with blood loss > 20% by volume	$490,000
5	Critical	Heart laceration, perforation; cervical spine cord laceration	$1,980,000
6	Fatal	Injuries that immediately or ultimately result in death.	$2,600,000

Step 4, Table 1. Federal values of statistical deaths and injuries avoided, in 1994 US$

The NIBS analysis applied these costs to estimates of the number of injuries and deaths avoided by the various FEMA-funded hazard mitigation grants. No attempt was made in that study to model the age distribution (or any other demographic characteristics) of victims whose deaths and injuries would be avoided by the mitigation efforts. It is unclear whether such distinctions would have made any difference in the results of the NIBS study.

OMB in Circular A-4, 2003, provided the following guidance on discounting in cost-benefit analyses (as reported in Institute of Medicine, *Valuing Health for Regulatory Cost-Effectiveness Analysis*, 2006):

> "Present costs and benefits undiscounted and **discounted at both 3 and 7 percent**; may consider other rates…" (Emphasis added)

As noted above, the CDC used 3% to discount future medical costs and productivity losses.

A following example seeks to "identify benefit distribution and metrics" for the "7-11 Residential Stairs" code change proposal by answering eleven questions:

- What are the categories of benefits attributable to the 7-11 residential stair code change?
- Is there information that compares these categories between alternative stairs?
- What are potential benefits of reduced falls on stairs, to whom, and how are they measured?
- Are there alternative sources of information for computing stair injuries?
- Can 'residential' stair injuries be disaggregated from broader categories of stair injuries?
- What metric relates total residential stair injuries to stair geometry changes?
- How to compute the cost per residential stair of fall injuries?
- How to compute the annual cost of falls on new residential stairs?
- How should fall-related quality of life costs be measured?
- How are the benefits of injury reduction from stair falls to be measured?
- Are there other benefits of stair code changes, to whom, and how measured?

Step 4 Example: 7-11 Residential Stairs

“Step 4: Identify Benefit Distribution and Metrics” involves either the identification and evaluation of existing sources of information or the documentation of original research results directly related to the proposed 7-11 residential stair code change. Lacking references for specific forensic data related to injuries on stairs of varying configuration in residences, ‘benefit distribution and metrics’ of the proposed code change will need to be based solely upon existing information sources. As a result, the ‘fit’ between information needs and information sources is indirect and often only inferential.

For this proposed code change, limitations in the available information and apparent inconsistencies between otherwise credible information sources lead to high uncertainty, require compromise, and are open to wide interpretation—hence, the same data sources may be used to both support and oppose this particular proposal. These limitations in existing information sources may, in the end, be the determining factor in the acceptance or rejection of this particular proposal.

Regardless of limitations in information, an analysis of ‘benefit distribution and metrics’ for 7-11 residential stairs should involve asking and answering, as thoroughly as possible, a series of questions regarding the code change proposal:

- What are the categories of benefits attributable to the 7-11 residential stair code change?
- Is there information available that compares each of these categories between 7 ¾-10 and 7-11 stairs?
- What are potential benefits of injury reduction from accidental falls on stairs, to whom do they accrue, and how are they measured?
- Are there alternative sources of information for computing residential stair injuries? (How do they agree with the CPSC information? What do the CDC sources tell us about stair injuries?)
- Can information related to ‘residential’ stair injuries be disaggregated from broader categories of stair injuries? (The injury costs reported above are for all stair injuries. How can residential stair injuries be estimated?)
- What should the metric be that relates total residential stair injuries to stair geometry changes?
- How to compute the cost per residential stair of fall injuries?
- How to compute the annual cost of falls on new residential stairs?
- How should fall-related quality of life costs be measured?
- How are the benefits of injury reduction from stair falls to be measured?
- Considering the other two categories of potential benefits, improved non-injurious usability of stairs and improved aesthetics of stairs, to whom do they accrue, and how are they measured?

Each of these questions is answered separately in the following analysis of ‘benefit distribution and metrics’ for 7-11 residential stairs. It should be noted that these questions are illustrative for purposes of this demonstration analysis. Other analysts will come up with different questions likely to address similar issues.

What are the categories of benefits attributable to the 7-11 residential stair code change?

The current IRC residential stair requirement is a 7 ¾-inch maximum rise and a 10-inch minimum tread. The 7-11 code change would change these dimensions to 7-inches and 11-inches respectively. Three categories of benefits have been attributed to this code change:

- Reduction in injuries from accidental falls by stair users
- Improved non-injurious usability of stairs
- Improved aesthetics of stairs.

Is there information that compares each of these categories between alternative stairs?

There is no readily available data that directly makes such a comparison. Therefore, it is necessary to identify and draw conclusions from injury statistics kept by the Consumer Products Safety Commission (CPSC) and the Centers for Disease Control and Prevention (CDC) with respect to the first category of benefits (reduction in injuries) and from a body of research on stairs with respect to all three categories of benefits in order to proceed with this methodology.

What are potential benefits of reduced falls on stairs, to whom, and how are they measured?

In order to quantify the benefit of reduction in injuries one must first identify the costs of injuries, and then estimate the reduction in these costs attributable to the particular intervention, in this case the 7-11 residential stair requirement.

Step 4 Example: "7-11 Residential Stairs"

Three specific categories of injury costs were identified in support of the 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle. All three categories were measured in dollars:

- Medical costs, which are incurred by the injured and by medical insurers
- Productivity losses, which are incurred by the injured
- Quality of life costs (pain and suffering), which are incurred by the injured.

CPSC was the source for estimating these costs in support of the code change. The source for CPSC costs begins with incidence data for nonfatal fall injuries treated in hospital emergency rooms. Nationally, for 1995, total stair related nonfatal injury costs were estimated (using CPSC's Injury Cost Model) in each of these categories, in 1997 dollars, as follows:

- Medical costs: $4.7 billion
- Productivity losses: $7.1 billion
- Quality of life costs: $38.1 billion

To estimate these costs for the year 2000 they were increased to reflect a 2% annual growth in injuries and inflation at 3%, resulting in the following:

- Medical costs: $6.0 billion
- Productivity losses: $9.0 billion
- Quality of life costs: $48.4 billion.

It should be noted at this point that these costs are attributable to injuries from falls on all stairs, not just residential stairs.

<u>Are there alternative sources of information for computing stair injuries? (How do they agree with the CPSC information? What do the CDC sources tell us about stair injuries?)</u>

The CDC provides an alternative source of injury information. This is found in *The Incidence and Economic Burden of Injuries in the United States,* Eric A. Finkelstein, Phaedra S. Corso, Ted R Miller, and Associates, Oxford University Press, 2006. The figures reported are based on CDC injury statistics (rather than the CPSC statistics reported above), and include information on fatalities, hospitalization, and treatment without hospitalization including, but not limited to, emergency room treatment. These figures have all been peer-reviewed and are considered the best available. It should be noted that only medical costs and productivity losses are reported. The reason for excluding quality of life costs was discussed and is elaborated below

Unlike the CPSC, *The Incidence and Economic Burden of Injuries in the United States* does not report costs for stair-related injuries. These must be estimated from the reported costs of all fall injuries for the year 2000:

- Incidence of fall injuries (including fatalities): 11,566,742 (14,052 fall fatalities)
- Rate of fall injuries per 100,000: 4,185
- Total lifetime medical costs of fall injuries (incl. fatalities; 3% discount rate for future costs): $26,892 Million
- Total lifetime productivity losses of fall injuries (incl. fatalities; 3% discount rate for future costs): $54,028 Million

The costs per fall incident are:

- Total lifetime medical costs: $2,325
- Total lifetime productivity losses: $4,671

In order to identify costs of stair fall injuries it is necessary to use the ratio of the incidence of stair falls to all falls and apply it to the costs for all falls.

<u>Incidence of stair falls treated in emergency rooms</u>--CDC has reported a total of 922,486 nonfatal fall injuries treated in emergency departments related to stairs in 2004 (private communication, Judy Stevens, National Center for Injury Prevention & Control; the source of this information may be the CPSC data).

<u>Incidence of stair falls treated at all locations</u>-- *The Incidence and Economic Burden of Injuries in the United States* reports total lifetime medical costs of injuries and unit medical costs of injuries by treatment location, including, for non-hospitalized injuries,

emergency department, outpatient, and doctor's office (information from Appendix Tables 2.3 and 2.2, respectively, are used in the calculations below).

All Falls-Medical Costs and Incidence by Location						
		Fatal	Hospitalized	Emegency	Outpatient	Doctor's Office
A	Total Lifetime Medical Costs ($Million)	232	15,247	8,192	142	3,079
B	Unit Medical Costs ($)	$16,487	$17,842	$1,129	$979	$934
A/B	Incidence*	14,071	854,556	7,255,978	145,045	3,296,573
Stair Falls-Incidence by Location						
Incidence (based on ratio for ED Treated)		1,788	108,644	922,486**	18,440	419,109
Total Incidence		1,470,467				

* *Note: Table 1.2 from the referenced book reports the following incidence counts for all falls:*

Fatal: 14,052
Hospitalized: 854,589
Nonhospitalized: 10,698,101
TOTAL: 11,566,742

These numbers are slightly different from the number obtained by the ratio A/B. The difference, however, is insignificant. Table 1.2 does not break down the Nonhospitalized category, which was necessary in order to estimate the incidence of stair fall.

*** Note that this figure is reported for the year 2004, while all the rest are reported for 2000.*

Thus, the total incidence of stair falls is rounded to an estimate of 1,470,000. Applying the costs per fall incident reported above results in the following estimate:

- Total lifetime medical costs of stair-related fall injuries: $3,418 Million
- Total lifetime productivity losses of stair-related fall injuries: $6,866 Million.

This CDC-based total of about $10.3 billion (year 2000) is comparable to the CPSC $11.8 billion reported above for 1997 (and escalated to $15.0 billion for the year 2000). About one half of this difference is attributable to the difference between the CPSC's 2.5% discount rate, and the OMB-mandated 3% used by the CDC (over a 40 period). The other half of this difference may be attributable in part to the differences in computation of costs of injuries between the CDC and CPSC, and to escalation from 1997 to 2000 (the escalation rate reported above, resulting $15 billion seems incorrect). Some of the difference may also be attributable to disproportionately higher costs of stair-related fall injuries than of all other fall injuries. Determining the reasons for the discrepancy requires research beyond the scope of this guide. *It is recommended to use the CDC figures as the baseline estimate of the costs of stair-related injuries, and to increase it by 15% (approximating the 1997 CPSC costs) in the analysis of uncertainties of the benefit/cost analysis.*

Can 'residential' stair injuries be disaggregated from broader categories of stair injuries? (The injury costs reported above are for all stair injuries. How are residential stair injuries estimated?)

The CPSC reports nonfatal fall injuries treated in emergency departments related to stairs in six categories, which for the year 2004 constituted the following percentages of the total:

- (0) Unknown 20.0%
- (1) Home/Apt/Mobile 68.9%
- (2) School/Sports 3.0%
- (3) Street 0.6%
- (4) Other Property 7.4%
- (5) Farm 0.1%.

Using contemporary information such as this, and assuming that some of the "unknown" locations were actually residential, it was estimated with the 7-11 residential stair proposal in 2003 that residential stairs account for between two-thirds and 85% of all stair injuries.

This estimate may be on the high side in that category (1) includes apartment stairs, which may be common stairs (already required by the ICC to be 7-11 stairs), mobile home stairs that are not governed by the 7-11 code change, and outdoor stairs around the home. Therefore, a baseline estimate of 67% residential stairs, and a high and low estimate of 85% and 45% for uncertainty analysis should be used. This results in the following baseline estimate of total residential stair injury costs for the year 2000:

- Medical costs: $2,290 million
- Productivity losses: $4,600 million
- TOTAL: $6,890 million.

Yielding an upper and lower range for uncertainty analysis:

- Medical costs: *Upper,* $2,905 million; *Lower,* $1,538 million
- Productivity losses: *Upper,* $5,836 million; *Lower,* $3,090 million
- TOTAL: *Upper,* $8,741 million; *Lower,* $4,628 million.

<u>What metric relates total residential stair injuries to stair geometry changes?</u>

The cost that would be developed in Step 3 of this methodology, Perform Cost Analysis, would be the cost differential between a 7-11 stair and a 7 ¾-10 stair. This cost can be computed per new residential stair constructed (which accrues to the owner/occupant of the dwelling), and/or it could be aggregated to the annual cost of all new residential stairs.

As noted above, most of the potential benefits of changes in stair geometry accrue to the stair users (primarily the owner/occupant, although some residential stair users are visitors and strangers), while some portion of the potential benefit of reduced medical costs accrues to health insurers. The simplest metrics to use from the perspective of the owner/occupant are the cost and benefits per residential stair. From the perspective of the health insurers it would be aggregated to a total annual national cost and benefit.

<u>How to compute the cost per residential stair of fall injuries?</u>

The 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle was accompanied by a calculation of the injury costs per residential stair, which computed the residential stair injury cost per US resident, assumed 3.5 residents per home stair, and multiplied the cost per resident by 3.5 to arrive at the cost per stair. This calculation appears flawed because not all US residents are users of residential stairs, and the basis for the 3.5 is not provided.

A more accurate estimate of stair related injury costs per home stair per year can be developed based on an estimate of the total number of residential stairs (i.e., stairs connecting two floors) from the 2003 American Housing Survey:

Occupied single family units (67,753,000 detached and 6,272,000 attached): 74,026,000
Total occupied units in 1-story structures (assumed to be all single family): 34,244,000
Hence, single family units in 2+-story structures: 39,782,000.

Assuming that the ratio of 2- to 3-story occupied single family structures is the same as the ratio for all structures (34,915,000/22,842,000), then:

2-story occupied single family units (w. 1 stair excluding basement): 24,048,000
3-story occupied single family units (w. 2 stairs excluding basement): 15,734,000
Yielding, a total number of residential stairs excluding basements: 55,516,000
1-unit buildings with basement under all or part of building: 33,067,000
For a grand total number of residential stairs including basements: 88,583,000.

Based on this estimate of over 88.5 million residential stairs in the United States, stair-related injury costs per home stair per year are:

- Medical costs (average): $26
- Productivity losses (average): $52
- Medical costs (range): $17-33
- Productivity losses (range): $35-66.

<u>How to compute the annual medical cost of falls on new residential stairs?</u>

As stated above, this computation may be useful for health insurers, who bear no costs for stair construction, but may benefit from the potential reduction in the cost of falls on newly constructed stairs.

The 2003 American Housing Survey reports a 4-year total for newly constructed single-family units, which averages at 1,206,000 units. A review of the data demonstrates that the new units are disproportionately more in 2+-story buildings, and disproportionately less with basements than the totals of occupied units. Therefore, the number of annual new construction of residential stairs is estimated based on the ratio of total number of stairs to total occupied units shown in the preceding section. This results in an estimate of 1,443,000 newly constructed residential stairs per year.

Multiplying the injury costs per home stair per year computed in the preceding section by the total annual number of new stairs provides the following estimate of annual injury costs from falls on all newly constructed stairs:

Medical costs (average):	$37.5 million
Medical costs (range):	$24.5-47.5 million.

<u>How should fall-related quality of life costs be measured?</u>

In the 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle quality of life costs were measured in dollars, and the dollar value of these costs were the most significant of the three cost elements reported, representing 78% of the total costs of injuries (medical and productivity costs together were about 22% of the total). However, quality of life costs were excluded from *The Incidence and Economic Burden of Injuries in the United States*. The reason is found in the book published recently by the Institute of Medicine, *Valuing Health for Regulatory Cost-Effectiveness Analysis*, Wilhelmine Miller, Lisa A. Robinson, and Robert S. Lawrence, Editors, 2006. The authors argue against monetizing quality of life for use in benefit-cost analyses, and in support of using other metrics in cost-effectiveness analyses that report the ratio of dollars to these other measures of quality of life. Health-adjusted life years (HALYs) are presented as population health measures permitting morbidity and mortality to be simultaneously described within a single number. Several HALY metrics have been used in the United States and internationally to analyze regulations that impact health, including quality-adjusted life years (QALYs) and disability-adjusted life years (DALYs). It is beyond the scope of this guide to discuss HALYs in any detail, and the interested reader is referred to the Institute of Medicine publication. At this time it is not known whether HALY metrics have been developed that are applicable to injuries, let alone fall injuries, which is probably why quality of life costs were omitted from *The Incidence and Economic Burden of Injuries in the United States*. In conclusion, quality of life benefits of the 7-11 residential stairs must be considered in a cost-effectiveness analysis, but that doing so is beyond the current state-of-the-art and requires additional research.

<u>How are the benefits of injury reduction from stair falls to be measured?</u>

In order to estimate the reduction in the injury costs that may result from using 7-11 residential stairs, one must estimate the percentage reduction in the incidence of falls attributable to shifting to 7-11 stairs. This is discussed in Step 5, Identify Benefit Measurement Models.

<u>Are there other benefits of stair code changes (e.g. improved non-injurious usability and improved aesthetics of stairs), to whom, and how measured?</u>

Improved non-injurious usability of stairs: The 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle included the following two explanations of this benefit:

> "In addition to some degree of injury reduction due to improved stair step geometry there is another huge benefit that is difficult to estimate in dollar terms. That is the benefit of normal, noninjurious uses; for homes these amount to a few million stair flight uses for every use that results in hospital emergency room treatment. Over a 50-year life of a typical home stair, such noninjurious uses amount to on the order of one million uses. Every one of these uses has a value that is chargeable against the stair cost. For example, at $0.002 per flight –use, the value totals $2,000 (in constant year 2000 dollars) per stair. In other words, we could charge the entire stair cost, of $800. against the usability benefit and have a credit of $1,200. What value can be placed on an improved step geometry in terms of improved usability? We know that, as we age, stair-use ability deteriorates. If the improved step geometry extends the usability of stairs by an average of ten years for elderly individuals before the two-story home has to be traded for a step-free home or has to have a lift installed, this is a major benefit. It can be expressed in dollar terms, say $0.20 per use for five uses per

> day over a ten-year period. This benefit, on the order of $7,000 per home—assuming there are two such residents over a fifty-year period, is comparable to the average cost of the benefit of having no injurious falls on the stair over its life (recalling here that the medical treatment cost of stair related injuries averages on the order of $3,000 as part of about $30,000 of comprehensive injury costs over a fifty-year period for an average home stair). As a point of reference, nursing home care can cost about $30,000 per year per individual. For all of the USA, over a fifty-year period, these usability benefits add up to about $1,125 billion."
>
> "Regarding usability, for every hospital-treated injury related to stairs there are, on average for all stairs in the USA, about 4 million flight uses, thus there are many uses of a stair that are injury free; each of these uses has an economic value. For example, over the lifetime of a home stair flight there will be on the order of one million uses. Assuming the entire stair cost is devoted to these benign uses, this works out to a benefit costing on the order of one-tenth cent per use. How many people would object to improved stairs if they knew, that aside from the injury reduction benefits and the greatly improved visual appearance, each use was going to cost on the order of one-tenth cent? Also, as home occupants age and, increasingly want to stay in their home (as AARP surveys continually highlight as very important for over 80 percent of people over 50 years of age), what is the benefit of more-usable stairs?"

The basis for estimating the number of stair uses, for monetization of utility of stair use, and for the cost estimates of $0.002 and $0.20 are not provided, nor were future costs discounted when computing the fifty-year benefits. Usability metrics must be developed on the basis of further research.

In order to estimate the improved usability that may result from using 7-11 residential stairs, one must relate usability to stair geometry, regardless of the usability metrics. This is discussed in Step 5, Identify Benefit Measurement Models.

Improved aesthetics of stairs: The 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle included the following reference to this benefit:

> "Indeed, once home buyers discover that there are yet more advantages to the improved stair geometry—especially the improved aesthetic quality of the "7-11" stairs—arguments over the extent of improved usability and safety will, I suspect, go away."

The metrics of this aesthetic quality were not presented. In order to identify and quantify this benefit, one needs to provide answers to the following questions:

- Are stair geometry differences of the order involved in moving to the 7-11 stair perceptible by humans? The answer can be determined in an empirical study.
- If perceptible, is it possible to quantify the value of the difference? The answer can be determined by an hedonic analysis.

Author's Note: The issue of aesthetic benefits raises an interesting question: The objectives of the building code are health, safety, and welfare. Aesthetics are not specifically mentioned, but are conceivably included, or may be included at some future time, under the category of welfare. Should aesthetics be covered in a methodology such as this one?

5. “Step 5: Identify Benefit Measurement Models and Their Characteristics”

Even if benefits can be identified, allocated to beneficiaries, and measured, they are often probabilistic, accrue over time, and uncertain to some degree, as can be seen from the metrics noted in the cases described in Step 4. In conducting a benefits analysis of code changes, one must relate specific building features put in place by the code change to these uncertain probabilistic benefits. In some cases, analytical models have been developed to do so. In the area of natural disasters FEMA has developed the model HAZUS-MH that relates building features to losses in earthquakes and hurricanes, and other models have been developed to measure the benefits of various disaster mitigation measures in buildings. In the area of fire safety models have been developed that may be used to measure the benefits of specific building improvements in specific fire scenarios. In the area of energy use models have been developed that may be used to measure the energy conservation attributed to specific building design features.

Where such models do not exist, the measurement of code change benefits must be based on assumptions and judgments made by experts in an organized format.

In this step of the methodology the model(s) or calculation method(s) for measuring the benefits must be specifically identified and described. An analyst who has used the model or calculation method in any application should fully describe its characteristics, the time and cost required to implement it, the hardware and software capabilities required, input requirements, ability to perform sensitivity analyses, and other relevant information. The applicability and ability (or inability) of the model to specifically measure the effects of the design and construction implications of the respective code change, as elaborated in step 2 of the methodology, should be discussed in detail.

Four examples of “identify benefit measurement models and their characteristics” are developed and described in the following, each addressing a series of questions relevant to the particular code change proposal:

- Foundation Anchorage
    - What analysis capabilities must the model be able to perform?
    - Are there existing models that can be adopted for this purpose or must a model be developed?
- Continuous Structural Panel Sheathing (separately treating both HAZUS-AEBM (Advanced Engineering Building Module) and ASSEMBLY-BASED VULNERABILITY AND PEER METHODOLOGY)
    - How does the model estimate economic and life-safety performance of an individual building
    - In what aspects and to what extent does the model rely on expert opinion?
    - Does it require substantial modeling simplifications beyond those employed in the state of the art or state of the practice in structural design?
    - Which uncertainties in the hazard, structural response, damage, and loss are reflected in the model?
    - How does it quantify and propagate those uncertainties, and how does that method of propagating uncertainties compare with a mathematically ideal approach?

  - To what extent has the method been validated against or built upon past earthquake performance of real buildings?
  - To what extent has the model been accepted by academics, professionals, and other authorities involved in loss estimation and performance-based earthquake engineering?
- 7-11 Residential Stairs
  - What does the research tell us about the relationship between stair geometry and falls on stairs?
  - Can a percentage reduction in the incidence of falls on stairs be related to their geometry?
  - Can additional research reduce the uncertainty in the percentage reduction in the incidence of falls on stairs be related to their geometry?
  - What does the research tell us about the relationship between stair geometry and utility of stair use?
- Sprinklers in the IRC
  - What types of losses are associated with sprinkler protected residential fires?
  - Can the losses from residential fires be quantified?
  - What are the reductions in losses from residential fires that can be attributed to sprinklers?

Step 5 Example: Foundation Anchorage

In this step of the Methodology, the intent is to identify or develop and implement a model that accurately or reasonably represents the performance impact (physical benefits or consequences) to features in the baseline code as changed by the code proposal. Because this step does not involve the actual model development or analysis of benefits, there are just two questions that must be answered:

- What analysis capabilities must the model be able to perform to process required inputs and produce useful results (benefit measures)?
- Are there existing models that can be adopted for this purpose or must a model be developed?

What analysis capabilities must the model be able to perform?

At this point in the Methodology, various required inputs and outputs for an acceptable benefit measurement model would normally have been identified in previous steps of the Methodology. However, only Step 1 was addressed for this example code change item. Therefore, the following assumptions are made in regard to Steps 2 through 4:

- *Step 2: Describe Design and Construction Implications of the Code Change* – It is assumed that this step has resulted in identification of representative building (or foundation) types, soil types and backfill placement conditions, foundation shape/geometry, floor framing and member orientation variations relative to foundation walls, and other variable factors that define a study matrix (inputs) for use with a suitable benefit measurement model to evaluate this code change. Given that the benefits are probabilistic and depend on the frequency of various conditions in the building population, it is also assumed that suitable frequency distributions have been identified, approximated, or bounded based on available data and expert judgment. Thus, the model must be able to evaluate these inputs probabilistically based on available frequency distributions for input variables as required in the study matrix defined in Step 2. In fact, this same study matrix would define conditions for cost analyses to be performed in Step 3 and combined with results of this Step 5 to facilitate an integrated cost-benefit analysis in Step 6 of the Methodology.
- *Step 3: Perform a Cost Analysis* – This step is irrelevant to identification of a benefit measurement model (Step 5) even though the results of Steps 3 and 5 are integrated in Step 6.
- *Step 4: Estimate Benefit Distribution and Metrics* – In this step, the beneficiaries and metrics for measuring beneficiaries is identified. In particular, Step 4 defines the type of results or output that the benefit measurement model must be capable of producing.

For this code change item, it will be assumed that all of the benefit metrics relate in some manner to a future physical condition of a newly constructed foundation or, more specifically, the lateral support anchorage of the foundation. Thus, the model must predict the physical condition of a foundation wall for various conditions or inputs to the model. The analysis will involve principles of engineering mechanics as well as empirical relations. In addition, the predicted physical condition must be associated with a probability of attaining or exceeding specific limit states over a selected time frame for the analysis. A limit state is a physical condition or state, such as an amount of deflection of the top of a foundation wall (or collapse) that is associated with a particular functional consequence.

Finally, limit states must be conditionally associated with economic impact or life-safety consequence (e.g., cost of repair or replacement of failed foundation walls and consequent damage to other building elements, or chance that a person was injured given that a foundation wall collapse occurred). It is unlikely that data exists to associate various degrees of deflection at the top of foundation walls with specific consequences (e.g., damage to wall, decision to repair wall, cost of repair). However, it should be possible to estimate these relationships and conduct sensitivity studies on modeled effects that do not have known variability. It is likely that key parametric relationships governing the modeled benefit measures will require expert judgment.

In summary, an evaluation of benefits of this code change requires a probabilistic treatment of the specific problem using unique input data, calculation procedures, and expert judgment to produce the required outputs. The main outputs of an acceptable benefit measure model must include:

- Probability of attaining various top or bottom of wall deflection limit states in a specified time period of analysis,
- Probable economic value (present worth) associated with reaching a particular limit state during the specified time period of analysis.

Are there existing models that can be adopted for this purpose or must a model be developed?

Step 5 Example: “Foundation Anchorage”

Conducting a search for and assessment of existing probabilistic risk benefit models for analysis of residential foundation wall performance is beyond the scope of this report. Unfortunately, it seems unlikely that an existing model would be found and that it would not require significant modification to address the unique features of this problem. It may be possible to find various components of the overall model required and integrate those components into a probabilistic benefit measurement tool suitable to this application.

Given the many factors and modeling components that must be considered, the starting point for selecting or developing a benefit measurement model is best accomplished by way of a flow-chart of the logic and inputs required to obtained desired outputs. Such a flow chart (in preliminary form) is shown in “Step 5, Foundation Anchorage, Figure 1.”

PERFORMANCE (BENEFIT) MEASUREMENT MODEL

MODEL COMPONENTS AND INPUTS		
Geometry of Problem*	Load/Hazard Model	Resistance/Fragility Model
• height of wall • height of backfill • length of wall (3D effects) *varies according to representative building (foundation) types defined in Step 2 of the Methodology	• Soil pressure data and variability relevant to residential backfill practices • Soil pressure distribution on foundation wall • Time effects • Variation due to difference in soil types/classes	• Representation of non-linear load deflection behavior of connections at top of wall • System effects on joint behavior (capacity and stiffness) • Wall analog effects (pinned base and top vs. partially restrained ends) • Consideration of soil friction effects on wall face • Consideration of 3D effects from orthogonal walls

PROBABILISTIC ENGINEERING ANALYSIS MODEL & PERFORMANCE MEASUREMENT OUTPUTS	
Risk (probability) of failure over a specified time period	Risk probability of reaching a specified top-of-wall deflection limit state over a specified time period

PROBABILISTIC BENEFIT MEASUREMENT OUTPUTS
Probable economic loss ($) associated with predicted performance
Probable life-safety or human health impacts associated with predicted performance

Step 5, Foundation Anchorage, Figure 1. Flowchart and components of a probabilistic benefit measurement model for evaluation of IRC foundation anchorage code change

While the general form of the model as shown in Figure 1 is not unique, the unique input and analysis requirements will mostly likely require a significant model development effort to be able to effectively measure benefits. This effort must also be coupled with an effort to obtain necessary input data as well as verify the predictive capability of the model through physical testing under specific conditions or comparison to field experience (if frequency of actual incidents of foundation damage or failures can be objectively quantified and associated with relevant causative factors).

The nature of this problem may also require that the structural performance characteristics of each representative building (foundation) type and matrix of input variables be solved using a three-dimensional structural model for the purpose of accurately determining the distribution of soil forces on foundation walls and, thus, the anchorage connections as part of an overall structural system. Furthermore, it may be important for the model to be able to model non-linear (inelastic) behavior of wood connections that serve to anchor the foundation wall against lateral movement. In this context, benefit measurement model development and verification will not be a trivial matter. However, with further study, modeling “short-cuts” may be possible provided that they are not considered to have a major impact on determining relative differences in performance of different foundation anchorage strategies. For example, it may be possible to use a two-dimensional structural analysis model with suitable assumptions regarding boundary conditions for individually modeled foundation wall configurations. However, any short-cut necessarily involves an assumption or analysis limitation that must be reported along with model results or addressed in the verification and calibration of the model.

Finally, time effects must be considered (or dismissed) in developing a model to measure performance benefits. Depending on soil type, soils represent “creep” behavior and soil pressures on foundation walls are affected by this property. For example, as a foundation wall deflects inward due to soil pressure, the pressure from the soil may be relieved for some time until stresses are redistributed in the soil material. Thus, a stiffer (and stronger) connection may tend to result in greater soil forces that offset some of the benefit of the code change for some soil conditions. In summary, the serviceability limits and failure limits to be considered may have time effects that have a cumulative effect over the life of a structure due to soil-foundation interaction effects. If considered important, this effect will complicate the modeling algorithm due to interaction effects between load/hazard and structural resistance.

Step 5 Example: Continuous Structural Panel Sheathing

In this step of the methodology the model(s) or calculation method(s) for measuring the benefits from the sheathing code change are specifically identified and described. The benefits attributed to this code change derive from improved performance when the building is subjected to extreme lateral loads from earthquakes and extreme winds. The following analysis focuses on earthquake loads. A similar analysis of benefit measurement models suitable for wind performance evaluation will have to be carried out for a complete analysis for this Step of the methodology.

A large number of models exist to estimate the future seismic performance of buildings, and hence can in principle be used to estimate benefits of a code change.

One can calculate the benefit of the sheathing requirement in terms of avoided future repair costs, casualties, and loss of use by combining seismic hazard (the relationship between shaking intensity and frequency of occurrence), seismic vulnerability (the relationship between shaking intensity and loss), and present-value calculation (the discounting of avoided future losses to present value, for a comparison with up-front cost). The US Geological Survey offers authoritative hazard information, and present-value calculation is addressed elsewhere in this report, so the present discussion focuses on competing vulnerability methods.

A review of approximately 30 vulnerability models concluded that two are capable of estimating the benefits of the sheathing requirement: HAZUS-MH’s Advanced Engineering Building Module (NIBS and FEMA 2003) and a second-generation performance-based earthquake engineering (PBEE) methodology referred to here as Assembly-Based Vulnerability or the PEER Methodology (e.g., Porter 2000 and Krawinkler 2005). The review of the other models and a brief overview of the engineering disciplines that deal with estimating future seismic performance of buildings are described in a companion resource document entitled *Identifying Benefit Measurement Models for Continuous Structural Panel Sheathing*.

The models are examined to assess the applicability and ability (or inability) of each to specifically measure the effects of the sheathing code change, by asking and answering 8 questions:

- How does the model estimate economic and life-safety performance of an individual building?
- Can the model reflect detailed structural differences such as result from the sheathing requirement, and if so, how?
- In what aspects and to what extent does the model rely on expert opinion?
- Does it require substantial modeling simplifications beyond those employed in the state of the art or state of the practice in structural design?
- Which uncertainties in the hazard, structural response, damage, and loss are reflected in the model?
- How does it quantify and propagate those uncertainties, and how does that method of propagating uncertainties compare with a mathematically ideal approach?
- To what extent has the method been validated against or built upon past earthquake performance of real buildings?
- To what extent has the model been accepted by academics, professionals, and other authorities involved in loss estimation and performance-based earthquake engineering?

The answers are summarized in “Step 5, Continuous Structural Panel Sheathing, Table 1” and are now discussed in detail.

	HAZUS AEBM	ABV, PEER
Building Performance: Empirical, analytical, or judgment	Analytical	Analytical
Structural Differences: Reflects sheathing requirement	Yes	Yes
Experts: Use of expert opinion	Extensive	None
Modeling Simplifications: Structural modeling	Simplified	State of the art
Uncertainties: Reflected in model	Many	Most to all
Uncertainties: Propagation	In fragilities	Various options
Method: Validation in earthquakes	Several	Several
Model: Acceptance	Wide	General

Step 5, Continuous Structural Panel Sheathing, Table 1. Summary of vulnerability models capable of modeling benefits of sheathing code change

HAZUS-AEBM

FEMA and the HAZUS developers recognized the need for a building-specific methodology to overcome the limitations of HAZUS' high-level view of building types. In 2003, the HAZUS developers adapted their methodology to building-specific loss estimation, leading at last to one of the methodologies examined here: the Advanced Engineering Building Module (AEBM), documented in NIBS and FEMA (2003). The AEBM follows the same damage-estimation methodology as HAZUS, but allows the user to set the parameters of the structural model to reflect a particular building, and to adjust the replacement costs and damageability parameters of the three broad categories of building component to those of the building in question.

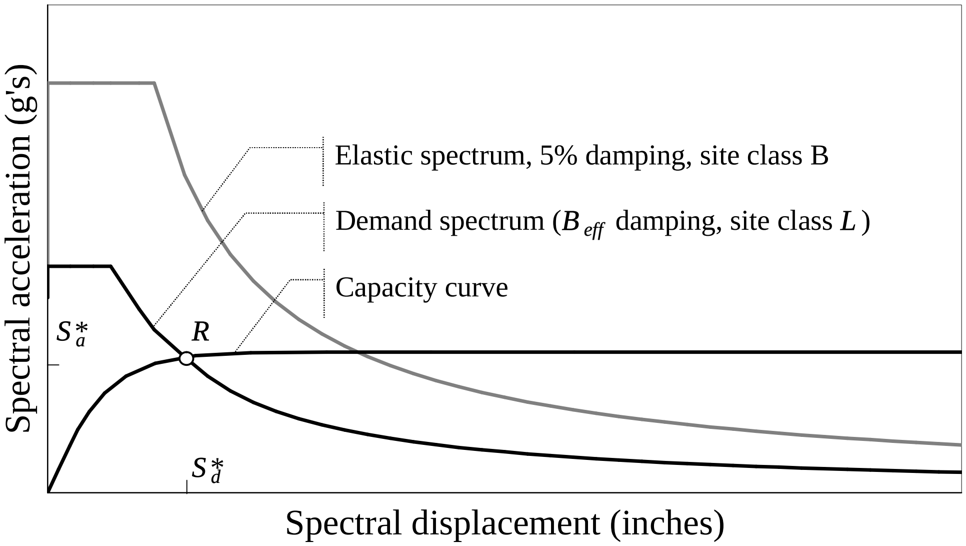
How does the model estimate economic and life-safety performance of an individual building?

This is a four-step process:

- hazard analysis
- structural analysis
- damage analysis
- loss analysis.

The hazard is quantified using USGS-derived maps of shaking intensity with various probabilities of exceedance; each earthquake is modeled using an idealized relationship called a *demand spectrum* that reflects the acceleration and deformation of a system comprising a simple oscillator (a mass and linear elastic spring with a dashpot damper) with varying natural frequency and damping.

The structural analysis is a nonlinear pseudostatic method referred to as the *capacity spectrum method*. In this method, the building is modeled as simple oscillator—this time with a spring whose stiffness decreases to zero as the spring is subjected to increasing deformation. The relationship between the acceleration and displacement of the building oscillator is referred to as the *capacity curve*. Where the capacity curve and demand spectrum cross, and agree in terms of damping, gives the estimated response of the building oscillator to the earthquake, from which the deformation of the actual building can be interpreted. The process is illustrated in Step 5, Continuous Structural Panel Sheathing, Figure 1." The process for constructing the capacity curve is detailed later.

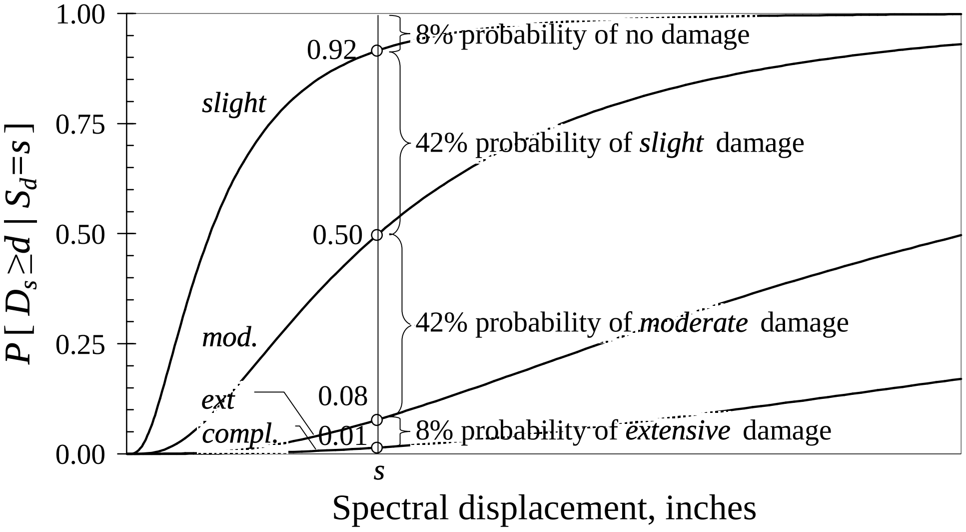


Step 5, Continuous Structural Panel Sheathing, Figure 1: Illustration of the capacity spectrum method of structural analysis

In the damage analysis, one models the structural and nonstructural aspects of the building as three generic components (structural, nonstructural drift-sensitive, and nonstructural acceleration-sensitive), and uses damageability models called *fragility functions* (in the form of lognormal cumulative distribution functions and illustrated in "Step 5, Continuous Structural Panel

Sheathing, Figure 2") to estimate the probability that each of the three components would be in each of 5 discrete damages (none to complete).

By assigning a repair cost to each component and damage state, HAZUS calculates the expected repair cost at each shaking intensity level. Finally, HAZUS integrates the relationship between repair cost and earthquake exceedance frequency to calculate the expected annual repair cost. Life safety is addressed by assigning to each structural damage state the probability of various levels of injury. Through a numerical integration of the number of deaths and injuries with the earthquake exceedance frequency, the model estimates the average annual numbers of deaths and injuries.

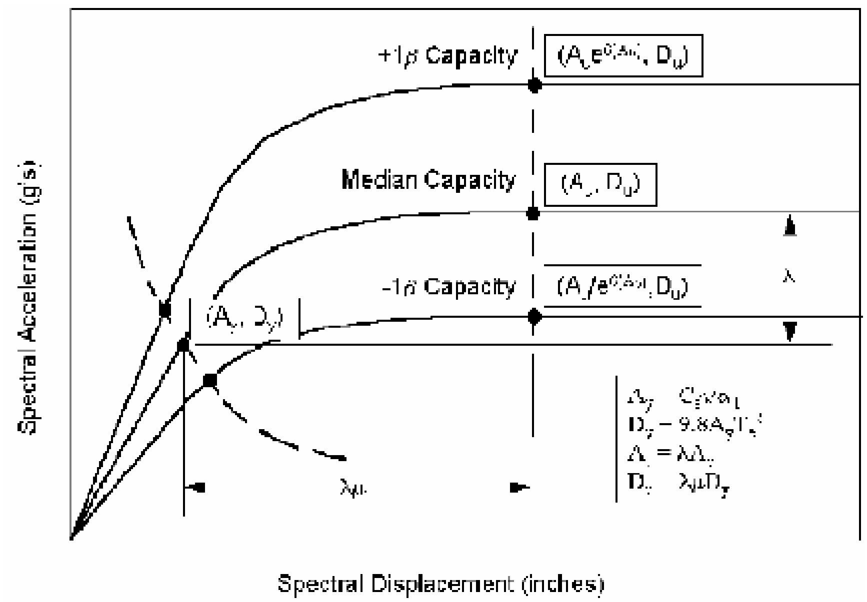


Step 5, Continuous Structural Panel Sheathing, Figure 2. Illustration of HAZUS fragility functions

HAZUS uses default values for most of the relevant parameters, but the AEBM allows the user to change virtually all of the key variables: building location, size, occupancy, number of daytime and nighttime occupants, replacement value of its three aggregate components, repair cost for each component and damage state, loss of function cost, capacity curve (which defines the structural response in the capacity spectrum method), and parameters of the component fragility functions.

How does the model reflect detailed structural differences such as result from the sheathing requirement?

Different capacity curves are provided for each of a large number of structure types and eras of construction, so for residential woodframe buildings HAZUS distinguishes the effects of four major code levels—i.e., differences in design force and detailing requirements—but the HAZUS model per se would not distinguish such a detailed difference as the sheathing requirement. However, the AEBM model user would calculate the overall stiffness and strength of the equivalent single-degree-of-freedom system representing the building as-is and under what-if conditions and enter these values into the control points shown in "Step 5, Continuous Structural Panel Sheathing, Figure 3." In the figure, C_s is the design strength as a fraction of building weight, γ denotes yield overstrength ratio (yield strength as a fraction of design strength), α_1 denotes fraction of building weight effective in push-over mode, T_e denotes true elastic fundamental-mode period of building (seconds), λ denotes overstrength factor relating ultimate strength to yield strength, and μ denotes the ductility factor relating ultimate displacement to λ times the yield displacement. The AEBM user could calculate some of these parameters from a detailed structural analysis of the building under as-is and what-if conditions (e.g., C_s and T_e) and assume accepted values for the rest.



Step 5, Continuous Structural Panel Sheathing, Figure 3. Constructing HAZUS capacity curve (NIBS and FEMA 2003).

<u>In what aspects and to what extent does the model rely on expert opinion?</u>

The HAZUS model employs expert opinion in important aspects: the capacity curves, component fragility functions, collapse probability given complete structural damage, and death and injury rates given damage levels, are based on a combination of test data, earthquake experience, and expert opinion. The manner in which expert opinion was applied and the sensitivity of the results to expert opinion are not documented in public sources. The AEBM relies on expert opinion to the extent that the user-supplied data listed above employs expert opinion and to the extent that remaining default values embedded in HAZUS reflect expert opinion.

<u>Does it require substantial modeling simplifications beyond those employed in the state of the art or state of the practice in structural design?</u>

Building details are reflected only through structure type, code level, and occupancy. The simple nonlinear oscillator that represents the structural model is a major simplification of the highly detailed structural system of most real buildings, although the AEBM user has the ability to input parameters of the oscillator to reflect the details of the building in question. The state of the practice and state of the art in structural design would be to model the building with a large number of such springs and masses, each reflecting its particular dimensions, materials, and mechanical properties. In the state of the practice, a pseudostatic nonlinear structural analysis would be performed; in the state of the art, a large number of dynamic nonlinear structural analyses would be performed.

In the damage analysis, the various damageable building components are simplified into three general components (structural, nonstructural drift-sensitive, and nonstructural acceleration-sensitive). In the state of the art for loss estimation, each damageable component would be reflected by a set of fragility functions developed from test data, earthquake damage, or analysis of that particular kind of component, using a library of 100 or more different components. Repair costs would be calculated at the same level of detail.

Collapse probability (and hence fatality risk) would be calculated from the structural analysis rather than by assuming a fraction of buildings in the complete damage state would collapse.

<u>Which uncertainties in the hazard, structural response, damage, and loss are reflected in the model?</u>

The model reflects uncertainties in hazard, structural response, and damage through its fragility functions. Uncertainty in repair cost and casualty rates are not modeled.

How does it quantify and propagate those uncertainties, and how does that method of propagating uncertainties compare with a mathematically ideal approach?

The uncertainties in hazard, structural response, and damage are reflected by calculating a measure of uncertainty called the logarithmic standard deviation for the fragility functions by combining logarithmic standard deviations from each source. It is unclear how well this approach compares with a Monte Carlo or other approach where one explicitly models each uncertainty separately.

To what extent has the method been validated against or built upon past earthquake performance of real buildings?

A validation study by the National Institute of Buildings Sciences (2001) compared HAZUS estimates of various total, societal-level losses with documented observations from 5 California earthquakes. Considering only direct economic losses, 3 of 8 estimates were within the same order of magnitude as the observed values (i.e., differing by a factor of less than $10^{0.5}$, or 3.2), and the remainder were within 2 orders of magnitude (i.e., differing by a factor of less than $10^{1.5}$, or 32). Indirect economic losses were within the same order of magnitude for 1 estimate, 2 orders for 1 more estimate, and had the wrong sign for 3 estimates.

Among casualties, 6 estimates were within 1 order of magnitude of the documented value, and 10 more were within 2 orders of magnitude.

Only 3 estimates dealt with building repair costs: the 1989 Loma Prieta earthquake, 1994 Northridge earthquake, and 2000 Napa earthquake. Agreement is good between predicted and documented losses in the 1989 and 1994 events, although the model was calibrated to hindcast these losses accurately. HAZUS overestimated building repair costs in the 2000 earthquake by a factor of 3, but the losses were relatively small in this event and could reasonably be considered to represent the lower bound of HAZUS’ domain of accuracy. The AEBM has does not appear to have been separately validated.

To what extent has the model been accepted by academics, professionals, and other authorities involved in loss estimation and performance-based earthquake engineering?

HAZUS represents the worldwide state of the art among academics and many professionals involved in loss estimation, especially those who do not have access to proprietary loss models such as those offered by RMS (www.rms.com), Applied Insurance Research (www.air-worldwide.com), and EQECAT (www.eqecat.com). It was developed by leading engineering practitioners under the sponsorship of the US Federal Emergency Management Agency, and therefore offers a degree of official authoritativeness that no other loss model does. Among academics and professionals involved in PBEE, HAZUS is recognized as appropriate for macroscopic loss estimation but not for single-building analysis.

A Google Scholar search for “HAZUS AEBM” produced 3 references not written by the developers, so academic use so far appears to be limited. Nonetheless, like HAZUS, the HAZUS AEBM was developed by leading engineering practitioners under the sponsorship of the US Federal Emergency Management Agency, and therefore offers a degree of official authoritativeness that no other loss model does.

ASSEMBLY-BASED VULNERABILITY AND PEER METHODOLOGY

Beginning in the late 1990s, researchers at Caltech, Stanford University, and elsewhere formulated and demonstrated a building-specific loss-estimation methodology entitled assembly-based vulnerability (ABV). It incorporates multiple nonlinear dynamic structural analyses, damage analysis at the level of individual building assemblies, and the calculation of repair cost and downtime using fairly standard construction-contracting principles (Beck 1999, Porter 2000, Porter et al. 2001). In this approach, one models the dynamic behavior of buildings with greater fidelity than the pseudostatic approach, although at a cost of greater computational effort. ABV involves somewhat more-rigorous propagation of uncertainty in each analytical stage, relative to earlier approaches, examines the performance of buildings components at a more-detailed level, and avoids the reliance on expert opinion common to HAZUS and AEBM, again at the cost of computational effort. ABV has been used to estimate repair costs and loss of use, both for research and practical applications, for a few dozen buildings of steel, concrete, and timber construction. Most notable among these studies is Porter et al. (2006), which included benefit-cost analysis of seismic retrofit and design alternatives of woodframe buildings.

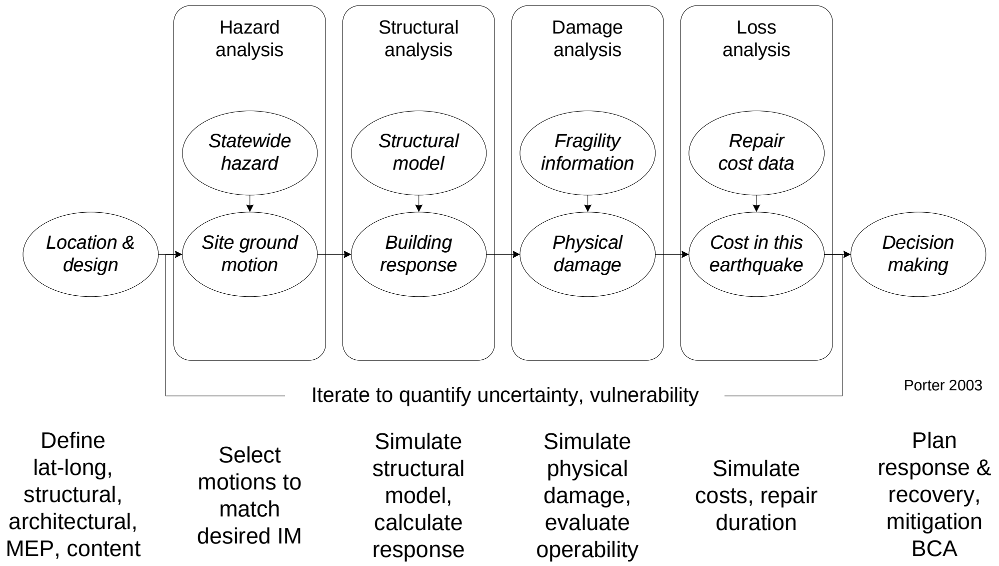
The ABV studies were followed recently by researchers at the Pacific Earthquake Engineering Research (PEER) Center (e.g., Krawinkler 2005 or Comerio 2005). The PEER methodology is similar to ABV, with a slightly different approach to treating uncertainty. Like ABV, the PEER approach employs multiple nonlinear dynamic structural analyses and examines building performance at the same level of detail as ABV. Actually there is no single “PEER methodology;” PEER researchers have used slightly different methods to characterize ground shaking, to deal with uncertainty in the characteristics of the structural model, and to propagate uncertainty in damage and loss. To date PEER researchers have performed end-to-end analyses of approximately 14 buildings, quantifying repair costs and fatality risk, although not downtime. Because of its similarity to ABV and because of PEER’s focus on concrete as opposed wood buildings, the PEER methodology will be considered with ABV.

How does the model estimate economic and life-safety performance of an individual building?
As with HAZUS, and as illustrated in “Step 5, Continuous Structural Panel Sheathing, Figure 4,” this is a four-step process, although the details differ:

- hazard analysis
- structural analysis
- damage analysis
- loss analysis,

The hazard for a particular site is spatially interpolated from USGS database of the exceedance frequency of various levels of shaking intensity (hazard curves). Intensity is measured using spectral acceleration response at two natural periods of vibration, interpolated to the approximate fundamental period of the building of interest, and adjusted to account for local soil conditions. For each of several levels of shaking intensity (typically 20 levels), 20 different earthquake accelerograms are selected, to reflect variability in ground motion.

The building is modeled with a number (typically 20) of detailed nonlinear structural model uncertainties; the models reflect uncertainty in mass, damping, and force-deformation behavior.



Step 5, Continuous Structural Panel Sheathing, Figure 4. Schematic overview of ABV and PEER methodology

Key: MEP stands for mechanical, electrical, and plumbing.
IM stands for intensity measure
BCA stands for benefit-cost analysis.

Nonlinear time-history structural analyses are performed by pairing accelerograms and structural models to calculate member forces and deformations.

In the damage analysis, the force or deformation imposed on each damageable component is used with a set of detailed fragility functions (particular to the kind of component in question) to simulate the uncertain damage to each structural and nonstructural component. The fragility functions are based on laboratory test data, earthquake experience, or analysis.

With the simulated knowledge of the number and degree of damage to each kind of component in the building, one uses construction contracting principles to calculate the uncertain repair cost and repair duration.

ABV has not been used to estimate deaths and injuries, although the closely related PEER methodology has been used to calculate deaths in reinforced concrete buildings, for which strong empirical evidence is available. By repeating the process at each intensity level, one creates a seismic vulnerability function which can then be integrated with the hazard curve to calculate the expected annual repair cost and downtime, or to produce other measures of loss.

One would then repeat the integration using hazard curves drawn from a large geographic area (in proportion to building population) to reflect variability in site hazard, soil conditions, and local construction costs. One would repeat the process again with a representative number of example buildings, to reflect the variability of building configuration.

How does the model reflect detailed structural differences such as result from the sheathing requirement?

The effect of the sheathing requirement would be calculated by analyzing particular, representative buildings with and without the sheathing requirement, and producing a vulnerability function for each, and integrating with hazard to calculate expected annualized loss. The analysis would reflect the difference three ways: a fully sheathed wall would have greater stiffness than one before the code change, which would change the building’s fundamental period and hence the hazard function to which it was exposed. Second, the sheathed wall would change the building’s structural response for any given earthquake time history, perhaps in certain circumstances affecting collapse probability and fatality risk. Finally, repair of any damage to the sheathed wall would be reflected in the total repair cost.

In what aspects and to what extent does the model rely on expert opinion?

Site hazard is taken from the US Geological Survey’s analytical model of seismic hazard, and from various state geological surveys’ soil maps, which are drawn from field observations. The structural model is entirely analytical, with material properties taken from laboratory experiments and analysis. Fragility functions are drawn from empirical observation or analysis, and repair costs are taken from cost manuals and professional cost estimators. For the most part therefore the model avoids expert opinion. One exception might be in calculating avoided deaths, since it is unclear whether adequate data exist to create an empirical relationship between woodframe building collapse and fatalities.

Does it require substantial modeling simplifications beyond those employed in the state of the art or state of the practice in structural design?

ABV and the closely related PEER methodology appear to represent the state of the art in PBEE.

Which uncertainties in the hazard, structural response, damage, and loss are reflected in the model?

The model reflects uncertainty in the moment-to-moment ground motion, structural mass, damping, and force-deformation behavior, component damageability, component repair cost, and building repair duration. Missing from ABV analyses to date are uncertainty in the hazard function and in site soil amplification.

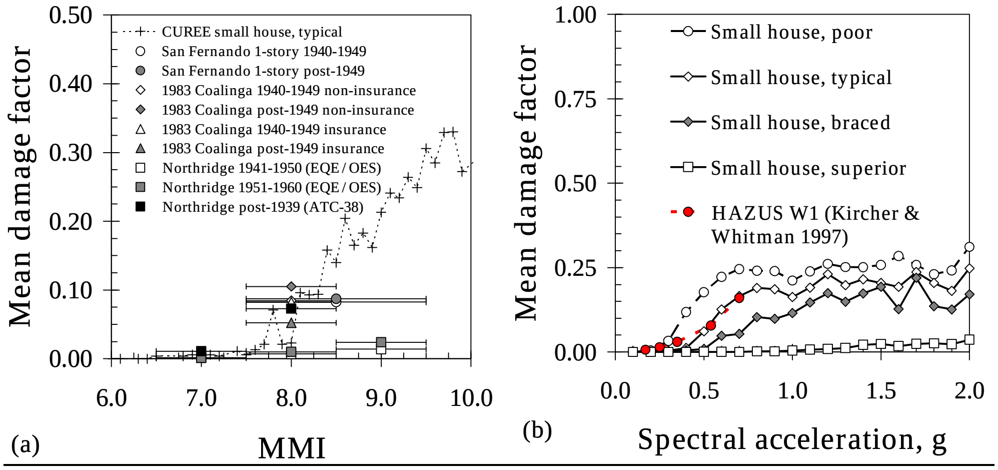
How does it quantify and propagate those uncertainties, and how does that method of propagating uncertainties compare with a mathematically ideal approach?

ABV analyses to date have used various combinations of Monte Carlo simulation, Latin hypercube simulation, and moment-matching simulation (see Julier and Uhlman 2002).

To what extent has the method been validated against or built upon past earthquake performance of real buildings?

As shown in “Step 5, Continuous Structural Panel Sheathing, Figure 5. Vulnerability functions,” ABV-generated vulnerability functions for certain woodframe buildings compare well with earthquake experience in several events and with HAZUS.

Step 5 Example: “Continuous Structural Panel Sheathing”



Step 5, Continuous Structural Panel Sheathing, Figure 5. **Vulnerability functions** (from Porter (2006) compared with (a) experience and (b) HAZUS)

<u>To what extent has the model been accepted by academics, professionals, and other authorities involved in loss estimation and performance-based earthquake engineering?</u>

The PEER methodology is widely accepted as valid by researchers worldwide to estimate the future seismic performance of buildings and bridges. The Federal Emergency Management Agency is current funding an extensive effort by several dozen leading researchers and practitioners to bring the PEER methodology to professional practice.

A Google Scholar search for “Assembly-based vulnerability,” or “PEER methodology” (the latter restricted to those that also mention Pacific Earthquake Engineering Research Center) turn up approximately 100 references.

Step 5 Example: 7-11 Residential Stairs

In this step of the methodology the model(s) or calculation method(s) for measuring the benefits from the proposed 7-11 residential code change are specifically identified and described. The applicability and ability (or inability) of the mode(s) or calculation method(s) to specifically measure the effects of the 7-11 stair are addressed by asking and answering a series of questions:

- What does the research tell us about the relationship between stair geometry and falls on stairs?
- Can a percentage reduction in the incidence of falls on stairs be related to their geometry?
- Can additional research reduce the uncertainty in the percentage reduction in the incidence of falls on stairs that can be related to their geometry?
- What does the research tell us about the relationship between stair geometry and utility of stair use?

It should be noted that these questions are illustrative for purposes of this demonstration analysis. Other analysts will come up with different questions likely to address similar issues.

What does the research tell us about the relationship between stair geometry and falls on stairs?

A body of research exists that analyzes the relationship between stair geometry and falls on stairs or other surrogates for falls, such as missteps. Both proponents and opponents of the 7-11 residential stair code change have referred to this research. Models that relate stair geometry to falls or to measures of utility, such as energy expenditure, have not been developed.

Can a percentage reduction in the incidence of falls on stairs be related to their geometry?

What percentage reduction of stair-related falls can be attributed to the 7-11 stair? The 7-11 residential stair proposal in the International Codes 2003/2004 Code Development Cycle included the following answer to this question:

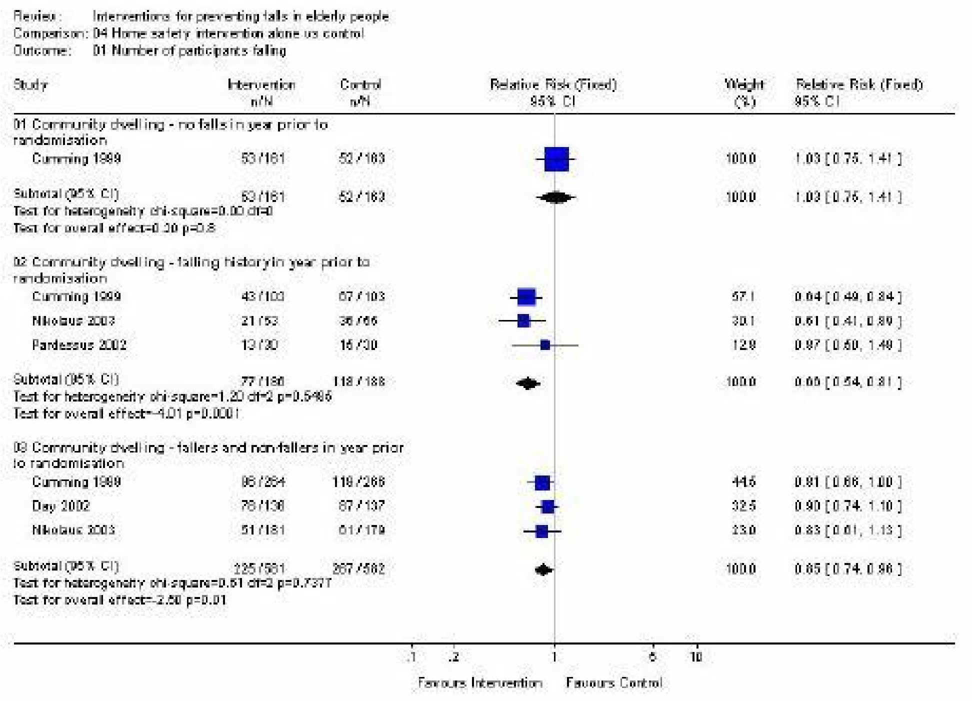
> “The best available insight on this comes from an estimate made (by Alessi et al. in NBS GCR 78-156, ‘Home Safety Guidelines for Architects and Builders’) by leading stair safety researchers during the late 1970s when CPSC was funding a major program of research at the U.S. National Bureau of Standards. A 25-percent reduction in injuries was projected if home stairs were built to the ‘7-11’ standard.”

A review of *Home Safety Guidelines for Architects and Builders* establishes that a panel of four safety reviewers (three from the CPSC and one from the National Bureau of Standards) were asked to make judgments on various impacts of specific “design ideas” (illustrated by small sketches) on specific single paragraph scenarios of various types of falls on stairs (extracted from NEISS narrative information). There were 12 scenarios of stair falls. One of the impacts subject to these judgments was “impact on accident reduction”. One of the “design ideas” was the use of 7” maximum risers and 11” minimum treads (the 7-11 stair), which was proposed for five of the 12 scenarios. For these five the expert judgments on accident reduction ranged from 60-75% accident reduction. The 25% estimate reduction appears to have been based on a weighting of these judgments. This is an inadequate basis for the baseline assumption of stair-related fall reduction.

A better estimate can be based on the 2003 *Interventions for Preventing Falls in Elderly People,* L.D. Gillespie, W.J. Gillespie, M.C. Robertson, S.E. Lamb, R.G. Cumming, and B.H. Rowe, referred to as the Rand Report. This report reviewed research on a variety of intervention to reduce fall injuries. Falls on stairs were not specifically studied. The interventions reviewed were:

- Exercise/Physical Therapy Interventions (23 studies)
- Home Hazard Modification (9 studies)
- Cognitive/Behavioral Interventions (7 studies)
- Medication Withdrawal/Adjustment (2 studies)
- Nutritional/Vitamin Supplementation (6 studies)
- Hormonal and other Pharmacological Therapies (2 studies)
- Referral for Correction of Visual Deficiency (1 study)
- Cardiac Pacemaker Insertion for Syncope-Associated Falls (1 study)
- Exercise, Visual Correction and a Home Safety Intervention (1 study)
- Multidisciplinary, Multifactorial, Health/Environment Risk Factor Screening and Intervention (21 studies)
- System Modifications to Prevent Falls in High Risk Hospital Patients (3 studies)
- Multifaceted Intervention in Nursing Home Residents (1 study).

The study found that fall interventions overall reduced the risk of falling by 11%. Home Hazard Modification is the intervention most closely related to changes in stair geometry (which was not studied). When home safety intervention was not combined with any other intervention, three studies (Cumming 1999, Day 2002, and Nikolaus 2003) that included both fallers and non-fallers in the year prior to randomization showed an average risk reduction of 15% (see "Step 5, 7-11 Residential Stairs, Figure 1").



Review: Interventions for preventing falls in elderly people
Comparison: 04 Home safety intervention alone vs control
Outcome: 01 Number of participants falling

Study	Intervention n/N	Control n/N	Weight (%)	Relative Risk (Fixed) 95% CI
01 Community dwelling - no falls in year prior to randomisation				
Cumming 1999	53/161	52/163	100.0	1.03 [0.75, 1.41]
Subtotal (95% CI)	53/161	52/163	100.0	1.03 [0.75, 1.41]
Test for heterogeneity chi-square=0.00 df=0				
Test for overall effect=0.20 p=0.8				
02 Community dwelling - falling history in year prior to randomisation				
Cumming 1999	43/100	67/103	57.1	0.64 [0.49, 0.84]
Nikolaus 2003	21/53	36/66	30.1	0.61 [0.41, 0.89]
Pardessus 2002	13/30	15/30	12.8	0.87 [0.50, 1.49]
Subtotal (95% CI)	77/186	118/188	100.0	0.66 [0.54, 0.81]
Test for heterogeneity chi-square=1.20 df=2 p=0.5486				
Test for overall effect=-4.01 p=0.0001				
03 Community dwelling - fallers and non-fallers in year prior to randomisation				
Cumming 1999	96/264	118/266	44.5	0.81 [0.66, 1.00]
Day 2002	76/136	87/137	32.5	0.90 [0.74, 1.10]
Nikolaus 2003	51/181	61/179	23.0	0.83 [0.61, 1.13]
Subtotal (95% CI)	225/581	267/582	100.0	0.85 [0.74, 0.98]
Test for heterogeneity chi-square=0.51 df=2 p=0.7377				
Test for overall effect=-2.50 p=0.01				

Step 5, 7-11 Residential Stairs, Figure 1. Summary of Three Falls Studies

Assuming that stair geometry does contribute to fall injuries, the baseline estimate of injury reduction for benefit/cost analysis will be 11%, with a possible upper bound of 15%.

Opponents of the 7-11 code change maintain that the research supports no risk reduction, or minimal risk reduction, attributable to stair geometry, thus lower injury reduction, approaching 0% will be used for purposes of sensitivity analysis. The reason for including this lower bound value is because the 11% to 15% reduction mentioned above is associated with causes or interventions un-related to stair geometry or minor modifications of stair geometry. At best, such estimates are extrapolations and, at worst, they are expert judgments in the absence of direct evidence. Thus, the possibility of a 0% reduction in injuries due to the stair geometry change in question cannot be excluded as a possibility. Given the uncertainty in characterizing benefits, the methodology may inadvertently be measuring variation in expert judgment more than actual uncertainty in the metrics of interest. In such a case, it may prove more useful to conclude that the measurement of benefits and the evaluation of the code change is inconclusive due to lack of data to substantiate key parameters. Such a conclusion would place a greater emphasis on following scientific method rather than expert judgment in making conclusions and may encourage the research necessary to provide data where expert judgment or extrapolations are too unreliable.

<u>Can additional research reduce the uncertainty in the percentage reduction in the incidence of falls on stairs be related to their geometry?</u>

Empirical studies comparing stairs in different countries could shed light on the relationship of stair geometry to falls.

Code requirements in the Netherlands mandate that residential stairs have a maximum riser of 18.5 cm (7.28 inches) and a minimum tread of 22.0 cm (8.66 inches). Said to be "ideal": 18-23 cm (7-9 inches). (Private communication, Jouke Post, Professor of Building Technology, Department of Architecture, Building and Planning, Technische Universiteit Eindhoven.)

This compares to the 7 ¾-10 residential stair currently mandated in the IRC and the 8 ¼-9 stair said to be favored by builders in the US. An initial research could compare the rates of falls on residential stairs in the US and the Netherlands.

The population of the United Kingdom is about 20% of that of the United States, and stair-related injuries (all stairs) in the U.K. are about 25% of those in the U.S. (D.A. Johnson, *An improved method for measuring stairways*). This apparently significant higher rate of stair-related injuries in the U.K. compared to the U.S. could become the subject a study of the relative effects of stair geometry.

<u>What does the research tell us about the relationship between stair geometry and utility of stair use?</u>

Utility of stair use in terms of energy expenditure was addressed in John Templer’s unpublished 1974 doctoral dissertation *Stair Shape and Human Movement*. John Archea summarized this research in 1981 in the Building Technology, Inc. unpublished report to HUD entitled *Building Regulations and Existing Buildings, Appendix B*:

> “Templer completes a doctoral dissertation on energy expenditure and gait while ascending and descending stairs as a function of various riser and tread combinations. Eight male and eight female subjects were tested on a mechanical treadmill stair that could be adjusted to produce various combinations of rise and tread dimension…In the study of energy expenditure, 19 different riser-tread combinations were used with oxygen consumption serving as the dependent variable. On the basis of 639 observations, stable rates of oxygen consumption could be determined as a function of riser height, tread depth, and the weight of the subject. It was found that people had great difficulty conserving energy while climbing stairs. Generally, people were found to be expending energy while climbing stairs at three times the rate found in level walking. Although the steeper stairs required the highest rates of energy expenditure, the overall amount of energy expended was actually less on a steep stair than on one that had a more gradual slope…”

The question of whether utility of stair use is a function of the rate of energy expenditure or the total energy expenditure has apparently not been addressed.

Subsequent stair research in the United States was focused on falls. In 2003 Jake Pauls reported on research by Mike Roys, UK Building Research Establishment:

> “Extensive testing with variable-tread stairway clearly shows—with multiple subjective and objective measures—the usability and safety benefits of tread depths of at least 11 inches. Note this testing was done with a fixed riser height of 175 mm (6.9 inches).”

As stated in the discussion of step 4, the monetization of utility of stair use for purposes of cost-benefit analysis has not been established.

Step 5 Example: Sprinklers in the IRC

It is difficult to estimate the losses that could potentially be avoided with the installation of a residential sprinkler system. Not all the benefits can be quantified or monetized. Residential sprinkler systems have benefits in terms of property protection and life safety. It may be difficult to determine the monetary value of items lost or it may not be possible to put a monetary value on the loss of some items, such as those with sentimental value like photographs and keepsakes. Life safety benefits are discussed elsewhere in this report. In addition, fire is a rare event so the probability of receiving the benefit is low. To attempt to measure the benefits of residential sprinklers, the following questions were addressed:

- What types of losses are associated with sprinkler protected residential fires?
- Can the losses from residential fires be quantified?
- What are the reductions in losses from residential fires that can be attributed to sprinklers?

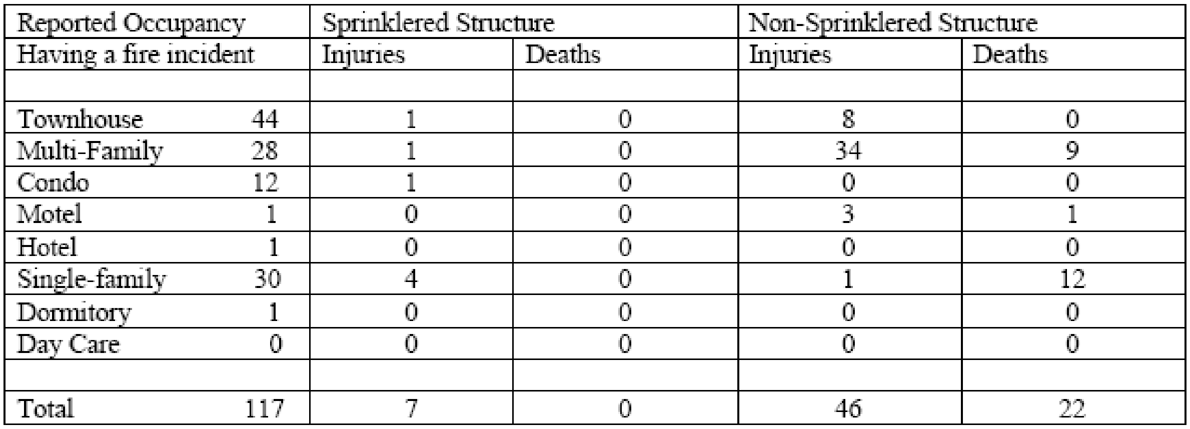
What types of losses are associated with sprinkler protected residential fires?

When a fire occurs in a sprinkler protected residence, there is water damage to deal with. The monetary loss associated with the water damage is significantly less than the loss associated with an unsuppressed fire. Additionally, the volume of water from a residential sprinkler system is considerably less than the amount of water used by the fire department to suppress a fire. As previously mentioned, the Scottsdale Report states that it took approximately 3,290 gallons (12,454 liters) of water to extinguish a fire in a home without sprinkler protection. However, for homes with sprinkler protection, only approximately 209 gallons (791 liters) of water were needed for extinguishment.

Can the losses from residential fires be quantified?

Property and life loss can be estimated in a variety of different ways. One source for fire loss data is the National Fire Protection Association (NFPA). A variety of reports are available from NFPA stating the cost of property loss in fires of homes both with and without residential sprinkler protection. There are also reports on the annual number of injuries and deaths from residential fires. (http://www.nfpa.org)

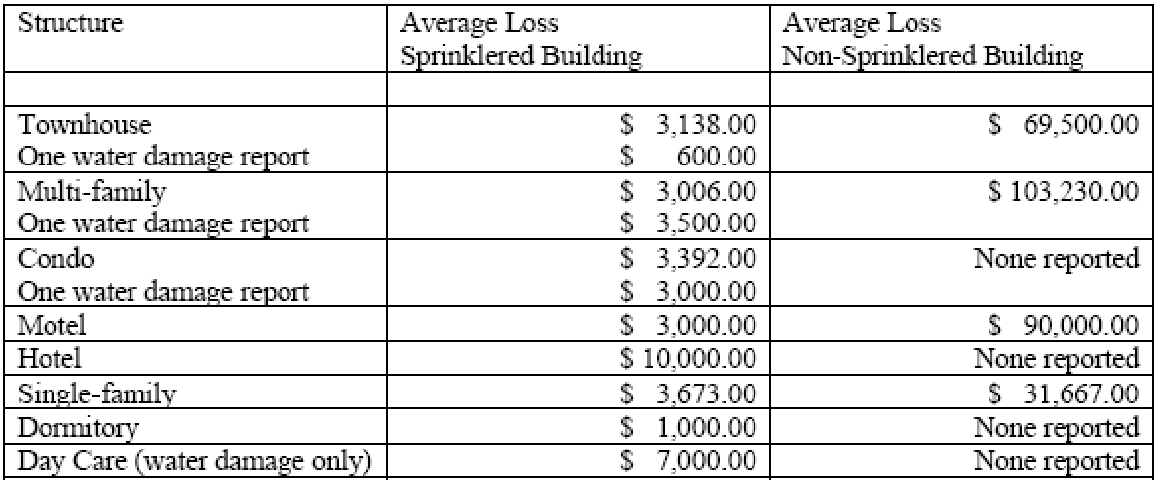
The Prince George's County report includes the following data comparisons for residential buildings with and without sprinkler protection (see "Step 5, Sprinklers in the IRC, Table 1" and "Step 5, Sprinklers in the IRC, Table 2"):



Reported Occupancy		Sprinklered Structure		Non-Sprinklered Structure	
Having a fire incident		Injuries	Deaths	Injuries	Deaths
Townhouse	44	1	0	8	0
Multi-Family	28	1	0	34	9
Condo	12	1	0	0	0
Motel	1	0	0	3	1
Hotel	1	0	0	0	0
Single-family	30	4	0	1	12
Dormitory	1	0	0	0	0
Day Care	0	0	0	0	0
Total	117	7	0	46	22

Step 5, Sprinklers in the IRC, Table 1. Prince Georges County comparison of injuries and deaths

Step 5 Example: “Sprinklers in the IRC”



Structure	Average Loss Sprinklered Building	Average Loss Non-Sprinklered Building
Townhouse One water damage report	$ 3,138.00 $ 600.00	$ 69,500.00
Multi-family One water damage report	$ 3,006.00 $ 3,500.00	$ 103,230.00
Condo One water damage report	$ 3,392.00 $ 3,000.00	None reported
Motel	$ 3,000.00	$ 90,000.00
Hotel	$ 10,000.00	None reported
Single-family	$ 3,673.00	$ 31,667.00
Dormitory	$ 1,000.00	None reported
Day Care (water damage only)	$ 7,000.00	None reported

Step 5, Sprinklers in the IRC, Table 2. Prince Georges County comparison of loss

Tables 1 and 2 include the following numbers of fire incidents:
Sprinklered: 44 townhouse and 30 single-family
Unsprinklered: 16 townhouse and 9 single-family
The “average loss” reported in Table 2 is per incident (the total loss divided by the number of incidents.)

The Consumer Product Safety Commission (CPSC) also issued a report on fire losses (both life and property) for 1999, *1999 Residential Fire Loss Estimates: US National Estimates of Fires, Deaths, Injuries, and Property Losses from Residential Fires*. (http://www.cpsc.gov/library/fire99.pdf#search='fire%20loss%20data')

The US Fire Administration (USFA) maintains the National Fire Incident Reporting System (NFIRS). NFIRS is s voluntary reporting system that maintains a database of fire incident information. Among other data, fire deaths and injuries are reported along with cost estimates for fire losses. (http://www.usfa.dhs.gov/downloads/pdf/publications/nfirsuse.pdf) The USFA also issued a report, *Fire in the United States 1992-2001 (Thirteenth Edition)*, which gives statistics for fire deaths, injuries, and property loss estimates. (http://www.usfa.dhs.gov/downloads/pdf/publications/fa-286.pdf)

The Scottsdale report stated that the average loss per fire in a sprinkler protected home was $2,166, while the average fire loss in a home without sprinklers was $45,019, a 95% reduction in property losses. The Prince George’s County study suggests 99% estimated potential reduction in losses. NFPA reports a 19% reduction in property damage based on fires reported to the fire department.

The NISTIR 7277 report includes the following fire data from the USFA, 2004:

- 410,500 residential fires
- 117 firefighter deaths, of which 41% were in residential fires
- 3,225 deaths in residential fires
- 14,175 injuries in residential fires
- $5.9 billion in direct losses in residential fires.

The Centers for Disease Control (CDC) data for 2000 (*The Incidence and Economic Burden of Injuries in the United States*, Eric A. Finkelstein, Phaedra S. Corso, Ted R. Miller, and Associates, Oxford University Press, 2006) includes the following injury data for fire/burn incidents:

- 3,922 fatalities—seems consistent with USFA since about 80% of fire fatalities are reported to occur in residences
- 770,454 injuries (24,519 hospitalized, 745,935 non-hospitalized)—appears to significantly exceed USFA, which may be attributable to the inclusion of burn injuries unrelated to residential fires.

Fire modeling is another means of determining potential fire loss. Computer programs such as FDS, cFast, and CONTAM can be used to predict the response times of sprinklers and heat and smoke detectors as well as the amount of heat or smoke generated from a fire. This information can be used to estimate the amount of damaged caused by a fire, with or without residential sprinklers present. FDS, cFast, and CONTAM were all created by the National Institute of Standards and Technology (NIST). Each of these models are summarized as follows:

- FDS stands for Fire Dynamics Simulator, which is a computational fluid dynamics (CFD) model. FDS can be used to predict the movement of heat and smoke in a multi-compartment fire. The program has a function for estimating the effect of sprinklers on the heat and smoke movement as well. Extensive validation work has been performed on FDS. (http://fire.nist.gov/fds/)
- cFast is a zone model that can be used to predict temperature, gas concentrations, and smoke layer heights in multi-compartment fires. cFast has only been partially validated against experimental results. (http://fast.nist.gov/)
- CONTAM is another multi-compartment modeling program. CONTAM can be used for assessing air movement in a building and is useful in evaluating toxicity and visibility in fire scenarios. (http://www.bfrl.nist.gov/IAQanalysis/index.htm).

Fire tests can also be used to demonstrate the potential difference in damage that would be experienced should a fire occur in a dwelling. Both scale and full size fire tests can be utilized to determine the effect of a residential sprinkler system on a house or room.

<u>What are the reductions in losses from residential fires that can be attributed to sprinklers?</u>

Two types of losses are present in residential fires: property loss and loss of life/injury. In terms of property loss, there can be a partial or complete loss of the home and its contents. There may be sentimental value associated with lost objects that are difficult to price. If a home is unfit for the residents to return to, there is also the cost of temporary housing to consider.

Deaths and injuries can be monetized as discussed elsewhere in this report. In 2000, the total lifetime costs (medical costs and loss of productivity) for fire and burn injuries were as follows:

Year 2000 ($M)

	Fatal	Hospitalized	Non-hospitalized	Total
All	3,051	1,174	3,322	7,546
Male	2,160	814	1,869	4,842
Female	891	360	1,453	2,704

From: *The Incidence and Economic Burden of Injuries in the United States*, Eric A. Finkelstein, Phaedra S. Corso, Ted R. Miller, and Associates, Oxford University Press, 2006

It should be noted that these costs are not solely based on burn injuries caused during residential fires.

According to *Basic Losses in One- and Two-Family dwellings in Fires*, from NFPA 2000 US Fire Loss Report, in one year fires cause:

- 2,920 deaths (this is consistent with the CDC's 3,922 fatal injuries from fire/burn)
- 12,575 injuries*
- $4.6 billion in damage.

** Note: "Estimates of civilian injuries are low because many aren't reported to the fire service. For example, many injuries occur at small fires to which fire departments don't respond, and firefighters are sometimes unaware of injured persons they don't transport to medical facilities."*

Since one needs to estimate the reduced losses attributable to sprinklers, which will be installed in houses with smoke alarms, one needs to know how many of the deaths and injuries occurred in dwellings with smoke alarms. It should be noted that the difference in property loss for dwellings that are protected with a sprinkler system compared to those with smoke alarms is not readily available.

The NFIRS report states that for one- and two-family dwellings, there are an estimated 9.7 deaths per 1,000 fires without sprinklers, but only an estimated 2.1 deaths in fires with sprinklers. This change is a reduction of 78%. It also reports that for one- and two-family dwellings, there is an estimated direct property damage amount of $9,600 without sprinklers and an estimated direct property damage amount of $7,800 when sprinklers are present, a reduction of 19%. The NFIRS figures are based on national averaged data while the Scottsdale and Prince George's County figures are based on a small number of case studies. The benefit derived from sprinkler protection in dwellings can be dependent on many a variables: size of house, construction practices, proximity to other dwellings (potential damage to adjacent properties), cost of repairs, maintenance of system, education of consumer, fire department response time, etc. This analysis uses the lower NFIRS reduction figures because they are the most comprehensive, and would reflect most of the above variables

The NFPA report *U.S. Experience with Sprinklers and Other Fire Extinguishing Equipment*, Kimberly D. Rohr and John R. Hall, Jr., August 2005, discusses an analysis conducted by the National Institute of Standards and Technology (NIST) of the estimated impact of sprinklers on home fires and associated losses. The NFPA report includes the following discussion of the reduction of deaths attributable to sprinklers:

> “Note that the NIST analysis shows how sprinklers and smoke alarms both have an essential role to play in providing life safety from fires in homes. If smoke alarms are introduced first (which is the way most people would do it), the NIST study estimates fire death rates would fall by 52%. Adding sprinklers would further reduce by 63% the 48% of the original death rate that remains, producing a 30% reduction relative to that original death rate, or a total reduction of 82%. Or, if sprinklers were introduced first, the original death rate would be estimated to fall by 69%. Then adding smoke alarms would reduce by 42% the 31% of the original death rate that remained, producing a 13% reduction relative to that original death rate, for the same total reduction of 82%. What this means is that sprinklers will save many people who would not be saved by smoke alarms, and smoke alarms will save many people who would not be saved by sprinklers.”

Deaths: The CDC reported: “Smoke alarms decrease the chances of dying in a house fire by 40 to 50%. However, about one quarter of U.S. households lack working smoke alarms [Ahrens 2001].” Therefore the number of deaths in dwellings with smoke alarms can be computed as follows:

- 2003 American Housing Survey (for estimating purposes we use these with 2000 loss estimates):
  - 74,026,000 occupied dwellings
  - 18,506,000 without smoke alarms (25% of dwellings)
  - 55,520,000 with smoke alarms.
- Assuming the chance of dying in a house with smoke alarms is 50% of the chance in a home without them, we compute that the 2,920 deaths reported by NFPA are as follows:
  - 1,168 deaths in unalarmed dwellings (18,506,000)
  - 1,752 deaths in alarmed dwellings (55,520,000).

Injuries: There is a huge discrepancy between NFPA estimate of 12,575 and CDC’s reported 24,519 hospitalized and 745,935 non-hospitalized fire/burn injuries. This difference is attributable in part to the fact that many fire/burn injuries are not caused by fires, and may also be due in part to the limitations of the NFPA estimates. In the absence of additional research, the NFPA estimate will be doubled to 25,000 injuries. In order to estimate the injuries that occurred in dwellings with smoke alarms we assume the same reduction in risk as for deaths: 1,752/2920 x 25,000 = 15,000 injuries in alarmed dwellings (55,520,000).

Quantification of Losses per Alarmed Dwelling

Deaths (based on CDC report)
Unit lifetime medical costs per fire/burn fatality: $ 16,801
Productivity losses per fire/burn fatality: $760,971
Total lifetime costs per fire/burn fatality: $777,771
Total lifetime costs of fatalities in alarmed dwellings: $1,362,654,792
Total lifetime costs of fatalities per alarmed dwelling: $24.50
Injuries (based on CDC report; assuming all the injuries are hospitalized, and ignoring the large number of non-hospitalized injuries)
Unit lifetime medical costs per fire/burn hospitalized injury: $18,818
Productivity losses per fire/burn hospitalized injury: $29,067
Total lifetime costs per fire/burn hospitalized injury: $47,875
Total lifetime costs of injuries in alarmed dwellings: $718,125,000
Total lifetime costs of injuries per alarmed dwelling: $12.93
Total costs of deaths and injuries per alarmed dwelling: $37.43
Damage (based on NFPA estimate)
Total damage in all dwellings: $4,600,000,000
Total damage per occupied dwelling: $62.14

Step 5 Example: "Sprinklers in the IRC"

Annual Reduction in Losses from Alarmed to Sprinklered Dwellings

Assuming a baseline reduction in deaths and injuries of 30% (NIST analysis reported by NFPA) the annual benefit per dwelling is $11.23. Assuming a baseline reduction in damage of 19% (NFIRS) the annual benefit per dwelling is $11.81. The total annual benefit from sprinkler installation per dwelling, ignoring the reduction in quality of life losses, is $23.04.

6. “Step 6: Perform a Benefit Analysis and Integrate It Into a Cost-Benefit Analysis”

Applicability

In the case of code changes where benefits can be measured by means of simple calculation methods and models, the benefit analysis should be implemented. The analysis should clearly document the beneficiary, the point in time (or year) at which the benefit is realized, or the annual probability that it will be realized.

In the case of benefits that are not directly monetized, such as reduced deaths and injuries or improved public health, a decision must be made whether Federal guidance on monetizing such benefits are applicable to the analysis, or whether the benefits should remain unmonetized, and reported as such.

In the case of code changes where benefits can be measured only by use of more elaborate models, it may not be possible to demonstrate the benefit analysis in this elaboration of the methodology. However, all the information necessary to do so will have been presented in step 5.

The combination of the cost analysis of step 3 of this methodology with the benefit analysis of this step can be done by applying ASTM E 964, *Practice for Measuring Benefit-to-Cost and Savings-to-Investment Ratios for Buildings and Building Systems*. Since both the costs and the benefits of code changes are characterized by varying uncertainties (uncertainties of estimation, uncertainties of probabilistic events, uncertainties of future conditions, etc.) it is necessary for the benefit cost analysis to be subjected to a sensitivity analysis. This analysis should be done in accordance with a methodology developed by the Office of Applied Economics at the Building and Fire Research Laboratory of NIST.

The Office of Applied Economics has not addressed building code provisions since the 1978 (NBSIR 78-1528, *An Economic Analysis of Building Code Impact: A Suggested Approach*, John S. McConnaughey, Jr., October 1978). However, in four recently published reports they have discussed the cost and benefit metrics that would be applicable to cost benefit analyses of code provisions:

- NISTIR 5863, *Benefits and Costs of Research: A case Study of the Fire Safety Evaluation System*, July 1996.
- NISTIR 6303, *Benefits and Costs of Research: A case Study of Cybernetic Building Systems*, March 1999.
- NISTIR 6501, *Benefits and Costs of Research: A case Study of Construction Systems Integration and Automation Technologies in Industrial Facilities*, June 2000.
- NISTIR 6763, *Benefits and Costs of Research: A case Study of Construction Systems Integration and Automation Technologies in Commercial Buildings*, December 2001.

The methodology used in these studies is a two-stage methodology that is summarized as follows:

> “*In the first stage, a baseline analysis was performed. In the baseline analysis, all input variables used to calculate the economic measures are set at their likely values. It is*

> *important to recognize that the term baseline analysis is used to denote a complete analysis in all respects but one; it does not address the effects of uncertainty. In the second stage…input variables were varied both singly and in combination according to an experimental design. Monte Carlo simulations are employed to evaluate how changing the value of these variables affects the calculated values of the economic measures”.*

Format for Summarizing the Economic Impacts of Code Changes

The results of the cost-benefit analysis conducted in this Step 6 should be summarized and reported in accordance with ASTM E 2204, *Standard Guide for Summarizing the Economic Impacts of Building-Related Projects*, which includes the following format (edited for this methodology, see “Step 6, Figure 1”):

<table>
<tr><td>1.a Significance of the Project: <i>[Step 1 of methodology]</i>
• Describe why the project is important and how the organization became involved.
• Describe the changes brought about by the organization.</td><td>1.b Key Points:
Highlight two or three key points which convey why this project is important.</td></tr>
<tr><td colspan="2">2. Analysis Strategy:
• Describe how the present value of total costs both internal and external [stemming from all contributors to the project was determined]. <i>[Steps 2 and 3 of methodology]</i>
• Describe how the present value of total benefits (savings) both internal and external [stemming from all contributions to the project was determined]. <i>[Steps 4 and 5 of methodology]</i>
• Describe how the present value of net benefits (savings) both internal and external was determined.
Summarize key data and assumptions: (a) base year; (b) length of study period; (c) Discount rate or minimum acceptable rate of return; (d) data; and (e) other. <i>[Step 6 of methodology]</i></td></tr>
<tr><td rowspan="2">3.a Calculation of Benefits, Costs, and Additional Measures: <i>[Step 6 of methodology]</i>
Total Benefits (Savings): Report the present value of the total benefits (savings) [attributable to the organization].
Total Costs: Report the present value of the total costs [attributable to the organization].
Net Benefits (Savings): Report the present value of the net benefits (savings) [attributable to the organization].
Additional Measures: Report the values of any additional measures calculated.</td><td>3.b Key Measure: <i>[Step 6 of methodology]</i>
Report the calculated value of the Present Value of Net Benefits or <i>the Present Value of Net Savings</i> [attributable to the organization carrying out the project or conducting the research] and at least one of the following:
• Benefit-to-Cost Ratio <i>or Savings-to-Investment Ratio</i>
• Adjusted Internal Rate of Return</td></tr>
<tr><td>3.c Traceability
Cite references to specific ASTM standard practices, ASTM adjuncts, or any other standards, codes, or regulations used.</td></tr>
</table>

Step 6, Figure 1. Edited format for summarizing benefit-cost analyses

The following example for “7-11 Residential Stairs” describes the analysis steps required to assess benefits and then integrate all prior analyses into a cost-benefit argument for or against a code change proposal. The example addresses the following topics:

1. Homeowners Benefit-Cost Analysis
    - Baseline analysis
    - Sensitivity analysis
    - Quality of life
    - Conclusion
    - Summary of the Economic Impacts of “7-11 Residential Stairs.”

2. Health Insurers Benefit Analysis

Step 6 Example: “7-11 Residential Stairs”

Step 6 Example: 7-11 Residential Stairs

Both the cost and benefit metrics are applicable to individual residential stairs, and it is recommended to conduct the owner/occupant’s benefit-cost analysis per individual residential stair. The 7-11 residential stair code change is characterized by a single initial capital investment (the incremental cost per stair of changing from the current IRC 7 ¾-inch maximum rise and 10-inch minimum tread to the proposed 7-inch maximum rise and 11-inch minimum tread) and uniform annual benefits (the reduction in the sum of annual medical costs and productivity losses per stair) over the foreseeable future. This is a relatively simple problem for life cycle cost-benefit analysis and requires no complicated computations. The analysis answers the question: “how many years will it take to pay back the initial capital investment when the annual benefit is discounted at a specified discount rate?”

The answer to this question can be found by referring to the Discount Factor Tables, Adjunct to ASTM Practice E 917, for Measuring Life-Cycle Costs of Buildings and Building Systems. The tables include six sets of figures:

- Single Compound Amount
- Single Present Value
- Uniform Capital Recovery
- Uniform Present Value
- Uniform Sinking Fund
- Uniform Compound Amount.

These sets of figures are presented for a period of up to 40 years in 15 tables for discount rates from 1% to 25% respectively.

To find the payback period of a single capital investment by a uniform annual return it is necessary to use the Uniform Present Value figures. Uniform Present Value is expressed by the following equation:

$$\frac{(1+i)^n - 1}{i(1+i)^n}$$

where i is the discount rate and n is the number of years.

OMB requires the use of both a 3% and a 7% discount rate in cost-benefit analyses of federal actions. The following table, “Step 6, 7-11 Residential Stairs, Table 1,” presents the Uniform Present Value factors for these two discount rates. For example, the investment paid back in 20 years by an annual payment of x is 14.88x at 3% discount rate and 10.59x at 7% discount rate.

Number of years	Discount Rate		Number of years	Discount Rate	
	3%	7%		3%	7%
1	0.9709	0.9346	21	15.42	10.84
2	1.913	1.808	22	15.94	11.06
3	2.829	2.624	23	16.44	11.27
4	3.717	3.387	24	16.94	11.47
5	4.580	4.100	25	17.41	11.65
6	5.417	4.767	26	17.88	11.83
7	6.230	5.389	27	18.33	11.99
8	7.020	5.971	28	18.76	12.14
9	7.786	6.515	29	19.19	12.28
10	8.530	7.024	30	19.60	12.41
11	9.253	7.499	31	20.00	12.53
12	9.954	7.943	32	20.39	12.65
13	10.63	8.358	33	20.77	12.75
14	11.30	8.745	34	21.13	12.85
15	11.94	9.108	35	21.49	12.95
16	12.56	9.447	36	21.83	13.04
17	13.17	9.763	37	22.17	13.12
18	13.75	10.06	38	22.49	13.19
19	14.32	10.34	39	22.81	13.26
20	14.88	10.59	40	23.11	13.33

Step 6, 7-11 Residential Stairs, Table 1. Uniform present value factors

Step 6 Example: "7-11 Residential Stairs"

The incremental cost per stair would have been fully analyzed under Steps 2 and 3, Describe Design and Construction Implications of the Code Change and Perform a Cost Analysis. For purposes of demonstrating Step 6 the cost figures discussed by the 7-11 code change proponent as "maximum conceivable additional cost" will be used. This comes to $150, average per-area added cost, plus $437.50, builder reported added-stair cost, totaling $587.50 per residential stair. (Clearly, in a full benefit cost analysis this number would be subjected to sensitivity analysis. Here we take it as the baseline assumption.)

Homeowners Benefit-Cost Analysis

Baseline analysis: The baseline estimate of the benefit is based on the following estimates.

- CDC estimate of the costs of fall injuries
- 11% reduction in the sum of annual medical costs and productivity losses per stair. (Note that quality of life costs are excluded at this time.)
- 67% of all stair falls are residential stair falls.

Medical costs and productivity losses for this baseline case are $78 per stair, and the 11% reduction is an annual benefit of $8.58 per stair. The payback period at both discount rates exceeds 70 year by a substantial number (beyond the range of Table 1). Note that at zero-percent discount rate, the payback period is nearly 70 years.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$8.58	68.5 years	70+ years	70++ years

Sensitivity analysis: Increasing the baseline estimate of the costs of fall injuries by 15% results in an annual benefit of $9.87 per stair, but does not shorten the payback period significantly.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$9.87	60 years	70+ years	70++ years

Maintaining the baseline estimate of the costs of fall injuries and changing the baseline assumption to 85% of all stair falls are residential, medical costs and productivity losses are $99 per stair, and the 11% reduction is an annual benefit of $10.89 per stair. The payback period is still beyond the range of Table 1.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$10.89	54 years	60+ years	60++ years

Changing the assumption for the latter case to a benefit of a 15% reduction in injuries, the annual benefit becomes $14.85 per stair and the payback period is still beyond the range of Table 1.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$14.85	40 years	50+ years	50++ years

Changing all three baseline assumptions to the maximum (increasing the baseline estimate of the costs of fall injuries by 15%, changing the baseline assumption to 85% of all stair falls are residential, and 15% reduction in injuries) results in an annual benefit of $20.25. The payback period at 0% discount rate is 29 years, but is till beyond the range of Table 1 at 3% and 7%.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$20.25	29 years	40+ years	40++ years

The annual benefit that would pay back in 20 years at a 3% discount rate is calculated to be $39.48, which would result from a 40% reduction of injuries per stair (assuming 85% of all stair falls are residential and the CDC estimate of the costs of fall injuries).

The initial cost that would be paid back in 20 years by an annual benefit of $14.85 at a 3% discount rate would be $221 (also assuming 85% of all stair falls are residential and the CDC estimate of the costs of fall injuries).

Quality of life: The preceding analyses demonstrate that the benefits of reduced medical costs and productivity losses will pay back the investment in 7-11 residential stairs in no less than 40 years, and probably well over that. In addition to reduced medical costs and productivity losses, the support for 7-11 residential stairs can be based on the reduction of quality of life costs. While the discussion on quality of life in Step 4 concluded that there are currently no accepted measures, and that monetization of quality of life is not recommended, it is still useful to examine its potential impact.

As reported in Step 4, the CPSC estimates for 1997 stair injuries consisted of $11.8 billion for medical costs and productivity losses and $38.1 billion for quality of life costs. Applying the ratio of the two to the baseline annual benefit per residential stair of $8.58 (medical costs and productivity losses results in an annual quality of life benefit of $27.70 per stair, and a total benefit of $36.28. Using this benefit with the base case assumption the payback periods are 22 years and over 40 years at 3% and 7% discount rates respectively.

Initial Cost	Annual Benefit	Payback period		
		0% discount rate	3% discount rate	7% discount rate
$587.50	$36.28	16 years	22 years	40+ years

Conclusion: In conclusion, support for the 7-11 residential stair can be based on the following conditions:

- Payback in approximately 20 years is acceptable
- An acceptable quality of life analysis is made
- Evidence is provided for injury reduction of 11% or more.

Step 6 Example: “7-11 Residential Stairs”

Summary of the Economic Impacts of “7-11 Residential Stairs”: The following, “Step 6, 7-11 Residential Stairs, Figure 1,” summarizes the preceding benefit-cost analysis.

1.a Significance of the Project:

Model codes have required stairs in commercial and institutional buildings to have maximum risers of 7-inches and minimum treads of 11- inches for over 15 years. Proposals to amend the model codes to require these limits for residential stairs have been made over the years and while their steepness has been reduced, the 7-11 proposals have been continuously rejected. Proponents of the code change have argued the deaths and injuries from stair accident will be significantly reduced with adoption of the code change. Opponents have denied this and have argued that the added cost of adopting this code change would reduce the affordability of housing. The arguments have become increasingly acrimonious on both sides of the question.

An economic analysis of the costs and benefits of the code change, one that included consideration of the costs of deaths and injuries and the benefits of the avoidance of deaths and injuries has the potential for introducing reason and rationality to the arguments over this code change, and to help resolve the question once and for all.

1.b Key Points:

1. Injuries and deaths from falls impose a significant economic burden in the United States.
2. Many falls occur in relation to the use of stairs.
3. Stair geometry may have an effect on the incidence of falls on stairs.
4. The use of the building code to make adjustments to stair geometry that may reduce the incidence of falls should be explored.
5. The beneficiaries from the potential reduction of injuries and deaths are the stair users (building occupants) health insurance companies.
6. In addition to the benefit of reduction in falls, two other benefits are attributed to stair geometry: utility and esthetics.

2. Analysis Strategy:

1. Benefits and costs from owner/occupant’s perspective were computed per individual residential stair newly constructed in compliance with the 7-11 code requirement.
2. Benefits are the annual reduction in the medical costs and productivity losses attributed to the reduction in incidence of fall on stairs. This number is based on three independent elements:
    - costs of fall injuries (base case from CDC data, uncertainty +15% based on CPSC data)
    - reduction in incidence of falls (11% as base case, and 15% and 0% assumed for sensitivity analysis
    - percentage of stair falls occurring on residential stairs (67% base case, uncertainty 85%)
3. Cost is the incremental cost to construct the 7-11 stair, with an agreed amount not subjected to sensitivity analysis in this example.
4. The analysis involves a fixed capital investment and a uniform annual return. Thus, it answers the question: “how many years will it take to pay back the initial capital investment when the annual benefit is discounted at a specified discount rate?”
5. The discount rates initially considered were 0%, 3%, and 7% (the latter two required by OMB for federal actions).

3.a Calculation of Benefits, Costs, and Additional Measures:

Total Benefits (Savings): (equal to net benefits because there are no annual costs attributable to the 7-11 stairs)

Annual benefit per residential stair

- $8.58 (base case)

Uncertainty analysis

- $9.87 (15% increase in injury costs)
- $10.89 (85% residential stair falls)
- $14.85 (15% reduction in injuries)
- $20.25 (all uncertainties at maximum)

Total Costs:

Total cost per residential stair: $587.50

Additional Measures:

N.A.

3.b Key Measure:

Payback periods at 3% discount rate:

- 70+ years (base case)
- 70+, 60+, 50+, and 40+ years for respective uncertainties

3.c Traceability

Discount Factor Tables

Adjunct to ASTM Practice E 917, for Measuring Life-Cycle Costs of Buildings and Building Systems.

Step 6, 7-11 Residential Stairs, Figure 1. Summary of the economic impacts

Step 6 Example: "7-11 Residential Stairs"

Health insurers benefit analysis

As discussed above, the health insurers' benefit-cost analysis may be conducted on the basis of annual construction of new residential stairs. The costs would be the insurers' efforts to bring about the 7-11 code change. The baseline value of annual medical costs related to all newly constructed residential stairs is determined in Step 4 to be $37.5 million (range: $24.5-47.5 million). The baseline estimate of the benefit is the 11% reduction in annual medical costs per annual newly constructed stairs. This benefit is as follows:

Baseline (67% residential stairs):	$4.125 million
Range (45-85% residential stairs):	$2.695-5.225 million.

Additionally, insurers should determine what percentage of this potential benefit would accrue to them.

The uncertainty analysis would examine the benefit of a 15% reduction and one approaching 0%.

Step 6 Example: “7-11 Residential Stairs”

7. “Step 7: Conduct an Economic Analysis of Housing Impacts”

Housing Impact Analysis, HUD, January 2006 describes an in-depth methodology, consisting of eight steps, for housing impact analysis of any regulation:

1. Identify the baseline trend without the regulation along with an appropriate timeframe and geography.
2. Get engineering estimates for direct costs to comply with the proposed regulation plus customary markups.
3. Collect or estimate supply and demand elasticities that apply to the regulated market(s).
4. Use the elasticities to calculate pass-through rates and consider the extreme cases of 0 percent and 100 percent pass-through rates.
5. Determine the range of house price changes based on the elasticities.
6. Consider indirect or secondary market effects given the size of the house price change.
7. Drill down to housing submarkets by type of housing structure and neighborhood.
8. Conduct affordability analysis by income and tenure groups with special consideration for vulnerable subgroups.

The first two steps are included in steps 1-3, and possibly steps 1-6 of the methodology proposed herein. An analyst wishing to conduct a more detailed economic housing impact analysis of a code change, including pass-through rates, house price changes based on elasticities of supply and demand, indirect or secondary market effects, and affordability analysis, is referred to *Housing Impact Analysis*, HUD, January 2006 for steps 3-8 of its in-depth methodology, as well as more detail on social costs and cost impacts on producers and competitiveness in its step 2.

APPENDIX A: Example Application of the Methodology to "Water Heater Pan" Code Change

Step 1—Description of the Code Change

Building Code	2000 International Residential Code ®
Chapter	28 - Water Heaters
Section	P2801 General
Code Text	P2801.5 Required Pan. Where water heaters or hot water storage tanks are installed in locations where leakage of the tanks or connections will cause damage, the tank or water heater shall be installed in a galvanized steel pan having a minimum thickness of 24 gage (0.016 inch) (0.4mm) or other pans listed for such use. P2801.5.1 Pan size and drain. The pan shall not be less than 1.5 inches (38 mm) deep and shall be of sufficient size and shape to receive all dripping and condensate from the tank or water heater. The pan shall be drained by an indirect waste pipe having a minimum diameter of 1 inch (25.4 mm) or the outlet diameter of the relief valve, whichever is larger. P2801.5.2 Pan drain termination. The pan drain shall extend full-size and terminate over a suitably located indirect waste receptor or shall extend to the exterior of the building and terminate not less than 6 inches (152 mm) and not more than 24 inches (610 mm) above the adjacent ground surface. (2000 International Residential Code. Copyright 2000. Washington, D.C.: International Code Council. Reproduced with permission. All rights reserved.)

Summary: The code text adds a requirement that did not previously exist in the 1998 International One- and Two-Family Dwelling Code. The code text requires an appropriate pan be installed under a water heater (storage-type or otherwise) in the event a water heater is located in a location where dripping or condensate will cause damage to the structure.

Water heater pans sit under the water heater and collect water from tank liner leaks or condensate. Typically, the pan is of sufficient size, shape, and dimension so as to catch all water and other discharge dripping from the water heater and its associated connections and usually accommodates tanks of various sizes.

Drip pans have an opening for a drain hose to act as a means for discharging water collected in the pan to the exterior of the home or a suitably located floor drain via waste plumbing. Therefore, in addition to the requirement to install a pan meeting certain specifications, the code text provides complementary requirements addressing proper draining and termination for piping away collected water.

Scope/Applicability: The code change affects all categories and types of new residential structures covered by the International Residential Code (single family dwellings and multiple single family dwellings not more than 3 stories in height with separate means of egress). The local building authority will have some discretion as to which water heater locations are determined to be subject to damage and whether storage-type and tankless/instantaneous water heaters are subject to the drip pan requirements. The application of the code requirement to existing construction is also subject to the discretion of the local building authority. However, this analysis only includes the application of the code requirement to new construction because the variables involved and research required to generate estimates for existing construction are beyond the scope of this research project

This code change language provides no other restrictions or distinct limitations on its application. However, geographic and regional construction practices can affect the potential impacts of the code requirement and such practices are further explored and explained in step 2.

Records of supporting and/or opposing statements: There is no readily available record of supporting or opposing statements on this specific issue for the code development cycles prior to 2000. The 2000 edition of the International Residential Code is the first edition and followed the 1998 International One- and Two-Family Dwelling Code. The 1997 International Fuel Gas Code, also in its first edition contained substantially similar code text, having the same design and construction impacts. Thus, the adoption of the requirements into the 2000 IRC may not have been subject to a great deal of scrutiny and opposition.

Step 2—Description of Design and Construction Implications of the Code Change

How many single family homes are constructed in the United States? In calendar year 2005, about 1,637,000 new single family homes were completed[4]. This code change analysis assumes that all newly constructed single family dwellings in the United States would be subject to this code requirement as it is beyond the scope of this project to ascertain specific code adoptions by the more than 44,000 individual authorities having jurisdiction. Further this analysis does not include affects on home remodeling and reconstruction projects where building permits and enforcement of current code requirements may or may not be enforced for existing structures.

How many single family homes will be subject to the code requirement? Since the code language allows for a subjective decision as to which water heater locations, upon dripping or condensation, may have potential to damage the structure, there is a certain number of new homes that will not be subject to the code requirement. In order to make preliminary estimates on the number of homes affected by the code change, a general analysis of new home characteristics must first be completed. Table 2-1, provides the geographic distribution of new home production reported by the US Census Bureau for calendar year (CY) 2005.

Table A-1, New Homes (CY 2005)

Region[1]	New Single Family Homes
Northeast	132,000
Midwest	307,000
South	761,000
West	437,000
Total	1,637,000

[1] For a breakdown of the states included in each region, visit the US Census Bureau at http://www.census.gov/const/www/newresconstdoc.html#regions

The construction practices of certain regional areas have an indirect affect on the design and construction impact of a code change. The design and construction impacts of the water heater drip pan requirement can depend on general home construction features such as the type of foundation and the option for an attached garage. For example, homes constructed over unfinished basement foundations are more likely to have water heaters installed in the basement and therefore such installations would not be likely to cause damage in the event of water drips or condensate. Similarly, water heaters installed in a garage may also be determined as unlikely to cause damage in the event of drips or condensation. In both examples, since the installations are not likely to cause damage, it is reasonable to conclude that there would not be a requirement for the drip pan and therefore no resulting impact.

This analysis takes into account the type of home foundation and type of parking facility as the two major factors in determining the overall impact of the code change and consequently any design and construction implications. Table A-2, identifies the type of foundations constructed for each region and Table A-3, identifies the type of parking facility and the general distribution of each among the four regions reported by the US Census Bureau.

Table A-2, Types of Foundation by Region

Region	Full or Partial Basement	Slab, crawlspace, or other type
Northeast	104,000	28,000

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[4] Source 2006 U.S. Census Bureau

Midwest	241,000	66,000
South	90,000	671,000
West	70,000	367,000

Table A-3, Types of Parking Facility by Region

Region	Garage	Carport or no parking facility
Northeast	112,000	20,000
Midwest	288,000	19,000
South	662,000	99,000
West	423,000	14,000

Upon reviewing the number of homes in each region and the distributions of the type of foundation and type of parking facility, it becomes possible to develop a representative housing type(s) allowing one to estimate the percent distribution within each region. Review of the census data indicates that garage-type parking facilities are most prevalent in all regions (incorporated in more than 90% new homes) and basement-type foundations are more common in the Northeast and Midwest (incorporated in more than 78% of new homes), and slab or crawlspace foundations are more common in the South and West (incorporated in more than 87% of new homes).

However, no data was found on the number of homes with a garage in which the water heaters are installed in the garages and similarly there was no data found on the number of homes constructed with finished basements or the extent to which water heaters are installed in unfinished basements. Therefore, in the absence of specific data further identifying the different combinations and installation locations of water heaters, certain rationally-based assumptions must be made. Thus, based upon industry experience and observation of construction practices, this analysis makes the following assumptions:

- 50% of basements are finished at the time of home construction
- 90% of homes constructed with a carport or without a parking facility are built on slabs or crawlspaces
- 25% of homes constructed with a garage but without a basement will have the water heater installed therein
- 5% of homes constructed with a garage and a basement will have the water heaters installed in the garage
- 5% of homes constructed with a garage and a basement will have the water heaters installed where it is likely to cause damage
- 90% of homes constructed with a garage and a basement will have the water heater installed in the basement

Taking into account these assumptions and the census data for calendar year 2005, Table A-4 provides a summary of results from applying the above assumptions to the census data:

Table A-4, Representative Characteristics for Housing Units

Region	Water Heater Located in Garage	Water Heater in Finished Basement	Water Heater in Unfinished Basement	Water Heater not in Garage or Basement
Northeast	7,600	46,900	46,900	30,600
Midwest	24,180	108,545	108,545	65,730

South	149,480	40,995	40,995	529,530
West	92,030	31,570	31,570	281,830
Total	273,290	228,010	228,010	907,690

Therefore, the total number of new housing units affected by the code change totals 1,135,700 (228,010 + 907,690).

How may water heater units are typically installed in an affected structure? Industry data indicates that over 9 million storage-type water heaters are sold each year, and industry experts suggest that about 80% of units sold (7,200,000) are to replace existing units. The industry experts also suggest that a certain number of water heater units sold are exported, however specific data quantifying exported units is not publicly available. Therefore, comparing this data to the number of newly constructed housing units indicates that one storage-type water heater is installed in each unit comprising about 20% of new water heater shipments.

This analysis does not consider the use of alternative water heating technologies such as tankless or instantaneous water heaters because they are relatively new to the market and currently do not have a major market share. In addition, uniform enforcement and applicability of the code provisions has not yet been established. Therefore, while the potential design and construction impacts relevant to alternative technologies are not considered herein, they are assumed to be insignificant in this analysis.

How do the requirements for termination affect design and construction? In addition to the prescriptive requirement to place a drip pan under each water heater, there is a complementary requirement that those installations be properly completed to ensure adequate draining of any collected water. This complementary provision requires the installation of drain piping to the exterior of the home, or to a drain. Thus, placement of the water heating appliance within the structure has a direct impact on the cost of materials and labor associated with completion of the drain piping. Some construction may include the placement of the water heating appliance on a second story or within an attic area, however it is not common and therefore determined not to be a representative type. Through industry experience and observation of construction practices, generally, water heating appliance installations are located near an exterior wall of a home, thereby keeping required materials and labor necessary to pipe the drain to the exterior to a minimum.

Step 3 – Perform a Cost Analysis

Net hard first costs of construction: Through first hand observation of construction that conforms to the requirements followed by research and investigation of actual material costs, estimates of the net hard first costs of construction can be formulated. Materials are identified as the drip pan itself, the required drain pipe and fittings necessary to route to the exterior of the home, including 3 elbow fittings to route the termination 6" above but no more than 24" above ground surface and an approved sealant to make the penetration of the exterior wall weather-tight.

It is estimated that skilled labor is required for about one-half hour in excess of the normal time it would take to install a water heater. The installer would complete installation of the pan as well as installation of necessary drain pipe to the exterior. Table A-5 provides a tabular summary and totals for both low and high bounds to comply with the code requirements for one housing unit.

Table A-5, Hard Cost Breakdown per Housing Unit

Cost Element	Low	High
Drip Pan	$10	$15
Drain Pipe (3/4" PVC)	$10	$15

Exterior Weathertight Sealant	$2	$4
Labor (30 minutes skilled labor)	$38	$50
Total	$60	$84

Thus the net hard first costs of construction have a potential range between $60 per housing unit and $84 per housing unit.

Soft costs of design and construction: Soft costs related to this code change include minimal engineering time to develop the method of compliance and actually design the drain pipe route to the exterior of the home. From observation of designs and specifications, as well as industry experience, this time requirement is estimated at 15 minutes per generic home model design or individual home design. Thus, it is necessary to complete two analyses: one analysis for soft costs applicable to a generic model where the cost is distributed over multiple homes, and another for the soft costs associated with a custom home. The time estimate for engineering labor is 15 minutes totaling $27.50 (at $110 per hour)

Upon analyzing this cost and apportioning this cost per housing unit, the soft cost impact becomes insignificant with respect to the hard costs of compliance. For the purposes of this analysis, it is conservatively assumed that a generic home model design used by large builders will be used in a minimum of 20 homes constructed in a given year. Thus, the per-unit soft cost for a generic home model design is calculated to be $1.38 ($27.50 / 20 homes) and the soft costs for a home built by a small home builder would amount to the entire $27.50.

Life cycle costs of operation and maintenance: All parts of the drip pan and drain line assembly, including the termination and penetration of the pipe to the exterior must be visually inspected by a homeowner on a routine basis to ensure that the water heater is not leaking and all components are performing as designed. This routine visual inspection is critical in order to realize the benefits associated with this code change as described in Steps 4 and 5. However, this analysis need not consider the costs associated with the homeowners’ time to conduct such inspections because homeowner analysis does not need to be extensive or intrusive. This analysis also assumes that all components have an anticipated life at least as long as the water heater unit itself. The life of a water heater has been estimated at 12 to 15 years by industry experts. Thus, there are no associated life-cycle costs of operation or maintenance.

Aggregated Costs: This analysis assumes 1,135,700 homes would be impacted by the code change annually based on the information from the Step 2 analysis. This requires all such single family homes to be subject to the hard and soft costs of complying with the water heater pan and drain requirements starting in year 2000.

Based on industry experience, it is estimated that about 70% of new home construction is completed by “small” home builders and the remaining 30% by “large” home builders. It is assumed that due an advantage in buying power and economies of scale, large home builders are in the best position to take advantage of the lowest hard and soft costs and conversely small builders tend to experience higher costs. Thus, the aggregate cost information is calculated based upon application of these cost differentials and shown in Table A-6.

Table A-6, Soft, Hard, and Aggregate Cost Information

Cost Type	Small Home Builders	Large Home Builders
Production	794,990 homes	340,710 homes
Hard Costs	$66,779,160[1]	$20,442,600[2]
Soft Costs	$21,862,225[3]	$470,180[4]
Total Costs	$88,641,385	$20,912,780
Unit Cost	$111.50 per home	$61.38 per home

Aggregate Cost	$109,554,164 (based on weighted average of hard and soft costs)

[1] $84 per home
[2] $60 per home
[3] $27.50 per home
[4] $1.38 per home

Step 4 – Benefit Distribution and Metrics
For this proposed code change, limitations in available information lead to some levels of uncertainty and thus are open to interpretation. Regardless of limitations in available information, an analysis of benefit distribution and metrics for a water heater drip pan should involve asking and answering a series of questions. Step 4 is designed to provoke thought and provide rationale answers on the benefit distribution and metrics for the water heater drip pan code change.

What are the categories of benefits attributable to the code change? The code change requiring a water heater drip pan, as incorporated into the 2000 International Residential Code, is design to reduce or eliminate water damages resulting from a failing water heater or excessive condensation formed on the exterior of the appliance. The primary benefit realized from this code change is the reduction in water damages to structures caused by leaking or condensation from water heater tanks.

What are the potential benefits of water damage reduction? In order to identify the benefit associated with reducing water damages, one must first identify the water damage costs and then estimate the reduction in these costs attributable to the specific code change.

There are several categories of costs associated with water damage to a home. The primary costs generally result from completing repairs necessary to rehabilitate the structure. Secondary costs result from productive time and personal property type losses and tertiary losses include the time and money needed to adjudicate legal proceedings that may result from liability-type lawsuits.

Primary Costs: The insurance industry is the best source for obtaining information on primary losses due to water damage. According to insurance industry experts, hot water heater tank leaks are now one of the largest costs covered by residential insurers because the majority of storage-type water heaters experience a major leak before internal components reach the end of their service life.

The insurance claims for water leaks caused by water heater tank failures and ruptures run into the hundreds of millions of dollars annually. Each water heater tank failure has the potential to cause significant damage to floors, walls, ceilings, furniture, electronics, and family possessions. Even a small, slow leak can soak into wood product flooring and cause the floor to decay and create conditions conducive to mold growth. Leaking water can also seep into carpeting, create mildew and permanently stain walls. The primary cost of a water leak comes in having to repair damages to drywall, foundation, and finished flooring.

In the United States literally billions of dollars in insurance claims are processed due to water damage. According to a recent nationwide analysis conducted by Safeco Insurance, one out of every 10 water-damage claims can be traced back to a malfunctioning hot water heater tank or washing machine.

Water heater industry experts claim the average life of a water heater is conservatively estimated at 12 years. It is also estimated by insurers that more than 250,000 water heater failures result in damage attributable to water heater leaks or tank liner failures. For its nationwide study, Safeco analyzed three years of water damage claims from approximately one million homeowner’s insurance customers in 44 states. The review found the typical cost to repair water damage is currently about $5,000 per claim. While this cost is reported for all water damages, it is reasonable to assume that regardless of water source, repair costs are typical because of the type and extent of repairs are similar. Typical deductibles carried on homeowner’s insurance policies are either $500 or $1,000. It is reasonable to add this deductible to the cost of a paid claim as it is a cost assumed by the homeowner that not accounted for by the insurance companies.

This analysis, based on the insurance industry study, assumes that the 250,000 water heater failures are attributed only to homes with insurance. Uninsured homeowners and renters are estimated to represent about 29% of occupied units based on data in the 2005 U.S. Census Bureau American Housing Survey. Extrapolating the number of water heater failures to account for water heater failures for uninsured properties yields a figure of 352,000 failures.

This analysis further assumes that twenty percent of 352,000 water heater failures will occur in units installed in new construction that contains a water heater drip pan, because it was previously determined that twenty percent of water heaters are installed in new construction. Therefore, it is reasonable to conclude that there would be 70,400 water heater failures from original installations completed to the new code requirement.

The code change subject to this analysis is directly aimed at reducing theses primary costs and in doing so creates potential primary benefits that can be identified as reduced insurance claims and losses and reduced deductible payments.

Secondary Costs: Associated with building damages, lives are disrupted by the damage, and much time is spent getting estimates and navigating through inconveniences caused by the actual repair work. Often the repairs require multiple skilled tradesmen (drywall, flooring, carpenters, etc.) over a period of weeks or months. In addition to dealing with the direct impacts of repairing the water heater leak, homeowners ultimately bear the cost of insurance claims through increased premiums and/or higher deductibles in addition to those associated with cleaning up all of the water, drying carpets and other possessions, etc.

Safeco Insurance indicates that some water damage is covered under homeowners insurance, but some damage is not. Thus, homeowners who fail to maintain appliances and plumbing systems may face the total costs for repairs.

The code change subject to this analysis also has potential to reduce these secondary costs and in doing so creates potential secondary benefits that can be identified as insurance premium discounts, reduced out-of-pocket expenses, and increased protection of personal property/assets. However, it is beyond the scope of this project to determine and estimate such secondary benefits.

Tertiary Costs: Another more recent concern is preventing mold from taking hold inside walls, floors or ceilings that may be more difficult or impossible to dry out completely. The growing frequency of mold-related claims and lawsuits in recent years has sent insurance premiums soaring and in many cases has led insurers to deny certain water damage claims. However, data is not readily available on the cost or number of lawsuits related to water damage or mold.

The code change subject to this analysis also has potential to reduce these tertiary costs and in doing so creates potential tertiary benefits that can be identified as increased customer satisfaction, reduced litigation, and increased demand for products meeting the code requirements.

Who accrues the benefits? A broad view of the potential benefits for the code change indicates the benefits for the water heater drip pan and drain requirement accrue over several years and to several beneficiary categories including homeowners, occupants, insurers, product manufacturers, home builders, and product installers. Table A-7 provides a listing of potential beneficiaries and the related measurable benefits.

Table A-7, Identification of Beneficiaries and Metrics

Beneficiary	Metric
Homeowner or occupant	Insurance premium discounts
	Peace of mind, protection of assets
	Possible lower insurance premiums
	Deductible savings
	Out of pocket expenses for repairs and clean up
Insurers	Reduced water damage claims and losses
	Increased customer satisfaction
Home Builders	Prevention or reduction of liability or other lawsuits
	Increased customer satisfaction
Product Installers	Prevention or reduction of liability or other lawsuits
	Increased customer satisfaction
Product Manufacturers	Increased demand for more or newly required product(s)
	Prevention or reduction of liability or other lawsuits
	Increased customer satisfaction

Step 5 – Benefit Measurement Models and Their Characteristics

No existing benefit/cost models appear to exist for analyzing the added cost of a required drip pan to water heaters such as exists for code changes addressing hurricane and fire. For example, the Florida Commission on Hurricane Loss Projection Methodology uses a Monte Carlo simulation tool (the HURLOSS model) to estimate the effect of code changes for damages incurred during hurricanes. NIST and the Building and Fire Research Laboratory have developed models to generate cost benefits to fire-based research and evaluation systems.

In addition, NIST and PATH have been quite involved with durability and life-cycle analysis of building materials. Stochastic models are the primary mathematic tool used by NIST for their material service life research. PATH has developed a web-based modeling tool called Durability Doctor designed to guide consumers to the optimal material based on cost and service life. These models and other life-cycle analysis efforts, while useful, have been focused primarily upon external claddings such as siding, roofing, coatings and sealants. Life cycle analysis has been supported by material interest groups representing wood, plastic, and alloy trade groups. Little publicly-available work has been performed on the service life and associated costs with internal building components including appliances such as water heaters.

Consequently, the benefit analysis for drip pans is approximate at best and involves many assumptions as discussed and rationalized in previous steps. These include the following:

Table A-8, Assumptions Used during Analysis

Category	Baseline	Upper Limit	Lower Limit
Number of Houses Affected	1,135,700	1,476,410	794,990
Drip Pan Hard Cost/Unit	$72	$84	$60
Design/Soft Cost/Unit	$19.66	$27.50	$1.38
Lifespan (years)	12	15	9
Discount Rate (%)	7	9	5
Water heater failures/year	70,400	91,520	49,280
Cost per failure	$5,750	$6,000	$5,500

Baseline values for many of the categories have been described in previous sections. For the number of houses affected, the upper and lower limits were established by arbitrarily adding or subtracting 30% of the baseline value respectively. The drip pan hard cost is based on the costs for custom and production builders with the baseline being the average of the two. The soft cost per unit baseline is a weighted average for the estimated soft costs for custom and production builders based on estimated volume for each builder type. The lifespan baseline is based on the lesser value for service life previously defined in step 3. The lower limit for lifespan based on the increment established between the baseline and the upper limit. The guidance given for federal decision-making by OMB is to use a 7 percent discount rate and to conduct sensitivity analysis using 5 and 9 percent rates[5]. (Note that this guidance may have been superseded by OMB Circular A-4 mentioned earlier.)

Benefits attributed to the water heater drip pans will only address the aforementioned primary costs referred to in Step 4. Secondary and tertiary benefits representing homeowner inconvenience/time and mold costs respectively will not be addressed by this analysis due to a lack of research correlating water heaters to these costs but may have significant impact of the results of a complete and thorough analysis. The number of water heater failures per year is assumed to be 70,400 based on insurance estimates and adjustments to account for uninsured property and original equipment. In a similar fashion for the number of homes affected by the code change, a 30% value was used to establish an upper and lower limit. The $5,750 per claim for the baseline benefit was adjusted from $5,500 to $6,000 to account for varying, common deductible payments.

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[5] OMB Circular A-94, http://www.whitehouse.gov/WH/EOP/OMB/html/circulars/a094/a094.html#5

Step 6 – Perform a Benefit Analysis and Integrate it into a Cost Benefit Analysis

NIST and the Department of Commerce list a summary of appropriateness for a variety of standardized evaluation methods based on decision type.[6] For decisions of accepting or rejecting a technology (in this case a code change), the methods of present value of net benefits (PVNB), present value of net savings (PVNS), benefit-to-cost ratio (BCR), savings-to-investment ratio (SIR), and the adjusted internal rate of return (AIRR) are suggested as being appropriate. For the purposes of demonstration, this analysis uses net present value in order to normalize costs and benefits. The constant dollars used for this analysis was assigned to 2006 – the year this analysis was performed.

The formula for Single Present Value as defined by *Discount Factor Tables, Adjunct to ASTM Practice E 917* was used as the discount factor multiplier for each year with 2006 used as the base year. The discount factor was then applied to each cost and benefit for the associated year, and summed over the 15 years. The difference between the sum of Present Value of Savings and Present Value of Costs over the 15 year time period is the Present Value of Net Savings. The ratio of the sum of present value for savings to costs is the Benefit-to-Cost Ratio. This analysis is summarized in Table A-9, with the detailed computations presented in the Annex to this appendix, Table 11.

Table A-9, Summary of the Economic Impacts

1.a Significance of the Project:	1.b Key Points:
In 2000, the International Code Council revised the International Residential Code to mandate the presence of a drip pan underneath water heaters for situations where a leak could cause substantial water damage. Water heater pans sit under the water heater and collect water from tank liner leaks or condensate. Typically, the pan is of sufficient size, shape, and dimension so as to catch all water and other discharge dripping from the water heater and its associated connections and usually accommodates tanks of various sizes. The code change affects all categories and types of residential structures covered by the International Residential Code (single family dwellings and multiple single family dwellings not more than 3 stories in height with separate means of egress). The local building authority will have some discretion as to which water heater locations are determined to be subject to damage and whether storage-type and tankless/instantaneous water heaters are subject to the drip pan requirements. This code change language provides no other restrictions or distinct limitations on its application. However, geographic and regional construction practices can affect the potential impacts of the code requirement. This project investigates the potential costs involved for the installation of drip pans and the benefits realized by their presence.	• Concern over moisture damage resulting from leakage or condensation of water heaters has resulted in a code change mandating drip pans. • The number of homes requiring water heater drip pans is not known • Damage resulting from water heater leaks is not clearly defined • The literature does not provide service life data by water heater or region • This analysis attempts to define categories of benefits and costs resulting from the code change and assign some value to these categories

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[6] Chapman, R.E, and Stephen Weber. 1996. Benefits and Costs of Research: A Case of Study of the Fire Safety Evaluation System. Building and Fire Research Laboratory, National Institute of Standards and Technology.

2. Analysis Strategy:

The objective of this project is to estimate the net cost savings, for the period 2000 through 2015, realized from adopting a code change reflected in the 2000 International Residential Code requiring drip pans for hot water heaters where the pan could prevent damage. The approach is to estimate the cost or savings in 2006 dollars.

Costs were obtained by estimating the annual number of homes affected by this code measure taking into account region, location of the home where water heater is located; and factoring the first cost of the pans and associated hardware and engineering.

Benefits attributed from drip pan installations were based on the reduction of flood damage resulting from failed water heaters. An estimate of the number of failures per year was multiplied by the estimated cost per failure. For each water heater, benefits did not accrue until after 12 years, the estimated life of the device.

Key assumptions used in this analysis include:

Category	Baseline	Upper Limit	Lower Limit
# Houses Affected	1,135,700	1,476,410	794,990
Drip Pan Hard Cost/Unit	$72	$84	$60
Design/Soft Cost/Unit	$19.66	$27.50	$1.38
Lifespan (years)	12	15	9
Discount Rate (%)	7	9	5
Water heater failures/year	70,400	91,520	49,280
Cost per failure	$5,750	$6,000	$5,500

3.a Calculation of Benefits, Costs, and Additional Measures (see Annex for present value calculations):

Present Value of Cost Savings nationwide:
Sum from 2000 to 2015 of present value of cost savings nationwide by year = $707.9 Million

Present Value of Investment Costs nationwide:
Sum from 2000 to 2015 of present value of investment costs nationwide by year = $1,579.1 Million

Present Value of Net Cost Savings nationwide:
Sum from 2000 to 2015 of present value of net cost savings nationwide by year = - $871.2 Million

3.b Key Measure: 2006 dollars

Present Value of Net Benefits: -$871.2 Million

Benefits-to-Cost Ratio: 0.45

3.c Traceability

Results reported as per ASTM E 2204 - 02

The extremely low benefit-to-cost ratios resulting from this analysis (less than 1.0) were surprising, and led the analysts to examine their assumptions. It was determined that limiting the analysis period to 16 years (2000-2015) was inappropriate for analysis of investments that do not pay back until the 13th year (baseline), or the 10th or 16th year (lower and upper limits). Under this assumption, the baseline analysis includes annual investments from 2003-2015 that provide no returns because they occur beyond the analysis horizon. A more appropriate analysis strategy should consider a much longer steady-state analysis period, such as 40 or 50 years. Alternatively, one could consider a single year's investment (2006, which is the year for which the costs were estimated), with the benefit occurring in a specific future year (10, 13, or 16). The benefit-to-cost ratios for such an investment can be computed under the various assumptions of the analysis. If it turned out to be a good investment for 2006, it would be a good investment in any other year, as long as the assumptions did not vary. The latter analysis is shown below.

<u>Baseline Analysis</u>

Investment in year 0: (based on unweighted average of hard and soft costs)	$104,100,000
Benefit in year 13:	$404,800,000
Present value of benefit (7% discount rate, single present value factor 0.4150):	$167,992,000
Benefit-to-cost ratio:	1.61

Sensitivity Analysis

This analysis of costs and benefits consists of numerous assumptions. A sensitivity analysis was performed to determine assumptions that have the greatest impact upon the results. Table 6-1 displays this analysis. All the benefit-to-cost ratios are greater than 1.00. The lowest ratios are related to the number of failures (as low as 1.13) and the number of homes (as low as 1.24). More research is recommended to provide a stronger basis for these assumptions.

Table A-10, Sensitivity of Assumptions upon Benefit-to-Cost Ratios

Variable	Range	Investment ($)	Benefit (present value) ($)	Benefit-to-Cost Ratio
Number of homes	794,990	72,900,000	167,992,000	2.30
	1,476,410	135,300,000	167,992,000	1.24
Discount rate	5%	104,100,000	214,665,440	2.06
	9%	104,100,000	132,045,760	1.27
Hard cost	$60	90,470,000	167,992,000	1.86
	$84	117,700,000	167,992,000	1.43
Soft cost	$1.38	83,340,000	167,992,000	2.02
	$27.50	113,000,000	167,992,000	1.49
Life span	9 years	104,100,000	205,759,840	1.98
	15 years	104,100,000	137,105,760	1.32
Number of failures	49,280	104,100,000	117,611,000	1.13
	91,520	104,100,000	218,373,000	2.10
Cost per failure	$5,500	104,100,000	160,688,000	1.54
	$6,000	104,100,000	175,296,000	1.68

Table A-11, Annex

Present Value Calculations Based on Affected Homes

n = 1,135,700 homes

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

n = 794,990 homes

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	72.9	-72.9	1.501	-109.4
2001	0	72.9	-72.9	1.403	-102.2
2002	0	72.9	-72.9	1.311	-95.6
2003	0	72.9	-72.9	1.225	-89.3
2004	0	72.9	-72.9	1.145	-83.5
2005	0	72.9	-72.9	1.070	-78.0
2006	0	72.9	-72.9	1.000	-72.9
2007	0	72.9	-72.9	0.935	-68.1
2008	0	72.9	-72.9	0.873	-63.7
2009	0	72.9	-72.9	0.816	-59.5
2010	0	72.9	-72.9	0.763	-55.6
2011	0	72.9	-72.9	0.713	-52.0
2012	0	72.9	-72.9	0.666	-48.6
2013	404.8	72.9	331.9	0.623	206.7
2014	404.8	72.9	331.9	0.582	193.2
2015	404.8	72.9	331.9	0.544	180.5
				Total	**-398.0**

n = 1,476,410 homes

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	135.3	-135.3	1.501	-203.0
2001	0	135.3	-135.3	1.403	-189.8
2002	0	135.3	-135.3	1.311	-177.4
2003	0	135.3	-135.3	1.225	-165.7
2004	0	135.3	-135.3	1.145	-154.9
2005	0	135.3	-135.3	1.070	-144.8
2006	0	135.3	-135.3	1.000	-135.3
2007	0	135.3	-135.3	0.935	-126.4
2008	0	135.3	-135.3	0.873	-118.2
2009	0	135.3	-135.3	0.816	-110.4
2010	0	135.3	-135.3	0.763	-103.2
2011	0	135.3	-135.3	0.713	-96.5
2012	0	135.3	-135.3	0.666	-90.2
2013	404.8	135.3	269.5	0.623	167.8
2014	404.8	135.3	269.5	0.582	156.9
2015	404.8	135.3	269.5	0.544	146.6
				Total	**-1344.5**

Present Value Calculations Based on Discount Rate

r = .07

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

r = .05

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.340	-139.5
2001	0	104.1	-104.1	1.276	-132.9
2002	0	104.1	-104.1	1.216	-126.5
2003	0	104.1	-104.1	1.158	-120.5
2004	0	104.1	-104.1	1.103	-114.8
2005	0	104.1	-104.1	1.050	-109.3
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.952	-99.1
2008	0	104.1	-104.1	0.907	-94.4
2009	0	104.1	-104.1	0.864	-89.9
2010	0	104.1	-104.1	0.823	-85.6
2011	0	104.1	-104.1	0.784	-81.6
2012	0	104.1	-104.1	0.746	-77.7
2013	404.8	104.1	300.7	0.711	213.7
2014	404.8	104.1	300.7	0.677	203.5
2015	404.8	104.1	300.7	0.645	193.8
				Total	**-764.9**

r = .09

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.677	-174.6
2001	0	104.1	-104.1	1.539	-160.2
2002	0	104.1	-104.1	1.412	-146.9
2003	0	104.1	-104.1	1.295	-134.8
2004	0	104.1	-104.1	1.188	-123.7
2005	0	104.1	-104.1	1.090	-113.5
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.917	-95.5
2008	0	104.1	-104.1	0.842	-87.6
2009	0	104.1	-104.1	0.772	-80.4
2010	0	104.1	-104.1	0.708	-73.7
2011	0	104.1	-104.1	0.650	-67.7
2012	0	104.1	-104.1	0.596	-62.1
2013	404.8	104.1	300.7	0.547	164.5
2014	404.8	104.1	300.7	0.502	150.9
2015	404.8	104.1	300.7	0.460	138.5
				Total	**-970.9**

Present Value Calculations Based on Hard Cost

Hard Costs = $72

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

Hard Costs = $60

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	90.47	-90.47	1.501	-135.8
2001	0	90.47	-90.47	1.403	-126.9
2002	0	90.47	-90.47	1.311	-118.6
2003	0	90.47	-90.47	1.225	-110.8
2004	0	90.47	-90.47	1.145	-103.6
2005	0	90.47	-90.47	1.070	-96.8
2006	0	90.47	-90.47	1.000	-90.5
2007	0	90.47	-90.47	0.935	-84.6
2008	0	90.47	-90.47	0.873	-79.0
2009	0	90.47	-90.47	0.816	-73.9
2010	0	90.47	-90.47	0.763	-69.0
2011	0	90.47	-90.47	0.713	-64.5
2012	0	90.47	-90.47	0.666	-60.3
2013	404.8	90.47	314.33	0.623	195.7
2014	404.8	90.47	314.33	0.582	182.9
2015	404.8	90.47	314.33	0.544	171.0
				Total	**-664.5**

Hard Costs = $84

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	117.7	-117.7	1.501	-176.6
2001	0	117.7	-117.7	1.403	-165.1
2002	0	117.7	-117.7	1.311	-154.3
2003	0	117.7	-117.7	1.225	-144.2
2004	0	117.7	-117.7	1.145	-134.8
2005	0	117.7	-117.7	1.070	-125.9
2006	0	117.7	-117.7	1.000	-117.7
2007	0	117.7	-117.7	0.935	-110.0
2008	0	117.7	-117.7	0.873	-102.8
2009	0	117.7	-117.7	0.816	-96.1
2010	0	117.7	-117.7	0.763	-89.8
2011	0	117.7	-117.7	0.713	-83.9
2012	0	117.7	-117.7	0.666	-78.4
2013	404.8	117.7	287.1	0.623	178.8
2014	404.8	117.7	287.1	0.582	167.1
2015	404.8	117.7	287.1	0.544	156.2
				Total	**-1077.6**

Present Value Calculations Based on Soft Cost

Soft Cost = $19.66

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

Soft Cost = $1.38

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	83.34	-83.34	1.501	-125.1
2001	0	83.34	-83.34	1.403	-116.9
2002	0	83.34	-83.34	1.311	-109.2
2003	0	83.34	-83.34	1.225	-102.1
2004	0	83.34	-83.34	1.145	-95.4
2005	0	83.34	-83.34	1.070	-89.2
2006	0	83.34	-83.34	1.000	-83.3
2007	0	83.34	-83.34	0.935	-77.9
2008	0	83.34	-83.34	0.873	-72.8
2009	0	83.34	-83.34	0.816	-68.0
2010	0	83.34	-83.34	0.763	-63.6
2011	0	83.34	-83.34	0.713	-59.4
2012	0	83.34	-83.34	0.666	-55.5
2013	404.8	83.34	321.46	0.623	200.2
2014	404.8	83.34	321.46	0.582	187.1
2015	404.8	83.34	321.46	0.544	174.9
				Total	**-556.3**

Soft Cost = $27.50

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	113	-113	1.501	-169.6
2001	0	113	-113	1.403	-158.5
2002	0	113	-113	1.311	-148.1
2003	0	113	-113	1.225	-138.4
2004	0	113	-113	1.145	-129.4
2005	0	113	-113	1.070	-120.9
2006	0	113	-113	1.000	-113.0
2007	0	113	-113	0.935	-105.6
2008	0	113	-113	0.873	-98.7
2009	0	113	-113	0.816	-92.2
2010	0	113	-113	0.763	-86.2
2011	0	113	-113	0.713	-80.6
2012	0	113	-113	0.666	-75.3
2013	404.8	113	291.8	0.623	181.7
2014	404.8	113	291.8	0.582	169.8
2015	404.8	113	291.8	0.544	158.7
				Total	**-1006.3**

Present Value Calculations Based on Lifespan

12 Years

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

9 Years

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	404.8	104.1	300.7	0.763	229.4
2011	404.8	104.1	300.7	0.713	214.4
2012	404.8	104.1	300.7	0.666	200.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-4.1**

15 Years

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	0	104.1	-104.1	0.623	-64.8
2014	0	104.1	-104.1	0.582	-60.6
2015	0	104.1	-104.1	0.544	-56.6
				Total	**-1579.1**

Present Value Calculations Based on Number of Failures

n = 70,400 failures/year

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

n = 49,280 failures/year

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	283.4	104.1	179.26	0.623	111.6
2014	283.4	104.1	179.26	0.582	104.3
2015	283.4	104.1	179.26	0.544	97.5
				Total	**-1083.6**

n = 91,520 failures/year

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	526.2	104.1	422.14	0.623	262.9
2014	526.2	104.1	422.14	0.582	245.7
2015	526.2	104.1	422.14	0.544	229.6
				Total	**-658.9**

Present Value Calculations Based on Cost per Failure

$5,750 per water heater failure

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	404.8	104.1	300.7	0.623	187.3
2014	404.8	104.1	300.7	0.582	175.0
2015	404.8	104.1	300.7	0.544	163.6
				Total	**-871.2**

$5,500 per water heater failure

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	387.2	104.1	283.1	0.623	176.3
2014	387.2	104.1	283.1	0.582	164.8
2015	387.2	104.1	283.1	0.544	154.0
				Total	**-902.0**

$6,000 per water heater failure

Year	Annual Cost Savings (Million $)	Annual Cost (Million $)	Net Cost Savings (Million $)	Single Compound Amount Factor by Year	Present Value of Net Cost Savings by Year (Million $)
2000	0	104.1	-104.1	1.501	-156.2
2001	0	104.1	-104.1	1.403	-146.0
2002	0	104.1	-104.1	1.311	-136.5
2003	0	104.1	-104.1	1.225	-127.5
2004	0	104.1	-104.1	1.145	-119.2
2005	0	104.1	-104.1	1.070	-111.4
2006	0	104.1	-104.1	1.000	-104.1
2007	0	104.1	-104.1	0.935	-97.3
2008	0	104.1	-104.1	0.873	-90.9
2009	0	104.1	-104.1	0.816	-85.0
2010	0	104.1	-104.1	0.763	-79.4
2011	0	104.1	-104.1	0.713	-74.2
2012	0	104.1	-104.1	0.666	-69.4
2013	422.4	104.1	318.3	0.623	198.2
2014	422.4	104.1	318.3	0.582	185.3
2015	422.4	104.1	318.3	0.544	173.1
				Total	**-840.5**

Appendix A: Example Application of Methodology to “Water Heater Pan” Code Change

APPENDIX B: Code Change Selection for Methodology Development--Stakeholder Meetings and Prioritization of Code Changes

Overview:

All members of the project team and several subject area experts selected twenty-eight code changes in a brainstorming session. These code changes were grouped in four categories in order to assure a broad representation of code changes for consideration by stakeholders at three stakeholder meetings. The four categories and the number of code changes in each were as follows:

- Structural—10 changes
- Fire and Life Safety—8 changes
- Plumbing, Mechanical, and Electrical—4 changes
- Energy—6 changes.

Each change was described in a one-page summary that generally reflected the seven selection criteria that were developed for use in the stakeholder meetings:

- Criterion-A: Identifiable design and construction implications
- Criterion-B: Identifiable cost impacts
- Criterion-C: Identifiable benefit impacts
- Criterion-D: Existence (and availability) of extensive documentation
- Criterion-E: Identifiable 'benefit' metrics
- Criterion-F: Measurable (model-able) building performance attributes
- Criterion G: Indirect, including unanticipated and/or unintended, consequences, if any.

The stakeholders were to prioritize the 28 code changes by applying the seven selection criteria. In order to structure the selection process, each group of changes was presented separately, and the stakeholders were asked to score the changes in order to arrive at the following selections:

- Structural—3 of the 10 (30% of candidates)
- Fire and Life Safety—3 of the 8 (37.5%)
- Plumbing, Mechanical, and Electrical—2 of the 4 (50%)
- Energy—2 of the 6 (33.3%).

The scoring method required each stakeholder to rate each code change for each criterion as follows: 1-strongly disagree; 2-somewhat disagree; 3-unsure/neutral; 4-somewhat agree; 5-strongly agree.

Following the initial experience at the first stakeholder meeting, the decision was to follow an absolute value scoring system: two points assigned to 1 and 5, one point assigned to 2 and 4, and 0 points assigned to 3. Thus, for each stakeholder the maximum possible score for a code change was 14 (2x7) and the minimum possible score was 0. This approach emphasizes the intensity of the positions held, rather than offsetting opposite points of view.

Characterization of the Three Stakeholder Meetings

Stakeholder meeting #1 was held at NIBS in Washington DC. It consisted mostly of trade association staff or others with a broad national policy-oriented point of view on the codes. Ten stakeholders attended of which two left early and did not participate in the scoring. The meeting was adjourned after addressing only three of the four code change categories, with an instruction to mail in scoring for the fourth category, which all but one did.

Stakeholder meeting #2 was held at the International Builders Show in Orlando. It consisted mostly of members of the NAHB Codes and Standards Committee, comprising senior personnel of homebuilders from most regions of the country. Thirteen stakeholders attended of which one left early. Eight stakeholders scored all the code changes.

Stakeholder meeting #3 was held at the Home Builders Association of Central Arizona in Phoenix. It consisted mostly of the architectural directors of local homebuilding companies who represented a local users' hands-on experience with the codes. Ten stakeholders attended, and all scored all the code changes.

Appendix B: Code Change Selection for Methodology Development—Stakeholder Meetings and Prioritization of Code Changes

Brief summaries of each of the stakeholder meetings are included in this appendix.

Scoring Results

Code Change Category		Stakeholder Meeting (selection rank)		
		1	2	3
	S	S2 – Impact protection (2)	S2 – Impact protection (3)	
		S4 – Seismic design—NEHRP (1)		
			S5 – Seismic design—panel sheathing (2)	S5 – Seismic design—panel sheathing (2)
		S8 – Foundation anchorage (3)	S8 – Foundation anchorage (1)	S8 – Foundation anchorage (3)
				S10 – Sloped roof live load (1)
	F	F2 – Sprinklers in IRC (3)		F2 – Sprinklers in IRC (3)
				F3 – 5' side yards (2)
			F4 – Stair geometry (1)	F4 – Stair geometry (1)
		F6 – Basement escape windows (1)	F6 – Basement escape windows (3)	
		F7 – Window sill height (2)	F7 – Window sill height (2)	
	P	P1 – Plumbing vent air valve (2)		
		P2 – Water heater pan (1)	P2 – Water heater pan (2)	P2 – Water heater pan (2)
			P4 – Arc fault circuit interruption (1)	P4 – Arc fault circuit interruption (1)
	E	E1 – Rewrite of Energy Code (1)	E1 – Rewrite of Energy Code (1)	
				E2 – Remove requirements that conflict with safety, health, or greatly increase expense (2)
		E4 – Incr./decr. wall insulation (2)	E4 – Incr./decr. wall insulation (2)	E4 – Incr./decr. wall insulation (1)

These are the scoring results for the top ten code changes in the four categories for each of the stakeholder meetings. The parenthetical number following each code change indicates the respective order of the selections. Sixteen code changes were scored in the top ten. The differences among the meetings may reflect the different orientation of the stakeholders.

Three code changes were scored in the top ten of all three meetings:

- S8 – Foundation anchorage
- P2 – Water heater pan
- E4 – Increased/decreased wall insulation.

Eight code changes were scored in the top ten of two of the three meetings:

- S2 – Impact protection
- S5 – Seismic design—panel sheathing
- F4 – Stair geometry
- F6 – Basement escape windows
- F7 – Window sill height
- F2 – Sprinklers in IRC
- P4 – Arc fault circuit interruption
- E1 – Rewrite of Energy Code.

The following lists all 28 code changes arranged in the order of their scoring in all three Stakeholder meetings.

1	F4 – Stair geometry	15	P2 – Water heater pan
2	E1 – Rewrite of Energy Code	16	E6 – Increase ceiling insulation in southern climates
3	F2 – Sprinklers in IRC	17	S2 – Impact protection of glazed openings
4	F7 – Window sill height	18	E5 – U-factor or SHGC limits on fenestration tradeoffs
5	E4 – Increased/decreased wall insulation	19	F8 – Garage separation
6	F6 – Basement escape windows	20	F5 – Stair lighting
7	S5 – Seismic design—panel sheathing	21	S4 – Seismic design—NEHRP

8	S8 – Foundation anchorage	22	P1 – Plumbing vent air valve
9	F1– Sprinklers in R-2	23	S7 – Seismic anchor bolts and plates
10	F3 – 5’ side yards	24	S9 – Hail exposure map & related provs.
11	P4 – Arc fault circuit interruption	25	S6 – Seismic design-interior braced wall lines
12	E2 – Remove requirements that conflict with safety, health, or greatly increase expense	26	S1 – Minimum wind speed of 10 psf
13	E3 – Permanent contact of insulation w. subfloor	27	P3 – Kitchen ventilation rates
14	S10 – Sloped roof live load	28	S3 – Internal pressurization alternative to impact protection

Note the following:

1. *The top eight code changes do not include any from the Plumbing, Mechanical, and Electrical category, with the first one, P4 – Arc fault circuit interruption, ranking 11th.*
2. *S4 – Seismic design—NEHRP, which was scored highest among Structural changes in Washington, scored 21st overall.*
3. *S2 – Impact protection of glazed openings, which scored in the top three Structural changes in both Washington and Orlando, scored 17th overall.*
4. *P2 – Water heater pan, which scored in the top two Plumbing changes in all three meetings, scored 15th overall.*

“Criteria Signatures”

The detailed scoring system enabled the project team to document “criteria signatures” for the code changes, based on whether the score was attributable to agreement or disagreement (scored equally) with regard to each of the seven criteria. The key to the signatures is as follows:

1.	strongly disagree	N
2.	somewhat disagree	n
3.	unsure/neutral	?
4.	somewhat agree	y
5.	strongly agree	Y

Following are the “criteria signatures” for the eight top-ranked changes.

F4 – Stair geometry	YYNNNny
E1 – Rewrite of Energy Code	Y?Yyy?Y
F2 – Sprinklers in IRC	YY??yYY
F7 – Window sill height	Yy?nnNY
E4 – Increased/decreased wall insulation	YY?yyyy
F6 – Basement escape windows	Yyyn???
S5 – Seismic design—panel sheathing	Yyyyyy?
S8 – Foundation anchorage	Yynn?yy

Implications for Methodology Development

Examination of the “criteria signatures” suggests strong disagreement related to several criteria for F4 – Stair geometry and some disagreement with regard to F7 – Window sill height. This suggests further that the methodology should be developed so that it addresses criteria with which there was general strong agreement as well as those with which there was strong disagreement.

The top eight code changes display variability in their respective “criteria signatures”, which is why they were recommended. In the category of Plumbing, Mechanical, and Electrical, P2 – Water heater pan was recommended.

Stakeholder Meeting 1 (Preliminary Report)

Stakeholder Meeting 1 was held on December 15, 2005 at NIBS in Washington DC. Fifteen stakeholders were invited to participate. Due to inclement weather five were unable to attend. The following stakeholders attended:

Charles Cottrell, North American Insulation Manufacturers Association
Michael Dorman, DBI Architects
Michael Fischer, Window and Door Manufacturers Association

Tom Frost, International Code Council
Jeffrey Inks, National Association of Home Builders
Rober Kordelak, National Association of Plumbing, Heating and Cooling Contractors
Ronald Majette, U.S. Department of Energy
Ronald Nickson, National Multi Housing Council
Robert Wessel, Gypsum Association
Zofia Zager, Fairfax County (ret.)

Charles Cottrell and Tom Frost left the meeting early. The following members of the project team attended: David Hattis, William Koffel, and William Whiddon. HUD GTR Dana Bres attended as well.

The meeting followed the pre-established agenda, which called for a 9 am start and a 4 pm adjournment. The purpose of the meeting was to discuss and recommend ten code changes from a list of 28, grouped into four categories: Plumbing, Mechanical, Electrical (select 2 of 4), Fire and Life Safety (select 3 of 8), Energy (select 2 of 4), and Structural (select 3 of 10). The agenda, listing and brief summary of the 28 code changes, seven criteria for recommending the selections, and scoring sheets were sent ahead of time to all the attendees. It was emphasized that discussions of the substance of the code changes and pro and con arguments were to be avoided, and merely a consideration of the appropriateness of the code changes for the development of a methodology for analyzing costs and benefits, following the seven criteria, was to be the focus of discussions.

Following a brief project overview and explanation of the purpose of the meeting, a summary of the code change selection criteria, and a presentation of the process proposed for the meeting, the first group of four changes (Plumbing, Mechanical, Electrical) were presented for discussion and voting. Despite the earlier instructions, a heated discussion developed about the substance of the first code change, and the allocated time for this group of code changes was exceeded. It was unclear if participants understood the scoring method, and the project team in the course of the voting modified it.

Three of the four groups of code changes were discussed and voted on. The fourth, Energy, was not discussed, and attendees were requested to return their selection sheets by mail. The meeting adjourned at 2 pm due to the deteriorating weather conditions.

The following eight code changes were recommended by the attendees in accordance with the scoring, and in the order of preference within each group:

Structural

S4 – Seismic design—NEHRP provisions in lower and moderate seismic regions
S2 – Impact protection of glazed openings in Wind Zones 1 and/or 2
S8 – Foundation anchorage spacing

Fire and Life Safety

F6 – Basement escape windows
F7 – Window sill height
F2 – Sprinklers appendix in IRC

Plumbing, Mechanical, Electrical

P2 – Water heater pan
P1 – Plumbing vent air admittance valve

Energy

E1 – Rewrite of the Residential Energy Code
E4 – Increased/decreased wall insulation from R13 to R15; from R19 to R21

Stakeholder Meeting 2 (Preliminary Report)

Stakeholder Meeting 1 was held on January 11, 2006 at the International Builders Show in Orlando, FL. Fourteen stakeholders were invited to participate, 13 attended and one left early. The following stakeholders attended:

Eric Borsting, ConSol, CA (left early)
Chip Dence, East End Builders, Victoria, TX
Tom Frost, International Code Council
Miles Haber, Monument Construction, Inc., Chevy Chase, MD
Ray Kothe, Kothe Contracting & Construction Management, LLC, Baton Rouge, LA

Mark Mikkelson, Andersen Corporation
Richard Reynolds, R G Reynolds Homes, Inc., Bradenton, FL
Bob Ross, G + R Construction Services LLC, Austin, TX
Matt Sigler, CP Morgan, Indianapolis, IN
Harry Smith, H. F. Smith Construction, South Weymouth, MA
Jeffrey Stone, American Forest and Paper Association
Joanne Theunissen, Howling Hammer Builders, Inc., Mount Pleasant, MI
Frank Thompson, Sweetwater Builders Inc., Cranberry Twp., PA

Jeffrey Inks, National Association of Home Builders, who helped organize the meeting, was in attendance. The following members of the project team attended: David Hattis, Christopher Fennell, and William Whiddon. HUD GTR Dana Bres attended as well.

The meeting followed the pre-established agenda, which called for a 10 am start and a 1 pm adjournment. The purpose of the meeting was to discuss and recommend ten code changes from a list of 28, grouped into four categories: Energy (select 2 of 6), Structural (select 3 of 10), Fire and Life Safety (select 3 of 8), and Plumbing, Mechanical, Electrical (select 2 of 4). The agenda, listing and brief summary of the 28 code changes, seven criteria for recommending the selections, and scoring sheets were sent ahead of time to all the attendees. It was emphasized that discussions of the substance of the code changes and pro and con arguments were to be avoided, and merely a consideration of the appropriateness of the code changes for the development of a methodology for analyzing costs and benefits, following the seven criteria, was to be the focus of discussions.

Following a brief project overview and explanation of the purpose of the meeting, a summary of the code change selection criteria, and a presentation of the process proposed for the meeting, the first group of six changes (Energy) were presented for discussion and voting. All four groups of code changes were discussed and voted on. The meeting adjourned at 1 pm as planned.

The following ten code changes were recommended by the attendees in accordance with the scoring, and in the order of preference within each group:
Structural
S8 – Foundation anchorage spacing
S5 – Seismic design—Continuous structural panel sheathing
S2 – Impact protection of glazed openings in Wind Zones 1 and/or 2

Fire and Life Safety
F4 – Stair geometry
F7 – Window sill height
F6 – Basement escape windows
Plumbing, Mechanical, Electrical
P4 – Arc fault circuit interruption
P2 – Water heater pan
Energy
E1 – Rewrite of the Residential Energy Code
E4 – Increased/decreased wall insulation from R13 to R15; from R19 to R21

Stakeholder Meeting 3 (Preliminary Report)

Stakeholder Meeting 1 was held on January 26, 2006 at the offices of the Home Builders Association of Central Arizona in Phoenix. Ten stakeholders were invited to participate and attended the meeting. Seven were the architectural managers, or similar, of homebuilders, and one each was a building components manufacturer/installer, a structural engineer, and a building official. The following stakeholders attended:
Rashel Beaver, Meritage Homes
Steve Curtis, D. R. Horton – Continental Series
Micheal Devereaux, The Ryland Group
Tracy Finley, Shea Homes
Alex Holmquist, Maracay Homes
Dominic Jarrett, U.S. Homes

Bryan Juedes, Felten Group Inc.
Bob Lee, Town of Carefree, AZ
Sue Mozer, Standard Pacific of Arizona, Inc.
Frank Serpa, Schuck & Sons Construction, Co.

Russ Brock, Vice President for Municipal Affairs at the Home Builders Association of Central Arizona, who helped organize the meeting, was also in attendance. The following members of the project team attended: David Hattis, Melvyn Green, and William Whiddon.

The meeting followed the pre-established agenda, which called for a 8 am start and a 1 pm adjournment. The purpose of the meeting was to discuss and recommend ten code changes from a list of 28, grouped into four categories: Energy (select 2 of 6), Structural (select 3 of 10), Fire and Life Safety (select 3 of 8), and Plumbing, Mechanical, Electrical (select 2 of 4). The agenda, listing and brief summary of the 28 code changes, seven criteria for recommending the selections, and scoring sheets were sent ahead of time to all the attendees. It was emphasized that discussions of the substance of the code changes and pro and con arguments were to be avoided, and merely a consideration of the appropriateness of the code changes for the development of a methodology for analyzing costs and benefits, following the seven criteria, was to be the focus of discussions.

Following a brief project overview and explanation of the purpose of the meeting, a summary of the code change selection criteria, and a presentation of the process proposed for the meeting, the first group of six changes (Energy) were presented for discussion and voting. All four groups of code changes were discussed and voted on. The meeting adjourned at 1 pm as planned.

The following ten code changes were recommended by the attendees in accordance with the scoring, and in the order of preference within each group:

Structural

- S10 – Sloped roof live load
- S5 – Seismic design—Continuous structural panel sheathing
- S8 – Foundation anchorage spacing

Fire and Life Safety

- F4 – Stair geometry
- F3 – 5’ side yards
- F2 – Sprinkler appendix in IRC

Plumbing, Mechanical, Electrical

- P4 – Arc fault circuit interruption
- P2 – Water heater pan

Energy

- E4 – Increased/decreased wall insulation from R13 to R15; from R19 to R21
- E2 – Remove requirements that conflict with safety, health, or greatly increase expense

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