Evaluation of Costs and Benefits of Significant Changes in the 2025 IBC

Executive Summary

The 2014 Indiana Building Code, based on the 2012 International Building Code, will be replaced by an updated code. The new 2025 Indiana Building Code will be based on the 2024 International Building Code, with Indiana amendments.

The new code is needed to address deficiencies in the current code that threaten public safety, correct clerical errors in the current code that create potential loopholes that could threaten public safety, recognize new technology that can reduce construction costs without an adverse effect upon public safety, and incorporate non-rule policies and interpretations that can reduce administrative burdens and reduce construction costs without an adverse effect upon public safety.

A detailed evaluation of costs and benefits was prepared using a refined version of the Affected Use Group Method of analysis that was developed by the Agency during the adoption of the 2008 and 2014 Indiana Building Codes. The evaluation shows that the fiscal impact on the regulated community as a whole is an overall ***reduction*** in cost of $4,568,000 in construction costs projected in the first year after adoption, as compared to the current code.

Updated building codes increase economic resiliency in the community. A recent study by the U.S. Chamber of Commerce found that every $1 in pre-disaster mitigation saves $13 in economic savings regardless of the cause of the disaster. For example, in 2011, a loophole in the statewide building code led to the Indiana State Fair Stage Collapse, which killed 7 people and resulted in over $50,000,000 in incurred losses to the state. Conservatively applying the methodology of the US Chamber report results in an additional $6M in savings, resulting in a total estimated fiscal savings of $10.5M.

Introduction

The current Indiana Building Code (IBC) was adopted in 2014, and is based on the 2012 International Building Code (model code). Construction practices, marketplace forces, technology changes, new product development, changing material standards, new federal regulations, and new scientific research findings are only a few of the many reasons the IBC must be updated. The current IBC, now over ten years old, is based on a model code that is over 13 years old. Codes and rules adopted by the Commission expire automatically if not re-adopted, and the code adoption and rule-making process for a new statewide building code can often take two years or more. Recent statutory changes regulate the adoption of new codes by the Indiana Fire Prevention and Safety Commission. (see, for example, IC 22-12-2.5-3 and 4.) For these reasons, the Commission began the process of adopting a new building code.

The Building Code Committee (Committee) was made up of 7 members from both the private and public sector selected by the Commission, along with a department staff member who acted as Secretary. The voting members included two fire officials, a building official, a contractor, a registered architect, a registered structural engineer, and a code consultant. The Committee held 17 public meetings from January 2024 through August 2025. Meetings were conducted in accordance with committee bylaws established by the Commission. In addition, interested members of the public attended many of the meetings both in person and virtually.

The Committee based their work upon a proposed adoption of the 2024 International Building Code (new model code), with Indiana amendments. The agenda for each meeting centered on a review of written code change proposals submitted online by voting members and the public. The proposals were discussed in a round-table format, and voted upon for approval, conditional approval, or disapproval. All meeting attendees were permitted to participate in the round table discussion, but voting was limited to the voting members present at each meeting. Fiscal impact summaries were included in the proposed changes. Staff developed a record of the adopted proposals. A record of the Committee's work was maintained by the Secretary and is posted at https://www.in.gov/dhs/boards-and-commissions/building-code-update-committee/ .

This report is an Evaluation of the Costs and Benefits of the proposed rule, based upon the work of the Committee.

Methodology

An instruction regarding the fiscal impact calculation methodology to be used by proponents of code change proposals was posted in the committee by-laws. The Commission's suggested method asked proponents to estimate the cost increase or decrease each proposal would have on a prototypical affected project. That cost was then multiplied by the number of similar projects constructed in the state in a calendar year. The later number was derived from a listing provided by the Agency that documented the number of projects filed with the Agency's Plan Review Division, broken down by use and occupancy classification. This list was posted online and is included below.

Approved Baseline Numbers for Fiscal Analysis

Occupancy Type	Sum of New Area (sq. ft.)	Total Projects
Assembly	1,749,411	933
Business	2,558,270	1,612
Educational	2,051,901	317
Factory/Industrial	4,174,493	283
High Hazard	83,769	9
Institutional	1,036,000	171
Mercantile	1,038,404	640
Mixed-Use Non-Residential	23,180,206	1843
Storage	27,152,680	882
Utility and Miscellaneous	103,850	304

- Apartments: 14,245 units
- Class II Structures: 21,778

The correlation between filed projects versus the number of released projects is assumed to be a close linear relationship, since few projects are filed and not subsequently released. It is further assumed that all projects released are actually constructed, since the agency does not have a record of abandoned projects.

In many cases code change proposals affecting all use groups are clerical items and not substantive changes, so the number of released projects does not change the calculated fiscal impact. For a substantive code change, the estimated cost impact of a single project was multiplied by an estimate of the number of projects affected from the chart. For example, if a code change impacted only assembly occupancies, the estimated cost per project was multiplied by 933. The listing of Class II structures was disregarded for this study. Class II buildings include single family homes, duplexes, and townhouses, and are regulated by the Indiana Residential Code. The Indiana Building Code regulates Class I buildings. Class I buildings are buildings that are not Class II buildings, and not Agricultural buildings.

The fiscal impact is analyzed against existing code requirements, not against new model code language that has not yet been adopted. For example, if a proposed code change would mean that a building would cost more to build than under the current code, the fiscal impact amount is listed as a positive number. If the proposed code change would mean that a building would cost less to build than under the current code, the amount is listed as a negative number.

If a proposed code change is to delete a new code requirement in order to prevent an increase in construction cost caused solely by the new code requirement, the net fiscal impact is zero. This is similar to the methodology that was developed by the Department in the August 2007 fiscal impact analysis for the adoption of the 2008

Indiana Building Code and the May 2014 fiscal impact analysis for the adoption of the current 2014 Indiana Building Code.

The individual fiscal impact statements in each code change proposal submitted by proponents were analyzed and the results of that analysis included in this report. The Committee's meeting minutes document numerous discussions about fiscal impact, and those discussions were considered in the calculations used in this evaluation. Where the Committee felt that the cost or savings that is different than the amount claimed in the code change proposal the number as adjusted by the Committee was used in the report. These differences are minor and are generally attributed to revision in the affected number of projects as listed in the remarks column of the spreadsheet.

Where a fiscal savings is attributed to no longer needing a variance, the cost is calculated using only the application fee of the variance. It is likely that many projects are constructed without knowledge or benefit of the variance process, and it is probable that a higher actual fiscal savings than the amount claimed would result from this category of code change proposal.

The size of the regulated community affected by the IBC is substantial. The IBC directly affects every citizen in the state who owns, builds, occupies, and uses a Class 1 structure. According to the website Statista, statewide GDP in the construction industry in 2023 is estimated at $16.38 billion. (https://www.statista.com/statistics/593096/indiana-real-gdp-by-industry/#:~:text=U.S.%20real%20value%20added%20to%20GDP%20in%20Indiana%202023%2C%20by%20industry&text=In%202023%2C%20the%20real%20GDP,to%20the%20total%20state%20GDP).

This amount has almost doubled from the time the current IBC was adopted. In 2011, statewide construction GDP was estimated to be $8.7 billion. The percentage of the economy impacted by construction has also increased since the last code cycle, increasing from 3.5% to 4.3%

According to the Associated General Contractors, private, non-residential construction spending in 2022 in the state totaled $6.5 billion. Spending by state and local governments totaled $6.8 billion. AGC estimated construction employment in July 2023 at 164,300, an increase of 5.6% year over year, and an increase of 9.5% from February 2020.
https://www.agc.org/sites/default/files/users/user21902/IN-US%20construction%20fact%20sheet_92023.pdf

The IBC regulates all public and private non-residential building construction and all residential building construction except one and two-family houses, so the proposed code affects somewhere in the neighborhood of $13 billion of statewide construction annually. As a result of the broad application of the IBC within the state, it is impossible to develop a single prototypical or model project that would accurately reflect the overall impact of a new building code as compared to the same project built under the current code. A similar analysis of a small group of model projects would be more time consuming and would not accurately show the fiscal impact on the regulated community as a whole. Similarly, detailed analyses of dozens of actual building types would take months of work and still risk omitting the onerous fiscal impact a small number of major code changes would have on even a few unique projects.

The affected use group method developed by the Commission for the fiscal impact study of the 2008 and 2014 IBC is more comprehensive in assessing the likely fiscal impact of code changes, and more accurate in predicting the direct impact to first year construction cost on the regulated community as a whole. The Department and Commission is made aware of the fiscal impact of various code requirements on myriad project types through the variance process with dozens of variance applications reviewed each month. The affected use group method is more effective at analyzing the fiscal impact on the state's overall Class 1 construction GDP than an analysis of a prototypical project, or a group of several prototypical projects.

While a weighing of the cost to benefit ratio of a code change that could very well mean the difference between life and death in any given scenario is difficult, especially for members who have a sworn duty to protect the public, the Committee took the issue of fiscal impact seriously and it was a topic of discussion in every proposed code change.

The committee's deliberations also factored the tendency of the market to adjust to economically significant changes. An unusually restrictive code requirement can have a chilling effect on construction of a particular type of project and construction practice; and a lenient code provision can promote certain types of projects and construction practices. This tendency was discussed and weighed by the Committee for some code changes, and the spreadsheet notes highlight where this was a major consideration.

Beyond attempting to objectively determine the impact of a new code on annual construction spending, the committee deliberations included discussions included the long term financial impact of a more resilient buildings. According to NOAA, in 2024 there were 27 weather events that each created over $1 billion in damage (https://www.ncei.noaa.gov/access/billions/). Updated building codes results in more resilient buildings, which reduce the need for emergency response after a disaster. A June 2024 report published by the U.S. Chamber of Commerce nots that every $1 spent on pre-disaster preparedness saves $13 in economic cost, damages and clean up. If the buildings in a community are resilient, a disaster response is lessened or not necessary because the buildings protected the community. The report notes that building codes are an important component to prevent or reduce the damage caused by hazards. Among the events analyzed by the report was a tornado in the Indianapolis-Carmel-Anderson metropolitan statistical area, with a population of 2.1 million people.

The committee also considered the impact of code improvements to eliminate loopholes. Drafting code language is difficult. A code provision for a Class I building can impact anything from a small single story apartment building to a new airport or a world class orangutan exhibit at a zoo. The unintended consequences of any provision has to be thoroughly considered, especially as it relates to companion codes. The market is highly adept at exploting loopholes in the code. An example of this is the 2011 Indiana State Fair Collapse. A loophole in Indiana's codes left unregulated stage rigging that was not physically attached to the stage. The collapse of the rigging killed 7 people. The disaster resulted in over $50,000,000 in incurred losses to the state.

One example of a loophole the proposed code closes is the conversion of buildings which were not previously regulated by an Indiana code. The proposed code places new limits on conversions of such buildings. At the same time, the proposed code incorporates new model code language which greatly expands the options for renovated buildings. Applying the methodology from the US Chamber of Commerce report, we conservatively estimate the new code would save another $6M in overall cost, resulting in a total estimated fiscal savings of $10.5M from the new code.

JH/jh

Revisions:

Reference from Model Code Publication	Significant differences between current code and most recent edition	Specific issues the updated code is designed to address	Change would require additional	Expected fiscal impact	Health or safety concerns addressed by code	Smartshe et #
Chapter 1	Incoroporates model code language with revisions to align with statute and GAR	Makes administrative requirements more readily available to users of the building code by following model code format instead of wholesale deleting chapter 1 as in previous codes	n/a	none	Could be argued that this would save money due to reducing potential for mistakes due to out of state design professionals, inspectors and regulated community not being familiar with GAR, but no reduction has been taken	
107	posting of live load capacity					
107.3.4.1 (now 108)	Delegated design	**Need to insert language from Alan's non-rule policy about trusses, and expand to delegated design in general**				
108.7	Delegeated design for fire alarm	**Need to add requirement for NICET fire alarm drawings, similar to sprinkler - provided at time of filing or by addendum**				
108.24.5.7	Truss language should be amended for delegated design	**Need ammendment**				
108.25	Need an amendmenet to align with "approved" definition in GAR	**Need ammendment**				
113	Need to add July 1, 1986 date					
114.6	Need to amend to reference online portal	**Need ammendment**				
202	Need definition of "Design professional" that incorporates "the Owner" for projects that don't need an architect or engineer	**Need ammendment**				
202	Amends definition of Townhouse - "See Indiana Code 22-12-1-5"	eliminates conflict with Indiana Statute	n/a	none	Adminstrative change	196
202	Deletes definition of "Townhouse Unit"	eliminates conflict with Indiana Statute	n/a	none	Adminstrative change	197

202	automatic flush bolt	Adds definition	n/a	none	Clarifies current code	
202	automatic sprinkler system	Adds definition	n/a	none	Clarifies current code	
202	basic wind speed (V)	Adds definition	n/a	none	Clarifies current code	
202	building integrated photovolatic roof covering and system	Adds definitions	n/a	none	Clarifies current code	
202	carbon monoxide source	Adds definition	n/a	none	Clarifies current code	
202	cast in place concrete equivalent diaphragm	Adds definition	n/a	none	Clarifies current code	
202	Change of Occupancy	Adds definition	n/a	none	conflict with GAR - "any change in the level of activity would become a change of use"	211-approved
202	Climate zone	Adds definition	n/a	none	Clarifies current code	
202	Coastal A Zone & High Hazard Area	Adds definition	n/a	none	Clarifies current code	
202	Combined Pile Raft	Adds definition	n/a	none	Clarifies current code	
202	Commercial Motor Vehicle	Adds definition	n/a	none	Clarifies current code	
202	Computer Room	Adds definition	n/a	none	Clarifies current code	
202	Constant Latching Bolt	Adds definition	n/a	none	Clarifies current code	
202	Continuity Head of Wall System	Adds definition	n/a	none	Clarifies current code	
202	Continuous Insulation	Adds definition	n/a	none	Clarifies current code	
202	Corridor damper	Adds definition	n/a	none	Clarifies current code	
202	Cripple wall clear height	Adds definition	n/a	none	Clarifies current code	
202	Critical circuit	Adds definition	n/a	none	Clarifies current code	
202	Cross laminated timber	Adds definition	n/a	none	Clarifies current code	
202	Custodial care	Revises definition	n/a	none	Clarifies current code	
202	Data Center	Adds definition	n/a	none	Clarifies current code	
202	Dead bolt	Adds definition	n/a	none	Clarifies current code	
202	Defend in place	Adds definition	n/a	none	Clarifies current code	
202	Deferred submittal	Adds definition	n/a	none	Conflict with GAR??	
202	Delayed action closer	Adds definition	n/a	none	Clarifies current code	
202	Direct access	Adds definition	n/a	none	Clarifies current code	

202	Doors - additional definitions				reference only	
202	Duration of Load	Definition in current code deleted	n/a	none	Clerical change	
202	Dwelling Unit, Efficiency	Adds definition	n/a	none	Clarifies current code	
202	Electric Vehicle charging station	Adds definition	n/a	none	Clarifies current code	
202	Electrical Circuit Protective System	Adds definition	n/a	none	Clarifies current code	
202	Emittance	Adds definition	n/a	none	Clarifies current code	
202	Energy Storage System, Electrochemical	Adds definition	n/a	none	Clarifies current code	
202	Engineered Wood Rim Board	Adds definition	n/a	none	Clarifies current code	
202	Exterior Exit Ramp	Adds definition	n/a	none	Clarifies current code	
202	Exterior Wall Assembly	Adds definition	n/a	none	Clarifies current code	
202	Fiber cement products	Adds definition	n/a	none	updates current code	
202	Fire Area	Revises definition	adds	$100,000	eliminates loophole in current code	
202	Fire protection rating	Adds definition	n/a	none	updates current code	
202	Fire protective curtain assembly	Adds definition	n/a	none	updates current code	
202	Fire retardant treated wood	Adds definition	n/a	none	updates current code	
202	Flammable gas	Revised definition	n/a	none	updates current code	
202	Gable	Adds definition	n/a	none	updates current code	
202	Gaming (area, machine, table)	Adds definition	n/a	none	updates current code	
202	Gas detection system	Adds definition	n/a	none	updates current code	
202	Glass Mat Gypsum Panel	Adds definition	n/a	none	updates current code	
202	Glued built-up member (deleted)	Definition in current code deleted	n/a	none	updates current code	
202	Greenhouse	Adds definition	n/a	none	updates current code	
202	Ground Snow Load	Adds definition	n/a	none	updates current code	
202	Guestroom	Adds definition	n/a	none	updates current code	
202	Gypsum sheathing	Adds definition	n/a	none	updates current code	
202	Gypsum wallboard	Adds definition	n/a	none	updates current code	
202	Hardware	Adds definition	n/a	none	reference only	

202	Higher Eductaion Laboratory	Adds definition	n/a	none	updates current code	
202	Hybrid Fire Extinguishing System	Adds definition	n/a	none	updates current code	
202	Hydrogen Fuel Gas Room	Adds definition	n/a	none	updates current code	
202	Impact Protective System	Adds definition	n/a	none	updates current code	
202	Information Technology Equipment	Adds definition	n/a	none	updates current code	
202	Insulated Metal Panel (IMP)	Adds definition	n/a	none	updates current code	
202	Insulated Vinyl Siding	Adds definition	n/a	none	updates current code	
202	Insulating Sheathing	Adds definition	n/a	none	updates current code	
202	Intumescent Fire Resistive Materials	Adds definition	n/a	none	updates current code	
202	Laboratory Suite	Adds definition	n/a	none	updates current code	
202	Landscaped Roof	Adds definition	n/a	none	updates current code	
202	Limit of Moderate Wave Action	Adds definition	n/a	none	updates current code	
202	Limited Verbal or Physical Assistance	Adds definition	n/a	none	updates current code	
202	Lodging House	Adds definition	n/a	none	updates current code	
202	Low Energy Power Operated Door	Adds definition	n/a	none	updates current code	
202	Low Slope	Adds definition	n/a	none	updates current code	
202	Manual Bolt	Adds definition	n/a	none	updates current code	
202	Masonry	Deletes some sub-definitions	n/a	none	updates current code	
202	Mass Timber	Adds definition	n/a	none	updates current code	
202	Mastic Fire Resistant Coatings	Deletes definition	n/a	none	updates current code	
202	Mechanical Access Enclosed Parking Garag	Adds definition	n/a	none	updates current code	
202	Mechanical Systems	Deletes definition	n/a	none	updates current code	
202	Membrane covered cable structure	Adds definition	n/a	none	updates current code	
202	Metal Building System	Adds definition	n/a	none	updates current code	
202	Nailable Substrate	Adds definition	n/a	none	updates current code	
202	Non combustible protection (mass timber)	Adds definition	n/a	none	updates current code	
202	Nonstructural concrete	Adds definition	n/a	none	updates current code	

202	Normal Temperature & Pressure	Adds definition	n/a	none	updates current code	
202	Occupiable Roof	Defines separate category for rooftop amenities	reduces	($10,000)	eliminates variances currently required by vagueness in current code as to when a roof becomes another story	
202	Open Air Assembly Seating	Adds definition	n/a	none	updates current code	
202	Open Ended Corridor	Adds definition	n/a	none	updates current code	
202	Ordinary Plain Concrete Structural Wall	Revised heading only	n/a	none	updates current code	
202	Overhead Doorstop	Adds definition	n/a	none	updates current code	
202	Peer Review	Adds definition	n/a	none	updates current code	
202	Penthouse (revised to include stairways)	Clarifies that uppermost portion of a stairway to a roof is not a story	reduces	($10,000)	eliminates variances currently required by vagueness in current code as to when a roof becomes another story	
202	Permanent Individual Truss Member . . .	Adds definition	n/a	none	updates current code	
202	Photovoltic (various definitions)	Adds definition	n/a	none	updates current code	
202	Plastic Composite	Adds definition	n/a	none	updates current code	
202	Plastic Lumber	Adds definition	n/a	none	updates current code	
202	Platform	Revised definition - removes 20' height limit	reduces	($50,000)	updates current code	
202	Play Structure	Adds definition	n/a	none	updates current code	
202	Power assisted door	Adds definition	n/a	none	updates current code	
202	Power Operated door	Adds definition	n/a	none	updates current code	
202	Precast concrete diaphragm	Adds definition	n/a	none	updates current code	
202	Preservative treated wood	recognizes new lumber treatment technology	n/a	($50,000)	Updates code to recognize new technology	
202	Prism (deleted)	Deletes definition	n/a	none	updates current code	
202	Public Occupancy Temporary Structure	Adds definition	n/a	none	conflict with GAR??	
202	Puzzle Room	Adds definition	n/a	none	updates current code	
202	Radiant Barrier	Adds definition	n/a	none	updates current code	
202	Rainscreen System	Adds definition	n/a	none	updates current code	
202	Raised Deck System	Adds definition	n/a	none	updates current code	

202	Registered Design Professional in Responsible Charge				conflicts with Indiana Design Build Law for public works	
202	Relocatable Building	Adds definition	n/a	none	conflict with GAR??	
202	Responsive Vapor Retarder	Adds definition	n/a	none	updates current code	
202	Risk Targeted MCE Accelerations	Deletes definition	n/a	none	updates current code	
202	Roof coating	Adds definition	n/a	none	updates current code	
202	Rubble Masonry	Deletes definition	n/a	none	updates current code	
202	Service Life	Adds definition	n/a	none	updates current code	
202	Shingle Fashion	Adds definition	n/a	none	updates current code	
202	Smoke Partition	Adds definition	n/a	none	updates current code	
202	Smoke Protective Curtain Assembly	Adds definition	n/a	none	updates current code	
202	Soft contained play equipment structure	Adds definition	n/a	none	updates current code	
202	Special Amusement Building	Revised definition	n/a	none	Format change only	
202	Special Event Structure	Adds definition	n/a	none	updates current code	
202	Sprinkler Express Riser	Adds definition	n/a	none	updates current code	
202	Stack Bond	Deletes definition	n/a	none	updates current code	
202	Standby Power System	Adds definition	n/a	none	updates current code	
202	Start of Construction	Deletes definition	n/a	none	updates current code	
202	Steel Element, Structural	Adds definition	n/a	none	updates current code	
202	Storage Racks (multiple definitions)	Adds definition	n/a	none	updates current code	
202	Temporary Event	Adds definition	n/a	none	conflict with GAR??	
202	Temporary Structure	Adds definition	n/a	none	conflict with GAR??	
202	Technically Infeasible	Deletes definition	n/a	none	updates current code	
202	Tensile Membrane Structure	Adds definition	n/a	none	updates current code	
202	Terminated Stops (hospital stop)	Adds definition	n/a	none	updates current code	
202	Thin bed mortar (deleted)	Deletes definition	n/a	none	updates current code	
202	Tsunami Design definitions	Adds definition	n/a	none	updates current code	
202	Type X	Adds definition	n/a	none	updates current code	

202	Umbrella Structure	Adds definition	n/a	none	updates current code	
202	Vapor Diffusion Port	Adds definition	n/a	none	updates current code	
202	Vapor Permeable	Revises definition	n/a	none	updates current code	
202	Vegetative Roof	Adds definition	n/a	none	updates current code	
202	Vertical Water Supply Zone	Adds definition	n/a	none	updates current code	
202	Wall	Deletes some sub-definitions	n/a	none	updates current code	
202	Wind Design Geodatabase	Adds definition	n/a	none	updates current code	
202	Workstation	Adds definition	n/a	none	updates current code	
302.1	Occupancy Classification	Adds occupiable roofs	n/a	($1,000)	eliminates need for variances	
304.1	Clarification of the occupancy for small food processing establishments	Small food processing establishments, such as a bakery or catering kitchen less than 2,500 s.f. become a B-occupancy, easing the requirements for such small-scale operations.	reduces	($20,000)	Improves current code	
304.1	Addition of training and skill development occupancies such as tutoring centers, and gymnastics studios to Business Group B.	These have frequently been interpreted to be assembly or educational occupancies under the current Indiana code, and have been the subject of a number of past variances as a result of the stricter classification.	reduces	($100,000)	Improves current code	
304.1	Adds lithium ion to B occupancy	Clarification.	n/a		Improves current code, recognizes marketplace changes	
306.1,307, 311	Distilleries, breweries, wineries, storage of beer, distilled spirits, wine in barrels or casks are no longer classified as group H	Clarifies code reqiurements for occupancies and uses currently not defined in Indiana code	reduces	($100,000)	Improves current code, recognizes marketplace changes	
306.1	Adds storage of lithium batteries and Electric vehicles with lithium batteris to F-1 & S-1	Clarification.	n/a	$0	Improves current code, recognizes marketplace changes	
306.3	Adds low alcohol beverages to F-2 & S-2; removes requirement for metal or glass containers	Clarification.	reduces	($1,000)	Improves current code, recognizes marketplace changes. Reduces variances.	
307	Provides numerous new exemptions from hazardous material classification	Clarification.	reduces	($1,000)	Improves current code, recognizes marketplace changes. Reduces variances.	
308.3	Revision of requirements for certain custodial care facilities	Aligns with common state licensing requirements. The changes include deleting outdated terms used in the code, and incorporation of new sub-categories to more closely align with common practices in the marketplace.	reduces	($50,000)	Updates code to recognize changes in marketplace and licensing regulations	

310	Defines lodging houses, expands uses permitted in R4 occupancy	Allows owner-occupied lodging houses with five or fewer guest rooms to be regulatedunder residential code. Expands R-4 occupancies to include custodial care	reduces	($100,000)	Improves current code, recognizes marketplace changes	
311	See above regarding alcohol, lithium					
311.3	See above regarding low alcohol					
403.2.2.1	Adds soft body impact to high rise walls	Clarification.			Improves code. Recognizes new test method	
403.3	Water supply to high rise buildings	Adds sprinkler express risers	adds	$50,000	Improves code. Recognizes new technology.	
403.3	Water supply to fire pumps in tall mass timber buildings	Addresses issue of contribution to fire load of mass timber structures	adds	$50,000	Improves current code, recognizes marketplace changes, closes loophole	
403.5	Stairway doors & communication systems in high rise stairwells	Clarifies requirements for locking stairway doors from re-entry; clarifies communication system must comply with NFPA 72	adds	$0	Improves current code, recognizes marketplace changes, closes loophole	
404	Numerous improvements in code requirements related to atriums	Clarifies requirements for issues such as egress travel through atriums, smoke control and horizontal assemblies	adds	$0	Improves current code	
404.6	Allows 3-story atribum open to floor in other than I-1 & I-2	Clarifies when a fire barrier is not required in other than I occupancies	reduces	($2,000)	Reduces variances	
406	New sections addressing private garages, including groupings of multiple private garages such as ones used in some multi-family housing developments	allows multiple small private garages to be grouped and classified as U occupancies if separated by fire barriers	reduces	($10,000)	Updates code to recognize marketplace changes	
407	Shared domestic cooking facilities, and shared living space regulations relaxed	Relaxed requirements for shared living spaces, group meeting rooms, therapeutic spaces and shared domestic cooking facilities in occupancies such as nursing homes. The requirements in the current Indiana code for such spaces have been the subject of numerous variances.	reduces	($400,000)	Updates code to recognize changes in marketplace and licensing regulations	
407.4.4.4	Circulation Paths within a Care Suite	Clarifies aisleways in I-2 do not have to meet corridor requirements	reduces	($1,000)	Reduces variances	
410.2.4	Proscenium wall at stage in Type I construction	Clarifies 2-hour wall can terminate at a 2-hour rated floor above instead of roof deck	reduces	($1,000)	Reduces variances	
410.2.5	Horizontal doors at stage openings	Allows 1-hour rated horizontal sliding doors to be used a stage proscenium openings, instead of fire rated curtains	adds	($10,000)	Updates code to recognize new technology	
410.6	Sprinklers at Stage catwalks and galleries	Sprinklers not required under catwalks & galleries per 903.3.1.1	reduces	($1,000)	Reduces variances	

411.5	Addition of puzzle rooms as a new occupancy type.	Commonly called "escape rooms", spaces such as these have been the subject of numerous variances because the current code is silent regarding these types of occupancies.	adds	($10,000)	Improves current code, recognizes marketplace changes, closes loopholes, reduces need for variances	
	Clarification of occupancy type and requirements for energy storage systems	Clarification.	adds	$0	Updates code to recognize new technology	
414.2.3	Additional clarification to allow fire walls to be used to create multiple control rooms in high hazard occupancies.	Allows larger Group H occupancy buildings	reduces	$0	Updates code to recognize new technology	
422.7	Domestic cooking in ambulatory care facilities	Relaxes requirements for domestic cooking under certain conditions	adds	($5,000)	Updates code to recognize new technology and marketplace changes	
423	Storm shelter requirements	Requires storm shelters in critical emergency operation facilities, and E occupancies	adds	$100,000	Addresses shifting of tornado alley eastward to more populated areas, improves building resiliences, protects schools from tornadoes. See NIST report	
424	Change in definition of and requirements for play structure occupancies	Expansion of play structure classifications to include uses for adults, such as rock-climbing walls, laser tag arenas, trampoline and skydiving facilities. Facilities such as these have been the subject of a number of past variances.	reduces	($20,000)	Updates code to recognize new technology and marketplace changes	
503	Clarification of requirements for occupied roofs	Clarification of requirements for occupied roofs, including clarifying that they are not to be considered in the allowable story restrictions. Numerous buildings now have occupied roofs, and they are often used as an amenity in some developments. Repeated variances have had to address these as the current code is lacking in information regarding current marketplace trends.	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
503, 504, 506	Revisions to the allowable height and area requirements	Makes code more user friendly. Formatting changes	n/a	$0	Improves code	
508, 509	Addition of fire classification requirements for mass timber structures	Adds provisions for new wood technology	reduces	$0	Updates code to recognize new technology.	
505	Clarifications to the open mezzanine requirements	Makes it easier to incorporate enclosed mezzanines in multiple occupancy types	reduces	($50,000)	Updates code to recognize new technology	
507	Basements in unlimited area buildings	Basements now allowed in unlimited area buildings	reduces	($100,000)	Updates code to recognize new technology	

508.5	Reformatting and clarification of requirements for Live/Work Units.	The current Indiana code was the first version of the model code to define and address live/work units such as an art studio, chiropractor's office, or small funeral home which also include a private residence. More recent model codes have greatly enhanced and improved the code provisions for these types of facilities. Another example frequently seen in past variance applications to the Commission has been small, one-room school buildings with an apartment used by certain religious communities common in Indiana.	reduces	($10,000)	Updates code to recognize new technology and marketplace changes	
510.2	Stairway construction in podium buildings	Allows combustible stairways to be used for the full height of the building. These types of buildings are commonly found in the largest cities in Indiana and are frequently the subject of multiple variances for each development	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
510.2	Allowance of horizontal fire separations in buildings.	This was the subject of an Indiana amendment in the current code. New codes provide much more comprehensive allowances to allow different types of construction and occupancies to be considered as separate buildings within the same structure	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
601, 602	Engineered lumber, cross laminated timber, and mass timber construction	Extensive coverage of new wood technology such as engineered lumber, cross laminated timber, and mass timber construction, and creation of new construction types related to such technology	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
603.1	Combustible materials in Type I & II construction	Allowance of freezers and coolers in Type I & II buildings to be constructed of combustible materials; Use of wood blocking in non-combustible roof decks and parapets allowed	reduces	($50,000)	Improves current code, recognizes marketplace changes	
703.6, 703.7	Mass timber construction protection	Recognizes new test data for contribution time of mass timber alone and protected by non-combustible construction such as drywall membranes	reduces	$0	Updates code to recognize new technology	

704	Clarification as to protection of secondary members. Horizontal assemblies permitted to be protectd with ceiling membrane	Eespecially in light frame construction such as Type VA apartments this issue is often a source of confusion and contradictory interpretations under the current code	reduces	($100,000)	Updates code to recognize new technology	
707.5	Exit passageway enclosures	Allows an enclosed top at exit passageways instead of extending enclosing walls full height to deck above	reduces	($50,000)	Updates code to recognize new technology	
706.2	Firewall structural requirements	Revises definition of structural stability, incorporates NFPA 221, allows double fire walls. Double walls are frequently the subject of variance requests	adds	($50,000)	Updates code to recognize new technology	
708	Supporting construction for fire partitions	Clarification to allow the use of non-fire rated type IIB and VB supporting construction for fire partitions,	reduces	($150,000)	Updates code to recognize new technology	
709.4	Smoke barrier continuity	Revisions to distinguish between smoke compartments in I-occupancies and smoke barriers for areas of refuge and elevator lobbies. Allows unprotected openings in certain conditions	reduces	($50,000)	Improves code	
711,712	Horizontal assemblies and vertical openings	Reformating and clarfication to make code more user-friendly	reduces	$0	Improves code	
713.12	Top of shaft termination	Requirements clarified. Additional options for termination provided	reduces	($50,000)	Improves code	
714.4	Membrane Penetrations	clarification that a double top plate may interrupt a rated ceiling membrane. This issue is a constant source of confusion and inconsistent enforcement	reduces	($500,000)	Improves code	
715	Protection of joints and voids	Reformating and clarfication to make code more user-friendly	reduces	$0	Improves code	
716	Doors in double fire barriers and fire walls	Incorporates NFPA 221 for double doors in fire walls, clarifies that two 3/4 rated doors may be used in double 1-hour rated walls such as at hotel rooms	adds	$0	Updates code to recognize new technology	
717	Duct transitions between shafts	Allows ducts to transition horizontally between two vertical shafts	adds	($50,000)	Improves code	
717.5.2	Flex duct penetrating a fire barrier	Allows a flex duct to penetrate a fire barrier without a fire damper	reduces	($150,000)	Updates code to recognize new technology	
722.7	Mass timber fire ratings	Provides fire ratings for mass timber asseblies based on new test data	adds	$0	Updates code to recognize new technology	

806.9	Wood lockers	Clarification that wood lockers may be considered an interior finish where they are applied along a wall	reduces	($10,000)	Updates code to recognize new technology and marketplace changes	
903.2	Upholstered furniture and mattresses	Clarification and reformatting of sprinkler triggers for F-1 occupancies used for the manufacture of upholstered furniture and mattresses.	adds	$0	Updates code to recognize new technology	
903.2	Sprinkler requirements for occupied roofs	Clarifies when an occupied roof used for assembly purposes triggers a sprinkler system in the building below.	adds	$50,000	Improves current code, recognizes marketplace changes, closes loophole	
903.2	Distilled spirit sprinkler requirements	Clarifies sprinkler reqiuirements for Group F-1 fire areas used for distilled spirit manufacturing and Group S-1 fire areas used for bulk storage of distilled spirits and wine.	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
903.2	Multiple Group A fire areas	Clarifies that multiple Group A fire areas sharing a common means of egress are combined in evaluating sprinkler requirements	adds	$0	Improves current code, recognizes marketplace changes, closes loophole	
903.2	Sprinkler requirements for Parking Garages	Requires sprinklers in certain open parking garages. Based on extensive use of plastics in automobile construction	adds	$100,000	Improves current code, recognizes marketplace changes, closes loophole	
903.2.7.3	Sprinkler requirements for lithium ion battery storage	Adds cross reference to fire code for lithium battery storage rooms	adds	$0	Updates code to recognize new technology and marketplace changes	
903.3.1.2	13R sprinklers at podium buildings	Clarifies height limitations for 13R sprinkler systems used in podium type buiildings	adds	$100,000	Improves current code, recognizes marketplace changes, closes loophole	
903.3.1.2.2	Corridor and Balcony sprinkler protection	Closes loophole for open corridors and shared balcony sprinkler protection in NFPA 13R systems	adds	$50,000	Improves current code, recognizes marketplace changes, closes loophole	
905.3.1	Standpipe requirements at parking garages	Revisions consistent with 903.2 changes regarding parking garages	adds	$50,000	Improves current code, recognizes marketplace changes, closes loophole	
907.2.10.1	Clarification of fire alarm requirements in multi-story self-storage buildings	Requires fire alarm system in self storage buildings > 2 stories	adds	$50,000	Updates code to recognize new technology	
907.2.10.2	Clarification of fire alarm requirements for lithium battery storage	Cross reference to fire code requirements for fire alarm systems at lithium battery storage	adds	$0	Updates code to recognize new technology and marketplace changes	
907.5.2.1.3	Low frequency fire alarm systems.	Recognition of low frequency fire alarm systems. These systems have proven to be six times more effective at waking certain at risk segments of the populations, such as children, the elderly, and people who are alcohol impaired	adds	$50,000	Updates code to recognize new technology	

903.2.8	Clarification of sprinkler requirements for attics used as living purposes	Provides multiple fire protection options for attics used for living purposes and not used for living purposes in group R-3 and R-4	adds	$0	Updates code to recognize new technology and marketplace changes	
903.3.1.1.2	Clarification of exempt locations such as small bathrooms in R-occupancies	Exempts bathrooms of < 55 s.f. from sprinkler protection in NFPA 13 systems	reduces	($100,000)	Updates code to recognize new technology and marketplace changes	
904.13	Requirements for domestic appliances and domestic hoods used in Group I-2 kitchen facilities have been clarified.	Provides options for protection of domestic cooking equipment	adds	$20,000	Updates code to recognize new technology and marketplace changes	
907.2.9.3	Fire alarm systems in R-2 College and University Buildings	Increase fire alarm requirements due to recent history of dormitory fires. Clarifies that requirements apply to housing operated by the university, but does not apply to housing over which the school or university does not have operational control	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
907.2.11	Smoke alarms near small bathrooms and near cooking appliances.	Clarification of placement of smoke alarms near small bathrooms and near cooking appliances. This is a source of frequent confusion in the current Indiana code	reduces	($50,000)	Updates code to recognize new technology	
911	Fire command centers in F-1 and S-1	Adds a requirement for a fire command center in F-1 and S-1 buidlings larger than 500,000 s.f.	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
915	Carbon monoxide detectors	Reformatting to clarify CO detector requirements in various occpancies	adds	$0	Improves code	
1006.2.1	Common path of travel requirements for unoccupied mechanical rooms	Common path of travel requirements for unoccupied mechanical rooms and penthouses eliminated.	reduces	($50,000)	Updates code to recognize new technology	
1006.3	Egress requirements from occupied roofs clarified.	Clarifies that even though an occupied roof is not a story, the occupant load of the roof does not need to be combined with the story below, but can be considerred as if the roof is a story	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1004.1.2	Inclusion of new occupant load factors, office occupant load factor for offices changed to 150 s.f./occupant	Reduces occupant load requirements based on recent research	reduces	($500,000)	Updates code to recognize new technology and marketplace changes	
1006.3.4	Single exit stories	Eliminates common path of egress requirement for single exit stories. Exiting requirements now based on travel distance	reduces	($250,000)	Updates code to recognize new technology and marketplace changes	
1007.1	Remoteness test requirements	New remoteness test requirements to address converging stairs	adds	$25,000	Improves current code, recognizes marketplace changes, closes loopholes	
1008.2.1	Stairway illumination	Light level increased in exit access stairs except at auditoriums and theatres	adds	$15,000	Improves current code, recognizes marketplace changes, closes loophole	

1009.2.1	Accessible elevators to occupied roofs	Clarifies when an accessible elevator is required to an occupied roof	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
1009.6.2	Interior areas of refuge at level of exit discharge	Interior areas of refuge are now allowed as an accessible means of egress on the level of exit discharge	reduces	($50,000)	Updates code to recognize new technology	
1009.6.3	Area of refuge floor space increase	Clear floor space for a wheelchair at an area of refuge increased from 30x48 to 30 x 52	adds	$0	deminimus change	
1010.1.1	Door widths	Maximum 48" door width limitation eliminated; new exception allows for reduced door sizes serving single user spaces such as dressing rooms	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1010.1.1.1	Projections into door openings	Additional elements now allowed to encroach into the clear door opening	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1010.2.4	Clarification as to when locks and latches shall be permitted to prevent operation of doors from the egress side.	Clarification as to when locks and latches shall be permitted to prevent operation of doors from the egress side. As the desire for more secure facilities continues, this is a critically important topic.	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1030.16	Handrails at social stairs	Incorporation of requirements for “social stairs”. These are a design element frequently incorporated in higher education facilities, and now is migrating to other uses. The design incorporates a seating area that steps up adjacent to an egress stair. The current Indiana code does not recognize this condition and variances are required.	reduces	($100,000)	Updates code to recognize new technology and marketplace changes	
1009.8	Two-way communication system from service and freight elevators, and residential elevators	Elimination of two-way communication system from service and freight elevators, and residential elevators	reduces	($25,000)	Updates code to recognize new technology and marketplace changes	
1011	Permanent ladders	Clarification regarding use of permanent ladders to provide access to certain areas. The current code is unclear regarding many common uses of permanent ladders	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1016.2	Clarification regarding means of egress through enclosed elevator lobbies	Means of egress is now allowed to be through an elevator lobby in certain conditions	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	

1017.2.2	Increased exit travel distances in Group F-1 and S-1	Increased exit travel distances in Group F-1 and S-1 facilities clarified. This has been a source of confusion for decades. Indiana amendments have attempted to resolve the issue. The newest model codes provide greater flexibility than current Indiana codes. Increased travel distance is now a function of clear height and is no longer tied to ESFR or smoke/heat vents	reduces	($100,000)	Updates code to recognize new technology and marketplace changes	
1018.3	Aisles in B & M occpuancies	Clarifies that minimum aisle width is a function of minimum corridor width	reduces	$0	Improves code	
1020.2	Corridor width in I-2 clarifications	Reduced width allowed where bed or stretcher movement is not necessary	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
1023.3.1	Stairway extensions	Clarifies that no separation is required between an exit stair and an exit passageway	reduces	($10,000)	Improves code	
1107.2	Accessible vehicle charging stations	Inclusion of vehicle charging stations into the accessibility requirements of the code.	adds	$0	Updates code to recognize new technology and marketplace changes	
1103.2.8	Raised and lowered areas in places of religious worship	New exception for raised or lowered areas in religious facilities. This topic has been the source of many variance applications	reduces	($20,000)	Improves current code, recognizes marketplace changes	
1404.3	Vapor retarder provisions revised	Significant improvement and clarification to the vapor retarder requirements for building envelopes in Climate Zone 4 & 5 (Indiana). The new codes incorporate the latest research and product technology for this vitally important element. The current Indiana code is outdated, and allows practices that can create serious mold and deterioration problems in a building.	reduces	($500,000)	Updates code to recognize new technology and marketplace changes	
1210.3	Restroom privacy	Updates regarding restroom privacy. The commission has seen numerous past variance applications related to this issue	adds	$50,000	Improves current code, recognizes marketplace changes, closes loopholes	
2612	Plastic composites	Adds provisions for the use of plastic composite materials and plastic lumber	reduces	($100,000)	Updates code to recognize new technology and marketplace changes	
2902.3	Public toilet facilities in limited size, quick service tenant spaces	Public toilet facilities no longer required in such spaces (employee toilet still required)	reduces	($100,000)	Improves current code, recognizes marketplace changes	

2902	Separate toilet facilities	Adds options for providing multiple user facilities serving all genders. Eliminates need for variances	reduces	($50,000)	Improves current code, recognizes marketplace changes	
3004	Elevator hoistway venting	All hoistway venting requirements have been deleted	reduces	($100,000)	Updates code to recognize new technology	
3115	Intermodal shipping containers	The use of intermodal shipping containers as buidings and structures is now allowed, and criteria defined for their use.	reduces	($50,000)	Updates code to recognize new technology and marketplace changes	
Chapter 34	Chapter 34 deleted	References added to International Existing Building Code. The IEBC provides a more consistent and coordinated document, and in addition to the contents of Chapter 34 from the building code, the IEBC provides options for different scale renovations. Several of these options do not require full compliance with all provisions of the building code	reduces	($500,000)	Updates code to recognize new technology and marketplace changes	
	Numerous improvements to the structural code provisions in Chapter 16, incorporating the latest research. AIA Indiana also supports adoption of Chapter 17 of the model IBC and asks the Commission and its staff to facilitate any statutory changes necessary to allow its adoption	See analysis by Structural Engineering Organization	reduces	($220,000)	Updates code to recognize new technology and marketplace changes	
		Total Fiscal Savings, First Year Construction Cost		($4,568,000)		

Summary of the Fiscal Impact of Structural Changes

1608 Snow Loads

- Fiscal Impact No fiscal impact

1609 Wind Loads

- Fiscal Impact No fiscal impact

1609.5 Tornado Loads

- Fiscal Impact Savings of $8.6M per year.

1611 Rain Loads

- Fiscal Impact No fiscal impact

1612 Flood Loads

- Fiscal Impact No fiscal impact since we are referencing current IDNR information.

1613 Earthquake Loads

- Fiscal Impact Savings of $1.8M per year.

1614 Ice Loads

- Fiscal Impact No fiscal impact

1616 structural Integrity

- Fiscal Impact No fiscal impact

Chapter 17 – Special Inspection

- Fiscal impact = $10.18M additional per year

Chapter 18 – Soils and Foundations

- Fiscal Impact No fiscal impact

Chapter 19 – Concrete

- Fiscal Impact		No fiscal impact

Chapter 21 – Aluminum

- Fiscal Impact		No fiscal impact

Chapter 21 – Masonry

- Fiscal Impact		No fiscal impact

Chapter 22 – Steel

- Fiscal Impact		No fiscal impact

Section 1608 – Snow Loads

<u>Purpose</u>: Identifying modifications to current 2014 Indiana Building Code in proposed 2024 IBC

<u>Section 1608 Table 1608.2</u>:
Indiana counties are listed with a ground snow load of 20 or 30 psf depending on the county. Exceptions are Lake, LaPorte, Porter, and St. Joseph Counties where 30 psf is the minimum and further investigation is required.

ASCE 7-22 has adopted a uniform risk-based snow loads, Strength Design – reliability analysis to prevent sudden failure and progressive damage, instead of uniform hazard, Allowable Stress Design (ASD) – 2% annual probability of being exceeded (50-yr mean recurrence interval). This is similar to the change wind loads underwent with ASCE 7-10.

The ground snow loads have increased; however, the load factors within the load combinations have decreased resulting in similar loading criteria when compared at ASD levels. The change in snow loads is based on nearly 30 years of snow load data since the previous studies were completed.

See the table below for a comparison of a few cities in Indiana.

City	2014 Indiana BC (Pg)	2014 Indiana BC (Pm) - ASD	2024 IBC (Pg)	2024 IBC (Pm) - ASD	Roof Live load	Comment
Evansville	20 psf	20 psf	22 psf	15.4 psf	**20 psf**	Reduction in roof design when using live load reduction
Indianapolis	20 psf	20 psf	30 psf	**21 psf**	20 psf	5% increase in snow loads
Fort Wayne	30 psf	21 psf	33 psf	**21 psf**	20 psf	No increase in snow loads
South Bend*	41 psf	28.7 psf	51 psf	**25 psf**	20 psf	12% reduction in snow loads

Assumed: Risk Category II; Ct, Ce, Ig = 1.0; Does not consider snow drifts
'*' indicates engineering statistical model required with a minimum of 30 psf per the 2014 Indiana Building Code.

<u>Impact Summary</u>:
Changes are minimal and have no fiscal impact.

Recommendation: Adopt, with no changes, frost depth table proposed to be moved to Chapter 18.

Section 1609 – Wind Loads

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 1609.1.1 Determination of Loads:
- 2024 adds an exception for temporary structures complying with 3103.6.1.2.
  - Addition of reduction factors on wind loads for public-occupancy temporary structures. Reduction factor varies from 0.65 to 1.0 depending on occupancy and risk category.

Section 1609.2 Protection of Openings:
- Exception 1 for wood structural panels updated language from "one- and two-story buildings" to "buildings with a mean roof height of 33 feet of less."

Figures 1609.3(1) through (4): ***(formerly Figures 1609A through C)***
- Category I Buildings and Other Structures – Basic Wind Speed, V decreases from 105 mph in all of Indiana to 103 mph in the northern quarter of the state and 98 mph in the rest of the state.
- Category II Buildings and Other Structures – Basic Wind Speed, V decreases from 115 mph to 107 mph.
- Category III Buildings and Other Structures – Basic Wind Speed, V decreases from 120 mph to 114 mph.
- Category IV Buildings and Other Structures – Basic Wind Speed, V decreases from 120 mph to 119 mph.

Section 1609.5 Tornado Loads:
- New Section in 2024 IBC
- The design and construction of Risk Category III and IV buildings and other structures located in the tornado-prone region as shown in Figure 1609.5 shall be in accordance with Chapter 32 of ASCE 7, except as modified by this code.
- All of Indiana falls within the tornado-prone region.
- See tornado loads discussion for more information.

Section 1609.6.3 Rigid Tile (Roof Systems):
- Wind directionality factor K_d has been added to the aerodynamic uplift moment formula (note that the value of K_d is always 1.0 or lower).

Section 1609.6 (IBC 2012 section numbering) Alternate all-heights method:
- Section deleted.
- This was a simplification of the ASCE 7 Directional Procedure given in Chapters 27 and 30. It was valid for regularly shaped buildings or other structures meeting certain requirements.

Section 1609.7 Elevators, escalators and other conveying systems
- Addition of language requiring that these systems, when exposed to outdoor environments, shall satisfy the wind design requirements of ASCE 7.

ASCE 7-22 Chapter 26 – Wind Loads: General Requirements

Purpose: Identifying modifications to current ASCE 7-10 in proposed ASCE 7-22

Table 26.6-1 Wind Directionality Factor, K_d:

- Octagonal tanks was added with K_d = 1.0 (0.95 for structures with nonaxisymmetric structural systems)
- Round tanks was modified from K_d = 0.95 to 1.0 (0.95 for structures with nonaxisymmetric structural systems)

Section 26.9 Ground Elevation Factor:

- The ground elevation factor was added to adjust for air density. It applies a factor K_e, to account for elevation of the site with respect to sea level.
- Table 26.9-1 shows factors varying from 1.00 at sea level to 0.80 at 6,000 ft above sea level.
- The lowest point in Indiana is 320 ft above sea level (Ke = 0.99) and the highest point in Indiana is 1,257 feet above sea level (Ke = 0.95).
- When applied to the wind velocity pressure equation, the net result is a 1-5% decrease in wind pressure.

Table 26.10-1 Velocity Pressure Exposure Coefficients, K_h and K_z:

- A minimum coefficient value of 0.70 has been added for use in Chapter 28, Exposure B, when z < 30 feet. Previously the coefficient was 0.57, 0.62 and 0.66 for heights 0-15 ft, 20 ft and 25 ft respectively. This change applies ONLY to buildings or other structures as indicated above.
- Coefficients for Exposure B decrease by 3-7% for heights of 40 feet and above.
- Coefficients for Exposure C decrease by approximately 1.5% for heights of 140 feet and above.

Section 26.12.1 Enclosure Classification – General:

- An enclosure classification of “partially open” has been added to address buildings and other structures that satisfy both the “open” and “partially enclosed” enclosure classification definitions. Previously, a building falling into this category would have been classified as “open”.

Table 26.13-1 Internal Pressure Coefficient, (GC_{pi}):

- Added an internal pressure coefficient of +/- 0.18 for “partially open” buildings. Previously these buildings would have been considered “open” and had a coefficient of 0.

ASCE 7-22 Chapter 27 – Wind Loads on Buildings: MWFRS (Directional Procedure)

Purpose: Identifying modifications to current ASCE 7-10 in proposed ASCE 7-22

Section 27.1 Scope:

- Part 2 of Chapter 27, applying to enclosed simple diaphragm buildings has been deleted.

Section 27.3.1.1 Elevated Buildings:

- Section added to address this building type

Section 27.3.2 Open Buildings with Monoslope, Pitched or Troughed Free Roofs:

- Provision added: For an open or partially enclosed building with transverse frames and a pitched roof (q <= 45deg), an additional horizontal force in the longitudinal direction (parallel to the ridge) that acts in combination with the roof load calculated in Section 27.3.3 shall be determined in accordance with Section 28.3.5.

ASCE 7-22 Chapter 28 – Wind Loads on Buildings: MWFRS (Envelope Procedure)

Purpose: Identifying modifications to current ASCE 7-10 in proposed ASCE 7-22

Section 28.1 Scope:

- Part 2 of Chapter 28, applying to enclosed simple diaphragm buildings has been deleted.

Section 28.3.2.2 Torsional Load Cases:

- Section has been added

Figure 28.3-3 Horizontal wind loads on open or partially enclosed buildings with transverse frames and pitched roofs

- Figure has been added

ASCE 7-22 Chapter 29 – Wind Loads on Building Appurtenances and Other Structures: MWFRS (Directional Procedure)

Section 29.1.1 Structure Types:

- Solar panel systems have been added

Section 29.4.2 Design Wind Loads: Circular Bins, Silos and Tanks

- Section added to specifically address this type of structure

Section 29.4.3 Roof top Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roofs with Slopes Less Than 7 Degrees

- Section Added to specifically address this type of structure

ASCE 7-22 Chapter 30 – Wind Loads: Components and Cladding

Section 30.1.1 Building Types:

- Part 2 containing a simplified approach applicable to enclosed low-rise building with heights less than or equal to 60 feet has been deleted.
- Part 4 containing a simplified approach applicable to enclosed buildings with heights less than or equal to 160 feet and roof types as listed has been deleted.
- A new Part 5 has been added to address non-building structures: Circular bins, silos, tanks, rooftop solar panels and roof pavers.

Section 30.3.2.1 Bottom Horizontal Surface of Elevated Buildings

- Section added to specifically address this condition that was not addressed previously.

Figure 30.3-2A Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – gable roofs, θ <= 7deg:

- Roof zone 1, 2 & 3 widths and shapes have changed
  - Equivalent a = 0.6h [versus smaller of 0.1*least dimension or 0.4h]
  - Zone 3 is now L shaped and 0.6h long by 0.2h wide in the corners
- Roof zone 1 was renamed to 1' and *new* zone 1 was added
- Negative roof pressure coefficients in zones 1-3 have increased:
  - Zone 1: (-1) to (-1.7) all tribs
  - Zone 2: (-1.8) to (-2.3) all tribs
  - Zone 3: (-2.8) to (-3.2) small tribs
- Negative roof pressure coefficients at overhangs in zones 2 and 3 have increased:
  - Zone 2: (-1.7) to (-2.3) small tribs
  - Zone 3: (-2.8) to (-3.2) all tribs

Figure 30.3-2B Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – gable roofs, 7deg < θ <= 20deg:

- Roof zone 2 was removed from eave edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-2.6) to (-3.6) small tribs up big tribs down
  - Zone 2 negative: (-1.7) to (-2.7) all tribs
  - Zone 3 negative: (-0.9) to (-2.0) all tribs
  - All zones positive: (0.5) to (0.6) small tribs
  - Overhang graph was removed

Figure 30.3-2C Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – gable roofs, 20deg < θ <= 27deg:

- Roof zone 2 was removed from eave edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-2.6) to (-3.6) small tribs
  - Zone 2 negative: (-1.7) to (-2.7) small tribs
  - Zone 3 negative: (-0.9) to (-2.0) all tribs
  - All zones positive: (0.5) to (0.6) small tribs
  - Overhang graph was removed

Figure 30.3-2D Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – gable roofs, 27deg < θ <= 45deg:

- Roof zone 2 was removed from eave edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-1.0) to (-1.8) small tribs
  - Zone 2 negative: (-1.2) to (-2.0) small tribs
  - Zone 3 negative: (-1.2) to (-2.5) small tribs
  - All zones positive: (0.8) to (0.5) big tribs
  - Overhang graph was removed

Figure 30.3-2E Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – hip roofs, 7deg < θ <= 20deg:

- Roof zone 3 now all around edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-0.9) to (-1.8) small tribs
  - Zone 2 negative: (-1.9) to (-2.4) all tribs
  - Zone 3 negative: (-2.0) to (-1.4) big tribs
  - All zones positive: (0.5) to (0.7) small tribs
  - Overhang graph was removed

Figure 30.3-2F Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – hip roofs, 20deg < θ <= 27deg:

- Roof zone 3 now all around edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-0.9) to (-1.4) small tribs
  - Zone 2 negative: (-1.7) to (-2.0) small tribs (down big tribs)
  - Zone 3 negative: (-2.6) to (-2.0) all tribs
  - All zones positive: (0.5) to (0.7) small tribs
  - Overhang graph was removed

Figure 30.3-2G Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings, θ <= 7deg – stepped roofs:

- Roof zone 3 now all around edges of roof
- Pressure coefficients have increase as follows:
  - Zone 1 negative: (-1.0) to (-1.5) small tribs (down big tribs)
  - Zone 2 negative: (-1.2) to (-1.8) small tribs
  - Zone 3 negative: (-1.2) to (-2.4) small tribs
  - All zones positive: (0.9) to (0.7) all tribs
  - Overhang graph was removed

Figure 30.3-3 Components and Cladding (h<= 60ft): external pressure coefficients (GC_p) for enclosed, partially enclosed and partially open buildings – gable roofs, θ <= 7deg:

- Roof zones 1, 2 & 3 added – similar to gable roofs (used to be much simpler)
  - Equivalent a = 0.6h [versus smaller of 0.1*least dimension or 0.4h]
  - Zone 3 is now L shaped and 0.6h long by 0.2h wide in the corners
- Roof zone 1 was renamed to 1' and *new* zone 1 was added
- Negative roof pressure coefficients in zones 1-3 have increased:
  - Zone 1: (-1) to (-1.7) all tribs
  - Zone 2: (-1.8) to (-2.3) all tribs
  - Zone 3: (-2.8) to (-3.2) small tribs
- Negative roof pressure coefficients at overhangs in zones 2 and 3 have increased:
  - Zone 2: (-1.7) to (-2.3) small tribs
  - Zone 3: (-2.8) to (-3.2) all tribs

Figure 30.3-8 Components and Cladding (all heights): external pressure coefficients, (GC_p), for enclosed, partially enclosed and partially open buildings and structures – arched roofs:

- Figure added to specifically address this type of roof (not explicitly addressed previously)

Figure 30.4-1A Components and cladding, part 3 (h > 60ft): external pressure coefficient zones for enclosed, partially enclosed and partially open buildings with partially enclosed spaces and areas beneath the elevated building – bottom horizontal surface of elevated buildings:

- Addition of coefficient zones for the bottom horizontal surface of elevated buildings.

Section 30.9 Attached Canopies on Buildings

- Section added to address a specific design type/element not explicitly addressed in previous code version

Part 5: Nonbuilding Structures

- Added procedures for calculating components and claddings loads not explicitly addressed in previous code version

Section 30.10 Circular Bins, Silos and Tanks with h <= 120ft

- Section added to address a specific design type/element not explicitly addressed in previous code version

Section 30.11 Rooftop Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roofs with Slopes Less than 7 Degrees

- Section added to address a specific design type/element not explicitly addressed in previous code version

Section 30.12 Roof Pavers for Buildings of All Heights with Roof Slopes Less Than or Equal to 7 Degrees

- Section added to address a specific design type/element not explicitly addressed in previous code version

ASCE 7-22 Chapter 31 – Wind Tunnel Procedure

Section 31.2 Test Conditions:

- Listed requirements have been removed and replaced with reference to ASCE 49

Section 31.4.3 Wind Directionality:

- Section added to specifically address how to handle wind directionality

Section 31.4.4 Limitations on Loads:

- Languauge is added to specifically address Chapter 29 Appurtenances or Other Structures.

Section 31.4.5 Limitations on Wind Loads for Ground-Mounted Fixed-Tilt Solar Panel Systems

- Section added to specifically address this type of system.

Section 31.5 Load Effects for Buildings, Other Structures and Components Used at Multiple Sites

- Section added to specifically address how to handle this issue.

Section 31.6 Peer Review Requirement for Wind Tunnel Tests

- Section/requirement added.

ASCE 7-22 Commentary Chapter C26 – Wind Loads: General Requirements

Section C26.1.1 Scope:

- Language has been added to specifically address storm shelters and safe rooms. Explanation of design of these structures per ICC 500 and FEMA P-361 is discussed. This is NOT new information, it merely has been added to the code for information.

Section C26.1.3 Performance-Based Procedures:

- A discussion of when performance-based procedures may be appropriate for use has been included.

Section C26.5 Wind Hazard Map:

- Explains that all the wind speed maps in ASCE 7 have been updated, based on a new analysis of nonhurricane wind data available through 2010, and improvements to the hurricane simulation model.
- Risk Category III and IV buildings now have separate wind speed maps to recognize the higher reliabilities required for essential facilities and facilities whose failure could pose a substantial hazard to the community.
- The standard now encourages use of the online Wind Design Geodatabase for more accurate wind speed design values.

Section C26.7 Exposure:

- Discussion of ground surface roughness B is expanded upon.

Section C26.10 Velocity Pressure:

- A lengthy discussion of velocity pressure exposure coefficients has been added.

ASCE 7-22 Commentary Chapter C29 – Wind Loads on Building Appurtenances and Other Structures: Main Wind Force Resisting System (Directional Procedure)

Section C29.4: Figures 29.4-1, 29.4-2 and 29.4-3:

- Language has been added to address lighting pole systems which have unique design and performance characteristics.

Section C29.4.2 Design Wind Loads: Circular Bins, Silos and Tanks:

- Design item added to code.

Section C29.4.3 Rooftop Solar Panels for Buildings of All Heights with Flat Roofs or Gable or Hip Roofs:

- Design item added to code

Section C29.4.4 Rooftop Solar Panels Parallel to the Roof Surface on Buildings of All Heights and Roof Slopes:

- Design item added to code

Section C29.4.5 Ground Mounted Fixed Tilt Solar Panel Systems:

- Design item added to code

ASCE 7-22 Commentary Chapter C30 – Wind Loads: Components and Cladding

Chapter Introduction

- Discussion of roof zone and pressure coefficient modifications that were based on a more recent wind tunnel database. Compared to previous code versions, the pressure coefficients have generally increased and are now more consistent with coefficients for buildings higher than 60 ft.
- Roof zone sizes are modified from previous versions to minimize the increase of pressure coefficients in zones 1 and 2.

Figures 30.3-1 and 30.3-2A-G:

- The negative roof GC_p values given in these figures are greater in magnitude that those given in versions 2010 and earlier but are consistent with those dictated by the updated wind tunnel tests.
- The smallest effective wind areas have been truncated 10 square feet. Thus GC_p values for some shapes and roof slopes have been reduced.

Figure 30.3-8:

- The pressure and force coefficient values in these tables have been updated from a 0.87 multiplier to 1.2. Note that the value of 0.87 was first used in ASCE 7-95 but there was no substantiation for the change, hence the change back to 1.2.

Economic Impact:

- 2024 update decreases basic wind speeds and adds a ground elevation factor. The impact of these updates yield a 3%-18% decrease in wind velocity pressures that varies depending on building category and location. For ONLY buildings less than 25’ tall in exposure category B, when designed using the envelope procedure (as opposed to the directional procedure), velocity pressure exposure coefficients have been increased, roughly offsetting the decrease described above. In most cases, wind loads for main wind force resisting systems have decreased by the percentages noted above.
- Tornado load impacts to be addressed in separate tornado loads summary.
- Components and cladding load pressure coefficients have changed in many cases. They increased in some cases, mostly for smaller tributary areas, but sometimes for larger ones

as well. Decreases are seen in a smaller number of cases, mostly for larger tributary areas. Larger wind loads will likely be necessary for the design of most fasteners.

- A number of new design elements such as attached canopies, bins and silos, solar panels and the underside of elevated buildings have been added to the code, allowing the engineer to do less guesswork and interpretation of the code.
- The removal of some simplified approaches streamlines the design process by decreasing the number of ways an engineer has to choose from when computing wind loads.

Recommendation: Adopt with no changes

Section 1609 – Tornado Loads

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 1609.5:

- Category 3 and 4 buildings in tornado prone requires shall be in accordance with asce 7 chapter 32.
- All of Indiana is listed as a tornado prone area
- NIST Technical Document 2214
    - The adoption of the new tornado load requirements in the ASCE 7-22 standard will impact asmall fraction of new buildings in the United States.When excluding residential occupancieswith less than 50 units, the building stock occupancy types for Risk Category III and IVbuildings in the tornado-prone regionrepresents15.0 % of the entire U.S. building stock and18.3 % of the building stock in the tornado-prone region.These results are effectively upperbound estimatesas tornado loads will not control over wind loads for all Risk Category IIIand IV buildings in the tornado-prone region.Whether tornado loads control any aspect ofthe building design over wind loads depends on many different climatological and buildingcharacteristics. Geospatial analyses are usedidentify the impacts of several of thesevariables. In general, the tornado design requirements will have the most impact in thecentral and southeast U.S.
    - For scenarios in which the tornado loads do control, the construction design is often not influenced. Of the nine cities considered in this study, three realize cost increases for at least one exposure category for the elementary school and six forthehigh school.Of all the building type–location–exposure combinations(36), only six(three for each building type) realize cost impacts greater than 0.07% of the project budget
    - For Kansas City,the tornado loads control for foundation anchorage androofjoistsand wideflangebeams and girdersfor both Exposure B and Exposure C and wall framing forExposure B. However,these only impact the design for the foundation anchorage androofjoists andwide flange beams and girdersfor Exposure B and Exposure C,leading to anincrease in construction costs of $28354 (0.16%) for Exposure B and $1658 (0.01%) forExposure C.
    - For Chicago andMinneapolis,the foundation anchorage tornado load controls for an elementary school withExposure B. However,the increase in the load is less than 30%,which is estimated to nothave a cost impact.
    - The cost study did not include the fire station or hospital examples. Risk Category IVfacilities similar in size and shape would have greater relative increases in tornado loadscompared to wind loads, which could lead toconstructioncost increases.
    - Even for the scenarios in which designing to meet the tornado load does control design,theincremental construction cost increase is minimal.For the elementary school, onlythreelocations realize higher costs–Kansas City and Memphis witheitherExposure BorC andDFWwith Exposure B, ranging from approximately $28000 to $29500 (0.13% to 0.14%of project budget) with Exposure B and $2135 (0.01%of project budget) or less withExposure C.For the high school, more cities realize higher costs for at least one exposurecategory because the high school has a larger building footprint. However, the cost impactrelative to the project budget remains minimal. Charlotte, Chicago, and Minneapolis realizecost impacts with

Exposure B whileDFW, Kansas City, and Memphis realize cost impactswith either Exposure B or C. The cost impacts with Exposure C range from approximately$22000to $27686 (0.01% of project budget) while the cost impacts with Exposure B rangefrom $2391 to $255530 (0.001% to 0.13% of project budget) or less with Exposure C.

Table 13. Estimated Cost Impacts from Tornado Loads – Elementary School

Building Element	DFW		Kansas City		Memphis	
	B	C	B	C	B	C
Roofing Fasteners	$0	$0	$0	$0	$0	$0
Diaphragm	$0	$0	$0	$0	$0	$0
Joists & Wide Flange	$24 240	$0	$25 370	$1542	$25 964	$1578
Wall Frame	$0	$0	$0	$0	$0	$0
Found. Anchor.	$3693	$0	$2984	$116	$3534	$557
Total	**$27 933**	**$0**	**$28 354**	**$1658**	**$29 498**	**$2135**
Budget ($million)	$20.00	$20.00	$19.86	$19.86	$22.27	$22.27
Percent of Budget	**0.14 %**	**0.00 %**	**0.14 %**	**0.01 %**	**0.13 %**	**0.01 %**
Note: No cost impact from tornado loads for all other locations and exposures.						

Table 14. Estimated Cost Impacts from Tornado Loads – High School

Cost Item	Charl.	Chicago	Minn.	DFW		Kansas City		Memphis	
	B	B	B	B	C	B	C	B	C
Roof Fasteners	$0	$0	$0	$300	$0	$11 943	$0	$8294	$0
Diaph.	$0	$0	$0	$0	$0	$0	$0	$0	$0
Joists & WF	$0	$165 023	$0	$139 778	$8495	$137 401	$8350	$140 616	$8546
Wall Frame	$0	$0	$0	$90 000	$0	$70 020	$0	$87 480	$0
Found. Anchor.	$2391	$20 835	$12 675	$20 000	$15 574	$16 160	$13 738	$19 140	$19 140
Total	**$2391**	**$185 857**	**$12 675**	**$250 077**	**$24 069**	**$235 525**	**$22 088**	**$255 530**	**$27 686**
Budget ($million)	$200.45	$280.68	$248.64	$200.00	$200.00	$198.64	$198.64	$222.73	$222.73
Pct of Budget	**0.001 %**	**0.07 %**	**0.005 %**	**0.13 %**	**0.01 %**	**0.12 %**	**0.01 %**	**0.11 %**	**0.01 %**
Note: Exposures not displayed had zero cost impacts from tornado loads									

Indiana Cost Impact

Per ASCE 7-22, tornado design is only required for Risk Category III and IV structures. Most of the building types in Indiana that fall under these categories would be educational facilities, High Hazard Facilities Institutional Facilities.

From State of Indiana Data:

High Hazard 83,769 SFT (Cat IV Buildings)
Educational 2,051901 SFT (Cat III Buildings)
Institutional 1,036,000 SFT (Cat IV Buildings)

From NIST Technical Note2214 Economic Analysis of ASCE 7-22Tornado Load Requirements:

- 0.14% cost impact educational uses. (This was at the high end of the spectrum, with most areas seeing less of an impact, but for the purposes of this analysis, we will use the high end to be conservative, and show the worst impact.
- High Hazard and Institutional categories were not looked at in the NIST study, but the NIST recommendations do indicate that there would be a higher cost impact. For the purposes of this analysis, we will use 0.25% cost impact, which is 78% higher than that for educational uses. This seems high, but will be used for this analysis.

Cost / Square Foot					Cost Cost * Sq Ft * Cost Impact
		Const. Cost	**Sq Ft**	**Cost Impact %**	**Estimated Cost Impact $ per Indiana Data**
High Hazard		$300	83,769	0.25%	$62,826.75
Educational		$350	2,051,901	0.14%	$1,005,431.49
Institutional		$400	1,036,000	0.25%	$1,036,000.00
					$2,104,258.24

From the baseline data, multiplying the building square footages by estimated construction costs would give an estimated yearly construction cost for these types of buildings. Further multiplying these by the cost impact factors would yield the yearly expected cost impact for initial construction. Based on the data presented, this would be expected to be $2,104,258.24

However, it can be expected that increased design for tornadoes would lessen the potential of insurance loss claims and therefore there would be savings yielded by reduced loss of property.

The Evansville Courier Press website Tornadoes in Indiana since 1950 courierpress.com indicates that in 2023 alone there were 6 fatalities attributable to tornadoes and over $41,000,000 in property damages that occurred in the State of Indiana.

Per the NIST study, it is estimated that 18.3% of the entire building stock in tornado prone areas are Risk Category III and IV buildings. Therefore, it is reasonable to assume that 18.3% of property damages occurred to these building, which means that of the $41M in property damages in 2023, 18.3% or $7.5M in damages occurred to Category III or IV buildings.

Using higher design standards may not result in a complete 100% savings, but it is reasonable to assume that these would reduce losses by about 35%. Using this number, this would result in savings in loss of property on the order of $2.6M a year. This exceeds the yearly cost impact of construction ($2.1M) noted above. Therefore, based on this analysis, we expect a savings of $0.5M a year in fiscal impacts by the adoption of IBC 2024 and ASCE 7/22 Tornado loads.

Additionally, it is expected that the potential loss of life would be mitigated with the adoption of the newer codes. The Environmental Protection Agency indicates that the Value of Statistical Life is $7.4 million. Per the data presented on the Evanville Courier Website, 6 deaths in 2023 were attributed to tornados. It is unclear what structures those deaths occurred in, but simple logic would say that if 18.3% of the buildings are Category III or IV, then there is an 18.3% chance that the death was in a Category III or IV structure. Therefore, 6 deaths * $7.4M * 18.3% = $8.1M .

Therefore, based on the analysis presented above, there would be a yearly expected savings of appromiately $8.6M by adopting the tornado loading requirements in IBC 2024.

Per economic Analysis, I recommend keeping the tornado loads in the Proposed 2024 IBC without Amendment.

Section 1611 - Rain Loads

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 1611.1 Design of Rain Loads:

- 2024 modifies calculation of rain loads to be in line with current ASCE 7 chapter 8 requirements.
    - Ponding head is now added to the Rain Load calculation
    - Design rain intensity adjusted to 15-minute storm durations where risk categories determine the storm return period

Section 1611.2 Ponding instability:

- No change

Section 1611.3 Controlled Drainage:

- No change

Economic Impact – 2024 update increases design rain loading by including roof member deflection from self-weight and roof dead load. This increase is negligible for typical construction in Indiana where roof snow loads typically control design, roofs meet minimum slope requirements of IBC section 1507, and an adequate roof drainage system is provided.

Recommendation: Adopt with no changes

Section 1612 - Flood Loads

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 1612.1 General:
- No Change

Section 1612.2 Definitions:
- Section deleted in 2024 and replaced with **Section 1612.4 Design and construction**
  - 2024 edition now reads – **Section 1612.2 Design and construction**

Section 1612.3 Establishment of floor hazard areas:
- No Change

Section 1612.3.1 Design flood elevations:
- No Change

Section 1612.3.2 Determination of impacts:
- No Change

Section 1612.4 Design and construction
- Section is relocated to **1612.2** in 2024 edition
- 'including flood hazard areas subject to high-velocity wave action' is modified in 2024 to 'including coastal high hazard areas and coastal A zones' to be in line with current Chapter 5 ASCE 7 and ASCE 24 versions
- 2024 adds 'Elevators, escalators, conveying systems and their components shall conform to ASCE 24 and ASME A17.1/CSA B44 as applicable.'
- 2024 adds an exception for temporary structures complying with **Section 3103.6.1.3**

Section 1612.5 Flood hazard documentation:
- Subsection 1
  - 2024 updates wording and referenced subsections for 2024 versions of ASCE 24
  - Adds requirement to include a flood emergency plan as specified in Chapter 6 of ASCE 24 to subsection 1.3
  - Adds new sub-section 1.4 which requires documentation of the elevation to which a building is dry floodproofed for final inspection for dry floodproofed nonresidential buildings.
- Subsection 2
  - 2024 updates wording and referenced subsections for 2024 versions of ASCE 24
  - 2024 updates subsection 2.3 by adding ultimate load requirement of 33 psf for breakaway walls. (Note: allowable stress design of 20 psf still in language)
  - 2024 adds new section 2.4 that requires break away walls that do not meet requirements of section 2.7.2.1 of ASCE 24 to include a statement on the construction documents from Engineer that design will provide equalization of hydrostatic forces per ASCE 24

Economic Impact – 2024 update does not change the minimum design requirements for flood loading where required. However, the 2024 update does require additional documentation from the design professional providing more information on the construction documents to make inspection and state plan review clearer. This increase in documentation is negligible/not required for typical construction in Indiana where major flood events are not a concern.

Recommendation: Adopt with no changes

Section 1613 – Earthquake Loads

<u>Purpose</u>: Identifying modifications to current 2012 IBC in proposed 2024 IBC

<u>Current Code Provision</u>:
2014 Indiana Building Code Amendment to the 2012 IBC:

> Section 1613.3.5 DETERMINATION OF SEISMIC DESIGN CATEGORY**:**
>
> "Add an exception to read as follows: Exception: For other than H and E occupancies, the seismic design category need not exceed Seismic Design Category C for buildings and structures in Risk Category Groups I, II, and III for Class 1 buildings and structures."

<u>High Seismic Risk Criteria:</u>
According to FEMA: "A jurisdiction has high seismic risk if it is located in a county which is categorized in the 2021 IBC for Risk Category II as having a design spectral response acceleration at short-periods (SDS) greater than or equal to 0.5g based on the most conservative of site class C or D, or as having a design spectral response acceleration at long-periods (SD1), greater than or equal to 0.2g."

Based on the above reference, more than 100 counties located in southwestern Indiana meet the criteria for HIGH SEISMIC RISK. Based on the 2010 Census Population in Indiana Exposed to High Seismic Hazard **<u>60,487</u>** people per FEMA Fact Sheet.

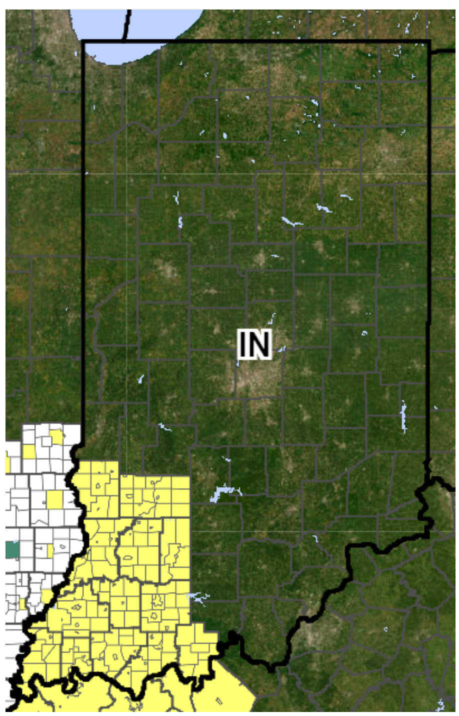


Figure 1: Indiana High Seismic Risk Counties
(Source: https://stantec.maps.arcgis.com/apps/MapSeries/index.html?appid=a053ac48343c4217ab4184bc8759c350)


INDIANA

0.0%

LOWER RESISTANCE

IBC

State adopts an outdated IBC (2012 edition). State weakens the flood provisions by removing establishment of flood hazard areas (Sec. 1612.3). State weakens the seismic provisions by eliminating Seismic Design Category D requirements for buildings and structures in Risk Categories I, II, and III in Sec. 1613.3.5, other than for H and E occupancies.

Figure 2: FEMA - 2023 Building Code Adoption Tracking: FEMA Region 5 Fact Sheet (Page 3)

Economic Impact:

FEMA Hazus Study 2023: 2022 dollars and 2020 census:

- Annualized Earthquake Losses include building repair costs, contents and business inventory losses, costs of relocation, capital-related wage and rental losses
- Annualized Indiana Earthquake losses **$87.4 million**.
    - Evansville Region ($24.4 million)
    - Indianapolis Region ($22.4 million)
- Estimated debris occurred after 250-year event 732,000 tons (29,280 truckloads)
- Annualized Estimates of Casualties:
    - **(20) minor injuries**
    - **(1) fatality**
        - (1) single human life is worth **$7.5 million** (FEMA).
- Estimated annualized losses have increased by 313% (2002 to 2018) by use of the 2014 Indiana Building Code and previous editions that included the exemption noted above.

FEMA ("PROTECTING COMMUNITIES AND SAVING MONEY The Case for Adopting Building Codes") estimates a building cost increase of **0.7%** to adopt latest seismic provisions.

The Association of General Contractors (AGC) document "The Economic Impact of Construction in the United States and Indiana" estimates $13.3 billion/year of private, local, state, and nonresidential construction spending in Indiana. Therefore, based on FEMA, the increase in construction cost will be 13.3B x 0.7% = $93.1M/yr across the entire state of Indiana.

City	2012 IBC (SDS)	2024 IBC (SDS)	2014 Indiana Building Code (Seismic Design Category)	2024 IBC (Seismic Design Category)	Comments
Evansville	0.51g	0.48 g	C	D	6% decrease in forces, increased detailing requirements
Indianapolis	0.169 g	0.21 g	C	C	25% increase in forces, if seismic controls
Fort Wayne	0.125 g	0.14 g	B	B	12% increase in forces, if seismic controls

Assumed: Risk Category II; Site Class D

Impact Summary:
Annualized Earthquake Losses (Indiana) = $87.4M + $7.5M = $94.9M
Increased Construction Cost due to Code Adoption = $93.1M
TOTAL = $94.9M – $93.1M = $1.8M net savings/year.

Adoption of the 2024 IBC will greatly reduce future potential building losses and casualties when the next seismic event occurs along the New Madrid fault.

Recommendation: Adopt with no changes

Section 1614 – Atmospheric Ice Loads

Purpose: Identifying modifications to the current 2014 Indiana Building Code in the proposed 2024 IBC

Section 1614 Atmospheric Ice Loads

Section 1614.1 General:

- No change to language, both require following Chapter 10 of ASCE 7
    - The below compares ASCE7-10 to ASCE7-22

ASCE7 Chapter 10, Ice Loads – Atmospheric Icing:

10.1 GENERAL

- No change

- 10.1.1: Site Specific Studies
    - Site specific no longer applies to Alaska (does not impact Indiana)
    - Removed option to not use mapped values when available
- 10.1.2: Dynamic Loads
    - Unchanged
- 10.1.3: Exclusions
    - Unchanged

10.2 DEFINITIONS

- Added a definition for '*Atmospheric Ice Geodatabase'*

10.3 SYMBOLS

Removed importance factor definitions from list. Note, the importance factors still apply

10.4 ICE LOADS CAUSED BY FREEZING RAIN

- 10.4.1: Changed header from "Ice Weight" to "Ice Load"
    - Area of ice equation, for prismatic shapes changed from

$$A_i = \pi t_d (D_c + t_d) \quad (10.4\text{-}1)$$

to

$$A_i = \pi \frac{t_d}{12}\left(D_c + \frac{t_d}{12}\right) \quad (10.4\text{-}1)$$

- Volume of ice equation on three dimensional objects changed from:

$$V_i = \pi t_d A_s \quad (10.4\text{-}2)$$

to

$$V_i = \pi \frac{t_d}{12} A_s \quad (10.4\text{-}2)$$

- Area of plate (As) of domes and spheres stayed the same

- 10.4.2: Nominal Ice Thickness
    - Language in paragraph stayed the same
    - Tables for ice thickness moved from 10-2 to 10.4-2 through 10.4-5. The extra tables break it down by risk category
    - To compare the ASCE7-10 thickness to the ASCE7-22 thickness, the Risk Category II chart is chosen to compare
    - In ASCE7-22, for the entire state, the design ice thickness is 1in. For southern Indiana, this is a 25% increase (was ¾"), for central Indiana this is the same, for northwestern Indiana this is a 25% increase (was ¾")
- 10.4.3: Height Factor

- Unchanged
- 10.4.4 Importance Factor
  - Removed due to presence of additional maps (refer to 10.4.2). The updated section 10.4.4 is now 'Topographic Factor', which was 10.4.5. See below, 10.4.5 for comparison
- 10.4.4 (ASCE7-22) Topographic Factor
  - Was 10.4.5 in ASCE7-10
  - Unchanged
- 10.4.5 (ASCE7-22) Design Ice Thickness for Freezing Rain
  - Was 10.4.6 in ASCE7-10
  - Equation for design ice thickness changed from:
  - $t_d = 2.0 t I_i f_z (K_{zt})^{0.35}$ (10.4-5) to $t_d = t f_z (K_{zt})^{0.35}$ (10.4-5)
  - This leads to a 50% reduction in ice thickness, if all other variables are equal

10.5 WIND ON ICE-COVERED STRUCTURES

- Figures for concurrent wind speed updated from 10-2 - 10-6 to 10.5-1 to 10.5-2. In ASCE7-22, the wind speed is 40 MPH in southern Indiana (a 10 MPH increase for most counties in ASCE7-10) and 50 MPH in central and norther Indiana (a 10 MPH increase for most counties in ASCE7-10)
- The remainder of the language stayed the same
- 10.5.1 Wind on Ice Covered Chimneys, tanks, and Similar Structures
  - Unchanged
- 10.5.2 Wind on Ice Covered Solid Freestanding Salls and Solid Signs
  - Updated reference table. The table is the same
  - Effect is no change
- 10.5.3 Wind on Ice Covered Open Signs and Lattice Frameworks
  - Updated reference table. The table is the same
  - Effect is no change
- 10.5.4 Wind on Ice Covered Trussed Towers
  - Updated reference table. The table is the same
  - Effect is no change
- 10.5.5 Wind on Ice Covered Guys and Cables
  - Unchanged

10.6 DESIGN TEMPERATURES FOR FREEZING RAIN

- Figures for design temperatures updated from 10.7 and 10.8 to 10.6-1 and 10.6-2. The temperature remains at 5 degrees Fahrenheit for the entire state

10.7 Partial Loading

- Unchanged

10.8 Design Procedure

- Table references updated, the rest is unchanged

10.9 CONSENSUS STANDARDS AND OTHER REFERENCED DOCUMENTS

- Referenced documents updated to current versions

Economic Impact – 2024 update decreases the design ice loading by reducing the design ice thickness by 2, in equation 10.4-5. This decrease does not mean a uniform 50% reduction in design ice loads, as the nominal ice thickness changed for portions of the state, but will mean a net decrease in ice load and structural cost associated with the design requirement. There is minimal fiscal impact as ice loads normally are not the controlling factor in designs, therefore there are no substantial fiscal impacts.

Recommendation: Adopt with no changes

Section 1616 – Structural Integrigy

Purpose: Identifying modifications to the current 2014 Indiana Building Code in the proposed 2024 IBC

Section 1616 Structural Integrity

Note – this was 1615 in the 2014 Code. All references below will say 1616, and refers to the corresponding 1615 subsection

Section 1616.1 General:

- Change to language, no change resulting from this modification

Section 1516.2 Definitions (missing from 2024 Code):

- Refers to definitions in chapter 2. 2024 IBC remove this section, the two definitions are the same between each code edition

Section 1616.2 Frame Structures (1615.3 in 2014 Code):

- Unchanged

Section 1616.2.1 Concrete Frame Structures (1615.3.1 in 2014 Code):

- Updates to tables and ACI sections referenced, the rest is unchanged

Section 1616.2.2 Structural Steel, Open Web Steel Joist or Joist Girder, or Composite Steel and Concrete Frame Structures (1615.3.1 in 2014 Code):

- Unchanged

Section 1616.3 Bearing Wall Structures (1615.4 in 2014 Code):

- Unchanged

Section 1616.3.1 Concrete Bearing Wall Structures (1615.4.1 in 2014 Code):

- Updates to tables and ACI sections referenced, the rest is unchanged

Section 1616.3.2 Other Bearing Wall Structures (1615.4.2 in 2014 Code):

- Unchanged
-

Economic Impact – 2024 update has not materially changed anything from the 2014 Indiana Code

Recommendation: Adopt with no changes

Chapter 17 – Special Inspections and Tests

Purpose: Identifying modifications to current 2014 Indiana Building Code in proposed Indiana Building Code Update. The 2014 Indiana Building Code did not adopt any of this chapter.

Section 1701.1 Scope:

- The provisions of this chapter shall govern the quality, workmanship and requirements for materials covered. Materials of construction and tests shall conform to the applicable standards listed in this code.

Section 1704.2 Special inspections and tests:

- Where application is made to the building official for construction as specified in Section 105 (anything requiring a permit), the owner or the owner's authorized agent, other than the contractor, shall employ one or more approved agencies to provide special inspections and tests during construction on the types of work specified in Section 1705 and identify the approved agencies to the building official. These special inspections and tests are in addition to the inspections by the building official that are identified in Section 110.
- Exceptions:
    - Special inspections and tests are not required for construction of a minor nature or as warranted by conditions in the jurisdiction as approved by the building official.
    - Unless otherwise required by the building official, special inspections and tests are not required for Group U occupancies that are accessory to a residential occupancy including, but not limited to, those listed in Section 312.1.
    - Special inspections and tests are not required for portions of structures designed and constructed in accordance with the cold-formed steel light-frame construction provisions of 2206.1.2 (detached one- and two-family dwellings and townhouses, less than or equal to three stories above grade plan, constructed according to AISI S230 Prescriptive Faming) or the conventional light-frame construction provisions of Section 2308 (light framed wood construction).
    - The contractor is permitted to employ the approved agencies where the contractor is also the owner.

Engineer Commentary:

- Special Inspections have been present in the building code in some form since the 1961 UBC. A further push was made when Congress got involved after a series of high-profile catastrophic structural failures in the 1970's and early 1980's. The congressional subcommittee noted the following:
    - "For various reasons, the structural engineer of record or disgnee is often not present on the jobsite during the construction of principal structural components. The absence of the structural engineer has permitted onsite flaws and changes to go unnoticed and uncorrected." It was also noted this situation "has consistently cited in cases in which structural failures have occurred."
- Most states and/or jurisdictions (do we have access to data on this?) have adopted special inspections in some form. Indiana is in the vast minority when it comes to adoption of this crucial life safety aspect of the construction process.

Economic Impact:

- The cost of a special inspector(s) for structural elements ensures that the project is built according to construction documents and significantly decreases the possibility of catastrophic structural collapse and loss of life in the future.
- Cost = salary of 1-2 individuals over the duration of construction of the structure. May or may not be on site full time. However, many current code savvy owner already project these types of inspections on their projects. Higher education clients such as Purdue and Indiana University already provide these inspections on their projects. Additionally, there are no inspections required for wood projects.
- Additionally, a recent survey of structural engineer's in Indiana estimates that 50% of current structural engineers require inspections as part of their construction documents. Therefore, we will only apply 50% of the approved baseline numbers as needing special inspection.

Type of Project	*# Projects*		*# Projects*	*Duration*	*%*	*#Hours*	*$35/hr*
Assembly	933	Assume these already have inspections by owners	0	120	0.25	0	$ -
Business	1612	Assume 30% of need inspection	483.6	90	0.25	87048	$ 3,046,680.00
Educational	317	Assume 30% of need inspection	95.1	120	0.25	22824	$ 798,840.00
Factory / Industrial	283	Assume 30% of need inspection	84.9	75	0.15	7641	$ 267,435.00
High Hazard	9	Assume these already have inspections by owners	0	90	0.5	0	$ -
Institutional	171	Assume these already have inspections by owners	0	90	0.5	0	$ -
Mercantile	640	Assume 30% of need inspection	192	90	0.3	41472	$ 1,451,520.00
Mixed Use - Non Resdential	1848	Assume 30% of need inspection	554.4	90	0.25	99792	$ 3,492,720.00
Storage	882	Assume 30% of need inspection	264.6	75	0.15	23814	$ 833,490.00
Utility and Misc	304	Assume 30% of need inspection	91.2	75	0.15	8208	$ 287,280.00
							0
Apartments	14,245	Units (Assume all wood and don't require them)	0	90	0.25	0	0
							$ 10,177,965.00
% - percentage of time of for periodic inspection based on the nature of the project as well as the types of inspections needed.							
$35/hr - Assumed hourly rate of inspector							
Duration - Assume project duration of structural work (Foudnations, steel erection, etc) that require structural inspections.							

Fiscal impact = $10,178,000

Recommendation: Adopt with no changes

Chapter 18 – Soils and Foundations

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Structural Changes with Significant Cost Implications:

Section 1809.5.1 Frost Protection at required exits

- Frost protection required at exterior landings for all required exits with outward-swinging doors. This would require a frost slab or similar at these locations.

Economic Impact – It is common practice in Indiana to have a frost slab at exits to ensure proper egress and life safety requirements, therefore an economic impact is not anticipated.

Recommendation: Adopt with no changes

Chapter 19 – Concrete

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 1901 General

- **Changes**
  - No longer exception for slabs-on-grade w/o vertical or lateral load transfer
  - Inclusion of Composite steel and concrete structures (Section 2206)
  - Anchoring to concrete
  - Glass reinforced concrete only allowed in SDC A
- Construction Documents – NO CHANGE
- SPECIAL INSPECTIONS – Look at Ch. 17
- References anchoring to concrete per ACI 318 – No cost implication
- References concrete tolerances for cast-in-place and precast concrete per ACI 117 and ACI ITG-7 – No cost implications

Section 1902 Coordination of Terminology

- Design displacement – Design Earthquake Displacement δ_{DE} per 12.8.6.3
- Rigid Diaphragms - δ_{DI} permitted to be zero
- Compare to 12.8.6 of ASCE 7-10

Section 1903 Specifications for Tests and Materials

- Reference to ACI – Allows for high-strength rebar – Cost savings
- Glass fiber reinforced – NO CHANGE
- Flat wall insulating concrete form systems – NO CHANGE

Section 1904 Durability Requirements

- Minimum specified compressive strength f'c now 3,000 (previously 2,500-3500 based on exposure)
  - Indiana was previously severe exposure - allowed for basement walls to be 2,500 psi – Potential cost increase

Section 1905 Seismic Requirements – (Really "Modifications to ACI 318")

Seismic shear has increased

Seismic rebar detailing will require more rebar in SDC B or higher – Significant detailing changes in Category IV buildings in Southern portion of the state

Life safety /damage cost savings in case of seismic event

Section 1906 Footings for Light-Frame Construction (Previously called Structural Plain Concrete) – NO CHANGE

Section 1907 Slabs-on-Ground – Same Requirements – NO COST CHANGE

Former Sections 1908 and 1909 : Anchorage to Concrete -ASD and Anchorage to Concrete – Strength – No longer a part of code – points to ACI – NO COST CHANGE

Section 1908 Shotcrete (Formerly Section 1910)

- Now points to ACI 318

Former section 1911 - Reinforced Gypsum Concrete – Deleted – NO COST CHANGE
Former Section 1912 – Concrete-filled pipe columns – Deleted (moved to AISC domain) – NO COST CHANGE

Recommendation: Adopt with no changes

Chapter 21 – Masonry

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Section 2101 General

- 2101.2 Design methods- points to TMS code vs IBC provisions – NO COST CHANGE
- 2101.3 – Triggers Special Inspections Ch. 17

Section 2102 Notations

- Defines variables vs. masonry terms – NO COST CHANGE

Section 2103 Masonry Construction Materials

- Complies with TMS 602 and 504 vs ASTM standards– NO COST CHANGE
- Mortar grout requirements – NO SIGNIFICANT CHANGES

Section 2104 Construction

- Removes references to tolerances/placing mortar/wall ties/chases/lintels and points to TMS
- No other changes – NO COST CHANGE

Section 2105 Quality Assurance

- Now points to TMS in addition to Chapter 17 – NO COST CHANGE

Section 2106 Seismic Design

- **NO CHANGES**

Section 2107 Allowable Stress Design

- References TMS aside from lap splice/development length design change – NO COST CHANGE

Section 2108 Strength Design of Masonry

- References TMS aside from lap splice/development length design change – NO COST CHANGE

Section 2109 Empirical Design of Adobe Masonry (Formerly Empirical Design of Masonry)

- Removes limitations on exterior wall finishes
- Adds requirements for clay plaster
- Increases minimum thickness for Portland cement plaster
- Overall – NO COST CHANGE

Section 2110 Glass Unit Masonry

- **NO CHANGES**

Section 2111 Masonry Fireplaces

- 2111.2 – Construction drawings now required for masonry fireplaces – small cost change
- 2111.4- Seismic anchorage required for structures outside of SDC A and B vs. previous only for C and D – NO COST CHANGE

Section 2112 Masonry Heaters

- 2112.2 – Allows for EN 15250 listed – NO COST INCREASE – possible savings

Section 2113 Masonry Chimneys

- 2113.4- Seismic anchorage required for structures outside of SDC A and B vs. previous only for C and D – NO COST CHANGE
- NO OTHER CHANGES

Section 2114 Dry-Stack Masonry (Formerly 209 – Empirical Design of Masonry)

- References TMS 402 Chapters 1 through 8 vs previous Ch 5
- Requires ASTM C90 units
- No longer references 110 mph wind limitation
- Overall- NO COST CHANGES

Recommendation: Adopt without changes

Chapter 22 - Steel

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Chapter 22 – Reorganization of Sections:

- 2024 IBC reorganizes Chapter 22 sections for better flow, usability, and clarification of the steel provisions of the building code.

Section 2202 STRUCTURAL STEEL AND COMPOSITE STRUCTURAL STEEL AND CONCRETE:

- Updated reference standards to 2022 AISC standards.

Section 2203 STRUCTURAL STAINLESS STEEL:

- Added new section not previously codified.

Section 2204 Cold-Formed Steel:

- Changed the reference standard from ASCE 8 to ASCE 7 and AISI S100/S400. Removal of ASCE 8 which no longer includes Cold-Formed carbon steel.

Section 2207 Cold-Formed Steel:

- Updated to the latest SJI Specifications.

Section 2208 Steel Deck:

- Changed the reference standard from ASCE 8 to AISI S310 and SDI SD standard that is new and not previously referenced.

Section 2209 Steel Storage Racks:

- Certification of steel storage racks over 8 feet in Seismic Design Category D, E, F are required to have a certificate of compliance to the owner.

Section 2210 Metal Building Systems:

- Added new section not previously codified. Many construction documents still reference the nonexistent Metal Building Manufacturers Association standards.

Section 2211 Industrial Boltless Steel Shelving:

- Added new section not previously codified.

Section 2212 Industrial Steel Work Platforms:

- Added new section not previously codified.

Section 2213 Stairs, Ladders and Guarding for Steel Storage Racks and Industrial Steel Work Platforms:

- Added new section not previously codified.

Economic Impact – 2024 IBC update provides updated reference standards that fabricators and manufacturers are already using around the country; by utilizing standards that no longer exist, the cost of construction increases as stronger materials are allowed in the new reference standards.

Also, the reorganization and added sections bring clarity and consistency across the design and construction industries and will lead to more consistent budgeting of construction projects. More consistent budgeting will prevent allowances from ballooning construction costs.

Recommendation: Adopt with no changes

Chapter 34 – Existing Structures

Purpose: Identifying modifications to current 2012 IBC in proposed 2024 IBC

Summary of Code reorganization:

- 2014 Indiana Building Code has numerous amendments to 2012 IBC Chapter 34.
- 2024 IBC removes Chapter 34 - Existing Structures and references the 2024 International Existing Building Code (IEBC).

Notes on Seismic Design Categories:

- Many of the provisions in the IEBC are triggered by the Seismic Design Category of the structure. The majority of structures in Indiana are Seismic Design Category B or C. Structures in southwest Indiana, with poor soil, or with high importance factor may be in a lower Seismic Design Category such as D. This will be impacted by if the 2014 Indiana Amendments which further limit Seismic Design Categories are carried forward to the new code.

2024 IEBC Structural Changes with Significant Cost Implications:

Chapter 3 Provisions for All Compliance Methods

Section 303.2 Addition to a Group E occupancy

- Additions to existing Educational Group E occupancy shall have a storm shelter.

Chapter 5 Prescriptive Compliance Methods

- Prescriptive compliance method is one path for code compliance.

Section 503.6 Bracing for unreinforced masonry parapets on reroofing.

- When reroofing more than 25 percent of the roof area on structures in Seismic Design Category D, E or F with unreinforced masonry parapets an analysis of the parapets for reduced seismic criteria is required.
- Parapets not meeting requirements require upgrades, such as parapet bracing.

Section 503.7 Anchorage for concrete and reinforced masonry walls.

- Where work area exceeds 50 percent of building area for Structures in Seismic Design Category C, D, E, or F that include concrete or masonry walls with a flexible roof diaphragm an analysis of the wall to diaphragm connection for reduced seismic criteria is required.
- Connections not meeting requirement require upgrades, such as wall anchors.

Section 503.8 Anchorage for unreinforced masonry walls in major alterations.

- Where work area exceeds 50 percent of building area for Structures in Seismic Design Category C, D, E or F that include unreinforced masonry bearing walls an analysis of the wall to diaphragm connection for reduced seismic criteria is required.
- Connections not meeting requirements require upgrades, such as wall anchors.

Section 503.9 Bracing for unreinforced masonry parapets in major alterations.

- Where work area exceeds 50 percent of building area for Structures in Seismic Design Category C, D, E or F with unreinforced masonry parapets an analysis of the parapets for reduced seismic criteria is required.
- Parapets not meeting requirements require upgrades, such as parapet bracing.

Section 503.10 Anchorage of unreinforced masonry partitions in major alterations.

- Where work area exceeds 50 percent of building area for Structures in Seismic Design Category C, D, E or F with unreinforced masonry partitions and non-structural walls adjacent to egress paths an analysis of the walls for reduced seismic criteria is required.
- Walls not meeting requirements require upgrades.

Section 503.11 Substantial structural alteration

- Where work area exceeds 50 percent of building area and there are “Substantial Structural Alteration” which is defined as “An alteration in which the gravity load-carrying structural elements altered within a 5-year period support more than 30 percent of the total floor and roof area of the building or structure.”
- Requires an analysis of the lateral load resisting system for current code required wind loads and either current code required seismic loads or ASCE 41 Tier 3 analysis.
- Structure in Seismic Design Category D or F and a Risk Category IV require an analysis of components and cladding for current code required seismic loads or ASCE 41.
- Structures not meeting requirements require upgrades.

Chapter 7 Alterations – Level 1

- Level 1 alterations apply to projects with the removal and replacement of existing materials and elements with new materials and elements that serve the same purpose.

Section 706.3.1 Bracing for unreinforced masonry bearing wall parapets.

- See 503.6 above.

Chapter 9 Alterations - Level 3

- Level 3 alterations apply where the work area exceeds 50 percent of the building area.

  Section 906.2 Existing structural elements resisting lateral loads.

  - See 503.11 above.

  Section 906.4 Anchorage for concrete and masonry buildings.

  - See 503.7 above.

  Section 906.5 Anchorage for unreinforced masonry walls.

  - See 503.8 above.

  Section 906.6 Bracing for unreinforced masonry parapets.

  - See 503.9 above.

  Section 906.7 Anchorage of unreinforced masonry partitions.

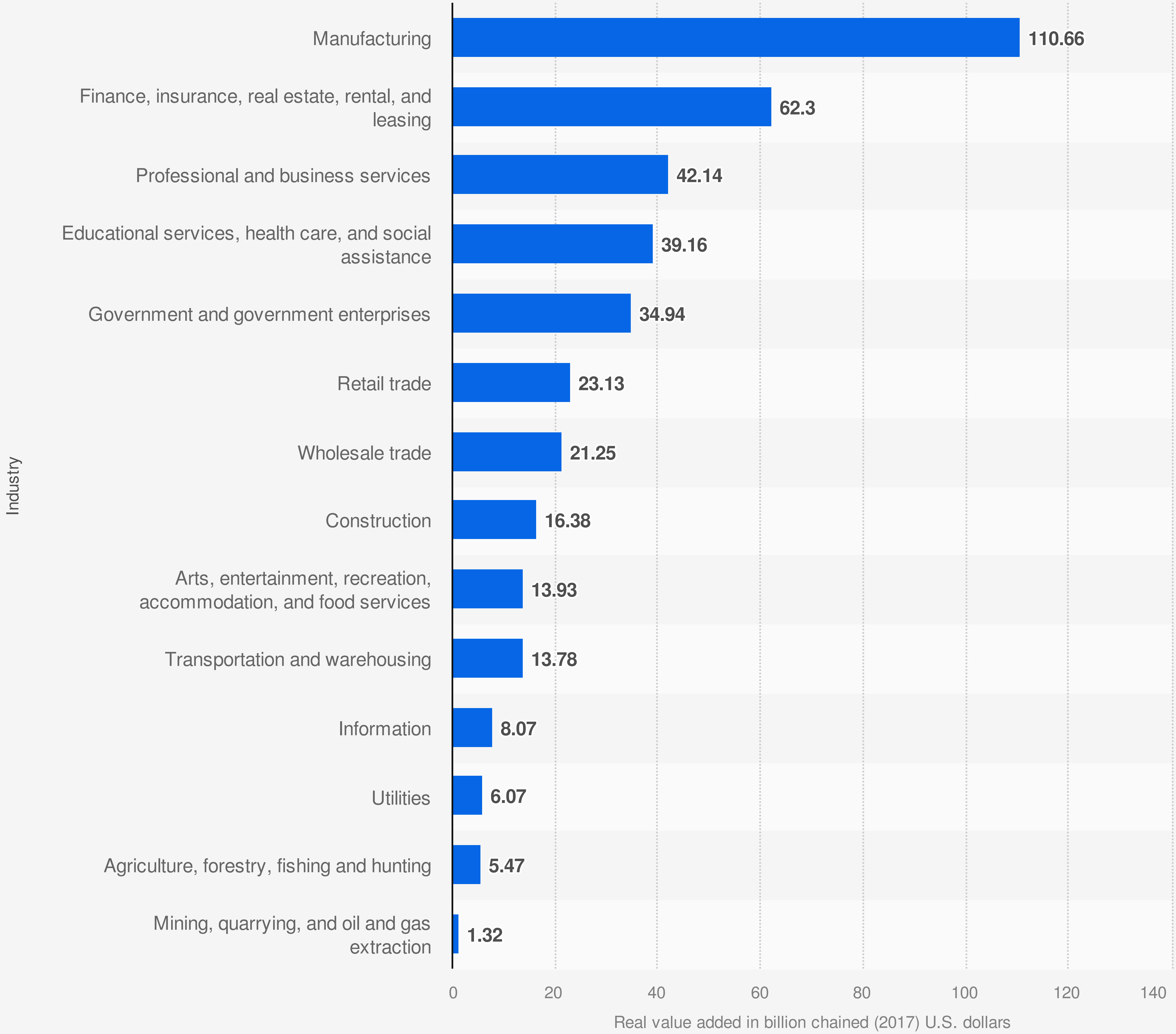
  - See 503.10 above.

Economic Impact – Changes will impact construction cost of major building renovations. However, the provisions in the IEBC are specifically targeted at the most vulnerable existing structural elements that most commonly fail causing loss of life and property and related negative economic impact.

Recommendation:

IEBC provisions are intended to provide a basic level of safety and not full compliance with the current building code. Structural upgrades are targeted at the most vulnerable existing structural elements and are triggered by level of renovation, with the intention that they can be cost effectively implemented during the renovation. We recommend the IEBC be adopted without amendments.

Real value added to the gross domestic product of Indiana in the United States in 2023, by industry (in billion chained 2017 U.S. dollars)



Source
BEA

Additional Information:
United States; BEA; 2023

AGC THE CONSTRUCTION ASSOCIATION

The Economic Impact of Construction in the United States and Indiana

Economic Impact of Construction:

- U.S. gross domestic product (GDP)—the value of all goods and services produced in the country—totaled $26.5 trillion at a seasonally adjusted annual rate in the 1st quarter of 2023; construction contributed $1.1 trillion (4.0%).
- In Indiana, construction contributed $20.9 billion (4.4%) of the state's GDP of $473 billion.
- There were 919,000 construction establishments in the U.S. in the 1st quarter of 2023, including 16,900 in Indiana. (An establishment is a fixed business location; about 99% of construction firms have only one establishment.)

Construction Spending:

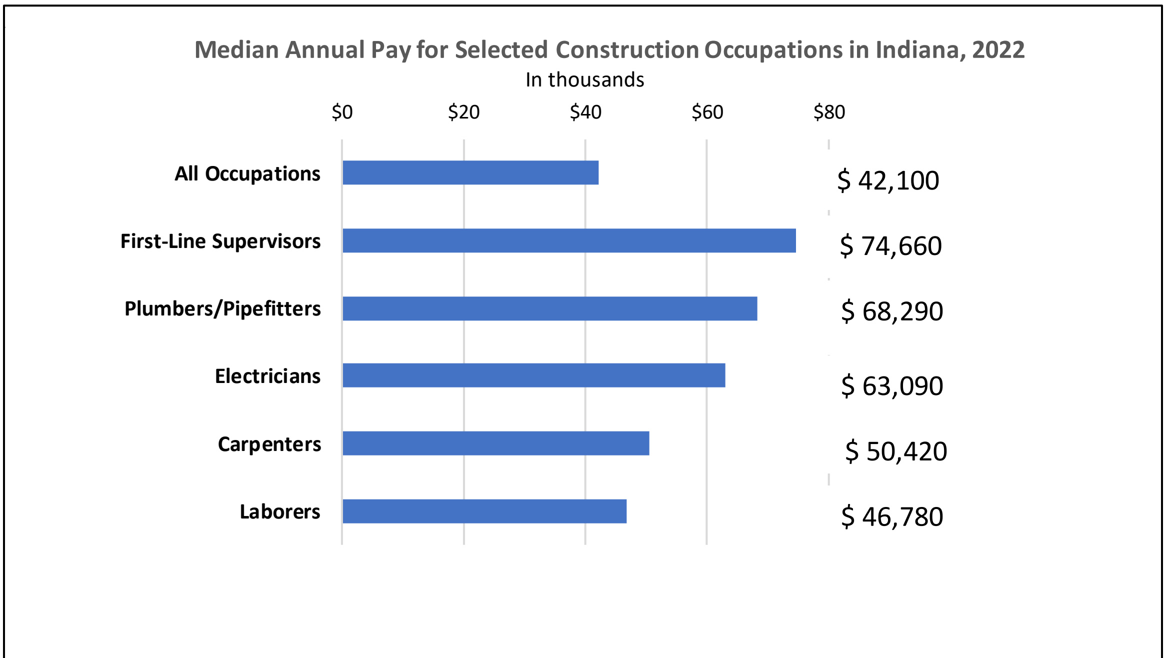
- Nonresidential spending in the U.S. totaled $921 billion in 2022 ($554 billion private, $367 billion public).
- Residential construction spending in the U.S. totaled $927 billion ($453 billion single-family, $110 billion multifamily, $355 billion improvements, $10 billion public).
- Private nonresidential spending in Indiana totaled $6.5 billion in 2022. State and local spending totaled $6.8 billion. (Totals are not available for residential, railroad, power, communication, or federal construction.)

Construction Employment (Seasonally Adjusted):

- Construction (residential + nonresidential) employed 7.9 million workers in July 2023, an increase of 198,000 (2.5%) from July 2022 and an increase of 4.8% from February 2020, the peak pre-pandemic month.
- Construction employment in Indiana in July 2023 totaled 164,300, an increase of 8,700 (5.6%) from July 2022 and an increase of 14,200 or 9.5% from February 2020.
- Contractors are having trouble filling positions, impeding the industry's recovery. In the September 2023 AGC-Autodesk Workforce Survey, 85% of firms had a hard time filling hourly craft positions.

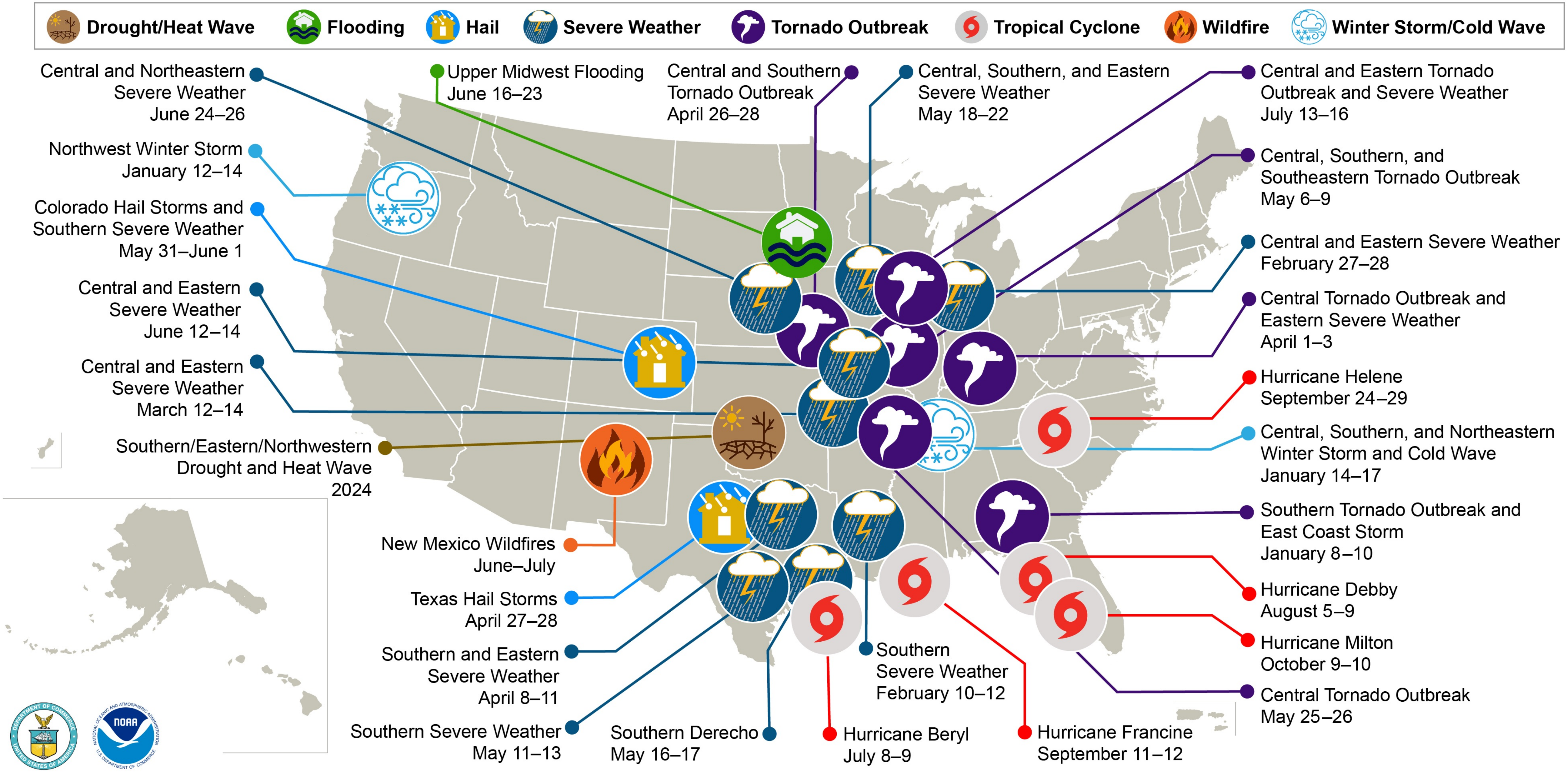
Construction Industry Pay:

- Construction jobs pay well. In Indiana, 5 out of the 5 most numerous construction occupations had median annual pay exceeding the median for all employees in 2022. (Half of workers earn more than the median; half earn less.)



Source: Macrina Wilkins, Senior Research Analyst, AGC of America, macrina.wilkins@agc.org, from Bureau of Economic Analysis (GDP); Census Bureau (spending); Bureau of Labor Statistics (national and state employment, median wages); AGC (outlook survey). September 18, 2023

U.S. 2024 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the **27 separate billion-dollar weather and climate disasters that impacted the United States in 2024.***

The Preparedness Payoff:
The Economic Benefits of Investing in Climate Resilience

2024 Climate Resiliency Report
Produced in partnership by the U.S. Chamber of Commerce, Allstate, and the U.S. Chamber of Commerce Foundation

U.S. Chamber of Commerce

Allstate

U.S. Chamber of Commerce Foundation

Table of Contents

Executive Summary

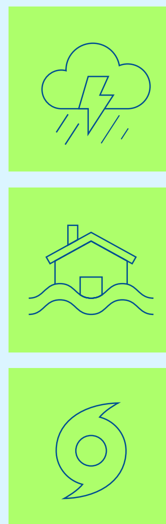
Preparing for climate-related catastrophes beats focusing on recovery alone

EACH $1 INVESTED IN DISASTER PREPARATION SAVES $13 IN ECONOMIC COSTS, DAMAGES, AND CLEANUP

The U.S. experiences a multitude of disasters each year. The cost of cleaning up and rebuilding destroyed homes, businesses, equipment, and infrastructure is immense and growing. In 2022 alone, the cost of natural disasters exceeded $360 billion across the globe, including more than 40 weather events causing over $1 billion in damage.[1]

Investments in resilience and preparedness can reduce the cost of damage after a disaster. An accepted ratio (see the Methodology section) is that $1 of investment reduces the damage and cleanup costs of a disaster by $6. What is less known—and what this study set out to find—is how investments in resilience and preparedness impact a community's local economy, including jobs, workforce participation, production (GDP), and earned income for residents.

The Climate Resiliency Report from the U.S. Chamber of Commerce, Allstate, and the U.S. Chamber of Commerce Foundation shows that investments in resilience and preparedness can substantially reduce the economic costs associated with disasters.



Natural disasters caused more than

$360 billion

in damage globally in 2022

The study revealed that each $1 of investment in resilience and disaster preparedness reduces a community's economic costs after an event by $7. That's the median ratio for the 25 disasters modeled as part of the study.

That $7 of savings for economic costs is in addition to the $6 of savings for damage already assumed in our model. Combining the two ratios finds that every $1 invested in resilience and disaster preparedness saves $13 in economic impact, damage, and cleanup costs after the event.

1 https://www.ajg.com/gallagherre/-/media/files/gallagher/gallagherre/gallagher-re-nat-cat-review-2022.pdf

Glossary

Climate-related catastrophe

A natural event in a weather cycle that is caused by climate change and has a significant negative impact. Examples include hurricanes, tornadoes, blizzards, droughts, floods, storms, heat waves, wildfires, and pollution.

Climate resilience

The ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate.

Natural disasters

The harmful impact on a society or community following a natural hazard event. Examples of natural hazard events include floods, droughts, earthquakes, tornadoes, and wildfires.

Pre-disaster mitigation

A sustained action taken to reduce or eliminate the long-term risk to human life and property from hazards.

Preparedness

Precautionary measures in the face of potential disasters.

Five of the 25 disaster scenarios that we modeled and analyzed are described below. They range in damage and cleanup costs from $1 billion to $130 billion and involve communities of different sizes across the country.

Each scenario highlights the jobs saved, workforce preserved, and economic savings that would come from investing up-front in resilience and disaster preparedness programs and resources. This is true in larger metropolitan areas as well as smaller rural areas and towns. It is also true for more severe major disasters and less severe events. For example—

- $10.8 billion of investments in resilience and preparedness for a Category 4 hurricane striking Miami would prevent the loss of about 184,000 jobs and save about $26 billion of production and $17 billion of income.
- $833 million of investments in resilience and preparedness for a major earthquake striking San Diego would save about 38,000 jobs. The amount of production and income saved would be about $5.8 billion and $3.3 billion, respectively.

- $83 million of investments in resilience and preparedness for a serious tornado hitting Nashville would save more than 5,300 jobs. The amount of production and income saved would be more than $683 million and $464 million, respectively.
- $83 million of investments in resilience and preparedness for a drought/heat wave in Redding, California, would save 474 jobs, keep $67 million of output, and preserve more than $31 million of income in the area.
- $83 million of investments in resilience and preparedness for a major wildfire in Santa Fe would save 388 jobs, keep almost $45 million of output, and preserve more than $20 million of income in the area.

Investments in resilience and preparedness won't prevent losses, but they can significantly reduce them. This has economic benefits for a community in terms of both continued economic growth and income. It is vital that community members, small business owners and decision makers at every level have a firm grasp of how such investments can substantially reduce the economic costs of disasters. This study is one small step in that direction.

Report Highlights

The U.S. averages about 10 $1 billion disasters each year.
From 1980 to the present, the U.S. has suffered 383 weather and climate disasters that caused more than $1 billion in damage. Those disasters caused more than $2.7 trillion of damage in total.[3]

Investment in disaster preparedness pays off.
Every $1 invested in resilience and preparedness saves $13 in economic savings, damage, and cleanup costs after the event.

3 https://www.ncei.noaa.gov/access/billions/summary-stats#temporal-comparison-stats

Amount spent on preparedness reduces the economic impact on the local community. Every $1 spent on preparing for disasters is worth $7 in saved economic costs for the community, including job losses, reduced incomes, and other economic impacts.

Disaster preparedness is a good idea in large cities and small communities alike. Investments in resilience and preparedness have large potential benefits in smaller communities whether it’s a large $1 billion disaster or a smaller one.

After investments in resilience and preparedness totaling $10.8 billion for **a Category 4 Hurricane striking Miami**, the area would prevent the loss of about 184,000 jobs. The amount of production and income saved would be $26 billion and $17 billion, respectively.

After $833 million of investments in resilience and preparedness for **a major earthquake striking San Diego**, the area would save about 38,000 jobs. The amount of production and income saved would be about $5.8 billion and $3.3 billion, respectively.

After $83 million of investments in resilience and preparedness for **a serious tornado hitting Nashville**, the area would save more than 5,300 jobs. The amount of production and income saved would be more than $683 million and $464 million, respectively.

After $83 million of investments in resilience and preparedness for **a drought/heat wave, Redding, California**, would save 474 jobs, keep $67 million of output, and preserve more than $31 million of income in the area.

After $83 million of investments in resilience and preparedness for **a major wildfire, Santa Fe** would save 388 jobs, keep almost $45 million of output, and preserve more than $20 million of income in the area.

Investments in resilience and preparedness have economic benefits even if a disaster never occurs. As investments in disaster preparedness climb, communities see more jobs, the workforce grows, more people move to the area, and production and incomes increase.

Disaster Scenarios and Their Impacts

We've quantified the losses associated with different disasters, and the benefits of preparing for them. These scenarios show how impacts vary with the size of the population affected and the severity of the disaster.

The larger the disaster (in severity/scope), the larger the destruction and subsequent costs. Not surprisingly, disasters that hit large urban centers as opposed to small towns and rural areas have larger overall costs. It follows that the benefits of pre-disaster mitigation, resilience, and preparedness are greater for larger population centers and larger disasters. Although the savings for smaller areas and less costly disasters are proportionally smaller, they are still large in absolute dollar terms.

Larger disasters such as hurricanes, large storms, and earthquakes also require more investment to reduce the potential damage.

A major hurricane in a highly-populated region

A large hurricane hitting Miami (population 6.2 million) causing $130 billion in damage would be a major disaster, but that price tag would tell only a fraction of the human—and economic—story.

Cleaning up and rebuilding, including replacing destroyed homes, businesses, and equipment, requires significant time. The lost economic activity during this recovery time carries additional economic costs.

Category 4 Hurricane Hitting the Miami Area

Damage Inflicted: $130 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	**Economic Losses Caused by the Disaster After Resilience and Preparedness Investment**	**Economic Savings From Cutting Damage in Half**	**Gains from $10.8 Billion Invested in Resilience and Preparedness**
Jobs	-361,106	-177,074	184,032	126,388
Population	-210,989	-46,512	164,477	37,047
Labor Force	-139,633	-33,221	106,412	24,225
GDP	-$46,176,420,797	-$19,788,000,000	$26,388,420,797	$12,855,000,000
Income	-$29,155,182,522	-$12,192,000,000	$16,963,182,522	$8,556,000,000

361,000
jobs lost without preparedness investment

$26 billion
saved in GDP with preparedness investment

These other economic impacts would be vast. In addition to direct damage and deaths, the Miami area would lose more than 361,000 jobs (8% of all the jobs in the region). About 140,000 workers (3% of all workers) would leave the labor force, and close to 211,000 people (4% of the population) would move away. The costs would be over $46 billion in lost production and over $29 billion of lost income for local residents as the area recovers.

If policymakers invested enough in the Miami area to cut the damage from the same storm in half ($10.8 billion), the economic costs would be substantially less, and people and communities would be better protected. Such investments cannot prevent loss completely, but they would significantly reduce the overall long-term losses.

The same storm hitting Miami after these investments in resilience and preparedness would result in about 177,000 jobs lost, meaning the investments in resilience and preparedness would prevent the loss of 184,000 jobs. Those investments would prevent about 106,000 people from leaving the labor force and more than 164,000 from leaving the area. The amount of production and income saved would be $26 billion and $17 billion, respectively.

The payoff from investments in resilience and preparedness is enormous in this scenario. For instance, the Miami region could spend up to $26 billion and it would still see a positive return compared to the production losses it would suffer from a Category 4 hurricane.

The $10.8 billion invested would create more than 126,000 jobs, attract more than 37,000 people to the area, grow the workforce by more than 24,000, increase production by close to $13 billion, and grow the area's income by more than $8.5 billion. Additional investment, above $10.8 billion and up to $26 billion, would likely result in even larger economic gains.

An earthquake in a large metropolitan area

An earthquake hitting the San Diego area (population 3.2 million) causing $10 billion in damage would result in almost 77,000 job losses (3% of all the jobs in the region) and about 26,000 workers (2% of all workers) leaving the labor force. Close to 32,000 people (1% of the population) would likely move away. The dollar costs are over $11 billion in lost production and almost $6.5 billion in lost income for residents while the area recovers.

After $833 million of investments in resilience and preparedness, the same earthquake would result in about 39,000 jobs lost, meaning the investments in resilience and preparedness would save about 38,000 jobs. Similarly, those investments would save about 15,000 people from leaving the labor force and 18,200 from leaving the area. The amount of production and income saved would be about $5.8 billion and $3.3 billion, respectively.

Earthquake Hitting the San Diego Area

Damage Inflicted: $10 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	**Economic Losses Caused by the Disaster After Resilience and Preparedness Investment**	**Economic Savings From Cutting Damage in Half**	**Gains from $833 Million Invested in Resilience and Preparedness**
Jobs	-76,656	-38,688	37,968	7,239
Population	-31,533	-13,288	18,245	2,060
Labor Force	-25,642	-11,260	14,382	1,823
GDP	-$11,393,343,555	-$5,614,000,000	$5,779,343,555	$938,000,000
Income	-$6,446,026,228	-$3,164,000,000	$3,282,026,228	$564,000,000

$3.2 billion

in earned income saved with preparedness investment

31,533

people leave the area without preparedness investment

In addition to lessening the destruction from a disaster, the payoff from investments in resilience and preparedness is large. For instance, if the San Diego region spent up to $5.8 billion, it would see a positive return compared to the lost output it would suffer from the earthquake. The $833 million invested would likely create about 7,200 jobs, attract more than 2,000 people to the area, grow the workforce by more than 1,800 workers, increase production by close to $1 billion, and grow the area's income by more than $560 million. Additional investment, above $833 million and up to $5.8 billion, would also mean larger economic gains, further mitigating the losses should a disaster strike.

A tornado in a medium-size community

A tornado hitting the Nashville area (population 2 million) causing $1 billion in damage would likely result in 10,500 job losses (1% of all the jobs in the region) and about 2,300 workers (0.2% of all workers) leaving the labor force. Close to 3,500 people (0.2% of the population) would move away. The costs would likely total over $1.3 billion in lost production and $911 million in lost income for residents while the area recovers.

The path of a tornado only strikes a concentrated area, but the Nashville metropolitan statistical area (MSA) has both dense urban and less dense suburban locations. If a tornado strikes the dense, urban downtown entertainment district, it would likely cause $1 billion in damage in a concentrated area. But, if it were to strike in a less-dense suburban area, the damage would be more spread out. The results here are the average across the MSA.

Tornado Hitting the Nashville Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-10,591	-5,267	5,324	965
Population	-3,463	-1,498	1,965	307
Labor Force	-2,308	-1,012	1,296	201
GDP	-$1,335,261,266	-$652,000,000	$683,261,266	$105,000,000
Income	-$911,023,444	-$447,000,000	$464,023,444	$84,000,000

2,308

people leave the labor force without preparedness investment

5,324

jobs saved with preparedness investment

The same tornado hitting Nashville after $83 million of investments in resilience and preparedness would likely save more than 5,300 jobs. Those investments would likely prevent about 1,300 people from leaving the labor force and almost 2,000 people from leaving the Nashville area. The amount of production and income saved would be more than $683 million and $464 million, respectively.

Aside from lessening the destruction from a disaster, the returns from the investments in resilience and preparedness would be huge. In this scenario, the Nashville region could spend up to $683 million and still see a positive return (when taking into account lost production alone). The jobs, population, production, and income saved are detailed in the table.

A drought/heatwave in a small community

A drought/heat wave hitting the Redding, California, area (population 180,000) causing $1 billion in damage would likely result in the loss of 975 jobs (1% of all the jobs in the region) and 246 workers (0.3% of all workers) leaving the labor force. Close to 265 people (0.1% of the population) would move away. That's about $124 million in lost production and about $61 million of lost income for residents while the area recovers.

The same drought/heat wave hitting Redding after $83 million of investments in resilience and preparedness would likely result in 501 jobs lost, 55 people leaving the workforce, and 37 people moving away. Those investments would preserve 474 jobs, keep 191 workers in the labor force, and cause 228 people to stay in the area. The investments would also save about $68 million of output and $31.7 million in income.

Drought/Heatwave Hitting the Redding, CA Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-975	-501	474	530
Population	-265	-37	228	143
Labor Force	-246	-55	191	134
GDP	-$123,740,847	-$56,000,000	$67,740,847	$63,000,000
Income	-$60,700,785	-$29,000,000	$31,700,785	$33,000,000

530

jobs gained from preparedness investment

$63 million

in GDP gained with preparedness investment

After accounting for the gains from these preparedness investments, Redding would likely see a net gain in all five economic measures after a disaster occurs. The investments would create 530 jobs, bring 134 people into the labor force, bring 143 people into the region, and lead to $63 million in increased economic output and $33 million in income. Each of these amounts is greater than the losses from the heat wave. Therefore, with the right investments in preparedness, the Redding area economy would likely be stronger after the drought/heat wave. Additional investment, above $83 million, for example, would also likely produce additional economic gains for the region.

A wildfire in a small community

A severe wildfire hitting the Santa Fe, New Mexico, area (population 89,000) causing $1 billion in damage would likely result in the loss of 788 jobs (1% of all the jobs in the region), and about 157 workers (0.2% of all workers)

Wildfire Hitting the Santa Fe Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-788	-400	388	405
Population	-188	-33	155	92
Labor Force	-157	-36	121	78
GDP	-$81,829,248	-$37,000,000	$44,829,248	$39,000,000
Income	-$38,262,181	-$18,000,000	$20,262,181	$19,000,000

$81 million
in lost GDP without preparedness investment

$44 million
in GDP saved with preparedness investment

leaving the labor force. Close to 188 people (0.1% of the population) would move away. That's nearly $82 million in lost production and $38 million of lost income for residents while the area recovers.

The same wildfire hitting Santa Fe after $83 million of investments in resilience and preparedness would likely result in about 400 jobs lost, 36 people leaving the workforce, and 33 people moving away. Those investments would preserve 388 jobs, keep 121 workers in the labor force, and cause 155 people to stay in the area. The investments would also save $44 million of output and $20 million in income.

After accounting for the gains from these preparedness investments, Santa Fe would likely see a net gain in all five economic measures after a disaster occurs. The investments would create 405 jobs, bring 78 people into the labor force, bring 92 people into the region, and lead to $39 million in increased economic output and $19 million in income. Each of these amounts is greater than the losses from the wildfire. Therefore, with the right investments in preparedness, the Santa Fe area economy would likely be stronger after the wildfire.

Additional investment, above $83 million, for example, would also likely produce additional economic gains for the region.

Other Scenarios

We simulated 21 other disasters using the same model (see Appendix). They show similarly large benefits from resilience and preparedness investments. In fact, these investments have large potential benefits in smaller communities, greater than the losses caused by a $500 million disaster.

For example, measures taken to prepare for $1 billion disasters in communities like Santa Fe, New Mexico, and Gulfport, Mississippi, would provide more benefits after a disaster than the up-front costs. The benefits in a community the size of Wilmington, North Carolina, are about equal to the costs of the disaster.

If a disaster does not hit, communities still enjoy the economic gains from investments in preparedness. Those gains are seen in the tables in the appendix.

In large or small metropolitan areas, whether rural or urban, investing in resilience and preparedness would likely preserve jobs and income that would otherwise be lost following a serious disaster. And the larger the investment, the larger the potential benefits.

Conclusion: Resilience and Preparedness Pay Big Dividends

Federal, state, and local policymakers—as well as families and businesses—face hard choices about how much to invest in resilience, preparedness, and pre-disaster mitigation. They must balance the need to spend on other priorities with the need to protect their communities, homes, and livelihoods in case of disaster.

Many often focus on the tangible cleanup and repair costs that are typically directly spent to recover after a disaster. However, there are frequently other economic costs that go unseen: lost jobs, lost homes, lost population, lower labor force numbers, reduced economic production, and missing income that must be accounted for in city budgets and by planning commissions.

While investments in resilience and preparedness cannot totally prevent these losses, they can significantly reduce them. In fact, as this study shows, dollars spent on preparedness and resilience are much more effective at reducing the overall cost of disasters than dollars spent after the fact on recovery. Over time, these preparedness investments can have economic benefits as quantified in this report.

Resilience, preparedness, and pre-disaster mitigation investments pay big returns—no matter what the disaster. They cannot prevent or erase the direct, obvious damage, but they can greatly lessen the human toll over the long term, which is more important than any economic benefits.

Actions To Improve Resilience to Disasters

Across a range of hazards, communities, businesses, and families have many options for reducing risk. The resilience and preparedness investments analyzed in this study were assumed to be in the following categories:

For communities investing in infrastructure

- **Reducing Underlying Risk**

  This approach focuses on encouraging preventive action before a disaster strikes through community-based efforts that ensure residents have access to basic services.

- **Early Warning Systems**

  To alert community members of impending disasters.

- **Mitigation Planning**

  Adopt zoning, land-use practices, and building codes to prevent or reduce damage from hazards.

For businesses

- **Hazard Mitigation Measures**

  These include structural improvements, adjustments based on professional hazard audits, accessibility updates, and employee training for emergency response.

- **Disaster Risk Reduction Practices**

  Apply one or more of the five essentials for businesses in their pursuit of disaster risk reduction. The five essentials as outlined by the United Nations Office of Disaster Risk Reduction are as follow:

  - Promote and develop public private partnerships.
  - Leverage private sector expertise and strengths.

- Foster a collaborative exchange and dissemination of data.
- Support national and local risk assessments.
- Support the development and strengthening of national and local laws, regulations, policies, and programs.

- **Integration of Preparedness With Disaster Response**

  This can foster resilience and support diversified, resilient livelihood strategies.

For families and households

- **Awareness and Education**

  Understand the types of disasters that could occur in your area and learn how to stay safe.

- **Preparedness**

  Create a family disaster plan that includes meeting places in case family members are separated.

- **Home Improvements**

  Make structural improvements so your home can withstand disasters. This could include elevating electrical appliances, using flood-resistant materials, and roof maintenance/upgrades.[4]

4 https://nap.nationalacademies.org/read/1840/chapter/6; https://preparecenter.org/story/how-to-create-effective-and-inclusive-early-warnings-11-recommendations-from-research/; https://www.nibs.org/reports/resilience-incentivization-roadmap-20; https://www.ready.gov/be-informed; https://fortifiedhome.org/frequently-asked-questions/

Methodology

We analyzed seven types of disasters to find the economic savings resulting from resilience and preparedness measures:

1. Hurricanes
2. Large Storms (mostly winter storms, but also including a superstorm like Sandy)
3. Earthquakes
4. Tornadoes
5. Floods
6. Wildfires
7. Droughts/heat waves

We used a variety of methods to calculate the destruction caused by these disasters. Those costs include cleanup and repairing and replacing destroyed property: residential buildings, business structures and business equipment, and civil infrastructure.

We estimated the indirect economic damage that results from the direct destruction and cleanup costs using the REMI PI+ model to conduct an analysis of jobs, population, labor force, GDP, and income.

Our analysis involved two components. The first was the direct damage from a disaster: for instance, a tornado that inflicted $1 billion in damage. We assumed the damage was distributed equally among households, businesses, and infrastructure. Our analysis also accounted for the negative impact on employment. Each type of disaster has unique impacts detailed in the specific modeling parameters below. We estimated the losses in five categories of economic well-being—jobs, population, labor force, economic production (GDP), and income—that resulted from the damage the disaster inflicted on a community.

Then we ran the analysis again, but with enough investment in resilience and preparedness spread equally among households, business structures, and equipment, to reduce the size of the various disasters in half—from $1 billion to $500 million, for instance.

To determine the amount of investment in each community, we used research from the National Institute of Building Sciences (NIBS), which determined that $1 of investment in resilience and preparedness from federal mitigation grants (provided by the Federal Emergency Management Agency, the Economic Development Administration, and the U.S. Department of Housing and Urban Development) reduces the amount of damage from disasters by $6.[5] The reduction of damage was divided by $6 to determine the amount of investment necessary to halve the damage.

That would be dividing $500 million (the amount of damage saved) by $6 to arrive at $83.3 million of investment. It then accounted for the loss of jobs, population, labor force, economic production, and income that would occur from the same disaster hitting the location again, but this time with the investments in preparedness and resilience fully in place.

The $6-$1 ratio was chosen for all disasters modeled after careful consideration of several factors. That ratio is a widely used industry standard and cited often by authorities such as FEMA. The source is NIBS.

NIBS presents a range of ratios for the different types of events modeled. It also presents a range based on the types of investment communities make. NIBS does not list a ratio for tornadoes because "necessary hazard information was in flux at the time of their publication, and the analysis might have quickly become obsolete."

5 https://www.nibs.org/files/pdfs/NIBS_MMC_MitigationSaves_2019.pdf

Table 1: Benefit-Cost Ratio by Hazard and Mitigation Measure

	ADOPT CODE	ABOVE CODE	BUILDING RETROFIT	LIFELINE RETROFIT	FEDERAL GRANTS
Overall Benefit-Cost Ratio	11:1	4:1	4:1	4:1	6:1
Cost ($ billion)	$1/year	$4/year	$520	$0.6	$27
Benefit ($ billion)	$13/year	$16/year	$2200	$2.5	$160
Riverine Flood	6:1	5:1	6:1	8:1	7:1
Hurricane Surge	not applicable	7:1	not applicable	not applicable	not applicable
Wind	10:1	5:1	6:1	7:1	5:1
Earthquake	12:1	4:1	13:1	3:1	3:1
Wildland-Urban Interface Fire	not applicable	4:1	2:1	not applicable	3:1

Given the wide ranges of the various ratios, using the $6-$1 ratio is a sensible middle ground because it is the industry standard and because it is approximately in the middle for each of the disasters listed in the table.

The ratio used in the model impacts the amount of investment a community must make to halve the damage from an event. The lower the ratio, the more the community has to invest to achieve that result. The higher the ratio, the less it must invest. The damage saved is fixed in the model at half the cost of the original disaster. Changing the amount invested would not alter the savings that result from cutting the damage in half. It alters the benefits of investment depending on if more (lower ratio) or less (higher ratio) investment is necessary to cut damage in half.

The results presented in this study are a high-level overview of the benefits of preparedness for a selection of disasters. The $6-$1 ratio was the best fit for this purpose. Future research could refine the results by applying different ratios to the types of disasters modeled as detailed in the NIBS report.[6]

The difference in the economic impacts of the five categories of economic well-being before and after the preparedness investments was measured. The difference in the two analyses is the savings from investing in resilience and preparedness.

The estimated jobs lost are full-time equivalents, meaning they equate to hours of work lost during the immediate aftermath of the disaster and while cleanup and recovery occur—many of which are fully lost during the recovery period, as well as permanently.

6 https://nap.nationalacademies.org/read/1840/chapter/6;
https://preparecenter.org/story/how-to-create-effective-and-inclusive-early-warnings-11-recommendations-from-research/;
https://www.nibs.org/reports/resilience-incentivization-roadmap-20;
https://www.ready.gov/be-informed

Analyses of the different types of disasters were simulated in Metropolitan Statistical Areas varying in size and geographic locations around the U.S. Disasters were assigned to locations where they generally occur, such as hurricanes in the Gulf and Southern states, large storms in places with intense winters, earthquakes near known fault lines, tornadoes in the Midwest and South, floods in traditional flood plains, and wildfires and droughts/heat waves in the West and Southwest.

Each disaster is assumed to occur in 2025. The investments in resilience and preparedness occur in the years before so that they are fully in place for the second analysis.

Following are more details about the assumptions made for each type of disaster.

Hurricanes

Four hurricanes were simulated using historical examples as a guide for damage caused by the hurricane and the approximate geographic location it struck.[7] The hurricanes used were Ian and Harvey (Category 4), Ike (Category 2), Charley (Category 4), and Sally (Category 2).

The following was assumed:

- The Ian and Harvey-type storm inflicted $130 billion in damage in the Miami-Fort Lauderdale-Pompano Beach, Florida, MSA (population 6.2 million).
- The Ike-type storm caused $54 billion in damage in the Tampa-St. Petersburg-Clearwater, Florida, MSA (population 3.3 million).
- The Charley-size storm caused $25 billion damage in the New Orleans-Metairie, Louisiana, area (population 1.2 million).
- The Sally-like storm caused $7 billion in damage in the Gulfport-Biloxi, Mississippi, MSA (population 420,000).

It assumed a sizable negative employment impact in the year the hurricane hit and then a declining impact for two additional years as cleanup and repairs continue.

A large initial negative impact to tourism in the immediate aftermath of the storm that declined over the two-year recovery was also assumed.

It was assumed the hurricanes hitting these areas after the investments in resilience and preparedness caused half the damage as they did before those investments, so $65 billion for the Miami hurricane, $27 billion for the Tampa hurricane, $12.5 billion for the New Orleans hurricane, and $3.5 billion for the Gulfport-Biloxi hurricane. The amount of investment necessary to achieve these reductions was $10.8 billion, $4.5 billion, $2.1 billion, and $583 million, respectively.

Large Storms

This report includes analyses of four large storms that were not hurricanes. The largest example was a Hurricane Sandy-like storm. The remaining three were $1 billion winter storms in metro areas often hit by such events.

The following was assumed:

- The Sandy-type storm inflicted $89 billion in damage in the New York, MSA (population 20 million).
- Three $1 billion winter storms in these MSAs: Boston-Cambridge-Newton, Massachusetts/New Hampshire (population 4.9 million); Denver-Aurora-Lakewood, Colorado (population 2.9 million); and Milwaukee-Waukesha, Wisconsin (population 1.6 million).

It assumed a sizable negative employment impact in the year the hurricane hit. For the Sandy-like storm, it assumed a reduced negative impact on employment one year after the storm and a one-year negative impact on tourism.

The storms hitting these areas after the investments in resilience and preparedness were assumed to cause half the damage as they did before those investments, so $44.5 billion for the New York storm and $500 million for the Boston, Denver, and Milwaukee storms. The amount of investment necessary to achieve these reductions was $7.4 billion and $83 million, respectively.

Earthquakes

Four earthquakes were analyzed using data from the 1989 Loma Prieta and the 1994 Northridge quakes to create a simulation in four MSAs:

- An earthquake that caused $40 billion in damage in Los Angeles-Long Beach-Anaheim, California (population 13 million).
- An earthquake that caused $25 billion in damage in San Francisco-Oakland-Berkeley, California (population 4.5 million).
- An earthquake that caused $10 billion in damage in San Diego-Chula Vista-Carlsbad, California (population 3.2 million).
- An earthquake that caused $1 billion in damage in Redding, California (population 180,000).

It assumed a sizable negative employment impact in the year of the earthquake and half that impact in the second year. It was assumed the earthquakes hitting these areas after the investments in resilience and preparedness caused half the damage as they did before those investments, so $20 billion for the Los Angeles quake, $12.5 billion for the San Francisco quake, $5 billion for the San Diego quake, and $500 million for the Gulfport-Biloxi hurricane. The amount of investment necessary to achieve these reductions was $3.3 billion, $2.1 billion, $833 million, and $83 million, respectively.

Tornadoes

Four tornadoes, all of which it is assumed caused $1 billion in damage, were analyzed. They were in the following locations:

- Atlanta-Sandy Springs-Alpharetta, Georgia, MSA (population 6.2 million).
- Indianapolis-Carmel-Anderson, Indiana, MSA (population 2.1 million).
- Nashville-Davidson—Murfreesboro—Franklin, Tennessee (population 2 million).
- Oklahoma City, Oklahoma, MSA (population 1.5 million).

It assumed a negative employment impact in the year of the tornado.

It was assumed the tornadoes hitting these areas after the investments in resilience and preparedness caused half the damage as they did before those investments, so $500 million in all of them. The amount of investment necessary to achieve these reductions was $83 million.

Tornadoes are incredibly destructive. There is no amount of investment in preparedness that will save a home, business, or infrastructure from a direct strike. The loss is almost always total in these cases.

Yet tornadoes are spawned from powerful storms that impact broader geographic areas than just the concentrated spots where the tornado causes catastrophic loss. There is damage from high winds, intense rain, hail, and swirling debris. Communities can prepare for these impacts. The analysis presented in this study focuses on this damage.

Floods, Wildfires, and Droughts/Heat waves

The study conducted analyses of floods, wildfires, and droughts/heat waves (droughts/heat waves were modeled together). It simulated three events for each category of disaster.

The three types of events were modeled together because their inputs are the same. They are all $1 billion disasters that are assumed to have the same impact on employment in the year the disaster occurs, including a separate negative impact on farm employment and farm output in the year of the events.

Floods were assumed in the following:

- Houston-The Woodlands-Sugar Land, Texas, MSA (population 7.3 million).
- Pittsburgh, Pennsylvania, MSA (population 2.4 million).
- Wilmington, North Carolina, MSA (population 300,000).

Wildfires were assumed in the following:

- Los Angeles-Long Beach-Anaheim, California, MSA (population 13 million).
- Phoenix-Mesa-Chandler, Arizona, MSA (population 5 million).
- Santa Fe, New Mexico, MSA (population 155,000).

Droughts/heat waves were assumed in the following:

- Dallas-Fort Worth-Arlington, Texas, MSA (population 8 million).
- Salt Lake City, Utah, MSA (population 1.3 million).
- Redding, California, MSA (population 180,000).

It was assumed that the events hitting these areas after the investments in resilience and preparedness caused half the damage as they did before those investments, so $500 million for all of them. The amount of investment necessary to achieve these reductions was $83 million.

Calculating the $7-to-$1 Ratio of Economic Savings to Investment in Resilience and Preparedness

To calculate the ratio for economic savings as a result of prior resilience and preparedness investment, we divided the production (GDP) saved in each disaster modeled by the amount invested in the area before the disaster struck.

For instance, the $26 billion of production saved in Miami after a Category 4 hurricane was divided by the $10.8 billion of investment to produce a ratio of $2.4 saved to every $1 invested.

We repeated this process for each of the 25 disasters modeled. The $7-to-$1 ratio is the median ratio of dollars of economic costs saved for $1 of investment in preparedness and resilience for the 25 disasters modeled.

The $7 of savings is for economic costs, on top of the reduction in damage assumed in the model. In the analysis, we assumed that $1 of investment reduced the damage and cleanup costs of each disaster by $6. Combining the two ratios finds that $13 can be saved for every $1 invested in resilience and preparedness when including reduced damage, cleanup costs, and less economic damage.

Appendix: Preparedness Saves in Other Disasters

A total of 25 disasters were modeled in this study. The main ones are described in the body of the report, and the remaining 20—simulated using the same model—are seen in the following tables. They show similarly large benefits from prudent resilience and preparedness investments in the face of disasters.

The scenarios are grouped by the type of disaster occurring.

Hurricanes

Table 1: Category 2 Hurricane Hitting the Tampa Area

Damage Inflicted: $54 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $4.5 Billion Invested in Resilience and Preparedness
Jobs	-141,373	-69,321	72,052	47,802
Population	-86,337	-19,746	66,591	14,197
Labor Force	-70,141	-18,970	51,171	13,037
GDP	-$17,454,987,552	-$7,699,000,000	$9,755,987,552	$4,879,000,000
Income	-$9,937,322,796	-$4,305,000,000	$5,632,322,796	$2,883,000,000

Table 2: Category 2 Hurricane Hitting the New Orleans Area

Damage Inflicted: $25 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $2.1 Billion Invested in Resilience and Preparedness
Jobs	-71,369	-27,386	43,983	18,589
Population	-34,488	-7,022	27,466	4,874
Labor Force	-28,108	-6,586	21,522	4,469
GDP	-$8,716,930,798	-$3,035,000,000	$5,681,930,798	$1,856,000,000
Income	-$4,989,194,111	-$1,710,000,000	$3,279,194,111	$1,125,000,000

Table 3: Category 2 Hurricane Hitting the Gulfport/Biloxi, MS Area

Damage Inflicted: $7 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $583 Million Invested in Resilience and Preparedness
Jobs	-6,284	-2,785	3,499	3,512
Population	-3,658	0	3,658	965
Labor Force	-2,931	-205	2,726	898
GDP	-$699,103,434	-$273,000,000	$426,103,434	$288,000,000
Income	-$324,478,066	-$113,000,000	$211,478,066	$157,000,000

Large Storms

Table 4: Super Storm Hitting the New York Area

Damage Inflicted: $89 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $7.4 Billion Invested in Resilience and Preparedness
Jobs	-455,866	-201,579	254,287	52,823
Population	-246,396	-90,981	155,415	12,577
Labor Force	-188,950	-70,992	117,958	11,822
GDP	-$90,541,679,319	-$37,749,000,000	$52,792,679,319	$7,619,000,000
Income	-$49,776,778,870	-$21,071,000,000	$28,705,778,870	$4,749,000,000

Table 5: Large Winter Storm Hitting the Boston Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-88,947	-44,477	44,470	745
Population	-27,594	-13,573	14,021	225
Labor Force	-17,288	-8,495	8,793	141
GDP	-$14,481,396,190	-$7,232,000,000	$7,249,396,190	$104,000,000
Income	-$8,460,133,209	-$4,226,000,000	$4,234,133,209	$70,000,000

Table 6: Large Winter Storm Hitting the Denver Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-59,930	-29,937	29,993	894
Population	-20,399	-9,912	10,487	302
Labor Force	-12,608	-6,126	6,482	187
GDP	-$7,931,957,609	-$3,951,000,000	$3,980,957,609	$110,000,000
Income	-$5,073,371,972	-$2,528,000,000	$2,545,371,972	$75,000,000

Table 7: Large Winter Storm Hitting the Milwaukee Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-23,660	-11,832	11,828	802
Population	-8,195	-3,880	4,315	280
Labor Force	-5,080	-2,410	2,670	175
GDP	-$2,852,547,304	-$1,416,000,000	$1,436,547,304	$90,000,000
Income	-$1,729,135,638	-$859,000,000	$870,135,638	$61,000,000

Earthquakes

Table 8: Earthquake Hitting the Los Angeles Area

Damage Inflicted: $40 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $3.3 Billion Invested in Resilience and Preparedness
Jobs	-339,177	-175,705	163,472	31,418
Population	-137,638	-61,454	76,184	8,487
Labor Force	-103,887	-47,564	56,323	7,008
GDP	-$54,393,928,968	-$27,118,000,000	$27,275,928,968	$3,995,000,000
Income	-$30,051,391,079	-$15,191,000,000	$14,860,391,079	$2,553,000,000

Table 9: Earthquake Hitting the San Francisco Area

Damage Inflicted: $25 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $2.1 Billion Invested in Resilience and Preparedness
Jobs	-130,503	-67,157	63,346	11,415
Population	-52,338	-23,275	29,063	3,012
Labor Force	-30,280	-13,440	16,840	1,758
GDP	-$35,188,820,679	-$17,540,000,000	$17,648,820,679	$2,221,000,000
Income	-$16,635,178,963	-$8,401,000,000	$8,234,178,963	$1,279,000,000

Table 10: Earthquake Hitting the Redding, CA Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-3,001	-1,548	1,453	530
Population	-1,182	-428	754	143
Labor Force	-1,014	-401	613	134
GDP	-$422,646,978	-$210,000,000	$212,646,978	$63,000,000
Income	-$192,502,868	-$95,000,000	$97,502,868	$33,000,000

Tornadoes

Table 11: Tornado Hitting the Atlanta Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-26,813	-13,409	13,404	828
Population	-8,231	-3,941	4,290	247
Labor Force	-6,178	-2,972	3,206	185
GDP	-$3,359,784,783	-$1,669,000,000	$1,690,784,783	$95,000,000
Income	-$1,957,336,522	-$974,000,000	$983,336,522	$59,000,000

Table 12: Tornado Hitting the Indianapolis Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-8,734	-4,355	4,379	775
Population	-2,923	-1,268	1,655	263
Labor Force	-2,048	-902	1,146	180
GDP	-$1,123,526,920	-$551,000,000	$572,526,920	$92,000,000
Income	-$716,738,828	-$353,000,000	$363,738,828	$63,000,000

Table 13: Tornado Hitting the Oklahoma City Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-5,154	-2,573	2,581	713
Population	-1,540	-622	918	211
Labor Force	-1,447	-613	834	199
GDP	-$516,591,610	-$251,000,000	$265,591,610	$65,000,000
Income	-$325,824,970	-$159,000,000	$166,824,970	$43,000,000

Floods

Table 14: Flood Hitting the Houston Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Billion Invested in Resilience and Preparedness
Jobs	-32,549	-16,267	16,282	1,027
Population	-9,762	-4,649	5,113	310
Labor Force	-8,058	-3,876	4,182	258
GDP	-$3,858,168,792	-$1,916,000,000	$1,942,168,792	$108,000,000
Income	-$2,576,242,248	-$1,281,000,000	$1,295,242,248	$79,000,000

Table 15: Flood Hitting the Pittsburgh Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-8,617	-4,332	4,285	796
Population	-2,574	-1,128	1,446	244
Labor Force	-2,469	-1,118	1,351	235
GDP	-$825,028,016	-$535,000,000	$290,028,016	$91,000,000
Income	-$636,611,491	-$316,000,000	$320,611,491	$59,000,000

Table 16: Flood Hitting the Wilmington, NC Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-1,768	-887	881	753
Population	-557	-110	447	238
Labor Force	-470	-116	354	185
GDP	-$186,866,465	-$85,000,000	$101,866,465	$73,000,000
Income	-$89,422,949	-$41,000,000	$48,422,949	$39,000,000

Wildfires

Table 17: Wildfire Hitting the Los Angeles Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-54,433	-27,333	27,100	786
Population	-14,964	-7,368	7,596	212
Labor Force	-12,267	-6,068	6,199	175
GDP	-$7,404,986,960	-$3,694,000,000	$3,710,986,960	$100,000,000
Income	-$4,479,085,184	-$2,244,000,000	$2,235,085,184	$64,000,000

Table 18: Wildfire Hitting the Phoenix Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-22,058	-11,055	11,003	1,052
Population	-8,009	-3,745	4,264	393
Labor Force	-6,175	-2,902	3,273	266
GDP	-$2,653,344,273	-$1,312,000,000	$1,341,344,273	$124,000,000
Income	-$1,594,790,980	-$793,000,000	$801,790,980	$79,000,000

Droughts/Heatwaves

Table 19: Drought/Heatwave Hitting the Dallas Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-39,768	-19,865	19,903	1,103
Population	-13,016	-6,235	6,781	357
Labor Force	-8,313	-3,992	4,321	225
GDP	-$4,783,715,764	-$2,375,000,000	$2,408,715,764	$125,000,000
Income	-$3,124,831,682	-$1,553,000,000	$1,571,831,682	$88,000,000

Table 20: Drought/Heatwave Hitting the Salt Lake City Area

Damage Inflicted: $1 Billion				
	Economic Losses Caused by the Disaster Before Resilience and Preparedness Investment	Economic Losses Caused by the Disaster After Resilience and Preparedness Investment	Economic Savings From Cutting Damage in Half	Gains from $83 Million Invested in Resilience and Preparedness
Jobs	-6,722	-3,373	3,349	816
Population	-2,007	-839	1,168	248
Labor Force	-1,281	-539	742	156
GDP	-$893,321,582	-$435,000,000	$458,321,582	$103,000,000
Income	-$401,450,713	-$198,000,000	$203,450,713	$51,000,000

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NIST Technical Note 2214

Economic Analysis of ASCE 7-22 Tornado Load Requirements

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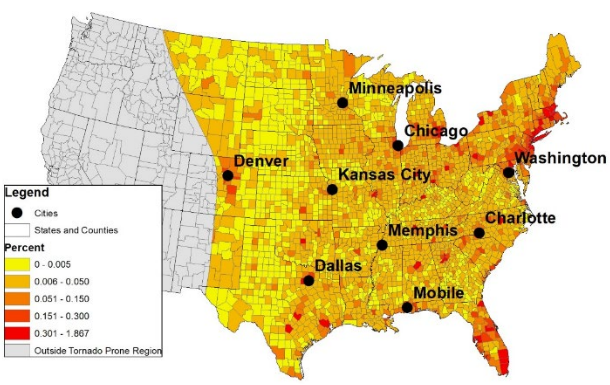

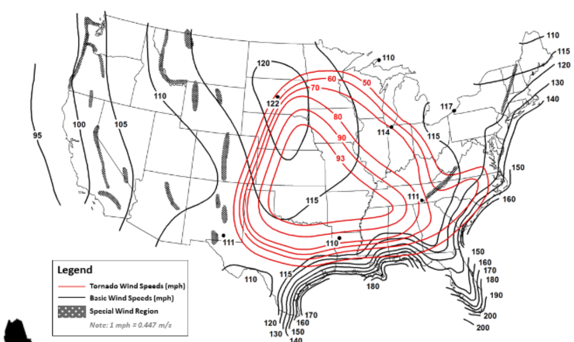

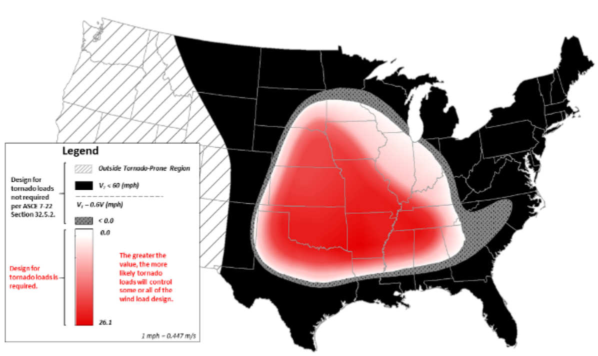

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Gina M. Raimondo, Secretary

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James K. Olthoff, Performing the Non-Exclusive Functions and Duties of the Under Secretary of Commerce for Standards and Technology & Director, National Institute of Standards and Technology

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Preface

This study was jointly conducted by the Applied Economics Office (AEO) and the Structures Group of the Materials and Structural Systems Division in the Engineering Laboratory (EL) at the National Institute of Standards and Technology (NIST), in collaboration with the Building Science Branch in the Federal Insurance and Mitigation Administration at the Federal Emergency Management Agency (FEMA), as well as Huckabee, Inc. and TLSmith Consulting Inc. The study is to support NIST's overall effort to implement recommendations NIST made as a result of the National Construction Safety Team Act technical investigation of the May 22, 2011 tornado in Joplin, Missouri [1]. It is designed to identify the potential impacts on the commercial building and institutional building sectors associated with adoption of the new tornado load requirements in the ASCE 7-22 Standard: Minimum Design Loads and Associated Criteria for Buildings and Other Structures [2]. The intended audience is standards and codes development organizations, all levels of government that might adopt the International Building Code (IBC) and/or directly adopt ASCE 7, policy makers in the commercial and institutional building sectors, building owners and designers, researchers, and others interested in building resiliency.

Disclaimers

The policy of the National Institute of Standards and Technology is to use metric units in all of its published materials. Because this report is intended for the U.S. construction industry that uses U.S. customary units, it is more practical and less confusing to include U.S. customary units as well as metric units. Measurement values in this report are therefore stated in U.S. customary units first, followed by the corresponding values in metric units within parentheses.

Abstract

This study analyzes the potential economic impacts from implementation of the new tornado load requirements in the ASCE 7-22 Standard: Minimum Design Loads and Associated Criteria for Buildings and Other Structures, by incorporation into the International Building Code (Proposal S63-22 in Ref. [3]) and/or direct adoption by Federal, state, and local governments. The Standard requires that Risk Category III and IV buildings located in the tornado-prone region (approximately equal to the area of the conterminous U.S. east of the Continental Divide) be designed to resist tornado loads in addition to wind loads from other types of storms. Risk Category III includes buildings that represent a substantial hazard to human life in the event of failure (e.g., theaters and other assembly occupancies, schools, nursing homes), while Risk Category IV is for essential facilities (e.g., hospitals, fire and police stations, emergency operations centers).

The approach in this study is to (1) identify the potential numbers of buildings that may be impacted, (2) compare tornado loads with existing wind load requirements to understand when and where tornado loads will control design, (3) determine what building elements will require changes in construction design when tornado loads control, and (4) estimate the cost of these changes in construction design.

The adoption of the new tornado load requirements in the ASCE 7-22 standard will impact a small fraction of new buildings in the United States. When excluding residential occupancies with less than 50 units, the building stock occupancy types for Risk Category III and IV buildings in the tornado-prone region represents 15.0 % of the entire U.S. building stock and 18.3 % of the building stock in the tornado-prone region. These results are effectively upper bound estimates as tornado loads will not control over wind loads for all Risk Category III and IV buildings in the tornado-prone region. Whether tornado loads control any aspect of the building design over wind loads depends on many different climatological and building characteristics. Geospatial analyses are used identify the impacts of several of these variables. In general, the tornado design requirements will have the most impact in the central and southeast U.S.

Case studies are used to estimate the relative magnitude of the potential cost impacts of five building elements (roof systems, roof diaphragm, roof joists and wide flange beams and girders, exterior wall framing, and foundation anchorages) for two building types (elementary school and high school) for wind Exposure Categories B and C baseline building designs across nine locations to provide a range of potential load requirements and resulting cost implications. The results of the case studies show that tornado loads can vary significantly, from less than wind loads to more than double the wind loads. Tornado loads will not control for many locations and building types, particularly those on the periphery of the tornado-prone region. For scenarios in which the tornado loads do control, the construction design is often not influenced. Of the nine cities considered in this study, three realize cost increases for at least one exposure category for the elementary school and six for the high school. Of all the building type – location – exposure combinations (36), only six (three for each building type) realize cost impacts greater than 0.07 % of the project budget.

Key words

Building economics; tornadoes; tornado loads; atmospheric pressure change; ASCE 7; economic analysis; commercial buildings; institutional buildings; essential facilities; building codes; building standards

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1. Introduction

Tornadoes are one of the most impactful natural hazards in the United States in terms of lives lost and property damage. Perhaps this is because the word "tornado" did not appear in any of the model building codes from the 20th century, and is only a recent addition to the International Building Code (related to requirements for tornado shelters) [4]. If the design of the built environment is conducted without explicit consideration of tornado hazards, is the poor life safety and property protection performance of buildings in tornadoes any surprise?

The American Society of Civil Engineers (ASCE) took a major step forward towards addressing this problem with the publication of the ASCE 7-22 Standard for Minimum Design Loads and Associated Criteria for Buildings and Other Structures [2], which for the first time includes tornado load requirements. These new requirements are based on a decade of research and development by the National Institute of Standards and Technology and others. It followed the EF-5 tornado that destroyed a third of Joplin, Missouri on May 22, 2011, which was the single deadliest (161 fatalities) and costliest (≈ $3 billion) tornado in the US since 1950 when official tornado records begin [1].

1.1. Tornado Impacts

The United States experiences more tornadoes and more violent tornadoes than any other country in the world [5]. Tornadoes cause more fatalities in the U.S. than earthquakes and hurricanes combined [6, 7], and most of these fatalities occur inside buildings (e.g., Ref. [1, 8, 9]). Tornadoes and tornadic storms cause more U.S. insured catastrophe losses than hurricanes and tropical storms combined [10] (Fig. 1). According to the Insurance Information Institute [10], "events including tornadoes" were the biggest source of insured catastrophe losses during the 20-year period from 1997 to 2016.

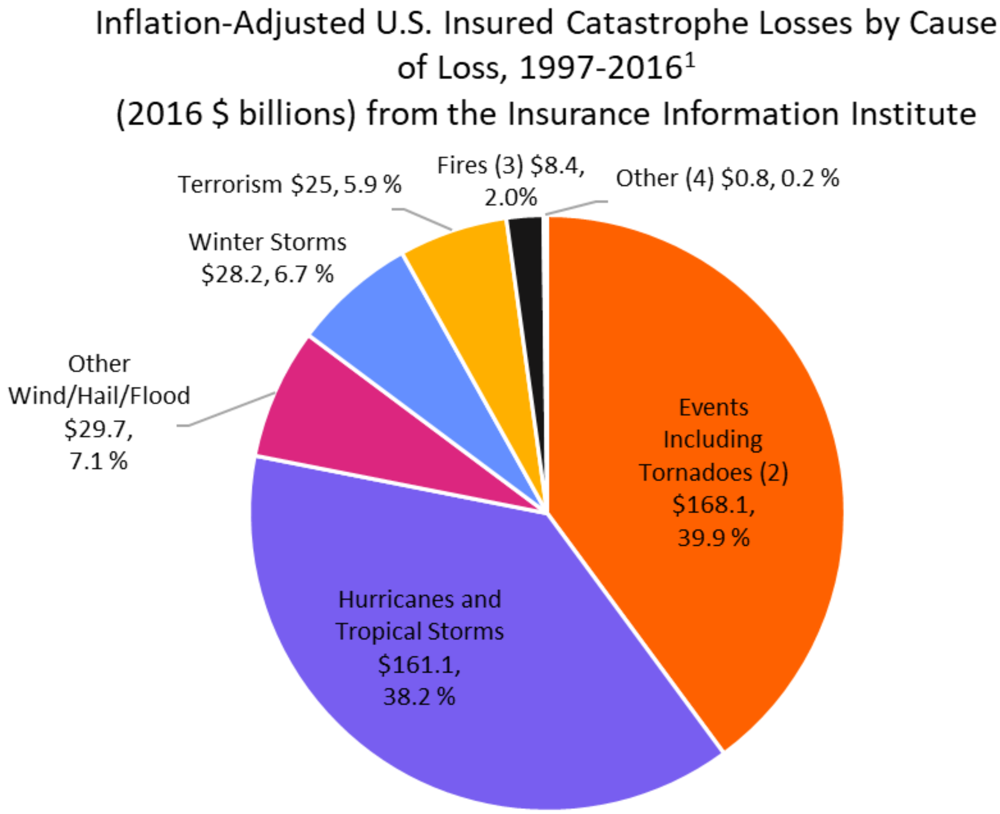


Fig. 1. Inflation-Adjusted U.S. Insured Catastrophe Losses by Cause[1,2,3,4,5]

Although it is the largest and most violent tornadoes that usually make the headlines, much of the total amount of property losses is caused by the less intense tornadoes (red curve in Fig. 2) because they are far more common. Of all recorded tornadoes from 1995 to 2016, 97.1 % were rated F/EF-2 or lower, as shown in Fig. 3. This histogram shows that the highest intensity tornadoes (F/EF-4 and F/EF- 5) make up only a fraction of a percent of all recorded tornadoes.

[1] Adjusted for inflation through 2016 by ISO using the GDP implicit price deflator. Excludes catastrophes causing direct losses less than $25 million in 1997 dollars. Excludes flood damage covered by the federally administered National Flood Insurance Program
[2] Includes other wind, hail, and/or flood losses associated with catastrophes involving tornadoes
[3] Includes wildland fires
[4] Includes losses from civil disorders, water damage, utility service disruptions, and any workers compensation catastrophes generating losses in excess of PCS's threshold after adjusting for inflation.[11]III , PCS (2022) Inflation-Adjusted U.S. Insured Catastrophe Losses By Cause Of Loss, 1997-2016 (2016 $ billions). (Insurance Information Institute and The Property Claim Services® (PCS®) unit of ISO®, a Verisk Analytics® company, https://www.iii.org/graph-archive/96104).
[5] Certain commercial entities, equipment, or materials may be identified in this document to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

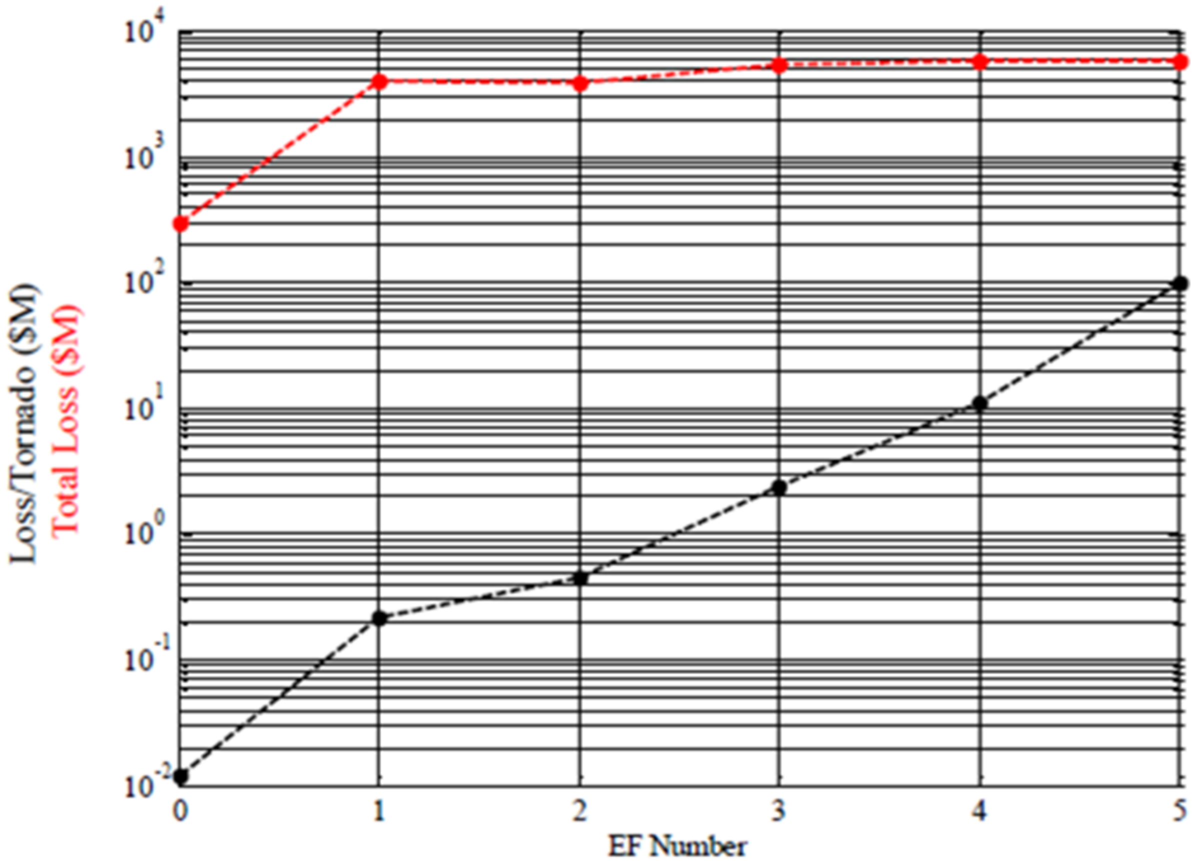
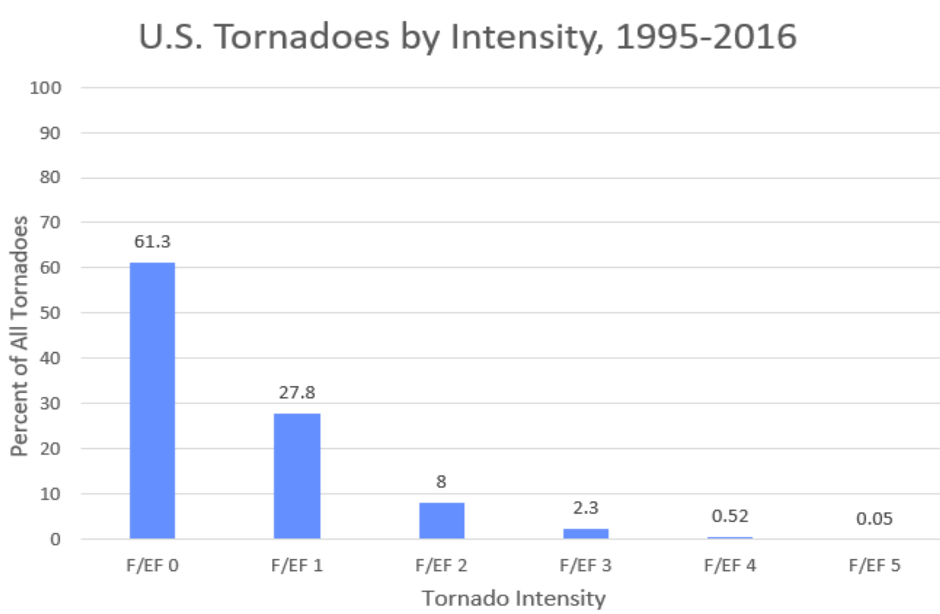


Fig. 2. Average loss per tornado and total loss by F/EF number for U.S. tornadoes from 1950-2011 (in 2011 $) [1]



Furthermore, even for the strongest tornadoes, most of the area impacted by a tornado does not experience the maximum winds speeds on which the tornado is rated. For example, in the 2013 EF-5 Newcastle-Moore Tornado in Oklahoma, EF-0 through EF-3 damage comprised the spatial majority of damage (Fig. 4) [13]. Even though this devastating tornado was rated as an EF-5, Fig. 4 demonstrates that most of the damage (spatially) was EF-3 and lower (blue, green, yellow, and orange areas). Another example is the 2011 EF-5 tornado that damaged or destroyed approximately 8000 buildings in Joplin, Missouri, where an estimated 72 % of the area swept by the tornado experienced EF-0 to EF-2 winds, while just 28 % experienced EF-3 and greater winds [1].

While design for life safety protection to resist EF-5 tornadoes is possible and not uncommon using ICC 500 storm shelters [14] and FEMA safe rooms [15], the vast majority of all tornadoes and much of the total tornado damage comes from EF-2 and lower intensity tornadoes, with wind speeds of 135 mph (60.4 m/s) and less. Design for tornadoes of this intensity is possible at much lower cost and impact than required for storm shelters and safe rooms, which are designed for 250 mph (111.8 m/s) across much of the central and southeast U.S.

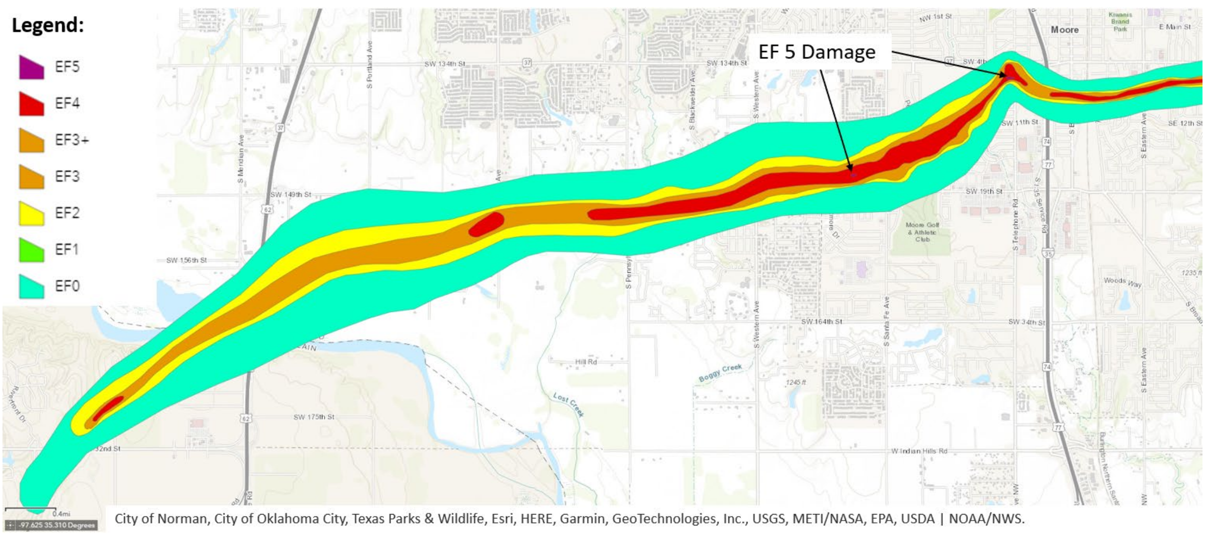


Fig. 4. 2013 Newcastle-Moore (Oklahoma) EF-5 Tornado Damage

1.2. ASCE 7-22 Tornado Load Requirements

While tornadoes are a type of windstorm, there are many and significant differences between tornadoes and other windstorms in terms of meteorology, climatology, wind, and wind-building and other structure interaction characteristics. Tornado loads are therefore treated completely separately from wind loads, hence their inclusion in a new chapter in ASCE 7-22 instead of as a subset of wind loads.

Tornado Load Procedures. The tornado load procedures are based on the overall framework of the ASCE 7 wind load procedures. Tornado velocity pressure and design pressure/design load equations are like those found in Chapters 26-31 (exclusive of Chapter 28 Envelope

Procedure, where the underlying methodology is incompatible with the tornado load approach). However, most of the terms used in the tornado load equations have some differences compared to their wind load counterparts, reflecting the unique characteristics of tornadic winds and wind-building or other structure interaction in contrast to straight-line winds. Several wind load parameters are not used in the tornado load chapter, while Chapter 32 also introduces a few new and significantly revised parameters.

Tornado Hazard Maps. A new generation of tornado hazard maps was developed taking spatial effects into account (since larger buildings are more likely to be struck by a tornado, tornado wind speeds increase with increasing plan (i.e., footprint) area of the building). These probabilistic tornado hazard maps identify tornado design wind speeds for a wide range of return periods and target building plan area sizes, enabling tornado-resistant design of conventional buildings and infrastructure, including essential facilities. Design tornado speed maps are provided for eight effective plan area (A_e) sizes, ranging from A_e = 1 ft2 (0.1 m^2) and 4 000 000 ft2 (371 612 m^2).

The mapped tornado speeds represent the maximum 3-s gust produced by the translating tornado at a height of 33 ft (10 m) anywhere within the plan area of the target building. The design tornado speeds for Risk Category III and IV buildings (for 1700- and 3000-year return periods, respectively) typically range from EF0-EF2 intensity, depending on geographic location, risk category, and plan size and shape (see Section 1.4 for information on risk category). For protection from more violent tornadoes, performance-based design is explicitly allowed, and commentary on additional design requirements for storm shelters is provided. At return periods of 300 and 700 years, tornado speeds are generally so low that tornado loads will not control over Chapter 26 wind loads, hence design for tornadoes is not required for Risk Category I and II buildings and other structures.

Tornado Velocity Pressure. While the effects of terrain and topography on tornado wind speed profiles are not yet well understood, a review of near-surface tornadic wind measurements from mobile research radar platforms plus numerical and experimental simulations consistently showed wind speed profiles with greater horizontal wind speeds closer to the ground than aloft. The tornado velocity pressure profile (K_zT_{or}) used has a uniform value of 1.0 from the ground up to a height of 200 ft (61 m), with a slightly smaller value at greater heights. In comparison, wind loads are based on an assumed boundary layer profile, where wind speeds are slower near the ground because of surface roughness.

Tornado Design Pressures. Atmospheric pressure change (APC) was found to have significant contributions to the tornado loads, particularly for large buildings with low permeability. The internal pressure coefficient was modified to also include the effects of APC. Since APC-related loads are not directionally dependent, the directionality factor was removed from the velocity pressure equation and added to the external pressure term in the design pressure/load equations. The directionality factor (K_d) was modified through analysis of tornado load simulations on building Main Wind Force Resisting Systems (MWFRS) and components and cladding (C&C) systems. The resulting tornado directionality factor K_{dT} has values slightly less than the corresponding wind K_d values, with the exception of roof zone 1' (in the field of the roof), which increased. External pressure and force coefficients for both the MWFRS and C&C remain unchanged, but a modifier (K_{vT}) was added to account for experimentally determinized increases to uplift loads on roofs caused by updrafts in the core of the tornado.

Reliability. A reliability analysis was conducted to evaluate the tornado load provisions for the purpose of identifying appropriate return periods for the tornado hazard maps. This effort was conducted by a working group composed of members from both the ASCE 7-22 Load Combinations and Wind Load Subcommittees. Monte Carlo analyses (adapted from the ASCE 7-16 wind speed map return period analysis) were used, in which significant uncertainties for system demands and capacity were identified and quantified in the form of random variables with defined probability distributions. The results of this series of risk-informed analyses showed that the tornadic load criteria of Chapter 32 provided reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for MWFRS; therefore, confirming that the 1700-year and 3000-year return periods used for Risk Category III and IV wind hazard maps (respectively) in Chapter 26 were also suitable return periods to use for the tornado hazard maps.

1.3. Defining Tornado-Prone Region

Although tornadoes occur in all 50 states, the over overwhelming majority and the most intense tornadoes occur east of the Continental Divide. ASCE 7-22 [2] defines the tornado-prone region as "The area of the conterminous United States most vulnerable to tornadoes", shown in Fig. 5. The tornado load provisions of ASCE 7-22 only apply to Risk Category III and IV buildings and other structures located in the tornado-prone region (see commentary Chapter C32 in [2] for more information).

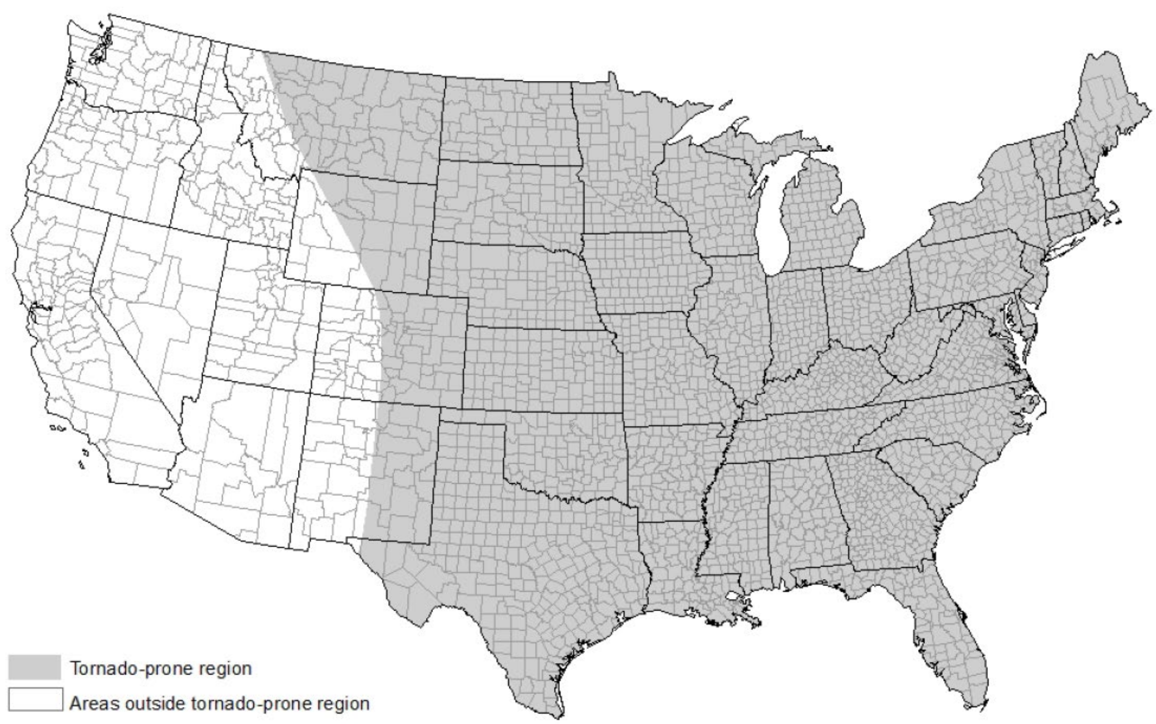


Fig. 5. Tornado-Prone Region

1.4. Applicable Risk Category of Structures

For design purposes, IBC (Table 1604.5) classifies buildings into four risk categories according to their occupancy type [16]. The building types associated with each of the four Building Risk Categories can be seen in Table 1 from Ref. [16]. This study focuses on Risk Category III and IV buildings, which are the subject of the adoption of the new tornado load requirements in the ASCE 7-22 standard [2].

Table 1. Structure Risk Categories[6]

Risk Category	Nature of Occupancy
I	**Buildings and other structures that represent a low hazard to human life in the event of failure, including but not limited to:** ● Agricultural facilities. ● Certain temporary facilities. ● Minor storage facilities.
II	**Buildings and other structures except those listed in Risk Categories I, III and IV.**
III	**Buildings and other structures that represent a substantial hazard to human life in the event of failure, including but not limited to:** ● Buildings and other structures whose primary occupancy is public assembly with an occupant load greater than 300. ● Buildings and other structures containing one or more public assembly spaces, each having an occupant load greater than 300 and a cumulative occupant load of these public assembly spaces of greater than 2500. ● Buildings and other structures containing Group E or Group I-4 occupancies or combination thereof, with an occupant load greater than 250. ● Buildings and other structures containing educational occupancies for student above the 12th grade with an occupant load greater than 500 ● Group I-2, Condition 1 occupancies with 50 or more care recipients. ● Group I-2, Condition 2 occupancies not having emergency surgery or emergency treatment facilities. ● Group I-3 occupancies. ● Any other occupancy with an occupant load greater than 5000. ● Power-generating stations, water treatment facilities for potable water, waste water treatment facilities and other public utility facilities not included in Risk Category IV. ● Buildings and other structures not included in Risk Category IV containing quantities of toxic or explosive materials that: ○ Exceed maximum allowable quantities per control area given in Table 307.1(1) or 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and ○ Are sufficient to pose a threat to the public if released.

[6] ICC (2021) Table 1604.5 Risk Category of Buildings and Other Structures

IV	**Buildings & other structures designated as essential facilities, including but not limited to:** ● Group I-2, Condition 2 occupancies having emergency surgery or emergency treatment facilities. ● Fire, rescue, ambulance and police stations and emergency vehicle garages. ● Designated earthquake, hurricane or other emergency shelters. ● Designated emergency preparedness, communications and operations centers and other facilities required for emergency response. ● Power-generating stations and other public utility facilities required as emergency backup facilities for Risk Category IV structures. ● Buildings and other structures containing quantities of highly toxic materials that: ○ Exceed maximum allowable quantities per control area as given in Table 307.1(2) or per outdoor control area in accordance with the *International Fire Code*; and ○ Are sufficient to pose a threat to the public if released. ● Aviation control towers, air traffic control centers and emergency aircraft hangars. ● Buildings and other structures having critical national defense functions. ● Water storage facilities and pump structures required to maintain water pressure for fire suppression.

1.5. Purpose and Approach

The purpose of this study is to analyze the potential economic impacts from implementation of the ASCE 7-22 tornado load requirements, by incorporation into the IBC (Proposal S63-22 in Ref. [3]) and/or direct adoption by Federal, state, and local governments. The approach in this study is based on four key steps to estimate the economic impact of the code change proposal.

First, identify where in the U.S. (within the tornado-prone region) and what building types may be impacted from inclusion of tornado load requirements into ASCE 7-22. This step immediately limits the need to consider tornado loads in design because the code change proposal only applies to specific building types (Risk Category III and IV) and locations in which expected tornado wind loads are sufficient to create concerns for building resilience.

Second, for the locations and building types that may be impacted, calculate the design wind pressures and design tornado pressures per ASCE 7-22 and determine whether the tornado loads control design. This step further narrows the potential impact because in many cases, the wind load requirements as defined in ASCE 7-22 are greater than those for tornado loads.

Third, for locations and building types for which tornado loads do control design, determine what building elements will require changes in construction design. This step accounts for the fact that current construction design practices may handle higher loads than the current load requirements. Therefore, even if tornado loads control an element of the design, the construction design for that element may not need to change.

Fourth, estimate the cost of these changes in construction design. This step calculates the estimated increase in construction costs resulting from any change in construction design to meet tornado loads relative to current ASCE 7-22 load requirements, both in total dollars and percent of total project construction budget.

Case studies are used to estimate the relative magnitude of the potential cost impacts for two building types (elementary school and high school) for wind Exposure Categories B and C baseline building designs across nine locations, to provide a range of potential load requirements and resulting cost implications.

2. Estimating Potentially Impacted Buildings and Structures

The adoption of the new tornado load requirements in the ASCE 7-22 standard will only impact a small fraction of new buildings in the United States. The only buildings that are eligible to be impacted are new buildings that meet or exceed the following requirements: (1) located within the tornado-prone region, (2) classified as Risk Category III or IV buildings, (3) located within an area where tornado speeds meet or exceed 60 mph (26.8 m/s), and (4) located within an area where the tornado speeds are greater than a specified fraction of the basic (non-tornado) design wind speeds. Requirements 3 and 4 represent approximate lower bounds on where tornado loads can begin to start controlling over wind loads for any element of a specific building or other structure.

This section of the report uses HAZUS building stock and building occupancy type data to estimate the percentage of existing buildings meeting requirements 1 and 2. Due to data limitations, inclusion of requirements 3 and 4, above, are not considered in estimating the percent of building stock impacted. This limitation will lead to an overestimation of potential impacts. Therefore, the results presented here are effectively upper bounds; the anticipated impacts of the code change are expected to be smaller, and perhaps substantially so. Section 3 provides several examples of the application of requirements 3 and 4, which are dependent on risk category, geographic location, the effective plan area of the building or facility, and the terrain exposure (e.g., roughness of the upwind terrain – which affects the non-tornadic wind loads).

2.1. HAZUS Building Stock Data

HAZUS provides a standardized methodology to assess losses from earthquakes, hurricane winds, and floods [17]. It leverages data from the Census Bureau, among other sources, to inventory the building stock for the U.S. and provides the data at the census tract level. For this study, the census tract data is aggregated to calculate a building count by occupancy type at the county level using data in HAZUS-MH MR4 Version 1.4 [18].

2.2. Building Stock in Tornado-Prone Region

Of the 3219 counties in the HAZUS database, 2820 counties are at least partially within the tornado-prone region Fig. 5. The following analysis assumes the building stock for the tornado-zone region includes the building stock data for these 2820 counties. The full number of buildings is included even for counties that are only partially in the tornado-prone region. Therefore, building stock counts are overestimates that will slightly bias the impacts reported as a percentage of the U.S. market, but should not have much effect on estimated regional impacts.

HAZUS occupancy types likely to be designated as Risk Category III or IV buildings in Table 2 were mapped against the IBC definitions (Table 1). Note that these selections are an approximation, as the occupancy categories in HAZUS and the Risk Categories in the IBC do not directly correspond, and no information is available on the occupant load of the building stock, which is a factor in the IBC table. (See Ref. [19] for a detailed description of a similar selection process.)

Table 2. HAZUS Occupancy Types and Assignment of Risk Categories

Occupancy Type		Risk Category III or IV
Code	**Description**	
RES1I	Residential Single-Family	
RES2I	Residential Manufactured Housing	
RES3AI	Residential Duplex	
RES3BI	Residential 3-4 Units	
RES3CI	Residential 5-9 Units	
RES3DI	Residential 10-19 Units	
RES3EI	Residential 20-49 Units	
RES3FI	Residential 50+ Units	
RES4I	Residential Temp Lodging	
RES5I	**Residential Institutional**	X
RES6I	**Residential Nursing Home**	X
COM1I	Retail Trade	
COM2I	Wholesale Trade	
COM3I	Personal Service	
COM4I	Professional	
COM5I	Banking	

Occupancy Type		Risk Category III or IV
Code	**Description**	
COM6I	**Hospital**	X
COM7I	**Medical Office**	X
COM8I	**Entertainment**	X
COM9I	**Theaters**	X
COM10I	Parking	
IND1I	Heavy Industrial	
IND2I	Light Industrial	
IND3I	Food/Drug	
IND4I	Metals	
IND5I	High Tech	
IND6I	Construction	
AGR1I	Agriculture	
REL1I	Religious	
GOV1I	**General Services**	X
GOV2I	**Emergency Center**	X
EDU1I	**Schools**	X
EDU2I	**Colleges**	X

Fig. 6 shows the estimated percentage of existing Risk Category III and IV buildings in the tornado-prone region based on the definition of building stock and applicable building occupancy types from Table 2. The percent of Risk Category III and IV buildings varies significantly, from 0 % to 1.9 %, depending on the county, with "hotspots" in and around the metropolitan areas.

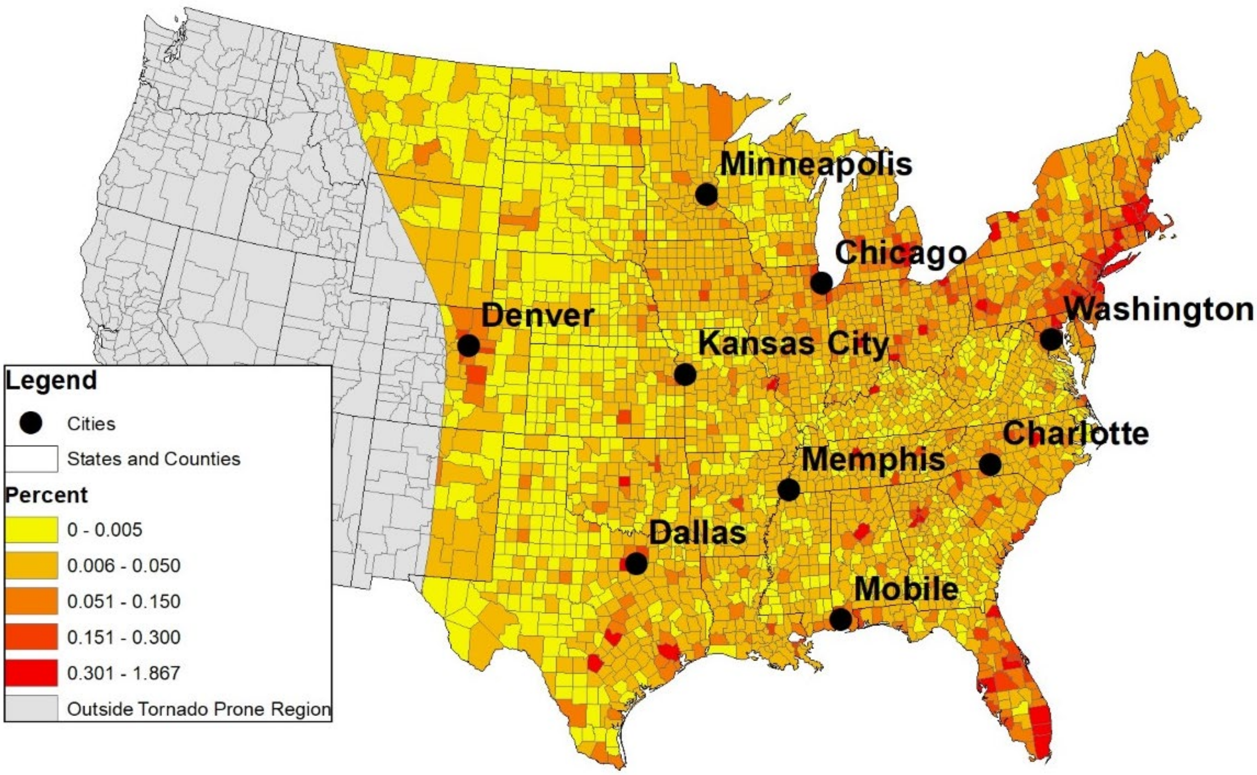


Fig. 6. Estimated Percentage of Risk Category III and IV Buildings, By State and County

Aggregation of the building stock for the tornado-prone region compared to the U.S. building stock is shown in Table 3. The tornado-prone region accounts for 81 % of the building stock, ranging from 69 % to 88 % depending on the occupancy type. Of the occupancy types identified as Risk Category III and IV buildings, the tornado-prone region accounts for 80 % to 88 % depending on the occupancy type, with an overall average of 81 %. The Risk Category III and IV buildings are estimated to comprise 1.4 % of the entire U.S. building stock and 1.7 % of the building stock in the tornado-prone region.

When excluding residential occupancies with less than 50 units, the building stock occupancy types for Risk Category III and IV buildings in the tornado-prone region becomes 15.0 % of the entire U.S. building stock and 18.3 % of the building stock in the tornado-prone region.

These results are effectively upper bound estimates; the actual values would be smaller, perhaps substantially so. This is due to limitations of the data and assumptions made in the analysis, all of which tend to bias the results towards overestimation of the impacts of the adoption of the new tornado load requirements in the ASCE 7-22 standard.

Table 3. Building Count by Occupancy Type and Count and Fraction Located in Tornado-Prone Region

Occupancy Type		Building Count		
Code	**Description**	**Total US**	**Tornado – Prone Region**	**Fraction of US in Tornado – Prone Region**
RES1I	Residential Single-Family	77 341 549	61 968 809	80 %
RES2I	Residential Manufactured Housing	8 585 222	7 077 132	82 %
RES3AI	Residential Duplex	4 701 077	4 092 341	87 %
RES3BI	Residential 3-4 Units	3 693 939	3 072 738	83 %
RES3CI	Residential 5-9 Units	2 649 603	2 208 626	83 %
RES3DI	Residential 10-19 Units	1 838 264	1 507 694	82 %
RES3EI	Residential 20-49 Units	1 389 157	1 123 895	81 %
RES3FI	Residential 50+ Units	1 059 443	845 988	80 %
RES4I	Temp Lodging	86 318	67 302	78 %
RES5I	**Institutional**	**205 116**	**163 536**	**80 %**
RES6I	**Nursing Home**	**40 295**	**33 489**	**83 %**
COM1I	Retail Trade	983 783	811 328	82 %
COM2I	Wholesale Trade	707 373	578 097	82 %
COM3I	Personal Service	1 039 452	856 493	82 %
COM4I	Professional	1 565 278	1 260 153	81 %
COM5I	Banking	141 214	119 220	84 %
COM6I	**Hospital**	**27 440**	**23 269**	**85 %**
COM7I	**Medical Office**	**404 628**	**330 495**	**82 %**
COM8I	**Entertainment**	**763 363**	**623 890**	**82 %**
COM9I	**Theaters**	**25 326**	**20495**	**81 %**
IND1I	Heavy Industrial	278 759	233 042	84 %
IND2I	Light Industrial	307 080	245 586	80 %
IND3I	Food/Drug	73 066	57 688	79 %
IND4I	Metals	43 899	38 255	87 %
IND5I	High Tech	8706	6039	69 %
IND6I	Construction	931 380	769 888	83 %
AGR1I	Agriculture	503 485	426 558	85 %
REL1I	Religious	504 437	429 596	85 %
GOV1I	**General Services**	**154 613**	**131 419**	**85 %**
GOV2I	**Emergency Center**	**30 576**	**26 946**	**88 %**
EDU1I	**Schools**	**176 226**	**142 313**	**81 %**
EDU2I	**Colleges**	**19 987**	**17 219**	**86 %**
TOTAL		**110 280 054**	**89 309 539**	**81 %**
TOTAL (Exclud. Resident. < 50 units)		**10 081 243**	**8 258 304**	**82 %**
TOTAL (Impacted Occupancy Types i.e., Risk Category III and IV)		**1 847 570**	**1 513 071**	**81 %**

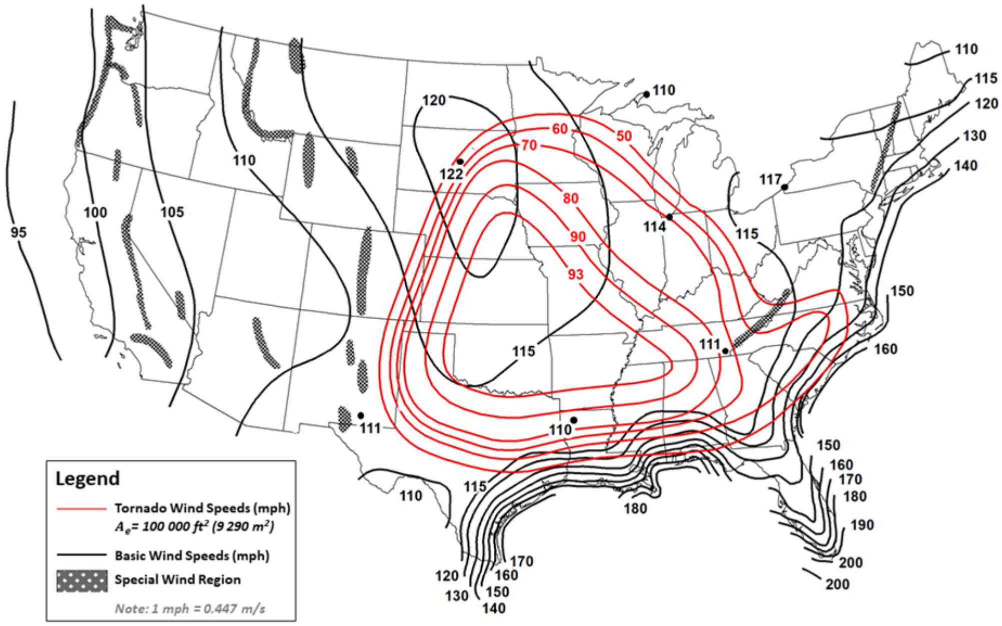
3. Where Design for Tornado Loads is Not Required

The ASCE 7-22 tornado load provisions (Section 32.5.2) include tools to help identify many of the situations where tornado loads will not control any aspects of the design and are therefore not required. This section describes those provisions and provides examples of their application.

3.1. Comparing Design Tornado and Design Wind Speed

Areas outside of the tornado-prone region do not require design for tornado loads. Even within the tornado-prone region, design for tornado loads is not always required. If the design tornado speed (V_T) is less than 60 mph (26.8 m/s) tornado loads will generally not control over wind loads. Additionally, if the tornado speed is less than a certain percentage of the basic (non-tornado) wind speed, V, tornado loads will not control. For buildings located in wind Exposure Category B or C, design for tornado loads is not required where $V_T < 0.5V$ or $V_T < 0.6V$, respectively (in this context, Exposure B means that the building is surrounded by urban, suburban, or wooded terrain, Exposure C is flat, open terrain). The exposure category does not change the tornado loads, but wind loads in Exposure B are less than those in Exposure C. Subsequently, a building located in Exposure B is more likely to have tornado loads control over wind loads, compared to the same building in Exposure C.

To understand the spatial differences between basic wind speed and tornado wind speed hazard maps, Fig. 7 shows overlays of wind speed contours for the two hazards for Risk Category III buildings and other structures (top) and Risk Category IV buildings and other structures (bottom). As described in Section 1.2, the design tornado speed is a strong function of effective plan area in addition to risk category and geographic location. The tornado speeds shown in the top and bottom plots are for A_e = 100 000 ft^2 (929 m^2) and 1 000 000 ft^2 (92 903 m^2), respectively. In both maps, the tornado speed contours are greatest in the central Great Plains region and extending into the Southeast of the U.S. and taper off in the west and northeast of the county as well as in the hurricane-prone regions of the Atlantic and Gulf Coasts. The greatest values for basic wind speed in the interior of the country are also located in the central US but are further north and west of the region of maximum tornado speeds. Basic wind speeds increase in the hurricane-prone region of the country, especially along the Gulf Coast and portions of the Atlantic Coast. The difference between the two design speeds for a specified location greatly influences whether tornado loads will control over wind loads.



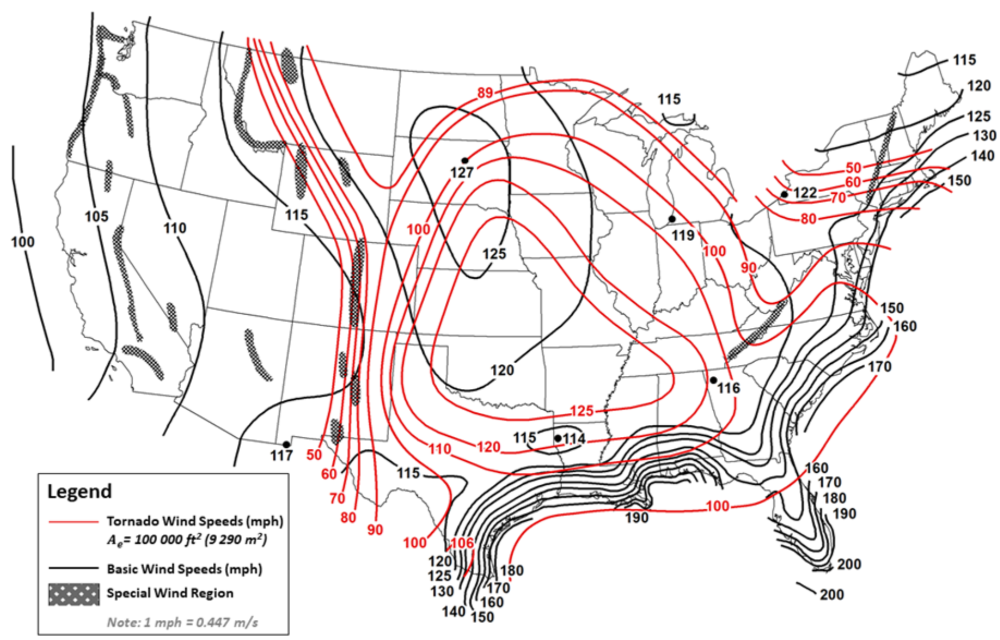
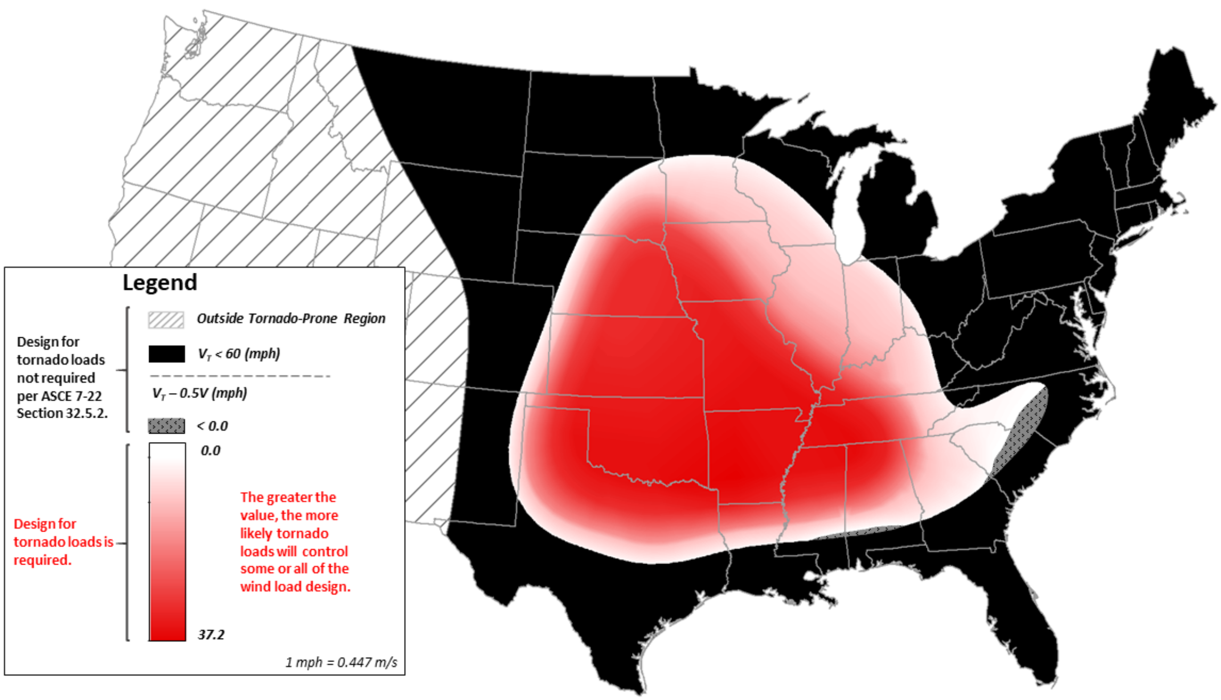


Fig. 7. Tornado speed and basic wind speed contours for Risk Category III buildings (top) and Risk Category IV buildings (bottom)

3.2. Example Maps Showing Where Design for Tornado Loads is Not Required

Maps were created to show where design for tornado loads is not required based on the risk category, exposure category, and design speeds for a specified location. Examples for a medium size (A_e = 100 000 ft^2 (929 m^2)) Risk Category III building and a large (A_e = 1 000 000 ft^2 (92 903 m^2)) Risk Category IV facility are shown in Fig. 8 and Fig. 9, for Exposures B and C. These maps were created using the Environmental Systems Research Institute ArcGIS Desktop 10.8 [20] software package and tools offered in the Spatial Analyst extension of the software. Underlaying basic and tornado wind speed data layers were collected in raster file format from the ASCE 7 Hazard Tool REST services website [21, 22] and the ArcGIS Desktop raster calculator tool [20] was used to perform the calculations required for each of the analyses described herein.

For the medium-sized Risk Category III building the tornado speeds are less than 60 mph (26.8 m/s) across much of the tornado prone region, as shown in black (Fig. 8). Locations where tornado speeds are less than the specified percentages of basic wind speeds, depending on exposure, are shown in grey. Tornado loads are only required in the areas shaded in the white-to-red spectrum which spans roughly between north Texas, central Minnesota, and the central Carolinas. In contrast, design for tornado loads is required across most of the tornado-prone region for very large Risk Category IV facilities, except for New England and small areas of south Florida and south Louisiana for Exposure C (Fig. 9). In both figures the darker reds indicate areas that tornado loads are more likely to exceed wind loads in the design of building elements. Section 4.4 will discuss the comparison of tornado versus wind pressures on different building elements in in more detail.



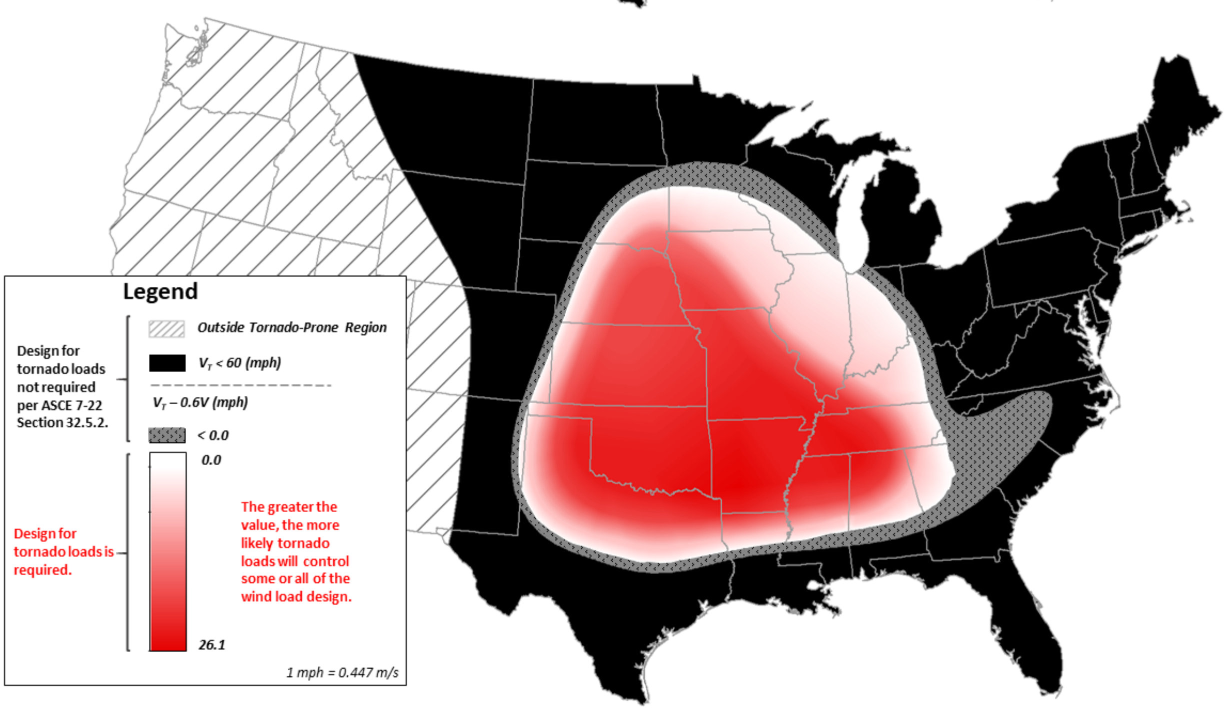


Fig. 8. Map of likelihood that design for tornado loads is required for a Risk Category III A_e = 100 000 ft^2 (9290 m^2) building or other structure in Exposure B (top) and Exposure C (bottom)

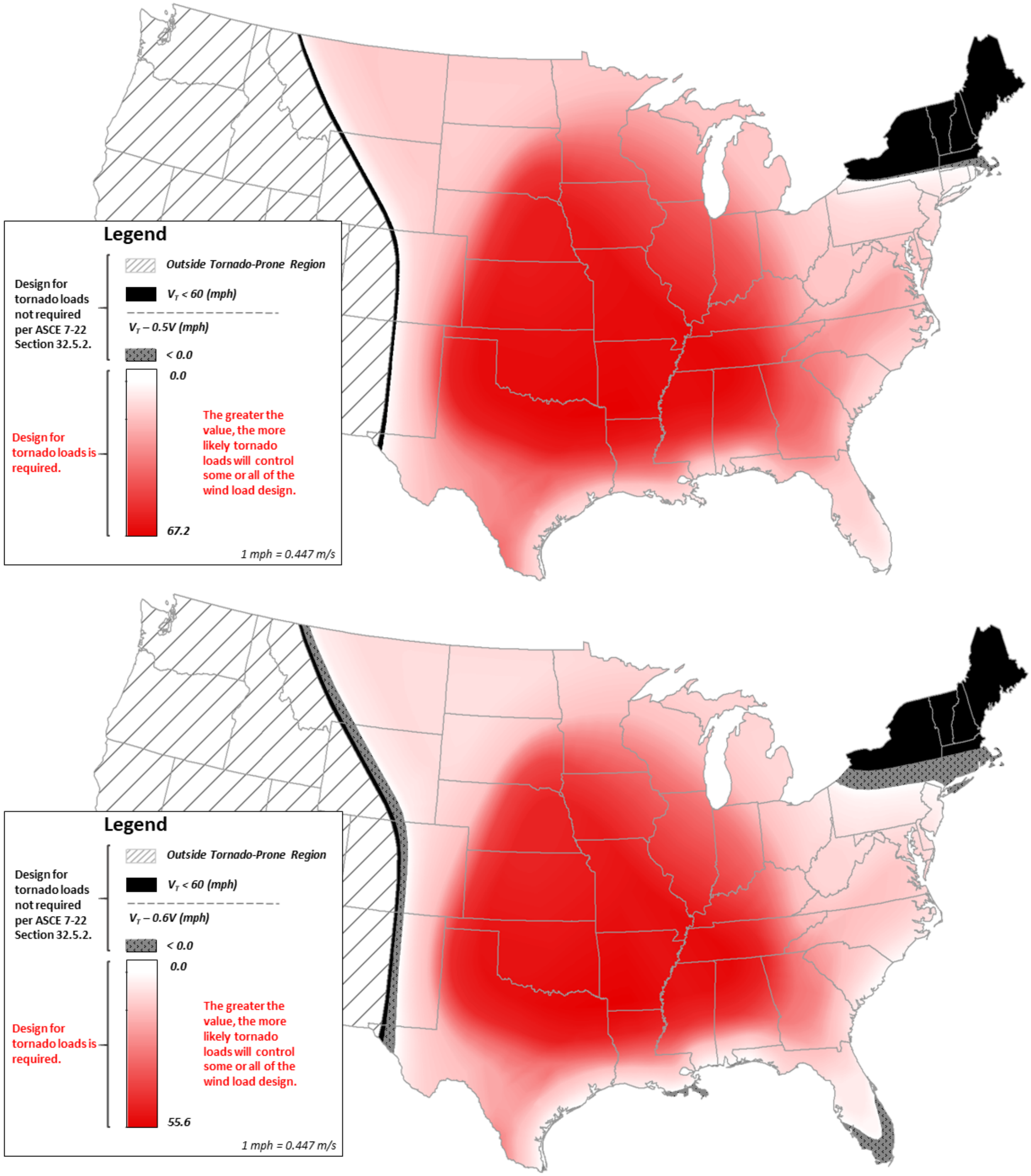


Fig. 9. Map of likelihood that design for tornado loads is required for a Risk Category IV A_e = 1 000 000 ft^2 (92 903 m^2) building or other structure in Exposure B (top) and Exposure C (bottom)

4. Impacts on Building Loads

The new ASCE 7-22 tornado provisions have a wide range of potential impacts to loads on buildings and other structures, compared to the basic wind load provisions already required by the standard. Depending on many variables related to tornado climatology and building characteristics, tornado loads can be smaller in magnitude than wind loads or more than double the wind loads – and sometimes both extremes apply to different elements of the same building. To demonstrate the range of impacts and trends, this section provides comparisons of wind and tornado loads on several building types, using three approaches with different combinations of spatial and analytical detail.

The complex interplay of the differences between the tornado load and wind load procedures makes it less than obvious which hazard will ultimately control the design. In many instances, tornado loads will control some, but not all, elements of the main wind force resisting system and/or components and cladding design. For example, outward-acting leeward wall pressures and uplift pressures in the field of the roof for enclosed buildings are comparatively greater in magnitude for tornado loads than for wind loads, due to the stronger influence of the effective internal pressure in tornadoes caused by atmospheric pressure change.

Whether or not tornado loads will ultimately control any aspects of the design for a particular building or structure is dependent on many factors. The relative hazard intensity (design speed) for both tornado and wind are obviously critical; however, many other parameters also come into play including, but not limited to:

- tornado speed, which is a function of
    - geographic location
    - risk category
    - effective plan area, which depends on footprint size and shape
- basic wind speed, which is a function of
    - geographic location
    - risk category
- wind exposure category
- designation as an essential facility or not
- building or other structure (and specific type of other structure)

For buildings, the following additional factors are also important:

- building plan shape
- roof geometry
- roof height
- enclosure classification

4.1. Building Types

Four different building types were used in this study – an elementary school, a high school, a fire station, and a hospital. Examples of actual buildings of these types in the Dallas-Ft. Worth (DFW) area were reviewed to develop typical dimensions for each. The elementary school and high school are two-story buildings. The fire station has one story, and the hospital has five stories. All buildings have low-slope roofs. The schools are considered Risk Category III and the fire station and hospital are Risk Category IV.

Other key building characteristics are summarized in **Table 4**, along with parameters used for each to calculate wind and tornado loads (for symbols and terms not previously defined in this report, see ASCE 7-22 [2]). The effective plan area, A_e, (similar to footprint area) assumed for each facility is shown in the first row of the table. This parameter is used in determination of the design tornado speed V_T. For the hospital, the effective plan area encompasses multiple buildings[7] on the hospital campus that are required to maintain functionality of the facility following an extreme environmental hazard. The design tornado speeds and basic (non-tornado) wind speeds shown are for the DFW area. The tornado speeds come from ASCE 7-22, while the basic wind speeds are from ASCE 7-16 [23] and used in Section 4.2 of this report only. Basic wind speeds used in Section 4.3 and later in the report are from ASCE 7-22. Per the minimum requirements of ASCE 7-22, the fire station and hospital are assumed to have either impact-resistant glazing (e.g., laminated glass) or impact protective systems (e.g., shutters or screens). The schools do not have impact-resistant or impact protected glazing.

Table 4. Building Characteristics, and Wind and Tornado Load Parameters[8]

SCHOOLS

Variable	ASCE 7-16 (Basic Wind)		Tornado: Elem. School	Tornado: High School
A_e (SF)	N/A		100,000	500,000
V or V_T (MPH)	112		90	102
Exposure	B	C	N/A for pressure calcs	
Mean Roof Height, h (ft)	33			
K_d or K_{dT}	0.85		Varies 0.75 to 0.9	
K_{zt}	1		N/A	
K_e	1			
K_z or K_{zTor}	0.72	1	1	
G or G_T	0.85			
Enclosure	Enclosed		Partially Enclosed	
GC_{pi} or GC_{piT}	+/-0.18		+/-0.55	
K_{vT}	N/A		Varies 1.05 to 1.3	

ESSENTIAL FACILITIES

Variable	ASCE 7-16 (Basic Wind)		Tornado: Fire Station	Tornado: Hospital
A_e (SF)	N/A		15,000	1,000,000
V or V_T (MPH)	115		97	123
Exposure	B	C	N/A for pressure calcs	
Mean Roof Height, h (ft)	20/80		20	80
K_d or K_{dT}	0.85		0.8 MWFRS, 1.0 C&C	
K_{zt}	1		N/A	
K_e	1			
K_z or K_{zTor}	0.62/0.93	0.9/1.21	1	
G or G_T	0.85			
Enclosure	Enclosed			
GC_{pi} or GC_{piT}	+/-0.18		+0.55/-0.18	
K_{vT}	N/A		Varies 1.05 to 1.3	

4.2. DFW-Area Comparisons of Wind and Tornado Loads

Wind and tornado pressures were computed for different elements of the main wind force resisting system (MWFRS) and component and cladding (C&C) on each of the four building types described in the previous section. This analysis was conducted during the development of the ASCE 7-22 load provisions and used to inform the committee regarding the impacts of the proposed addition of tornado loads to the standard. Since the revisions to the wind load provisions for ASCE 7-22 were not yet completed, the comparison was made between ASCE 7-22 tornado loads and ASCE 7-16 wind loads. All later sections of this report use ASCE 7-22 to determine both wind and tornado loads. The change to wind loads between 7-16 and 7-22 as related to the four example buildings in the region studied were very modest (a few percent).

[7] The heights of the various buildings are not needed for determination of A_e, just their size and location on the hospital campus.
[8] Unit Conversions: 1 mph = 0.44704 m/s; 1 ft = 2.54 cm; 1 m^2 = 10.7639 ft^2

This initial study was limited to the prototype buildings located in the DFW area. It should be noted that the DFW region is one of the most heavily impacted parts of the country with respect to increases in loads for tornadoes. DFW is situated close to the area of most intense tornado activity, so has relatively large tornado speeds compared to much of the rest of the country, but far enough away from the coast that the basic wind speed is not impacted by hurricanes, and it is located south of the greater wind speeds on the high plains (see Fig. 7 through Fig. 9).

Fig. 10 through Fig. 12 demonstrate that tornado loads are often greater than wind loads on the same building elements for the four building types in the DFW area. Wind loads in these figures are shown in solid bars, while tornado loads have hatched bars, with all bars color-coded by building type. Tornado design pressures on the MWFRS exceed wind design pressures in all cases shown (windward and leeward walls, uplift on the windward edge and in the field (middle) of the roof), for the buildings with Exposure B (urban, suburban, and/or wooded areas, which reduces the wind load), as shown in the top of Fig. 10. Increases range from 14 % to 184 %. Since wind loads increase by approximately 1/3 when moving from Exposure B to Exposure C, the relative differences are lower between tornado and wind loads in Exposure C. This is demonstrated in the bottom half of Fig. 10, where wind loads now control over tornado loads in a few instances, and the maximum increase of tornado to wind load is reduced to 118 %.

The middle block of comparison bars on Fig. 10 shows the effects on the net lateral force (i.e., base shear) on the building for one wind direction. The net lateral force from tornado loads was less than from wind loads in Exposure C for all buildings, and increased modestly for 3 of the 4 buildings for wind Exposure B.

Comparisons of tornado and wind loads for C&C on the roof (Fig. 11) and wall (Fig. 12) show similar trends. Tornado loads generally control over wind loads in Exposure B for the locations and effective wind areas shown, although the increases are somewhat less than for the MWFRS. For Exposure C, wind loads sometimes control over tornado loads, and when tornado loads control, it is by a smaller margin.

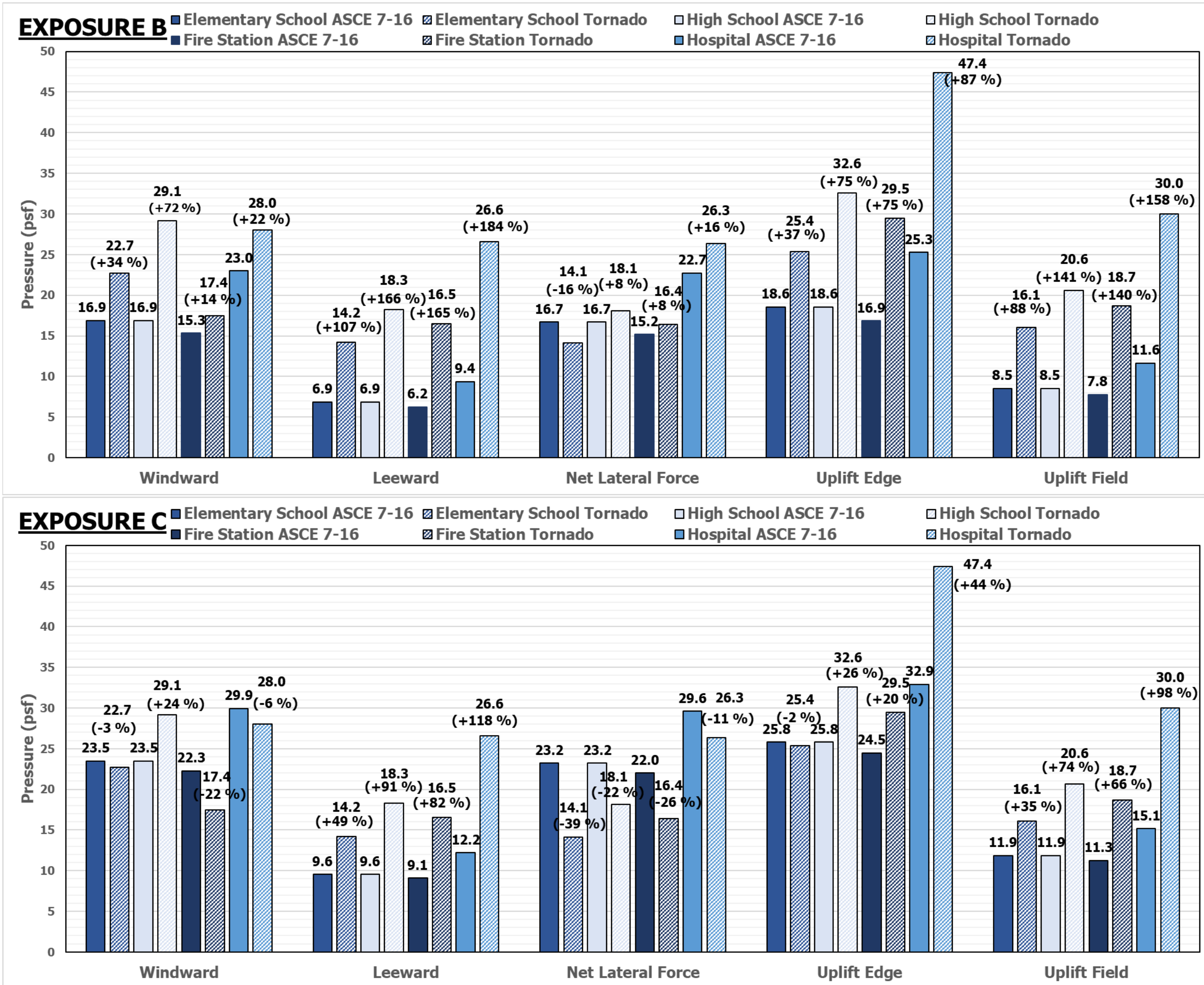


Fig. 10. Main Wind Force Resisting System (MWFRS) Load Comparisons, for DFW Area

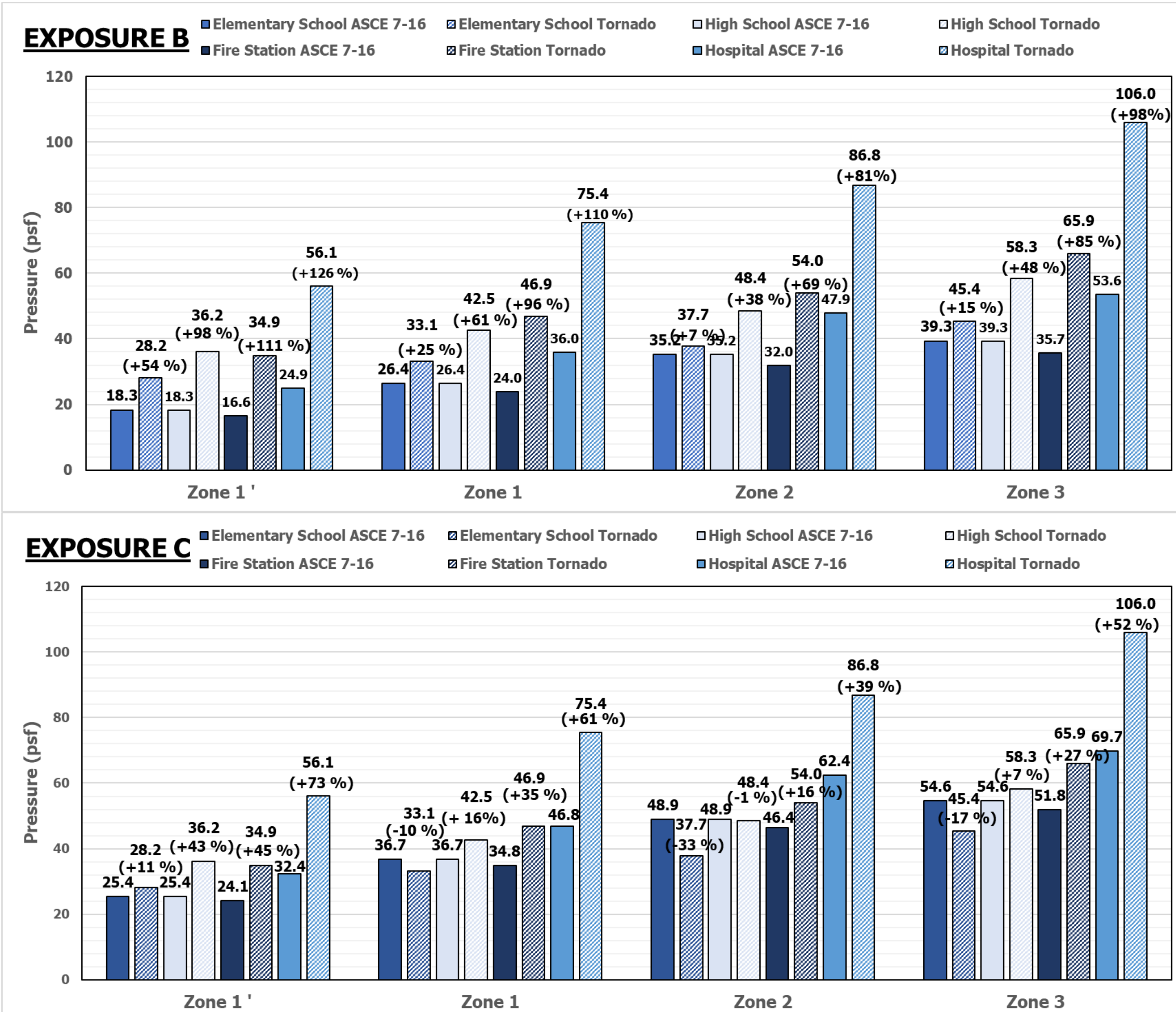


Fig. 11. C&C Roof Load Comparisons for Effective Wind Area = 200 ft^2 (18.6 m^2), for DFW Area

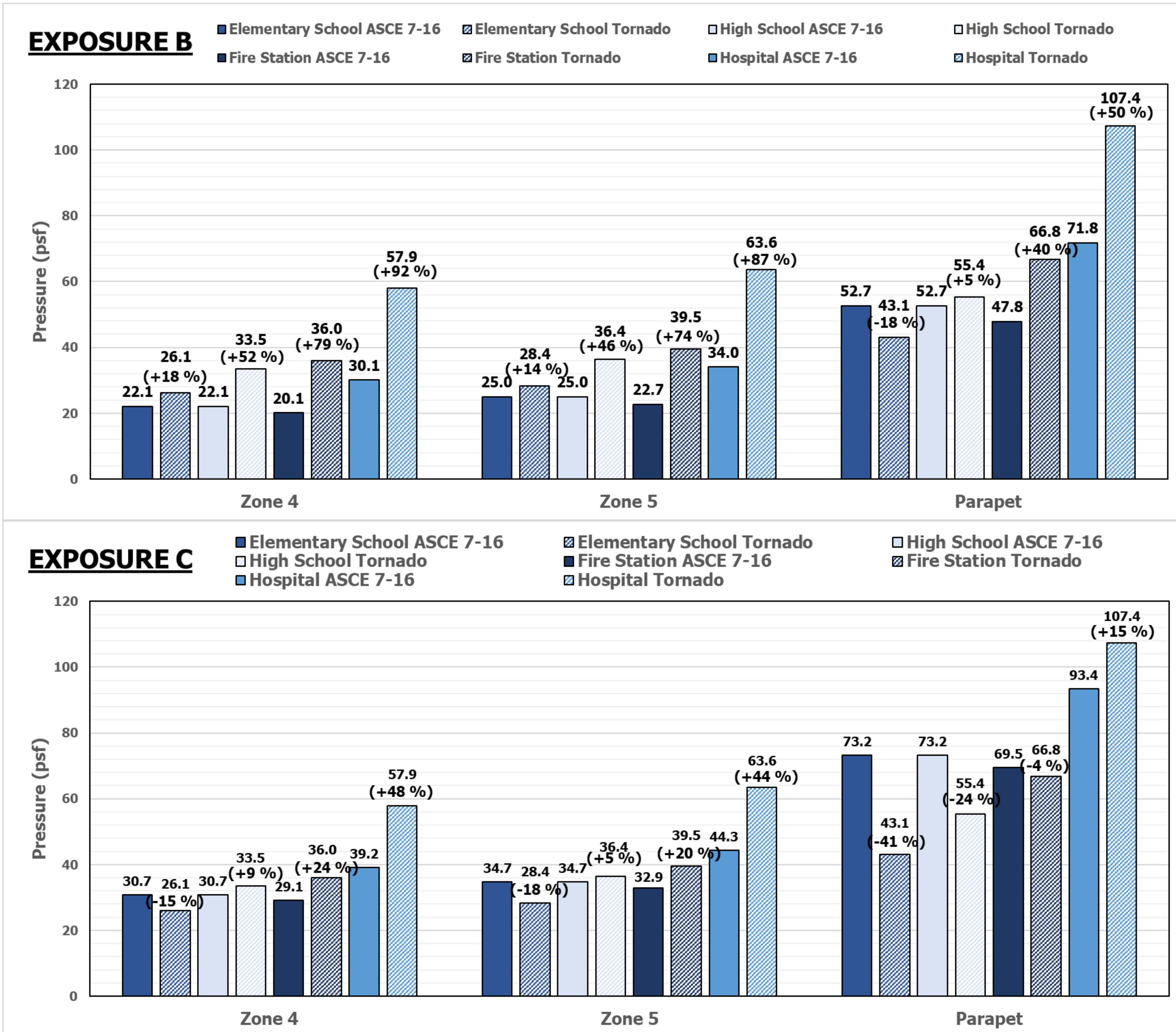


Fig. 12. C&C Wall Load Comparisons for Effective Wind Area = 75 ft^2 (7.0 m^2), for DFW Area

4.3. Extending the DFW-Area Case Study to Additional Cities

A subset of the DFW-area comparison study was extended to other parts of the country for the elementary school and the hospital. Table 5 displays tornado and wind pressures[9] on the same elements of the MWFRS shown in Fig. 10, for the DFW area and the eight other cities shown in Fig. 6. Where cells in Table 5 are shaded in black or dark grey, tornado loads are either not required or do not control over wind loads. The light gray and white shaded cells show where tornado pressures exceed the corresponding wind pressures. For cities located on the periphery of the tornado-prone region (Denver, Mobile, Charlotte, Washington DC), tornado loads do not control the design of any elementary school elements in either exposure

[9] Note that the wind pressures in this section were computed using ASCE 7-22. The basic (non-tornado) wind speeds for DFW increased by approximately 2 % compared to ASCE 7-16 basic wind speeds, so the wind pressures shown here are slightly different than those in **Fig. 9**. The tornado pressures are unchanged.

category. In the remaining cities, tornado loads will control at least some element of the design, especially if the school is located in Exposure B. By contrast, tornado loads will control at least some aspect of the design of the hospital in all nine cities if the building is in Exposure B, and 7 of the 9 cities when the building is in Exposure C.

Table 6 shows similar comparisons for C&C roof uplift pressures on the elementary school and hospital for a small effective wind area, as would be used to design the roof covering (see Section 5). Tornado loads have a relatively smaller impact on these C&C design pressures compared to MWFRS pressures, only controlling some roof zones on the elementary school in three selected cities (DFW, Kansas City, and Memphis). Tornado controlling cases for the hospital are reduced as well.

Table 5. Comparison of MWFRS Wind and Tornado Design Pressures

Elementary School

Surface	Location	Charlotte		Chicago		DFW		Denver		Kansas City		Memphis		Minneap.		Mobile		Wash. DC	
	Exposure	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**
Wwrd Wall	Wind Pr	18	25	17	24	18	24			18	25	18	25	18	25				
	Tor Pr	10	-	13	13	**22**	22			**23**	23	**24**	24	13	-				
Lwrd Wall	Wind Pr	7	10	7	10	7	10			7	10	7	10	7	10				
	Tor Pr	6	-	**8**	8	**14**	**14**			**15**	**15**	**15**	**15**	**8**	-				
Wwrd Roof	Wind Pr	20	27	19	26	19	27			20	27	19	27	20	27				
	Tor Pr	11	-	15	15	**25**	25			**26**	26	**27**	27	15	-				
Lwrd Roof	Wind Pr	9	13	9	12	9	12			9	13	9	12	9	13				
	Tor Pr	7	-	**10**	10	**16**	**16**			**17**	**17**	**17**	**17**	**9**	-				

Hospital

Surface	Location	Charlotte		Chicago		DFW		Denver		Kansas City		Memphis		Minneap.		Mobile		Wash. DC	
	Exposure	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**	**B**	**C**
Wwrd Wall	Wind Pr	24	33	23	31	23	31	19	26	24	33	24	32	24	32	48	64	26	35
	Tor Pr	18	18	21	21	**28**	28	10	10	**28**	28	**29**	29	21	21	22	22	16	16
Lwrd Wall	Wind Pr	10	13	9	13	9	12	8	10	10	13	10	13	10	13	19	26	11	14
	Tor Pr	**17**	**17**	**20**	**20**	**27**	**27**	**10**	10	**27**	**27**	**27**	**27**	**20**	**20**	**20**	20	**16**	**16**
Wwrd Roof	Wind Pr	27	**36**	26	34	25	34	21	28	27	36	26	36	26	35	52	70	29	39
	Tor Pr	**31**	31	**36**	**36**	**47**	**47**	17	17	**47**	**47**	**49**	**49**	**35**	**35**	37	37	28	28
Lwrd Roof	Wind Pr	12	17	12	16	11	15	10	13	12	17	12	16	12	16	24	32	13	18
	Tor Pr	**19**	**19**	**23**	**23**	**30**	**30**	**11**	11	**30**	**30**	**31**	**31**	**22**	**22**	23	23	**18**	18

Legend

Black	Tornado Speed < 60 mph	Design for tornado loads not required
Dark gray	Tornado Speed <0.5V for Exp. B or 0.6V for Exp. C	Design for tornado loads not required
Medium gray	Tornado Pressure < Wind Pressure	Design for tornado loads required but does not control
Light gray	Tornado Pressure > Wind Pressure for Exposure B	Design for tornado loads is required and controls over wind loads
White	Tornado Pressure > Wind Pressure for Exposure C	Design for tornado loads is required and controls over wind loads

Note 1: Pressures shown in psf

Note 2: 1 psf = 47.88 N/m^2

Table 6. Comparison of C&C Wind and Tornado Design Roof Uplift Pressures, for Effective Wind Areas =10 ft^2 (0.93 m^2)

Elementary School

Roof Zone	Location	Charlotte		Chicago		Dallas		Denver		Kansas City		Memphis		Minneap.		Mobile		Wash. DC	
	Exposure	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
1'	Wind Pr	23	31	22	30	22	31			23	31	22	31	23	31				
	Tor Pr	14	-	19	19	**31**	**31**			**33**	33	**33**	**33**	19	-				
1	Wind Pr	39	55	38	52	38	53			39	54	39	54	39	54				
	Tor Pr	19	-	26	26	**42**	42			**45**	45	**46**	46	25	-				
2	Wind Pr	52	72	49	69	51	70			52	72	51	71	52	72				
	Tor Pr	21	-	29	29	48	48			51	51	**52**	52	72	-				
3	Wind Pr	71	98	67	94	69	96			70	98	69.5	97	70	98				
	Tor Pr	28	-	38	38	63	63			66	66	67	67	37	-				

Hospital

Roof Zone	Location	Charlotte		Chicago		Dallas		Denver		Kansas City		Memphis		Minneap.		Mobile		Wash. DC	
	Exposure	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C	B	C
1'	Wind Pr	31	41	29	39	28	38	24	32	31	41	30	41	30	40	51	69	33	44
	Tor Pr	**41**	41	**48**	**48**	**63**	**63**	23	23	**63**	**63**	**65**	**65**	**47**	**47**	43	43	**37**	37
1	Wind Pr	53	72	51	69	50	67	42	56	53	71	53	71	52	70	74	100	57	77
	Tor Pr	**65**	65	**76**	**76**	**100**	**100**	36	36	**100**	**100**	**103**	**103**	**75**	**75**	58	58	**59**	59
2	Wind Pr	70	95	67	90	65	88	55	74	70	94	69	93	69	93	99	133	76	102
	Tor Pr	**74**	74	**87**	87	**115**	**115**	41	41	**115**	**115**	**118**	**118**	**86**	86	67	67	67	67
3	Wind Pr	96	129	92	123	89	120	75	101	96	128	95	127	94	126	111	149	103	139
	Tor Pr	**98**	98	**114**	114	**151**	**151**	54	54	**152**	**152**	**155**	**155**	**113**	113	74	74	88	88

Legend

- Tornado Speed < 60 mph
- Tornado Speed <0.5V for Exp. B or 0.6V for Exp. C
- Tornado Pressure < Wind Pressure
- Tornado Pressure > Wind Pressure for Exposure B
- Tornado Pressure > Wind Pressure for Exposure C

} Design for tornado loads not required (first two)
Design for tornado loads required but does not control
} Design for tornado loads is required and controls over wind loads (last two)

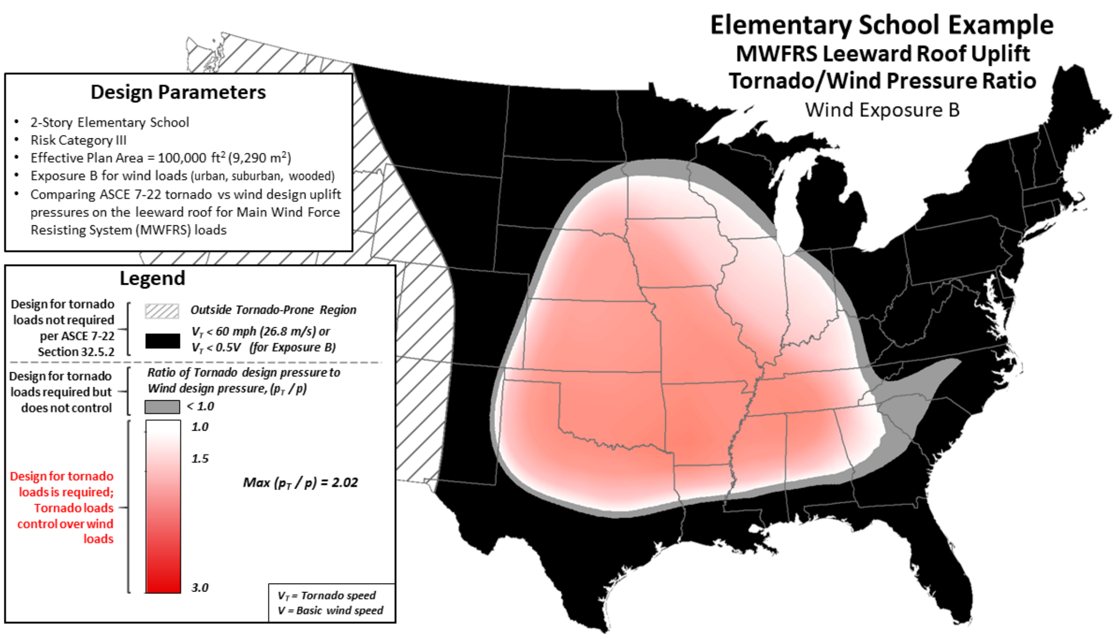
Note 1: Pressures shown in psf

Note 2: 1 psf = 47.88 N/m^2

4.4. National Comparisons of Wind and Tornado Loads

Although it would not be feasible to expand the design examples to all areas of the tornado-prone region, maps are provided here to illustrate nationwide load comparisons for the school and hospital examples. These maps show where tornado loads will control for select building elements for the elementary school and hospital examples described earlier.

Fig. 13 shows the ratio of design tornado pressure, p_T, to design wind pressure, p, for the elementary school when considering uplift loads on the leeward roof for design of the MWFRS for Exposure B (top) and Exposure C (bottom). For reference, see the 1st set of bars under "leeward" in Fig. 10 for the corollary of the DFW example for this building element. The ratio of tornado pressure to wind pressure p_T/p is increasingly larger in areas depicted by increasingly deeper shades of red. The spatial comparison for this design element is similar to that observed in Fig. 8, where the tornado design controls for the central Great Plains region and extending into the southeast. The maximum ratio of tornado pressure to wind pressure for the leeward roof is 2.02 for buildings in Exposure B and 1.5 for buildings in Exposure C. Tornado design is not required or does not control in the black and grey shaded areas, respectively.



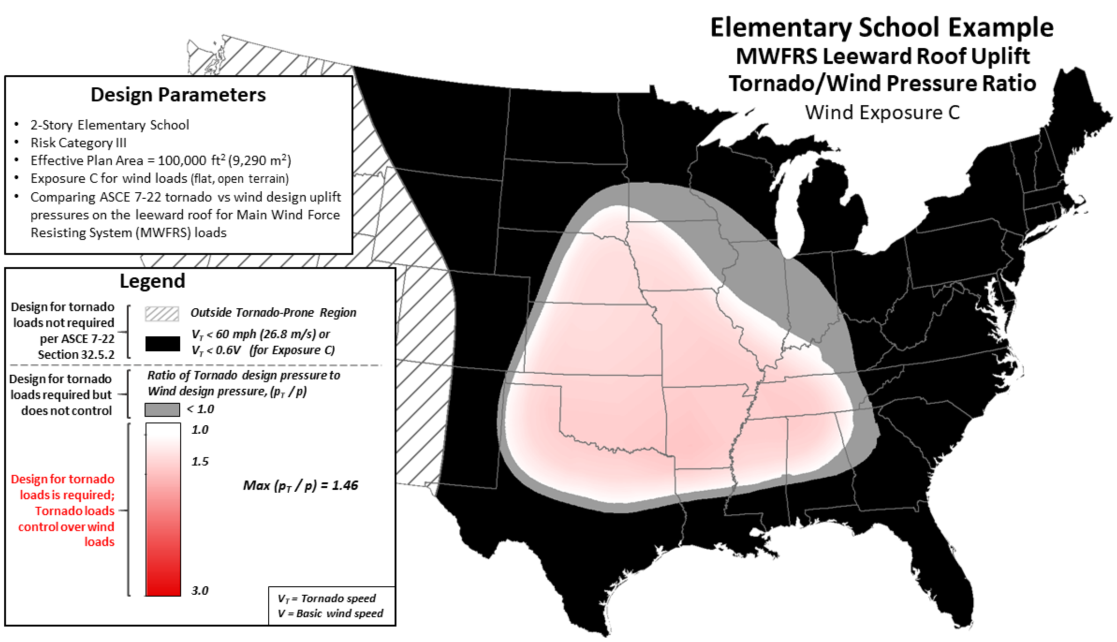


Fig. 13. Comparison of design tornado and wind pressures for leeward roof uplift on the MWFRS of the elementary school in Exposure B (top) and Exposure C (bottom)

Fig. 14 shows the pressure comparison for the hospital example, considering the MWFRS windward roof edge uplift design for Exposure Category B (top) and Exposure Category C (bottom). For reference, see the 4th set of bars under "windward" in Fig. 10 for the corollary of the DFW example for this building element. Due mostly to the larger effective area of the hospital compared to that of the elementary school and the change from Risk Category III for the elementary school to Risk Category IV for the hospital, tornado load design for this building element is required for a much larger area of the country and the tornado load design controls in more of the country compared to the elementary school example. The maximum ratio of design tornado pressure to wind pressure is 1.91 for buildings in Exposure Category B and 1.47 for buildings in Exposure Category C.

Fig. 15 shows another pressure comparison for the hospital example, considering the MWFRS of the leeward part of the roof, for Exposure Category B (top) and Exposure Category C (bottom). For reference, see the 4th set of bars under "windward" in Fig. 10 for the corollary of the DFW example for this building element. The areas where design for tornado loads is not required is the same as for the MWFRS windward roof edge uplift shown in Fig. 14, but tornado loads control for a much larger portion of the country for the leeward roof uplift due to the smaller magnitude of the pressures and the greater relative contribution of internal pressure and atmospheric pressure change. The maximum ratio of design tornado pressure to design wind pressure is 2.63 for buildings in Exposure Category B and 2.02 for buildings in Exposure Category C.

These example maps show the spatial implications of the introduction of the ASCE 7-22 tornado pressures on overall building design for specific building elements. Comparison of the maps for different building elements shows that the magnitude of the difference between design tornado and wind pressures is also a strong function of the design element being considered.

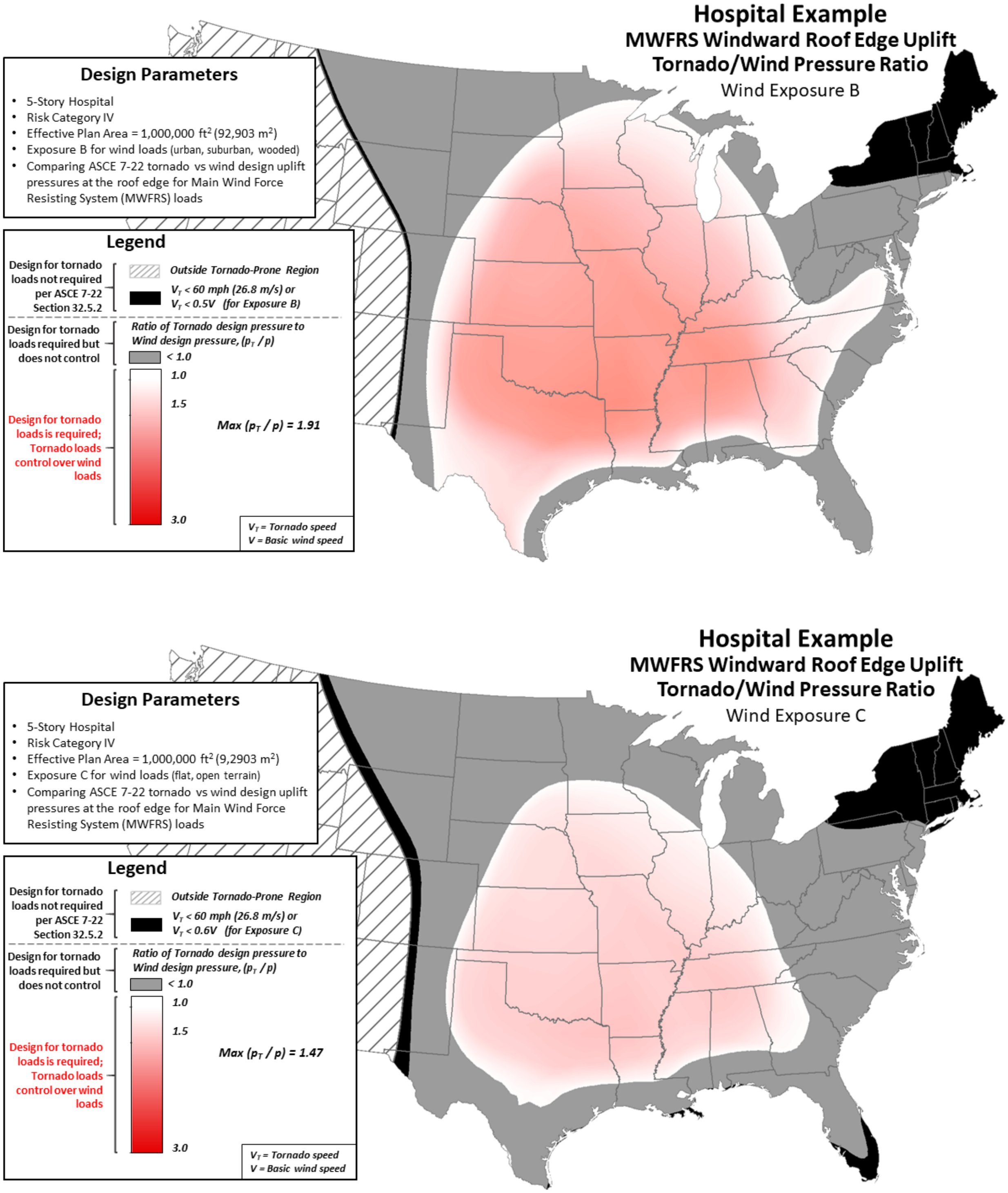
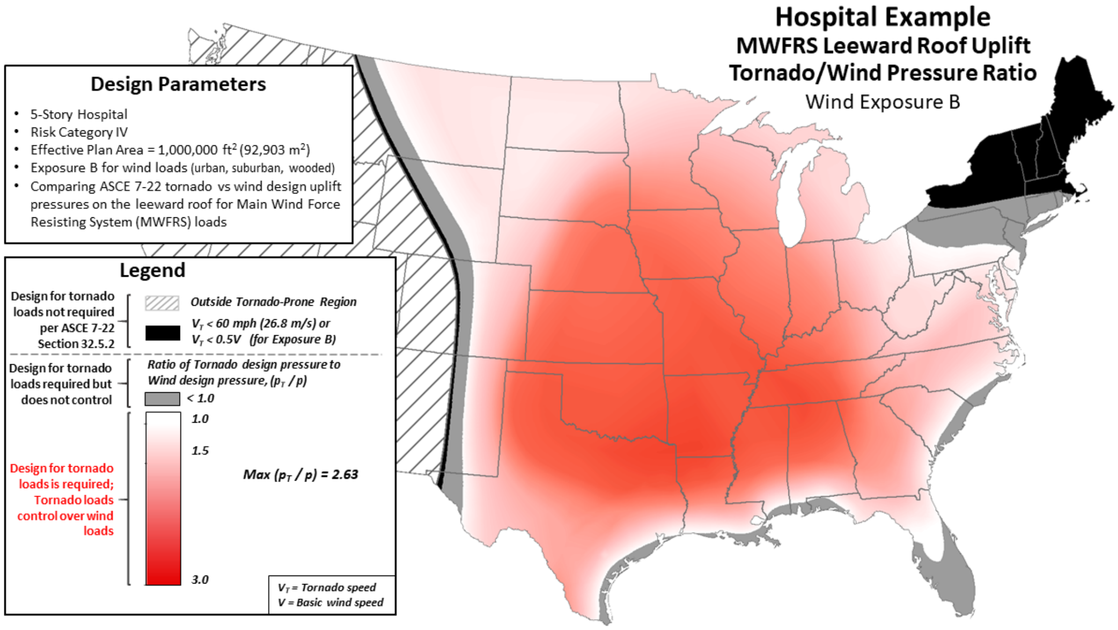


Fig. 14. Comparison of design tornado and wind pressures for windward roof edge uplift on the hospital in Exposure B (top) and Exposure C (bottom)



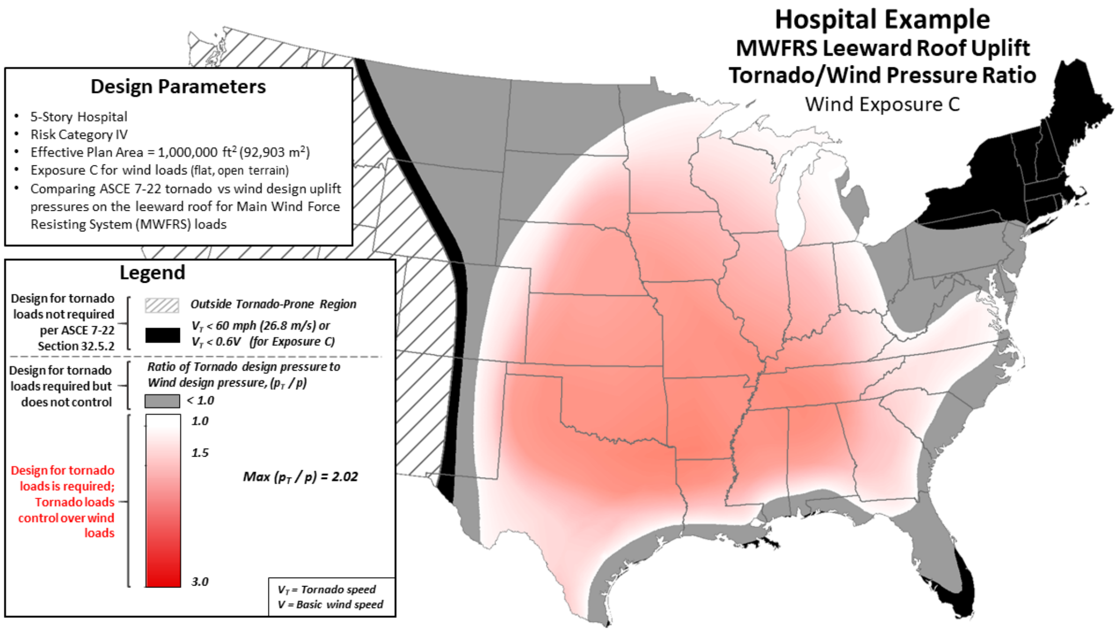


Fig. 15. Comparison of design tornado and wind pressures for the leeward roof uplift on the hospital in Exposure B (top) and Exposure C (bottom)

5. Impacts on Roof Systems

This section discusses potential impacts on roof systems with adoption of the new tornado load requirements in ASCE 7-22. Four different systems were studied, applied to the example buildings described in Section 4.1. Each system was evaluated at the nine cities shown in Fig. 6. The studied roof systems are as follows:

Elementary school: Fully adhered membrane over steel roof deck:,
- Adhered membrane (either modified bitumen or single-ply)
- Cover board, set in foam ribbon adhesive
- Polyisocyanurate roof insulation, 4 ft x 4 ft (1.2 m x 1.2 m), set in foam ribbon adhesive
- Polyisocyanurate roof insulation, 4 ft x 8 ft (1.2 m x 2.4 m), mechanically attached
- Steel roof deck

High school: Mechanically attached membrane over steel roof deck:,
- Mechanically attached single-ply membrane
- Cover board, 4 ft x 8 ft (1.2 m x 2.4 m), mechanically attached
- 2 layers of polyisocyanurate roof insulation, 4 ft x 8 ft (1.2 m x 2.4 m), loose-laid
- Steel roof deck

Fire station: Structural standing seam metal panel system
- Structural standing seam metal panel system, concealed clips
- Steel roof deck or steel purlins

Hospital – Roof System 1: Fully adhered membrane over steel roof deck – same as elementary school roof system.

Hospital – Roof System 2: Fully adhered membrane over concrete roof deck:,
- Adhered membrane (either modified bitumen or single-ply)
- Cover board, set in foam ribbon adhesive
- 2 layers of polyisocyanurate roof insulation, 4 ft x 4 ft (1.2 m x 1.2 m), set in foam ribbon adhesive
- Modified bitumen membrane, torched to primed concrete roof deck
- Normal weight concrete roof deck

All studied roof systems are commonly used throughout the U.S. on commercial buildings and essential facilities.

5.1. Evaluation Process

A six-step process was used to evaluate the potential impact on the roof system for each of studied roof systems at each city, as follows:

(1) The ultimate design uplift load was calculated for each roof zone (i.e. zones 1’, 1, 2 and 3), in accordance with ASCE 7-22 Chapter 30 for design pressures on low-slope roofs, for an effective wind area of 10 ft^2 (0.93 m^2). Tornado loads were calculated along with wind loads for Exposure B and C.

(2) The ultimate design uplift load was converted to an allowable stress design (ASD) uplift load per ASCE 7 (i.e., ultimate design load x 0.6 equals the ASD load).
(3) A 2.0 safety factor was applied to the ASD load to determine the minimum required laboratory test pressure.
(4) The minimum uplift resistance Class was determined. The Class was based on testing in accordance with ANSI/FM 4474 (one of the test standards listed in Section 1504.4.1 of IBC 2021) [24]. The lowest Class is 60. A Class 60 roof assembly passed the test at a pressure of 60 pounds per square foot (psf) (2872 N/m^2). A Class 60 assembly is suitable for ASD uplift loads less than or equal to 30 psf (1436 N/m^2). Classes are stepped by 15 psf (718 N/m^2) increments (e.g., Class 60, 75, 90, 105, 120, …).
(5) After determining the minimum required Class, a database of tested assemblies was searched to find a studied system that had the minimum required Class. Key characteristics of the system that affected costs were identified (e.g., the number of fasteners per insulation board and spacing of foam ribbon adhesive).
(6) The system's key characteristic requirements for Exposure B, C, and tornado were compared to determine if tornado design impacted the Exposure B or C requirements. The impacts are summarized in Section 5.2. Section 6 identifies the cost impacts for the elementary school and high school.

Table 7 illustrates this process for the high school in Memphis (mechanically attached single-ply membrane roof system on top of a steel deck).

Table 7. High School – Memphis – Roof Assembly Loads and Construction Example

Wind Exposure B						
Zone	Ult design uplift load (psf)	ASD uplift load (psf) (Ult x 0.6)	Min. test pressure (psf) (ASD load x 2.0 safety factor)	Min. uplift resistance Class (psf)	Row spacing, fasteners along row,	Fasteners per 4 ft x 8 ft board
1'	22.2	13.32	26.64	60	9.5 ft x 12 in oc	4
1	38.6	23.16	46.32	60	9.5 ft x 12 in oc	4
2	51	30.60	61.20	75	9.5 ft x 12 in oc	4
3	69.5	41.7	83.40	90	7.5 ft x 12 in oc	4

Wind Exposure C						
Zone	Ult design uplift load (psf)	ASD uplift load (Ult x 0.6)	Min. test pressure (ASD load x 2.0 safety factor)	Min. uplift resistance Class	Row spacing, fasteners along row	Fasteners per 4 ft x 8 ft board
1'	30.8	18.48	36.96	60	9.5 ft x 12 in oc	4
1	53.7	32.22	64.44	75	9.5 ft x 12 in oc	4
2	70.8	42.48	84.96	90	7.5 ft x 12 in oc	4
3	96.5	57.90	115.80	120	9.38 ft x 6 in oc	4

Tornado						
Zone	Ult design uplift load (psf)	ASD uplift load (Ult x 0.6)	Min. test pressure (ASD load x 2.0 safety factor)	Min. uplift resistance Class	Row spacing, fasteners along row	Fasteners per 4 ft x 8 ft board
1'	42.6	25.56	51.12	60	9.5 ft x 12 in oc	4
1	58.2	34.92	69.84	75	9.5 ft x 12 in oc	4
2	66.1	39.66	79.32	90	7.5 ft x 12 in oc	4
3	85.9	51.54	103.08	105	9.58 ft x 6 in oc	4

Note 1: Tornado pressure controls for zones 1' and 1 for Exposure B and C. Tornado pressure controls for zone 2 and 3 for Exposure B
Note 2: The tornado minimum resistance Class is not changed for zone 1' compared with Exposure B and C. For zones 1 – 3, the Class is increased compared with Exposure B, but the membrane fastener spacing is the same at zone 1**.** Hence, tornado increases the roof system cost for zones 2 and 3 verses Exposure B.
Note 3: Tornado does not increase the roof system cost compared with Exposure C.
Note 4: Unit Conversions: 1 in = 2.54 cm; 1 m = 3.28084 ft; 1 psf = 47.88 N/m^2

5.2. Summary of Tornado Impacts on Roof Systems

Tornado load impacts on the roof design as a function of building type, roof system, and city are shown in Table 8. Despite the sometimes significant (more than double) increases in uplift pressures, in no case did the tornado designs require the use of a different type of roof system or different roof system components than needed to resist the wind loads. There were no net impacts on the design of the elementary school roof or the hospital roof with the steel deck in any of the cities for either wind exposure. Where tornado loads had an impact on the studied roof systems, the impact consisted of requiring additional foam ribbon adhesive and/or additional fasteners. Given that buildings in Exposure C (flat, open terrain) have greater wind loads than the buildings with the same characteristics located in Exposure B (urban, suburban, or wooded areas), the relative impact of tornado loads on buildings in Exposure C were less than for Exposure B. Note that the under no scenario did roof deck design change.

Table 8. Tornado Load Impacts on Studied Roofing System Construction, by Location and Exposure

Building Type	Roof Construction	Cities	Exposure (Zones)	Construction Design Change
High School	steel roof deck, mechanically attached membrane	Memphis, Kansas City	B (2 & 3)	Additional membrane fasteners
		DFW	B	Additional membrane fasteners
Fire Station	structural standing seam metal panel system	Memphis, Kansas City, & DFW	B (all zones)	panel rib spacing is reduced
Hospital	steel roof deck, adhered roof system	Memphis, Kansas City, & DFW	B (all zones)	Additional insulation board fasteners
			B (1, 2)	Additional foam ribbon adhesive
			C (all zones)	Additional insulation board fasteners
			C (Zone 1)	Additional foam ribbon adhesive
		Chicago	B (Zone 1-3)	Additional insulation board fasteners
			B (Zone 1 & 2)	additional foam ribbon adhesive
			C (zone 1)	Additional insulation board fasteners & foam ribbon adhesive
		Minneapolis	B (Zone 1-3)	Additional insulation board fasteners
			B (Zone 2)	additional foam ribbon adhesive
		Charlotte	B (zone 1)	Additional insulation board fasteners & foam ribbon adhesive
Note 1: No impact for any location or exposure for elementary school (fully adhered membrane over steel roof deck) or hospital with concrete roof deck (adhered roof system). Note 2: No impact for all other locations, exposures, and zones for high school, fire station or hospital with steel roof deck.				

Wind-borne debris is another consideration in the design of roofs. Information on this hazard and design strategies to minimize the consequences of debris impacts is presented in the Appendix.

6. Construction Cost Analysis

The construction cost analysis of the ASCE 7-22 tornado load requirements is discussed in detail in this section, including an explanation of the general methodology, construction design options considered to meet the design pressures, cost data collection and development for these construction design options across locations, and cost comparison approach. This study updates and expands on previous analysis completed by Huckabee, Inc. for two building types (elementary school and high school) and two wind exposures (B and C) for the DFW area and replicates the process for eight other locations to provide examples of cost impacts under different tornado load conditions.

6.1. Methodology

The general methodology to estimate the construction cost impacts of ASCE 7-22 tornado loads for a given building type in a specific location is defined in the following steps:

1) Calculate the design wind pressures for Exposure B, Exposure C, and design tornado pressure as defined by ASCE 7-22
2) Estimate construction costs for building elements for each of the three cases in step 1
3) Calculate the difference in costs for each building element
4) Sum costs for all building elements for which costs increase to meet the tornado loads
5) Replicate Steps (1) to (4) for other locations
6) Replicate Steps (1) to (5) for other building types

These calculations require the following information for each building type and location:

- Initial project budget for the building
- Design wind and tornado pressure the building is required to withstand
- Building element design options to meet the different pressures
- Construction costs of these building element design options

The design wind and tornado pressures are calculated as described in Section 4. Whether design tornado pressure loads control over wind pressure loads varies by building type, location, and exposure category. Below are the four design loads used for selection and cost estimation of the building element constructions and the range of design tornado loads as a percentage of wind load:

- MWFRS Roof Field: -79 % to +144 %
- Zone 2 Roof Uplift C&C pressure, EWA 10 ft^2 (0.93 m^2): -89 % to +30 %
- Zone 1' Roof Net Uplift[10]: -92 % to +137 %
- Zone 4 C&C Pressure, EWA 75 ft^2 (6.97 m^2): -87 % to +52 %

Clearly, design tornado loads will not control in some cases while in other cases there are large load increases. In general, the tornado loads have a greater percentage increase relative to the existing load requirements for the high school (i.e., larger building footprint), buildings with Exposure B, and locations in the central and southern United States.

[10] Zone 1' Roof Net Uplift is a function of Roof Uplift C&C pressure, EWA 200 ft^2 (18.58 m^2) = 0.6* Uplift - 3

The initial project budget, building element design options, and construction cost data were collected by Huckabee for a single location (DFW area). City cost indexes for construction costs are applied to adjust the cost data for other locations. The exception to this process is roofing, which was not provided by Huckabee and is calculated using location-specific cost data.

6.1.1. Building Element Options and Maximum Loads

There are five building element construction designs impacted by tornado loads considered in this cost analysis: diaphragm, joists and wide flange beams and girders, foundation anchorage, exterior wall framing, and roofing. For each of the five considered building elements there is an associated wind load requirement. Table 9 provides the maximum load value for a given building element construction design option.

The diaphragm construction must meet calculated Zone 2 uplift for Effective Wind Area (EWA) 10 ft^2 (0.93 m^2) load thresholds. The construction options developed by Huckabee are based on a conventional design using ⅝ in (1.6 cm) arc puddle welds (PW) support fastener, 36/4 support pattern, #12 TEK screw sidelap fasteners. The design options are based on the number of sidelap fasteners per span (3 to 8) based on maximum load requirement thresholds (42 psf to 116 psf or 2011 N/m^2 to 5554 N/m^2). Diaphragm attachments were designed for concurrent uplift and diaphragm shear. Expert judgement determined typical design will meet MWFRS diaphragm shear of 600 pounds per linear foot (plf) or 813 N-m, which remains constant across all designs considered for diaphragm connectors.

The roof joists and wide flange beams and girders construction must meet calculated Zone 1' Net Uplift (assuming 5 psf (239 N/m^2) deadload) load thresholds factored using the ASD combination $0.6D + 0.6W$, where D is the deadload and W is the wind load, or in this case the wine or tornado load, as appropriate. The assumed minimum construction is a 25 ft x 25 ft (7.6 m x 7.6 m) framing bay with joists spaced at 6 ft 6 in (2 m) on-center (OC). Wide flange girders span 25 ft (7.6 m) between columns perpendicular to the joists. The wide flange girders' bottom flange is assumed to be unbraced for lateral torsional buckling under net uplift loading. The joist construction options were developed by a joist manufacturer engineer with minimal changes to the design. The construction options for the wide flange beams were developed by Huckabee and cover a range of beams as shown in Table 5. The combined construction design options cover uplift values for up to 33 psf (1580 N/m^2).

The foundation anchorage construction requirements (concrete, rebar, and steel) developed by Huckabee are based on the fraction increase in the calculated MWFRS Roof Field load. Increases in the maximum load values are limited to between 30 % and 75 %. Any increase of less than 30 % or greater than 75 % is assumed to be 30 % or 75 %, respectively. Additional anchorage includes additional concrete, rebar, and/or steel to meet the higher loads. This will be discussed further in Section 6.1.2.

The wall framing selection is based on calculated Zone 4 C&C Pressure load thresholds. Per Huckabee's assessment, a maximum load value less than 31.8 psf (1523 N/m^2) can be met using typical 18 gauge (ga) metal stud construction while any value between 31.8 psf (1523 N/m^2) and 39.8 psf (1906 N/m^2) is met by switching to 16 ga metal studs. The flange width on the stud was assumed to be 1-5/8 in (4.1 cm). The loads are not expected to be greater than 39.8 psf (1906 N/m^2) for any scenario in this analysis. These values assume a typical stud span of 15 ft (4.6 m) and the wall studs are backing masonry veneer.

As discussed in Section 5.1, the roofing construction is based on minimum test pressure (ASD uplift load x 2.0 safety factor) and are categorized into minimum uplift resistance classes ranging from 60 psf (2873 N/m^2) to 120 psf (5746 N/m^2) based on testing in accordance with ANSI/FM 4474. The assumed high school roof assembly (per Section 5) is a mechanically attached single-ply membrane with mechanically attached cover board (4 ft x 8 ft (1.2 m x 2.4 m)), polyisocyanurate insulation (2 layers of loose-laid 4 ft x 8 ft (1.2 m x 2.4 m) sheets), and a steel roof deck. No change is necessary for the steel deck properties or attachment. The only change in construction is the number of fasteners required for the membrane installation to meet the minimum uplift load. The required number of fasteners vary based on loads for each roof zone.

Table 9. Load Values for Construction Assembly Design Options

Building Assembly, Material and Load Categories		**Construction Description**	**Max Load Value (psf)**
Roof	Diaphragm Zone 2 Uplift EWA 10 ft^2	Convent, 5/8 in PW, 36/4, #12 TEK, 3	42
		Convent, 5/8 in PW, 36/4, #12 TEK, 4	72
		Convent, 5/8 in PW, 36/4, #12 TEK, 5	91.5
		Convent, 5/8 in PW, 36/4, #12 TEK, 6	103.5
		Convent, 5/8 in PW, 36/4, #12 TEK, 7	111
		Convent, 5/8 in PW, 36/4, #12 TEK, 8	116
	Joist & Wide Flange Zone 1' Net Uplift (5 psf deadload)	Joist \$1.20/ft^2, W16x26, 1.04 psf	12
		Joist \$1.22/ft^2, W14x30, 1.2 psf	14
		Joist \$1.24/ft^2, W14x30, 1.2 psf	21
		Joist \$1.25/ft^2, W14x34, 1.36 psf	25
		Joist \$1.25/ft^2, W14x38, 1.52 psf	31
		Joist \$1.25/ft^2, W16x40, 1.6 psf	33
Foundations	Anchorage MWFRS Roof Field	Minimum Fractional Increase	0.300
		Maximum Fractional Increase	0.750
Exterior Walls	Framing Zone 4 C&C Pressure	6 in wall cold-formed metal studs, 18 ga	31.8
		6 in wall cold-formed metal studs, 16 ga	39.8
Roofing	Roof Membrane Fasteners Min. Uplift Resistance Class	9.5 ft oc, with fasteners 12 in oc	60
		9.5 ft oc, with fasteners 12 in oc	75
		7.5 ft oc, with fasteners 12 in oc	90
		9.58 ft oc, with fasteners 6 in oc	105
		9.38 ft oc, with fasteners 6 in oc	120
Unit Conversions: 5/8 in = 1.6 cm; 1 m = 3.28084 ft; 1 m^2 = 10.7639 ft^2; \$1.00/ft^2 = \$10.7639/m^2; 1 psf = 47.88 N/m^2			

6.1.2. Converting Load Requirements to Cost Estimates

Initial cost data was developed by Huckabee for an elementary school and high school in the DFW area in 2019. The assumed budget for construction in DFW was $20 million for the elementary school and \$200 million for the high school. The cost estimates per unit of roof or wall area are completed for each of the construction options defined in Section 6.1.1 and provided in Table 10.

The diaphragm costs are estimated for a 200 ft x 200 ft (61 m x 61 m) roof area and then converted to a cost per unit of area, which ranges from \$0.1834/ft^2 to \$0.1928/ft^2 (\$1.97/m^2 to \$2.08/m^2) of roof area based on costs from the manufacturer.

The joist and wide flange costs are estimated and combined for a cost per unit of roof area, which range from \$3.28/ft^2 to \$4.45/ft^2 (\$35.31/m^2 to \$47.90/m^2). The joist cost data was provided by the joist manufacturer's engineer based on cost data in 2019. For wide flange beams and girders, Huckabee estimated the costs based on a quantity of steel at \$4000/ton unit price (2019). The combined costs are converted to a cost per unit of area. The fraction of the costs associated with the joists range from 29.1 % to 36.6 % with the share decreasing as the maximum load value increases. Therefore, the wide flanges account for most of the costs with their share increasing from 63.4 % to 70.9 % as the load value increases. Joist cost data was provided to Huckabee by a joist manufacturer.

Foundation anchorage costs are also costs per unit of roof area, and are based on the fraction increase in MWFRS Roof Field loads. Based on expert judgement by Huckabee, an increase of less than 30 % is assumed to not require a change in construction and, therefore, add no additional costs. An increase of greater than 75 % is assumed to lead to the highest potential additional construction costs. The per unit cost estimate was developed by Huckabee based on the total cost of approximately \$20 000 for additional anchorage for a high school with 386 126 ft^2 (35 872 m^2) of roof area (\$0.0518/ft^2 or \$0.558/m^2). Based on their expert judgment, the cost of an increase in MWFRS Roof Field loads between 30 % and 75% is interpolated between these two cost values.

Exterior wall framing costs are estimated per unit of exterior wall area. The two cost estimates are for two gauges (18 ga and 16 ga) of 6 in wall cold-formed metal studs. The 18 ga steel studs are used until loads are greater than 31.8 psf (1523 N/m^2), at which time costs increase by \$0.44/ft^2 (\$4.74/m^2) of exterior wall area based on the quantity of steel, estimated by Huckabee at a \$4000/ton unit price (2019).

The roofing construction costs are based on the per square foot of roof area impacted. The change in construction is based on the number of fasteners required for the membrane installation. The cost of fasteners is assumed to be minimal and is excluded from the cost estimate. The labor costs are assumed to be linear based on the number of fasteners installed, ranging from \$0.48/ft^2 to \$0.97/ft^2 (\$5.17/m^2 to \$10.44/m^2) for DFW assuming "open shop" labor type in RSMeans Commercial New Construction Assembly database (Year 2019 Q1) [25]. The uplift resistance class requirements are calculated for each roof zone with varying uplift load by roof zone and, therefore, could have different roofing installation cost impacts for each zone.

Table 10. Cost Per Unit (ft^2) by Maximum Load Value for Schools in DFW, TX

Building Assembly, Material and Load Categories		Max Load Value (psf)	Cost Unit (ft^2)	DFW ($\$/ft^2$)
Roof	Diaphragm Zone 2 Uplift EWA 10 ft^2	42	Roof Area	$0.1834
		72	Roof Area	$0.1852
		91.5	Roof Area	$0.1871
		103.5	Roof Area	$0.1890
		111	Roof Area	$0.1909
		116	Roof Area	$0.1928
	Joist & Wide Flange Zone 1' Net Uplift (5 psf deadload)	12	Roof Area	$3.28
		14	Roof Area	$3.62
		21	Roof Area	$3.642
		25	Roof Area	$3.97
		31	Roof Area	$4.29
		33	Roof Area	$4.45
Foundations	Anchorage MWFRS Roof Field	0.300	Roof Area	$ -
		0.750	Roof Area	$0.0518
Exterior Walls	Framing Zone 4 C&C Pressure	31.8	Ext Wall Area	$3.47
		39.8	Ext Wall Area	$3.83
Roofing	Roof Membrane Fasteners Min. Uplift Resistance	60	Roof Area Impacted	$0.48
		75	Roof Area Impacted	$0.48
		90	Roof Area Impacted	$0.61
		105	Roof Area Impacted	$0.95
		120	Roof Area Impacted	$0.97
Unit Conversions: 1 psf = 47.88 N/m^2; 1 m^2 = 10.7639 ft^2; $\$1.00/ft^2 = \$10.7639/m^2$				

6.1.3. City Cost Indexing

The cost data in Section 6.1.2 was developed for the DFW area. Two approaches could be used to replicate the cost estimates in other locations: (1) replicate the "bottom-up" cost estimate approach used for DFW or (2) use city cost indexes to account for relative differences in costs by building element. Option 1 may be more accurate but is labor-intensive and requires access to cost data and expertise in cost estimating in each location. Option 2 may be less accurate but can be completed quickly with no additional expertise. Based on limited funding, time, and the resulting magnitude of the incremental cost impacts, Option 2 was determined to be the most appropriate for this study. The only exception is roofing, which uses Option 1 based on expert guidance from TLSmith Consulting. If deemed beneficial, future analysis could adopt Option 1 for a more rigorous, detailed analysis.

The DFW cost data is adjusted using RSMeans City Cost Indexes to control for cost variation across locations [26]. Indexes for Quarter 1 (Q1) of 2019 were selected to match the cost data provided by Huckabee as well as exclude any pandemic-related effects. Each building construction element is mapped to the appropriate Level 2 building element using the standards classification standard UNIFORMAT II [27], and then matched to that Level 2 group element cost index as shown in **Table 11**. The total project budget is mapped to the weighted average cost index for each location.

Table 11. City Cost Indexes (RSMeans 2019 Q1)

UNIFORMAT	Diaphragm	Joists	Wide Flange	Wall Frame	Foundation Anchorage	Weighted Average
Level 2	Superstructure			Exterior Closure	Substructure	Baseline Building Cost
Level 3	Roof			Exterior Walls	Foundations	
DFW	79.3	79.3	79.3	83.9	82.2	88.0
Charlotte	85.1	85.1	85.1	75.4	86.1	90.4
Kansas City	105.3	105.3	105.3	97.7	98.2	101
Chicago	125.7	125.7	125.7	130.4	136.4	123.5
Mobile	98.3	98.3	98.3	77.8	80.8	87.4
Memphis	90.1	90.1	90.1	80.2	85.9	88.2
Washington	100.6	100.6	100.6	97.2	95.7	98.0
Minneapolis	109.3	109.3	109.3	114.8	109.5	109.4
Denver	95.7	95.7	95.7	86.8	93.8	93.2

The city cost indexes are normalized to the DFW City Cost Index and then the cost data are adjusted using that normalized city cost index adjustment factor, creating the data in **Table 12**. The only building element not implementing the city cost index adjustment approach is roofing because it was not included in Huckabee's initial analysis, and instead uses city-specific labor cost data for installing single-ply ethylene propylene diene terpolymer (EPDM) membrane from the RSMeans 2019 Q1 assembly database as is used for DFW. These per unit costs are used for completing the cost estimates for each location.

Table 12. Cost Per Unit ($/ft^2) by Load Requirement and Location

Area Unit	Load Unit	Value	DFW	Charlotte	Kansas City	Chicago	Mobile	Memphis	Washing.	Minn.	Denver
Roof Area	Zone 2 Uplift EWA 10 ft^2	42	$0.18	$0.16	$0.19	$0.23	$0.18	$0.17	$0.18	$0.20	$0.18
		72	$0.19	$0.16	$0.20	$0.23	$0.18	$0.17	$0.19	$0.20	$0.18
		91.5	$0.19	$0.16	$0.20	$0.24	$0.18	$0.17	$0.19	$0.20	$0.18
		103.5	$0.19	$0.16	$0.20	$0.24	$0.19	$0.17	$0.19	$0.21	$0.18
		111	$0.19	$0.16	$0.20	$0.24	$0.19	$0.17	$0.19	$0.21	$0.18
		116	$0.19	$0.16	$0.20	$0.24	$0.19	$0.17	$0.19	$0.21	$0.18
	Zone 1' Net Uplift	12	$3.28	$2.79	$3.45	$4.12	$3.22	$2.96	$3.30	$3.59	$3.14
		14	$3.62	$3.08	$3.81	$4.55	$3.56	$3.26	$3.64	$3.96	$3.46
		21	$3.64	$3.10	$3.84	$4.58	$3.58	$3.28	$3.66	$3.98	$3.49
		25	$3.97	$3.38	$4.18	$4.99	$3.90	$3.58	$3.99	$4.34	$3.80
		31	$4.29	$3.65	$4.52	$5.39	$4.22	$3.87	$4.32	$4.69	$4.11
		33	$4.45	$3.79	$4.69	$5.59	$4.37	$4.01	$4.48	$4.86	$4.26
	MWFRS Roof Field	0.3	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
		0.75	$0.05	$0.05	$0.05	$0.07	$0.04	$0.04	$0.05	$0.06	$0.05
Ext Wall Area	Zone 4 C&C Pressure	31.8	$3.47	$2.62	$3.39	$4.53	$2.70	$2.78	$3.37	$3.98	$3.01
		39.8	$3.83	$2.89	$3.74	$4.99	$2.98	$3.07	$3.72	$4.40	$3.32
Roof Area Impacted	Min. Uplift Class	60	$0.48	$0.47	$0.72	$1.02	$0.48	$0.50	$0.61	$0.81	$0.52
		75	$0.48	$0.47	$0.72	$1.02	$0.48	$0.50	$0.61	$0.81	$0.52
		90	$0.61	$0.60	$0.91	$1.29	$0.61	$0.63	$0.77	$1.03	$0.66
		105	$0.95	$0.93	$1.43	$2.02	$0.95	$0.99	$1.21	$1.61	$1.03
		120	$0.97	$0.95	$1.46	$2.07	$0.97	$1.01	$1.24	$1.64	$1.05
Unit Conversion: 1 m^2 = 10.7639 ft^2; $1.00/ft^2 = $10.7639/m^2											

6.1.4. Calculating Construction Cost Impacts

The cost data is used to estimate the costs of meeting the maximum wind pressure loads for each building element based on the current requirements for Exposure B, Exposure C, and tornado loads. The cost estimates for both the Exposure B and Exposure C designs are compared to the cost estimates for the tornado loads. There are three potential outcomes for each building element where $C_{c,e}$ is the cost of meeting the code (*c*) for a given exposure (*e*) and C_T is the cost of meeting the tornado loads:

(1) Design option to meet tornado loads costs less than the design option to meet current code requirements ($C_T < C_{c,e}$)
(2) Design option to meet tornado loads is the same as the design option to meet current code requirements ($C_T = C_{c,e}$)
(3) Design option to meet tornado loads costs more than the design option to meet current code requirements ($C_T > C_{c,e}$)

For outcome (1) and (2), the cost impact is assumed to be zero because the building element must be constructed to meet the current code requirements. For outcome (3), the cost impact is simply the difference between the costs of the two building element design options $\left(C_T - C_{c,e}\right)$. Alternatively, the cost impact for a building element can be expressed as $max\left\{0\,, \left(C_T - C_{c,e}\right)\right\}$.

The cost impacts of each building element are aggregated to estimate the total cost impact from the code change for a given building type-location-exposure.

Alternatively, the aggregated cost impact for all building elements can be expressed as the following where i is the building element: $\sum_{i=1}^{5} max\left\{0, \left(C_{T,i} - C_{c,e,i}\right)\right\}$.

6.2. Cost Impact Results

There are three general outcomes from estimating the impact of ASCE 7-22 tornado loads on the building construction costs. First, the tornado speed for a given location is below 60 mph (26.8 m/s) and does not need to be considered for any building design. Second, the construction design requirements based on the tornado loads do not control because the already required wind loads are greater. Third, the construction design requirements based on the tornado loads control for at least one construction element for at least one exposure type. In the first two cases, there is no impact on the construction and, therefore, no impact on construction costs. In the third case, the construction costs must be calculated to determine if there is and the magnitude of cost impacts.

6.2.1. Elementary School Example

For elementary schools, only three locations realize an impact on construction costs from meeting the tornado load requirements. In fact, four locations can be excluded from the cost analysis: Mobile, Washington, D.C., and Denver because the tornado wind speed is less than 60 mph (26.8 m/s) and Charlotte because the tornado loads do not control over wind load requirements. DFW, Kansas City, Chicago, Minneapolis, and Memphis have tornado loads control for at least one construction element for at least one exposure type. For Chicago and Minneapolis, the foundation anchorage tornado load controls for an elementary school with Exposure B. However, the increase in the load is less than 30 %, which is estimated to not have a cost impact. Therefore, cost analysis is only necessary for DFW, Kansas City, and Memphis. Results for which are provided in Table 13, both in total costs and fraction of the project construction budget.

For DFW, the tornado load controls for the foundation anchorage and roof joists and wide flange beams and girders for both Exposure B and Exposure C as well as wall framing for Exposure B. However, these only impact the design for the foundation anchorage and joist and wide flange for Exposure B, leading to an increase in construction costs of $27 933 or 0.16 % of the project budget.

For Kansas City, the tornado loads control for foundation anchorage and roof joists and wide flange beams and girders for both Exposure B and Exposure C and wall framing for Exposure B. However, these only impact the design for the foundation anchorage and roof joists and wide flange beams and girders for Exposure B and Exposure C, leading to an increase in construction costs of $28 354 (0.16 %) for Exposure B and $1658 (0.01 %) for Exposure C.

For Memphis, the tornado loads control for foundation anchorage and roof joist and wide flange beams and girders for both Exposure B and Exposure C and wall framing for Exposure B. However, construction for wall framing for Exposure B is not impacted. The impact on the design for the foundation anchorage and roof joists and wide flange beams and girders leading to an increase in construction costs of $29 498 (0.15 %) for Exposure B and $2135 (0.01 %) for Exposure C.

Table 13. Estimated Cost Impacts from Tornado Loads – Elementary School

Building Element	**DFW**		**Kansas City**		**Memphis**	
	B	**C**	**B**	**C**	**B**	**C**
Roofing Fasteners	$0	$0	$0	$0	$0	$0
Diaphragm	$0	$0	$0	$0	$0	$0
Joists & Wide Flange	$24 240	$0	$25 370	$1542	$25 964	$1578
Wall Frame	$0	$0	$0	$0	$0	$0
Found. Anchor.	$3693	$0	$2984	$116	$3534	$557
Total	**$27 933**	**$0**	**$28 354**	**$1658**	**$29 498**	**$2135**
Budget ($million)	$20.00	$20.00	$19.86	$19.86	$22.27	$22.27
Percent of Budget	**0.14 %**	**0.00 %**	**0.14 %**	**0.01 %**	**0.13 %**	**0.01 %**
Note: No cost impact from tornado loads for all other locations and exposures.						

6.2.2. High School Example

The design wind pressures are the same for high schools as those for elementary schools because both were assumed to be two-story buildings. The design tornado pressure is greater for the high school since it has a much larger building footprint than the elementary school and hence a larger design tornado speed. Therefore, the cost impact is expected to be greater for the same three locations and exposures as elementary schools, as well as potentially lead to cost increases in other locations not impacted for elementary schools.

For high schools, three locations can be excluded from the cost analysis: Mobile, Washington, D.C., and Denver because the tornado wind speed is less than 60 mph (26.8 m/s). The six other locations have tornado loads control for at least one construction element for at least one exposure type. Three locations realize an increase in costs for both Exposure B and Exposure C: DFW, Kansas City, and Memphis. Three locations realize an increase in costs for Exposure B only: Charlotte, Chicago, and Minneapolis. Results are provided in Table 14, both in total costs and fraction of the project construction budget.

For Charlotte, the foundation anchorage, roof joists and wide flange beams and girders, and roof fastener tornado load controls for a high school with Exposure B. However, these only impact the design for the foundation anchorage, leading to an increase in construction costs of $2391 or 0.001 % of the project budget.

For Chicago, the tornado load controls for the foundation anchorage for both Exposure B and Exposure C as well as roof joists and wide flange beams and girders, wall framing, and roof fasteners for Exposure B. However, these only impact the design for the foundation anchorage and roof joists and wide flange beams and girders for Exposure B, leading to an increase in construction costs of $185 857 or 0.08 % of the project budget.

For Minneapolis, the tornado load controls for the foundation anchorage for both Exposure B and Exposure C as well as roof joists and wide flange beams and girders, and wall framing for Exposure B. However, these only impact the design for the foundation anchorage for Exposure B, leading to an increase in construction costs of $12 675 or 0.006 % of the project budget.

For DFW, the tornado loads control for foundation anchorage, roof joists and wide flange beams and girders, and wall framing for both Exposure B and Exposure C and diaphragm and roof fasteners for Exposure B. However, these only impact the design for the foundation anchorage, roof joists and wide flange beams and girders for both Exposure B and Exposure C and wall framing and roof fasteners (Zone 3) for Exposure B, leading to an increase in construction costs of $250 077 (0.14 %) for Exposure B and $24 069 (0.01 %) for Exposure C.

For Kansas City, the tornado loads control for foundation anchorage, roof joists and wide flange beams and girders, and wall framing for both Exposure B and Exposure C and diaphragm for Exposure B. However, these only impact the design for the foundation anchorage and roof joists and wide flange beams and girders for both Exposure B and Exposure C and wall framing and roof fasteners (Zone 2 and Zone 3) for Exposure B, leading to an increase in construction costs of $223 582 (0.13 %) for Exposure B and $22 088 (0.01 %) for Exposure C.

For Memphis, tornado loads control for foundation anchorage, roof joists and wide flange beams and girders, and wall framing for both Exposure B and Exposure C and diaphragm for Exposure B. However, these only impact the design for the foundation anchorage and roof joists and wide flange beams and girders for both Exposure B and Exposure C and wall framing and roof fasteners (Zone 2 and Zone 3) for Exposure B, leading to an increase in construction costs of $247 236 (0.13 %) for Exposure B and $27 686 (0.01 %) for Exposure C.

Table 14. Estimated Cost Impacts from Tornado Loads – High School

Cost Item	**Charl.**	**Chicago**	**Minn.**	**DFW**		**Kansas City**		**Memphis**	
	B	**B**	**B**	**B**	**C**	**B**	**C**	**B**	**C**
Roof Fasteners	$0	$0	$0	$300	$0	$11 943	$0	$8294	$0
Diaph.	$0	$0	$0	$0	$0	$0	$0	$0	$0
Joists & WF	$0	$165 023	$0	$139 778	$8495	$137 401	$8350	$140 616	$8546
Wall Frame	$0	$0	$0	$90 000	$0	$70 020	$0	$87 480	$0
Found. Anchor.	$2391	$20 835	$12 675	$20 000	$15 574	$16 160	$13 738	$19 140	$19 140
Total	**$2391**	**$185 857**	**$12 675**	**$250 077**	**$24 069**	**$235 525**	**$22 088**	**$255 530**	**$27 686**
Budget ($million)	$200.45	$280.68	$248.64	$200.00	$200.00	$198.64	$198.64	$222.73	$222.73
Pct of Budget	**0.001 %**	**0.07 %**	**0.005 %**	**0.13 %**	**0.01 %**	**0.12 %**	**0.01 %**	**0.11 %**	**0.01 %**
Note: Exposures not displayed had zero cost impacts from tornado loads									

6.2.3. Results Summary

In summary, the new tornado load requirements in ASCE 7-22 have minimal initial construction cost impacts for schools regardless of location or wind exposure for the two example facilities considered in this study. For most of the U.S. the cost impact on similarly sized schools is zero because the tornado loads often do not control, and when tornado loads do control the building element designs are typically not impacted. Even in the most extreme scenarios for the two case studies where tornado loads control for multiple building elements, the cost impact is less than $30 000 for elementary schools and $256 000 for high schools, accounting for project budget increases of 0.14 % or less under all building type-location-exposure combinations. Of the nine cities considered in this study, three realize cost increases for at least one exposure category for the elementary school and six for high school. Additionally, of all the building type – location – exposure combinations, only six (three for each building type) realize cost impacts greater than 0.07 % of the project budget.

The cost study did not include the fire station or hospital examples. Risk Category IV facilities similar in size and shape would have greater relative increases in tornado loads compared to wind loads, which could lead to construction cost increases. Additionally, Risk Category IV facilities are required to have impact-resistant glazing or impact protective systems, which may also add to construction costs. The magnitude of these potential additional cost increases relative to the total construction budget is unclear. For example, the construction cost per unit of floor area for a hospital is greater than most other types of buildings, which may lead to similar or smaller percentage increases than for those estimated in the school case studies.

7. Summary

This study analyzes the potential economic impacts from implementation of the new tornado load requirements in the ASCE 7-22 Standard: Minimum Design Loads and Associated Criteria for Buildings and Other Structures, by incorporation into the IBC (Proposal S63-22 in Ref. [3]) and/or direct adoption by Federal, state, and local governments. The Standard requires that Risk Category III and IV buildings and other structures located in the tornado-prone region (approximately equal to the area of the conterminous U.S. east of the Continental Divide) be designed to resist tornado loads in addition to wind loads from other types of storms. Risk Category III includes buildings that represent a substantial hazard to human life in the event of failure (e.g., theaters and other assembly occupancies, schools, nursing homes), while Risk Category IV is for essential facilities (e.g., hospitals, fire and police stations, emergency operations centers).

The approach in this study is based on four key steps to estimate the economic impact of the code change proposal. The first step identifies the potential numbers of buildings that may be impacted. This step limits the need to consider tornado loads for locations not in the tornado-prone region or Risk Category I and II building types. The second step compares tornado loads with existing wind load requirements to understand when and where tornado loads will control design. This step further narrows the potential impact because in many cases that existing wind load requirements are greater than those of the tornado loads. The third step determines what building elements will require changes in construction design when tornado loads control. Consideration of construction design includes five building elements (roof systems, roof diaphragm, roof joists and wide flange beams and girders, exterior wall framing, and foundation anchorages). This step accounts for the fact that current construction design practices can often handle much higher loads than the existing wind load requirements. Therefore, even if tornado loads control, the construction design may not need to change. The fourth step estimates the cost of these changes in construction design. This step calculates the estimated increase in construction costs resulting from any change in construction design to meet tornado loads relative to current ASCE 7-22 load requirements, both in total dollars and percent of total project construction budget.

Case studies are used to estimate the relative magnitude of the potential cost impacts of five building elements (roof systems, roof diaphragm, roof joists and wide flange beams and girders, exterior wall framing, and foundation anchorages) for two building types (elementary school and high school) for wind Exposure Categories B and C baseline building designs across nine locations to provide a range of potential load requirements and resulting cost implications.

7.1. Potential Impacts of Adopting ASCE 7-22

Section 2 shows the adoption of the new tornado load requirements in the ASCE 7-22 standard will impact a small fraction of new buildings in the United States. The only buildings that are eligible to be impacted are new buildings that meet the following requirements:

(1) located within the tornado-prone region
(2) classified as Risk Category III or IV buildings
(3) located within an area where tornado speeds meet or exceed 60 mph (26.8 m/s)

(4) located within an area where the tornado speeds are greater than a specified fraction of the basic (non-tornado) design wind speeds.

Requirements 3 and 4 represent approximate lower bounds on where tornado loads can begin to start controlling over wind loads for any element of a specific building or other structure.

When excluding residential occupancies with less than 50 units, the building stock occupancy types for Risk Category III and IV buildings in the tornado-prone region represents 15.0 % of the entire U.S. building stock and 18.3 % of the building stock in the tornado-prone region. These results are effectively upper bound estimates as tornado loads will not control over wind loads for all Risk Category III and IV buildings in the tornado-prone region. Whether tornado loads control any aspect of the building design over wind loads depends on many different climatological and building characteristics. Geospatial analyses are used identify the impacts of several of these variables. In general, the tornado design requirements will have the most impact in the central and southeast United States.

Section 3 through Section 5 explain how the tornado loads are calculated, which tornado loads to consider, when tornado loads control, and whether the tornado load impacts the construction design. Section 3 shows that the likelihood of tornado load controlling varies by building risk category, effective plan area, and exposure category. Additionally, the tornado load has the greatest probability of controlling in the central and southeast U.S. (excluding the hurricane-prone southern coastline). Section 4 provides additional detail on the factors that influence the likelihood of the tornado load controlling design, including relative hazard levels, tornado speed, basic wind speed, effective plan area, and wind exposure category as well as building characteristics (building plan shape, roof geometry, roof height, and enclosure classification). A range of impacts and trends are demonstrated through comparisons of wind and tornado loads on several building types using three approaches with different combinations of spatial and analytical detail. Section 5 provides a detailed assessment of the impact of ASCE 7-22 tornado load requirements on roof systems, providing an example of the analysis necessary to determine whether the tornado loads result in changes in construction design.

Section 6 completes a construction cost analysis of adopting ASCE 7-22 tornado load requirements, including an explanation of the methodology, construction design options for five building elements considered (roof systems, roof diaphragm, roof joists and wide flange beams and girders, exterior wall framing, and foundation anchorages), cost data collection and development for these construction design options across locations, and cost comparison approach. This study updates and expands on previous analysis completed by Huckabee, Inc. for two building types (elementary school and high school) and two wind exposures (B and C) for the DFW area and replicates the process for eight other locations to provide examples of cost impacts under different tornado load profiles. For each building type and location, the following process is implemented:

1) Calculate the design wind pressures for Exposure B, Exposure C, and design tornado pressure as defined by ASCE 7-22
2) Estimate the construction costs of each building element for each of the three cases in step 1
3) Calculate the difference in costs for each building element
4) Sum costs for all building elements for which costs increase to meet the tornado loads

The design wind and tornado pressures are calculated as described in Section 4. Whether design tornado pressure loads control over wind pressure loads varies by building type, location, and exposure category. Below are the four design loads used for selection and cost estimation of the building element constructions and the range of design tornado loads as a percentage of wind load:

- MWFRS Roof Field: -79 % to +144 %
- Zone 2 Roof Uplift C&C pressure, EWA 10 ft^2 (0.93 m^2): -89 % to +30 %
- Zone 1' Roof Net Uplift[11]: -92 % to +137 %
- Zone 4 C&C Pressure, EWA 75 ft^2 (6.97 m^2): -87 % to +52 %

Clearly, design tornado loads will not control in some cases while in other cases there are large load increases. In general, the tornado loads have a greater percentage increase relative to the existing load requirements for the high school, buildings with Exposure B, and locations in the central and southern United States.

The results of the school case studies suggest that tornado loads will not control for many locations and building types. Construction designs for both the elementary school and high school with either Exposure B and C located in Mobile, Washington D.C., and Denver remained unchanged. Additionally, the elementary school in Charlotte is unchanged with either Exposure B or C and the high school in Charlotte is unchanged with Exposure C. For those scenarios in which the tornado load does control, the construction design is often not influenced. For the elementary school, the construction design for Chicago and Minneapolis with either Exposure B or C and DFW with Exposure C are unchanged. For high school, the construction for Chicago, Minneapolis, and Charlotte with Exposure C are unchanged.

Even for the scenarios in which designing to meet the tornado load does control design, the incremental construction cost increase is minimal. For the elementary school, only three locations realize higher costs – Kansas City and Memphis with either Exposure B or C and DFW with Exposure B, ranging from approximately $28 000 to $29 500 (0.13 % to 0.14 % of project budget) with Exposure B and $2135 (0.01 % of project budget) or less with Exposure C. For the high school, more cities realize higher costs for at least one exposure category because the high school has a larger building footprint. However, the cost impact relative to the project budget remains minimal. Charlotte, Chicago, and Minneapolis realize cost impacts with Exposure B while DFW, Kansas City, and Memphis realize cost impacts with either Exposure B or C. The cost impacts with Exposure C range from approximately $22 000 to $27 686 (0.01% of project budget) while the cost impacts with Exposure B range from $2391 to $255 530 (0.001 % to 0.13 % of project budget) or less with Exposure C.

The results of the case studies show that tornado loads can vary significantly, from less than wind loads to more than double the wind loads. Tornado loads will not control for many locations and building types, particularly those on the periphery of the tornado-prone region. For scenarios in which the tornado loads do control, the construction design is often not influenced. Of the nine cities considered in this study, three realize cost increases for at least one exposure category for the elementary school and six for high school. Of all the building

[11] Zone 1' Roof Net Uplift is a function of Roof Uplift C&C pressure, EWA 200 ft^2 (18.58 m^2) = 0.6* Uplift - 3

type – location – exposure combinations (36), only six (three for each building type) realize cost impacts greater than 0.07 % of the project budget.

7.2. Limitations

Determining how the tornado load provisions of ASCE 7-22 will impact construction costs across the entire U.S. is complicated because of the variability in building types, typical construction practices, and tornado and non-tornado related wind loads. Additionally, a lack of resources (data and labor) limited the scope of this study. Below is a non-exhaustive list of limitations identified for this study.

There is a lack of data necessary to quantify the share of new construction that may be impacted by the code change proposal with great precision. First, the data available for this study is the existing building stock data from HAZUS. Therefore, this study assumes that the existing building stock is representative of new construction. Second, the HAZUS data building type categories are not as precise as necessary to perfectly match language in ASCE 7-22 defining Risk Category III and IV buildings. For example, buildings labeled as "medical office and entertainment" in HAZUS are categorized as Risk Category III and IV although though many of these buildings may not meet the definitions of Risk Category III or IV (e.g., small dental office in a strip mall or a residence by be included in the HAZUS database as medical office). Therefore, this study overestimated (setting an upper bound on) the fraction of the building stock potentially impacted by the code change proposal.

There are several limitations on the cost analysis that should be highlighted. This study completes cost analysis for only two case studies (elementary school and high school). Huckabee specializes in school construction and could provide detailed cost data for the DFW area. Therefore, the focus of the cost analysis is on schools and leverages city cost indexes to adjust the estimated costs provided by Huckabee to apply to other cities. A more rigorous analysis using detailed cost data for each location, other building types, and different construction practices (e.g., typical school size and geometry) would provide more robust results that could provide a more holistic economic analysis of the total impacts across the U.S. of adopting the code change proposal. However, given limited resources and time, such an analysis was not feasible for this study.

Additionally, this cost study considered primary structural steel, foundation concrete and reinforcing, exterior wall stud costs, and roof deck and roofing assemblies. It does not include other building element costs that may be impacted by the proposal, including but not limited to rooftop equipment (including anchorages), or miscellaneous steel.

Glazing varies significantly across buildings, even within the same building type. However, to get a general magnitude estimate, Huckabee obtained information from a window manufacturer to ballpark the worst-case additional glazing cost for a high school. The cost of glass is not expected to increase while the aluminum mullion costs would rise slightly. Assuming a base case of 32.1 psf (1537 N/m^2) Exposure C pressure, the incremental cost increases would not exceed 0.36/ft^2 or \$10 852 due to more significant framing to meet the higher pressure (35.2 psf or 1685 N/m^2) for Memphis. Kansas City and DFW would realize even lower cost increases of \$8402 and \$2800, respectively. With general magnitudes of \$10 000 or less for a typical high school in DFW with a footprint of roughly 380 000 ft^2

(35 303 m^2), these additional costs would have negligible impacts on the construction costs of schools.

Another limitation of this study is that it excludes any economic benefits and avoided costs from adoption of ASCE 7-22. Avoided costs include the estimated repair costs and lost service time for the building from a potential future tornado strike. Projected benefits include improved life safety, resulting in avoided fatalities and injuries from potential future tornado strikes. Other benefits and avoided costs include those related to the additional building protection from potential non-tornadic windstorms.

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Appendix: Wind-borne Debris Impact on Roof Systems

Neither the IBC nor ASCE 7-22 have wind-borne debris (WBD) requirements for roof systems in either the hurricane Wind-borne Debris Region or tornado-prone region. However, WBD can penetrate most roof coverings (including all the coverings included in this study). To avoid water leaking into a building after the roof is penetrated by WBD, a secondary membrane is needed.

For example, the hospital with the concrete deck has a modified bitumen membrane over the deck. The purpose of this membrane is to protect the insulation from moisture migrating from the concrete. However, it also functions as a secondary membrane if the primary membrane is punctured by WBD. Secondary membranes are particularly important for buildings such as hospitals that need to remain functional after a storm, because without a secondary membrane, water leakage from a punctured roof membrane can preclude building occupancy.

A secondary membrane can be incorporated into a roof system that is over a steel deck. For example, a modified bitumen membrane could be applied to a cover board that is mechanically attached to the deck. The remainder of the roof system could then be adhered to the secondary membrane. WBD roof system design guidance is provided for hurricanes and tornadoes in Ref. [28, 29].