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Making Buildings Part of the Climate Solution by Enforcing Aggressive Commercial Building Codes

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ABSTRACT

This paper examines the impact of an aggressive commercial building codes policy in the United States. The policy would require both new construction and existing buildings that undergo major modifications to comply with higher building shell efficiency and more stringent equipment standards similar to the latest versions of the ASHRAE 90.1 Standard. Using the Georgia Tech version of the National Energy Modeling System (GT-NEMS), we estimate that the building codes policy could reduce the energy consumption of commercial buildings by 0.94 Quads in 2035, equal to 4% of the projected energy consumption of commercial buildings in that year. In the four targeted end-uses – space heating and cooling, water heating and lighting – estimated energy consumption would be 17%, 15%, 20% and 5% less than the Reference case forecast in 2035, respectively. The reduction of electricity and natural gas prices along with the consumption decline could save commercial consumers $12.8 billion in energy bills in 2035 and a cumulative $110 billion of bill savings between 2012 and 2035. The environmental benefits of the policy could also be significant. In 2035, 47 MMT of CO_2 emissions could be avoided, generating cumulative benefits of $17 billion by 2035. The estimated benefit-cost ratio of this policy within the commercial sector is 1.4, with a resulting net benefit of $59 billion. The positive spillover effect of this policy would lead to an even higher economy-wide benefit-cost ratio.

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1. Introduction

The commercial buildings sector accounted for 18% of U.S. energy consumption in 2010, and this percentage is expected to increase to 21% by 2035 (EIA, 2011, Table 2). In order to make commercial buildings more energy efficient, President Obama announced the Better Buildings Initiative in February 2011, aiming to reduce the energy consumed in commercial buildings by 20% in 2020.[1]

Commercial building codes could improve building energy efficiency, reduce the sector's energy consumption, and save building owners and occupants' money (Granade et al., 2009). However, as of July 1, 2012, 11 U.S. states have either no commercial building code or their code precedes ASHRAE Standard 90.1-1999. The remaining 39 states and Washington, D.C., have adopted building codes that range from ASHRAE 90.1-2001 to 90.1-2010 (Figure 1). There is a need for policies that can encourage a wider adoption of building codes, more aggressive building codes nationwide, and improved compliance.

The building codes policy described in this paper aims to achieve these goals through promoting nationwide implementation of an aggressive commercial building energy codes policy that sets higher building shell efficiency requirements and more stringent energy efficiency standards for space heating and cooling technologies. To maximize code adoption and compliance, the Department of Energy (DOE) and the state energy offices would facilitate the establishment of building code compliance assistance programs at the state and local level to help developers and builders analyze and comprehend the code, train code officials and inspectors to oversee the code compliance, provide information and training opportunities to parties involved in the building industry, and engage utilities to promote the adoption and compliance of the codes. The policy would also suggest establishing a building code liability structure under which relevant parties including developers, design companies, builders, building owners, and others who apply have the responsibility to ensure their project is in compliance with the building code. Code officials and inspectors at the state and local level would be able to exercise their authority established by law to enforce the codes and hold the relevant parties accountable in case of non-compliance. In order to achieve the goal, building codes need to establish the responsibilities of key parties involved in building construction and maintenance once the code is adopted into law, and specify the liability and potential penalties for non-compliance.

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[1] DOE, Better Buildings: http://www1.eere.energy.gov/buildings/betterbuildings/

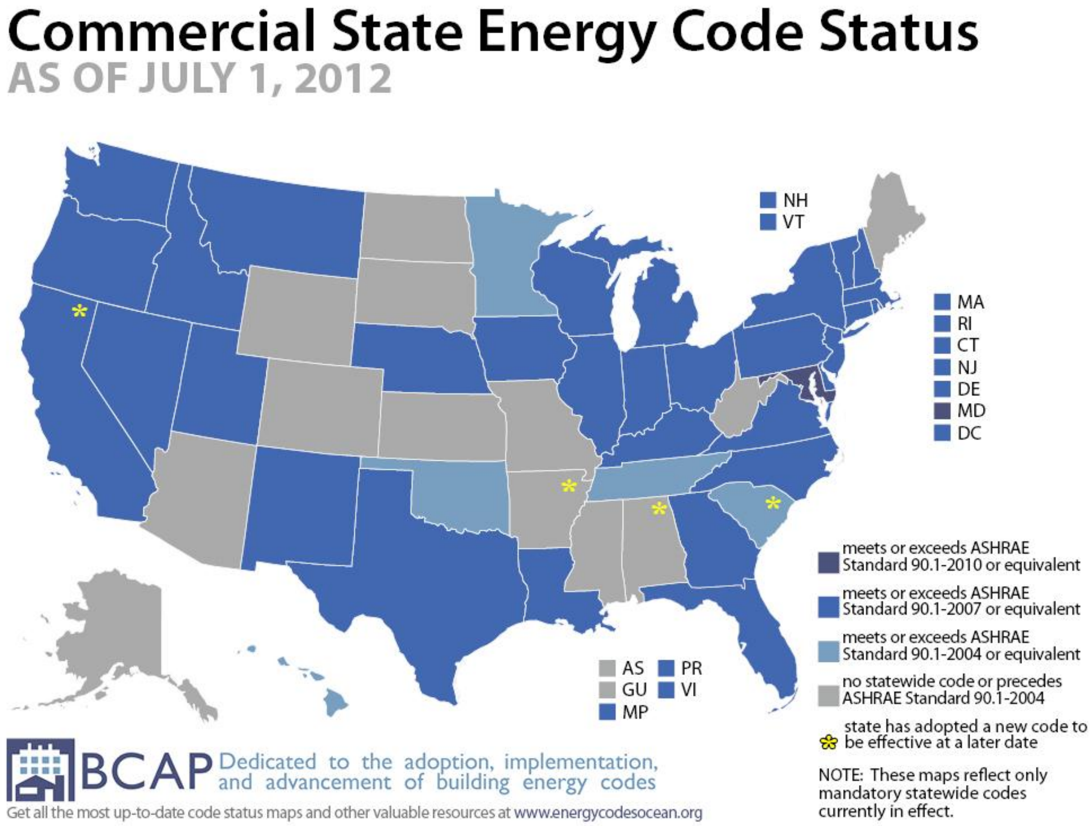

Figure 1. State-by-State Commercial Building Code Status
Source: Online Code Environment and Advocacy Network
http://bcap-ocean.org/code-status-commercial

2. Background on Commercial Building Codes

2.1 Policy Experience

Building codes in the U.S. are impacted by local, state, and federal actions.

Federal Experience
DOE has a longstanding history of modeling commercial building codes. The 1975 Energy Policy and Conservation Act (EPCA, 42 USC 6833) and the Energy Policy Act of 1992 (EPAct) established a role for DOE to conduct code determinations. For commercial buildings, when a new edition of ASHRAE Standard 90.1 is released, DOE would issue a determination based on analysis by the Building Energy Codes Program to determine whether revisions to the building codes would improve energy efficiency in buildings. If the determination finds that the newest edition of Standard 90.1 is more energy efficient than the previous one, states would be required by the Energy Policy Act to certify that their building energy codes meet the requirements of the new Standard within two years, or justify why they cannot comply.

DOE also encourages using new technologies and better building practices to improve energy efficiency. DOE's Building Energy Codes Program works with the International Code Council (ICC), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Illuminating Engineering Society of North America (IESNA), American Institute of Architects (AIA), the building industry, and state and local officials to develop and promote more stringent and easy-to-understand building energy codes and to assess potential code barriers to new energy-efficient technologies.

The Advanced Energy Design Guides for small to medium office buildings and K-12 school buildings were released by DOE in 2011 as one step forward to pursue deeper energy reductions. The Guides provide detailed directions for achieving 50% energy savings compared to buildings that meet the minimum requirements of ASHRAE Standard 90.1-2004. The latest design guides for small to medium office buildings, medium to big box retail buildings, and large hospitals were published in early 2012.[2] The modeled building codes have helped states understand the potential energy savings of the codes and have encouraged energy-efficiency improvement in the building sector (Halverson, Gowri, and Richman, 2006; Winiarski et al., 2003).

The American Recovery and Reinvestment Act (ARRA) of 2009 also encouraged the adoption of more stringent building codes. Section 410(a) 2 of ARRA requires states that want to qualify for the State Energy Program funding to adopt a commercial building energy code throughout the state that meets or exceeds ASHRAE Standard 90.1-2007. Since then, all 50 states have committed to comply with the terms of Section 410 of ARRA, meaning all U.S. states would adopt at least one of the stringent commercial building codes and would develop plans to achieve 90% compliance with the targeted codes by 2018, which is also required by the same section of ARRA (117 Congress of United States of America, 2009). The Building Energy Codes Program at DOE has been developing compliance evaluation procedures and tools to help states enforce building codes.[3]

DOE is actively involved in code compliance improvement. DOE's Technical Assistance Program (TAP) provides information on new codes, online trainings, tools to determine code compliance and other resources to states. DOE also awarded $7 million from its leftover State Energy Program funding to 24 states that engaged in various programs and projects that aim to enforce building codes.

In addition to its own initiatives, DOE also supports the building code assistance efforts led by other organizations. For instance, the Building Code Assistance Project (BCAP)[4] is a joint initiative started by the Alliance to Save Energy, the American Council for an Energy-Efficient

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[2] ASHRAE Advanced Energy Design Guides. http://www.ashrae.org/technology/page/938#planned

[3] DOE Building Energy Code Program, Compliance Evaluation http://www.energycodes.gov/compliance/evaluation

[4] Building Code Assistance Project (BCAP) http://ase.org/programs/building-codes-assistance-project

Economy and the Natural Resource Defense Council; and DOE has partnered with BCAP to promote the adoption and enforcement of building codes for nearly two decades. In order to assist the 90% code compliance pledge put forward by ARRA, BCAP launched Compliance Planning Assistance (CPA) that helps states to first understand the gap and barriers in code compliance and then develop a strategic compliance plan to improve long-term building code compliance.

State Experience

States are critical to the success of building energy codes. State programs and policies influence the effectiveness of codes and their ability to meet federal requirements not only because states have the authority to mandate the codes but also because of the policy innovations that are often observed at the state level.

Many states have taken actions to either increase the stringency of their current codes or improve compliance with the codes. As has been true in so many energy policy arena, California has been a pioneer of developing and adopting aggressive building codes. The California Building Standard Commission (CBSC) implemented their first building energy codes in 1978. Since then, CBSC keeps the requirement up-to-date through various revisions. Named California Code of Regulation, Title 24 (CCR Title 24), the California building codes are published approximately every three years with more stringent standards on building envelope (roof, windows, insulation, etc.), and equipment used in space heating and cooling, lighting and water heating, along with other requirements such as fire code and accessibility. It is estimated that Title 24 has saved Californians more than $66 billion in energy bills and averted 250 MMT of greenhouse gas emissions.[5]

California State law requires local government to enforce CCR Title 24 through a local building department and/or fire district; CCR Title 24 applies to all buildings and occupancies in the state regardless of whether local governments reference the regulation in their ordinances or not. The state CCR does not preempt stronger local action. Local government is allowed to adopt more stringent code requirements. In terms of enforcement, CCR Title 24 requires that builders provide code compliance information to enforcement agencies at city, county, and state levels that are responsible for issuing building permits and inspecting the code compliance. California State law establishes criminal and civil penalties for violating some provisions of the CCR Title 24, although the penalties tend to emphasize the fire code and accessibility requirements of the codes rather than energy performance (CBSC, 2010).

California is currently implementing the 2008 version of Title 24. In May 30, 2012, the California Energy Commission voted 4-0 to adopt the latest building code, i.e., the 2013 version, starting in January 2014. The new code is expected to save Californian homeowners and renters 25% of their energy consumption and 30% for commercial buildings.

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[5] California Energy Commission
http://www.energy.ca.gov/title24/2013standards/rulemaking/documents/2013_Building_Energy_Efficiency_Standards_infographics.pdf

Besides California, the state energy offices in many other states and utilities have worked together to implement measures to improve building code adoption and compliance. Arizona, Georgia, Illinois, New York, and Rhode Island have set up training programs to increase the capacity of building code officials and building contractors to enforce building codes. Nebraska has formed a Building Codes Advisory Council to engage stakeholders, including utilities, in the code adoption and compliance process.

Arizona, California, Iowa, Massachusetts, and Minnesota have adopted Energy Efficiency Resource Standards (EERS) and included building code compliance assistance as part of their program. Because EERS has an explicit focus on quantifiable energy savings, it encourages utilities to participate in code compliance via various energy efficiency programs, and gives utilities credits toward energy efficiency goals for savings achieved through building codes (Cooper and Wood, 2011; Elnecave, 2012; Foster et al., 2012, Wagner and Lin, 2012). Allowing utilities to claim credits from their building code assistance efforts and be financially rewarded has motivated utilities to engage in building code adoption and compliance and achieved significant energy savings (Cooper and Wood, 2011). In addition, multiple states have worked with utilities to develop “above code” programs that propose building codes that are more stringent than the current version; these “above-code” programs are coupled with utility incentive packages such as appliance rebate programs. Experiences from Massachusetts, Iowa, and Oregon show that the “above code” programs fostered by the public-private partnership have improved the outlook of future code adoption by preparing the industry for more stringent codes; they also expand the industry’s capacity in code compliance (Wagner and Lin, 2012).

Third party inspection is also considered an important approach to improving code compliance. Fairfax County, Virginia, implemented a Certified Third Party Inspections Program to its commercial building sector to improve code compliance.[6] The program offers building construction contractors the option for certain construction inspections to be performed by certified third party inspectors under the supervision of the County’s Commercial Inspections Division. Qualified third party inspectors that have no personal and financial interests in the project would conduct building code inspections with a particular focus on the non-health-and-safety component of the codes. The program lists specific inspection items that include building shell elements (covered under Building Inspections), insulation and energy conservation material (covered under Mechanical Inspections). The program became effective on March 1, 2012. It is expected to expand inspectors’ attention from a narrow focus on health and safety to a broader scope including an energy perspective.

A similar program in Washington State improved the code compliance rate from 55% to 94%.[7] Under the Special Plans Examiners and Inspectors (SPE/I) program, local jurisdictions can

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[6] Fairfax County, VA, Certified Third Party Inspections Program. http://www.fairfaxcounty.gov/dpwes/publications/thirdpartyinspections.pdf

[7] Policy and Procedures for Enhancing Code Compliance, DOE Technical Assistance Program. http://www1.eere.energy.gov/wip/solutioncenter/pdfs/Policies%20and%20Procedures%20for%20Enhancing%20Code%20Compliance.pdf

voluntarily participate in the program so that it allows qualified individuals to provide special plans review and inspection as specified in the building code. The compliance rate improved significantly in the following two principal ways that are enabled by the SPE/I program: the inspectors' competence level was increased due to the credential requirement of the program, and the market takes the SPE/I program as a signal that code compliance is being taken seriously.[8]

Workforce training is deemed to be an important means to improve the compliance of building codes. Programs are set up on multiple levels to help train building constructors and inspectors to better understand the code requirements and learn the best practices around the country. DOE's Building Energy Code University is a one-stop shop providing information about the latest trend in building codes compliance through information displays, webinars, and workshops.[9] Because building codes are adopted at the state level, particular programs are designed to tailor the training to specific regional trainees to give them on-the-ground hands-on experience about the building code they would be enforcing. For example, Southface has partnered with several southern states such as Georgia and Alabama to offer energy codes related training opportunities.[10]

International Experience

In many industrialized and developing countries, building code innovations are being developed to foster more efficient construction practices. In May 2010, the European Union (EU) adopted a Directive stipulating that by the end of 2020, all EU member states must ensure that all newly constructed buildings consume "nearly zero energy" or climate-neutral[11] (European Parliament and the Council of the European Union, 2010). Besides the EU Directive, Germany has taken additional steps to strengthen its building energy efficiency by periodically updating its building codes (energy saving ordinance – EnEv) to reflect more stringent requirements for the minimum energy performance of buildings (Schimschar, Blok, Boermans, and Hermelink, 2011).

Beginning in 1986, China began to issue national standards for energy efficiency of residential and public buildings for all major climate zones, which specifies the building design, construction, and acceptance requirements. It is worth noting that since 2007, China started to issue the Codes for Acceptance of Energy Efficiency Building Construction that mandates compliance with building energy efficiency standards as one of the requirements for occupancy of a newly constructed building. Multiple regulations have outlined the responsibilities of key stakeholders regarding building codes compliance and the potential penalties for violations. In addition to the regulatory approaches, China also promoted the use of economic incentives such as tax rate adjustment for fixed asset investment, corporate income tax, and value added tax (Bin and Lin, 2012). The latest standard for public buildings was published in 2005 and is enforced nationwide (GB 50189, 2005). According to building code compliance inspection

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[8] ACEEE Conference Presentation, 2009 http://aceee.org/files/pdf/conferences/mt/2009/B4_Price.pdf

[9] Building Energy Codes University http://aceee.org/files/pdf/conferences/mt/2011/B1%20-%20Eric%20Makela.pdf

[10] Southface Trainings http://www.southface.org/learning-center/trainings/?p=2

[11] Both energy efficiency and the use of renewable energy count towards meeting the goal.

results published by the Chinese Ministry of Housing and Urban-Rural Development (MOHURD, 2009, 2010, 2011), the compliance rate exceeded 90% in 2010. The high compliance rate is rooted in the third-party facilitated inspection system and the clearly announced code compliance responsibilities and penalties for non-compliance (Bin, 2012; Bin, Lin, Nadel, and Song, 2012), although the limited number of buildings that are subject to compliance inspection has been a source of concern.

2.2 Policy Rationale

The energy efficiency of commercial buildings has long-lasting impacts on the energy consumption of the sector because of the longevity of commercial buildings, which are usually designed and constructed to last for at least a few decades. As of 2003, 25% of the commercial floorspace was built prior to 1960 (DOE, 2009). The decision made for buildings built today will affect the energy perspective in the far future, and the energy-efficient design and construction of buildings would have much greater cumulative impact on the sector's energy consumption, CO_2 emissions, and criteria pollution than any other end-use consumption category. Besides, it is relatively easier and cheaper to address building energy efficiency at the design and construction stage comparing to ex post improvements (Li and Colombier, 2009). Therefore, it is crucial to emphasize energy efficiency during these initial stages. A building code would provide sufficient guidance on building design and construction to ensure that efficiency measures are incorporated before buildings are first occupied.

The importance of building codes extend beyond their role in new buildings. Codes also serve as a standard for existing building retrofits and a benchmark for consumers who choose between building new establishments and renovating existing buildings (Laustsen, 2008).

However, the decision making process to improve commercial building energy efficiency is complex and fragmented because it involves numerous stakeholders, such as building owners, occupants, developers, code and standards officials, equipment manufacturers, suppliers, lenders, insurers, realtors, and so forth. Each of these players has distinct interests and impacts in the design, construction and use of commercial buildings at different points, and the long-term interests of building owners and occupants are often not shared by other stakeholders (Brown et al., 2009; CCCSTI, 2009).

In the case of new construction, builders, and sometimes developers as well, emphasize the need to limit upfront construction costs and pay less attention to means to minimize the post-construction operational cost since their financial interest ends at the point when the building is sold. This is particularly the case for speculative developments and is less true for construction projects where owners are also the intended occupants. This "principal-agent problem" creates an obstacle to energy efficiency in commercial buildings and is a barrier to widely adopting and enforcing stringent building codes because a building code would increase the upfront costs for the parties who bear them while allowing the building tenants to enjoy the benefit of low energy bills. Federal policy, such as a national building code for commercial buildings that mandates buildings to be built to a certain standard could align the interests of builders and building occupants and therefore, widen the adoption of commercial building codes and improve compliance.

In states with building code mandates, code compliance is often limited. In a study that examined the compliance of selected building code measures in California, the researchers found that noncompliance rates for two lighting measures and three building shell requirements ranged from 44% to 100% (Lee and Benningfield, 2007). The enforcement of building codes appears to be difficult for many states because of the lack of consistent code enforcement and support programs (Yang, 2005; Zing Communications, 2007). In addition, code compliance is often hard to quantify due to the underdevelopment of measurement and verification (M&V) protocols and lack of professional workforce. Federal actions that can enhance code compliance through establishing a liability structure, designing M&V protocols, and developing workforce training programs would directly tackle these barriers and improve building code compliance.

2.3 Stakeholders and Constituencies

Wider adoption of commercial building codes and better compliance would involve multiple stakeholders across different sectors, and those stakeholders with diverging stances would react to the building codes policy differently. Building code officials, code development organizations, and environmental and efficiency advocacy groups are among the likely supporters of the policies. One might expect resistance from developers, builders, and contractors who might see a short-term shrinking profit due to the higher cost to implement and comply with stricter building codes. Commercial banks, other debt lenders, and other financial players would see the federal action as a double-edged sword. The perceived risks to the financial sector could be higher due to the larger size of the loan required by the developer and builders. However, greater energy efficiency usually allows building owners to charge a rent premium and the energy savings attracts more tenants leading to higher occupancy rates (Christmas, 2011; Campbell, 2011; Miller, Spivey, and Florance, 2008; Jackson, 2009; Das, Tidwell, and Ziobrowski, 2011). As a result, the borrowers' likelihood to pay back would increase under a building code scenario, thereby lowering financial risks.

2.4 Elements of the Recommended Policy Approach

Based on recommendations from participants in the "Policy Options Workshop: Accelerating Energy Efficiency in Commercial Buildings" held in Washington, D.C., on November 29, 2011, and follow-up discussions with workshop participants, the policy evaluated here is comprised of multiple elements, as described below.

Building Code Performance Analysis

DOE and its associated national laboratories have a tradition of modeling ASHRAE and ICC commercial building codes. DOE issues a code determination every time a new ASHRAE and ICC building code is released. The determinations compare the new code with the earlier one and estimate the additional source and site energy savings that would be achieved by the new code. Pacific Northwest National Laboratory's (PNNL) Building Energy Code Program conducts analysis on building codes comparison and evaluates the building code practice in various regions in the U.S.[12] These modeling efforts have helped the commercial building sector to better understand building code performance, and they would be continued in the future in the "building code" scenario of this study.

Survey of Stakeholders to Understand Building Code Compliance

Though multiple versions of building codes have been implemented across the country, the effort to understand code compliance, especially cases of non-compliance has been inadequate. More analysis is needed to examine the real world code compliance practice, particularly with the commitment of all 50 states to achieve 90% compliance by 2018. To improve compliance, the policy option examined here would involve surveying building owners, professional engineers, and architects to collect feedback on code enforcement, understand the achievements of building codes, and more importantly the reasons for non-compliance.

Construction of a Code Compliance Liability Structure

In the case of building code non-compliance, the lack of liability means that no party is held accountable. To address this problem, a liability structure that includes building owners, developers, design and construction companies, and other relevant parties could be established. With such a liability structure, parties involved in building code compliance have their respective responsibilities and would be held accountable in a non-compliance case. The responsibilities and liabilities of each party would need to be established by state and/or local level governments who adopted building codes into regulations.

Currently, ASHRAE Standards and other equivalent standards do not include articles on liability, and the implementation of these standards is voluntary until or unless a legal jurisdiction makes compliance mandatory through legislation. States like California (in Title 24) and Massachusetts (Massachusetts State Building Code) have indicated the responsibilities of enforcement agencies and builders in their state building codes although no potential penalties related with non-compliance are included. The lack of legal establishment creates barriers to improving the code compliance through a liability structure. In addition, the insurance that construction engineers carry does not cover the liability of building code non-compliance, which creates a reverse incentive for the engineers to actively support ideas like the code compliance liability structures. Nevertheless, successful examples can be found internationally. China has significantly improved its building code compliance rate by specifying the possible civil and criminal penalties involved in a non-compliance case in its building codes. Building developers, design companies, and construction companies are all responsible for the compliance of a building and are subject to civil or even criminal penalties in case of violation (Bin et al., 2012).

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[12] PNNL Building Energy Code Program: http://eere.pnnl.gov/building-technologies/codes_standards.stm

Measurement and Evaluation of Building Code Compliance

The measurement and evaluation of building code compliance are often found challenging by code officials, partly due to the lack of M&V protocols and tools. DOE is currently developing procedures to help states measure their compliance.[13] Given the importance of M&V, DOE should continue its current efforts to collaborate with building code organizations and industry partners to update existing M&V protocols and develop new ones when they are needed. The new/updated protocols are supposed to provide states with step-by-step compliance guidance and evaluation tools so that the implementation of building codes can be better monitored.

To ensure sufficient staff capacity to carry out building code implementation, this policy package includes workforce training programs along with the development and updating of M&V protocols to. It is envisioned that DOE would facilitate state and local authorities to provide training and education to the building industry and code officials.

Expanded, More Stringent, and Enforced Building Code Coverage of Existing Buildings

Since three quarters of the nation's commercial buildings that would exist in 2020 have already been built today (EIA, 2011, Table 5), it is important for the commercial building energy code to cover not only new construction but also existing buildings when major modifications are underway. Starting from ASHRAE 90.1-2001, building energy codes extended their coverage to existing buildings with additions and alterations made to their systems. In the subsequent ASHRAE 90.1-2007 and -2010 codes, the energy standards for existing buildings with major modifications were further updated.

In 2008, commercial buildings consumed over 18 Quadrillion Btu, and building owners spent $194 billion on their energy bills (DOE, 2009). An expanded, more stringent, and better enforced building code that covers both new construction and existing buildings with major modifications could harness more energy savings and reduce consumers' energy expenditure significantly. Nevertheless, careful design of the policy is a key to achieving deeper savings. A potential issue faced by the enforcement of commercial building codes to existing buildings with major modifications is that it might create an incentive for building owners to delay proceeding with their energy upgrades. Delays might be prompted by the possibility that a more costly building retrofit could be required for code compliance. Similar problems have troubled the "new source review" provision under the Clean Air Act, where plant improvements can become more costly and are sometimes avoided as the result of regulatory review (Brown and Chandler, 2008).

In order to resolve the problem, the policy could be designed in a "two-phase" fashion. In the first phase, all new construction needs to comply with the adopted building codes while the existing buildings are given a three to five year buffer period to develop their own building code compliance plan. The second phase would start once the buffer period ended and would require all new construction and existing buildings with major retrofits to comply with the code.

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[13] DOE: http://www.energycodes.gov/compliance

Engaging Utilities to Enhance Building Code Adoption and Compliance[14]

Utilities could play an important role in facilitating the code adoption and increasing the compliance rate by promoting alternative, more stringent building codes that require “above code” performance. Energy and building code authorities at all levels could engage utilities to participate in the design and promotion of the “above code” and couple it with utility offered financial incentive packages such as appliance rebate programs to motivate more builders, contractors, and building owners to boost their compliance efforts. In states with energy efficiency resource standards, utilities could be rewarded by claiming energy efficiency credits from the energy savings resulted from their code compliance assistance effort.

2.5 Policy Evaluation

Appropriateness of the Federal Role

The federal government uses multiple channels to provide training opportunities to code officials, liaisons, construction professionals, and third-party verifiers. DOE’s Building Energy Codes University is a one-stop shop for all training needs; the Building Codes Assistance Project (BCAP) network is another major venue that DOE works with various energy-focused organizations to promote training and education in the building code community.[15] Training and providing assistance to state and local jurisdictions has precedence.

Recent action in the U.S. Congress shows some motivation to aid the enforcement of building codes. Consider, for example, the Safe Building Code Incentive Act of 2011 (H.R. 2069);if it passes the Congress, it would amend the Robert T. Stafford Disaster Relief and Emergency Assistance Act to enhance existing programs providing mitigation assistance by encouraging states to adopt and actively enforce state building codes.

H.R. 4461 “Community Building Code Administration Grant Act (CBCAG)”, which passed the House of Representatives on July 9, 2008, but did not move forward in the Senate, would have authorized a grant program through the U.S. Department of Housing and Urban Development (HUD) to provide competitive matching-fund grants to local jurisdictions to strengthen their building code administration and enforcement capabilities.

The Community Development Block Grant (CDBG)[16] program under HUD provides funding to various community development and neighborhood facility and service improvement projects including building code enforcement. Cities and local communities are encouraged to apply for funding that would enhance their building code enforcement.

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[14] Utility Engagement is not among the policy recommendations the authors received from the “Policy Options Workshop: Accelerating Energy Efficiency in Commercial Buildings”. However, multiple studies suggest that engaging utilities in building code adoption and compliance is an effective measure. Therefore, it is added as an additional element of the policy approach examined in this study.

[15] Building Codes Assistance Project http://ase.org/programs/building-codes-assistance-project

[16] Community Development Block Grant Program http://portal.hud.gov/hudportal/HUD?src=/program_offices/comm_planning/communitydevelopment/programs

The Federal Public Transportation Act of 2012 (H.R. 4348) includes provisions that require nationally recognized building codes to be considered as part of the floodplain management criteria. It also calls on the Community Development Block Grant to assist the building code related education, training and enforcement.

Broad Applicability

A commercial building energy code would prescribe the minimum level of efficiency that must be achieved in both new construction and existing buildings with major modifications. It can impact the energy use in large and small office buildings, schools, hospitals, warehouses, retail sales, and service buildings as well as government buildings.

Significant Potential Benefits

Aggressive commercial building energy codes coupled with proper compliance measures would improve the energy efficiency of buildings and would subsequently reduce the energy consumption and the associated greenhouse gas and other air pollutant emissions. The energy, carbon, and environmental benefits of stricter and better enforced building codes have been shown in past studies to be significant in both the short- and long-term. It would also save the commercial customers' expenditure on energy (Energy Modeling Forum, 2011; Granade et al., 2009; Laitner et al., 2012). Estimating the magnitude of potential savings from enforcing stricter codes is one of the principal goals of this paper.

Technology Readiness

High performance building materials and equipment are widely available, but the technologies to monitor compliance are inadequate (Elnecave, 2012). DOE's Building Energy Codes Program currently offers code-compliance support through COMcheck, which is a software tool that helps commercial buildings track their compliance efforts vis-à-vis all versions of IECC (through the 2009 version) and ASHRAE Standards 90.1 (through the 2010 version). However, there is a need to develop new or improved compliance tools so that the software can work in accordance with the more recent versions of the commercial building codes.

Cost Effectiveness

The cost of an aggressive building codes policy would include the administrative expenses of public agencies to manage and operate the code-related program. For effective code implementation and compliance, administrative expenses include training workforces, establishing the partnership between state energy offices and private sector players, and engaging stakeholders through various forms. Besides the public costs are the private investments that developers and builders would incur in the process of complying with building codes. Similarly, the benefits of the policy could be felt by both the private and the public sector. Consumers would have lower energy expenditures, and the avoided carbon and environmental pollution emissions would bring significant social benefits. The actual cost effectiveness of the policy will be estimated using GT-NEMS.

Administrative Practicality

The M&V of code compliance is challenging because states adopt different editions of commercial building codes. As a result, multiple versions of M&V protocols need to be developed to meet the specific need of each building code. A shortage of adequately trained code officials is another barrier to code enforcement. More workforce training programs and the proper inspection tools are needed to ensure the proper enforcement of commercial building codes.

Additionality

The proposed policy could close the building code adoption gap, tighten the stringency of the codes in states with outdated commercial building codes, and improve code compliance. It would generate additional energy savings that are missed by previous energy-efficiency efforts with similar focus.

Timing of Results

In the mid- to long-term, if ASHRAE 90.1-2010 were implemented nationwide, the energy savings could reach up to 30% compared to the ASHRAE 90.1-2004 code.[17] However, the actual amount of energy savings depends on the type and magnitude of new construction in the near-, mid-, and long-term.

3. Methodology for Modeling the Impacts of an Aggressive Commercial Building Codes Policy

The Georgia Institute of Technology's version of NEMS is the principal modeling tool used in this study to examine the likely impacts of carbon taxes on the energy efficiency of commercial buildings, supplemented by spreadsheet calculations. Since the model is run on Georgia Tech computers, we call it the "GT-NEMS".[18] Specifically, we derive GT-NEMS from the version of NEMS that generated EIA's Annual Energy Outlook 2011 (EIA, 2011), which forecasts energy supply and demand for the nation out to 2035. The GT-NEMS "bottom-up" engineering economic modeling approach is well suited to a carbon tax analysis focused on understanding the likely response of the commercial buildings sector. By characterizing nearly 350 distinct commercial building technologies, and by enabling the separate analysis of nine Census division, nine end-uses (e.g., lighting and air conditioning), and eleven building types, GT-NEMS offers the potential for a rich examination of policy impacts. Its bottom-up technology configuration enables an assessment of technology investments, energy prices, energy consumption and expenditures, carbon abatement, and pollution prevention over time and across regions of the U.S. Many studies evaluate the impact of carbon taxes by using Computable General Equilibrium (CGE) modeling (Energy Modeling Forum, 2011; Weyant, de

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[17] DOE's Building Codes Involvement
http://www.bpa.gov/Energy/N/Utilities_Sharing_EE/doc/BuildingCodesofTomorrow.pdf

[18] This nomenclature recognizes that even when the same NEMS code is used on two hardware systems with the supporting software programs – e.g., FORTRAN and the IHS Global Insights macroeconomic optimization tool – the results could be distinct from those of the EIA.

la Chesnaye, and Blanford, 2006). None of these have as detailed a technology inventory as GT-NEMS.

NEMS models U.S. energy markets and is the principal modeling tool used to forecast future U.S. energy supply and demand. Twelve modules represent supply (oil and gas, coal, and renewable fuels), demand (residential, commercial, industrial, and transportation sectors), energy conversion (electricity and petroleum markets), and macroeconomic and international energy market factors. A thirteenth “integrating” optimization module ensures that a general market equilibrium is achieved among the other modules. Beginning with current resource supply and price data and making assumptions about future consumption patterns and technological development, NEMS carries through the market interactions represented by the thirteen modules and solves for the price and quantity of each energy type that balances supply and demand in each sector and region represented (EIA, 2009). Outputs are intended as forecasts of general trends rather than precise statements of what will happen in the future. As such, NEMS is well suited to projecting how alternative assumptions about resource availability, consumer demand, and policy implementation may impact energy markets over time.

In the commercial demand module, NEMS employs a least-cost function within a set of rules governing the set of options from which consumers may choose technologies. Capital costs are amortized using “hurdle rates.” There are six commercial sector sub-modules (Cullenward, Wilkerson, and Davidian, 2009). For modeling the building codes policy, the Forecast Commercial Floor Space Sub-module, the Service Demand Sub-module, and the Technology Choice Sub-module are particularly important.

- The **Forecast Commercial Floor Space Sub-module** provides forecasts of floor space by Census Division and building types based on population, economic effects, and historic growth patterns.
- The **Service Demand Sub-module** estimates service demand (SD) based on service demand intensity (SDI) and floor space projection for each major service, building type, and region.
- The **Technology Choice Sub-module** determines the equipment chosen to meet service demand. Commercial consumers purchase equipment to meet three classes of demand: new, which represents the demand in newly-constructed buildings; replacement, which represents the demand formerly met by retiring equipment; retrofit, which represents the demand met by equipment at the end of their economic life. The choice of a technology in NEMS is partially determined by the discount rates employed by consumers. Discount rates are calculated for end-uses by year for different subsets of the population by summing the yield on U.S. government ten year notes (endogenously determined) and the time preference premium of consumers (exogenous inputs to the model). Then the sub-module divides service demand using three behavior rules: least cost (where consumer decisions are determined by the lowest annual cost of the equipment); same fuel (where consumer decisions are determined by the lowest annual cost of equipment using the same fuel currently employed by the consumer); and same

technology (where consumer decisions are determined by the lowest annual cost of equipment using the same technology class currently employed by the consumer). In combination, the demand class, discount rate, and behavior rule determine the technology selected to meet a given service demand.

The GT-NEMS “Reference case” projection described in this study uses the same computer code as is used in creating the published Reference case used by EIA. It is based on federal, state, and local laws and regulations in effect at the time of the analysis. For the building code scenario, GT-NEMS incorporates changes specific to this study, including modifications to the building shell efficiency improvement factors for both new construction and existing buildings and a commercial technology profile with more stringent space heating and cooling equipment standard. The next section has detailed discussion of both approaches.

3.1 Design of an Aggressive National Commercial Building Codes Policy

As pointed out in Section 1, great diversity in building code adoption exists across the states. Eleven states currently do not have 21st century building codes; the other 39 states and Washington, D.C., have adopted various versions of building codes that were released since 2001. The building code adoption gap undermines the efficiency of commercial buildings, resulting in more carbon emissions and criteria pollutant emissions that damage the environment and harm the public health. In this study, we use GT-NEMS to characterize an aggressive commercial building code that has stringent building shell efficiency requirements and high standards for the energy efficiency of space heating, cooling, water heating, and lighting equipment, and it would be implemented across the U.S. In the real world, there is buffer time for code adoption that prepares developers, builders, and building owners to adjust to more stringent codes. However, GT-NEMS does not allow users to specify alternative years for initiating a building code. Rather, the more stringent code must start in 2012.

In addition, GT-NEMS does not model variable levels of building code compliance. The six elements of building codes policy studied in this paper would all work toward strengthening the code compliance across the nation. Therefore, the code compliance in the building code scenario would reach a higher level than the Reference case; in an ideal case, 100% compliance could be achieved. For simplicity, we assume 100% compliance in this study.

Higher Building Shell Efficiency

The building shell, also known as the building envelope, refers to the exterior plus the semi-exterior portions of a building.[19] Common elements of the building shell include windows, doors, roof, exterior walls, etc. A commercial building code would require the design, insulation, and material choice of any part of the building shell to meet certain standards. A better-designed,

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[19] ASHRAE 90.1-2010 defines building envelope, exterior as the elements of a building that separate conditioned spaces from the exterior. ASHRAE 90.1-2010 defines building envelope, semi-exterior as the elements of a building that separate conditioned space from unconditioned space or that enclose semi-heated spaces through which thermal energy may be transferred to or from the exterior, or to or from unconditioned spaces, or to or from conditioned spaces.

well-insulated building shell could enhance the quality of the working environment, reduce the size and cost of needed heating and cooling equipment, and decrease energy consumption and associated environmental emissions.

In the building codes policy option studied in this paper, starting in 2012 we would implement ASHRAE Standard 90.1-2010's requirements of building shell efficiency in all 50 states; both new construction and existing buildings that go through major modifications are covered under the code. We assume that commercial buildings built after 2012 will all comply with the ASHRAE standard by integrating the building shell efficiency requirements into the design and construction of the buildings. For buildings that were constructed prior to 2012, they are also required to comply with the building code whenever major modifications specified by the code are conducted.

The ideal approach to simulate the impact of such building shell efficiency improvement is to implant the standard into GT-NEMS by setting the minimum efficiency requirement for building shell technologies such as windows and roof. However, unlike the commercial end-use technologies that have detailed characteristics profiles, GT-NEMS does not include a building shell technology profile. Instead, the shell efficiency improvement over time is indexed by a set of efficiency factors that represent the overall shell efficiency improvement of the U.S. commercial building stock in 2035 over the 2003 level. The efficiency factors take into account current building practices, rate of adoption for building codes, research, development, and program deployment, and the “green building” movement, as well as the long-lived nature of commercial buildings. For example, in the “ksheff” file, the commercial shell efficiency input file of GT-NEMS, the EIA Reference case forecast assumes that the building shell efficiency of new construction in 2035 would improve by 14% over the 2003 level. Shell efficiency of existing buildings would achieve a 6% improvement over the same baseline by 2035. New construction receives additional improvement to account for adoption of the building shell measures in ASHRAE 90.1-2007, with which standard all states need to comply by 2018, according to American Recovery and Reinvestment Act of 2009.

In addition to the Reference case, EIA also offers two alternative technology side cases, the “High Technology” (High Tech) case and the “Best Technology” (Best Tech) case. Despite their different assumptions about consumer behavior, both side cases assume more aggressive shell efficiency improvement for new and existing buildings. The shell efficiency of new buildings would become 17.4% and 20.8% more efficiency in 2035 than the 2003 baseline building stock in the “High Tech” and “Best Tech” side case, respectively. The improvements for the building shell in existing buildings in these two side cases are 7.5% and 9%, respectively.

Although EIA's building technology side cases represent a better state of the building shell efficiency, they are less stringent than the latest ASHRAE Standard and thereby do not guide commercial buildings to explore their full building energy efficiency potential. In this study, we compare the building shell efficiency required by ASHRAE 90.1-2004, 90.1-2007 and ASHRAE Standard 90.1-2010, which is the blueprint of the shell efficiency component of the “Building Code” Scenario in this study by using the building code determinations issued by DOE's Office of Energy Efficiency and Renewable Energy. The determinations (DOE, 2011a, 2011b) find that the 2010 edition of ASHRAE standard would achieve approximately 18.5% more site energy savings (18.2% more source energy savings), than the 2007 edition; the 2007 edition would save 4.6% more site energy savings (3.9% more source energy savings) compared to the 2004 edition. If we assume the energy savings are perfectly correlated with the improvement of the building shell efficiency and the implementation of ASHRAE Standard 90.1-2010 is nationwide, the shell efficiency for new construction in 2035 would become 30% more efficient than the 2003 baseline stock, a 16 percentage-point increase from the EIA Reference case shell efficiency. Existing buildings in 2035 would experience a 19% improvement in 2035 relative to the 2003 baseline, representing a 13 percentage-point improvement from the EIA Reference case assumption. Table 1 summarizes the building shell efficiency assumptions compared in this study.

Table 1. Commercial Building Shell Efficiency Improvement*

	New Construction	Existing Buildings
EIA Reference case	14%	6%
EIA High Tech Case	17.4%	7.5%
EIA Best Tech Case	20.8%	9%
Building Code Scenario	30%	19%

* Improvement of 2035 efficiency over 2003 efficiency

More Stringent Equipment Standards in Space Heating and Cooling, Water Heating and Lighting

Space heating and cooling are closely linked to the improvement of building shell efficiency. A better insulated building shell would reduce the space heating and cooling demands inside the building and affect the technology choice in these two end-uses, possibly allowing less expensive, smaller heating and cooling equipment. Water heating is often linked with space heating by providing water to the heating process. Widely adopted building energy codes such as IECC and ASHRAE both include these three end-uses.

Lighting is also considered to be an integral part of the building code for two reasons. First, the choice of building shell technologies such as low emissivity windows and skylights would impact the building lighting demand. Further, the lighting demand would in turn affect the space heating and cooling load because of thermal radiance from lighting equipment.

An equipment standard would set the minimum energy efficiency level for each type of space heating and cooling, water heating equipment and lighting technologies, and the minimum efficiency level increases over time to reflect the future R&D improvement.

According to EIA, in the business-as-usual world, eight types of space heating technologies, which include 53 vintages are, or will be available, to commercial building consumers between now and 2035. Consumers have more space cooling technology options to choose from: 93

vintages in 12 technologies. Water heating includes eight technologies that are further divided into 41 vintages. Lighting technologies are categorized using 11 technology types and 37 vintages. Information such as energy efficiency (measured in Coefficient of Performance, except for lighting which is measured in lighting efficacy), initial cost and operational and maintenance costs about the technologies and their respective vintages in the seven major commercial end-uses is contained in the commercial technology profile in GT-NEMS, i.e., “ktek” file. Table 2 summarizes the space heating and cooling technologies included in “ktek.” Vintages within each technology category represent different states of the technology and they differ from each other in capital cost, energy efficiency, technology cost decline parameters, and year of availability.

Both “High Tech” and “Best Tech” side cases employed by EIA uses the “High Tech” version of the commercial technology profile, which assumes lower costs, higher efficiency, earlier availability, and more vintages with higher efficiency for a number of technologies, as shown in Table 2. When examining the impact of the commercial building code, we adopt the High Tech version of the commercial technology profile and then impose an equipment standard for the space heating and cooling, water heating and lighting technologies by eliminating technologies with low efficiency. In the ideal case, the equipment standards studied in this paper would also follow the ASHRAE Standard 90.1-2010 so that it is consistent with the building shell efficiency improvement discussed earlier. However, the ASHRAE standard and the “ktek” file measure equipment efficiency in different terms,[20] and categorize technologies using different criteria.[21]

There has not been a method, to the researchers’ knowledge, that can easily convert the units and still account for the technology characterization difference between ASHRAE Standard 90.1-2010 and “ktek.” However, in the Technology Forecast Updates-Residential and Commercial Building Technologies (Navigant Consulting, 2011) that was presented to EIA, Navigant Consulting characterized the major commercial technologies, including their energy efficiency using inputs from industry, government, R&D organizations, and manufacturers. Among these sources, ASHRAE Standard 90.1-2007 was the major input for space heating and cooling, and water heating technologies. Therefore, as an alternative, we developed the equipment standard for the building code scenario according to the 2007 edition of the ASHRAE standard. In fact, the building code determination (DOE, 2011a) issued by DOE that compares the 2007 and 2010 standard shows that the additional energy savings resulted from the later standard is small, indicating the difference between the equipment efficiency requirements between the two versions of ASHRAE standard is minimal.

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[20] ASHRAE Standard 90.1 2010 measures equipment efficiency in Energy Efficiency Ratio (EER) or Seasonal Energy Efficiency Ratio (SEER). EIA “ktek” file uses Coefficient of Performance (COP).

[21] ASHRAE Standard 90.1 2010 assigns different efficiency factors for technologies that have the same characteristics except for size or operational temperatures. “ktek” considers neither equipment size nor temperature.

Table 2. Space Heating, Cooling, Water Heating, and Lighting Technologies in the Commercial Building Sector

Space Heating		Space Cooling	
Rooftop Air Source Heat Pump-Heat	(7, 8, 8)	Rooftop Air Source Heat Pump-Cool	(7, 8, 8)
Commercial Ground Source Heat Pump-Heat	(7, 11, 11)	Commercial Ground Source Heat Pump-Cool	(7, 11, 11)
Electric Boiler	(2, 2, 0)	Scroll Chiller	(5, 5, 4)
Other Electric Packaged Space Heating	(2, 2, 2)	Screw Chiller	(8, 8, 6)
Residential Type Gas Heat Pump-Heat	(6, 8, 8)	Reciprocating Chiller	(8, 11, 9)
Gas Furnace	(9, 9, 8)	Centrifugal Chiller	(9, 9, 8)
Gas Boiler	(8, 8, 8)	Rooftop Air Conditioner	(8, 9, 9)
Oil Furnace	(4, 4, 1)	Wall-Window Room Air Conditioner	(9, 10, 10)
Oil Boiler	(7, 7, 7)	Residential Type Central Air Conditioner	(11, 11, 11)
		Residential Type Gas Heat Pump-Cool	(6, 8, 8)
		Gas Rooftop Air Conditioner	(7, 7, 4)
		Gas Chiller	(7, 7, 7)
Summary Reference: 8 technologies; 53 vintages EIA High Technology case: 8 technologies; 60 vintages Building code scenario: 8 technologies; 54 vintages		**Summary** Reference case : 12 technologies; 93 vintages EIA High Technology case: 12 technologies; 105 vintages Building code scenario : 12 technologies; 96 vintages	

Water Heating	Lighting
Electric Booster Water Heater (3, 3, 3)	100W Incandescent (1, 1, 0)
Solar Water Heater (6, 7, 7)	26W CFL (2, 2, 2)
Heat Pump Water Heater (7, 7, 7)	90W Halogen PAR38 (2, 2, 2)
Electric Water Heater (2 , 2, 1)	70W HIR PAR-38 (2, 2,2)
Gas Instantaneous Water Heater (7, 7, 7)	LED (10, 11, 11)
Gas Booster Water Heater (5, 5, 5)	T12 (3, 3, 3)
Gas Water Heater (7, 7, 4)	T8 (14, 16, 12)
Oil Water Heater (4, 4, 4)	T5 (1, 3, 3)
	MV (2, 2, 2)
	MH (2, 2, 2)
	HPS70 (2, 2, 2)
Summary Reference: 8 technologies; 41 vintages EIA High Technology case: 8 technologies; 42 vintages Building code scenario: 8 technologies; 38 vintages	**Summary** Reference case : 11 technologies; 37 vintages EIA High Technology case: 11 technologies; 42 vintages Building code scenario: 11 technologies; 37 vintages

Note: The numbers in the bracket represent the numbers of vintages of each technology from the following scenarios (Reference case, EIA High Tech case, building code scenario)

The building code scenario in this study is designed to remove these inefficient technologies from the market place so that the overall energy efficiency in these four end-uses could improve in order to reduce the energy consumed in commercial buildings. A comparison between ASHRAE Standard 90.1-2007 and the High Tech version of “ktek” reveals that even in EIA’s

High Tech side case there are space heating and cooling, and water heating technologies that have energy efficiency factors below the standard, as shown in Table 3. ASHRAE Standard 90.1-2010 includes lighting standards that are measured in Light Power Density (LPD) for buildings used for various purposes. This creates difficulties in modeling the lighting standards using the same method as for the other three end-uses through GT-NEM's "ktek" file because the relationship between lighting technologies and building type is currently missing from GT-NEMS. As an alternative, we design a standard to remove the low-efficiency lighting technology in the incandescent and fluorescent categories while acknowledging the niche market each lighting technology fulfills by ensuring the availability of alternative technology vintages in each technology class. In so doing, this standard would allow consumers to move from low-efficiency technologies to high-efficiency ones without limiting their ability to choose from the whole spectrum of technologies.

As a result of this more stringent equipment standards for the four type of commercial end-uses, six low-efficiency space heating technology vintages, nine low-efficiency space cooling technology vintages, four water heating technology vintages, and five low-efficiency lighting technology vintages would be removed from the market place between now and 2035, as shown in Table 3. For example, there are eight different screw chiller vintages in the High Tech scenario: 2003 installed base, 2007 typical/high, 2010 typical/high, 2020 typical/high, and 2030 high. The COP ranges from 2.34 (2003 installed base screw chiller) to 3.91 (2030 high efficient screw chiller). The equipment standard modeled in this study requires a minimum COP of 2.80 for screw chillers that are sold in the market since 2003, which leads to three less efficient vintages being eliminated from the marketplace from 2012 forward (Table 3). As a result, the screw chillers that are available for commercial consumers purchase in the 2010s would have a COP of at least 2.93, comparing to a minimum COP of 2.34 in EIA's reference and High Tech cases. Starting from 2020, more advanced screw chillers with higher efficiency (a COP of 3.63) will come to the marketplace and they are expected to replace the older less efficient ones. In 2030, the most energy efficient screw chillers would have a COP as high as 3.91.

Table 3. Eliminated Commercial Building End-Use Technologies

Technology	Equipment Standard (Measured in COP)*	Ktek Efficiency (Measured in COP)
Space Heating		
Gas Furnace 2020 Typical	0.80	0.79
Oil Furnace 2007 Current Standard/Typical	0.81	0.79
Oil Furnace 2010 Typical	0.81	0.79
Oil Furnace 2020 Typical	0.81	0.79
Electric Boiler 2003 Installed Base	0.98	0.94
Electric Boiler 2010 Typical	0.98	0.94
Space Cooling		
Scroll Chiller 2003 Installed Base	2.80	2.64
Screw Chiller 2003 Installed Base	2.80	2.34
Screw Chiller 2007 Typical	2.80	2.71
Reciprocating Chiller 2003 Installed Base	2.80	2.34
Reciprocating Chiller 2007 Typical	2.80	2.71
Centrifugal Chiller 2003 Installed Base	5.00	4.69
Gas Rooftop AC 2010 Typical	1.10	0.70
Gas Rooftop AC 2010 High	1.10	1.00
Gas Rooftop AC 2020 Typical	1.10	0.70
Water Heating		
Electric Water Heater 2007 Current Standard / Typical	0.98	0.97
Gas Water Heater 2010 Typical	0.80	0.78
Gas Water Heater 2020 Typical	0.80	0.78
Gas Water Heater 2020 High	0.96	0.93
Lighting**		
72W Incandescent		12.2
F32T8		56.4
F32T8 with Magnetic Energy Efficient Ballast		59.0
F96T8 Typical		73.5
F96T8 High Output Low Bay		71.8

*COP is measured in Btu Out / Btu In

** Lighting efficacy is measured in Lumen/Watt. ASHRAE Standard for lighting is not commensurate with the “ktek” standard.

3.2 Advantages and Disadvantages of GT-NEMS

GT-NEMS has detailed a commercial end-use technology profile that includes characteristics such as equipment efficiency, initial purchase prices, operation and maintenance costs, and lifetime in the market for over 350 technologies in the seven major end-uses. This enables the technology level analysis for the equipment standards aspect of the commercial building codes, which allows us to not only identify the entrance and exit of various end-use technologies but also the associated energy savings and investment costs.

However, compared to the well-specified end-use technology profile, the building shell technologies are a missing piece of the commercial module of GT-NEMS. The improvement of building shell efficiency is represented by a percentage number indicating the efficiency gain between the average building stock in 2003 and 2035. The model does not articulate specific window, wall, or roof technology that could enable the shell efficiency improvement and neither is there any cost associated with them. As a result, the lack of building shell technology profile does not provide the technology level analysis of shell efficiency improvement and the estimation of cost that is required to make the building envelope better.

As a further limitation, GT-NEMS also has limited ability to assess the whole building design. It does not explicitly incorporate any consideration of building construction practice, building operation, system control and commissioning.

The Census division based geographic resolution of GT-NEMS presents another limitation to the building codes analysis. The highest geographic resolution in NEMS is the Census division level; this means that the adoption of different codes by states is, at best, aggregated to the Census division level while in reality each state has autonomy in deciding whether to adopt a building code and which version.

4. Results

In this section, we discuss the impacts of the building codes policy on the commercial building sector’s energy consumption, energy prices and expenditures, criteria pollutants, and carbon dioxide.

4.1 Impacts on Commercial Energy Consumption

EIA estimates that energy consumption in the commercial building sector would reach 24.0 Quads in 2035 in a business-as-usual world, a 1.1% compound annual increase from 18.3 Quads consumption in 2010. The building codes policy improves the building shell efficiency and, therefore, reduces the service demand required by space heating and cooling end-uses in the commercial building stock. In addition, the higher commercial equipment efficiency standards allow the heating and cooling, water heating and lighting service demands to be met by less delivered energy than the Reference case would otherwise require. As a result, the commercial building codes policy would reduce the energy consumption in the sector by 0.43 Quads in 2020 and 0.94 Quads in 2035, which represent 2.1% and 4.0% reductions relative to the Reference case, respectively (Figure 1). These reductions are not enough to curtail the growing energy consumption of commercial buildings.

The modest energy savings are expected because the building shell efficiency improvement and equipment standards would only impact the energy demand of four commercial end-uses, which account for only 44% of the commercial total energy consumption in 2010, declining to only 37% in 2035. In fact, the impacts of the building codes policy on the four targeted end-uses are significant, and in each end-use, less energy would be consumed in 2035 than is consumed today:

- Space heating and cooling would use 16.4% and 14.5% less energy in 2035, respectively.
- Water heating would see its energy consumption drop by one fifth by 2035, the greatest of the four end-uses.
- Energy used to light commercial buildings would be reduced by about 5% by the same time, relative to the Reference case.

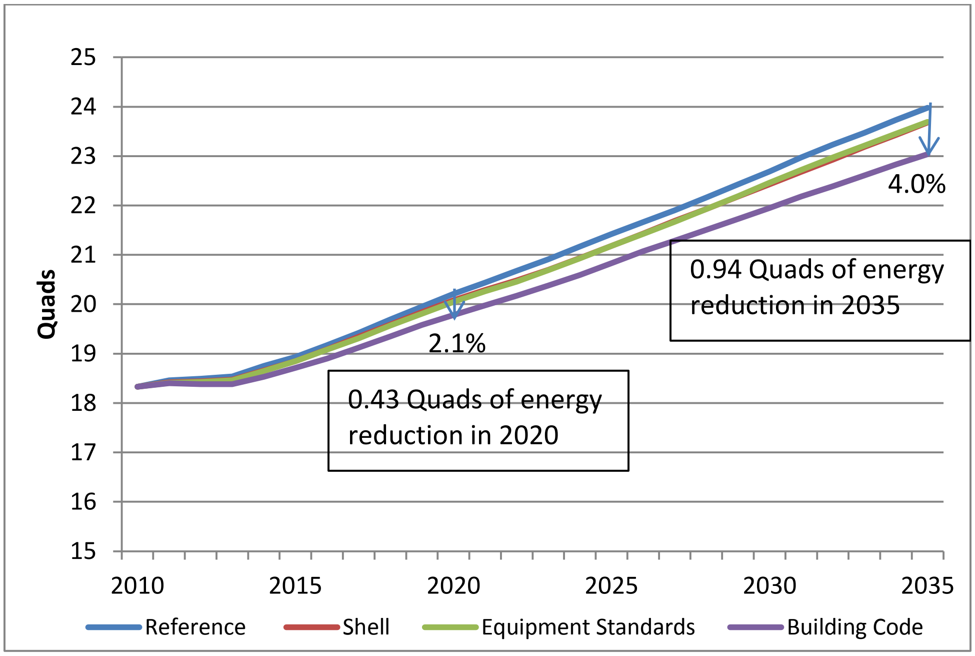

Figure 1. Commercial Energy Consumption (Quads): Building Code Scenario Versus Reference case

As a result, the energy savings from the four targeted commercial end-uses would reach 1.02 Quads in 2035 (Table 4), higher than the energy savings of the entire sector which indicates the rebound effect in other commercial end-uses. As shown in Table 4, all other commercial end-uses (ventilation, cooking, refrigeration, office equipment, and other) together consumes 0.18 Quads more energy in 2035. Cheaper energy prices resulting from lower demand are likely to be the cause of this rebound effect. Section 4.2 will have more discussion about energy price and its impacts on energy consumption.

Table 4. Energy Consumption by Commercial End-uses: Building Code Scenario Versus Reference case

		2010	2020			2035		
End-use	Energy Consumption (Quad)	2010 Reference	2020 Reference	Building code	Change (Percent Change)	2035 Reference	Building code	Change (Percent Change)
Space Heating	Purchased Electricity	0.18	0.17	0.15	-0.02 (-14.1%)	0.18	0.14	-0.04 (-22.9%)
	Natural Gas	1.62	1.76	1.56	-0.20 (-11.2%)	1.77	1.52	-0.25 (-14.1%)
	Delivered Energy	1.79	1.93	1.71	-0.22 (-11.4%)	1.94	1.65	-0.29 (-14.9%)
	Total Energy	2.31	2.40	2.11	-0.29 (-12.0%)	2.40	2.01	-0.40 **(-16.4%)**
Space Cooling	Purchased Electricity	0.58	0.58	0.50	-0.08 (-14.5%)	0.61	0.52	-0.09 (-14.6%)
	Natural Gas	0.04	0.36	0.34	-0.02 (-6.3%)	0.35	0.31	-0.04 (-11.3%)
	Delivered Energy	0.62	0.94	0.84	-0.11 (-11.4%)	0.97	0.84	-0.13 (-13.4%)
	Total Energy	1.86	1.70	1.55	-0.15 (-8.6%)	1.88	1.61	-0.27 **(-14.5%)**
Water Heating	Purchased Electricity	0.09	0.09	0.06	-0.04 (-39.3%)	0.09	0.04	-0.06 (-60.3%)
	Natural Gas	0.46	0.56	0.55	0.01 (-0.7%)	0.64	0.63	-0.01 (-1.3%)
	Delivered Energy	0.55	0.65	0.61	-0.04 (-6.3%)	0.73	0.67	(-0.07 (-8.9%)
	Total Energy	0.76	0.86	0.74	-0.12 (-13.7%)	0.94	0.76	-0.18 **(-19.1%)**
Lighting	Purchased Electricity	1.02	1.09	1.09	-0.01 (-0.5%)	1.25	1.19	-0.06 (-4.8%)
	Delivered Energy	1.02	1.09	1.09	-0.01 (-0.5%)	1.25	1.19	-0.06 (-4.8%)
	Total Energy	3.32	3.34	3.35	0.01 (0.3%)	3.75	3.58	-0.18 **(-4.7%)**

End-use	Energy Consumption (Quad)	2010	2020			2035		
		2010 Reference	**2020 Reference**	**Building code**	**Change (Percent Change)**	**2035 Reference**	**Building code**	**Change (Percent Change)**
All Others	Purchased Electricity	2.37	3.27	3.33	0.07 (2.1%)	4.30	4.31	0.01 (0.2%)
	Natural Gas	1.06	0.91	0.97	0.0.7 (7.6%)	1.16	1.23	0.07 (6.3%)
	Delivered Energy	3.79	4.17	4.31	0.14 (3.3%)	5.46	5.54	0.08 (1.5%)
	Total Energy	10.08	11.91	12.02	0.11 (0.9%)	15.00	15.08	0.08 **(0.6%)**
Commercial Sector	Purchased Electricity	4.60	5.20	5.12	-0.08 (-1.6%)	6.43	6.20	-0.24 (-3.7%)
	Natural Gas	3.18	3.58	3.43	-0.16 (-4.3%)	3.92	3.69	-0.23 (-5.8%)
	Delivered Energy	7.78	8.79	8.55	-0.24 (-2.7%)	10.35	9.89	-0.46 (-4.5%)
	Total Energy	18.33	20.21	19.78	-0.43 (-2.1%)	23.98	23.04	-0.94 **(-3.9%)**

Electricity supplies the most energy demand in commercial buildings. The Reference case projects that 6.43 Quads out of the 10.35 Quads delivered energy consumed in the commercial sector in 2035 would be electricity. However, from the energy saving perspective, natural gas has more saving potential under this building codes policy than electricity. As Table 5 suggests, energy savings in both Quads and percentage terms are higher in natural gas than in electricity in 2015, 2020 and 2035. Natural gas consumption in space heating would be reduced by 0.25 Quads in 2035 under the building code scenario, making it the biggest end-use fuel saving source followed by space cooling electricity consumption (Table 4).[22]

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[22] In fact, the commercial sector as a whole saves only 0.23 Quads of natural gas in 2035 (Table 2), which is 0.03 Quads less than the natural gas saved in the space heating end-use along. This is because of the consumption increase in end-uses other than space heating and cooling which is a modeling artifact. GT-NEMS assumes the 30% commercial building shell efficiency improvement required by the building codes policy would spread between 2003 and 2035. In other words, the building shell of pre-2012 building stock would also become more efficient than it is in the reference case. As a result, the overall electricity and natural gas consumption in commercial minor end-uses slightly increases.

Table 5. Building Codes Scenario’s Impact on Commercial Energy Consumption (Quads)

Commercial Sector Energy Use		Natural Gas	Electricity	Electricity Related Losses
2015	Reference	3.46	4.83	9.92
	Building Codes Scenario	3.36	4.79	9.85
	Energy Savings (Quads)	-0.10	-0.04	-0.07
	% Change	-3.0%	-1.0%	-0.3%
2020	Reference	3.58	5.20	10.71
	Building Codes Scenario	3.43	5.12	10.54
	Energy Savings (Quads)	-0.15	-0.08	-0.17
	% Change	-4.3%	-0.16%	-1.6%
2035	Reference	3.92	6.43	12.93
	Building Codes Scenario	3.69	6.20	12.47
	Energy Savings (Quads)	-0.23	-0.23	-0.46
	% Change	-5.8%	-3.9%	-2.4%

The impact of the aggressive building codes policy on commercial energy intensity, measured in thousand Btus/ square foot, closely resemble the energy consumption trend (Figure 2). It is almost a 1:1 ratio between the reduction in sectoral energy consumption and energy intensity, indicating that the building codes policy does not dis-incentivize the construction of new commercial floor space. This is contrary to the myth that a stringent commercial building code would discourage builders and developers to build new buildings. Because commercial building construction is closely related to broader economic activities, the building code’s minimal impact on commercial building construction also suggests that the national GDP is not likely to be significantly affected. Our analysis shows that the implementation of the more stringent building code would decrease the national GDP by $4 billion and $2 billion in 2020 and 2035, respectively relative to the Reference case. More on GDP impact can be found in Section 4.4.

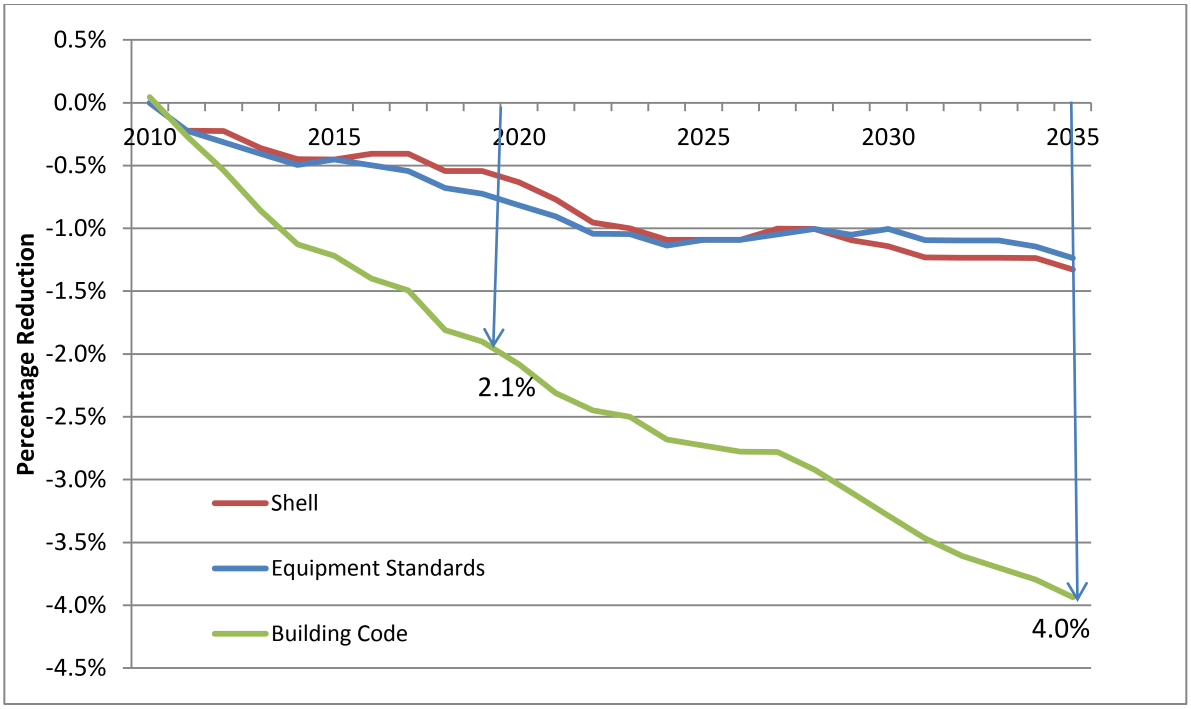

Figure 2. Building Code's Impacts on Commercial Energy Intensity

4.2 Impacts on Energy Prices and Energy Expenditures

GT-NEMS projects that an aggressive commercial building codes policy would reduce the natural gas and electricity consumed by commercial buildings. Basic microeconomics theory suggests that with static supply, the prices for normal goods, such as electricity and natural gas, would decrease when the demand decreases. Our findings confirm this point by showing that the prices for natural gas and electricity both decline in the building code scenario relative to the Reference case (Figure 3). For natural gas, the 0.6% price decline in 2035 is modest compared to the overall increase in natural gas prices forecast by GT-NEMS in the Reference case, which are seen as growing at a compound annual growth rate of 1.7% between 2011 and 2035. With the recent surge in shale gas production in the U.S., the future price of natural gas is a hotly debated subject. The significant uncertainty is a function of the broader range of possible future natural gas prices (reflecting their historic volatility) compared with electricity prices, which have been more stable in the U.S. Thus, the 1.9% decline in electricity prices in 2035 (from 9.22 cents/kWh in the Reference case to 9.05 cents/kWh in the building code scenario) is significant relative to the modest increase in electricity price that is forecast in the Reference case to have a compound annual growth rate of 0.10% following an initial period of decline.

As a result of the decline in both energy prices and consumption, the building codes policy is estimated to save the commercial building sector $5.3 billion in 2020 and $12.8 billion in 2035 in energy expenditures, which represent 2.9% and 5.5% reductions from the Reference case (Figure 4). The cumulative energy expenditure savings would reach $104.6 billion by 2035, using a 3% discount rate (Table 6).

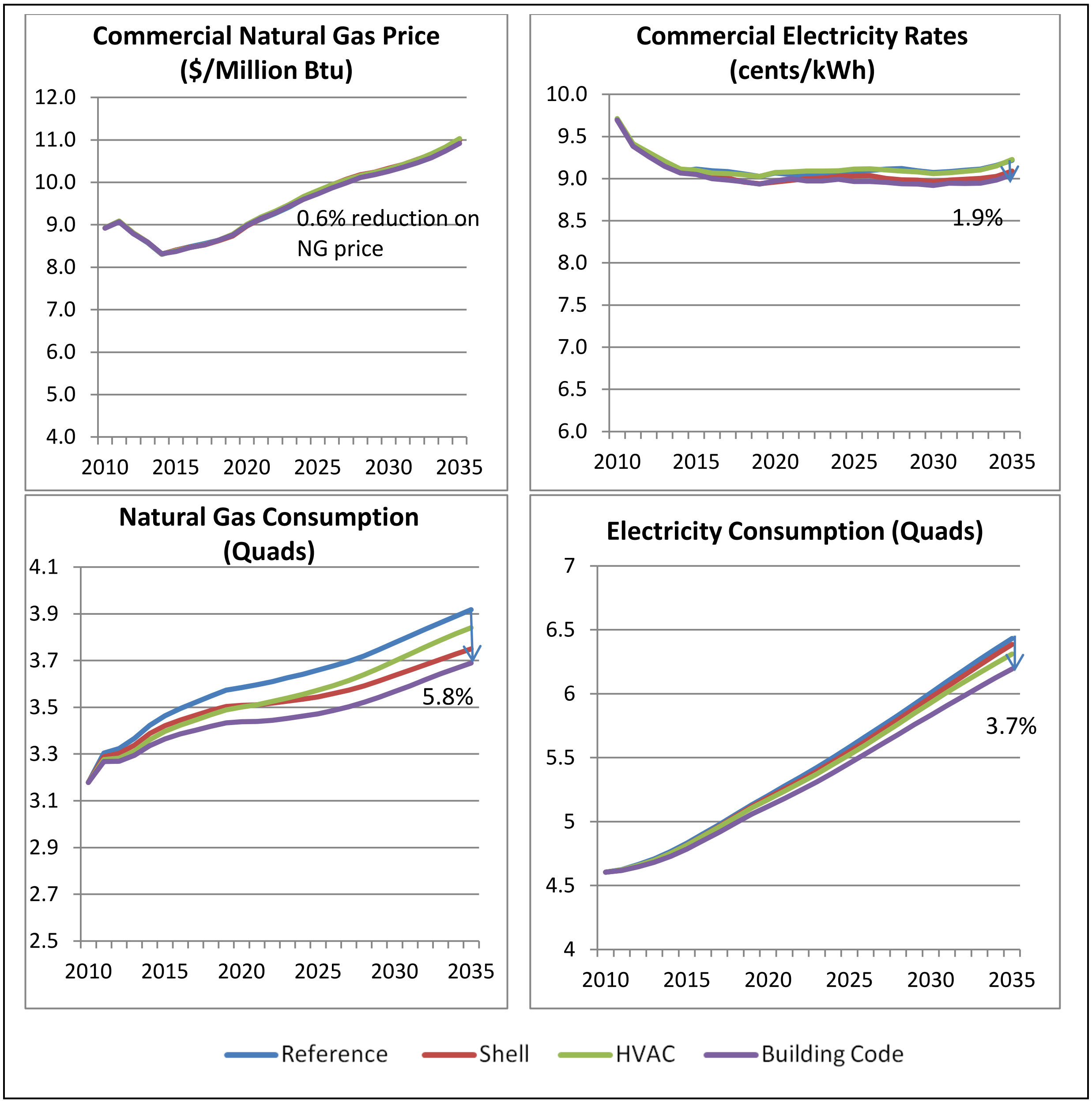

Figure 3. Commercial Sector Natural Gas and Electricity Rates and Consumption: Building Code Scenario Versus Reference case

Table 6. Energy Expenditures (Billion 2009-$)

Year	Decrease in Energy Expenditures: Annual	Decrease in Energy Expenditures : Cumulative*
2020	5.3	27.3
2035	12.8	104.6

*Presented values at calculated using a 3% discount rate

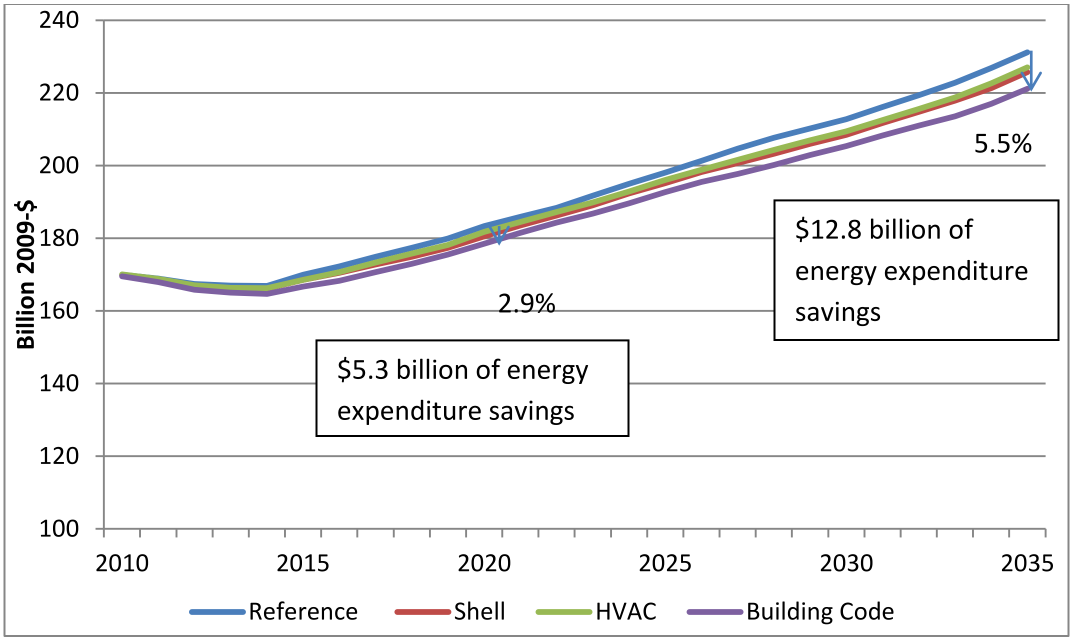

Figure 4. Commercial Sector Energy Expenditures (in Billion 2009-$): Building Code Scenario Versus Reference case

4.3 Impacts on CO_2 Emissions from Commercial Buildings

Our analysis suggests that the building codes policy would reduce the CO_2 emissions from the commercial building stock at a pace that is comparable to the energy consumption reduction in the sector. Natural gas related CO_2 emission falls by 5.8% by 2035, barely higher than the decline of natural gas consumption. Emissions from commercial electricity use would decrease by 3.2% in 2035 relative to the Reference case, a rate that is slightly lower than the sector electricity consumption reduction. The similar scale of consumption and emission reduction indicates that our policy's impact on power sector fuel composition is minimal. In fact, the power sector under the building code scenario only reduces its emission by 23 million metric tons (0.9%), as Figure 5 shows. The amount is smaller than the total emission reduction from the commercial sector, indicating the power sector is relative unresponsive to the policy.

A closer look at the fuel composition in the power sector shows almost identical fuel mix between the building code scenario and the Reference case. Hence, we can conclude that unlike a carbon tax policy, the commercial building codes policy would likely affect sectoral emission to only a modest extent and it does not transform the carbon intensity of the power sector.

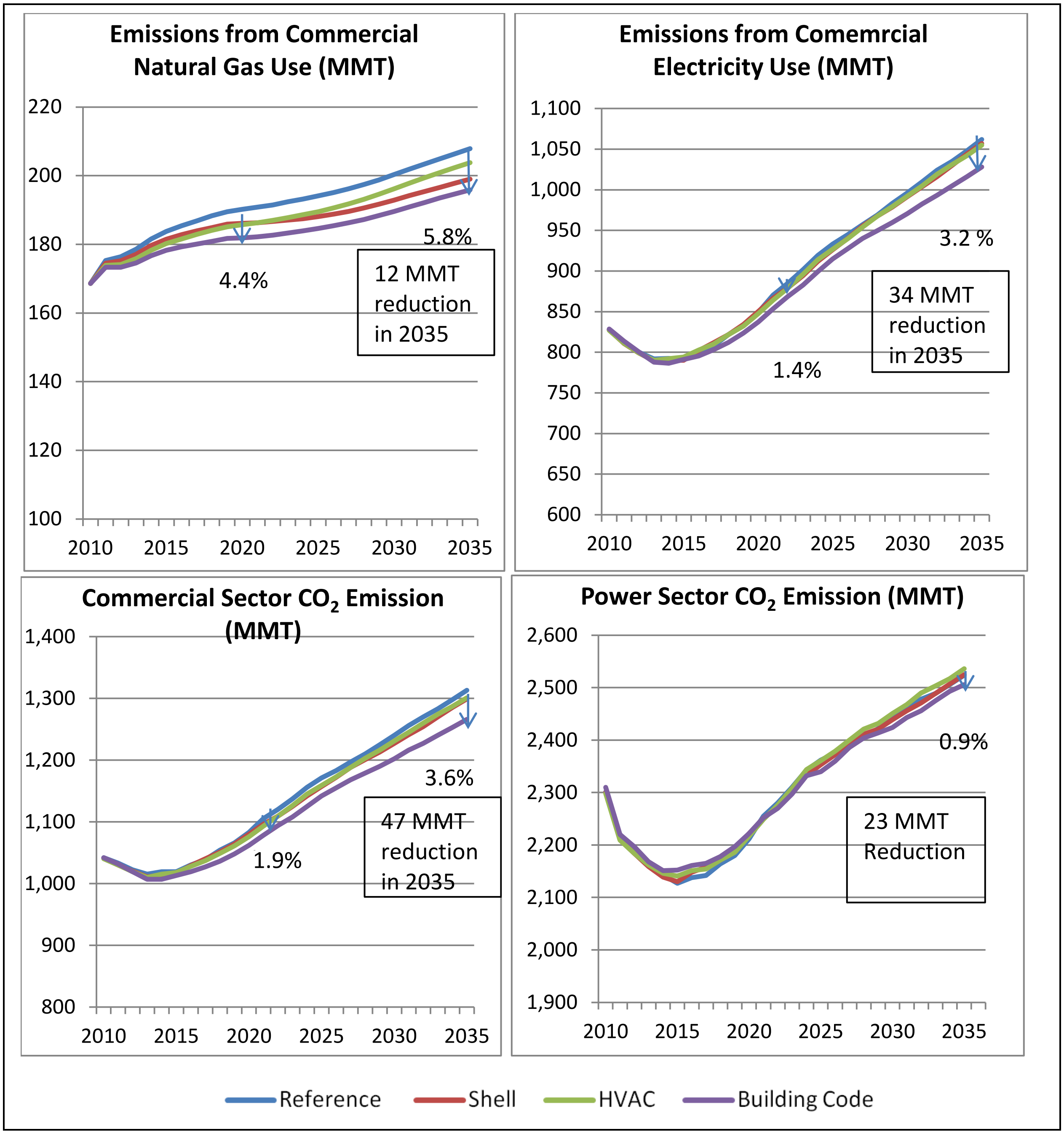

Figure 5. CO_2 Emission Reductions from the Commercial and Power Sectors: Building Code Scenario Versus Reference case

4.4 Impacts on Investment Costs, Shell Efficiency Improvement Cost, and GDP

As earlier mentioned, the commercial building codes policy modeled in this study has limited impact on national GDP. Table 7 illustrates the GDP change between the reference and the building code scenario. The policy would first have a modest negative impact on the national economy in the near term with at most $4 billion decrease in GDP in 2019 and 2020. Starting from 2022, the economy under the policy scenario would grow at approximately the same pace as in the Reference case; and in the case of 2026 to 2032, the policy scenario economy would even outpace the Reference case economy by $1-3 billion. The economy would eventually slow down slightly by 2035. The Reference case predicts that the national economy would reach $28,217 trillion in 2035; the implementation of the commercial building codes policy would lower the GDP by $3 trillion, which is equal to less than an hour of national production.

Table 7. Commercial Building Code's Impact on National GDP

	2015	2020	2035
Reference (Trillion 2009-$)	16,847	19,138	28,217
Building code (Trillion 2009-$)	16,847	19,140	28,214
Change (%) (Trillion 2009-$)	0% (-2)	0.01% (-4)	-0.01% (-3)
GDP Delay (Hour)	0.6	2.0	0.7

Under the aggressive building codes policy, new commercial buildings and buildings that undergo major modifications are subject to the equipment standards. As a result, more energy-efficient equipment would be deployed, which leads to significant energy savings as shown earlier. However, there are costs associated with the equipment upgrades. GT-NEMS does not directly calculate the capital investment costs to upgrade the end-use equipment including space heating and cooling, water heating and lighting equipment. Nevertheless, it provides the unit cost, coefficient of performance and capacity factor for each commercial technology and the service demand it fulfills. Based on this information, we developed a spreadsheet analysis tool that calculates the capital investment cost for every end-use technology vintage in the commercial sector and use it to analyze the equipment investment costs under both the reference and building code scenarios.

The results show that the aggressive building codes policy would cause commercial buildings in the U.S. to spend $6.9 billion more on purchasing and retrofitting end-use equipment in 2020. The vast majority of these additional expenditures (92%) would be spent on space heating and cooling end-uses. The annual total incremental costs to upgrade equipment and renovate buildings stay above $7 billion between 2012 and 2029 before dropping to $6.9 billion in 2035. These slightly front-loaded investment costs are caused by the equipment standards that limited the application of cheaper but inefficient commercial equipment that was scheduled to enter the market during the 2007 and 2020 period in the Reference case. The cumulative incremental investment costs are estimated to reach $127 billion in 2035 (Table 8). Using the area of commercial floorspace reported by the 2003 Commercial Building Energy Consumption Survey (EIA, 2006a) and the growth rate of commercial floor space provided by GT-NEMS, we estimate that the building code scenario would require a $96 additional equipment investment for each thousand square feet commercial building space in 2020 and this additional cost stays mostly below $100 per thousand square feet commercial space in the post-2020 period.

Table 8. Social Benefit/Cost Analysis of Building Code*

(Billions 2009-$)

	Cumulative Social Benefits				Cumulative Social Costs				Benefit/Cost Analysis	
Year	Energy Expenditure Savings	Value of Avoided CO_2	Value of Avoided Criteria Pollutants	Total Benefits	Higher Equipment Outlays	Building Shell Improvement Cost	Administrative Costs	Total Costs	Social B/C Ratio	Net Social Benefits
Commercial Sector										
2020	27.9	1.5	-3.5	25.9	60.2	1.5	0.6	62.3		
2035	109.9	17.3	0.7	128	126.9	3.5	1.4	132		
Total Impact**	160.5	27.0	3.5	191	126.9	3.5	1.4	132	1.4	59
National										
2020	47.5	1.4	-1.9	47.0	60.2	1.5	0.6	62.3		
2035	165.7	10.1	1.9	177.7	126.9	3.5	1.4	131.9		
Total Impact**	242.1	15.8	4.3	262.3	126.9	3.5	1.4	131.9	2.0	130

*Present values were calculated using a 3% discount rate.

**The total impact accounts for the energy savings and its related benefits occurred throughout the lifetime the commercial equipment, assuming an average lifetime of 20 years.

GT-NEMS does not provide a direct estimate of the costs associated with shell efficiency improvement either. As discussed earlier, the building shell efficiency improvement is handled by increasing efficiency indices over a 32-year period for the existing and new building stock; the model does not include the cost and efficiency information on building shell technologies. Therefore, it is impossible to use endogenous NEMS data to complete the building shell improvement cost calculation.

As an alternative, we conducted a literature review and found the Brown and Dirks (2000) estimate that the average cost for building shell efficiency improvement among federal buildings is $324.57[23] per thousand square foot. The 2003 Commercial Building Energy Consumption Survey (EIA, 2006b) contains the number and square footage of buildings that were built before 1980 and went through various types of renovation. Among the renovation types, wall or roof replacement, window replacement, and insulation upgrades fall into the building shell efficiency improvement category defined in this study. However, because the number of buildings and their square footage are not mutually exclusive among the renovation types in CBECS, we estimated a higher bound (when the buildings are perfectly mutually exclusive among different

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[23] CPI adjusted.

renovation types) and a lower bound (when renovation type with the largest square footage, i.e., wall or roof replacement, encompasses the other two types), and then we used the average of the higher and lower bounds as the estimate of pre-1980 commercial floor space that conducted building shell improvement. We further assume the same portion of buildings that were built after 1980 undertook or will conduct shell efficiency improvement projects, and the projects will be equally spread between 1980 and 2035. This method gives us an annual building shell renovation rate of about 0.7% (a range between 0.4% and 0.9%) for the existing commercial building floor. Using the cost estimate given by Brown and Dirks, the annual investment cost to improve building shell efficiency would be \$0.20 billion in 2020 and \$0.24 billion in 2035. The cumulative cost to improve the building shell efficiency amounts to \$1.5 billion by 2020 and \$3.5 billion by 2035 as shown in Table 8.

The policy studied in this paper also includes building code enforcement carried out by state building code officials and inspectors. The administrative costs are based on each state's adding one administrative office requiring \$150,000 per annum and one code official at \$75,000 salary per annum. It also includes two additional building code inspectors for the verification of every 100 million square feet in the state at \$75,000 per year (Brown et al., 2009). The overall cumulative cost of the building codes policy is estimated to be \$60.2 billion by 2020 and rises to \$127 billion by 2035 (Table 8).

Tables 8 summarizes the social benefits and social costs of the building codes policy within the commercial sector. The value of avoided CO_2 is evaluated at the social cost of carbon suggested by the inter-agency working group (EPA, 2010). The value of avoided pollutants is calculated using estimates published in a National Research Council report (NRC, 2009). These two benefits from the avoided emissions plus the reduction in energy expenditure complete the social benefit of this aggressive building codes policy.

The result of the benefit-cost analysis suggests that the cumulative benefits within the commercial building sector outweigh the cumulative costs by \$59 Billion by the time the full impact of the policy ends. It translates into a positive benefit-cost ratio of 1.4. Therefore, we conclude that a national aggressive building codes policy is cost-effective in both the short and long term for the commercial building sector.

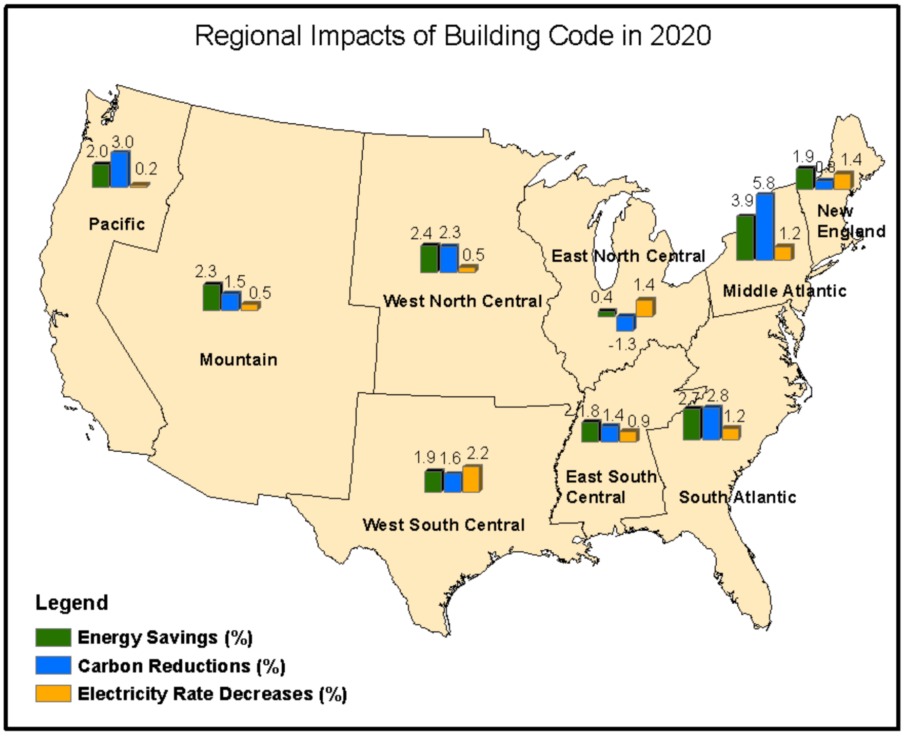
The commercial building codes policy appears to be more favorable from the national perspective. The efficiency measures taken place in the commercial sector not only reduce the energy price to commercial consumers but also the cost to consumers from other sectors of the economy. This positive spillover effect is estimated to lead to more than 1% decline in both residential electricity and natural gas price and a 2% reduction in those prices in the industrial sector. Although the cheaper energy prices could cause a slight consumption rebound in these two sectors, the level of this rebound effect is a magnitude smaller than the rate decline. The highest consumption rebound among major fuel types is observed at year 2035 in residential electricity consumption, but it is less than 0.3% relative to the Reference case. As a result, the residential and industrial consumers would experience sizable energy expenditure savings: the commercial building codes policy would save \$0.82 billion and \$1.13 billion for the residential and industrial consumers in 2020, respectively, and \$2.2 billion and \$3 billion in 2035, as it is shown in Table 8. The cumulative national energy expenditure savings amount to \$242 billion by the time the impact of this policy ends. The modest fuel switching from electricity to natural gas would lead to a greater avoided CO_2 emission and criteria pollutants benefits at the national level. The overall total social benefits would reach \$262 billion, twice as much as the costs to implement the commercial building codes policy, leaving society a net social benefit of \$130 billion.

4.5 Variations Across Regions and Building Types

The costs and benefits of the building codes policy would vary geographically. Although all Census divisions would save energy in the building codes scenario, the savings in 2020 relative to the Reference case see a wide range, from 0.4% in East North Central to 3.9% in Middle Atlantic, as shown in Figure 6. The energy savings would continue to expand over time, with all divisions cutting their energy consumption by at least 3% in 2035 (Figure 6). According to our GT-NEMS analysis, the Middle Atlantic would have a quick response to the building codes policy, reducing almost 4% of its total energy consumption in 2020 and then maintaining a steady energy savings through 2035. Unlike its neighboring Census division, New England would respond to the policy relatively slowly; the energy saving in the division is the second lowest in 2020 (1.9%, only higher than East North Central). However, its energy savings quickly increase after the initial slow response as the stringent appliance standards replace the low-efficiency equipment in the region, especially the low-efficiency natural gas space furnaces and boilers. As a result, energy savings in New England could reach 7.2% in 2035.

Carbon emissions generally track energy consumption reductions, decreasing in all nine divisions in 2020 except East North Central. Reductions in CO_2 emissions range from 0.8% in New England to 3.0% in the Pacific division in 2020, and the gap is further widened in 2035, reflecting the different capability of Census divisions to switch away from fossil-fuel-based electricity. However, unlike the trend in other divisions, CO_2 emissions in East North Central would see a 1.3% increase in 2020. A close look at the region's electricity generation profile indicates that East North Central is a heavily coal-dependent region and it would embrace more coal in its power sector in the first ten years after the building codes policy is implemented. This abundant coal use leads the region to a lower electricity rate and it spurs more consumption. Therefore, even though the electricity rate in East North Central decreases as it does in all other regions, the cheap coal effect outweighs the consumption reduction due to the building codes policy, resulting in a higher consumption level. The same effects also make East North Central the only region in the country that increases its carbon emissions in 2020 (Figure 6). However, the significance of coal gradually declines after 2021 while the building codes policy continues to drive the rate down. The region eventually turns into a carbon-saving region, and would reduce its energy consumption by 4.0% and carbon emissions by 3.2% in 2035. New England would also experience a similar resurgence of coal between 2015 and 2030, which results in modest CO_2 emission reductions until the last five years of the study period. Unlike these two Census divisions, the Pacific and Middle Atlantic Census divisions are forecasted to reduce generation from coal-fired plants in response to the declining demand for electricity, producing significant emission reductions in 2020 (Figure 6). Although this trend slows down in the later period in these two divisions, New England would switch from consuming more coal-based electricity to reducing it. Coupled with strong energy saving, the carbon emission reduction in New England would reach 8.6% in 2035, the highest of all divisions.

As a result of less energy demand from commercial buildings (and the cheap coal effect in divisions mentioned above), all divisions would enjoy lower electricity rates in the commercial sector in 2020 relative to the Reference case rate forecast. Nevertheless, the rates escalation is dampened to various degrees, from 0.2% in the Pacific region to 2.2% in West South Central. The tradeoff of having a less carbon-dependent electric grid in the Pacific division is that the electricity rate would remain relatively high in those states even with declining energy consumption. In contrast, West South Central would continue to enjoy lower electricity rates in the post-2020 period due to the increasing generation from base-load plants like conventional coal-fired plant and less from more expensive combined cycle plants. In 2035, the electricity rates escalation forecasted in the Reference case would be further dampened under the Building Codes Scenario in most regions except for New England and East North Central. The rate in New England would grow 1.4% less in 2020, compared to the Reference rate projection, but only 0.5% less in 2035. This is because after expanding the generation from conventional coal-fired plants in the initial period, the region is forecasted to retire more coal-fired plants starting from 2030 while keeping the relatively more expensive oil and natural gas steam engines online, which lead to a smaller rate reduction in the division comparing to other regions.



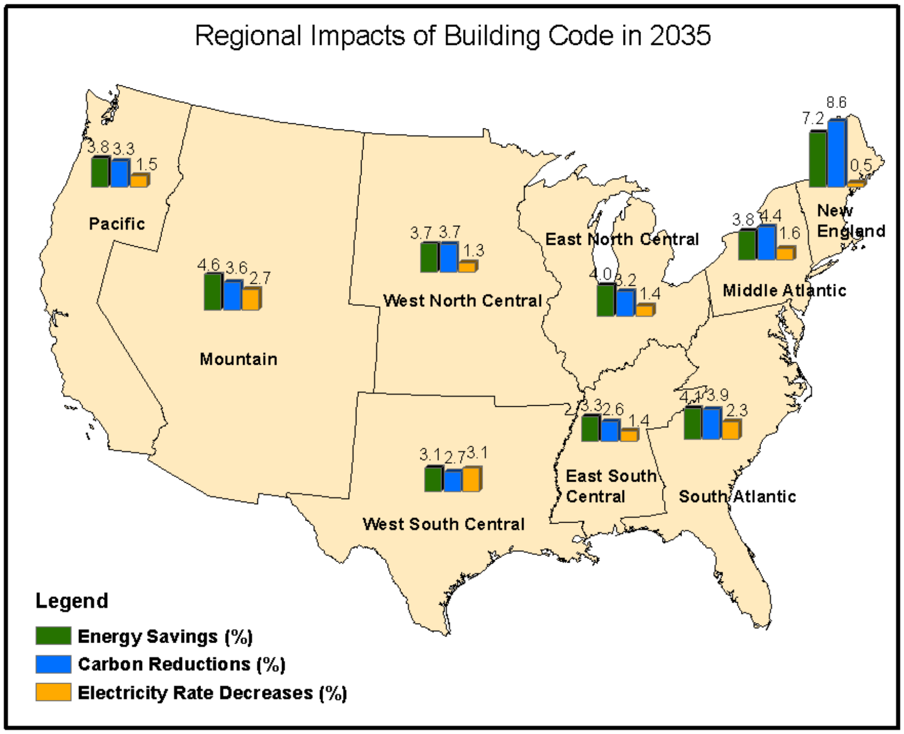


Figure 6. Commercial Energy Consumption, Carbon Emissions and Electricity Rates by Census Division in 2020 and 2035

Chronologically speaking, the energy savings from the commercial building codes policy are slightly back-loaded in all building types. By 2020, all types of buildings except food sales and large offices could achieve at least 4% of primary energy savings (Figure 7). All building types except health care buildings would continue to get deeper energy savings in later years, and they would achieve greater than 4% primary energy saving in 2035. Mercantile buildings are the largest energy consumer in the commercial sector; and also have the largest energy saving potential under the building codes policy. Mercantile buildings would reduce their overall energy consumption by 91 trillion Btus in 2020 and double the 2020 saving in 2035, which is equal to 8% of its total energy use. In contrast, food retailers have the smallest share of energy consumption among all commercial building types and smallest energy saving potentials, too. Health care buildings is the only building type that saves relatively less energy in later years, although the absolute energy reduction in 2035 (36 trillion Btus) almost doubles the 2020 reduction (20 trillion Btus).

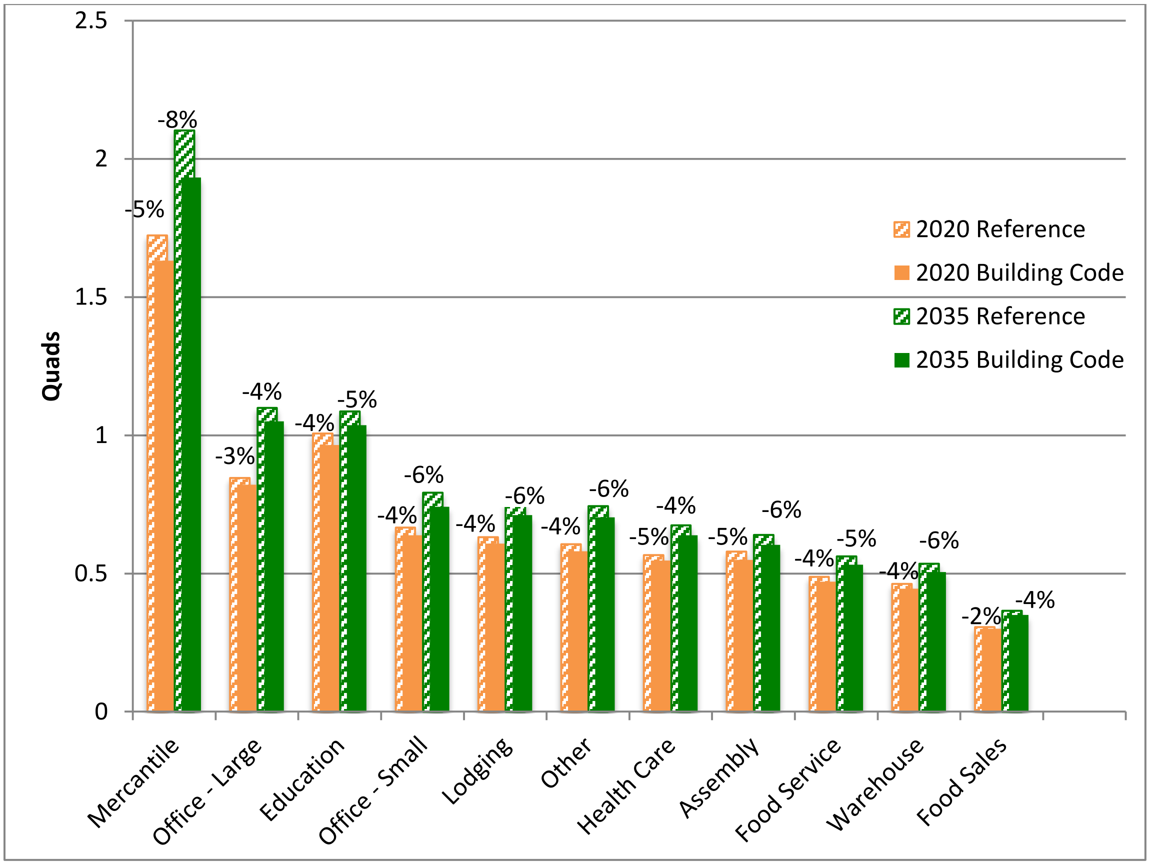


Figure 7. Energy Savings by Building Type

4.6 Technology Shift

One would expect that more stringent efficiency standards for end-use technologies could stimulate the adoption of high-efficiency commercial equipment in the four targeted end-uses, which in turn could lead to less deployment of low-efficiency technologies. A comparison between the service demand of commercial end-use technologies from the Reference case and the building code scenario confirms this trend (Table 9).

The term “ascendant technologies” is used to describe technologies that see more adoption in the building codes scenario than in the Reference case. Conversely, “declining technologies” are those that lose service demand because of the implementation of the policy. Table 9 presents the technologies that gain or lose the most service demand in each end-use, although there are more technologies with changing service demand than it is presented here.

Among all electric space heating technologies, ground source heat pumps with a Coefficient of Performance (COP) of 3.5 gains the most service demand throughout the study period. Although the same model with investment tax credit is favored early on in the market. The attraction of this technology does not phase out when the tax credit expires in 2020, it continues to be the technology that experiences the most market gain till 2035. A similar ground source heat pump technology with even higher efficiency (COP=3.8) also gains service demand under the building code scenario, but the adoption is limited by its more expensive price tag. Rooftop air source heat pumps would see a significant service demand decline, greater than the service demand gains of all the ascendant technologies, due to both the rising demand for high-efficiency technologies and the shrinking overall space heating service demand because of the tighter building shell efficiency. Low-efficiency electric boilers under the building code scenario would also lose a big part of its market share in the Reference case, which is expected because its availability has been limited to only 2012 and earlier. Similarly, the overall service demand for natural gas space heating declines and low-efficiency gas furnaces (78-80% efficiency) are replaced by high-efficiency gas furnaces (94% efficiency) that are available to the market in the early stage (starting from 2010).

In electric space cooling, mid-efficiency rooftop AC (COP=3.28) with a relatively low cost would gain the most service demand, replacing a similar but more expensive model because the former makes more economical sense to the consumers. Low-efficiency centrifugal chillers (COP=4.69) would also exit the marketplace, giving space to high-efficiency centrifugal chillers (COP=7.0). The same high-efficient centrifugal chiller technology would also replace the inefficient reciprocating chillers early in the study period.

Mid-efficiency heat pump water heaters (COP=2.3) and high-efficiency solar water heaters (COP=2.5) are the biggest winners in electric water heating end-use under the building codes policy. As it is expected, they would replace the electric water heater, which would recede after 2012. The cost of the mid-efficiency heat pump water heaters would decline over time, which would result in consumers purchasing cheaper heat pump water heaters. However, cost does not seem to be a limiting factor for solar water heaters. The market for solar water heaters continues to expand even after the initial investment tax credit expires. On the natural gas water heater side, the technology shift trend is simply moving from mid-efficiency gas water heaters (COP=0.93) to the high-efficiency ones (COP=0.95). The market shares of other water heater technologies mostly remain intact.

Table 9. Building Codes Scenario Versus Reference Case

End Use	2010-2020	2020-2035
Electric Space Heating		
– Ascendent Technologies	Ground source heat pumps with investment tax credit (COP 3.5)	Ground source heat pumps (COP 3.5)
– Declining Technologies	Rooftop air source heat pumps (COP 3.3)	Rooftop air source heat pumps (COP 3.3)
Natural Gas Space Heating		
– Ascendent Technologies	High-efficiency gas furnaces (94%)	High-efficiency gas furnaces (94%)
– Declining Technologies	Low efficiency furnaces (78-80%)	High efficiency gas (94%) furnaces coming to market in 2020 and 2030, and low efficiency gas furnaces (80%) coming to market in 2020 and 2030
Electric Cooling		
– Ascendent Technologies	Mid-efficiency (COP 3.28) rooftop AC; high-efficient centrifugal chillers (COP 7.0)	Mid-efficiency (3.28 COP) rooftop AC; high-efficient centrifugal chillers (COP 7.0)
– Declining Technologies	More expensive mid-efficiency rooftop AC, Reciprocating (COP 2.34) and centrifugal chillers (COP 4.69)	More expensive mid-efficiency rooftop AC, and centrifugal chillers (COP 4.69)
Electric Water Heating		
– Ascendent Technologies	Mid-efficiency (COP 2.3) heat pump water heater; high-efficiency (COP 2.5) solar water heater used in the South with ITC	Mid-efficiency (COP 2.3) heat pump water heater with lower cost; high-efficiency (COP 2.5) solar water heater used in the South
– Declining Technologies	Low-efficiency (COP 0.97) electric water heater	Low-efficiency (COP 0.97) electric water heater
Natural Gas Water Heating		
– Ascendent Technologies	High-efficiency (COP 0.95) gas water heater	High-efficiency (COP 0.95) gas water heater
– Declining Technologies	Mid-efficiency (COP 0.93) gas water heater	Mid-efficiency (COP 0.93) gas water heater
Lighting		
– Ascendent Technologies	High-efficiency F32T8 (63.6 Lumens/Watt); Mid-efficient (86.8 Lumens/Watt) less expensive LED	High-efficiency (181 Lumens/Watt) LED
– Declining Technologies	Low-efficiency F32T8 (56.4 Lumen/Watt); low-efficiency (84.6 Lumens/Watt) more expensive LED	26W CFL (41.3 Lumens/Watt)

Lighting technologies show a diverse trend over time. Because the building codes policy eliminates the low-efficiency florescent light bulb F32T8 starting from 2012, the market niche that used to be fulfilled by this technology in the Reference case would shift to a more energy efficient models of F32T8 under the building code scenario between 2012 and 2025. During the same time, affordable mid-efficiency LED technologies would also be adopted in a larger scale to replace those less efficient but more expensive LED light bulbs. However, after 2025, the technology trend changes completely from the pattern described previously to shifting away from CFLs to high-efficiency LEDs, due to the steady decline of LED cost. This trend is so predominant that it accounts for over three quarters of the shifted service demand among all lighting technologies in 2035.

5. Conclusions

This paper analyzes an aggressive commercial building codes policy that would require better building shell performance and more efficient space heating, cooling, water heating and lighting equipment. Under such a policy, the building shell efficiency of new construction would increase by 30% by 2035 comparing to the 2003 baseline shell efficiency; existing buildings that conduct major modifications would experience a 19% improvement over the same period. Space heating and cooling technologies as well as water heating and lighting equipment that are below the ASHRAE Standard 90.1-2007 efficiency requirements would no longer be available for purchase in the marketplace.

We estimate that this aggressive codes policy could reduce the energy consumption of commercial buildings by 0.43 Quads in 2020 and 0.94 Quads in 2035, which represent 2.1% and 4.0% of the sector's annual energy consumption. Among the four targeted end-uses, water heating is most responsive; it would use 19.6% less primary energy in 2035 under the building codes policy scenario relative to the Reference case. Space heating and cooling would reduce the primary energy consumption by 16.4% and 14.5%, respectively, in 2035. Energy use in commercial lighting would also see a 5% decrease. From the delivered energy perspective, electricity has less on-site energy saving potentials than natural gas under the building codes policy. Although both forms of energy could achieve 0.23 Quads of energy savings in 2035, on-site natural gas consumption would be reduced by 5.8% by 2035 while electricity consumption would decline at a more modest pace, 3.9% by 2035. However, after the electricity related losses are incorporated, the total electricity related primary energy saving sum up to 0.69 Quads in 2035, which is three times as much as the natural gas energy saving.

Although the impact of the aggressive codes policy on natural gas price is modest, only 0.6% reduction in 2035 relative to the Reference case, commercial electricity rates could drop by 1.9% by 2035, significantly offsetting the Reference case trend, which forecasts an average annual electricity rate increase of 0.1% between 2012 and 2035. As a result of reductions in both energy consumption and energy prices, the commercial building sector would save $5.3 billion (2.9%) and $12.8 billion (5.5%) respectively in 2020 and 2035. The avoided CO_2 emissions resulting from the avoided commercial sector energy consumption are estimated to amount to 47 MMT in 2035, a 3.6% drop from the Reference case. The similar scale of consumption and emission reduction reflects the fact that the building codes policy does not impact the carbon intensity of the sector. CO_2 emission reductions from electricity savings account for more than 70% of the total CO_2 emission reduction, although natural gas has larger relative percentage reductions. Furthermore, different Census divisions also face different degree of energy savings, energy price changes, and CO_2 emission reductions.

Our analysis suggests that an aggressive commercial building codes policy could be cost-effective. It would have minimal impact on the national economy (no more than two hours of the national productivity would be sacrificed). In addition to the reduction in energy expenditure, the commercial sector and society would also benefit from avoided CO_2 emission. The total cumulative social benefits (both private and public benefits included) stemmed from the commercial sector could reach $128 billion by 2035 and increase to $190 billion by the time the impact of the policy ends. The benefits are estimated to outweigh the investments needed to realize the goals by 1.4 times, resulting in estimated net social benefits of $59 billion. The efficiency measures taken place in the commercial sector also have a positive spillover effect on other parts of the economy such as the residential and commercial sectors, resulting even greater net social benefits of $130 billion for the entire U.S. economy.

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