White Paper

The Cost and Effectiveness for Health, Safety, and Security of Energy Conservation Systems in 3 to 6 Unit Residential Buildings

Issued by the
State Board of Building Regulations and Standards

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Abstract

This White Paper examines:

1. energy code requirements through various changes in the MA state building code. Since 1994 more energy systems are regulated; since 2003 the code change cycle has been shortened to 3 years; and since 2008 there exists in effect two different state energy codes (base and 'stretch'),
2. the effect on annual heating and cooling loads from changes to various building thermal envelope components for 3, 4, and 6 unit low rise residential buildings. For example, an increase in ceiling insulation (an R-value change from 38 to 49) for the 3-Unit building reduced the total annual heating load by 1.7 MMbtu for a yearly savings of $23.

and recommends:

3. issuance of a stretch code that is identical to the base code performance compliance path with the exception of the value of the performance target,
4. setting identical effective dates for the base and stretch codes and fix all energy code changes for a predetermined period of years,
5. development of a code change proposal for 3, 4, and 6 unit residential buildings that incorporate conclusions and recommendations of this paper and the paper on fire protection systems

Section 1: Introduction

The Massachusetts Board of Building Regulations and Standards (BBRS) is a Massachusetts Board of eleven members established by M.G.L. c. 143, §93 , nine of whom are appointed by the Governor. The BBRS is authorized by M.G.L. c. 143 §94 (h) to formulate and periodically update the state building code, which has been in effect since 1975. Additionally, the BBRS has a statutory duty pursuant to M.G.L. c. 143, §94 (c) *"[to] make a continuing study of the operation of the state building code, and other laws relating to the construction of buildings to ascertain their effect upon the cost of building construction and the effectiveness of their provisions for health, safety, energy conservation and security."* [1] No Massachusetts board with oversight of construction including the plumbing code, the electrical code, the sheet metal code, or the fire code, has the same duty.

The price of homes in MA and the USA is a function of many market variables including the health of the national, state, and local economies, which influence supply of and demand on the housing stock. However, irrespective of other variables one thing is certain; the type and quality of building construction for new or existing residential units can be directly tied to the purchase price of a home. For example, two new homes, constructed by the same builder on identical and adjacent parcels of land; one built to the 4th edition of the code and the other built to the 8th edition of the code will not be priced equally, because more code regulation almost invariably leads to higher construction costs.

Although the public has an opportunity via M.G.L. c. 30A, §20 to provide comment to the BBRS, the citizens of the Commonwealth are not really 'at the table' with the BBRS. Instead, building officials, fire officials, builders, code consultants, and others associated with the building industry are the usual participants; each advocating for a special interest. Without actual widespread public comment the BBRS seeks to protect the interests of the consumer and maintain an independent and reasonable approach when reviewing and promulgating building code requirements.

The BBRS has prepared this paper to assist in meeting its statutory obligation to continually review the cost of construction and to assure that for all building code requirements there is commensurate energy conservation, health, or life safety benefit. Onerous and costly code requirements too often have a negative ripple effect, for example; the owner will meet the requirement and increase unit rent or sale price to offset the construction costs; the owner will take units out of service[2] which further exacerbates an already tight housing market; or the owner will do cosmetic touch up and avoid high cost items that the code may require. Thus, if the energy conservation, health, or life safety benefits do not justify the cost then it is the responsibility of the BBRS to explore alternatives such as reducing or eliminating the requirement.

Section 2: Background

This section contains a timeline[1] of various editions of the Massachusetts State Building Code (780 CMR or the 'code') and a general description of the scope of requirements and on what national or local standard(s) it was based on.

1st and 2nd Editions	1/1/1975.
3rd Edition	6/1/1979.
4th Edition	9/1/1980.
5th Edition	3/1/1991.
6th Edition	2/28/1997 (Commercial) and 1998 (One- and Two-Family)
7th Edition	9/1/2008 (Commercial) and 1/1/2008 (Residential)
8th Edition	8/6/2010 (Commercial) and 2/4/2011 (Residential)

The early editions of the code were influenced by the Boston Building Code, while later editions were based on commercial codes issued by Building Officials and Code Administrators International, Inc. (BOCA), and the one and two family codes issued by The Council of American Building Officials (CABO). The 7th and 8th editions were based on the International Code Council (ICC). The ICC codes are in use to some extent by many states.

The 1st through 6th Editions were unique MA documents that utilized the BOCA Code requirements for commercial buildings and the CABO Code for one- and two-family dwellings. Both the BOCA and CABO codes were modified to incorporate unique MA requirements.

The 7th Edition utilized the ICC's *International Building Code 2003* and the *International Residential Code 2003* and incorporated a significant quantity of unique MA requirements into these documents.

The 8th Edition utilized the ICC's *International Building Code 2009* and the *International Residential Code 2009*, but placed the unique MA requirements in a separate document. In this manner it was much easier to see the sheer number of additional requirements that building owners and developers in the Commonwealth need to deal with. All of the New England states use some version of the ICC codes, and none has as many requirements as MA. Two points of this edition change should be highlighted: 1) the BBRS directed its technical advisory committees to make the 8th edition 'with equivalent life safety' to the 7th edition, in essence meaning that a building constructed to either edition would have similar code requirements; and 2) the technical advisory committees were not explicitly directed to consider the cost of construction in this effort. However, in 2011 the BBRS directed its advisory committees to review unique MA requirements which add to cost of construction relative to the requirement as found in the *International Building Code 2009* (IBC). As a result of this effort[2] many MA requirements were removed from the code.

Over the past several decades the code has undergone regulatory expansion[3] including, but not limited to:

- *Energy conservation* due to national initiatives on climate change and energy dependence on foreign supplies of oil, etc. For residential buildings this has resulted in requirements for air tight buildings and the need to hire experts to verify building performance via blower door and duct leakage testing. Recently mandatory mechanical ventilation is required. In addition the Commonwealth was the first state in the nation to develop and utilize a Stretch Energy Code (Appendix 115AA) which in turn heavily influenced the development of the *International Energy Conservation Code 2012* to the point where blower door testing is now a standard requirement in many states across the nation.
- *Building design and construction* since 1992 when Hurricane Andrew devastated parts of Florida. Consequently, the Home Insurance Industry became heavily involved in the national code-writing process, and since 1992 the residential code has been impacted by requirements for 'hurricane fastening of framing' and 'wind-borne debris' of doors and windows.
- *Fire protection* has always been an area where the Commonwealth has invoked more requirements[4] than any other New England state. In addition, the 6th Edition of the code was likely the most stringent new construction commercial state building code in the nation as it significantly "upped the ante" and required fire sprinklers in most new commercial buildings. This was a move away from a traditional construction method which allowed an architect or engineer to separate different 'uses' in the same building with fire rated walls and ceilings. The code required many residential and commercial buildings to be sprinklered in 1997; ahead of any national code at that time. As the national codes evolved since then it is apparent that sprinkler advocates have had significant influence; the ICC codes also now require sprinklers for most uses (educational, mercantile, residential, etc.). However, key differences between the Commonwealth requirements and ICC codes and even neighboring New England states exist. As just one example a building constructed for a 'business' use in the Commonwealth requires sprinklers via M.G.L c. 148 §26G when its area is just 7500 sq ft as opposed to 12,000 sq ft elsewhere in New England and in most other states across the nation.

In summary, the BBRS has reviewed the costs of construction as the code and laws evolved from 1975 to present. The purpose of this paper is to ensure that the BBRS continues to comply with its statutory obligation to review the cost of construction in response to the concerns raised with respect to energy conservation of new and existing R-2 residential buildings. The background herein provides historical context that will be considered in the conclusions and recommendations that follow in Section 8.

Section 3: Home value vs. Income

This section examines national and local data[1] on home value and income, not including data on rental housing and income. Because the construction costs of residential buildings can be directly tied to 'price,' it is important to provide background on home affordability with regard to purchase and ownership. In the USA individuals and families, have in general been afforded a choice to either ***buy or rent a home***. The data and trends shown in the next sections indicate that fewer people in the USA including MA residents are capable of purchasing a home, which is why the BBRS should maintain a focus on the cost of construction and, when necessary, amend the code if appropriate.

Section 3a: USA Data

The US Census at 10-year intervals publishes income[2] and home value[3] data. Figure 3a shows the ratio of median home value to median household income data from the US Census at 10-year intervals. The trend in the USA from 1970 to 2000 indicates that home values are outpacing household income. Another perspective using the same data is that median US home values increased 85% (65K$ to 120K$) from 1970 to 2000 while median US household income increased 21% (43K$ to 52K$) in the same time period.

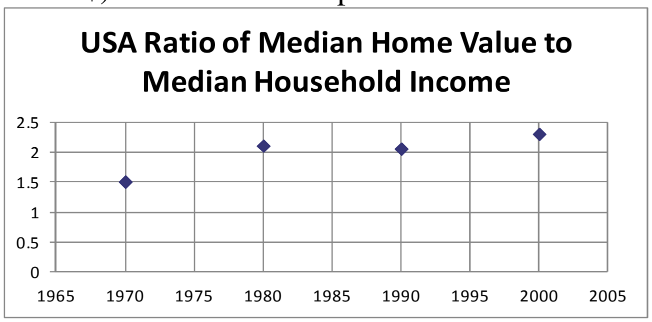

Figure 3a

Section 3b: MA Data

The national trend indicates the gap between home value and income is increasing. However, since the BBRS is focused on the MA State Building Code it is more pertinent for this paper to examine home price and income data in the Commonwealth. For this two sources of data were studied; median sale price of residential units and median household income in MA. The sale price data are from the Greater Boston Association of REALTORS[4] (GBAR) and the income data are from American Community Survey[5] by the US Census Bureau. Figure 3b(1) shows median sale price of single-family homes and condominiums in MA from 2005 to 2012 and Figure 3b(2) shows median household income for 2005 to 2012. The ratio of sale price to household income is shown in the Figure 3b(3). Although the trend of the ratio is relatively flat through the years 2005 to 2012, it should be noted that the value of the price to income ratio is nearly double the USA ratio. In other words, in the year 2000 the US median home value is about double the household income, while in the year 2012 the MA median home price is more than four times the household income.

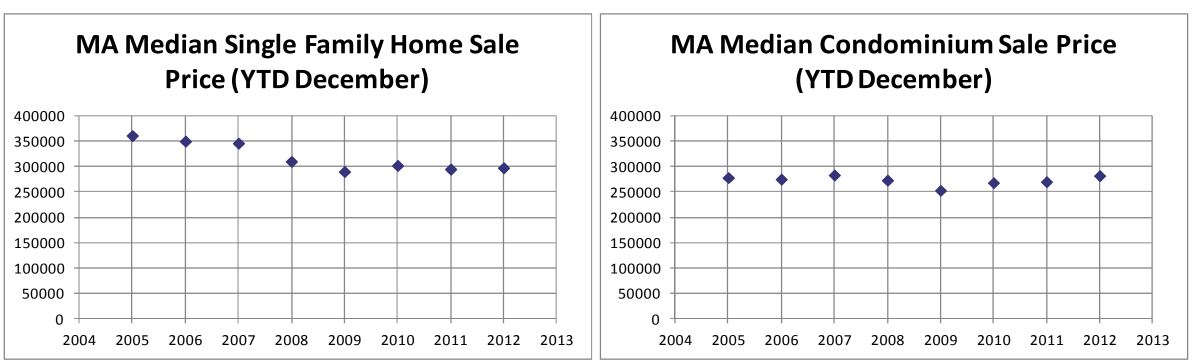

Figure 3b(1)

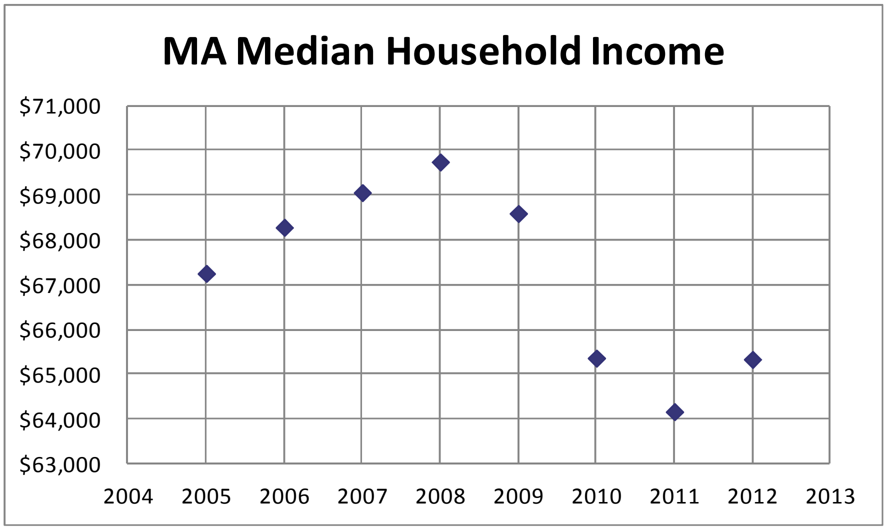

Figure 3b(2)

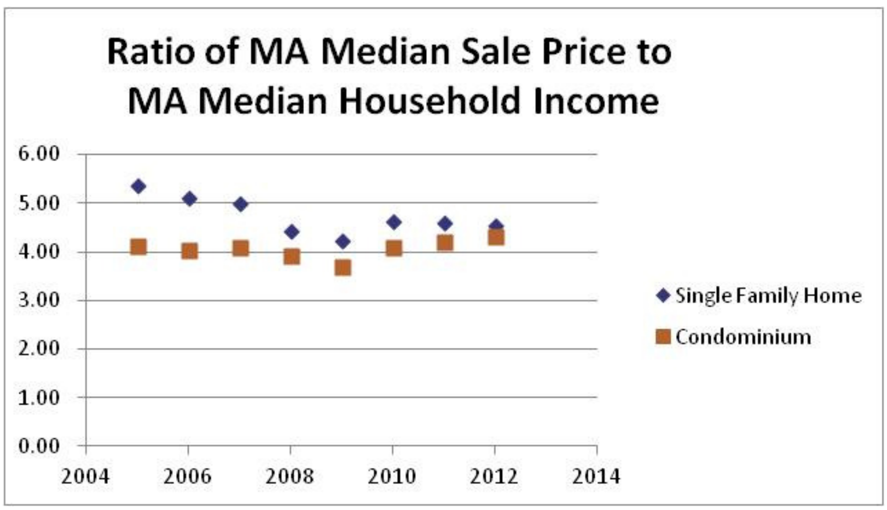

Figure 3b(3)

Section 3c: Affordability

The trends and comparisons of income and home value data appear to reveal an erosion of the ability of a household to purchase a home. Another perspective can be found by examining the method by which lenders qualify potential buyers for a home mortgage loan. There are various tools[6] available to do this. However, assumptions should be made to simplify but not skew the results. For this analysis various down payment values are used; no preexisting debt is assumed; property tax of 1% of the purchase price is used; insurance of .5% is used; and a 30-year mortgage at 4.64% APR is assumed. Figure 3c(1) shows the gross income required to qualify for a mortgage loan for a home at a particular price. For example, a household with an income equal to the 2012 MA median value of $65,300 and a down payment of $20,000 can qualify for a mortgage for a home priced at $240,000, which is $40,000 below the median condominium price in MA in 2012. This example may not even represent a realistic case because households may have existing debt or not hold a down payment of $20,000 or $40,000. And this example uses median household income[7]; the situation becomes worse for individual wage earners.

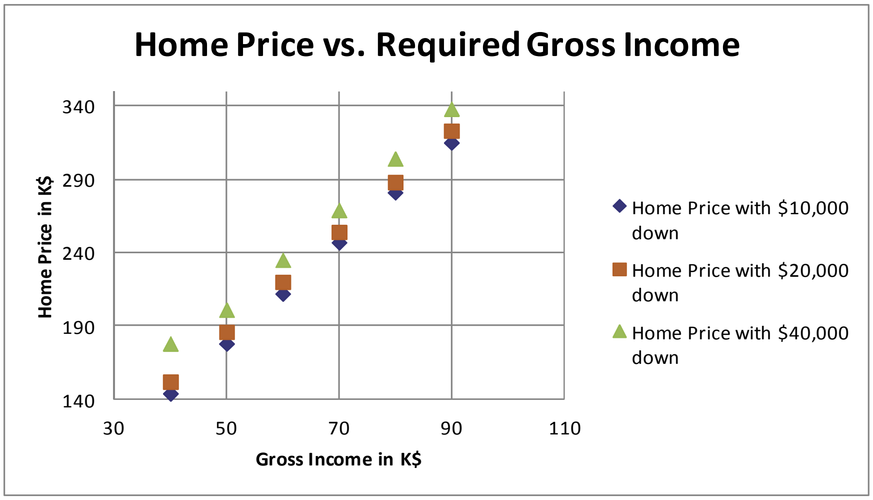

Figure 3c(1)

This review shows that 'affordability' of home ownership in MA may be much different in 2012 than it has been historically. US Census data on home ownership rates[8] is presented in Figure 3c(2), which shows the percentage of homes that are owned by the occupants in the USA and in New England. Maine, New Hampshire, and Vermont had and continue to have higher rates than the USA and the other New England states. All of New England and the USA are trending to a slower increase in ownership rates since the 1960-1970 timeframe but Massachusetts and Rhode Island significantly lag the leaders by 10% and Massachusetts lags Connecticut (a similar southern New England state) by 5%. To convert these percentages to potential persons affected by this lag the total population (2010 US Census) of the Commonwealth is 6.5 million.

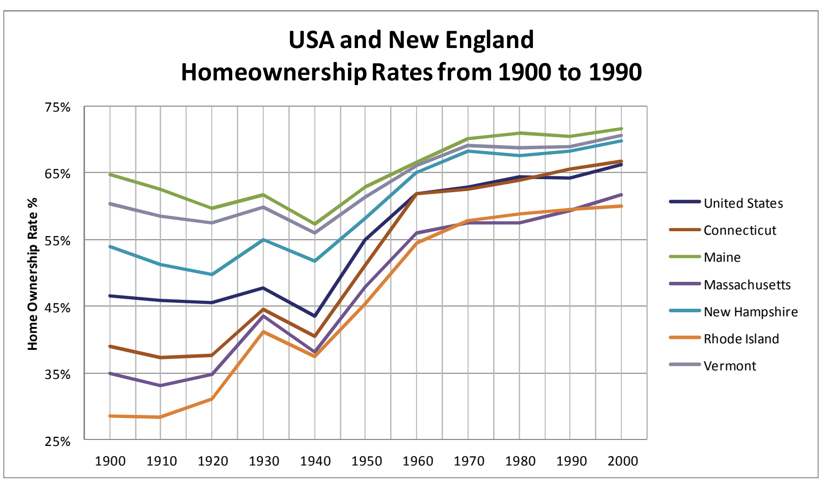

Figure 3c(2)

Numerous studies indicate that there is a shortage of residential housing in the Commonwealth, and other studies[9,10] indicate that the shortage will be deeper in greater metropolitan Boston in future years, creating unfavorable impacts to the city and state. In addition, impediments to housing development including Title V, zoning, and duplicative and conflicting building requirements are illustrated in the Executive Office of Administration and Finance Policy Report Bring Down the Barriers: Changing Housing Supply Dynamics. Although this report was published in 2000 it is still relevant in 2014. The recommendations contained in Section 8 are designed to assist in the development of safe and lower cost of construction residential units, which will facilitate the Commonwealth's effort to meet the growing demand on housing stock.

Section 4: Energy Conservation Systems (ECS) for Residential Buildings

Section 4a: Code Requirement Progression of ECS

The code for energy conservation systems (ECS) and other systems for residential buildings have steadily evolved in the past twenty years.

In 1992 the 5th edition energy conservation requirements were primarily 'prescriptive'. The energy requirements could be determined and followed in a relatively simple manner and a builder or designer could create a plan without pre consideration of these requirements. For example, 2x4 wall framing was a construction standard and this fit well with R-12.5 batt insulation which the code allowed. Other ECS like Heating Ventilation and Air Conditioning (HVAC) could be chosen from prescriptive tables as well. No computer software was needed to design the ECS and the building science of energy conservation[1] was not far along.

Since the 1990s an emphasis on energy conservation and sustainability in buildings from federal and state government and the private sector has changed this. New energy codes[2], which in the USA are dominated by the International Code Council via its publication of the *International Energy Conservation Code,* are developed and adopted nearly nationwide at three-year intervals. These new codes may represent a significant departure from existing design and construction practices[3], which requires effort on the part of building owners, developers, design professionals, and builders to understand what's changed. All of this applies to building officials who must ensure that what is built matches what is on the plans and that both meet the code.

Section 4a(1): Unique MA Requirements

The BBRS has received significant feedback on ECS. The bulk of the feedback is focused on these two recent realities: the MA energy code changes often and is not consistent state-wide[4]. This is turn creates a perpetual learning curve on technical requirements and uncertainty of where and when the regulations are in full force and effect. These two issues are problematic for owners to put a construction plan together.

It is useful to understand if the ECS code requirements have changed significantly for multi-unit residential buildings. ECS have been regulated by the MA code extensively since the 5th edition in 1992. For example, the 5th edition like the 8th edition today, had an air leakage requirement for the building thermal envelope. Fenestration had air leakage requirements as well; today the fenestration has to be tighter than before but a leakage value has been present for *two decades*. Performance compliance options, like those available today via HERS or REScheck, were available to owners since at least since the 6th edition although they were more rudimentary in nature. Since 1992 more ECS, like service water heating, come under the umbrella of the code, but little feedback is received on relatively minor requirements like these.

Thus, there are essentially similar overarching requirements on ECS in 2014 compared to 1992. However, the *details* of these requirements have been expanded. For example the building thermal envelope required insulation and air sealing then and still does now. However in years past no verification was required, whereas now a blower door test[5] and duct leakage testing are required, both typically done by skilled individuals, and hired by the builder. In 1992 the prescriptive cavity insulation was a relatively low R value (12.5) and today it is 20. In 1992 the framing was 2x4 but today most buildings with cavity insulation only are framed with 2x6. There is no structural reason (dead, live, wind, or snow loads) for using 2x6 studs; the framing size is driven by the R-20 batt insulation. Although in 2014 a designer or builder can still use 'prescriptive' requirements of the code it may not make good economic sense[6] to do so. Relatively simple construction of 3 to 6 unit residential buildings can be complicated by the energy code, and a prudent owner will seek input from knowledgeable and experienced professionals to provide reliable cost tradeoffs at the building planning stage. If instead the construction follows the 'prescriptive' requirements of the code the owner/consumer may not be getting the "best" product for the money.

Section 4b: ECS Cost and Effectiveness Overview

A number of energy conservation studies on the cost effectiveness of code requirements on one- and two-family dwellings have been done. Fewer studies[7] and less data are available on multi-unit residential buildings. This may be due to the fact that most people in the USA live in one- or two-family dwellings[8] and therefore there is simply a higher demand for cost information. Also energy code requirements likely have a higher cost impact per unit in one- and two-family dwellings compared to the cost impact per unit in multi-unit residential buildings, because the latter typically have less habitable space[9] and therefore less 'conditioned space'[10] than the former.

Noting the differences above a general statement can be made: the cost of energy code construction will be lower per dwelling unit in a multi-unit residential building compared to the cost per dwelling unit in a one- or two-family dwelling. However, multi-unit residential housing can be more cost-sensitive than one- and two-family dwellings if construction costs are constrained by predicted rental income or sale price. And since local market conditions determine the demand for multifamily housing and set rental rates, escalation of construction cost can price a building out of its intended market[11]. This can be exacerbated for affordable projects per M.G.L. c. 40B, §21, where rent income has an upper bound.

Beyond just direct construction costs associated with ECS there are *indirect* costs associated with construction to meet specific energy conservation options that are available in MA. These are related to the incentives that bring more energy conservation focus on buildings including:

- direct cash rebates or tax incentives to owners/builders of solar PV or HERS homes, and
- home energy audits which are available to at no cost to a building owner, and
- cash rebates on various weatherization and/or lighting improvements, and
- cash rebates on conversion to high efficiency boilers, furnaces, and water heating units, and
- marketing campaigns[18] by utility companies, and

all of these cash or tax incentives come from utility companies, or the state and federal governments. Citizens who pay taxes and utility bills fund these programs and although more and more citizens take advantage of them, there are those who don't for one reason or another, and most importantly those who can't because they lack the wherewithal to do so.

This paper is not intended to examine all ECS code requirements, but instead narrowly focus on the primary ones. As stated earlier the IECC covers each energy aspect of a building. They may be categorized as follows:

- Building Thermal Envelope[12] which encloses the habitable or conditioned space, and contains the volume of air that is heated in the winter and cooled in the summer. The amount of heating or cooling that is required is dependent on several features of the envelope including but not limited to:
  - air leakage, which can be thought of as how freely air can move from inside the envelope to outside or from outside the envelop to inside and,
  - fenestration, which includes doors and windows, and their inherent insulating value (U-Factor), leakage rates, and solar heat gain coefficients, and
  - insulation, which includes fiberglass, cellulose, mineral wool, plastic foam, or other and placed in the cavities of the building frame and may include 'continuous' insulation that wraps the outside of the building for example and thereby eliminates thermal breaks at the framing members.
- Mechanical Systems which consume energy to provide a service to the occupants and include but are not limited to:
  - ventilation for the bath and kitchen and more recently, because buildings are required to be more air tight, for intake of outside air to ensure for good indoor air quality, and
  - heating or cooling and lighting of living space, and
  - water heating for the bath, kitchen, and clothes washer, and
  - appliances and other plug loads (range, washer, dryer, etc.) and in some situations
  - renewable energy like solar photovoltaic (PV) or other.

The focus of this paper will be the building thermal envelope and ventilation but only to the extent that mechanical ventilation is now necessary per the code. Mechanical systems and equipment like appliances can be a significant portion of construction costs but they are systems over which the BBRS has less control. For example, traditional heating systems have not changed much over the past two decades and the federal government regulates the efficiency requirements of the equipment in any event. In addition, the BBRS may go beyond its regulatory authority if it mandated energy efficiency for plug load appliances like dishwashers or clothes dryers. However, for a builder to optimize the HVAC systems, that is to 'right-size' the heating system for example, all aspects of the builder thermal envelope must be known. Otherwise a heating contractor may install higher capacity systems to avoid situations where the living space cannot reach a comfortable temperature on the extreme cold or hot days.

As noted earlier, changes to the building thermal envelope requirements may change the way in which a building is constructed because insulation values have increased and air leakage allowance has been tightened and now must be verified. Some of these requirements may have major cost impacts for multi-unit residential construction. However, ECS, unlike other building systems, can have a return on investment (ROI) via lower utility cost. Another benefit to the reduction in energy use in buildings is the commensurate reduction in carbon emissions, which in the past two decades has received much governmental attention; accordingly carbon emissions will be computed[12a] for various cases. There may be other benefits to the owner like elevated home value due to market demand for green buildings, and more comfortable and less noisy interior environments. These benefits are not readily quantified, and are considered outside the scope of this paper.

While continual enhancement of energy conservation in buildings remains a goal of federal, state[13], and even local governments, the BBRS has a duty to continually focus on the cost of construction of current or proposed energy conservation requirements which may exist either in code or MA general law. In addition the BBRS seeks to ensure that ECS requirements do not increase the risk to health via the tightening of air leakage requirements or with the installation of new products like foam plastic in the building envelope.

In summary this paper will focus on the building thermal envelope for three cases: 3, 4 and 6 unit low rise residential buildings, all with a flat roof, front and rear top to bottom stairways, and wood frame construction. The 3 and 6 unit buildings have three stories and the 4 unit building has two stories. These configurations represent a sampling of existing multi-unit residential buildings that are found across the Commonwealth and could potentially be built at relatively low cost because of simple geometry, standard ceiling height, and traditional framing methods.

Section 4c: Building Thermal Envelope Effectiveness

Section 4c(1): Insulation and Air Leakage

The purpose of this section is to determine the key variable(s) of the overall effectiveness of the building thermal envelope and the items that could be examined more closely to create an ECS of optimum cost versus effectiveness. Fenestration U-Factor and leakage, insulation R-Value, and total air leakage contribute to some extent to the annual heating and cooling loads for a building. To determine the extent of each, energy modeling was done by a certified HERS rater using REM/Rate 14.3 software using models of 3, 4, and 6 unit buildings of simple rectangular geometry; both in plan and elevation.

As with any modeling exercise several assumptions were made:

1. The 3 unit residential building is flat roof, plan area 48 ft by 24 ft, 15% fenestration area, with an interior floor to ceiling height of 8 ft, one foot thick floors and ceilings to produce a building 28 ft height as measured from the top of the foundation wall.
2. The 4 unit residential building is flat roof, plan area 48 ft by 48 ft, 15% fenestration area, with an interior floor to ceiling height of 8 ft, one foot thick floors and ceilings to produce a building 19 ft height as measured from the top of the foundation wall.
3. The 6 unit residential building is flat roof, plan area 48 ft by 48 ft, 15% fenestration area, with an interior floor to ceiling height of 8 ft, one foot thick floors and ceilings to produce a building 28 ft height as measured from the top of the foundation wall.
4. Heating and cooling degree days, HDD65F = 6300, CDD50F = 3300, respectively.
5. All wall framing is 16 in. on center and 2x4 studs for R13 or R13 + 5ci or 2x6 studs for R19/20 and all ceiling framing 16 in. on center and 2x10 joists with R30 batt in cavity and continuous insulation (ci) above. Batt and ci to closely meet the various required R values. Insulated sheathing, in standard commercially available sizes, to be used for ci to allow for roof covering attachment.

6. Solar heat gain coefficient (SHGC) for the fenestration = .30
7. No concealed space above the top floor ceiling (i.e. hot roof configuration)
8. Each unit contains 2 bedrooms
9. Total building air leakage values were pulled directly from the applicable code, except for values assumed for the IECC 2003 and 2006[14]. Window and door leakage rates[15] are specified in the IECC but the modeling does not account for these specifically; only the total building leakage (ACH at 50 Pa) is utilized.
10. The basement is considered enclosed unconditioned space but a temperature of the space is not assumed or input in the analysis.
11. For one run continuous mechanical ventilation was used for each unit per the mandatory requirement of the IECC 2012. The flow values in cubic feet per minute (cfm) were calculated using the methodology of the MA requirement (see Section 4c(2)).

The modeling runs for the 3-unit building are shown in Figure 4c(1)a and they contain the prescriptive requirements for the key building thermal envelope components. For the IECC 2003 the leakage rate is assumed to be 8 ACH at 50 Pa and for the IECC 2006 and 2009 it is assumed that the air leakage is 7 ACH at 50 Pa. Two runs, 5 and 6, were done with an air leakage of 5 ACH at 50 Pa even though the requirement for the IECC 2012 is 3 ACH at 50 Pa. Runs 7 and 8 were done to simulate the IECC 2012. And Runs 17 and 18 were done to determine the effect of mandatory continuous ventilation, which most commonly will be done with a bathroom fan in each unit operating continuously at a low flow rate setting.

Several key findings include these ***<u>less effective efficiency</u>*** improvements:

- Increasing (1st) floor insulation from R-19 to R-30 reduced the annual heating load by 1.9 MMBtu/year[16]. (see No. 3 vs. No. 2), and
- Increasing ceiling insulation from R-38 to R-49 reduced the annual heating load by 1.7 MMBtu/year.   (see No. 9 vs. No. 11), and
- Decreasing fenestration U-factor from .35 to .32 reduced the annual heating load by 2.4 MMBtu/year.   (see No. 11 vs. No. 15), and

<u>similar efficiency</u> of R-20 cavity only insulation compared to R-13 cavity with R-5 continuous, but only if the building is more air tight. (No. 5 vs. No. 6 are about equal with ACH = 5 whereas with ACH = 7, R-13 + 5 is more effective by 2.8 MMBtu; see No. 2 at vs. No. 4), and
<u>most effective efficiency</u> improvement results from decreasing air leakage (ACH at 50 Pa) from 8 to 7 to 5 to 3 as indicated in Figure 4c(1)b. If the leakage is 7 ACH, 5 ACH, or 3 ACH, the annual heating load in MMBtu hovers around the upper 70s, 50s, or 40s, respectively, and seems to be pretty much independent of fenestration and insulation requirements. However, when mandatory continuous mechanical ventilation is incorporated then the ‘air tight’ building becomes less so and the efficiency improvement associated with air leakage is diminished (see No. 17 at 48.4 vs. No. 18 at 53.1)

	3 Unit Residential; Building Thermal Envelope Modeling Insulation R-Value or Fenestration U-Factor for Zone 5 and Leakage									
Model Number	**IECC[e]**	**Fenestration**	**Ceil/Attic**	**Wall[a]**	**Floor[b]**	**Building Leakage (ACH @ 50 Pa)**	**Annual Heating Load (MMBtu/yr)**	**Annual Cooling Load (MMBtu/yr)**	**Annual Heating CO2 Production[d]**	
1	2003	.45	30	13	19	~8	106.1	15	5.6	
2	2006/2009	.35	38	19/20	30	~7	77.2	16.8	4.1	
3	2006/2009	.35	38	19/20	19	~7	79.1	16.6	4.2	
4	2006/2009	.35	38	13 + 5ci	30	~7	74.4	16.9	3.9	
5	2012 with 5 ACH	.32	49	20	30	5	58	18.6	3.1	
6	2012 with 5 ACH	.32	49	13 + 5ci	30	5	57.8	18.6	3.1	
7	2012	.32	49	20	30	3	48.7	18.8	2.6	
8	2012	.32	49	13 + 5ci	30	3	48.5	18.8	2.6	
9	2006/2009 hybrid	.35	38	13 + 5ci	30	5	62.2	17.8	3.3	
10	2006/2009 hybrid	.35	38	13 + 5ci	30	3	50.4	18.7	2.7	
11	2006/2009 hybrid	.35	49	13 + 5ci	30	5	60.5	17.7	3.2	
12	2006/2009 hybrid	.35	49	13 + 5ci	30	3	48.8	18.7	2.6	
13	2006/2009 hybrid	.32	38	13 + 5ci	30	5	59.5	18.7	3.2	
14	2006/2009 hybrid	.32	38	13 + 5ci	30	3	47.9	19.6	2.5	
15	2006/2009 hybrid	.32	49	13 + 5ci	30	5	58.1	18.6	3.1	
16	2006/2009 hybrid	.32	49	13 + 5ci	30	3	46.6	19.5	2.5	
17	2012 hybrid (no mech. ventilation)	.32	49	13 + 5ci	30	3	48.4	21.7	2.6	
18	2012 hybrid[c]	.32	49	13 + 5ci	30	3	53.1	21.2	2.8	

Notes:
a. Framing cavity or if continuous insulation is used then cavity + continuous
b. 30 or insulation sufficient to fill the framing cavity but no less than 19
c. Assumes continuous mechanical ventilation for each unit per the MA code 8th edition
d. Assumes natural gas as the fossil fuel for heating and values in metric tons.
e. 'hybrid' indicates some variation on the requirements in IECC.

Figure 4c(1)a

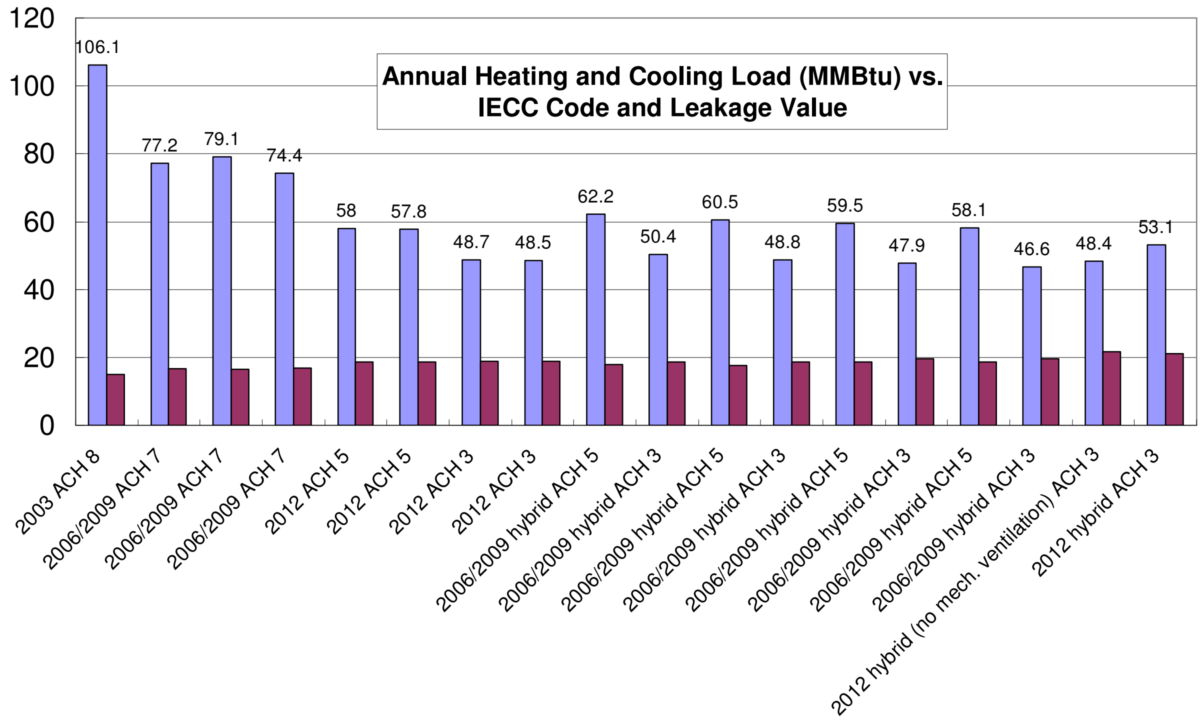

Figure 4c(1)b

The modeling runs for the 4 and 6-unit buildings are shown in Figure 4c(1)c and they contain the prescriptive requirements for the key building thermal envelope components. Fewer runs were made for these building types versus the 3-unit buildings and similar assumptions for the 3 unit building were carried over and repeated here. For the IECC 2003 the leakage rate is assumed to be 8 ACH at 50 Pa and for the IECC 2006 and 2009 it is assumed that the air leakage is 7 ACH at 50 Pa. Runs 4 and 5 were done to evaluate the effect of decreasing the fenestration U-factor and increasing the ceiling R-Value. Runs 5 and 6 were done to evaluate the effect of decreasing air leakage from 5 ACH at 50 Pa to 3 ACH at 50 Pa. And Runs 6 and 7 were done to determine the effect of mandatory continuous ventilation.

Several key findings include a *less effective efficiency* improvement of decreasing fenestration U-Factor and increasing ceiling insulation reduced the annual heating load about 5 MMBtu/year (see No. 4 and No. 5) and *similar efficiency* of R-20 cavity only insulation compared to R-13 cavity with R-5 continuous (see No. 2 and No. 3) and the *most effective efficiency* improvement results from decreasing the total building air leakage.

Another noteworthy result is a comparison of the annual heating and cooling loads on a per unit basis for each building type (using IECC 2012 with mandatory mechanical ventilation) which shows the benefit of units which share interior walls, as summarized below:

3-Unit Building: 17.7 heating and 7.1 cooling MMBtu/year per Unit (see No. 18)
4-Unit Building: 12.5 heating and 5.8 cooling MMBtu/year per Unit (see No. 7)
6-Unit Building: 11.8 heating and 5.8 cooling MMBtu/year per Unit (see No. 7)

	4 Unit Residential; Building Thermal Envelope Modeling Insulation R-Value or Fenestration U-Factor for Zone 5 and Leakage									
Model Number	**IECC**[e]	**Fenestration**	**Ceil/Attic**	**Wall**[a]	**Floor**[b]	**Building Leakage (ACH @ 50 Pa)**	**Annual Heating Load (MMBtu/yr)**	**Annual Cooling Load (MMBtu/yr)**	**Annual Heating CO2 Production**[d]	
1	2003	.45	30	13	19	~8	110.7	18.9	5.9	
2	2006/2009	.35	38	19/20	30	~7	78.9	20.7	4.2	
3	2006/2009	.35	38	13 + 5ci	30	~7	76.3	20.7	4.0	
4	2006/2009 with 5 ACH	.35	38	13 + 5ci	30	5	62.4	21.9	3.3	
5	2012 with 5 ACH	.32	49	13 + 5ci	30	5	57.3	22.5	3.0	
6	2012	.32	49	13 + 5ci	30	3	44.3	23.7	2.3	
7	2012 hybrid[c]	.32	49	13 + 5ci	30	3	50	23.1	2.7	
	6 Unit Residential; Building Thermal Envelope Modeling Insulation R-Value or Fenestration U-Factor for Zone 5 and Leakage									
1	2003	.45	30	13	19	~8	165.7	27.6	8.8	
2	2006/2009	.35	38	19/20	30	~7	120.3	30.4	6.4	
3	2006/2009	.35	38	13 + 5ci	30	~7	122.7	26.8	6.5	
4	2006/2009 with 5 ACH	.35	38	13 + 5ci	30	5	92.1	32.5	4.9	
5	2012 with 5 ACH	.32	49	13 + 5ci	30	5	85.8	33.6	4.5	
6	2012	.32	49	13 + 5ci	30	3	63.1	35.7	3.3	
7	2012 hybrid[c]	.32	49	13 + 5ci	30	3	70.1	34.9	3.7	

Notes:
a. Framing cavity or if continuous insulation is used then cavity + continuous
b. 30 or insulation sufficient to fill the framing cavity but no less than 19
c. Assumes continuous mechanical ventilation for each unit per the MA code 8th edition
d. Assumes natural gas as the fossil fuel for heating and values in metric tons.
e. 'hybrid' indicates some variation on the requirements in IECC.

Figure 4c(1)c

Section 4c(2): Mechanical Ventilation

Mandatory ventilation (exchanging indoor air with outdoor air) will be required in residential buildings on July 1, 2014 with the adoption of the IECC 2012. The requirement was the result of concerns with the quality of indoor air in buildings with low 'natural' air leakage through doors, windows, walls, floors, and ceilings. All of these components of the building thermal envelope are 'sealed' which has to be done to produce a building with a leakage of 3 ACH at 50 Pa. Further, a MA amendment offers a mechanical ventilation compliance method that is prescriptive and can be met by continuous (365/24/7) operation of a bathroom fan for example. The required airflow is dependent on several variables including the size and story location (1st, 2nd, or 3rd) of the dwelling unit, the location of the building in the state, and the air tightness (verified air leakage value) of the unit. For each building type (3, 4, or 6 unit) the mechanical flow rate is: the same for all 1st floor units; the same for all 2nd floor units; and the same for all 3rd floor units. Flow rate values[16] were calculated for both 2 and 3 bedroom units but the model runs for this paper used only 2 bedroom values.

As was noted in the Section 4c(1) if continuous mechanical ventilation operates in a building then the annual heating and cooling loads will increase accordingly. It can be seen that if mechanical ventilation is included in the model, with all other variables held constant, then the annual heating loads are increased. For example, comparing runs 17 and 18 indicates that the annual heating load increases 4.7 MMBtu/year for a $50 total cost[17] per year to the occupants of the 3 unit building. The cost of control modifications to a bathroom fan, for example, to meet this requirement is relatively low. However, there is a flow verification test that will add to the cost of construction as well. As part of recommendation 2 a detailed review of the cost and effectiveness of mandatory mechanical ventilation requirements should be done, including whether or not a heat recovery ventilation system provides favorable return on investment (ROI).

Section 4c(3): Foundations

This paper assumes for all building types that the basement is not habitable space and is unheated and for modeling purposes is considered enclosed unconditioned space. Also as noted earlier a temperature of the space is not assumed or input in the software. In addition no detail on construction of the basement footings, walls, and floor slab is included. However, as part of the recommendation 2 a detailed review of the cost and effectiveness of insulation and moisture control requirements of these building components should be done.

Conclusion 1:

The BBRS receives more comments and questions from builders, owners, designers and building officials on ECS than any other building system. These comments and questions are related to, and arise as a result of the fact that two very different energy codes are in effect in the state and that effective dates of each code are not in synch.

Conclusion 2:

The code requirements of the building thermal envelope for 3 to 6 unit residential buildings are moving to diminishing ROI; that is more insulation, increased air tightness, or lower U-factor fenestration, which all increase the cost of construction, will not lower appreciably the annual and heating and cooling loads or the carbon footprint of the building.

Conclusion 3:

Today's energy conservation requirements may have a ripple effect on the cost of other building systems including:

- the building framing (2x6 vs. 2x4 for example), and

- finish carpentry for windows and doors, and
- foundations and basement slabs, and
- exterior siding and roof covering, and to a lesser extent
- plumbing and electrical systems.

Recommendation 1:

The BBRS should adopt a state-wide energy conservation code and fix it for a predetermined period of time. If a ‘stretch’ code is required and adopted it should be identical to the ‘base’ code with the exception of a single performance target value, and both codes should be in sync. This recommendation will eliminate much confusion, restore the ECS requirements to a near state-wide consistency, and enhance compliance and enforcement.

Recommendation 2:

In order to foster cost effective energy conservation in wood frame 3 to 6 unit residential buildings the BBRS should gather experienced builders, designers, and building officials to create construction details and other requirements as necessary, which reflect industry best practices in cost effective and reliable ECS for the thermal envelope and mechanical systems, if necessary, of these buildings. Cost offsets will not be considered; instead the effectiveness of any ECS should be compared to the direct cost of construction and ultimate price to the consumer and off set only by ROI that the consumer may see via reduction in utility or life cycle costs. The recommendation to the BBRS shall include but not be limited to a code change proposal(s) and construction drawings.

Notes to Section 1

1. Additionally the General Objectives of the BBRS pertaining to the cost of construction are found in M.G.L. c. 143, §95 (b) & (c)
2. Discussions with several building departments, including those in Brockton, Northampton, and Holyoke revealed anecdotal evidence of this. For example, some Brockton owners are converting 3 unit buildings to 2 family dwellings while some Northampton owners are doing the same thing or allowing buildings to sit vacant.

Notes to Section 2

1. The dates shown should be considered approximations. For precise dates please check with the Secretary of State .
2. The Model 15 effort was approved at the September 2011 meeting and is copied here in part:

    BBRS requests that the Energy Advisory Committee (EAC), the Structural Advisory Committee (SAC), the Geotechnical Advisory Committee (GAC), the Fire Prevention and Fire Protection Advisory Committee (FPFP), and the Chapter 34 Advisory Committee (34AC) to evaluate each current Massachusetts amendment to the model codes against the following questions:

    1. Does the amendment reduce or show equivalency to construction costs relative to the 2009 ICC code? (Y or N)
    2. Does the amendment address the specific intent of MA General Law? (Y or N)
    3. Does the amendment address a unique Massachusetts condition that warrants it? (Y or N)

    The initial selection filter is as follows:

    - If the answer is 'yes' to any of these questions the amendment may remain. If the amendment that remains adds cost then the committee will provide the cost increase analysis.
    - If the answer is 'no' to all three questions then the amendment may be deleted. However, if the BBRS is presented with valid life safety statistics that justify the increased initial construction costs and/or increased life cycle costs then the amendment shall remain.
    - If the amendment deletes an I-Code requirement then the committee shall identify the unique criteria as to why it is deleted.
3. Not included in this list are accessibility requirements which are governed by the Architectural Access Board and enforced by building officials. Since 1996 the Commonwealth has been a national leader via 521 CMR in providing access to its citizens with disabilities.
4. Overarching the code are requirements in Massachusetts General Law for sprinklers in buildings. M.G.L. c.148 §26G has been in effect statewide since January 1, 2010 , and requires sprinklers in new commercial buildings over 7500 sq. ft. as well as existing buildings undergoing significant renovations. It should be noted that this law does not allow the building to be separated with fire rated walls or ceilings. M.G.L. c.148, §26G came on the heels of a tragic fire in Newton where 5 lives were lost. MA State Representative Ruth Balser who has the city of Newton in her district was an instrumental figure in the passage of this legislative act. Her views on sprinklers can be seen at this NFPA Sprinkler Blog.

Notes to Section 3

1. This paper reviews and analyzes 'raw' data for the various topics addressed; a simpler path could have been to reference reports or papers or conclusions issued by Realtor groups, the National Fire Protection Association, the National Association of Home Builders, or other entities. However, business entities whether for profit and not for profit may have a bias on the subject matter within their scope. Feedback which examines data in an industry accepted manner on any topic in this paper is anticipated and welcome, as it will make this paper a more accurate and valuable document.
2. Many sources can be accessed for these data including the US Census. At this particular site http://www.russellsage.org/research/chartbook/social-inequality one can view income data from multiple perspectives and trends over time, and across gender and race. For this paper median values are used in order to be consistent with the median home price and home value data.
3. US Census data on home values from 1940 to 2000 in adjusted and unadjusted dollars can be found at http://www.census.gov/hhes/www/housing/census/historic/values.html. Ellen Wilson at the US Census Bureau indicated in a phone conversation on January 2, 2014 that the home value data is supplied by the US Census respondents on their census form, in response to what the value of the home would be on the local housing market. When asked: *"Do these home values accurately reflect market home price?"* Ellen indicated that they do. A comparison (see below) of sale price of homes in MA from 1970 to 2000 with US Census home values corroborates this opinion.

Year	MA Median Home Value US Census	MA Average Sale Price	MA Median Value to Average Value using Single Family Factor		MA Median Value to Average Value using Condo Factor	
2000	185,700	261,293	227,023		211,603	
1990	162,800	181,225	199,027		185,509	
1980	48,400	59,269	59,170		55,151	
1970	20,600	25,125	25,184		23,473	
	Equivalence Factor to Convert Median to Average					
		MA Median Sale Price Single Family	Average Sale Pr Single Family	Single Family Factor		
	Jan-04	323,000	394,876	1.223		
		MA Median Sale Price Condo	Average Sale Pr Condo	Condo Factor		
	Jan-04	245,000	279,175	1.139		

4. John Dulczewski., the executive director of the Greater Boston Association of REALTORS has supplied Massachusetts home sale data which span the time frame 2005 to 2012 along with discrete data points of average home sale prices dating back to the 1940's.
5. American Community Survey by the US Census Bureau can be found at http://www.census.gov/acs/www/
6. Home affordability tools are numerous. The one used for this study is found here: http://www.hsh.com/calc-howmuch.html
7. As defined by the US Census Bureau… *"the median household income includes the income of the householder and all other individuals 15 years old and over in the household, whether they are related to the householder or not. Because many households consist of only one person, average household income is usually less than average family income. The median divides the income distribution into two equal parts: one-half of the cases falling below the median income and one-half above the median. For households and families, the median income is based on the distribution of the total number of households and families including those with no income. The median income for*

individuals is based on individuals 15 years old and over with income. Median income for households, families, and individuals is computed on the basis of a standard distribution."

8. Rate of home ownership data were pulled from http://www.census.gov/hhes/www/housing/census/historic/owner.html
9. For example the State House News recently issued this:

REPORT: HOUSING BOOM NEEDED TO FUEL STATE'S ECONOMY

By Michael Norton
STATE HOUSE NEWS SERVICE

STATE HOUSE, BOSTON, JAN. 16, 2014…Massachusetts must significantly boost its housing supply to attract the younger workers needed to increase its labor force and help drive economic growth in the next decades, according to a new report.

The Metropolitan Area Planning Council report found the metro Boston area will need 435,000 new housing units by 2040 to attract younger workers while also accommodating the state's growing senior population. The report suggests the new units would mostly be situated in multi-family settings and in urban areas.

Under a slow-growth scenario the region's population would grow 6.6 percent over three decades, with its 65 and older population increasing 82 percent and its working-age population essentially unchanged. Without an influx of younger workers, jobs in the region could grow by less than 1 percent from 2010 to 2040, the report said.

The report's "stronger region" growth scenario envisions a population increase of 12.6 percent, with the population between 25 and 64 years old increasing 7 percent and adding 175,000 new workers to the labor force.

The report says 435,000 new housing units would be needed from 2010 to 2040 under the "stronger region" scenario and 305,000 under the slow-growth, "status quo" scenario, which would still represent a 17 percent increase. The demand exists for new housing, including apartments and condominiums, even though a "senior sell-off" may provide most of the single-family homes needed by younger families.

"Which scenario is more likely to occur depends on decisions yet to be made," the report said. "Individual households will make their own choices about where to live, but they will do so in a context influenced by public sector actions and investments. Policies to promote housing construction will facilitate the higher in-migration rates that characterize the Stronger Region scenario. Conversely, continued widespread opposition to new housing will likely result in less."

In the report, the council says it favor the "stronger region" approach for municipalities and says that approach is already the basis behind the state Executive Office of Housing and Economic Development's multi-family housing production goals.

"More than a million of the region's workers will be retired by the year 2030," Marc Draisen, the council's executive director, said in a statement. "To fill those jobs and grow the economy we need to reverse the trends that see so many young workers leaving Metro Boston."

The report, which includes projections by municipality, says the number of school-age children in the region peaked in 2000 and is likely to decline in the coming decades. It warns that without an effort to increase housing production, one of the state's biggest assets - a skilled and educated workforce - is in jeopardy.

END
01/16/2014

The full report is found here: http://www.mapc.org/data-services/available-data/projections. The Metropolitan Area Planning Council has statutory authority via M.G.L. c. 40B, §24

10. A November 2013 report issued Barry Bluestone, Director of the Dukakis Center for Urban & Regional Policy, is another source on this subject. It has a lot of data in chart form but is relatively easy to understand and follow. The report is found here: http://www.gbreb.com/uploadedFiles/GBAR/GBAR_Education_and_Events/BBLUESTONEPRES2014.pdf?n=5679 Particular attention should be paid to pages 30 and 31.

Notes to Section 4

1. As just one example, an understanding of the movement of air and water vapor through buildings has always been necessary and is needed to avoid moisture problems and serious issues that may arise when construction is done without this knowledge. The varied products and installation methods used today for insulation and sealing require a very extensive knowledge base.
2 Energy codes play an important role in the design and cost of multifamily buildings. The *International Energy Conservation Code* (IECC) is the most widely adopted of these codes, and is published by the International Code Council. The IECC focuses on the construction of the building envelope, building insulation, efficiencies in mechanical systems and efficiencies in power systems. The code is broken into Residential and Commercial chapters, and builders must focus on both. Multi-unit buildings of three stories or less (commonly called low-rise) follow the residential provisions, while multi-unit buildings of four stories or more fall into the commercial chapter. It also separates the country into climate zones, which provide differing requirements for building components based on geographic area. The requirements listed in the IECC are intended to provide minimum design and construction standards. State and local jurisdictions can adopt the code in whole, in part, with amendments or adopt provisions that exceed the code minimums. New IECC editions are typically adopted several years after their publication, and each state has its own system for code adoption, implementation, and enforcement.
3. For example, the IECC 2012 requires R-49 ceiling and attic insulation compared to R-38 for the IECC 2009 for buildings up to three stories in height. For residential building over 3 stories in height the IECC 2009 (Table 502.2(1) requires:
   a. R-13 in the stud cavity and R-3.8 ci* wall insulation (increased from R-13),
   b. R-38 ceiling/attic insulation (increased from R-30),
   c. R-7.5 ci for below grade walls (not required in the IECC 2003),
   and for the IECC 2012
   a. wall insulation requirements increase to: R-13 cavity and R-7.5** ci or R-20 cavity and R-3.8 ci, and
   b. the ceiling/attic insulation requirements increase to R-49.

   * continuous insulation ** R-7.5 continuous insulation is typically 1 ½ inch thick and may cause builders to modify door and window systems and the finish trim.
4. The 'Base' energy code is effective in about 2/3 of the municipalities across the state and the 'Stretch' energy code is effective (by local option) in the remaining 1/3. Feedback includes a letter dated March 11, 2014, titled '*Real Estate Industry Opposition to the Stretch Energy Code*' to Mark Sylvia, Commissioner of the MA Department of Energy Resources and cc'd to the BBRS Chair from NAIOP, Greater Boston Real Estate Board, MA Association of Realtors, and the MA Home Builders Association and discussed at

the April 8 BBRS meeting, and a small sample of emails sent to DPS in March/April 2014:

> I have been following the BBRS website, including the link below. I see the 12/6/2013 Change that has IECC 2012, with amendments (all of which appear to apply to the Commercial buildings section) going into effect 7/1/2014.
> However, I still see no changes to the Stretch Energy Code, Appendix AA(780 CMR 115.AA), and no mention of discussion of such changes in any of the recent BBRS minutes or agendas. Will there be a revised Stretch Energy Code going into effect 7/1/2014, or has there been a decision made, conscious or otherwise, to put off the implementation of a new Stretch Energy Code to a later date?
> We are down to just over 3 months to 7/1/2014 and I want to let the builders that I work with know how to plan their projects for the rest of 2014.
> Thanks,
> Name withheld
>
> I am aware of the current concurrency period for the IECC 2009 and IECC 2012 which in effect until July of this year.
> My question is regarding projects that are new commercial additions or new buildings which are in the late design stage and likely to bid out between now and July.
> Does the permit of the project establish if the project can be designed to IECC2009 and if the project's permit is filed after July 2014, then the IECC2012 becomes the only code in effect.
> Am I correct to assume that when the IECC 2012 is the only code based on permit filing date?
> I can't find anything on the BBRS to define this.
> Thx,
> Name withheld
>
> My firm is working on a number of DCAMM state projects that are in the design phase – not yet permitted. With the switch of the MA Energy Code (780 CMR) to IECC 2012 projects in Massachusetts will now reference ASHRAE 90.1-2010. It is my understanding that Stretch Code communities will continue to reference IECC 2009 and subsequently 20% more efficient than ASHRAE 90.1-2007 until an agreed upon "stretch" percentage above the new standards can be determined.
> But, what about State projects, those governed by Executive Order 484? These are not projects in jurisdiction complying with Stretch Code. However the mandate reference 20% more efficient than "current code." Should our project team assume we are referencing ASHRAE 90.1-2010?
> I tried to review the MGL 143-94, which I believe governs Stretch Code. But I was unable to determine if this is applicable to DCAMM projects as well.
> Can you help me sort this out or provide me with a contact that might be able to provide direction? There is such thing.
> Name withheld
>
> The Stretch Code referred to the bypass v enclosure checklist. Which is the one to use?...There are very big differences in the two check lists from what my HERS rater tells me so I was just making sure.
> Thanks.
> Name withheld
>
> Trying to nail down a definitive answer in regards to whether the current 2009 IECC / ASHRAE 90.1-2007 based Stretch Energy Code will still be applicable in stretch communities on and after July 1 this year.
> Or if the current Stretch Code will sunset and everyone will be required to use the new 2012 IECC until a new Stretch Energy Code is promulgated.
> Thanks in advance for your assistance.
> I hope that this email finds you well.
> Name withheld

Beginning in July, the 2012 IECC as adopted and amended by Massachusetts will be in force in non-stretch code communities. When the 2012 IECC makes reference to another code such as International Mechanical Code we want to confirm that the reference is to the Mechanical Code adopted by the State of Massachusetts (2009 IMC). Here is a specific example:
Section C403.2.5 of the IECC states: "Ventilation, either natural or mechanical shall be provided in accordance of Chapter 4 of the International Mechanical Code. Where mechanic ventilation is provided the system shall provide the capability to reduce the outdoor air supply to the minimum required by Chapter 4 of the International Mechanical Code."
We want to confirm that the reference to the mechanical code means the 2009 Edition of the IMC as currently adopted by the State and not the 2012 Edition of the IMC, which is referenced by the 2012 IECC.
Name withheld

Can you please advise whether or not a newly constructed skating rink (not heated or cooled, but dehumidified) qualifies for exemption from the stretch energy code, or whether a code variance would be required to exempt such a building?
Best regards,
Name withheld

5. To get a general idea of what a blower door test entails there are numerous videos including this https://www.youtube.com/watch?v=icZG05XU9pM
6. For example a report by Ekotrope commissioned by the Home Builders Association of MA (HBAM) was presented to the BBRS in May 2013. It is titled "Cost of Building Energy Codes in MA" and indicates that *"the 8th edition MA Energy Code can be met via three paths: Prescriptive, Performance, or HERS Alternative Performance….and ….that the HERS Alternative Performance Path was the least expensive route, a full $5,000 less expensive than the Prescriptive Path."* Although this study examined single family homes it is relevant to small multi-unit residential buildings because many of the cost trade-offs are relevant since the construction techniques of these building types can be similar.
7. For example, The Benningfield Group, Inc. in 2009 examined the US Multi Family Energy Efficiency Potential by 2020
8. The US Census has data for 2012 here http://quickfacts.census.gov/qfd/states/00000.html which indicate a total of 132,452,405 housing units. Of this total, 25.9% are units in multi-unit structures which are structures containing 2 or more housing units. So the majority of homes (74.1%) are single unit dwellings.
9. The US Census has data on this at https://www.census.gov/construction/chars/mfu.html which indicates that the median size of new single family homes in the northeast in 2012 was 2302 sq ft versus 1148 sq ft for the median size of new units in multi unit residential buildings in the northeast in 2012.
10. Conditioned space as defined by IECC 2009 is an area or room within a building being heated or cooled, containing uninsulated ducts, or with a fixed opening directly into an adjacent conditioned space.
11. Economic constraints of the local market, including costs associated with building codes and other regulatory requirements, typically are recognized by owners of any building project. In addition an owner/developer of multi-unit residential buildings look to offset and recapture building and others costs to determine whether a project will even move forward and they may not directly benefit from operational savings stemming from reduced energy usage, as building residents may be billed for their individual utility use. Therefore, the up-front capital costs of code-required energy improvements must be

recouped through other means including higher rents, the use of subsidies like tax benefits, or other financial incentives and, possibly, enhanced building value.

12. A 4 minute video of a builder describing a building thermal envelope is a useful primer https://www.youtube.com/watch?v=zYiymdjTKH8

12a. The EPA http://www.epa.gov/cleanenergy/energy-resources/refs.html has conversion examples. One MMBtu of natural gas contains 14.46 kg of carbon and the molecular weight of CO2 to C is 44/12, and therefore 1 MMBtu of natural gas produces 53 kg of CO2.

13. For example, M.G.L. c. 25a, § 10 contains provisions which must be met for a city or town to qualify as a Green Community, and was the basis for creation of the MA Stretch Code found at 780 CMR 115AA .

14. See table below:

Building Thermal Envelope: Air Leakage				
IECC	**Verification**	**Value**[1]		
2003	N/A[2]	~8 ACH at 50 Pa		
2006	N/A[2]	~7 ACH at 50 Pa		
2009	Testing or Inspection	7 ACH at 50 Pa		
2012	Testing	3 ACH at 50 Pa[3]		
2015	Testing	3 ACH at 50 Pa		

Notes:

1. "~" indicates estimate
2. IECC 2006 has a list of 10 items to be caulked, gasketed, or otherwise sealed; two less than IECC 2009 which adds 'attic access openings' and 'rim joist junction'. IECC 2003 specifies certain items to be sealed but is less clear than IECC 2006. It is assumed that with these sealing requirements the leakage rates for the IECC 2003 and 2006 are approximately 8 and 7 ACH at 50 Pa, respectively.
3. To examine the effectiveness of air leakage, 5 ACH at 50 Pa was used in some cases.

15. Since IECC 2006 door leakage ≤ 0.5 cfm/ft^2 and window leakage ≤ 0.3 cfm/ft^2 have remained unchanged.

16. **R403.5** Replace as follows but retain R403.5.1:

R403.5 Mechanical ventilation (Mandatory).
Each *dwelling unit* of a *residential building* shall be provided with continuously operating exhaust or balanced mechanical ventilation that has been site verified to meet a minimum airflow per

1. the Energy Star Homes' Version 3 or
2. ASHRAE 62.2 - 2013 or
3. the following formula for one- and two-family dwellings and townhouses of three or less *stories above grade plane*: $Q = .03 \times CFA + 7.5 \times (N_{br} + 1) - 0.052 \times Q_{50} \times S \times WSF$

Where: CFA is the *conditioned floor area* in sq ft
N_{br} is the number of bedrooms
Q_{50} is the verified blower door air leakage rate in cfm measured at 50 Pascals
S is the building height factor determined by this table:

stories above grade plane	1	2	3
S	1.00	1.32	1.55

WSF is the shielded weather factor as determined by this table:

County	WSF	County	WSF
Barnstable	0.60	Hampshire	0.59
Berkshire	0.52	Middlesex	0.55
Bristol	0.54	Nantucket	0.61
Dukes	0.59	Norfolk	0.52
Essex	0.58	Plymouth	0.53
Franklin	0.52	Suffolk	0.66
Hampden	0.49	Worcester	0.59

Mechanical Ventilation Flow Rate (Q) in CFM at 50 Pa					
Unit ceiling height =			8	ft	
Condition Floor Area (CFA) = 24 ft x 48 ft			1152	sq ft	
Unit volume (CFA x Ceiling Height) =			9216	cu ft	
N_{br} (Number of Bedrooms)			2		
N_{br} (Number of Bedrooms)			3		
Q_{50} for 8 ACH or air leakage in CFM			1229	cu ft per min	(8 ACH x Unit Volume/60)
Q_{50} for 7 ACH or air leakage in CFM			1075	cu ft per min	(7 ACH x Unit Volume/60)
Q_{50} for 5 ACH or air leakage in CFM			768	cu ft per min	(5 ACH x Unit Volume/60)
Q_{50} for 3 ACH or air leakage in CFM			461	cu ft per min	(3 ACH x Unit Volume/60)
S (building height factor 1st floor)			1		
S (building height factor 2nd floor)			1.32		
S (building height factor 3rd floor)			1.55		
WSF (shielded weather factor for Worcester			0.59		
Q (2 bedroom units) = .03 x CFA + 7.5(Nbr +1) -.052 x Q50 x S x WSF					
	ACH	**1st floor**	**2nd floor**	**3rd floor**	
	8	19.4	7.3	-1.4	
	7	24.1	13.5	5.9	
	5	33.5	26.0	20.5	
	3	42.9	38.4	35.1	
Q (3 bedroom units) = .03 x CFA + 7.5(Nbr +1) -.052 x Q50 x S x WSF					
	ACH	**1st floor**	**2nd floor**	**3rd floor**	
	8	26.9	14.8	6.1	
	7	31.6	21.0	13.4	
	5	41.0	33.5	28.0	
	3	50.4	45.9	42.6	

17. The US Energy Information Administration (EIA), an arm of the US Department of Energy, provides statistics and information on many energy topics including energy conversion methods. For example, to assign a 'price' to the heating loads produced by this paper, start here http://www.eia.gov/tools/faqs/faq.cfm?id=45&t=8 with EIA's frequently asked questions. Gas utilities essentially compute billing price on a dollar amount per *delivered* Therm. One Therm is equivalent to 100,000 Btu or 0.10 MMBtu, and a gas utility bill (NSTAR) for March 2014 indicates that one Therm is priced at $1.03, while another (NationalGrid) has a Therm priced at $1.70. An average of $1.37 and therefore 1 MMBtu will be priced at $13.70. Natural gas prices swing up and down through the year but for the purpose of this paper, $13.70 will be used to compute price for each 1 MMBtu of annual heating load. No price computations for electricity or fuel oil or other will be done.
18. For example, an NSTAR utility customer received a monthly notice from this utility indicating in graphical form how much more natural gas his building has used compared to *'all neighbors'* and *'efficient neighbors'*. In this particular case irrelevant information was provided since a single boiler supplies the entire building (two-units) with heat and hot water versus a typical two-unit building individually metered. If the only cost passed to the consumer is the $.49 for postage (clearly this is unreasonably low because the paper, printing ink, software and personnel to generate the data all have costs associated with these monthly mailings) then each customer is charged $6 per year. With approximately 300,000 NSTAR natural gas customers this amounts to $1.8M per year.