Strategies and Costs to Exceed ASHRAE 90.1-2004 Requirements in a Multifamily Apartment Building

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EXECUTIVE SUMMARY

Scope

Recent proposals to increase requirements by 30% to 50% over today's energy codes and standards may have a dramatic impact on certain types of multi-family buildings. Apartments, already some of the most sustainable residential buildings given their high density and efficient building systems, are of particular interest because of the role they play in providing affordable housing.

This study addresses how increases in energy efficiency standards will impact apartments in selected locations – Chicago, Houston, and Atlanta. These cities were selected to investigate impacts across multiple climate zones. Further, construction practices and infrastructure to support market preferences vary across these cities.

In this study, we focused on technologies and building systems which would be needed to surpass the 2004 edition of ASHRAE 90.1 – "Energy Standard for Buildings Except Low-Rise Residential Buildings" by 15%, 30%, and 50%. The technology packages which were modeled were in keeping with the realistic limits of what can be accomplished in building assemblies with commercially available envelope and HVAC systems.

Standard and Modeling Background

ASHRAE 90.1 is perhaps the most widely adopted energy conservation standard in the United States. As the title indicates, this standard regulates energy performance in a wide range of commercial buildings as well as some residential buildings. It is frequently referenced as an alternative compliance option in other energy codes, including the International Energy Conservation Code (IECC).

The most direct way to identify how a building performs relative to ASHRAE 90.1, or any other code, is to conduct computer simulations on a proposed building design and then compare it to a base code-compliant building. ASHRAE 90.1 offers a method called the "cost budget method" that permits this approach using energy simulation software. We selected a software package for the primary simulations called Energy Gauge Premier Summit Version 3.11, distributed by the University of Central Florida's Florida Solar Energy Center. Energy Gauge is somewhat unique in that it automatically generates a reference code-compliant building based on the inputs that a designer uses for their proposed design. The reference building design represents the costs that a building would incur for the items covered by 90.1 if the building is designed to comply with the *minimum* requirements of the standard. By automatically creating this reference building, this software tends to reduce user bias, which can be significant in modeling the energy use of the reference building.

Energy Simulation Results

The results of the energy simulations conducted in this project demonstrate significant barriers to reaching different levels of efficiency relative to the 2004 ASHRAE 90.1 standard. Table ES1 shows the reference design annual energy cost budget generated for a four-story building with 32 apartments of approximately 1000 square feet each.

Table ES1 - Annual Energy Costs for Reference Buildings

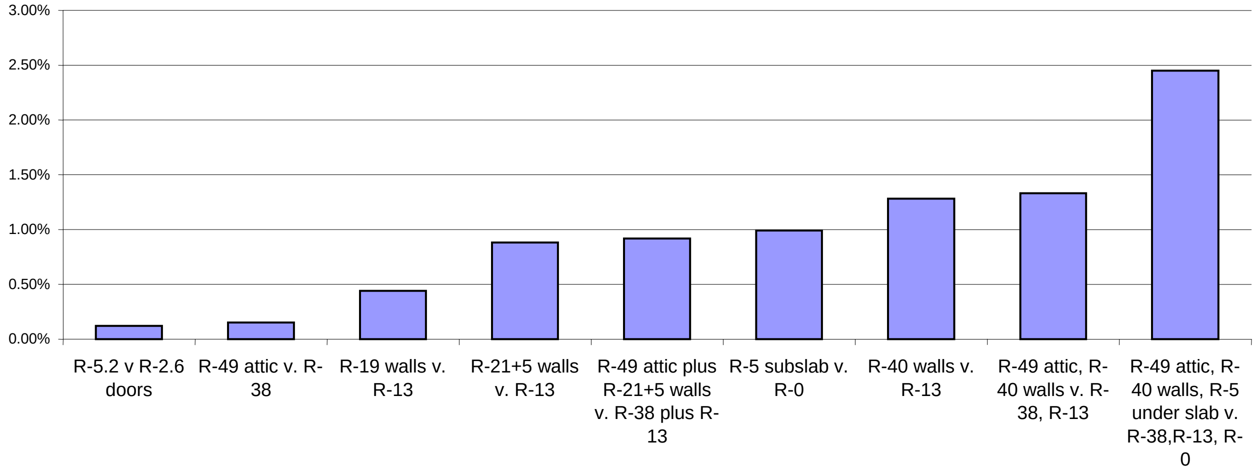
	Atlanta 90.1 Reference	**Chicago 90.1 Reference**	**Houston 90.1 Reference**
Electricity	$32,946	$25,323	$64,960
Natural gas		$31,628	
Total Cost Budget	$32,946	$56,951	$64,960

The total cost budget in Table ES1 is the starting point. To improve upon a building's performance, a building would have to incur a lower total cost budget than shown in the table. Note that Chicago's costs include natural gas for a hot air furnace whereas electric heat pumps are more typical in Houston and Atlanta.

Improvements to the Building Envelope Provide only Modest Gains

Because improvements to the opaque envelope (walls, roofs, floors) are typically the first items targeted for code changes, it is important to understand how they could impact the performance of a building. The chart below illustrates selected envelope improvements from the simulations in Atlanta. Most envelope improvements, when assessed in isolation, provided less than 1% energy savings. Even combining multiple improvements to the envelope resulted in less than a total of 2.5% improvement. Similar results were found in Chicago and Houston. The only exception seems to be the addition of R-5 subslab insulation in Chicago, which produced about a 3-1/2% savings over R-0 subslab insulation.

Figure ES1 - Improvement due to selected component changes over base building (Atlanta)



It is not possible to save the same energy multiple times, so it is not accurate to simply add the results of different simulations to arrive at a combined savings estimate. The different systems tend to interact with each other. Thus, only when multiple options are evaluated simultaneously in a simulation do the results reflect their combined contribution.

From Figure ES1, it became obvious that the traditional approach of adding more and more insulation would not get us very far toward the goals of 30% and 50% improvement. More emphasis has to be placed on higher efficiency heating and cooling equipment.

Significant Better-than-Code Gains Require Significant HVAC Upgrades

Table ES2 shows the results of the most promising options and the highest levels of improvement that were obtained. Note that a specific building configuration would not always provide exactly 15%, 30% or 50% improvements. Thus, the table shows the options that are enough to surpass the stated goals, but they often go beyond the goal.

Missing from the table is an entry close to the 15% threshold for Atlanta. This is because none of the options we explored could reach this goal without moving up to a ground source heat pump (GSHP), and this technology provided such a significant improvement that it met both the 15% and 30% thresholds in Atlanta.

Table ES2 - Building System Packages to Exceed 90.1 Requirements for three U.S. Cities

Atlanta	**% better than 90.1**
GSHP (3.7 COP, 16.9 EER)	31
R-49 attic, R-21+5 walls, advanced windows (U=0.3, SHGC=0.19), R-5.2 door, R-5 subslab insulation, GSHP (COP 3.7, EER 16.9)	39
Chicago	
96 AFUE furnaces	15
GSHP (3.7 COP, 16.9 EER)	37
R-49 attic, R-40 walls, R-5 subslab insulation, GSHP (3.7 COP, 16.9 EER)	46
Houston	
SEER 15 HP w/ 8.3 HSPF, R-40 walls, R-49 attic, advanced windows (U=0.3, SHGC=0.19)	15
GSHP (3.7 COP, 16.9 EER)	41
R-40 walls, R-49 attic, advanced windows, GSHP (3.7 COP, 16.9 EER)	48

None of the improvements we explored were able to achieve the 50% goal, although the modeling for Houston approached this threshold. Reaching the 15% threshold in Houston and Chicago was achievable by using high efficiency conventional HVAC equipment. For the 30% level in Houston and Chicago, as well as the 15% level in Atlanta, only the use of a GSHP allowed the efficiency goal to be reached.

Payback Periods for the Required Upgrades present Challenges

To illustrate the potential impact on costs and payback, Table ES3 shows these values for the building simulations in Atlanta.

As mentioned earlier, GSHPs played a significant role in meeting many of our performance goals. These systems come with a significant increase in upfront cost. It many cases, the payback period for this technology will exceed the life of the system, or at least the time when significant replacement components are needed.

Table ES3 – Cost and payback for selected improvements in Atlanta

Building system package	% better than 90.1	Simple payback in years[1]
GSHP (3.7 COP, 16.9 EER)	31 (closest set of improvements achieving at least 30%)	16 (25)
R-49 attic, R-21+5 walls, advanced windows (U=0.3, SHGC+0.19), R-5.2 door, R-5 subslab insulation, GSHP (COP 3.7, EER 16.9)	39 (maximum achieved in simulations)	14 (21)

[1] Costs and thus payback of GSHPs vary greatly. The paybacks are based on an average of the high and low end of estimated costs. The payback associated with the high end of the cost estimates is shown in ( ).

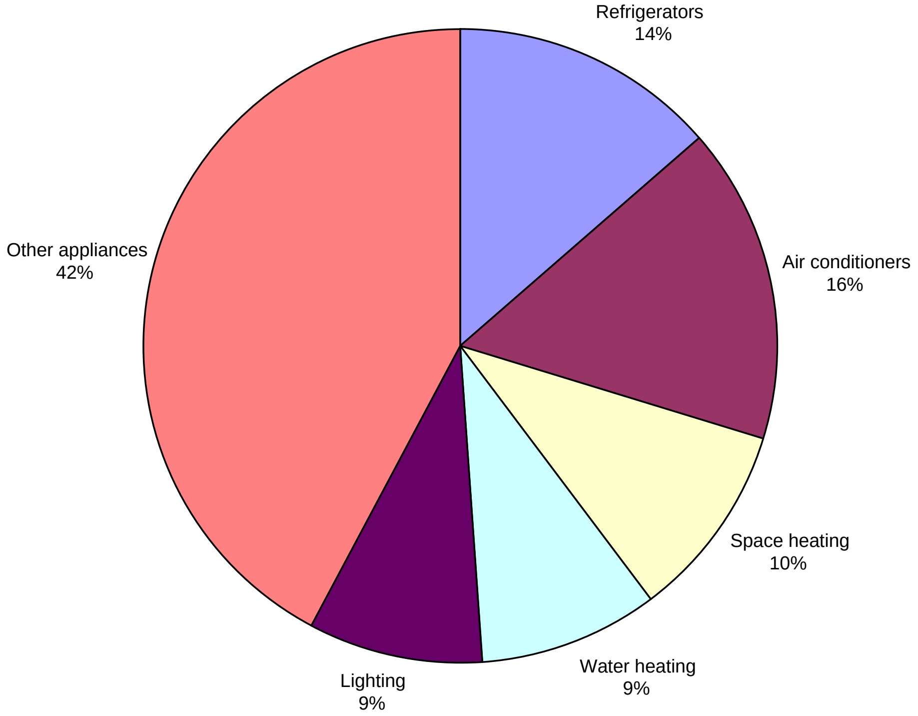
ASHRAE 90.1 Does Not Cover All Building Energy Use, Which Limits the Ability to Reach Better-than-Code Efficiency Targets

It is important to understand that not all of a building's energy use is regulated in ASHRAE 90.1. For example, lighting within dwellings is outside the scope of 90.1. Likewise, the energy use associated with water heating in an apartment is not covered. Appliance energy is also not regulated by the standard.

Figure ES2 shows the electric energy use in residential buildings as a way to illustrate where energy is used in a building. This demonstrates that even if codes and standards like 90.1 are made to be 30% or 50% better than today, the overall impact on total energy use would be substantially less in a building like an apartment. This is because 90.1 does not directly address items like appliances and refrigerators that make up a large part of a residential building's energy use.

Figure ES2 – Residential electricity by end use (2001)

Source : US. Energy Information Agency RECS data



On-Site PV Systems could Allow Buildings to Meet the 50% Goal, but are Costly and are not within 90.1's Scope

If the scope of 90.1 were broadened to capture more energy uses, it might be possible to reach the 50% goal in each city by generating electricity at the site through the use of electric photovoltaic (PV) systems or other renewable energy. Assuming that PV was recognized by ASHRAE 90.1, the costs to make up the gap between the highest levels of efficiency realized in the modeling and the 50% goal are shown below. Because there are wide ranges of costs associated with specific PV systems, a range is shown in Table ES4.

Table ES4 - PV System Cost Estimates to Supplement Other Technologies and Meet 50% Threshold

	Atlanta	Chicago	Houston
Normalized low-end cost of installed system ($/W DC)	$7.00	$7.00	$6.00
Normalized high-end cost of installed system ($/W DC)	$9.00	$9.00	$8.00
Total low-end cost of PV system ($)	$240,885	$154,778	$42,527
Total high-end cost of PV system ($)	$309,709	$199,000	$ 56,703

There may be options other than PV that can be used to make up the deficits in each location. In any case, applying them in an effort to meet better-than-code targets would require significant change to the ASHRAE 90.1 scope. If for example, lighting for dwelling units were added to the scope for the standard, then something as simple as using CFLs might provide enough savings to reach the 50% threshold in Chicago and Houston. Other improvements such as high efficiency water heaters would likely be needed in Atlanta.

Conclusions

Specific conclusions from this study include the following:

- The 30% and 50% "better than ASHRAE 90.1" levels will clearly present some practical and cost barriers for designers, builders and owners. In fact, it will be nearly impossible to reach the 50% level for an apartment building of the type studied in this project with today's technology without some type of scope change to the 90.1 standard to allow credit to be taken for improvements in energy uses not currently regulated by the standard.
- Even in climates or with buildings where it may be possible to reach the 50% level, the cost to do so will be significant. Most likely, a building will need to be fitted with GSHP technology, which in many areas does not have a well developed support infrastructure at this time to support the number of buildings in question. The cost to use GSHPs in the building we simulated could be several hundred thousand dollars over conventional equipment used in today's buildings.
- The simple payback to achieve an improvement over ASHRAE 90.1 of 30% or higher is likely to be outside of the range that would normally be accepted for this type of analysis. For example, the average payback of about 16 years for the 30% improvement level in Atlanta is somewhat excessive. Furthermore, this is only an average payback. Some buildings could be penalized with paybacks as high as 25 years depending on the local cost of items such as GSHPs, which vary greatly.
- The costs associated with reaching the 30% and 50% performance levels would be nearly impossible for a builder or owner to recapture. Increased rents would be hard to realize when renters have a choice of lower cost, older apartments – which would also tend to be less efficient. Conversely, the energy savings would accrue to the renter in a newer building where most utilities are paid by the renter. This disconnect needs to be considered in any cost benefit analysis before modifying codes and standards.
- Traditionally, energy codes and standards have targeted increased levels of insulation as the primary method for increasing a building's performance. Additional insulation offers diminishing returns – almost all increases will improve the building by less than 1%, and most by only a fraction of a percent. Even when insulation levels in all of the major components of a building (roofs, floors, walls) are increased simultaneously, they do not begin to come close to reaching even the 15% threshold.

- Designers will need to specify high efficiency equipment to make significant gains in building performance. In most cases, this should be the starting point rather than additional insulation since the costs of additional insulation can be significant and the benefit very small.
- Changes to the 90.1 scope could help designers and builders to more easily reach the proposed increases in performance. For example, it would be easy and not very costly to use CFLs in lighting fixtures and save a significant amount of energy in an apartment. Currently, the 90.1 standard exempts the inside of dwelling units from the lighting requirements. There may be good reasons for this exemption related to enforceability, but if the standard allowed a designer to submit to the lighting requirements, it would provide an opportunity for them to move closer to the 30% or 50% levels. Appliances, water heaters, and air leakage (infiltration) are other items where similar opportunities exist.
- Onsite generation of renewable energy also could help a designer to reach the 30% or 50% performance levels. As with lighting, the 90.1 standard would need to be revised to allow for any electricity generated by PV, wind, or other systems to offset energy costs in the 90.1 energy cost budget method.
- The methods used in this study relied heavily on building simulations. Simulations are good methods to estimate the *relative* performance of changes to the same building. They should not be used to predict the actual overall energy use of a building, since there are too many factors besides design that influence energy use. Simulation tools have many limitations and require assumptions that introduce a heavy user bias. Further, use of the prescriptive methods in codes and standards is the more typical approach for designing a building. When a simulation approach is introduced, the cost and time for the simulations could be significant. Modeling results from this and similar studies could help reduce the costs by providing designers with a head start in deciding what to simulate.
- Policy makers and codes/standards developers should recognize that the market infrastructure, climate, and consumer preferences all influence the design of a building. Climates and markets can be radically different around the United States. Approaches that seem reasonable in one part of the country should not be automatically adopted elsewhere. For example, just because a high efficiency heat pump may be the best choice for a building from an energy savings perspective, in some climates it is unlikely that homeowners will be accepting of anything but a hot-air furnace system. Forcing them to accept something else could have a negative impact on energy efficiency if they are so accustomed to warmer air that they end up running their heat pump in back-up or emergency electric resistance mode as a way to provide warmer air.
- Overall, for multi-family buildings like the ones analyzed in this project, the uniform imposition of higher efficiency standards without scope changes to 90.1 could have negative, unintended consequences. Builders and owners will absorb added costs, yet the building occupants will accrue energy cost savings benefits. The required capital for engineering and constructing such buildings

will increase substantially, yet the return on this investment is uncertain at best. Ultimately these dynamics could undermine the viability of new high-performance multi-family buildings and instead push the market towards the continued use of older, far less efficient dwellings.

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DEFINITIONS AND TERMINOLOGY

AC – Acronym for air-conditioner. In this study, we assumed that a building can be cooled by either a separate electric AC system, or by a heat pump.

Air-source Heat Pump – A heat pump is a technology that provides both heating and cooling using a single compressor for both purposes. An air source heat pump heats and cools a building by exchanging heat with the outside air.

AFUE – Acronym for Annual Fuel Utilization Efficiency, a measure used to define the efficiency of a gas furnace. The higher the AFUE, the more efficient the system will be.

ASHRAE – Acronym for American Society of Heating, Refrigerating and Air-Conditioning Engineers. ASHRAE is a professional society for energy and mechanical engineers, contractors, and related disciplines. They produce the ASHRAE Standard 90.1 that is one of the most widely adopted standards for energy efficiency in buildings and is the backdrop for this study.

Btu – Acronym for British Thermal Unit, a unit typically used to define the size of heating and cooling loads and the capacity of HVAC equipment. Trade contractors, manufacturers, and designers often use Btu to define the size of a heating or cooling system (e.g., a 24,000 Btu air conditioner).

Cavity insulation – In light framed construction, building walls are constructed of 2x4 or larger studs spaced 16 or 24 inches apart. The space between the studs is called the cavity. Typically, fiberglass, cellulose, mineral wool, or some other type of insulation is installed in the cavity, hence the term “cavity insulation.”

CFL - Acronym for compact fluorescent light. In layman’s terms, CFLs are long lasting, highly efficient light bulbs that can be used in many fixtures that take an incandescent bulb.

Continuous insulation – Continuous insulation typically goes on the outside of a wall as opposed to inside the wall framing cavity. In this report and in many codes and standards, when both cavity and continuous insulation is required, the cavity R-Value is expressed first followed by the R-Value of the continuous insulation. For example, R21+5 would indicate that R-21 insulation is required in the cavity in addition to R-5 on the exterior of the studs. Continuous insulation is typically a foam-based product.

COP - Acronym for Coefficient of Performance. COP is typically used to describe the efficiency of a heat pump and refrigeration systems. In this report, COP is used to express the efficiency of a ground source heat pump in the heating mode. The higher the COP, the more efficient the system will be.

EER - Acronym for Energy Efficient Ratio, a term used to define the efficiency of a cooling system. In this report, EER is used to define the efficiency of a ground source heat pump in the cooling mode. The higher the EER, the more efficient the system will be.

Envelope (thermal) – The insulation in a building is designed to separate the inside, conditioned space from outside conditions. This physical separation is often called the thermal envelope. Items outside the thermal envelope, such as in an attic, are considered to be outside the conditioned space of the building.

GSHP - Acronym for Ground Source Heat Pump. Also called a geothermal heat pump because heat is exchanged with the earth through a well, surface water, or underground loop to provide heating, cooling, and water heating for a building. This differs from the typical air-source heat pump which exchanges heat with outside air. A GSHP is generally much more efficient than other HVAC systems.

HSPF - Acronym for Heating Seasonal Performance Factor. HSPF is used to define the efficiency of a heat pump in the heating mode. The higher the HSPF, the more efficient the system will be.

HVAC - Acronym for Heating, Ventilating, and Air-Conditioning. Even when there is no mechanical ventilation component, it is not uncommon for a heating or cooling system in a building to be called an HVAC system.

IECC - Acronym for International Energy Conservation Code, published by the International Code Council. The IECC is the most widely used energy efficiency code for buildings in the United States. It adopts by reference the ASHRAE 90.1 standard.

NFRC – National Fenestration Rating Council. NFRC is generally recognized as the authoritative source for information on the thermal performance of windows. They maintain a listing of certified products which was used as a resource for this study.

Performance requirements – Building codes and standards often contain both performance and prescriptive requirements. A performance requirement tends to specify a result and lets the user determine how to achieve it.

Prescriptive requirements - A prescriptive requirement in a code or standard is very specific in explaining what exactly is required at the component level. For example, a code may have specific R-Values for wall or attic insulation. This is in contrast to a performance requirement that typically allow for numerous ways to comply.

PV - Acronym for photo-voltaic. PV is a technology that is used to generate electricity using energy from the sun. PV panels can be used on the roofs of buildings to minimize or offset the amount of electricity needed from the utility provider. It is also frequently referred to as “solar-electric.”

Reference Design – Performance options in codes allow a designer to evaluate the overall performance of a building against a specific standard using an energy simulation software program. The standard that a proposed design is compared against is called the reference design.

R-Value – A measure of the resistance of a building component to the flow of heat. R-Value is the inverse of the thermal conductance, or U-Factor. Insulation levels in a building are typically defined as an R-Value. The higher the R-Value, the better the wall or other building component is at slowing heat loss.

SEER - Acronym for Seasonal Energy Efficiency Rating used to measure the efficiency of an air-conditioning system. The higher the SEER, the more efficient the system will be.

SHGC - Acronym for Solar Heat Gain Coefficient. SHGC is a measure of the ability of a windows and other glazing to block solar radiation. In most cases, the lower the SHGC, the better the window will be from an energy efficiency standpoint.

U-Factor - A measure of the thermal conductance of a building component. U-Factor is the inverse of the R-value. The lower the U-factor of a window, wall, or other assembly, the more efficient it will be.

PROJECT BACKGROUND

Rationale for the Study

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the U.S. Department of Energy (DOE) recently announced a cooperative program to significantly increase the efficiency requirements for buildings. In a July 30, 2007 release, the organizations announced a goal of a 30% increase over today's standards by 2010 (www.ashrae.org/pressroom/detail/16399). This dovetails with legislation before Congress in 2007 that would have required DOE to develop Federal standards if building and energy codes did not increase their efficiency requirements. Performance increases as high as 50% over today's codes by 2020 were addressed in the legislation. Although these parts of the legislation were ultimately removed in House-Senate conference negotiations as part of the Energy Independence and Security Act, proponents have made it a priority to bring them before Congress again.

> ***This new initiative provides an opportunity for ASHRAE and DOE to expand our collective energy conservation efforts, our energy conservation education initiatives and strategic research program focus in leading our country and the world toward a sustainable energy future***
>
> \- Kent Peterson, ASHRAE president in news release announcing a goal of 30% improvement in ASHRAE energy efficiency standards by 2010.

The feasibility of such increased building performance requirements and their impact on building costs are important issues that need to be understood. This study provides one of the few detailed looks at the costs and feasibility of large increases in energy efficiency for apartments and similar multi-family buildings. The results are intended to assist legislators, codes and standards developers, and other policy makers in addressing energy efficiency in multi-family buildings in a balanced and informed manner.

Multi-family Housing – A Unique and Efficient Form of Housing

The impact on building costs due to increased regulations is an important issue for owners, developers, builders, and renters of all buildings, but apartments and other multi-family buildings in particular. One-size-fits-all goals for energy efficiency improvements can lead to consequences that were never intended. Considering that newer multi-family buildings are often the most sustainable form of housing – due to their higher density, lower material use per unit, and inherently lower utility costs – it is particularly important that society carefully weigh the impacts of how and whether to layer additional regulatory requirements on this important part of the housing market. Sustainable policies should encourage already efficient types of construction and be carefully evaluated so as to not discourage their selection by developers.

Regulating Building Energy Efficiency through Codes and Standards

There are a wide variety of ways in which energy efficiency is regulated in the United States. Although manufactured homes are regulated under a Federal standard administered by the U.S. Department of Housing and Urban Development, almost all other buildings are regulated by state or local governments.

Some states like California have developed their own energy efficiency codes geared to specific needs of the state. At the other extreme, some states have no requirements at all, or limit them to only certain types of buildings. Within these states, local communities may adopt their own codes and standards. Adoption of a model code or standard developed by a third party is the primary way local communities and states create their building code regulations.

The two most widely recognized third-party energy documents adopted by state or local jurisdictions are the ASHRAE Standard 90.1 (*Energy Standards for Buildings Except Low-Rise Residential Buildings*) and the International Energy Conservation Code (IECC).

ASHRAE 90.1 has a scope that covers all buildings except single-family and other low-rise residential buildings, whereas the IECC covers all types of buildings. The 2006 IECC and 2004 90.1 standard each have multiple options for compliance.

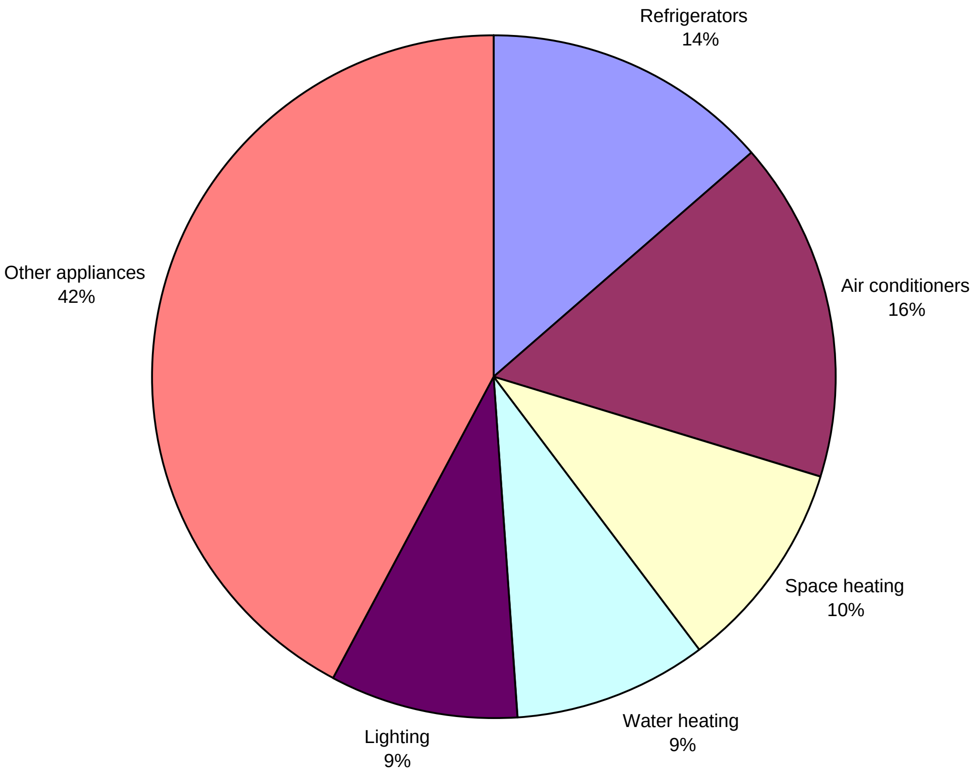
Interestingly, one compliance option within the IECC is to comply with the requirements of ASHRAE 90.1. Thus, many people believe that the IECC and 90.1 provisions result in a similar level of performance. Technically, they do have significant differences.

Perhaps more important than the differences between the IECC and 90.1 are those items not regulated by either document. These include energy use related to TVs, radios, office equipment, computers, and other plug or miscellaneous loads; refrigerators, washers, dryers, and other large appliances; and portable lighting within dwellings. Both documents also only indirectly address the heating and cooling energy related to air infiltration.

The electrical energy related to various end uses in a residential building is shown in Figure 1. Refrigerators, other appliances, and lighting represent 65% of the electrical energy in a residential building even though these end uses are not regulated directly by 90.1 or the IECC for dwelling units.

Figure 1 – Residential electricity by end use (2001)

Source : US. Energy Information Agency RECS data



It is important that policy makers realize that a 30% or 50% increase in code requirements will not result in an equivalent decrease in whole-building energy consumption. On the other hand, there will be extreme practical and economic limitations that should be considered if end uses that, for example, only amount to 35% of the energy in an all electric building must shoulder a 30% or 50% reduction for the entire building.

ASHRAE 90.1 versus the International Energy Conservation Code

ASHRAE Standard 90.1 has a scope that covers all buildings except single-family and other low-rise residential buildings. These smaller residential building types are covered under a separate ASHRAE standard.

The IECC scope includes all types of buildings, although residential requirements are contained within a separate chapter than other buildings. The 2004 IECC has multiple options for compliance of large residential and commercial buildings, one of which is meeting the requirements of ASHRAE 90.1. The IECC also has its own prescriptive and performance options for compliance.

The IECC performance approach requires the same simulation tool be used for the proposed design and the reference design but otherwise provides little additional information on how to select a simulation tool. On the other hand in ASHRAE 90.1, the standard specifies explicit criteria for how to use the performance (modeling) approach (e.g., the model must be an hourly simulation tool) and gives examples of acceptable modeling tools including BLAST and DOE2. Both documents require input and output files as documentation for the simulations.

The 90.1 performance method is called the “energy cost budget” method. Table 11.3.1 of the standard provides specific instructions for how to model the proposed design and the reference design under this approach. Unfortunately, the energy cost budget method tends to restrict the scope of areas where a designer could make more energy efficient selections for a building. For example, individual domestic water heaters within apartments must be identical in the reference design and proposed design, effectively taking this significant item off the table in terms of reaching the proposed goals of 30 or 50% better than 90.1. Lighting inside dwellings and infiltration are other similar examples.

The energy simulation software we used to develop the cost budget method in this study calculates a report that shows the overall energy costs for all energy uses covered by 90.1. To perform this analysis, location-specific fuel costs are required as inputs. It also shows the energy use associated with the building and breaks this item and the costs into the following components: Total electricity, area lights, miscellaneous electric loads, pumps, space cooling, space heating, vent fans, total natural gas, and space heating for gas. Note that no water heating costs are reported, although water heaters must be input since they must still meet the minimum prescriptive efficiency requirements.

Use of Standard 90.1 over IECC for this Study

In performing this analysis of what it takes to reach “better-than-code” efficiency targets, we based our study on the ASHRAE 90.1 requirements over the IECC for three main reasons:

1. The two documents are often considered equivalent standards, but the IECC offers one compliance path that requires meeting the 90.1 requirements. Thus, complying with 90.1 technically results in compliance with both documents.
2. There are no recognized simulation tools that automatically develop a reference design for an apartment building under the IECC, whereas there is a respected modeling tool that does so for 90.1. This takes some of the user bias out of the process that can be introduced with tools that require the user to develop the reference design themselves.
3. ASHRAE requirements often are used as the basis for requirements in other codes. Further ASHRAE has already initiated efforts to increase their

> performance levels by 30% in the next edition of 90.1. Thus, the impact of more stringent requirements may be more time sensitive for 90.1 than the IECC.

Note that when we refer to ASHRAE 90.1 throughout this document, we are discussing the 2004 edition unless otherwise indicated.

STUDY METHODOLOGY

A computer simulation offers the most direct method for comparing how a proposed design compares to the 90.1 standard or the IECC. For this study, we selected three cities that have relatively large numbers of apartments built each year and that are located in very different climate zones. The simulations were run on a four-story apartment building in each climate location using the energy cost budget method described in Chapter 11 of ASHRAE 90.1 (2004 edition). The four-story building prototype was based on typical multi-family designs being constructed in the market today, based on dialogue with industry experts.

The energy cost budget method is frequently used by designers to establish compliance or to see how their design otherwise compares to 90.1. Although our study was based heavily on results of simulations following the energy cost budget method in the 2004 edition of ASHRAE 90.1, where appropriate, we used other estimation methods to address unique situations.

In addition to the computer simulations, we also conducted the following activities:

1. Developed cost estimates of the options necessary to achieve energy performance of 15%, 30% and 50% above ASHRAE 90.1.
2. Described any obstacles to the 15%, 30% and 50% thresholds including technical barriers, problems with product availability.
3. Provided guidance or comments on how the feasibility of achieving energy performance 15%, 30% and 50% above 90.1 might improve in the future or under different scenarios.

There are dozens of simulation tools available to assess a building’s performance. We chose Energy Gauge Premier Summit (V.3.11) for this study. Energy Gauge (EG) is maintained by the Florida Solar Energy Center at the University of Central Florida. The rationale for selecting EG and its advantages and limitations are provided in Appendix A.

Assumptions

Assumptions for the study are addressed in the following sections:

Locations

We selected Atlanta, Chicago and Houston as the locations. These cities gave us a mix of climates including cooling dominated (Houston: 90.1 Climate Zone 2), heating dominated (Chicago: Climate Zone 5) and a mixed climate (Atlanta: Climate Zone 3). We also were able to look at different fuels for heating since the norm for apartments in Houston and Atlanta is an electric heat pump but it is a gas furnace in Chicago.

Fuel Costs

Fuel costs assumed for each location are shown in Table 1. Within each location, there are generally several options a consumer can select for their rates. We chose the flat rate plan for each location. Rates are those in place as of October 2007.

Table 1 – Electricity and natural gas charges

Location	Electric use and distribution rate ($/kWh)	Electric monthly account fee ($/month)	Natural Gas use and distribution rate ($/therm)	Natural Gas monthly account fee ($/month)
Atlanta	0.0783	7.50	0.999	8.99
Chicago	0.0766	6.69	1.23	8.99
Houston	0.15	none	0.967	10.50

Building Characteristics

There are many different types and sizes of apartments and multi-family buildings, making it difficult to determine the impact of energy efficiency standards on these building as a whole. We selected an apartment building with components designed to meet the minimum prescriptive requirements of 90.1. In other words, we started with typical materials and systems used for low-rise (four-story or less) apartment buildings and selected prescriptive minimums for each thermal component.

The base building is a four -story apartment with eight units per floor of roughly 1000 square feet each. The building has a slab foundation and a 6/12 pitch gable end roof with an unconditioned attic. All duct work and equipment was assumed to be in conditioned space. Each apartment unit was assumed to have an individual heating, cooling, and hot water system serving only that specific unit, all typical practices in the apartment market.

Other characteristics of the base building are shown in Table 2 and Figure 2 below.

Figure 2- Sketch of floor plan of apartment building
(all floors are identical)

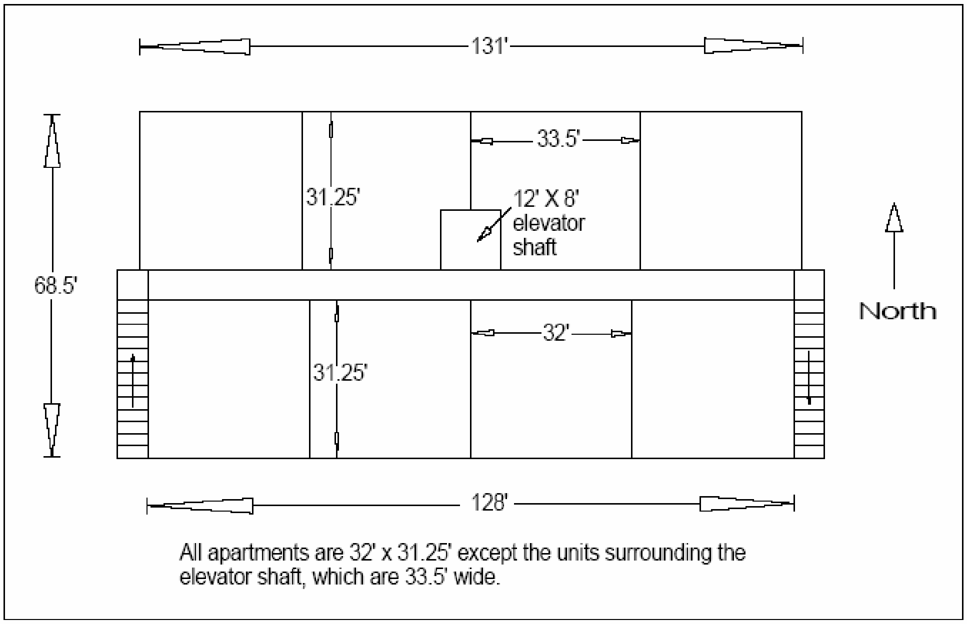


Table 2– Building characteristics

General size/shape characteristics

- Four-story building
- Type V (wood) framing
- 8 units per story
- One bedroom units
- Approximately 1000 sf per unit
- 8' ceiling height
- Exits from units are direct to common center corridor within the thermal envelope.
- Elevator located in center of corridor within thermal envelope.
- Building exit stairs are outside of the conditioned space (open to outside air)
- Long dimension runs east to west (most windows on the north and south sides)
- Roof framing materials are wood trusses on a 6/12 pitch.
- Walls are wood stud with vinyl siding
- Foundation type: Slab on grade in all locations

Equipment

- Individual water heaters in each unit meeting 90.1 minimum efficiency requirements (40 gallon tank type, gas)
- Individual HVAC units with minimum 90.1 efficiency in each dwelling
    - SEER 12 heat pumps in Atlanta and Houston
    - 80 AFUE gas furnace with separate SEER 12 AC in Chicago
- Through the wall ductless SEER 10 units in corridors
- All equipment, supply and return ducts are inside the conditioned envelope

Thermal envelope properties[1]

	Atlanta	Chicago	Houston
Roof insulation: minimum prescriptive R Value	R-38	R-38	R-38
Exterior door: Steel with minimum R value	R-2.6	R-2.6	R-2.6
Wall framing: minimum prescriptive R Value	R-13	R-13	R-13
Window type: double hung, operable with closest values as is commercially available that are under the maximum code prescriptive SHGC and U values (from NFRC listings)	SHGC and U vary by climate and orientation – see inputs in appendix for specific window properties		
Average window to wall ratio (expressed as percentage)	About 23% of gross wall area (these vary by wall, see the input files in appendix for specific areas)		
Unit separation walls: Wood frame (Note: not significant since all adjacent to conditioned space)	R-13	R-13	R-13
Raised floors: Wood frame (Note: not significant since all adjacent to conditioned space)	R-19	R-19	R-19
Infiltration	ASHRAE crack method for proposed and reference design. (not governed by 90.1 except in prescriptive option)		

Thermal zones for building simulations

- Dwelling units: 18 conditioned zones arranged so that only units with the same orientation and exposure conditions were grouped
- Corridors: 3 conditioned zones (4th floor, 1st floor, combined 2nd and 3rd floor zone)
- Attic: One unconditioned zone
- Elevator: One unconditioned zone but located entirely within other conditioned space.
- Stairways: Not included as zones since outside of the thermal envelope

[1] U values corresponding to these R-values were selected from the 2004 ASHRAE 90.1 Normative Appendices for all components exposed to unconditioned space, except where not covered in the normative appendices. For example, an R-40 was used for a SIPS panel since wall framing in the normative appendices is based on stud wall assemblies.

SIMULATION RESULTS

Review of Energy Upgrades and Resultant Savings

The simulation results are the focus of this study because they identify the options that can most help a designer reach a certain goal above the 2004 ASHRAE 90.1. Table 3 shows the outputs for the design of the base buildings in Atlanta, Chicago, and Houston. The 90.1 reference costs in the table are automatically generated by Energy Gauge to represent the energy cost budget that is required for compliance with 90.1.

Table 3 – Base annual building energy cost budget simulation results

	Atlanta 90.1 reference	Chicago 90.1 reference	Houston 90.1 reference
Total Cost Budget	$32,946	$56,951	$64,960
Electricity	$32,946	$25,323	$64,960
Area lights	$6,895	$6,746	$13,175
Misc. Equipment	$4,733	$4,630	$9,044
Pumps & Misc.	$39	$836	$67
Space cool	$4,491	$2,078	$18,733
Space heat	$8,781	$2,653	$8,138
Vent fans	$8,007	$8,380	$15,804
Natural gas		$31,628	
Space heat		$31,628	

The 90.1 reference costs for each location represent the metric against which changes to the building were evaluated in later simulations. In other words, as changes were made to upgrade a component in the base building (for example, increasing attic insulation), a new proposed design energy cost budget was developed. The total energy cost associated with the building was compared to the reference total costs in Table 3 to derive a percentage better than the 90.1 reference. Thus, a building with a proposed design energy cost budget of $90,000 would be 10% better than a reference design with an energy cost budget of $100,000.

As mentioned earlier, the outputs and input files are required by 90.1 to support use of the energy cost budget method. Because each input file is more than 20 pages in length, for practical purposes we have only included the input reports for the three base buildings in Appendix B of this report. For subsequent simulations, summary tables showing the results indicate what items were modified in the inputs.

Initially, only individual components were changed and all other inputs to the building were held constant. We then went on to evaluate combinations of improvements to see what was necessary to reach the 15%, 30%, and 50% levels of improvement above ASHRAE 90.1.

Results of the simulations are shown in Tables 4 to 6. Everything in the baseline building was held constant except for the items in the far left column of the tables. As an example, the entry "R-49 attic" indicates that the baseline building attic insulation was increased to R-49. Likewise, "R-49 attic, R-19 wall" indicates that the attic insulation was increased to R-49 and the exterior wall insulation was increased to R-19, but all other inputs are as defined in the baseline building characteristics in Table 2 and the input files in Appendix B were unchanged. Where required by the standard, R-values were selected to be equivalent to the inverse of the U-Factors as described in the 90.1 Normative Appendices.

Over 110 simulations were run in the three locations. Not all of the results are shown in Tables 4, 5, and 6, nor are all of the options shown identical for each city. Generally, items that made little difference in the energy cost budget were omitted unless they were related to the envelope R-Values. We specifically included R-Value improvements even if they had little improvement because these are the items that are most often thought to provide meaningful improvement to a building's performance.

Table 4 - Atlanta Simulations

Description (items in parenthesis are the baseline building characteristics for the item or items that were changed for each simulation)*	**% of 90.1 Reference Building**	**% Better than Reference Building**
Baseline building	100	
Doors R-5.2 (R-2.6)	99.88	0.12
R-49 attic (R-38)	99.85	0.15
R-19 walls (R-13)	99.56	0.44
U=0.3, SHGC=0.19 *	99.39	0.61
R-21+5 walls (R-13)	99.12	0.88
R-49 attic, R-21+5 walls (R-38,R-13)	99.08	0.92
R-5 subslab (R-0)	99.01	0.99
R-40 walls (R-13)	98.72	1.28
R-49 attic, R-40 walls (R-38,R-13)	98.67	1.33
R-49 attic, R-40 walls, R-5 under slab (R-38,R-13, R-0)	97.55	2.45
SEER 15/HSPF 8.3 Heat pump (SEER 12/HSPF 7.4)	95.60	4.40
SEER 19,/HSPF 10 Heat pump (SEER 12/HSPF 7.4)	90.42	9.58
SEER 19,/HSPF 10 Heat pump, R-49 attic, R-21+5 walls, U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R-38, R-13) *	89.25	10.75
SEER 19,/HSPF 10 Heat pump, R-49 attic, R-21+5 walls, R-5.2 door, U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R-38, R-13, R-2.6)	89.15	10.85
SEER 19,/HSPF 10 Heat pump, R-5 subslab, R-21+5	88.90	11.10
SEER 19,/HSPF 10 Heat pump, R-49, R-21+5, R-5.2 door, R-5 subslab, U=0.3, SHGC=0.19 , (SEER 12/HSPF7.4, R-38, R-13, R-2.6, R-0) *	88.26	11.74
GSHP (3.7 COP, 16.9 EER) (SEER 12/HSPF 7.4)	68.85	31.15
GSHP, R-49attic, R-21+5 walls, , R-5.2 door, R-5 subslab, , U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R-38, R-13, R-2.6, R-0) *	60.62	39.38

* Windows in the baseline building vary by wall orientation. See Appendix B for specific values.

Some options made significant differences in one climate but not necessarily in all climates (e.g., subslab insulation). Many different variations of shading and window orientation also are not shown because they contributed little to no improvement in the building's overall performance. Lighting variations were simulated because lights represent a significant potential for energy savings. However, lighting was omitted from tables 4, 5 and 6 because it is an item that cannot be used to improve compliance within dwellings in 90.1. Lighting is discussed in a different context in the next section (Opportunities with 90.1 scope changes) since it does represent a large potential opportunity if 90.1 were restructured.

Table 5 - Chicago Simulations

Description (items in parenthesis are the baseline building characteristics for the item or items that were changed for each simulation)	**% of 90.1 Reference Building**	**% Better than Reference Building**
Baseline building	92.52	7.48
R-5.2 alum/poly door (R-2.6)	92.51	7.49
R-49 attic(R-38)	92.32	7.68
R-19 wall (R-13)	91.71	8.29
R-21+5 walls (R-13)	90.89	9.11
R-49 attic, R-21+5 walls (R-38, R-13)	90.68	9.32
R-21+10 walls (R-13)	90.55	9.45
R-40 Walls (R-13)	90.12	9.88
R-49 attic, R-40 walls (R-38, R-13)	89.92	10.08
R-5 subslab (R-0)	89.10	10.90
96 AFUE Furnace (78 AFUE)	84.81	15.19
96 AFUE furnace, SEER 19 AC (78 AFUE, SEER 12)	83.94	16.06
R-49 attic, R-40 walls, 96 AFUE furnace, SEER 19 AC, R-5 subslab (R-38, R-13, 78 AFUE, SEER 12, R-0)	78.78	21.22
3.7 COP/16.9 EER GSHP (78 AFUE furnace + 12 SEER AC)	54.96	37.15
3.7 COP/16.9 EER GSHP, R-49 attic, R-40 walls, R-5 subslab (78 AFUE furnace + 12 SEER AC, R-38, R-13, R-0)	47.93	46.07

Table 6 - Houston Simulations

Description (items in parenthesis are the baseline building characteristics for the item or items that were changed for each simulation) *	**% of 90.1 Reference Building**	**% Better than Reference Building**
Baseline building	93.51	6.49
R-5.2 alum/poly door (R-2.6)	93.43	6.57
R-49 attic (R-38)	93.41	6.59
32 inch shading N side (none)	93.34	6.66
32 inch shading SEW sides (none)	93.28	6.72
R-19 wall (R-13)	93.19	6.81
32 inch shading all sides (none)	93.11	6.89
R-21+5 walls (r-13)	92.85	7.15
R-49 attic, R-21+5 walls (R-38, R-13)	92.75	7.25
R-21+10 walls (R-13)	92.71	7.29
R-40 Walls (R-13)	92.54	7.46
R-49 attic, R-40 walls (R-38, R-13)	92.44	7.56
U=0.3, SHGC=0.19*	92.38	7.62
SEER 15/HSPF 8.3 Heat pump (SEER 12/HSPF 7.4)	86.52	13.48
SEER 15 HP/8.3 HSPF Heat pump, R-40 walls, R-49 attic, U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R-13, R-38)*	84.76	15.24
SEER 19/HSPF 10 Heat pump	83.99	16.01
SEER 19/HSPF 10 Heat pump, R-40 walls, R-49 attic, U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R13, R-38)*	80.49	19.51
3.1 COP/14.6 EER GSHP (SEER 12/HSPF 7.4)	59.23	40.77
3.1 COP/14.6 EER GSHP, R-40 walls, R-49 attic, U=0.3, SHGC=0.19 (SEER 12/HSPF 7.4, R-13, R-38)*	52.39	47.61

* Windows in the baseline building vary by wall orientation. See Appendix B for specific values.

The table entries are shown to the second significant digit. This does not imply that the simulations are that precise. Typically, we would round the numbers to the nearest whole number. The digits to the right of the decimal point are shown only to illustrate just how small the associated impact is due to some of the items that are typically thought to contribute significantly to improved performance.

As shown in the tables, obtaining performance levels of 15% above 90.1 in Chicago and Houston would require a combination of improvements to the envelope and higher efficiency equipment. In fact, one could reach the 15% level without changes to the envelope by simply selecting high efficiency equipment (e.g., jumping to a SEER 19 heat pump in Houston).

The methods, materials and equipment to reach 15% in Chicago and Houston would fall within the range of what we might call normal upgrades to a building. The biggest barrier to this level of performance is generally higher first costs, rather than any type of technological feasibility issue.

Reaching the 30% and 50% threshold in Houston and Chicago, and the 15% threshold in Atlanta, would require a jump to what we might call extraordinary equipment or practices, and/or changes to the 90.1 scope. For example, the equipment efficiency that would be required to reach these levels would generally require ground source heat pumps (GSHP) or similar advanced technology. Higher end air source heat pumps or other conventional equipment that is currently commercially available is not efficient enough to reach these goals, even when combined with extensive envelope improvements. In the three climates examined, even very advanced equipment would be unlikely to achieve the 50% goal for an apartment building. The scope of 90.1 would need to change to recognize lighting, water heating energy, and onsite renewable energy production (e.g., PV or wind) as an allowable method to offset building energy use in the energy cost budget method.

The Baseline Building Compared to the Reference Building

Except for the Atlanta results in Table 4, the reader should not interpret that a specific option or group of options is solely responsible for the improvement over the 90.1 reference shown in the far right column of the Tables 4 to 6. The actual contribution of an option is the difference between the far right column and the baseline buildings "% of 90.1 reference building" in the center column. For example, the use of R-49 attic insulation in Houston (Table 6) would result in a 0.10% improvement over the baseline building. In Houston, the baseline building designed to 90.1 prescriptive minimums (or in the case of windows, the nearest commercially available window to the minimum) already performed better than the reference design by 6.49%. Thus increasing attic insulation from R-38 to R-49 yields a 0.10% improvement (93.51% versus 93.41%).

This also helps explain why it was more difficult to reach the 15% goal in Atlanta without resorting to extraordinary equipment as opposed to the other locations. The baseline building in Atlanta, designed to 90.1 prescriptive minimums, was at about 100% of the reference design energy cost budget. Thus, in Atlanta, the building did not have the same "head start" as Chicago and Houston where the minimum prescriptive requirements resulted in a building that was already 6.5% to 7.5% under the reference energy cost budget.

Energy Savings from Envelope Improvements

Since opaque envelope improvements are typically the first items targeted for code changes, it is important to understand how they could impact the performance of a building. Figure 3 illustrates selected envelope improvements from the simulations in Atlanta. Note that most envelope improvement by themselves provided less than 1% energy savings. Even combining multiple improvements offered less than a total of 2.5% improvement. Similar results were found in Chicago and Houston. The only exception seems to be the addition of R-5 subslab insulation in Chicago, which produced about a 3-1/2% savings over R-0 subslab insulation.

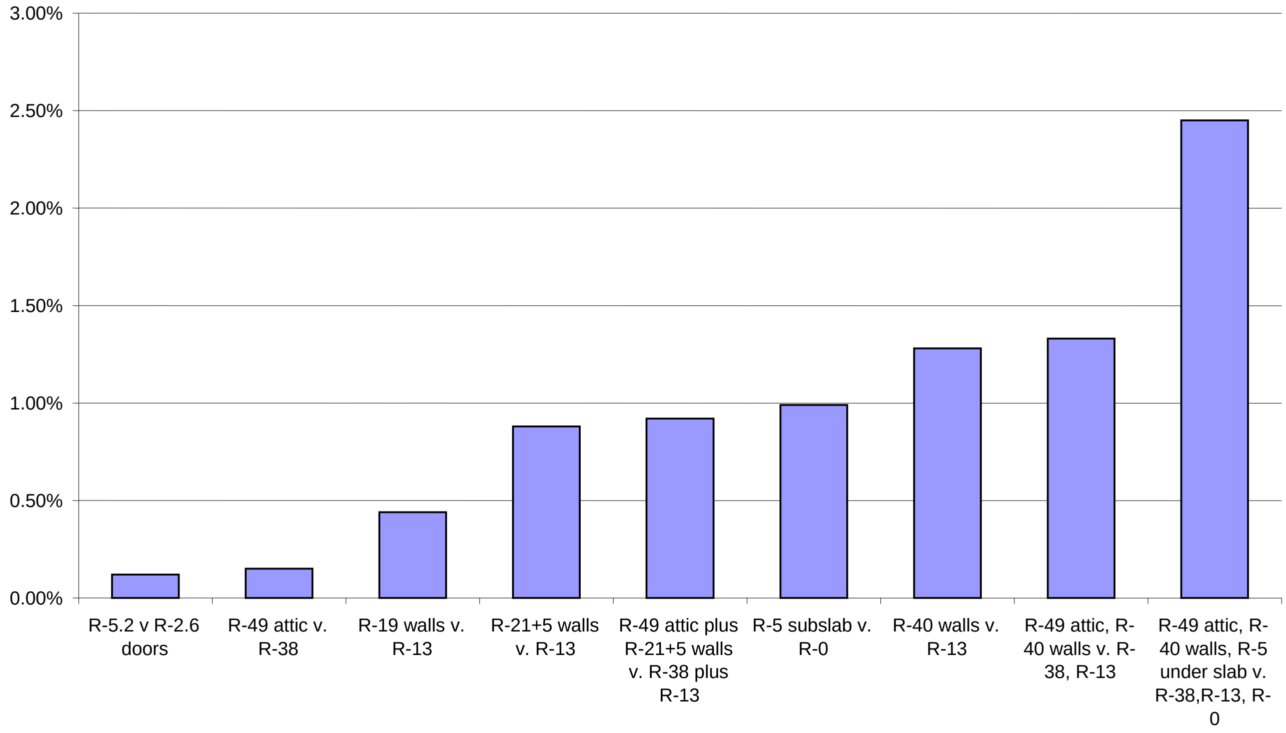


Figure 3 - Improvement due to selected component changes over base building (Atlanta)

It is not possible to save the same energy multiple times so the reader is also cautioned against adding the results of different simulations. The impact of any two or more individual options is not always additive because the options tend to interact with each other. Thus, only when multiple options are input simultaneously in a simulation do the results reflect their combined contribution.

Further discussion of the simulation results is provided in a later section of this report. However, we would caution that results from this study should not be taken as definitive measures of how the options we simulated will impact every building. All buildings are unique. Utility rates vary by location. Likewise, different simulation tools or estimating methods would likely yield different results for a similar building. Thus percentage of improvements should not be taken as firm indicators in every situation. Rather they illustrate the likely range of improvements with different design options.

In addition, we found it necessary to apply some judgment and other estimation tools for some system options. These impacted the way we addressed GSHPs and lighting. Details of these analysis steps are presented in Appendix D.

Unexpected Outcomes

Not all of the simulations provided outcomes that were intuitive. We were surprised by at least a few. These are addressed in the following paragraphs.

Advanced windows and shading provided little benefit: Designers have been taught for decades that thermal characteristics, shading and orientation of windows are critical factors in energy efficiency. A common rule of thumb in cold climates is to use adequate windows on the south-facing orientation for winter heat gain while providing sufficient shading to minimize heat gain in the summer. Also, the lower the U Factor and SHGC, the better in cooling-dominated climates.

So why did the simulations show that window characteristic did not add all that much to the building's overall performance? There are several possible answers. One is that apartment buildings like the one we simulated have a small amount of window area compared to floor area relative to single-family homes and other buildings. A second is that the baseline windows that we used are already fairly good performers. Minimum requirements in codes and standards have pushed up the quality of windows over the years. Thus the combination of better baseline windows and small relative window area would already "use up" some of the improvements we would have expected when we went to a better window.

To test our theory on why windows did not have as much impact as we expected, we ran additional simulations on the Houston building with windows having relatively poor thermal performance. In this case, we assumed a U=0.9 and a SHGC=0.73. This would roughly correlate to a double pane metal window or a single pane wood window.

The building with the "poor" performing window was compared to the advanced windows (U=0.3, SHGC=0.19) to show the potential range of improvement. Whereas the advanced windows generally provided about 0.5% improvement over the baseline windows, the advanced windows provided a 3.5% difference in the 90.1 energy costs compared to the poor performing window. This equates to about 5.4% of the heating and cooling energy costs, which is more in line with our initial expectations and conventional thinking on this subject.

Insulation on ducts did not improve the building's performance: Adding R-8 insulation to the ducts did not show any improvement relative to the baseline building we simulated. Typically, duct losses are understood to contribute a significant amount to the energy use in a building. However, in the case of newer apartment buildings, ducts are typically inside the conditioned space. We thus also assumed ductwork within the conditioned space for the simulations. Once inside conditioned space, the addition of insulation would not be expected to improve the building's energy performance, although there are other benefits attributable to insulating these ducts.

Subslab insulation was not very effective in Atlanta and showed no benefit in Houston: We expected that subslab insulation might have more of an impact in Atlanta because it has a significant heating load and that it would have at least some impact in Houston. One explanation for the results is that complete coverage of the subslab area “blocks” “free cooling” from the soil. Thus, the net heat gain for the building rises in the cooling season more than the heat loss that is reduced in the heating season. In a colder climate like Chicago the subslab insulation would be much more effective than in a cooling-dominated climate like Houston, or a mixed climate like Atlanta where there are significant heating and cooling seasons.

OPPORTUNITIES WITH 90.1 SCOPE CHANGES

Results of the simulations show the difficulty that designers may face in reaching levels of 30% and 50% above ASHRAE 90.1. However, there may be some changes to 90.1 - specifically in broadening the scope of the standard to include items that are currently not part of the energy cost budget method - that could help a designer reach these levels of performance. This section discusses the major opportunities that could help make the 30% and 50% thresholds more obtainable.

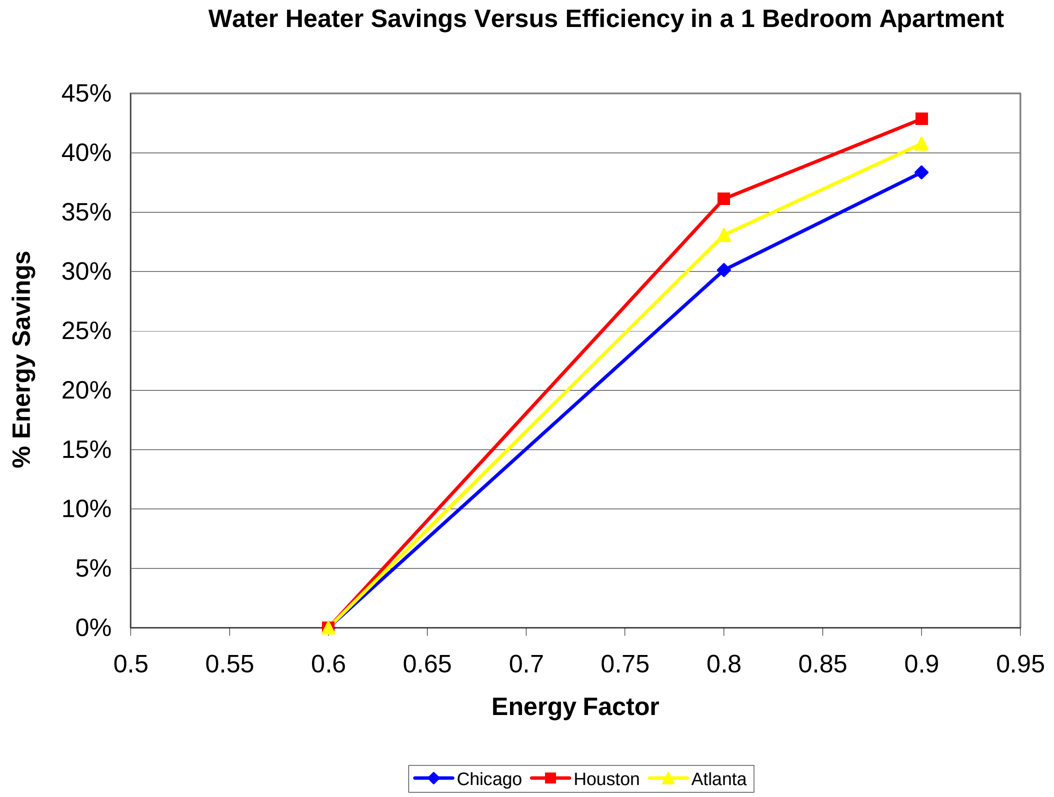
Water Heaters

In Table 11.3.1 of 90.1, individual domestic water heaters in dwellings are effectively excluded from the cost budget method since the same system and characteristics must be applied to the design and reference buildings. The lone exception is where a boiler provides space heating and water heating. Water heaters are relegated to a pass/fail test for compliance based on the unit efficiency compared to the 90.1 minimum. This is also the method used in the IECC performance approach for commercial (including multi-family) buildings. Interestingly, the IECC performance approach for single-family homes *does* allow the designer to take credit for more efficient water heating equipment.

There may be good reason to explain why 90.1 does not recognize energy savings due to increased water heater efficiency in the energy cost budget method. It may be that water use in a building varies so much that the developers of 90.1 did not want to give credit to a design that could result in a broad range of savings in buildings. However, even when taking into account the variability and making conservative assumptions on water use patterns, there is a considerable amount of potential savings related to selection of more-efficient water heaters. Perhaps the 90.1 committee reasoned that a residential water heater is not a permanent part of a building and could be replaced with less efficient equipment in the future.

Figure 4 shows the percent increase in energy savings that higher efficiency water heating equipment could achieve in the three climates we examined, relative to the 0.6 minimum efficiency specified in 90.1. In terms of energy costs, the 0.9 efficiency (expressed as EF or energy factor) equipment in the chart could save approximately $1500 annually in Atlanta and Houston and about $2200 in Chicago in the baseline building. This translates into about a 4.5% reduction in the baseline energy cost budget for the buildings we modeled in Atlanta. A similar savings would be seen in Chicago and about 2.3% in Houston. The potential savings with water heating is much more significant than the changes to the building envelope.

Figure 4 – Performance of Water Heaters at Various Efficiencies relative to a 0.6 EF unit



Lighting

Section 9.1.1 (Scope) of 90.1 provides an exception for lighting inside dwellings from compliance with Chapter 9 requirements that govern lighting. Increasing the scope of 90.1 to include lighting inside dwelling units could help industry reach the 30% or 50% thresholds. A designer could specify high efficiency lighting fixtures and come in well below the lighting power allowance while still providing sufficient illumination for safety, task and general lighting.

The lighting power allowance for a dwelling in 90.1, which is expressed in Watts per square foot, appears to be generous for dwellings. It may be difficult for ASHRAE to lower the allowance in future editions of 90.1 without creating conflicts with corresponding lighting design standards, thus leaving significant opportunity to show savings under the 90.1 energy cost budget method.

Assuming that one could consider lighting in a better-than-code design effort, simply using CFL bulbs in all fixtures would enable a designer to improve upon the baseline building in Atlanta by just over 6%. As with water heater efficiency, improved lighting offers a much greater opportunity than envelope improvements and other more typical items governed by 90.1 and the IECC.

The downside to pursuing lighting in 90.1 is that expanding the scope of a standard always brings the risk of changes in the future that could be very difficult to exceed. From a long-term perspective, it could also be easy to replace CFLs with less efficient bulbs down the road, effectively negating the savings claimed during the design stage. Regulators may be tempted to require efficient fixtures rather than just bulbs to give them some assurance that the savings would be more permanent.

Renewable Energy

Renewable energy generated on-site is not permitted to be used to offset energy use in a building when evaluating designs according to the 90.1 energy cost budget method. However, if the goal of 50% is to be taken seriously, then this type of trade off may need to be considered by ASHRAE. In the three cities where buildings were simulated, we were unable to reach the 50% goal even with extremely high levels of insulation, top of the line windows and doors, and the most efficient HVAC technology.

Of the available options, PV (photo-voltaic or solar electric) is the renewable technology that would be most suitable and practical for a multi-family building, although it is not without limitations. Some of the issues that would need to be addressed include:

- Initial costs and on-going maintenance.
- Building orientation. This is perhaps the most important design consideration. The buildings in our simulations are ideally suited for PV because ½ of the roof surface faces due south. A designer would not always be able to take advantage of the orientation depending on a number of variables including but not limited to shape and size of the lot and building, shading, setbacks and other land use regulations.
- Available space on the roof. PV can be installed on exterior walls but it is much less efficient when installed vertically. For most buildings, available roof space probably will not be an issue to get to the 50% goal, assuming that significant HVAC equipment upgrades are also implemented. More important will be having enough roof space in the south-facing orientation.
- State regulations on net metering. Net metering policies at the state level are essential to the success of PV. Net metering allows a building owner to get credit on a utility bill for sending electricity back to the grid. This is the most efficient way to capture the energy that PV produces. Without net metering, prospects for efficient use of electricity generated by PV are severely limited, since the time frame when most electricity is generated from solar does not coincide with the peak demands in a dwelling.

- Adjacent shading. On buildings in the inner city or where other higher buildings effectively block the sun, PV is not very useful. Trees can also have the same impact, but less so for a three or four-story building than for lower height apartment buildings. Even partial shading can severely reduce the power production from a PV panel.

The energy that would need to be supplied by PV to eliminate the gap between the highest performing options in the simulations and the 50% threshold is provided in Table 7. If as much as 25 kW of PV were needed on the roof, as is shown for Atlanta, about ½ of the south-facing roof space would be needed. If the building were oriented in a different direction, it might require significant changes to the roof shape and building design to provide the necessary space. Available roof area is very specific to a given building even though it happens to work out well for the buildings we studied.

Table 7 – PV requirements to meet the 50% threshold

	90.1 reference costs		
	Atlanta	Chicago	Houston
Total	$32,946	$56,951	$64,960
Electricity	$32,946	$25,323	$64,960
Natural gas (Space heat)		$31,628	
% maximum savings w/o PV	39	46	48
Max $ savings w/o PV	$12,848.94	$26,197.46	$31,180.80
50% goal	$16,473.0	$28,475.5	$32,480.0
Amount to make up to get to 50%	$3,624.06	$2,278.04	$1,299.20
Electric rate ($/kWh)	0.0783	$0.0766	$0.15
PV energy required to reach goal (kWh)	46,284	29,739	8,661
Expected energy production (kWh/kW DC)	1345	1345	1222
Derating factor	0.7	0.7	0.7
Array tilt (degrees)	26.56	26.56	26.56
Array Azimuth (degrees)	180	180	180
PV array size needed (kW DC)	34.4	22.1	7.1
Power density (W/sf)	10	10	10
Panel area required (sf)	3441	2211	709
Roof area available (sf)	4978	4978	4978
Sufficient roof area to mount?	Yes	Yes	Yes

Infiltration

Chapter 11 of 90.1, which addresses the energy cost budget method, does not directly address infiltration when there is no mechanical ventilation. One could logically assume that infiltration in the proposed design should be set equal to the reference building, since Section 11.3.2 (d) specifies that outdoor air ventilation rates should be equal in both buildings. This is consistent with the prescriptive requirements in 90.1 Section 5.4.3, which does not specify a minimum or maximum air change rate for buildings but instead requires envelope sealing at specific locations. The Energy Gauge developers interpret 90.1 in a manner consistent with our interpretation – they do not allow the user to input a different infiltration airflow rate for the reference or design buildings. Rather, they use the ASHRAE crack method to estimate the infiltration rate for both buildings.

Infiltration is a large component of the heating and cooling load of a building. ASHRAE's Handbook of Fundamentals (2001 edition, page 26.9) states that air exchange typically represents 20 to 50% of a building's thermal load. However, most data on infiltration has been limited to single-family buildings. The US EPA Energy star website claims 25 to 40% of energy used for heating and cooling is due to infiltration (http://www.energystar.gov/index.cfm?c=new_homes_features.hm_f_reduced_air_infiltration) but it does not cite specific references for this range.

There is little information in the literature on larger buildings. A multi-family building may be more like an office building in regard to the impact of infiltration on loads. According to a study (Emmerich et. al., *Investigation of the impact of commercial building envelope air-tightness on HVAC energy use*, National Institute of Standards and Technology, 2005) of infiltration in office buildings, 33% of the heating load is due to infiltration in a typical building in the United States. The same study showed that infiltration may increase or decrease the cooling load, but on average increases it by about 3%.

Even if one takes a conservative estimate for amount of the thermal load due to infiltration, say 20%, this still represents a significant opportunity for ASHRAE to consider in 90.1. Of course, all of the infiltration load could not be accounted for in the cost budget method, nor should it. Some maximum level would need to be identified within the 90.1 standard and credit given for anything below the maximum. Otherwise, a designer could set an artificially high air infiltration rate and then get credit for reducing it without any intention of ever constructing the building with a tighter envelope. At some point, a lower threshold would also limit the credit one could receive toward compliance under the cost budget method, since mechanical ventilation would be necessary if the building were too tight. A maximum infiltration rate perhaps set to a regional average could be considered. Even within these limitations, even if only 5% of the infiltration load could be open for a credit toward compliance, this would represent an improvement of over 3% to 3-1/2% in the total energy cost budget of a 90.1 reference building in the three locations we examined. Again, this type of improvement would be much more significant than other changes to the building thermal envelope.

Plug Loads

Miscellaneous electrical loads, mostly in the form of plug loads, are another potential area for ASHRAE to consider expanding the scope of 90.1 to cover. In the buildings we simulated, these loads accounted for about 14% of the 90.1 reference building's energy cost budget in Atlanta and Houston and about 8% in Chicago.

There are many potential problems that could arise if plug loads were to be part of the 90.1 scope for an apartment building. Perhaps most significant is that the developer or builder does not have control over occupants or how they use miscellaneous equipment, small appliances, and consumer electronics. Thus, even though there is a lot of energy at stake, regulating plug loads within 90.1 would likely prove difficult to implement.

Building Orientation

The direction a facade faces, combined with the amount and type of glazing on the façade, influences the heating and cooling losses and gains in a building. In the northern hemisphere, it is generally understood that south-facing glazing helps with the heating of the building but can increase the cooling load.

Shading of windows helps to reduce the impact on cooling and allows the winter sun, which is lower in the sky, to provide heat in the winter. However, simulations conducted with shading did not show much impact on the building performance. Improving the windows also did not improve the overall building very much. Some of the low performance illustrated with shading and higher performance windows could be attributed to the fact that the baseline windows in each climate were already very good performers.

Orientation of the building may offer more advantages than window upgrades or shading, but credit for optimizing the orientation is not allowed in the 90.1 cost budget method. In order to assess the potential, we ran the baseline building simulations while varying the orientation. The results are shown in Table 8. Note that there are only four orientations since further rotation of the building would simply duplicate one of these four due to the nearly symmetrical design of the building.

Table 8 – Energy cost budget totals for the baseline building rotated to different orientations

Location	Baseline design costs	Baseline rotated 45° clockwise	Baseline rotated 90° clockwise	Baseline rotated 135° clockwise
Atlanta	$32,946	$33,538	$33,376	$33,378
Chicago	$56,951	$57,450	$57,492	$57,466
Houston	$64,960	$65,912	$66,316	$65,594

The difference between the worst orientation and the best orientation in Atlanta is 1.8%, just under 1% in Chicago, and slightly over 2% in Houston. Although orientation alone does not contribute anywhere near as much reduction as high efficiency HVAC equipment, it does provide greater improvement seen than most of the changes to the envelope which were simulated.

Windows

Although window orientation, shading, U-Factor, and SHGC can be varied in a proposed design to help comply with or exceed 90.1, the amount of window area is another factor influencing heat loss and gains through exterior walls. However, Table 11.3.1 in 90.1 is not completely clear as to whether a reduction in window area can be credited to the proposed design. In part 5 of the table, it suggests that all components of the envelope shall be identical except as identified in three specific exceptions. The exception dealing with fenestration requires the window area to be reduced to the maximum allowable by Section 5.5.4.2. It does not address what to do if the window area of the proposed design is less than the maximum (50% of wall area) for vertical fenestration).

In our simulations, the window area for the proposed and reference designs were the same. Energy Gauge only allows the areas to differ if the proposed design is greater than the 50% threshold. In this case, the reference building is set to 50% but the proposed design is set to the actual amount in the building.

One might ask why a building would be penalized for exceeding the 50% threshold but not given credit for being under the threshold. One possible answer is that the 90.1 energy cost budget method does not want to give credit for a building that was designed with an excessive amount of windows that was never intended to be built. However, it seems that picking a reasonable average or typical window area for a given building type should not be difficult and giving credit for reducing window areas below that area should result in a credit toward compliance under the energy cost budget method.

There is a practical limit to how much this can be reduced if it were included as an acceptable item in the energy cost budget method. Other code requirements for ventilation, natural light, and emergency egress would establish a lower limit of window area.

As an example of how much energy cost is at stake with window area under the 90.1 energy cost budget method, we reduced the window area from five windows per unit on north and south facing walls to two windows and from three to one window on the east and west sides. This is probably an extreme example for an apartment building, since it would cover emergency egress in a bedroom and leave only one to two other windows (depending if a center or end unit) for other rooms. None the less, for the Houston building the reduction in the total energy costs for the proposed design decreased by 1-1/2% under this scenario. Although this does not compare in magnitude to the improvements available with high efficiency HVAC equipment, it does compare well to the other envelope improvements.

COST ESTIMATES FOR EFFICIENCY UPGRADES

For each of the locations, the cost to achieve specific thresholds relative to ASHRAE 90.1 is summarized in Tables 9, 10 and 11. Costs do not include any utility company or tax incentives that may exist as these are limited by statute or program and/or vary by location.

Table 9 – Atlanta Costs

<table>
<tr><th colspan="8">Improvements required to meet 15% or 30% threshold (actual is 31%)</th></tr>
<tr><th>System</th><th>System items</th><th>Units in building</th><th>Sq. Ft. in building</th><th>Cost per unit or Sq. Ft.</th><th>Baseline building costs</th><th>Cost with improvements</th><th>Cost difference</th></tr>
<tr><td rowspan="2">Heat pump</td><td>SEER 12, 7.4 HSPF air source heat pump</td><td>32</td><td></td><td>$4,038</td><td>$129,200</td><td></td><td rowspan="2">$62,800 to $254,800</td></tr>
<tr><td>3.7 COP, 16.9 EER ground source heat pump</td><td>32</td><td></td><td>$6,000 - $12,000</td><td></td><td>$192,000-$384,000</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><th colspan="7">Maximum improvement over 90.1 reference (39%)</th><td></td></tr>
<tr><td rowspan="2">Heat pump</td><td>SEER 12, 7.4 HSPF air source heat pump</td><td>32</td><td></td><td>$4,038</td><td>$129,200</td><td></td><td rowspan="2">$62,800 to $254,800</td></tr>
<tr><td>3.7 COP, 16.9 EER ground source heat pump</td><td>32</td><td></td><td>$6,000 - $12,000</td><td></td><td>$192,000-$384,000</td></tr>
<tr><td rowspan="2">Attic</td><td>R-38</td><td></td><td>3168</td><td>$0.47</td><td>$1,489</td><td></td><td rowspan="2">$412</td></tr>
<tr><td>R-49</td><td></td><td>3168</td><td>$0.60</td><td></td><td>$1,901</td></tr>
<tr><td rowspan="2">Exterior walls</td><td>R-13 wood frame</td><td></td><td>8871</td><td>$2.95</td><td>$26,169</td><td></td><td rowspan="2">$6,831</td></tr>
<tr><td>R-21+5 wood frame</td><td></td><td>8871</td><td>$3.72</td><td></td><td>$33,000</td></tr>
<tr><td rowspan="2">Windows</td><td>Closest commercially available meeting both max U and max SHGC</td><td>200</td><td>2700</td><td>$8.00</td><td>$21,600</td><td></td><td rowspan="2">$5,400</td></tr>
<tr><td>Advanced window (U= 0.3, SHGC=0.19)</td><td>200</td><td>2700</td><td>$10.00</td><td></td><td>$27,000</td></tr>
<tr><td rowspan="2">Exterior doors</td><td>R-2.6 steel</td><td>8</td><td></td><td>$129.00</td><td>$129</td><td></td><td rowspan="2">$0</td></tr>
<tr><td>R-5.2</td><td>8</td><td></td><td>$129.00</td><td>$129</td><td>$0</td></tr>
<tr><td rowspan="2">Slab insulation</td><td>R-0</td><td></td><td>3168</td><td>$0.00</td><td>$0</td><td></td><td></td></tr>
<tr><td>R-5 XPS</td><td></td><td>3168</td><td>$0.53</td><td></td><td>$1,679</td><td>$1,679</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td></td><td></td><td></td><td>$77,122 to $269,122</td></tr>
<tr><td colspan="8"><i>Note: a 13 SEER split system was priced for this exercise. SEER 12 equipment is no longer on the market, even though this is the minimum efficiency permitted in 90.1-2004.</i></td></tr>
</table>

Table 10 – Chicago Costs

Improvements required to meet 15% threshold (actual is 16%)							
System	System items	Units in building	Sq. Ft. in building	Cost per unit or Sq. Ft.	Baseline building costs	Cost with improvements	Cost difference
Heating	80 AFUE gas furnace	32		$2,083	$66,656		$73,216
	96 AFUE gas furnace	32		$4,371		$139,872	
Total							$73,216
Improvements required to meet 30% threshold (actual is 37%)							
Heating and cooling	80 AFUE gas furnace	32		$2,083	$66,656		$23,744 to $215,744
	12 SEER AC	32		$4,038	$101,600		
	3.7 COP, 16.9 EER ground source heat pump	32		$6,000 - $12,000		$192,000-$384,000	
Total							$23,744 to $215,744
Maximum improvement over 90.1 reference (46%)							
Exterior wall	R-13 wood frame		3168	$3.55	$11,244		$17,788
	R-40 SIPs		3168	$9.16		$29,032	
Attic	R-38		8871	$0.60	$5,360		$1,552
	R-49		8871	$0.78		$6,911	
Subslab	R-0		8871	$0.00	$0		$6,071
	R-5 XPS		8871	$0.68		$6,071	
Heating and cooling	80 AFUE gas furnace	32		$2,083	$66,656		$23,744 to $215,744
	12 SEER AC	32		$4,038	$101,600		
	3.7 COP, 16.9 EER ground source heat pump	32		$6,000 - $12,000		$192,000-$384,000	
Total							$49,155 to $241,155
Note: a 13 SEER split system was priced for this exercise. SEER 12 equipment is no longer on the market, even though this is the minimum efficiency permitted in 90.1-2004.							

Table 11 – Houston Costs

Improvements required to meet 15% threshold							
System	System items	units in building	Sq. Ft. in building	Cost per unit or Sq. Ft.	Baseline building costs	Cost with improvements	Cost difference
Heat pump	SEER 12, 7.4 HSPF air source heat pump	32		$4,038	$129,200		$77,200
	SEER 15, 8.3 HSPF air source heat pump	32		$6,450		$206,400	
Exterior wall	R-13 wood frame		3168	$2.86	$9,055		$12,469
	R-40 SIPs		3168	$6.79		$21,523	
Attic insulation	R-38		8871	$0.45	$3,992		$1,153
	R-49		8871	$0.58		$5,145	
Windows	Best commercially available meeting both max U and max SHGC	200	2700	$8.00	$21,600		$5,400
	Advanced window (U= 0.3, SHGC=0.19	200	2700	$10.00		$27,000	
Total							$96,222
Improvements required to meet 30% threshold (actual improvement is 41%)							
Heat pump	SEER 12, 7.4 HSPF air source heat pump	32		$4,038	$129,200		$62,800 to $254,800
	3.7 COP, 16.9 EER ground source heat pump	32		$6,000 - $12,000		$192,000- $384,000	
Total							$62,800 to $254,800
Maximum improvement over 90.1 reference (48%)							
Exterior wall	R-13 wood frame		3168	$2.86	$9,055		$12,469
	R-40 SIPs		3168	$6.79		$21,523	
Attic insulation	R-38		8871	$0.45	$3,992		$1,153
	R-49		8871	$0.58		$5,145	
Windows	Best commercially available meeting both max U and max SHGC	200	2700	$8.00	$21,600		$5,400
	Advanced window (U= 0.3, SHGC=0.19	200	2700	$10.00		$27,000	
Heat pump	SEER 12, 7.4 HSPF air source heat pump	32		$4,038	$129,200		$62,800 to $254,800
	3.7 COP, 16.9 EER ground source heat pump	32		$6,000 - $12,000		$192,000- $384,000	
Total							$81,822 to $273,822
Note: a 13 SEER split system was priced for this exercise. SEER 12 equipment is no longer on the market even though this is the minimum efficiency permitted in 90.1-2004.							

There is no single source for construction cost data. RS Means, Craftsman and others publish estimating guides, but they do not cover every system or subsystem nor every variation within a type of component. Thus, our cost estimates were derived from multiple sources including published data and quotes from suppliers and contractors in each city.

Exterior wall system costs were obtained from RS Means 2006 and 2007 *Residential Cost Data*, with location factors applied for the different cities. R-5 continuous insulation costs were also obtained from RS Means. All other insulation costs were obtained from supplier quotes in each city.

Window cost estimates were based on quotes from building supply outlets. As much as possible, costs were estimated within a manufacturer's brand and particular product line to ensure that the only difference in price was due to thermal improvements in glazing, versus changes in style or material quality. Incremental costs of windows were then normalized according to square footage, arriving at a single incremental cost per square foot for high performance windows. Because multiple quotes were returned from suppliers in Chicago and Houston versus none in Atlanta with the same window types, we elected to combine all quotes for each window type and use an average cost independent of location cost factors. We believe this is acceptable because the incremental cost of windows in all of the quotes was fairly consistent, and the incremental cost is our main interest.

Window jamb extensions were not included in costs. The cost of extensions could range from zero to $30 or more per window. It is likely that the baseline building and the upgraded building would both be built using 2x6 or wider studs. Thus, there would be no jamb extensions due to increased cavity insulation. The exceptions would be when a 10 inch SIPs wall or continuous insulation is used. With one-inch continuous insulation is it sometime possible to order a wider frame at little to no added cost. Other options include purchasing jamb extensions or trimming them out onsite. With the 10 inch SIPs wall, custom made extensions would be required.

The costs of furnaces, heat pumps, air conditioners, and ground source heat pumps were estimated based on quotes from contractors. Ducted systems were chosen for the heating and cooling systems. Contractor-sourced quotes included material and labor. Air conditioners, furnaces, and air source heat pumps were priced as turnkey systems minus the material and labor costs of the duct system. We assumed that an identical duct system would be required for all systems, so this component was excluded from the quotes. Results indicated that the pricing was less dependent on geography than on the discretion of the individual contractor, so all quotes were averaged together to estimate the retail cost of installed systems at 1.5 tons. No volume-based discounts were sought when seeking quotes.

Cost for ground source heat pumps are highly variable and heavily dependent on drilling conditions, soil thermal conductivity and soil composition. For large, multifamily projects, test wells are typically drilled on-site and soil thermal conductivity tests run to determine the loop field size required to match the heating and cooling loads of the units. Due to the large variability of loop field sizes and installation costs, turnkey costs for geothermal heat pumps were taken as a range that was normalized on a per ton basis. This range was based on contractor quotes and industry data. Quotes did not include the cost of the duct system. A vertical, closed loop system was assumed for the analysis. We recognize that the range of costs for a GSHP is wide, but this is reflective of the market that exists for this technology.

Since we were not able to reach the 50% threshold in any of the locations, we assumed that the remaining energy cost to do so would need to be made up by other means. We provided the costs for PV as one example in Table 12.

There may be options other than PV that can be used to make up the deficits in each location. In any case, applying them would require a change to the ASHRAE 90.1 scope. If for example, lighting were added to the scope for dwelling units, then something as simple as using CFLs might provide enough savings to reach the 50% threshold in Chicago and Houston. Other improvements such as high efficiency water heaters would likely be needed in Atlanta.

Table 12 - PV costs to meet 50% threshold

	Atlanta	Chicago	Houston
Normalized low-end cost of installed system ($/W DC)	$7.00	$7.00	$6.00
Normalized high-end cost of installed system ($/W DC)	$9.00	$9.00	$8.0 0
Total low-end cost of PV system ($)	$240,885	$154,778	$42,527
Total high-end cost of PV system ($)	$309,709	$199,000	$ 56,703

PV costs were based on turnkey installation quotes from suppliers. No battery storage was included. The systems were based on a net metering set-up where the electricity generated from the PV panels was sent back to the grid. Because of a wide variety in quotes, PV costs are expressed as a range from the low to high end. As mentioned previously, tax credits that may be available are not considered in the costs.

DISCUSSION/CONCLUSIONS

The use of energy simulations with various models is a recognized method for determining compliance in most major building codes and standards. Chapter 11 of the ASHRAE Standard 90.1 provides for the use of a cost budget method to assess how much better or worse a building would perform relative to the requirements of the standard.

While simulations using the energy cost budget method offer opportunity for more flexibility than following the prescriptive requirements, it is worth noting that this option may be not be all that practical for a building owner or designer. The effort to run multiple simulations for a building is no small task for a complex building. Costs associated with modeling will be a significant barrier on many projects. Thus, it is not uncommon for even leading edge designers/builders to strive to meet the prescriptive requirements of ASHRAE 90.1 rather than run simulations.

The simulation results and other estimates from this work suggest that reaching a goal of 15% better than ASHRAE 90.1-2004 may not be that difficult from a technical and practical view point. However, the traditional approach of improving the insulation levels in the building envelope will not achieve this level of performance, and will not even begin to approach the 30% and 50% improvement levels. The impact of envelope improvements over current practice is small even in combination with other similar envelope improvements.

In order to make substantial gains against the backdrop of the 2004 90.1 standard, higher efficiency equipment will be a core component of most designs of apartment buildings in the range of four stories or less. At the 15% level, this was accomplished in two of the three cities we examined with what might be termed conventional high efficiency equipment, including air source heat pumps and AC units or natural gas furnaces. The technology for these systems exists and is commercially available through typical supply channels.

Reaching the 30% level is possible in all three climates for the buildings we simulated, but efficiency of the HVAC equipment needed to do so would require advanced technology. For an apartment building with separate heating and cooling systems, a ground source heat pump (GSHP) is the technology most likely to provide this efficiency. In fact, GSHP technology would likely reach the 30% target in all three locations we examined even without other improvements to the buildings. It is commercially available, but is still very much a specialty product. The vast majority of buildings do not use this technology and the level of experience with it by trade contractors is limited. Despite a growing market share, the infrastructure for GSHPs is still in an early state of development in many areas.

We were not able to reach the 50% level in Atlanta, Houston, or Chicago with the apartment building we studied. Every building is different, so it may be possible to reach the 50% level using high efficiency GSHP technology and significantly enhancing the envelope for other building designs. In any case, the 50% threshold is a very optimistic goal and may not be feasible without significant changes to the scope of 90.1 or significant improvements in technologies.

Although the 15% and 30% goals can be achieved in these cities, the cost to do so is significant. Table 13 shows the cost of combinations of technologies that most closely match the various levels of performance. The table also shows costs for the maximum levels obtained.

Table 13 – Costs and simple payback for various levels of performance over 90.1 for three cities

Atlanta	% better than 90.1	Added cost in dollars
GSHP (3.7 COP, 16.9 EER)	31	$62,800 to $254,800
R-49 attic, R-21+5 walls, advanced windows (U=0.3, SHGC+0.19), R-5.2 door, R-5 subslab insulation, GSHP (COP 3.7, EER 16.9)	39	$77,122 to $269,122
Chicago		
96 AFUE furnace	15	$73,216
GSHP (3.7 COP, 16.9 EER)	37	$23,744 to $215,744
R-49 attic, R-40 walls, R-5 subslab insulation, GSHP (3.7 COP, 16.9 EER)	46	$49,155 to $241,155
Houston		
SEER 15 HP w/ 8.3 HSPF, R-40 walls, R-49 attic, advanced windows(U=0.3, SHGC+0.19)	15	$96,222
GSHP (3.1 COP, 14.6 EER)	41	$62,800 to $254,800
R-40 walls, R-49 attic, advanced windows, GSHP (3.1 COP, 14.6 EER)	48	$81,822 to $273,822

The costs do not include additional design costs that will be incurred. With prescriptive changes to the 90.1 standard (meaning that prescriptive pathways were established to meet higher efficiency levels), the added design costs would be minimized. If simulations are required (e.g., a performance approach), then the design costs could be significant. Results from projects like this can be useful in reducing analysis costs by showing designers the most likely pathways for reaching a specific level of improvement.

One key finding relative to costs is that GSHPs have a wide range of costs associated with them. Even on the low end, they are quite expensive compared to conventional heat pumps and air conditioners. One interesting finding is that a large portion of the cost of a GSHP in a location like Chicago could be offset if a gas furnace with separate AC unit is used as the baseline. This same type of offset would also be available with a high efficiency conventional heat pump, since in either case, the proposed design would replace two systems (AC and gas furnace) with one system (a heat pump).

In terms of realizing the energy cost savings tied to high performance multi-family buildings, the renter in an apartment would see the savings benefits while the builder/owner would incur the costs. There is no evidence to suggest that the increased costs could be returned to the owner in the form of higher rents. It is easy to see where excessive upfront costs, if they eat into profits or inhibit financing, may be the deciding factor in whether to construct a multi-family building in the first place. This could have the unintended consequence of limiting housing choices in the market and driving renters, many of whom struggle with housing costs, into older, less efficient buildings with higher monthly utility costs.

Simple payback expressed in years is one way to analyze the costs and benefits of an improvement. This approach would only be applicable where the building owner is also the party responsible for paying the utilities. Very few new apartments would fall into this category, so for the payback analysis to have any credibility, we need to assume that there is some other way that the benefits are accruing to the owner.

A simple payback is typically expressed as the number of years it would take for estimated energy savings to offset the initial additional costs of construction. We elected to examine only the paybacks for Atlanta, since the Atlanta baseline building was almost identical to a minimum 90.1 building. (See Appendix C for a discussion on the baseline versus reference designs). Atlanta provides the cleanest comparison of performance versus costs of the three cities.

The paybacks for Atlanta are shown in Table 14. Note that there is no consensus on what is an acceptable timeframe for a simple payback. In the United States, valid arguments have been made for as little as 3 years or as high as 7 to 10 years in regard to energy efficiency in buildings. The paybacks in Table 14 exceed even the higher range of what is acceptable on average in the United States, and substantially exceed them at the high end of the cost estimates for given building system packages.

Internationally, there are different perspectives than in the United States. Recent proposals in the EU are attempting to designate 30 years as the basis for payback analysis.

Table 14 – Cost and payback for selected improvements in Atlanta

Building system package	**% better than 90.1**	**Simple payback in years[1]**
GSHP (3.7 COP, 16.9 EER)	31 (closest set of improvements achieving at least 30%)	16 (25)
R-49 attic, R-21+5 walls, advanced windows (U=0.3, SHGC+0.19), R-5.2 door, R-5 subslab insulation, GSHP (COP 3.7, EER 16.9)	39 (maximum achieved in simulations)	14 (21)

[1] Costs and thus payback of GSHPs vary greatly. The paybacks are based on an average of the high and low end of estimated costs. The payback associated with the high end of the cost estimates is shown in ( ).

Other findings from this study that could be helpful to builders, building owners, and designers include:

- Running a simulation on a building that is marginally out of compliance with prescriptive requirements in a code or standard may be all that is required to comply. When we developed a baseline building in the modeling software using prescriptive minimums from 90.1, the buildings in Houston and Chicago passed with plenty of room to spare.

- One of the reasons for surpassing the reference design by such a wide margin is related to the way that the reference building's HVAC system is determined. For example, in Chicago, the reference building was assigned a boiler even though a natural gas furnace was used in the proposed design. The 90.1 committee should develop criteria so that the same system is used in proposed and reference buildings.
- There is a disconnect between what is available on the market and the minimum requirements in energy codes and standards. For example, in order to meet window requirements, a designer has to select a window that meets the SHGC and the U-Factor requirements. Unfortunately, there are not any windows found that meet both of these criteria in the NFRC listings for major window manufacturers. Because we selected products that were at or below (better than) the SHGC, we ended up with a U-Factor much lower than the maximum. Thus, common products or practices in today's buildings by themselves can result in much better performance than minimum code or standards requirements.
- HVAC equipment is often not available at higher efficiencies in the same size or capacities as less efficient equipment. Finding a SEER 19 heat pump for a 12,000 Btu through-the-wall heat pump would be a challenge.
- Fan energy assumptions for relatively small equipment found in apartments and similar spaces are not well documented. Yet fan energy can be a significant consumer of energy for heating and cooling. Many simulation tools including Energy Gauge default to 0.9 watts/cfm based on requirements for larger equipment taken from 90.1. Recent work in California and Florida suggest that actual power for heat pumps depends on the size of the units (Wilcox et. al., Workshop Presentations, *2008 California building energy efficiency standards*, July 12, 2006 and Parker and Proctor, *Hidden power drains: Trends in residential heating and cooling fan watt power demand*, Florida Solar Energy Center, 2001). For sizes typically used in homes and apartments, the range is from about 0.4 to 0.55 watts/cfm. In our simulations, we did not look at changing the fan energy consumption as a way to improve the performance of the proposed design. As more information develops through research and data from manufacturers, fan energy could be an area where significant energy savings could be realized and applied to code compliance.
- As building envelopes improve, HVAC systems can be downsized to reflect smaller loads. These changes were not considered in this study because there are practical limitations to how small a unit can be in a building. For example, it is difficult to find a 30,000 Btu gas furnace, even though this capacity may be adequate for a given building space.
- Standards and codes, including 90.1, are not perfect nor do they always match up well with simulation tools. When running simulations, a designer must make some assumptions when guidance is not provided in the standard. User bias and other factors can often make a difference in whether a building complies with a specific standard or code.

- ASHRAE must consider changes to what is within the scope of covered items in 90.1 and the energy cost budget method in Chapter 11of the standard if the 50% goal is to be achieved. Water heating energy use, lighting inside dwellings, building orientation, and infiltration are examples where benefits could be obtained if brought into the energy cost budget method.

Although it may be outside the scope of this study, one comment relative to the declared goals of the ASHRAE president and the Department of Energy is worth noting. The consensus process has served both regulators and industry well in bringing many different points of view into the development of standards for the building industry. It is a well respected process worldwide. Further, ASHRAE 90.1 has a long history of basing committee decisions on strong technical support. Declaring that 90.1 will be a certain percentage better than today in future editions may unduly influence the consensus process. Although the idea of improving building performance is good, the process needs to be respected so that all points of view, economic benefits, practical limitations, and other issues are understood and considered.

Finally, policy makers and standards developers should recognize that the market infrastructure, climate, and consumer preferences all influence the design of a building. Climates and markets can be radically different around the United States. Approaches that seem reasonable in one part of the country should not automatically be adopted elsewhere. In some climates where more energy is used, it may be reasonable and more cost-effective to expect more efficiency improvements compared to buildings in milder climates.