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Comparison of Commercial Building Energy Design Requirements for Envelope and Lighting in Recent Versions of ASHRAE/IESNA Standard 90.1 and the International Energy Conservation Code, with Application to the State of Arizona

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August 2005

Completed for the Building Standards and Guidelines Program,
U.S. Department of Energy under Contract DE-AC06-76RLO 1830

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Executive Summary

The state of South Dakota is considering adopting a commercial building energy standard. This report evaluates the potential costs and benefits to South Dakota residents from requiring compliance with the most recent edition of the *ANSI/ASHRAE/IESNA 90.1-2001 Energy Standard for Buildings except Low-Rise Residential Buildings* (hereafter referred to as 90.1-2001 or ASHRAE 90.1-2001). These standards were developed in an effort to set minimum requirements for the energy efficient design and construction of new commercial buildings. The quantitative benefits and costs of adopting a commercial building energy code are modeled by comparing the characteristics of assumed current building practices with the most recent edition of the ASHRAE Standard, 90.1-2001. Both qualitative and quantitative benefits and costs are assessed in this analysis. Energy and economic impacts are estimated using results from a detailed building energy simulation tool (Building Loads Analysis and System Thermodynamics [BLAST] model) combined with a Life-Cycle Cost (LCC) approach to assess corresponding economic costs and benefits.

The state of South Dakota currently has no state-wide mandatory or recommended minimum commercial building energy code. Even with state adoption, it is expected that local jurisdictions would need to formally adopt this standard as a building code in order to make it mandatory for commercial builders. Because South Dakota does not have a mandatory statewide energy code, this study uses two separate baseline building efficiency levels to assess the impacts, generally described as: (1) Low-efficiency Buildings and (2) High-efficiency Buildings. It is assumed that the "Low-efficiency" buildings would tend to be smaller commercial buildings that do not employ professional architectural and engineering firms to design and construct the buildings. The "High-efficiency" buildings are considered "well-engineered" larger buildings that meet or exceed many of the requirements of Standard 90.1-2001 and employ architectural and engineering firms as part of the design and construction process.

The energy simulation and economic results of the building prototypes selected for this study suggest that adopting a standard equivalent to ASHRAE 90.1-2001 as the commercial building energy code in South Dakota would have little impact on the manner in which High-Efficiency buildings are currently built, as these buildings appear to already be meeting or exceeding most of the minimum requirements of ASHRAE 90.1-2001. Adopting ASHRAE 90.1-2001 as the minimum standard would have an impact, however, for Low-Efficiency buildings, which may tend to use lower levels of insulation, less efficient windows, and lighting fixtures with higher electricity consumption. For the Low-Efficiency buildings, ASHRAE 90.1-2001 could potentially provide positive net benefits relative to the current building designs and characteristics. For a few of the Low-Efficiency building types, there are no significant net economic benefits to complying with the 90.1-2001 envelope requirements; however, the ASHRAE 90.1-2001 lighting requirements appear to provide significant net economic benefits and energy savings to the building owner. In all cases for Low-Efficiency buildings, the combined envelope and lighting LCC savings of adopting the respective 90.1-2001 requirements is positive relative to the base cases.

Contents

Acronyms and Abbreviations

ACP	Alternate Component Packages
AIRR	Adjusted internal rate of return
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BLAST	Building Loads Analysis and System Thermodynamics
BLCC	Building Life-Cycle Cost
CBECS	Commercial Buildings Energy Consumption Survey
CDD	Cooling Degree-Days
CFL	Compact Fluorescent Light
DOE	U.S. Department of Energy
EIA	Energy Information Administration
EPCA	Energy Policy and Conservation Act
EUIs	Energy Use Intensities
FEMP	Federal Energy Management Program
HDD	Heating Degree-Days
HID	High Intensity Discharge
HVAC	Heating, Ventilation, and Air-Conditioning
IES	Illuminating Engineering Society
LCC	Life-Cycle Cost
LPD	Lighting Power Densities
NEMS	National Energy Modeling System
NIST	National Institute of Standards and Technology
OMB	Office of Management and Budget
PNNL	Pacific Northwest National Laboratory
SC	Shading Coefficient
SIR	Savings-to-Investment Ratio
SWH	Service Water Heating
TMY	Typical Metrological Year
TSD	Technical Support Document

1 Introduction

Arizona is currently one of the fastest growing states in the nation and is expected to remain so for decades to come. The recently released population projections by the U.S. Census Bureau show Arizona as one of only two states (along with Nevada), whose population is projected to more than double between 2000 and 2030.[1] Given this projection, the stock of residential and commercial buildings in Arizona could also be expected to roughly double over this period. Clearly, to support such growth, there will be tremendous demands placed upon the energy resources in the state.

Arizona has no statewide mandatory building energy code for private construction and relies on local jurisdictions to adopt building energy codes. While many jurisdictions in Arizona have not enacted a building energy code, that situation is changing. Phoenix, the largest city in Arizona with a population over 1.3 million, has recently adopted the 2004 version of the International Energy Conservation Code (IECC). The second largest city in the state, Tucson, adopted the 2000 version of the IECC several years ago and is currently considering an update to the 2003 version. As other jurisdictions in the state consider adopting a building energy code for the first time or updating a current code, they must decide among a number of options. These options involve different versions of the IECC, exemplified by the different choices in Phoenix and Tucson, as well as the potential influence of the national building standard formulated by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

This study was undertaken for the Arizona Department of Commerce, who requested the U.S. Department of Energy (DOE) to provide technical assistance with regard to identifying the major differences in the national energy codes as they might be applied to various locations in Arizona. This study focuses upon the requirements for commercial (nonresidential) buildings in these codes. In both codes, "commercial" buildings include high-rise multifamily buildings as well as traditional "commercial" occupancies such as offices, retail buildings, and assembly buildings.

The most recent edition of the energy code published by the International Code Council (ICC) was in 2003. A 2004 Supplement was published in late 2004. There are several major differences between the 2003 Edition and the 2004 Supplement: 1) insulation and window requirements no longer depend upon the amount of window area on the building exterior, and 2) the definition of climate zones has been substantially simplified. While Phoenix has adopted the 2004 Supplement as its energy code, prior experience has shown that most states or municipalities choose not to adopt or update to a code supplement, but prefer to wait until the next complete published edition of the code. The next edition of IECC is expected in early 2006.

ASHRAE and the Illuminating Engineering Society of North America (IESNA) have jointly developed building standards for nonresidential buildings since the late 1970s. Known as Standard 90.1, this standard has been published in 1989, 1993, 1999, 2001, and 2004.[2] While the ASHRAE/IESNA publications are more technically building standards of recommended building

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[1] U.S. Census Bureau, web page titled "State Interim Population Projections by Age and Sex: 2004-2030." Web page dated April 21, 2005. Web address: http://www.census.gov/population/www/projections/projectionsagesex.html

[2] In 1993, ASHRAE published a codified version of the 1989 standard, which served as the reference standard for subsequent editions of the IECC.

practice, beginning with the 1999 edition they have been more explicitly written in code enforceable language. Many states have adopted 90.1 as their sole building energy code for nonresidential buildings.[3] The translation into more code enforceable language has prompted more widespread adoption, aided by software programs that demonstrate compliance.

The IECC and ASHRAE/IESNA codes are not completely independent. The ASHRAE/IESNA standard, in fact, provides the technical basis for many of the commercial building requirements in the IECC. As recognition of that fact, the IECC typically allows the use of the most recent ASHRAE/IESNA code as an alternative compliance path for commercial buildings. Differences in the various requirements between the two codes thus may influence the compliance path that may be chosen by builders of commercial buildings. Thus, an understanding of these differences is important aspect when a jurisdiction considers adoption of a specific code.

This report also provides a comparison of requirements in the two most recent standards developed jointly developed by ASHRAE and IESNA, Standard 90.1-2001 or 90.1-2004, both termed *Energy Standard for Buildings Except Low-Rise Residential Buildings*. These codes are compared to the IECC 2003 and IECC 2004 Supplement. The purpose is to examine the requirements and relative stringency of the individual codes with regard to energy efficiency in commercial building design and construction. For jurisdictions considering adoption of the IECC in whole or part, this review will help determine where the requirements of the IECC 2003 or IECC 2004 versions stand in relation to ASHRAE/IESNA Standard 90.1-2001 and ASHRAE/IESNA 90.1-2004. Note that jurisdictions adopting either the 2003 edition of IECC or its 2004 Supplement have the option of using ASHRAE/IESNA Standard 90.1-2001 as the reference standard for those codes.

The jurisdictions in Arizona that have adopted energy codes for nonresidential buildings have all chosen the IECC, as one of the family of building codes published by the ICC. Thus, the comparison here is based primarily on the IECC 2003. However, we have noted where the 2004 version of the IECC has modified the IECC requirements or incorporated new requirements for commercial buildings. Assuming that other jurisdictions may also choose the IECC option in the future, the comparison with ASHRAE/IESNA is relevant, as it can be used as an alternative compliance path under the IECC.

[3] The status of state energy codes can be found on the web site maintained by DOE: http://www.energycodes.gov/implement/state_codes/index.stm

2 General Background

2.1 International Energy Conservation Code

The International Energy Conservation Code (IECC) is one of a number of building codes promulgated by the International Code Council (ICC). Known informally as the "I-codes", these codes cover electrical, plumbing, mechanical, sewage disposal, and building structural requirements as well as energy efficiency in buildings.

The first edition of the IECC was published in 1998 and was based upon the 1995 edition of the *Model Energy Code*, developed by the Council of American Building Officials (CABO). With the publication of the initial IECC, CABO assigned all rights and responsibilities for the code to the ICC. In 2000, the IECC became part of a comprehensive and coordinated set of building codes published by the ICC.

The IECC provides minimum requirements for energy efficient buildings via prescriptive and performance design and construction requirements. The code covers both residential and commercial building construction. In the 1998, 2000, and 2003 editions of the IECC, commercial building requirements are covered in two chapters (7 and 8). These chapters represent alternative compliance approaches. Compliance via Chapter 7 is accomplished by meeting the requirements of the ASHRAE/IESNA 90.1 Standard for nonresidential buildings. In these editions of the IECC, Chapter 7 is nothing more than a reference to the existing ASHRAE/IESNA Standard 90.1. On the other hand, chapter 8, "Design by Acceptable Practice for Commercial Buildings" was developed as an alternative compliance path, with the aim of providing a simplified prescriptive set of requirements that attains comparable efficiency levels to the ASHRAE/IESNA standard. (The language in the IECC 2004 Supplement (2004S) has combined chapters 7 and 8, but these two separate compliance paths remain).

Chapter 8 in the 2003 IECC is composed of six sections. The first section (801) defines the scope of coverage of Chapter 8. The next four sections define four principle areas of coverage:

802 Building Envelope Requirements
803 Building Mechanical Systems
804 Service Water Heating
805 Lighting Systems

The last section (806) defines a whole building performance approach to compliance that may be used as long as specific mandatory requirements defined in 802 - 805 are met.

The scope section of Chapter 8 states that "the requirements of sections 802, 803, 804, and 805 shall each be satisfied on an individual basis." Where <u>all</u> the requirements of any of the four previous sections are not met, compliance for that section may be demonstrated by meeting the applicable provisions for that section in the ASHRAE/IESNA Energy Code. Thus, sections 802, 803, 804, and 805 can each be thought of as alternative compliance paths provided in the IECC 2003 to meeting the corresponding requirements in the ASHRAE/IESNA energy standard.

2.2 ASHRAE/IESNA Standard 90.1

ASHRAE published the first national energy standard for buildings (Standard 90) in 1975, with subsequent revisions in 1980, 1989, 1993, 1999, 2001, and 2004. In 1980, separate versions of the standard were developed for residential buildings and nonresidential buildings. The version that applied to nonresidential buildings including high-rise residential was later designated as Standard 90.1. With regard to (low-rise) residential buildings, the standard was subsequently termed Standard 90.2. Formally, the past three editions of the 90.1 Standard have been released under the title *Energy Standard for Buildings Except Low-Rise Residential Buildings*. Beginning with the 1980 edition, Standard 90.1 (then called Standard 90A) was published under the auspices of both ASHRAE and the Illuminating Engineering Society of America of North America (IESNA).

The 1999 edition of the standard was a substantial revision of the 1989 edition.[4] Major changes included new equipment and building envelope efficiency levels based upon both economic and feasibility criteria, an expanded scope to cover existing buildings, a rewrite of the entire document into mandatory enforceable language suitable for code adoption, and significant reduction in the electric power allowances for interior lighting. Standard 90.1-1999 is the current EPAct-mandated commercial building energy standard based on DOE's formal determination of energy savings of that standard.[5]

The 2001 edition of Standard 90.1 clarified a number of ambiguities in the 1999 edition, making it more amenable to enforce. In only a few instances were there changes to the stringency levels for specific building components. Standard 90.1-2001 is recognized as a compliance path for nonresidential (commercial) buildings in both the IECC 2003 and IECC 2004S.

The 2004 edition of the 90.1 standard includes some major changes from the 1999 and 2001 editions. The climate zones were reduced from 26 to 8, and are now consistent with those in the IECC. The lighting power density requirements were reduced significantly and are generally comparable with those in the IECC 2003 and the IECC 2004S. The entire document was also reformatted to improve usability of the standard.

2.3 Relationship between the Codes

Because meeting the requirements of ASHRAE/IESNA Standard represents one path to compliance with the IECC 2003, the IECC 2003 is by definition no more stringent than ASHRAE/IESNA 90.1-2001. However a goal in the development of the IECC has been to provide a secondary path to compliance that, on balance, provides a level of building energy

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[4] The intervening 1993 publication was an initial attempt to express the ASHRAE/IESNA requirements in terms of code enforceable language.

[5] Under the 1992 Energy Policy Act (EPAct) of 1992, states were required to update their building codes based upon the most recent edition of the national model code (ASHRAE 90.1 for commercial buildings) within a certain time frames after their publication and the determination by DOE that the revised code yields energy savings.

efficiency in commercial buildings comparable to that in ASHRAE/IESNA 90.1, while being easier to use during building construction and enforcement.

The major purpose of this report is to compare the stringency of the IECC 2003 and IECC 2004S requirements outlined in Chapter 8 with corresponding requirements in Standard 90.1-2001. This is done through review of the scope of the relevant documents with respect to the envelope and lighting requirements. There are also differences between the two codes with regard to mechanical requirements, i.e. HVAC and service water heating. These differences have not been addressed in this report. The report also indicates the major differences in the 2001 and 2004 editions of the 90.1 Standard. The 2004 ASHRAE/IESNA Standard is expected to be referenced in the next IECC to be published in early 2006.

Table 2.1 shows the various ASHRAE/IESNA 90.1 standards referenced in various versions of the IECC (Chapter 7). Column three in the table summarizes key features introduced in Chapter 8 in the latest two versions of the IECC and how these differ from the latest ASHRAE standard. The last column of the table shows that major congruence between the two codes will likely be achieved in the 2006 cycle of the IECC.

Table 2.1 *ASHRAE 90.1 Standards Referenced by Recent Versions of the IECC*

IECC Version	Reference to ASHRAE 90.1	Key Features in the IECC (Chapter 8)	Major difference from 90.1 reference
1998	ASHRAE 90.1-1989 (93 codified version)		
2000	ASHRAE 90.1-1989 (93 codified version)		
2001 Supplement	ASHRAE/IESNA 90.1-1999		
2003	ASHRAE/IESNA 90.1-2001	More stringent lighting requirements, compared to 2000 and 2001	Lighting requirements in 90.1-2001 are less stringent (overall by 20-30%)
2004 Supplement	ASHRAE/IESNA 90.1-2001	Consolidated climate zones, envelope requirement no longer function of window-wall ratio	Many climate zones based upon degree-days; lighting less stringent than IECC 2004S
2006 (early 2006)	ASHRAE/IESNA 90.1-2004		General consistency in climate zones and lighting requirements

3 Scope

3.1 IECC 2003 (IECC 2004S)

The scope of IECC 2003 with regard to commercial buildings is expressed in section 101.4 of Chapter 1, Administration and Enforcement. In general, the IECC 2003 establishes minimum prescriptive and performance related regulations for the design of energy-efficient commercial buildings as well as those portions of industrial buildings designed primarily for human occupancy. Commercial buildings are defined by the IECC as all buildings *other than* detached one- and two-family dwellings, townhouses, and residential buildings (Groups R-2 and R-4), three stories or less in height above grade.[6] Commercial buildings designed with a peak design energy usage for space conditioning less than 3.4 Btu/h (1 watt) per square foot of floor area as well as buildings and portions of building that are neither heated nor cooled are exempt from the requirements outlined in the IECC 2003.

The IECC 2003 is applied to new building construction, building additions, alterations or repairs. In general, none of the requirements of the code are mandatory for buildings classified or eligible for classification as historically significant by the state or local jurisdiction or the National Register of Historic Places. In addition, the code requires that if the occupancy of the building changes, resulting in an increase in demand for fossil fuel or electrical energy supply, the code official shall certify that the building or structure has been made to comply with the requirements of the code for the new occupancy, and that the change in occupancy will not result in any increase in demand for fossil fuel or electrical energy.

3.2 Standard 90.1-2001 (90.1-2004)

As mentioned above, ASHRAE/IESNA Standard 90.1 was originally developed as a building standard, not a code. However, recognizing the unique status of ASHRAE/IESNA Standard 90.1 due to its place in federal legislation as a minimum standard for state commercial building energy codes, the ASHRAE 90.1 committee chose to formulate Standard 90.1-1999 and subsequent editions as much as possible in mandatory and enforceable "code-like" language. This was to help in interpretation of 90.1 requirements and facilitate adoption of 90.1 requirements into state and local jurisdiction energy codes.

The scope of Standard 90.1-2001 is defined as: a) new buildings and their systems, b) new portions of buildings and their systems, and c) new systems and equipment in existing buildings. Exempt are single family residences, manufactured houses, multi-family buildings three stories or less above grade, buildings and portions of building systems that use energy primarily to provide for industrial, manufacturing or commercial processes, and buildings that do not use either electricity or fossil fuels.

Buildings systems that are covered in 90.1-2001 are HVAC equipment, service water heating systems, electric power distribution and metering, motors and belt drives, and internal and external building and grounds lighting. The building envelope is only required to meet 90.1-2001 requirements if the heating system output capacity in the building is greater than or equal to 3.4 Btu/h per square foot (of floor area), or the cooling system output capacity is greater than or equal to 5 Btu/h per square foot (of floor area).

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[6] R-2 covers apartment houses, convents, dorms, fraternities and sororities, monasteries, vacation timeshare properties, hotels (nontransient). R-4 covers residential care/assisted living facilities with between 5 and 16 occupants. The common theme is that all of them have occupants that live in the space more or less permanently.

As noted, both Standard 90.1-2001 and the IECC 2003 cover both new buildings, and repairs or alterations to existing buildings. Standard 90.1-2001 is somewhat broader with respect to the types of buildings it covers, as it includes residential-type buildings such as dormitories, timeshare properties, and nursing care facilities. The 90.1 Standard, however, often specifies different requirements for these buildings as compared to those used for commercial purposes (distinguished by 90.1 as nonresidential buildings)

Table 3.1 summarizes the key differences in the scope between the ASHRAE/IESNA 90.1 Standard and the IECC

Table 3.1 *Commercial Building Scope Comparison -- ASHRAE/IESNA Standard 90.1 and IECC.*

General Scope	Standard 90.1 (Qualifiers)	IECC (Qualifiers)
New commercial buildings, multi-family residential 4 stories or more above grade, and portions of industrial or manufacturing facilities designed primarily for human comfort.	HVAC, SWH, Lighting covered. Envelope covered if heating capacity ≥ 3.4 Btu/h-ft^2 or sensible cooling capacity ≥ 5 Btu/h-ft^2	SWH and Lighting covered for all buildings in this category. Other requirements exist only if the peak design rate of energy use for space conditioning ≥ 3.4 Btu/h-ft^2.
Existing Buildings – Additions and Alterations	Additions or alterations to existing building shall conform to provisions of code as they relate to new construction only and where such building components would be covered for new construction.	Additions or alterations to existing building shall conform to provisions of code as they relate to new construction only and where such building components would be covered for new construction. Historic buildings exempted from scope.

4 Climate Zones

Until the 2004 edition, climate zones in the ASHRAE/IESNA 90.1 building standard have been defined along the lines of heating and cooling degree-days. Specifying various ranges of the heating and cooling degree-days ASHRAE/IESNA Standard 90.1-2001 defined 26 separate climate zones across the continental U.S. and Alaska. To comply with the prescriptive requirements of the standard, the user is referred to one of 26 separate tables in the ASHRAE/IESNA publication. A list of major cities in each state is provided in an appendix that points the user to a particular table in the text.

Beginning with 1998 IECC, each county in the U.S. was assigned a single climate zone, translating from the predominant climate defined by ASHRAE/IESNA 90.1. Establishing the zones along county lines was deemed to aid adoption and compliance of the code. Across the U.S., more than 30 climate zones were defined in the IECC, each composed of multiple counties.

During 2002 and 2003 the U.S. Department of Energy sponsored a research program with the goal of simplifying the climate zones used by ASHRAE/IESNA and the IECC. The development of revised climate zones was spurred by a number of issues that were evident in the existing categorization of climate-based code requirements. The two predominant issues were the division of major metropolitan areas into multiple zones with different requirements, and zones that did not recognize differences in humidity. The result of this research process was to substantially reduce the number of climate zones nationwide, yielding fourteen zones with delineation of dry, moist, and marine humidity conditions. Following the precedent of the IECC, all climate zones are defined in terms of contiguous counties. These revised zones were first employed in the 2004 IECC and later adopted by ASHRAE/IESNA in the 90.1-2004 Standard.

Table 4.1 shows the climate zones assigned to the 15 Arizona counties under the IECC 2003 and IECC 2004S. The eight separate climate zones across the state have been reduced to four. A key point is that the two most populous counties in Arizona, Maricopa and Pima, are now in the same climate zone (zone 2). Under the revised climate zones, nearly 85% of the population in Arizona is in climate zone 2

Table 4.1. *Climate Zones for Arizona Counties in the IECC 2003 and IECC 2004S.*

County	Climate Zone/IECC 2003	Climate Zone/IECC 2004 Supplement	Key Cities	2002 Population
Apache	13B	5	Chinie, St. Johns	68,800
Ochise	6B	3	Sierra Vista, Douglas	120,000
Coconino	14A	5	Flagstaff, Sedona	120,000
Gila	8	4	Globe, Payson	52,000
Graham	6B	3	Safford	33,000
Greenlee	6B	3	Clifton, Eagar	8,000
La Paz	3C	2	Parker	20,000
Maricopa	3C	2	Phoenix, Mesa, Glendale, Scottsdale, Chandler, Tempe Gilbert, Peoria	3,304,000
Mohave	7B	3	Lake Havasu, Bullhead City	166,000
Navajo	10B	5	Holbrook, Show Low	102,000
Pima	4B	2	Tucson, Green Valley	881,000
Pinal	4B	2	Casa Grande	196,000
Santa Cruz	6B	3	Nogales	40,000
Yavapai	10B	4	Prescott, Prescott Valley	179,000
Yuma	3C	2	Yuma	167,000

The next chapter provides a comparison of the major envelope components, whose requirements in all of the codes vary according to climate. Five separate locations have been selected for the comparison, as shown in Table 4.2. These locations represent the four climate zones in Arizona now defined in the IECC 20004S and ASHRAE/IESNA 90.1-2004. We chose to use principal cities in each climate zone, as they may provide some greater familiarity to readers than the use of counties. Table 4.1 provides a ready means to identify those counties that have the same requirements as the five selected cities.

For each of the cities listed in Table 4.2, the discussion in the following chapter treats the requirements under the 2003 IECC (and, by reference 90.1-2001). Because the two population centers in the state, the Phoenix and Tucson metropolitan areas, are in separate climate zones under the 2003 IECC (and ASHRAE/IESNA 90.1-2001), these locations are discussed separately. The remaining selected locations, Lake Havasu, Prescott, and Flagstaff represent major cities in their respective climate zones defined by the 2003 IECC (7B,10B, and 14A from Table 4.1), and thus the discussion about changes in requirements apply both to these cities and other locations in the same (2003) climate zone. Requirements under the 2003 IECC (and ASHRAE Standard 90.1-2001) may differ in the less populous counties with different IECC 2003 climate zones (e.g., Apache or Graham counties) and are not presented in the report. However, the requirements under the IECC 2004S and 90.1-2004 can be determined for any location (county) in the state, as all Arizona counties fall into one of the four climate zones defined in these most recent editions of the codes.

Table 4.2 *Locations Selected for Code Comparison*

City or Area	**Climate Zone IECC 2003**	**Climate Zone IECC 2004 Supplement**
Phoenix Metropolitan	3C	2
Tucson	4B	2
Lake Havasu	7B	3
Prescott	10B	4
Flagstaff	14A	5

5 Building Envelope Requirements

5.1 Compliance Paths

IECC 2003 Chapter 8 has a single compliance path that prescribes minimum requirements for all envelope components. The Department of Energy has developed a software tool called COMCheck-EZ that aids in the determination of whether the building meets the IECC requirements. COMCheck-EZ actually allows trade-offs among the stringency of envelope components such that the overall heating and cooling energy use remains equivalent to that achieved by the totally prescriptive path. Most jurisdictions that adopt any IECC version (or 90.1 version for that matter) use COMcheck-EZ as a "Deemed to comply" option. COMcheck is not mentioned in either the IECC or Standard 90.1, but is available through the DOE's building energy codes web site (http:\\www.energycodes.gov) as an option.

The IECC also permits compliance via ASHRAE/IESNA 90.1 that, in turn, also has several paths for compliance. Chapter 5 in the ASHRAE/IESNA Standards 90.1-2001 and 90.1-2004 presents two compliance paths, one with tables of prescriptive envelope requirements and one allowing trade-offs. Similar to the IECC, the trade-off option uses a mathematical algorithm (embodied in a software program ENVSTD 3.0 and also in the COMcheck-EZ software) to allow the user to trade off the stringency of individual components in order to develop a building envelope that will, in aggregate, provide an equivalent energy cost to a building using the prescriptive envelope requirements.[7] The algorithm assumes comparable levels of internal loads and identical occupancy schedules.

Energy Efficiency Impact: The presence of both IECC and ASHRAE/IESNA compliance paths provides great flexibility to the designer. Moreover, tradeoffs available with either the IECC (through COMCheck-EZ) or ASHRAE/IESNA (through ENVSTD 3.0 or COMCheck-EZ) are designed to provide equivalent energy performance between a compliant envelope and the prescriptive envelope requirements.

5.2 Building Types and Requirements

The IECC 2003 has a single set of prescriptive envelope performance requirements for all buildings that depend on climate zone and on which of four window-to-wall ratio (WWR) bins in which the building fits. IECC 2004S has dropped any dependence upon the window-to-wall ratio for any envelope characteristics. In ASHRAE/IESNA Standard 90.1-2001 (and 2004) only the window thermal transmittance (U-factor) and solar heat gain (SHGC) requirements are functions of WWR.

[7] The user will note that both the IECC and 90.1 effectively provide flexibility in building design by providing a means to trade-off efficiencies of various envelope components. The trade-off algorithm was originally developed by ASHRAE for the 90.1-1989 Standard, and revised for the 90.1-1999 Standard. As embodied in the COMCheck-EZ software, the IECC 2003 and 2004S continue to use the algorithm developed for the 90.1-1989 ASHRAE Standard (as written into the version 2.4 of the ENVSTD software). The procedure for ASHRAE/IESNA 90.1-2001 and 90.1-2004 uses the trade-off method that was revised for the 90.1-1999 Standard. The revised trade-off procedure introduces (fixed values of) fuel prices into the algorithm and thus makes the use of the trade-off feature yield equivalent energy cost.

The ASHRAE/IESNA standard has three sets of envelope requirements based on space type: non-residential, residential (four stories and above), or semi-heated. Nonresidential is appropriate for most commercial buildings. Residential requirements are used for spaces classed primarily as living space, including high-rise dwelling units and hospital patient rooms. Semi-heated spaces are spaces with no cooling and with limited heating capacity. The insulation requirements are generally the least stringent in semi-heated spaces.

Energy Efficiency Impact: The presence of multiple building types in Standard 90.1 attempts to link the envelope requirements to expected cooling and heating needs that are strongly related to differences in installed HVAC equipment, internal temperature settings, internal heat gains and schedules characteristic of the non-residential, residential, and semi-heated space-types. The largest impact of the different building envelope is expected to be the reduced stringency of the envelope thermal transmittance requirements for semi-heated buildings. It is expected that this will result in a net increase in energy use compared to the IECC, but at the same time, likely results in more cost-effective requirements for semi-heated building spaces.

5.3 Air Leakage

Both Standard 90.1 and the IECC have requirements for sealing of the building envelope, with 90.1 more explicit in detailing where sealing must be done for individual envelope components.

Both documents have leakage rates requirements for windows and doors. Standard 90.1-2001 (and 90.1-2004) has a requirement that air leakage not exceed 1.0 cfm/ft^2 for glazed, swinging entrance doors and be less than 0.4 cfm/ft^2 for all other windows and doors. These products shall be certified by the manufacturer and labeled accordingly. Leakage rates shall be determined using NFRC 400 as the test procedure. Garage doors shall have their leakage rates tested in accordance with the ANSI/DASMA 105 test standard (DASMA is the Door and Access Systems Manufacturers Association). Field fabricated fenestration and doors are exempted, from leakage rates requirements, but have specific sealing requirements.

The IECC (2003 and 2004S) has requirements that windows, doors, and curtain wall assemblies that are part of the building envelope be tested and listed as meeting AAMA/WDMA 101/I.S.2 or 101/I.S.2/NAFS-02, or NFRC 400. The leakage standards are slightly more stringent than 90.1, 0.5 cfm/ft^2 for glazed, swinging entrance doors and less than 0.3 cfm/ft^2 for all other windows and doors. As with 90.1, the IECC similarly exempts field-fabricated fenestration and from leakage rates requirements, as long as they have been sealed in a prescribed manner.

For cold climates, both Standard 90.1 and the IECC include a requirement for loading dock weather seals and also a requirement for vestibules in commercial building entrance doors. For Arizona under the IECC 2003, these requirements were exempted for climate zones 3A and 4B (See Table 4.1 above). With the revised climate zones in the IECC 2004S and 90.1-2004, these provisions are not required in climate zone 2, thus exempting the most populated counties in Arizona (see Table 4.1).

Energy Efficiency Impact: The impact of these changes on energy efficiency is expected to be minimal. Both 90.1 and the IECC have similar requirements for building sealing and for door and window leakage. Air leakage requirements for different types of doors and windows are expected to be marginally more stringent in the IECC than Standard 90.1-2001 (and 90.1-2004); however, Standard 90.1 has some additional requirements as well as being more explicit in terms of envelope sealing requirements. Since both standards attempt to regulate the same components to similar levels of stringency, it is expected that the minor differences will have minimal impact on energy efficiency.

5.4 Moisture Migration

Both the ASHRAE/IESNA Standard 90.1 and the IECC require that insulation be protected from moisture migration that could lead to deterioration of insulation performance. Standard 90.1 requires a protective cover of some sort for exterior insulation to prevent damage from sunlight, moisture and other hazards, but provides no detail on what sort of protection should be used. The ASHRAE/IESNA standard requires that insulation materials in contact with the ground shall have a water absorption rate of no more than 0.3%, thus limiting the water uptake of these materials.

In cold climates, the IECC 2003 requires the use of vapor retarders with a rating of 1 perm *except* where moisture or freezing will not harm the construction materials used, or where other approved means are used to avoid condensation. In Arizona, these requirements apply to only 5 counties, whose climate zone number exceeds 7 (in column two) in Table 4.1. Under the IECC 2004S, these requirements are unchanged, as the code calls for a vapor retarder in the (revised) climate zones 4 and 5 (column three in Table 4.1), comprising the same five Arizona counties.

Energy Efficiency Impact: Given that neither document is particularly explicit about what is necessary to best mitigate moisture migration, the overall impact of these differences is expected to be minimal. The IECC is the more explicit of these documents in terms of requiring a vapor retarder. At this point, however, there is little evidence that a vapor retarder would have a significant impact on building energy usage. The intent of this requirement in both the IECC and ASHRAE/IESNA Standard 90.1 is to protect insulation from potential moisture damage. Overall, the more explicit language in the IECC may provide some possible improvement in preventing moisture related insulation damage. However, this requirement would apply to only a small fraction of new building construction in Arizona, given its potential effect in only five sparsely-populated counties.

5.5 Insulation Installation

90.1-2001 (and 2004) require that insulation be installed in substantial contact with the inside surface of cavities and in accordance with the manufacturer's recommendation for the framing system used. It also requires that lighting fixtures, heating, ventilating, and air-conditioning, and other equipment not be recessed in such a manner as to affect the insulation performance. The ASHRAE/IESNA standard also bans installation of insulation on suspended ceilings with removable ceiling panels.

The IECC has similar insulation installation requirements, as discussed in Section 102 of the code. Beginning with the 2001 edition of the IECC, specific requirements were also added to use either IC rated ceiling light fixtures with no ceiling penetrations, sealed boxes built around the backs of ceiling light fixtures, or fixtures rated to lose less than 2 cfm of air between conditioned space and the ceiling cavity. This requirement should serve to reduce exfiltration from conditioned space to roof cavity in a more explicit manner than the Standard 90.1 language does, although only for lighting fixture.

Energy Efficiency Impact: Insulation installation requirements are essentially the same in both sets of documents. The ban on insulation installed on suspended ceilings in Standard 90.1 may save energy in a few commercial buildings.

5.6 Skylights

Thermal Transmittance

Standard 90.1-2001 contains prescriptive requirements for skylights that are a very strong function of climate. Table 5.1 shows the Standard 90.1-2001 requirements for glass skylights with curbs, plastic skylights with curbs, and skylights without curbs. The comparison shown in Table 5.1 is for skylights with curbs. No separate category for skylights without curbs is provided in the IECC. In 90.1, the U-factor requirement for a skylight without curb is lower by 30-40% from the glass skylight with curb values

Table 5.1 *Skylight Thermal Transmittance Requirements*

Location	**IECC 2003**	**IECC 2004S**	**Standard 90.1-2001/90.1-2004**		
			Non-Residential	**Residential**	**Semi-heated**
Phoenix	U-factor =1.0	U-factor =1.05	U-factor = 1.98 (glass) or 1.90 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)
Tucson	U-factor =1.0	U-factor =1..05	U-factor = 1.98 (glass) or 1.90 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)
Lake Havasu	U-factor =1.0	U-factor =0.9	U-factor = 1.17 (glass) or 1.30 (plastic)	U-factor = 1.17 (glass) or 1.30 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)
Prescott	U-factor =0.8	U-factor =0.6	U-factor = 1.17 (glass) or 1.30 (plastic)	U-factor = 1.17 (glass) or 1.30 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)
Flagstaff	U-factor =0.8	U-factor =0.6	U-factor = 1.17 (glass) or 1.30 (plastic)	U-factor = 1.17 (glass) or 1.10 (plastic)	U-factor = 1.98 (glass) or 1.90 (plastic)

Standard 90.1-2001 (2004) limits the prescriptive requirements to 5% skylights, but there is provision in Standard 90.1 to trade off skylight area with other portions of the building envelope (using the ENVSTD 3 software program or the tradeoff equations in Appendix C of the Standard[8]). The IECC limits skylights to 3%. The 2003 edition of the IECC provides different envelope tables for each of four window-to-wall ratios categories for each of the IECC climate bins; however a review of all of the WWR shows only a few places across the U.S. where the

[8] This trade-off capability is incorporated as well into the COMCheck-EZ software.

performance for skylights varies. There is no variation across the WWR for any of the Arizona climate zones. In the IECC 2004S do not vary by the window-to-wall ratio. As shown in Table 5.1, the thermal requirements in the IECC for skylights have become slightly less stringent the in hot southern areas of the state, and more stringent in the rest of the state.

Energy Efficiency Impact: In general, it appears that the IECC is considerably more stringent than Standard 90.1, both in terms of required U-factor for skylights and the lower fraction of skylight area allowed. The overall impact of this difference will be lower heating energy use in the IECC as compared to 90.1.

Solar Heat Gain

Solar heat gain from skylights is not addressed by the IECC 2003; however the U-factor requirements for skylights will tend to require skylight designs (like double pane low-e glass) that have lower Solar Heat Gain Coefficients (SHGC) that may range from 0.5 to 0.8. The IECC 2004S sets explicit SHGC requirements for glass skylights, making the requirements equal to those for vertical windows (i.e., 0.4 for all but the coldest climates in the U.S.). The SHGC requirements for plastic skylights are somewhat lower in warm and moderate climates and higher in colder climates.

Standard 90.1-2001 has solar heat gain coefficient (SHGC) requirements on skylights in residential and nonresidential spaces for all but extremely cold climates. The 90.1-2001 requirements require low SHGC in most moderate to warmer climates (down to 0.16 SHGC, but vary widely depending on space-type, climate, and skylight roof area fraction). The SHGC requirements are generally lower for residential compared to nonresidential buildings, and are generally lower for warmer climates or for skylight roof fractions greater than 2%.

The consolidation of climate zones in ASHRAE/IESNA 90.1-2004 has generally resulted in somewhat more stringent SHGC requirements for skylights in Arizona. The change with the most impact is the reduction of the nonresidential SHGC for glass skylights in Tucson (Pima County) from 0.25 to 0.19 (denoted in Table 5.2 in the form of 0.25/0.19). Compliant values for the SHGC are also more stringent for nonresidential buildings in the more northern portions of the state, exemplified by Prescott and Flagstaff.

Table 5.2 *Skylight Solar Heat Gain (SHGC) Requirements*

Location	IECC 2003	IECC 2004S	Standard 90.1-2001/90.1-2004		
			Non-Residential	Residential	Semi-heated
Phoenix	NR	SHGC=0.4 (glass) or 0.35 (plastic)	SHGC = 0.19 (glass) or 0.34 (plastic)	SHGC = 0.19 (glass) or 0.27 (plastic)	NR
Tucson	NR	SHGC=0.4 (glass) or 0.35 (plastic)	SHGC = 0.25/0.19 (glass) or 0.39/0.34 (plastic)	SHGC = 0.19 (glass) or 0.27 (plastic)	NR
Lake Havasu	NR	SHGC=0.4 (glass) or 0.35 (plastic)	SHGC = 0.39 (glass) or 0.34/0.39 (plastic)	SHGC= 0.19 (glass) or 0.34 (plastic)	NR
Prescott	NR	SHGC=0.4 (glass) or 0.35 (plastic)	SHGC = 0.39 (glass) or 0.62/0.34 (plastic)	SHGC = 0.19 (glass) or 0.27 (plastic)	NR
Flagstaff	NR	SHGC=0.4 (glass) or 0.35 (plastic)	SHGC = 0.49/0.39 (glass) or 0.77/0.62 (plastic)	SHGC = 0.49/0.39 (glass) or 0.77/0.62 (plastic)	NR

Values are taken for 5% of the roof area in skylights, as this is the maximum prescriptive level in Standard 90.1-1999. Requirements are somewhat less stringent in 90.1 when the percentage of roof area in skylights is less than 2%.

Energy Efficiency Impact: The solar heat gain requirements for skylights have undergone some significant changes in the most recent cycles of the IECC and ASHRAE/IESNA codes. Even with inclusion of requirements under the IECC for skylights, the 90.1 requirements are much lower in the southern, most populated, portions of the state. Cooling energy requirements would be expected to be lower under 90.1 in these areas, although a careful analysis of the lighting impacts is required to quantify the differences.

5.7 Slab-on-Grade and Below-Grade Walls

Practically speaking, insulation for unheated slabs or for below-grade walls is not required in Arizona in either building energy code. In general, the IECC 2003 requires no slab-on-grade insulation for unheated slabs for climates with HDD65 <5500. This requirement depends upon the window-wall ratio (WWR), with buildings exceeding a WWR of 25% requiring R-8 insulation of the edge of the slab. For Arizona, this IECC 2003 requirement would apply to only two counties: Coconino and Apache. The dependence upon WWR was dropped in the IECC 2004S, resulting in no part of Arizona requiring slab insulation to meet the IECC. In the ASHRAE/IESNA 90.1-2001 and 2004, insulation for unheated slabs is required only in buildings built in Alaska.

Generally, the same requirements in ASHRAE/IESNA and the IECC apply to below-grade walls as to slab insulation. Only under the IECC 2003, in buildings with a WWR greater than 25%, and in the two counties cited above are any insulation requirements relevant in Arizona.

5.8 Roofs

The IECC 2003 provides roof R-values (opaque roof component only) for both insulation between framing and for continuous insulation installed for each of five different roof assemblies: All-wood joist/truss, Metal joist/truss, Concrete slab or deck, Metal purlin with thermal block, and Metal purlin without thermal block.

For each climate bin in the IECC 2003, requirements can differ depending on the window-wall ratio of the building. As mentioned in Section 1, the 2004 Supplement to the IECC dropped the relationship between envelope requirements and the window-wall ratio. For attic-style roofs, the 2004S requirements have become more stringent compared to all but a few of the window-wall ranges defined in the 2003 code. For other categories-- "Insulation entirely above deck" and metal buildings--the insulation requirements on balance are slightly lower in the 2004 Supplement as compared to the 2003 edition of the IECC.

Standard 90.1 provides 9 possible U-factors depending on building space-type (nonresidential, residential, or semi-heated) as well as on each of the three different roof assemblies: a) Insulation entirely above deck, b) Metal buildings, and c) Attic and other roof assembly. The 90.1-2001 and 90.1-2004 requirements tables list both minimum R-values for the insulation material or the maximum U-factor for the entire roof assembly. Compliance can be satisfied by meeting either requirement. The U-factor is consistent with the R-value using what ASHRAE deems to be a typical assembly. For buildings constructed with variations of the assembly or insulation placement, both of the recent editions of 90.1 provide tables of default U-factors in Appendix A that can be used in establishing compliance.

The Standard 90.1 nonresidential requirements are used for most commercial buildings. The 90.1 residential requirements are appropriate for residential space types (high-rise apartment buildings, lodging facilities, hospital patient rooms, etc), and have U-factors that are generally at or more stringent than the nonresidential requirements. The semi-heated U-factors are designed for spaces which have limited heating system capacity and are without cooling. A common semi-heated application is expected to be warehouse buildings heated primarily for freeze protection.

Because of the different ways each code organization uses to establish the roof thermal transmittance requirements, it is not easy to compare the two documents. Table 5.3 compares the roof requirements for four classes of roofs: attics with metal frame construction, attic roofs with wood frame construction, roofs with insulation above deck (shown compared to the IECC concrete roof class), and metal roofs. The comparisons are made in terms of U-factors rather than R-values, as U-factors better reflect the relative differences in overall insulating value. These four classes are those defined by ASHRAE/IESNA 90.1, with the attics broken out separately for metal and wood frame construction. Metal and wood truss roof assemblies have different insulation requirements under the IECC 2003. The 90.1-2001 insulation above deck construction has been shown alongside the IECC category for a concrete roof, however

Table 5.3 *Comparison of Roof Thermal Transmittance Requirements (U-factors)*

	International Energy Conservation Code (IECC)								ASHRAE		
				2003				2004S	90.1-2001/90.1-2004		
	Climate Zone	*Climate Zone*		*Window-Wall Ratio (%)*							
Location	IECC 2003	IECC 2004S	Wall Type	0-10	10-25	25-40	40-50	Any	*Non-residential*	*Residential*	*Semi-heated*
Phoenix	3C	2	Attic- metal frame	0.048	0.048	0.048	0.048	0.041	0.034	0.027	0.081
Tucson	4B	2	Attic- metal frame	0.048	0.048	0.048	0.048	0.041	0.034	0.034/0.027	0.081
L. Havasu	7B	3	Attic- metal frame	0.058	0.048	0.048	0.048	0.041	0.034	0.034/0.027	0.081
Prescott	10B	4	Attic- metal frame	0.048	0.048	0.048	0.048	0.041	0.034	0.034/0.027	0.081
Flagstaff	14A	5	Attic- metal frame	0.048	0.048	0.041	0.041	0.041	0.034	0.034/0.027	0.053
Phoenix	3C	2	Attic- wood frame	0.053	0.043	0.043	0.043	0.034	0.034	0.027	0.350
Tucson	4B	2	Attic- wood frame	0.053	0.053	0.053	0.053	0.034	0.034	0.034/0.027	0.350
L. Havasu	7B	3	Attic- wood frame	0.053	0.043	0.043	0.043	0.034	0.034	0.034/0.027	0.069
Prescott	10B	4	Attic- wood frame	0.053	0.053	0.043	0.043	0.034	0.034	0.034/0.027	0.069
Flagstaff	14A	5	Attic- wood frame	0.053	0.043	0.034	0.034	0.034	0.034	0.034/0.027	0.069
Phoenix	3C	2	Ins. Above deck	0.060	0.051	0.051	0.051	0.063	0.063	0.063	0.218
Tucson	4B	2	Ins. Above deck	0.060	0.060	0.060	0.060	0.063	0.063	0.063	0.218
L. Havasu	7B	3	Ins. Above deck	0.068	0.051	0.051	0.051	0.063	0.063	0.063	0.218
Prescott	10B	4	Ins. Above deck	0.056	0.051	0.051	0.051	0.063	0.063	0.063	0.218
Flagstaff	14A	5	Ins. Above deck	0.056	0.051	0.042	0.042	0.048	0.063	0.063	0.173
Phoenix	3C	2	Metal building	0.056	0.051	0.051	0.051	0.065	0.065	0.065	0.167
Tucson	4B	2	Metal building	0.056	0.056	0.056	0.056	0.065	0.065	0.065	0.167
L. Havasu	7B	3	Metal building	0.056	0.051	0.051	0.051	0.065	0.065	0.065	0.097
Prescott	10B	4	Metal building	0.056	0.056	0.051	0.051	0.065	0.065	0.065	0.097
Flagstaff	14A	5	Metal building	0.051	0.051	0.046	0.046	0.065	0.065	0.065	0.097

realistically it could also be compared to the metal or wood truss- type roof assemblies if continuous insulation is installed on top of the roof. For metal building roofs, the IECC U-factors shown were from the “metal purlin with thermal blocks” requirements.

The IECC 2004S no longer distinguishes between wood frame and metal frame in its insulation requirements for attic-style roofs. For climate zones 1 through 6, the requirement is uniformly R-30. As shown Table 5.3, with common framing assembly materials and dimensions, this R-value translates into a U-factor of 0.034 for wood frame construction and 0.041 for metal (steel) frame construction. Standard 90.1 requires a minimum U-factor or 0.034 regardless of the framing material.

Energy Efficiency Impact: The IECC 2003 is more stringent than Standard 90.1-2001 for roofs with insulation above deck, whether they are concrete roofs, or a truss type roof, or even a metal buildings roof. 90.1-2001 is more stringent for nonresidential and residential buildings which use attics, but would be less stringent for semi-heated buildings using attics. Overall because of the predominance of built-up roofs (either similar to the IECC category of concrete roofs, or based on some type of although not necessarily concrete roofs) in commercial construction, the IECC 2003 roof requirements will be more energy efficient. However, under the IECC 2004 Supplement, these differences have narrowed. For roofs with insulation above deck, metal buildings, and wood frame attic buildings, the requirements are identical for commercial buildings in all climate areas in Arizona. As discussed in the previous paragraph, because the IECC 2004S shows only a single R-value for attic roofs, it now is somewhat less stringent for metal frame roofs as compared to 90.1-2004. As most attic-style roofs are wood frame, this difference leads to only a minor impact on energy savings.

5.9 Floors

A comparison of U-factors for floors over unconditioned spaces is shown in Table 5.4. The IECC 2003 provides insulation R-value requirements for floors over unconditioned spaces as a function of climate zone and separately for concrete slab floors, wood joist, or metal joist floor assemblies. In contrast to other envelope components, the floor insulation requirements in the IECC do not depend upon the percentage of window area. The R-value requirements differ depending on whether continuous insulation is used or whether the insulation is between framing members. For concrete (mass) floors, the only applicable insulation is continuous (rigid foam).

In the IECC 2004S, the insulation requirements were simplified as a function of climate. For *mass* floors, this new requirements have become more stringent in the warmest climates, as shown in Table 5.4. Assuming the use of rigid foam as the insulating material, the new requirement calls for R-5 insulation in climate zone 2. Previously, in the 2003 IECC, the requirements for mass floors could be satisfied with R-2 foam in Phoenix and R-4 foam in Tucson. In other areas in the state, the IECC 2004S requirements for mass floors have been relaxed. This general pattern holds for floors built with joists or truss, with more stringent requirements in the warmest areas and some relaxation in the colder areas. The uniform U-factor for either wood or steel construction is R-19. (IECC 2004S no longer distinguishes between insulation installed between the joists or continuous insulation in joint/truss floors. Continuous insulation with a comparable U-factor would yield a higher insulating performance than (batt) insulation between the framing, but cost considerations would make the use of continuous insulation uncommon.)

Standard 90.1-2001 provides separate U-factor requirements by climate bin and by each of three separate space types (non-residential, residential, and semi-heated spaces) for floors over unconditioned spaces based on either mass, steel joist, or "wood frame and other" construction assembly categories. Default R-values for the most common framing and insulation placement are shown in the Appendix B requirement tables for various climate zones in the 90.1-2001 publication. It should be noted, however, that the actual requirement is based on a U-factor. Standard 90.1-2001 Appendix A provides default U-factors for other framing designs, insulation levels or insulation placement to help in determining compliance. Because of the consolidation of climate zones in the 90.1-2004 edition, the U-factor requirements for a few locations have declined relative to their values in the 2001 code. Three instances are shown on the right-hand side of Table 5.4.

Table 5.4 *Comparison of Floor Thermal Transmittance Requirements (U-factors)*

				International Energy Conservation Code					ASHRAE		
				2003				2004S	90.1-2001/90.1-2004		
	Climate Zone	*Climate Zone*		Window-Wall Ratio (%)							
Location	IECC 2003	IECC 2004S	Floor Type	0-10	10-25	25-40	40-50	Any	*Non-residential*	*Residential*	*Semi-heated*
Phoenix	3C	2	Mass	0.196	0.196	0.196	0.196	0.123	0.137	0.107	0.322
Tucson	4B	2	Mass	0.141	0.141	0.141	0.141	0.123	0.137	0.107	0.322
L. Havasu	7B	3	Mass	0.09	0.09	0.09	0.09	0.123	0.107	0.087	0.322
Prescott	10B	4	Mass	0.049	0.049	0.049	0.049	0.076	0.107	0.087	0.322
Flagstaff	14A	5	Mass	0.045	0.045	0.045	0.045	0.076	0.107	0.087/0.074	0.322
Phoenix	3C	2	Steel Joist	0.078	0.078	0.078	0.078	0.052	0.052	0.052	0.350
Tucson	4B	2	Steel Joist	0.078	0.078	0.078	0.078	0.052	0.052	0.052	0.350
L. Havasu	7B	3	Steel Joist	0.078	0.078	0.078	0.078	0.052	0.052	0.052	0.069
Prescott	10B	4	Steel Joist	0.052	0.052	0.052	0.052	0.052	0.052	0.052/0.038	0.069
Flagstaff	14A	5	Steel Joist	0.043	0.043	0.043	0.043	0.052	0.052	0.038	0.069
Phoenix	3C	2	Wood Joist	0.074	0.074	0.074	0.074	0.051	0.051	0.051	0.282
Tucson	4B	2	Wood Joist	0.078	0.078	0.078	0.078	0.051	0.051	0.051	0.282
L. Havasu	7B	3	Wood Joist	0.078	0.078	0.078	0.078	0.051	0.051	0.033	0.282
Prescott	10B	4	Wood Joist	0.051	0.051	0.051	0.051	0.051	0.051	0.033	0.066
Flagstaff	14A	5	Wood Joist	0.039	0.039	0.039	0.039	0.051	0.051/0.033	0.033	0.066

Energy Efficiency Impact: For commercial (nonresidential) buildings, the IECC 2003 is generally less stringent than 90.1-2001 in warm climate zones, the areas where most of the projected building construction in Arizona would be expected. It is not clear in these warm climates that more floor insulation will result in any substantial reduction in cooling requirements in most commercial buildings. In their most recent editions, the insulation requirements for floors are essentially the same between the IECC and ASHRAE/IESNA 90.1.

5.10 Walls

The IECC 2003 provides prescriptive wall insulation requirements by climate for framed wall construction (metal and wood), walls constructed with concrete masonry blocks, and "other" masonry wall types. As with the other IECC envelope requirements, requirements differ depending on which of the four building WWR bins into which the building falls. For each wall type, insulation requirements are shown as combinations of cavity wall insulation and continuous insulation R-values. Wall insulation requirements are shown separately for walls using metal framing and walls using wood framing. No allowances are made for differing designs of wall framing and no overall U-factor requirements are provided. (These IECC 2003 requirements generally represent a simplification of the requirements that could be developed using real building assemblies and the ASHRAE 90.1-1989 tradeoff software ENVSTD 2.0 or the COMcheck-EZ software.) The requirements were basically unchanged between the 1998, 2000 and 2003 editions of the IECC).

Standard 90.1-2001 by contrast has separate wall requirements for three space types, nonresidential, residential, and semi-heated spaces, but does not have separate requirements by building WWR. The Standard 90.1-2001 requirements are provided in terms of a maximum building wall U-factor for four wall assembly types: mass walls (primarily masonry construction), metal building walls, steel framed walls, and wood framed and "other" wall assemblies. Minimum R-values are provided in the requirements tables for the most typical constructions; however, the Standard also provides tables of default U-factors for walls with various combinations of cavity and continuous wall insulation for each of the four generic assembly types. There is very little change between the 2001 and 2004 editions of 90.1 with regard to wall insulation in Arizona locations.

Table 5.5 compares the requirements for mass and frame walls based on the required U-factors for the five selected locations in Arizona. Shown are the U-factor requirements for the four wall types and three space types in 90.1-2001 (and 2004) as compared to U-factors developed by applying the IECC R-value requirements to the same typical constructions. For this comparison, the metal wall U-factors calculated for IECC 2003 are based on the assembly U-Factors for metal building wall published in Standard 90.1.[9]) Mass wall U-factors for IECC are based on application of the required R-value to a 115 lb/ft3 concrete wall in which the insulation in not interrupted by framing. Mass wall U-factors given for Standard 90.1-2001 (2004) do not include the exception provided for filling the cores of concrete masonry units.

Table 5.5 *Comparison of Opaque Wall Thermal Transmittance (U-factors)*

				2003				2004S	90.1-2001/90.1-2004		
	Climate Zone	*Climate Zone*		*Window-Wall Ratio (%)*							
Location	IECC 2003	IECC 2004S	Wall Type	0-10	10-25	25-40	40-50	Any	*Non-residential*	*Residential*	*Semi-heated*
Phoenix	3C	2	Mass	0.57 (NR)	0.57 (NR)	0.149	0.149	0.57 (NR)	0.58 (NR)	0.151	0.58 (NR)
Tucson	4B	2	Mass	0.57 (NR)	0.57 (NR)	0.149	0.149	0.57 (NR)	0.58 (NR)	0.151	0.58 (NR)
L. Havasu	7B	3	Mass	0.149	0.149	0.142	0.142	0.57 (NR)	0.151	0.123	0.58 (NR)
Prescott	10B	4	Mass	0.149	0.149	0.149	0.149	0.143	0.151	0.104	0.58 (NR)
Flagstaff	14A	5	Mass	0.149	0.149	0.149	0.149	0.108	0.123	0.09	0.58 (NR)
Phoenix	3C	2	Metal	1.18 (NR)	1.18 (NR)	1.18 (NR)	0.158	0.113	0.113	0.113	0.184
Tucson	4B	2	Metal	1.18 (NR)	1.18 (NR)	1.18 (NR)	0.158	0.113	0.113	0.113	0.184
L. Havasu	7B	3	Metal	0.123	0.123	0.123	0.123	0.113	0.113	0.113	0.184
Prescott	10B	4	Metal	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.134
Flagstaff	14A	5	Metal	0.113	0.113	0.113	0.113	0.057	0.113	0.113	0.123
Phoenix	3C	2	Steel Framed	0.35 (NR)	0.132	0.132	0.132	0.124	0.124	0.124	0.352
Tucson	4B	2	Steel Framed	0.132	0.132	0.132	0.124	0.124	0.124	0.124	0.352
L. Havasu	7B	3	Steel Framed	0.132	0.132	0.124	0.124	0.124	0.124	0.084	0.352
Prescott	10B	4	Steel Framed	0.132	0.132	0.132	0.132	0.124	0.124	0.084/0.064	0.124
Flagstaff	14A	5	Steel Framed	0.124	0.124	0.124	0.124	0.124	0.124/084	0.064	0.124
Phoenix	3C	2	Wood Framed	0.29 (NR)	0.29 (NR)	0.096	0.096	0.089	0.089	0.089	0.292
Tucson	4B	2	Wood Framed	0.096	0.096	0.096	0.096	0.089	0.089	0.089	0.292
L. Havasu	7B	3	Wood Framed	0.096	0.096	0.089	0.089	0.089	0.089	0.089	0.089
Prescott	10B	4	Wood Framed	0.096	0.096	0.096	0.096	0.089	0.089	0.089	0.089
Flagstaff	14A	5	Wood Framed	0.096	0.096	0.096	0.096	0.089	0.089	0.089	0.089

NR = no requirement

[9] Table A-9 (Section 3.2) in ASHRAE/IESNA 90.1-1999.

Energy Efficiency Impact: For lightweight frame wall constructions of wood, metal frame, and metal building type walls, 90.1-2001 is more stringent for nonresidential and residential spaces in almost all instances, but particularly so for wood frame buildings with little window area in hot climates (specifically in Arizona for La Paz, Maricopa and Yuma counties). In the 2003 IECC, these buildings require no wall insulation (which translates to a U-factor of 0.29 as shown in Table 5.5). In most other areas in Arizona, the U-factor requirements between the IECC and 90.1-2001 correspond to R-11 and R-13 insulation between the framing members, respectively. For semi-heated spaces, however 90.1-2001 is generally less stringent with the exception of wood framed construction in cooler climate zones where R-13 is required.

For mass (masonry) walls, 90.1-2001 is generally about the same in stringency for mild to warm climates, and of greater stringency for cold climates. The sole exception is for buildings in Phoenix and Tucson with a large amount of glazing--more than a 25% window-wall ratio—where the IECC 2003 calls for R-5 insulation (U-factor = 0.149). Overall, 90.1-2001 is more stringent in reducing heat loss through walls.

For commercial buildings, these differences largely vanish when the IECC 2004S is considered. The 2004 Supplement dropped any dependence of wall insulation level to the window-wall ratio. The more recent IECC code increases the stringency for frame walls in the hottest climates; R-13 insulation (U-factor = 0.124) is required for any type of commercial building across Arizona (identical to ASHRAE/IESNA with the exception of the coldest climate zone represented by Flagstaff). On the other hand, the requirements for insulation of mass walls are dropped entirely in the most populated areas of the state (revised climate zones 2 and 3). In climate zone 3, represented by Lake Havasu, ASHRAE/IESNA 90.1 requires a modest level of insulation for buildings with mass walls.

5.11 Windows

Thermal Transmittance

The IECC 2003 provides prescriptive window U-factor requirements by climate for windows and glass doors by each of four WWR ranges (0-10%, 11-25%, 26-40%, and 41-50%). The 2004 Supplement to the IECC drops the dependence of the U-factor requirements upon the window-wall ratio, and generally sets the single U-factor requirement more stringent than previously required for the highest window-wall ratio.

Standard 90.1 lists prescriptive window U-factor requirements by climate for windows and glass doors by each of five WWR ranges (0-10%, 11-20%, 21-30%, 31-40% and 41-50% and for the three 90.1 space types, nonresidential, residential, and semi-heated spaces. The U-factor requirements are the same for WWR ranges through 40% and become more stringent beyond that percentage.

Table 5.6 compares the window thermal transmittance requirements for the five selected locations in Arizona. By default, if the IECC does not have a nominal U-factor requirement, an appropriate level of 1.23 for a single pane of 1/8” clear glass was assumed; however this is effectively the same as the 1.22 U-factor shown in the Standard 90.1-2001.

Table 5.6 *Comparison of Window Thermal Transmittance Criteria (U-factors)*

				International Energy Conservation Code					ASHRAE				
	Climate Zone	*Climate Zone*		2003				2004S	90.1-2001/90.1-2004				
				Window-Wall Ratio (%)					*Window-Wall Ratio (%)*				
Location	IECC 2003	IECC 2004S	Building Type	0-10	10-25	25-40	40-50	< 40	0-10	10-20	20-30	30-40	40-50
Phoenix	3C	2	*Nonresidential*	1.23	1.23	0.70	0.70	0.75	1.22	1.22	1.22	1.22	1.22
			Residential						1.22	1.22	1.22	1.22	1.22
			Semi-heated						1.22	1.22	1.22	1.22	1.22
Tucson	4B	2	*Nonresidential*	1.23	1.23	0.70	0.70	0.75	1.22	1.22	1.22	1.22	1.22
			Residential						1.22	1.22	1.22	1.22	1.22
			Semi-heated						1.22	1.22	1.22	1.22	1.22
L. Havasu	7B	3	*Nonresidential*	1.23	0.70	0.70	0.70	0.65	0.57	0.57	0.57	0.57	0.46
			Residential						0.57	0.57	0.57	0.57	0.46
			Semi-heated						1.22	1.22	1.22	1.22	0.98
Prescott	10B	4	*Nonresidential*	1.23	0.60	0.50	0.50	0.40	0.57	0.57	0.57	0.57	0.46
			Residential						0.57	0.57	0.57	0.57	0.46
			Semi-heated						1.22	1.22	1.22	1.22	0.98
Flagstaff	14A	5	*Nonresidential*	1.23	0.60	0.50	0.40	0.35	0.57	0.57	0.57	0.57	0.46
			Residential						0.57	0.57	0.57	0.57	0.46
			Semi-heated						1.22	1.22	1.22	1.22	0.98

Energy Efficiency Impact: Overall the 2003 IECC window U-factors are a stronger function of WWR than those in 90.1-2001 (as a result of their basis in the 90.1-1989 ENVSTD 2.0 tradeoff procedure). As a result, for buildings with WWR of up to 25% the IECC 2003 is essentially equivalent in stringency in warm climates (i.e. similar to Phoenix and Tucson), but generally of lesser stringency in cooler climates for both nonresidential and residential buildings. For the semi-heated buildings, the IECC is more stringent in cooler climates. For buildings with WWR of over 25% the IECC 2003 is more stringent, requiring at least double pane glass in almost all warm climates as compared to single pane glass with 90.1-2001. In cooler climates the IECC is also more stringent, but by a lesser margin. We note that for many buildings types, 25% represents a high WWR, and for this reason 90.1-2001 generally has more stringent U-factor requirements for these buildings types. However, in the case of office buildings, where WWRs often exceed 25%, the IECC 2003 requirements are likely more stringent.

The 2004 Supplement makes a dramatic increase in stringency from the 2003 edition of the IECC. Double pane glass is required in all climate locations, regardless of the window-wall ratio. The ASHRAE/IESNA standard (both 2001 and 2004) permits single pane glass in (revised) climate zone 2, covering Phoenix and Tucson. (In practice, however, the solar heat gain requirements of the codes, as discussed below, and noise attenuation qualities of double pane windows suggest that few commercial buildings would install single pane windows.) For the colder climates (as represented by Prescott and Flagstaff), the IECC 2004S U-factor requirements are more stringent than those in Standard 90.1, in essence requiring double-pane low-e glazing to meet the requirements.

Solar Heat Gain

The IECC 2003 provides prescriptive window solar heat gain coefficient (SHGC) requirements by climate for windows and glass doors by each of four WWR ranges (0-10%, 11-25%, 26-40%, and 41-50%) and for three different ranges of window projection factor (PF) (which accounts for other window shading). As for the U-factor requirements, the IECC 2004S has only a single requirement for each climate zone, regardless of the WWR.

Standard 90.1 has prescriptive window SHGC requirements by climate for windows and glass doors by each of five WWR ranges (0-10%, 11-20%, 21-30%, 31-40% and 41-50%) and for two of the three 90.1 space types, nonresidential and residential. The ASHRAE/IESNA 90.1 Standard does not have SHGC requirements for semi-heated spaces, because shading windows in these spaces will not reduce energy use. The ASHRAE/IESNA standard also provides SHGC multipliers that can be used to adjust the SHGC requirements for windows with projection factors from 0.10 to 1.00.

Table 5.7 compares the window SHGC requirements for the five Arizona locations and the various WWR conditions. The requirements pertain to projection factors less than 0.25 (i.e., little or no shading from the building structure or awnings).

Energy Efficiency Impact: For nonresidential and residential buildings, the IECC 2003 SHGC requirements are considerably less stringent than those in Standard 90.1-2001, which will result in higher solar heat gains and increased cooling loads for buildings built under the IECC. This is particularly the case for the hotter climate areas represented by Phoenix and Tucson. For semi-heated buildings, the IECC is more “stringent” in that it has an SHGC requirement, however there is no energy benefit to requiring a low SHGC on a building without a cooling system, and in fact the lower SHGC may result in greater heating energy use for these buildings. For this reason it does not make sense to apply these SHGC requirements to these buildings unless they provide for greater occupant comfort. Overall, the lower SHGC requirements in 90.1 for the residential and nonresidential spaces will result in reduced cooling energy use under that standard as compared to the 2003 IECC. They may result in a slight increase in heating energy use also.

Table 5.7 *Comparison of Window Solar Heat Gain Criteria (SHGC)*

				International Energy Conservation Code					ASHRAE				
	Climate Zone	*Climate Zone*		2003 *Window-Wall Ratio (%)*				2004S	90.1-2001/90.1-2004 *Window-Wall Ratio (%)*				
Location	IECC 2003	IECC 2004S	Building Type	0-10	10-25	25-40	40-50	< 40	0-10	10-20	20-30	30-40	40-50
Phoenix	3C	2	*Nonresidential*	NR	0.50	0.40	0.40	0.40	0.25	0.25	0.25	0.25	0.17
			Residential						0.39	0.25	0.25	0.25	0.17
			Semi-heated						NR	NR	NR	NR	NR
Tucson	4B	2	*Nonresidential*	NR	0.60	0.40	0.40	0.40	0.39/0.25	0.25	0.25	0.25	0.17
			Residential						0.61/0.39	0.44/0.25	0.44/0.25	0.4/0.25	0.29/0.17
			Semi-heated						NR	NR	NR	NR	NR
L. Havasu	7B	3	*Nonresidential*	NR	0.50	0.40	0.30	0.40	0.39	0.39/0.25	0.39/0.25	0.39/0.25	0.27/0.19
			Residential						0.39	0.39	0.39/0.25	0.39/0.25	0.26/0.19
			Semi-heated						NR	NR	NR	NR	NR
Prescott	10B	4	*Nonresidential*	NR	0.50	0.40	0.30	0.40	0.49/0.39	0.39	0.39	0.39	0.26/0.25
			Residential						0.49/0.39	0.39	0.39	0.39	0.26/0.25
			Semi-heated						NR	NR	NR	NR	NR
Flagstaff	14A	5	*Nonresidential*	NR	0.50	0.40	0.40	0.40	0.49	0.49/0.39	0.49/0.39	0.49/0.39	0.36/0.26
			Residential						0.49	0.49	0.49	0.49	0.36
			Semi-heated						NR	NR	NR	NR	NR

The difference between the IECC and ASHRAE/IESNA 90.1 narrows with the publication of the 2004 IECC supplement. In this latest version of the IECC, buildings with small fenestration area (< 10% WWR) are required to meet the SHGC requirements. While the ASHRAE/IESNA standard is still more stringent in the two warmest climate zones (Phoenix, Tucson, and Lake Havasu), the requirements are essentially the same in the colder areas of the state.

5.12 Doors

Section 802.2.2 of the IECC 2003 states that "nonglazed doors shall meet the applicable requirements for windows and glazed doors and be considered as part of the gross area of above grade walls that are part of the building envelope". This statement is not terribly clear, but it may be interpreted to mean that the U-factor of non-glazed doors must be no greater than the U-factor requirement for windows, and in addition, the area of non-glazed doors is to be counted in the opaque wall area when determining window area percentage (WWR). It does not mean that doors are to be insulated to the levels of opaque walls.

Glazed doors are to meet the window U-factor and SHGC requirements. If the doors have less than 50% glazing area, the actual glazed area is used in determining the glazed area of the door and the WWR for the building. If the doors have 50% or greater glazing area, the entire door area is counted as the glazed area for the building.

Standard 90.1 contains explicit requirements for both swinging and non-swinging doors (e.g. rollup doors), with requirements ranging across the nation from a U-factor of 0.5 (for both types in cold climates) to 0.7 for swinging doors and 1.45 for non-swinging doors of both types. Glass doors that are more than one-half glass are considered to be equivalent to vertical fenestration and need to meet vertical glazing U-value and SHGC requirements only. It is assumed that the SHGC applies to the glazed portion only.

Table 5.8 shows door requirements for the IECC 2003, IECC 2004S, ASHRAE/IESNA Standards 90.1-2001 and 90.1-2004 for the selected Arizona locations. As with other envelope components, the IECC 2004S dropped any relationship between stringency of the U-factor and the window-wall ratio. As the table shows, the latest IECC requirements for commercial buildings are identical to 90.1 for all locations in Arizona. In only one instance, did the recent revision in the climate zones lead to any change in the ASHRAE/IESNA 90.1 requirements for doors—an increase in stringency in non-swinging doors in residential buildings for the climate represented by Lake Havasu (few doors of this type are installed in residential buildings.)

Table 5.8 *Comparison of thermal transmittance for opaque doors (U-factors)*

				International Energy Conservation Code 2003				2004S	ASHRAE 90.1-2001/90.1-2004		
				Window-Wall Ratio (%)					*Non-residential (U-Factor)*	*Residential (U-Factor)*	*Semi-heated (U-Factor)*
Location	IECC 2003	IECC 2004S	Door Type	0-10	10-25	25-40	40-50	Any			
Phoenix	3C	2	Swinging	1.23	1.23	0.70	0.70	0.70	0.70	0.70	0.70
Tucson	4B	2	Swinging	1.23	1.23	0.70	0.70	0.70	0.70	0.70	0.70
L. Havasu	7B	3	Swinging	1.23	1.23	0.70	0.70	0.70	0.70	0.70	0.70
Prescott	10B	4	Swinging	1.23	0.60	0.50	0.50	0.70	0.70	0.70	0.70
Flagstaff	14A	5	Swinging	1.23	0.60	0.50	0.40	0.70	0.70	0.70	0.70
Phoenix	3C	2	Non-swinging	1.23	1.23	0.70	0.70	1.45	1.45	1.45	1.45
Tucson	4B	2	Non-swinging	1.23	1.23	0.70	0.70	1.45	1.45	1.45	1.45
L. Havasu	7B	3	Non-swinging	1.23	1.23	0.70	0.70	1.45	1.45	1.45/0.5	1.45
Prescott	10B	4	Non-swinging	1.23	0.60	0.50	0.50	1.45	1.45	0.50	1.45
Flagstaff	14A	5	Non-swinging	1.23	0.60	0.50	0.40	1.45	1.45	0.50	1.45

Energy Efficiency Impact: A glance at *Table* 5.8 suggests that for swinging doors, the IECC 2003 is less stringent for warm climates and more stringent for cold climates as compared to either 90.1-2001 or 90.1-2004. However, it is noted that a U-factor of 0.7 represents a typical uninsulated steel door, and the higher U-factors are representative of windows, but not commercial swinging doors. For this reason, the IECC 2003 is of equal stringency in warm climates and of greater stringency in cooler climates.

For non-swinging doors, the IECC 2003 is more stringent in almost all cases except in the case of non-swinging doors for residential spaces. The latter is not a common construction practice and is of limited relevance.

The publication of the 2004 Supplement has effectively eliminated any difference between the two codes in all Arizona locations. For residential buildings, the U-factor requirements under 90.1 are more stringent in areas outside the climate zone including Phoenix and Tucson (zone 2), but as noted above, such doors are not common in such buildings.

6 Lighting Requirements

6.1 Interior Lighting - Lighting Power Density

During 2001 and 2002, ASHRAE and IESNA, with support from the U.S. Department of Energy, undertook a major reexamination of the technical basis for the lighting power density requirements in nonresidential buildings. The prevailing set of lighting requirements at the time was defined in the ASHRAE/IESNA 90.1-1999 Standard, based upon the most recent research and expert judgment by lighting designers as of the mid-1990s. The reexamination prompted a complete revision of the lighting power density models incorporating new research and recently published (2000) light level recommendations form the IESNA. The overall result of the revision was substantial reduction of the Lighting Power Density (LPD) requirements (expressed in watts/sq. ft. of installed lighting fixtures) for nearly all building types. Because of the differences in the publication cycles of the IECC and ASHRAE, most of these more stringent requirements were first incorporated in the 2003 IECC. As a result of this particular circumstance, the alternative compliance path in the 2003 IECC—ASHRAE/IESNA 90.1-2001—can be achieved with the less stringent requirements first established in 90.1-1999 Standard and repeated in the 90.1-2001 Standard.

Both the IECC and ASHRAE/IESNA 90.1 have two methods by which compliance with LPD requirements can be achieved. The first is a straightforward comparison of the installed wattage per square foot for the entire building with the published requirements for the appropriate building type. ASHRAE/IESNA terms this method the "Building Area" method and the IECC terms it the "Entire building" method. (Commonly, this method is termed the "whole building" method, as it will be referred to below).

The second method is termed by ASHRAE/IESNA the "Space-by-space" method. The IECC refers to this method as the "Tenant area or portion of building method." In this method, both codes define LPDs for particular *spaces* that are commonly used in all buildings, such as lobby, restroom, hallway, etc. Other space types are more specific to particular types of buildings, such as laboratory, patient room, courtroom, exhibit space, etc. The area of each space type is multiplied by the LPD for that space and is summed across all the space types used in the building. This sum establishes the upper limit (or allowance) on the total lighting power for the building. This second method often allows more flexibility in the design process because the designer can call for an increase the lighting power in one or more spaces as long as it is offset by a reduction in other areas of the building, such that the total lighting power allowance is not exceeded.

The 2003 IECC code includes 25 specific "whole building" Lighting Power Density (LPD) values plus a LPD defined for "*other*" building types. It also contains 28 "tenant area" LPD values plus a defined LPD for "*other*" tenant area types.

Standard 90.1-2001 presents 31 specific "whole building" and approximately 90 "space type" LPD values. The IECC 2003 includes two building LPD values not specifically provided in the list of ASHRAE/IESNA whole building LPDs. These include *Grocery store* (listed separately from Retail sales) that Standard 90.1-2001 considers part of its *Retail* categories, and *Other*, a catch-all category not defined by 90.1. Standard 90.1-2001 provides LPDs for an additional 5 building types that are not included in the IECC building list. These include *Gymnasium, Manufacturing facility, Sports arena, Transportation, Workshop,* separate LPDs for *Court House* and *Town Hall*, and two additional *Dining* (Restaurant) building types. In general, the identification of more building types provides finer tuning of the lighting power to the needs of the space type, and may provide an easier to apply standard by reducing the amount of interpretation necessary for unlisted building types. However, this latter concern is partially avoided in the IECC by the presence of the "*other*" category, which provides a catch-all for buildings which don't fit into the identified categories.

For ASHRAE/IESNA, the lower lighting requirements from the ASHRAE/IESNA work during 2002 and 2003 were first published in the 2004 edition of ASHRAE/IESNA Standard 90.1. The building types remain essentially unchanged from the 90.1-2001, except that health care clinics have been separately identified from hospitals.

Table 6.1 presents all of the IECC 2003 whole (or “entire”) building LPD values and compares them with the ASHRAE/IESNA LPD values where there is a match. The whole building LPDs are the same for IECC 2003 and ASHRAE/IESNA 90.1-2004 for all of the building types where there is a direct match. In the case of the restaurant (dining) building type, the IECC presents one LPD value while ASHRAE/IESNA breaks out this category into three types of buildings. ASHRAE/IESNA also defines separate whole building LPDs for medical clinics and hospitals.

Table 6.2 compares the LPDs of the space types in the IECC and ASHRAE/IESNA. Where the definitions of the spaces are the same, the 2003 IECC and ASHRAE/IESNA 90.1-2004 values are identical (kitchen, hotel lobby, etc.). The major difference between the two codes under this compliance path is that ASHRAE/IESNA provides significantly greater detail in defining the various space types. For example, the medical and clinical care space type in the IECC is represented in ASHRAE/IESNA by 9 different values that reflect different types of hospital or clinic spaces that have different lighting requirements.

Table 6.1 *LPD Requirements Using Whole Building (Building Area) Method: IECC vs. ASHRAE/IESNA*

Building Type (IECC)	**IECC 2003 LPD (W/ft²)**	**Building Type (ASHRAE/IESNA)**	**ASHRAE/IESNA 90.1-2004 (W/ft²)**	**ASHRAE/IESNA 90.1-2001 (W/ft²)**
Automotive facility	0.9	Automotive facility	0.9	1.5
Convention center	1.2	Convention center	1.2	1.4
Courthouse/town hall	1.2	Courthouse Town hall	1.2 1.1	1.4 1.4
Dormitory	1.0	Dormitory	1.0	1.5
Exercise center	1.0	Exercise center	1.0	1.4
Grocery store	1.5	Not defined, pt. of retail	1.5	1.9
Gymnasium (playing surface)	NA (surface defined as space type, see T. 6.2)	Gymnasium	1.1	1.7
Hotel function	1.0	Hotel	1.0	1.7
Library	1.3	Library	1.3	1.5
Medical and clinical care	1.2	Hospital Health care - clinic	1.2 1.0	1.6
Motel	1.0	Motel	1.0	2.0
Multifamily	0.7	Multi-family	0.7	1.0
Museum	1.1	Museum	1.1	1.6
Office	1.0	Office	1.0	1.3
Parking garage	0.3	Parking garage	0.3	0.3
Penitentiary	1.0	Penitentiary	1.0	1.2
Police/fire station	1.0	Police/fire station	1.0	1.3
Post office	1.1	Post office	1.1	1.6
Religious worship	1.3	Religious worship	1.3	2.2
Restaurant	1.6	Dining: Bar Lounge/Leisure Dining: Cafeteria/Fast food Dining: Family	1.3 1.4 1.6	1.5 1.8 1.9
Retail sales, wholesale Showroom	1.5	Retail sales, wholesale Showroom		
School	1.2	School/University	1.2	1.5
Storage, industrial and commercial	0.8	Warehouse	0.8	1.2
Theaters – motion picture	1.2	Motion Picture Theater	1.2	1.6
Theaters – performance	1.6	Performing Arts Theater	1.6	1.5
Transportation	1.0	Transportation	1.0	1.2
Other	0.6	Not defined		
		Manufacturing facility	1.3	2.2
		Workshop	1.4	1.7

__Table 6.2__ IECC 2003 and ASHRAE/IESNA 90.1 LPD Requirements for Space-by-space Method

Building or Area Type (defined by IECC)	IECC 2003 Tenant Area or Portion of Building	ASHRAE/IESNA 90.1-2004 Space-by-Space	ASHRAE/IESNA 90.1-2001 Space-by-Space
Auditorium	1.6	Audience/Seating Area 0.9 (General) 0.4 (For Gymnasium) 0.3 (For Exercise center) NA (For Civil service buildings) 0.7 (For Convention center) 0.7 (For Penitentiary) 1.7 (For Religious buildings) 2.6 (For Performing arts theater) 1.2 (For Motion picture theater) 0.5 (For Transportation)	Audience/Seating Area NA (General) 0.5 For Gymnasium) 0.5 (For Exercise center) 1.6 (For Civil service buildings) 0.5 (For Convention center) 1.9 (For Penitentiary) 3.2 (For Religious buildings) 1.8 (For Performing arts theater) 1.3 (For Motion picture theater) 1.0 (For transportation)
Bank/financial institution	1.5	1.5	2.4
Classroom/lecture hall	1.4	1.4 (General) 1.3 (Penitentiary)	1.6 (General) 1.4 (Penitentiary)
Convention, conference or meeting center	1.3	1.3	1.5
Corridor, restroom, support area	0.9	0.5 (Corridor-general) 1.0 (Corridor- For Hospital) 0.5 (Corridor-For Manufacturing) 0.9 (Restrooms) 0.6 (Stairs)	0.7 (Corridor-general) 1.6 (Corridor-Hospital/Health) 0.5 (Corridor-Manufacturing) 1.0 (Restrooms) 0.6 (Stairs)
Dining	0.9	0.9 (General) 1.4 (Bar Lounge/Leisure) 2.1 (Family) 1.3 (For Penitentiary) 1.3 (For Hotel) 1.2 (For Motel)	1.4 (General) 1.2 (Bar Lounge/Leisure) 2.2 (Family) 1.4 (For Penitentiary) 1.0 (For Hotel) 1.2 (For Motel)
Exercise area	0.9	0.9	1.1
Exhibition hall	1.3	1.3 (Exhibit space-convention center)	3.3 (Exhibit space-convention center)
Grocery store	1.6	2.1	2.1
Gymnasium playing surface	1.4	1.4 (Gymnasium playing area) 0.9 (Exercise area)	1.4 (Gymnasium playing area) 0.9 (Exercise area)
Hotel function	1.3	1.1 (Hotel/motel guest rooms)	2.5 (Hotel/motel guest rooms)
Industrial work, < 20 ft ceiling height	1.2	1.2 (Low Bay [< 25 ft ceiling]) 2.1 (Detailed manufacturing) 1.2 (Equipment room) 0.5 (Control room) 1.9 (Workshop)	2.1 (General low bay) 6.2 (Detailed manufacturing) 0.8 (Equipment room) 0.5 (Control room) 2.5 (Workshop)
Industrial work, > 20 ft ceiling	1.7	1.7 (High Bay > 25 ft ceiling)	3.0 (General high bay)
Kitchen	1.2	1.2	2.2
Library	1.7	1.1 (Card File/Catalog) 1.7 (Book Stacks) 1.2 (Reading Area)	1.4 (Card File/Catalog) 1.9 (Book Stacks) 1.8 (Reading Area)
Lobby- -hotel	1.1	1.1	1.7
Lobby – other	1.3	1.1 (Lobby-general) 3.3 (Lobby-Performing Arts) 1.1 (Lobby-Motion Picture)	1.8 (Lobby-general) 1.2 (Lobby-Performing Arts) 0.8 (Lobby-Motion Picture)
Mall, arcade, or atrium	0.6	0.6 (Atrium - first 3 floors) 0.2 (Atrium – add’l floors) 1.7 (Mall Concourse)	1.3 (Atrium - first 3 floors) 0.2 (Atrium – add’l floors) 1.8 (Mall Concourse)

Building or Area Type (defined by IECC)	IECC 2003 Tenant Area or Portion of Building	ASHRAE/IESNA 90.1-2004 Space-by-Space	ASHRAE/IESNA 90.1-2001 Space-by-Space
Medical and clinical care	1.2	2.7 (Emergency) 0.8 (Recovery) 1.0 (Nurse Station) 1.5 (Exam/Treatment) 1.2 (Pharmacy) 0.7 (Patient Room) 2.2 (Operating Room) 0.6 (Nursery) 1.4 (Medical Supply) 0.9 (Physical Therapy) 0.4 (Radiology) 0.6 (Laundry – washing)	2.8 (Emergency) 2.6 (Recovery) 1.8 (Nurse Station) 1.6 (Exam/Treatment) 2.3 (Pharmacy) 1.2 (Patient Room) 7.6 (operating Room) 1.0 (Nursery) 3.0 (Medical Supply) 1.9 (Physical Therapy) 0.4 (Radiology)
Museum	1.0	1.0 (General Exhibition) 1.7 (Restoration)	1.6 (General Exhibition) 2.5 (Restoration)
Office	1.1	1.1 (Office-Enclosed) 1.1 (Office-Open plan)	1.5 (Office-Enclosed) 1.3 (Office-Open plan)
Religious worship	2.4	2.4 (Worship/Pulpit/Choir) 0.9 (Fellowship Hall)	5.2 (Worship/Pulpit/Choir) 2.3 (Fellowship Hall)
Restaurant	0.9	1.2 (Dining -Bar Lounge) 1.4 (Dining -Cafeteria/Fast) 2.2 (Dining Area-Family)	1.2 (Dining -Bar Lounge) 1.4 (Dining -Cafeteria/Fast) 2.2 (Dining Area-Family)
Retail sales, wholesale showroom	1.7	1.7	2.1
Storage, industrial and commercial	0.8	1.4 (Fine Material Warehouse) 0.9 (Med/Bulk Warehouse) 0.8 (Active storage-general) 0.9 (Active storage-hospital) 0.3 (Inactive storage-general) 0.8 (Inactive storage-museum)	1.6 (Fine Material Warehouse) 1.1 (Med/Bulk Warehouse)
Transportation	NA	0.6 (Airport – concourse) 1.0 (Any—baggage area) 1.5 (Ticket counter)	0.7 (Airport – concourse) 1.3 (Any—baggage area) 1.8 (Ticket counter)
Other	1.0	NA	NA

Exemptions: The IECC 2003 code presents a shorter list of exceptions (lighting that does not have to be included in the UPD compliance) than the ASHRAE/IESNA 90.1 standard (both 2001 and 2004). Both standards exempt accent/display lighting for art/gallery/museum/monument displays, medical/dental procedure lighting, professional televised sport lighting, emergency lighting, and lighting in living units. The IECC 2003 (and 2004S) exempts professional sports arena playing field lighting.

Standard 90.1 further exempts lighting that is an integral part of equipment as installed by the manufacturer, lighting in refrigerator and freezer cases, lighting for food warming and plant growth, lighting for spaces designed for the visually impaired, lighting in enclosed retail display windows, advertising signage lighting, exit signs, theatrical and performance production lighting, lighting for sale or for educational displays, and casino gaming area lighting. Standard 90.1 clearly exempts a longer list of specific lighting that is commonly not considered when addressing building space lighting. All of the exemptions in ASHRAE/IESNA must be controlled by an independent *control device*. The longer list of exemptions in ASHRAE/IESNA suggests a potentially less restrictive stance than that in the IECC. However, many of these additional exemptions relate to items that would not normally be included during compliance calculation because their existence in the space would often be unknown at the time of compliance. This includes lighting that is an integral part of equipment as installed by the manufacturer, lighting in refrigerator and freezer cases, lighting for food warming and plant growth, advertising signage lighting, and lighting for sale or for educational displays. Of the remaining additional ASHRAE/IESNA exemptions, theatrical and performance production lighting, and casino gaming area lighting may also not be undefined at the time of compliance. The inclusion of more specific and potentially unusual lighting items in the list of exemptions provides for a standard that is easier to enforce by eliminating potential undefined situations.

Energy efficiency impact: The new LPD requirements in the 2003 IECC, the 2004 IECC Supplement, and in ASHRAE/IESNA 90.1-2004 are significantly lower than previous codes (IECC 2000, IECC 2001, and ASHRAE/IESNA 90.1-2001). The major issue is that an unmodified adoption of the 2003 IECC or the 2004 IECC Supplement may provide a less stringent compliance alternative for lighting via a choice of ASHRAE/IESNA 90.1-2001 as the reference standard (See Table 2.1). A jurisdiction seeking to close this loophole would need to either adopt ASHRAE/IESNA addenda “g” and “ag” to 90.1-2001 (which modify LPD tables 9.3.1.1 and 9.3.1.2) or change the reference to ASHRAE/IESNA 90.1 in the IECC to explicitly identify 90.1-2004. Without these changes, adoption of the 2003 IECC may not achieve the potential energy savings implicit in the most recent codes.

If such amendments are adopted for the 2003 IECC, there is expected to be little difference in the energy impact from the choice of either IECC or ASHRAE/IESNA 90.1 as a compliance path for lighting. As shown in Table 6.1, the lighting requirements between the IECC and ASHRAE/IESNA are virtually identical, with the exception of a few more detailed building types in ASHRAE/IESNA.   The space type LPDs are very similar; differences in stringency between the IECC and ASHRAE/IESNA could vary for specific buildings using the space-by-space compliance path, but on balance such differences are judged to be small.

The difference in exemptions could affect application of the code/standard and resulting energy use. However, it is not possible without additional data regarding the prevalence of the exempted building components to determine the net energy impact of the differences in exceptions. For the most part, the allowed lighting power densities should be considered equivalent between the most recent versions of the IECC and Standard 90.1.

6.2 Lighting Controls

Both the IECC 2003 and Standard 90.1-2001 require manual or automatic controls for individual spaces and include additional requirements for whole building lighting shutoff control in buildings larger than 5,000 square feet.   The IECC 2003 code includes an additional provision for bi-level switching. None of these provisions , however, need to be followed if occupant-sensing controls are in place.   Both standards exempt from these control requirements lighting intended for 24 hour use such as security lighting. Exemptions from the bi-level switching requirement in the IECC 2003 standard include: 1) areas that have only one luminaire, 2) particular spaces including corridors, storerooms, restrooms, and public lobbies, and 3) spaces with less than 0.6 Watts per square foot of installed lighting.

Energy efficiency impact: It is clear that there is potential energy savings from both bi-level switching and automatic whole building lighting shutoff controls. However, both of these systems depend at some point on human intervention, either for direct lighting controls (as with bi-level switching), or for setting of the automatic shutoff control. Without a careful metering study for a large number of buildings, there is no clear method of quantifying these savings at this date.

6.3 Additional Lighting Power Allowances

The IECC 2003 allows additional power allowances for specific spaces and activities through footnotes to the LPD table. Standard 90.1-2001 includes a text section with references to specifically marked space types in the LPD tables. The levels provided for these additional lighting power allowances are the same for both documents. The current interpretations and proposed addenda language to 90.1-2001 make the interpretation of how these allowances can be applied within spaces types essentially the same. The IECC 2003 code does add one additional allowance for emergency, recovery, pharmacy, and medical supply spaces that is not included in Standard 90.1-2001. A distinction between the two documents is that the IECC 2003 footnoted allowances are restricted to specific space types whereas the allowances in the 90.1-2001 standard can apply in any space type where the allowance is applicable. Both IECC 2003 and 90.1-2001 restrict the application of the additional allowances to the space by space compliance method. These additional lighting power allowances remain unchanged in the most recent (2004) versions of the IECC and 90.1.

Energy efficiency impact: The intent of both of these additional allowances systems is the same – to provide for additional lighting where needed. The specific building and space types to which the allowances may apply are different between the two codes and the IECC code includes one additional allowance. These factors make it difficult to quantify any potential energy difference in actual application, however, it appears that the additional lighting power allowances are essentially equivalent between the two codes.

6.4 Exterior Lighting

The 2003 IECC (and the 2004 Supplement) places a minimum requirement of 45 lumens per watt for exterior lighting equipment with exceptions for low voltage landscape lighting and safety/historical concerns. Standard 90.1-2001 (and 90.1-2004) provides LPD limits for lighting associated with the building and its immediate surroundings (building entrance, exit and facades) and specifies a minimum of 60 lumens per watt efficacy to all remaining grounds and parking area lighting.

Energy Efficiency Impact: It is possible that the setting of LPD limits can have a greater stringency than a simple efficiency requirement. However, there is little evidence to show this is in fact the case. A lighting efficacy requirement coupled with a builder’s own desire to reduce fixture costs may provide the most effective means of reducing energy use. The 45 lumens per watt requirement in the IECC eliminates the use of any incandescent lighting, with the potential for a substantial reduction in lighting energy use. The ASHRAE/IESNA requirement of 60 lumens per watt for grounds and parking lighting serves to eliminate both incandescent and low efficiency compact fluorescents, perhaps providing some greater stringency than the IECC for these areas. The IECC 2003 provisions should be simpler to apply because no wattage count or area calculation is required – only verification of efficacy.

6.5 Lighting Fixtures

The IECC has several requirements that attempt to match wattage of installed lights with the labeled wattage for each appropriate luminaire. Standard 90.1 has similar requirements to match wattage of installed lamps with the labeled wattage of the luminaire. Both also require the use of tandem wired ballasts where luminaires with odd numbers of lamps and low-frequency ballasts are to be used.

7 Conclusions

The previous sections in this report describe the major differences in the envelope and lighting requirements between the IECC 2003/2004 codes and Standard 90.1-2001 and 90.1-2004 across representative locations in Arizona. The biggest single difference pertains to the building envelope, with the IECC 2003 version having a strong variation in envelope thermal transmittance and fenestration requirements as a function of window-wall-ratio (WWR). Standard 90.1-2001 fenestration U-factor requirements show a very weak variation with window-wall-ratio, and SHGC requirements show somewhat more variation. However all other roof, wall, and floor thermal transmittance requirements do not vary with the WWR.

A large portion of this difference between the IECC and 90.1 was eliminated with the publication of the IECC 2004 Supplement, where the dependence upon the WWR was dropped for opaque envelope components. However, the IECC also dropped any dependence of *fenestration* requirements upon the WWR, thus creating some difference between the latest versions of the codes, as 90.1-2004 continues to set fenestration requirements by WWR.

The requirements in ASHRAE/IESNA Standard 90.1 vary depending on the several types of buildings; most notable are the weak stringency levels of the building envelope requirements for semi-heated buildings. While the relative stringency of the IECC and 90.1-2001 building envelopes for most nonresidential buildings will depend strongly on the window-wall-ratio, it is clear that the semi-heated requirements represents a drop in stringency in ASHRAE/IESNA as compared to IECC. It is noted here that in many cases, the higher stringency of component requirements in the IECC for semi-heated buildings are likely not cost-justified for many buildings and in the case of the IECC SHGC requirements, may actually be detrimental to energy efficiency.

The lighting power densities differ significantly between the IECC 2003 (and 2004 S) and the older ASHRAE/IESNA 90.1-2001 standard, because the IECC editions both incorporate major reduction in the allowable power densities generated by the 2002-2003 ASHRAE/IESNA research. This difference is essentially eliminated in ASHRAE/IESNA Standard 90.1-2004. For the most part, the allowed lighting power densities should be considered equivalent between IECC 2003, IECC 2004S and Standard 90.1-2004.

Table 7.1 presents a qualitative assessment of the differences between the two codes for the major envelope and lighting requirements. The first two columns compare the IECC 2003 and 90.1-2001 for the two general climate areas in Arizona. The “hot” climate is typical of the

Phoenix and Tucson metropolitan areas (revised climate zone 2). The "cold" climate is represented by Prescott and Flagstaff (revised climate zones 4 and 5). In general, the question of which code is overall more stringent is not readily apparent by a glance at these columns. The major difference is in the lighting area, only because the IECC 2003 was the first published code to include the more stringent LPD requirements, but references 90.1-2001 as an alternative compliance path.

The two codes have clearly become more congruent in their most recent versions (2004S and 90.1-2004), as evidenced by the last two columns in the tables. This is due to both the IECC dropping the dependence of requirements on the WWR as well as the use of the same mapping for climate zones. For the hot climate zone (Phoenix, Tucson), the requirements for opaque envelope components under the two codes are essentially the same. The major difference now pertains to the SHGC requirements. The IECC requires an SHGC of 0.40 for glazing, while 90.1 calls for an SHGC of 0.25 in buildings up to 40% WWR and 0.17 in buildings with more than 40% WWR. This difference may have a large influence on cooling requirements. A comparison of the cost-effectiveness of these requirements in typical types of commercial building has not been performed.

In the colder areas of Arizona, the difference between the codes is more dependent upon the specific choice of floor and wall construction. Required roof insulation levels (for insulation above deck) are slightly greater under the IECC. With regard to windows, the U-factor requirements under the IECC are more stringent than those in 90.1, but the SHGC requirements are about the same. On balance, it appears that energy use would be about the same, regardless of which code (or compliance path) is chosen.

Table 7.1 *Summary Comparison: IECC vs. ASHRAE/IESNA 90.1 for Hot and Cold Climates in Arizona*

Envelope component	**IECC 2003 : 90.1-2001 (Hot)**	**IECC 2003 : 90.1-2001 (Cold)**	**IECC 2004S : 90.1-2004 (Hot)**	**IECC 2003 : 90.1-2004 (Cold)**
Slab Insulation	No difference (NR)	No difference (NR)	No difference (NR)	No difference (NR)
Mass floor over unconditioned space.	IECC less stringent	IECC more stringent	IECC more stringent	IECC more stringent
Joist floor over unconditioned space.	IECC less stringent	IECC more stringent	No difference	IECC less stringent
Mass Wall	IECC more stringent	IECC less stringent	No difference (NR)	IECC more stringent
Frame Wall (steel or wood)	IECC less stringent	IECC less stringent	No difference	IECC less stringent
Roof (Insulation above deck)	IECC more stringent	IECC more stringent	No difference	IECC more stringent
Door – swinging	IECC less stringent	Small difference	No difference	No difference
Window – U	IECC more stringent	IECC more stringent	IECC more stringent	IECC more stringent
Window – SHGC	IECC less stringent	Small difference	IECC less stringent	Small difference
Skylight – U	IECC more stringent	IECC more stringent	IECC more stringent	IECC more stringent
Skylight – SHGC	IECC less stringent	IECC less stringent	IECC less stringent	Small difference
Lighting Power Density	IECC more stringent (20 – 30%)	IECC more stringent (20 – 30%)	Small difference	Small difference
Exterior Lighting	Small difference	Small difference	Small difference	Small difference

Note: NR = No Requirement

8 References:

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and Illuminating Engineering Society of North America (IESNA). 2001. *ASHRAE Standard: Energy Standard for Buildings Except Low-Rise Residential Buildings.* ASHRAE/IESNA Standard 90.1-2001, Atlanta, GA.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) and Illuminating Engineering Society of North America (IESNA). 2004. *ASHRAE Standard: Energy Standard for Buildings Except Low-Rise Residential Buildings.* ASHRAE/IESNA Standard 90.1-2004, Atlanta, GA.

International Code Council. 2003. *International Energy Conservation Code 2003*. Country Club Hills, IL.

International Code Council. 2004. *International Energy Conservation Code 2004 Supplement*. Country Club Hills, IL.