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Energy Performance Evaluation of AAC

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ENERGY PERFORMANCE EVALUATION OF AAC

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A DISSERTATION

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ENERGY PERFORMANCE EVALUATION OF AAC

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ABSTRACT

The U.S. building industry constitutes the largest consumer of energy (i.e., electricity, natural gas, petroleum) in the world. The building sector uses almost 41percent of the primary energy and approximately 72percent of the available electricity in the United States. As global energy-generating resources are being depleted at exponential rates, the amount of energy consumed and wasted cannot be ignored. Professionals concerned about the environment have placed a high priority on finding solutions that reduce energy consumption while maintaining occupant comfort. Sustainable design and the judicious combination of building materials comprise one solution to this problem.

A future including sustainable energy may result from using energy simulation software to accurately estimate energy consumption and from applying building materials that achieve the potential results derived through simulation analysis. Energy-modeling tools assist professionals with making informed decisions about energy performance during the early planning phases of a design project, such as determining the most advantageous combination of building materials, choosing mechanical systems, and determining building orientation on the site. By implementing energy simulation software to estimate the effect of these factors on the energy consumption of a building, designers can make adjustments to their designs during the design phase when the effect on cost is minimal.

The primary objective of this research consisted of identifying a method with which to properly select energy-efficient building materials and involved evaluating the potential of these materials to earn LEED credits when properly applied to a structure. In addition, this objective included establishing a framework that provides suggestions for improvements to currently available simulation software that enhance the viability of the estimates concerning energy efficiency and the achievements of LEED credits. The primary objective was accomplished by using conducting several simulation models to determine the relative energy efficiency of wood-framed, metal-framed, and Aerated Autoclaved Concrete (AAC) wall structures for both commercial and residential buildings.

Keywords: Energy-efficiency, Energy Modeling, Energy Modeling Tools, AAC, Thermal Mass, LEED Optimize Energy Performance credit.

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LIST OF ABBREVIATIONS

AAC	autoclaved aerated concrete
AACPA	Autoclaved Aerated Concrete Products Association
AHS	American Housing Survey
AIA	American Institution Architect
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BBP	baseline building performance
BLAST	Building Loads Analysis and System Thermodynamics
BLCC	building life cycle cost
BPT	balance point temperature
CADD	Computer Aided Design and Drafting
CMU Block	concrete masonry unit block
CO2	carbon dioxide
3D image	three dimension image
DOE	US Department of Energy
DXF	drawing exchange format
EA	energy atmosphere
EASE	Education of Architects on Solar Energy
EDR	Energy Design Resources
EIA	Energy Information Administration

EPA	Environmental Protection Agency
EPBD	European Energy Performance of Building Directive
FEDS	the Federal Energy Decision System
FRESA	Federal Renewable Energy Screening Assistant
FSEC	Florida Solar Energy Center
HAP	Hourly Analysis Program
HTM	high thermal mass
HVAC	Heating, Ventilation, Air Conditioning
ICF	insulated concrete form
IECC	International Energy Conservation Code
IES	Integrated Environmental Solution
IESNA	Illuminating Engineering Society of North America
IPCC	Intergovernmental Panel on Climate Change
IPD	integrated project delivery
LBNL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Environmental Design
MNECC	Model National Energy Code of Canada
NBS	National Bureau of Statistics
NBSLD	National Bureau of Standards Load Determination
NC	new construction
NEED	National Energy Education Development
OPEC	Organization of Petroleum Exporting Countries

PBP	proposed building performance
PCA	Portland Cement Association
R-value	thermal resistant- value
SBIC	Sustainable Buildings Industry Council
SIP	structural insulated panel
U-factor	overall heat transfer coefficient- factor
USGBC	United States Green Building Council
USGSA	General Services Administration
VAV	variable air volume
WBDG	Whole Building Design Guide
WGBC	World Green Building Council

1. INTRODUCTION

2.1. Environmental Impact of Buildings

The U.S. building industry constitutes the largest consumer of energy (i.e., electricity, natural gas, petroleum) in the world. Residential and commercial buildings have different functions but use energy in a similar way, with respect to heating and cooling needs, lighting, heating of water, and operation of appliances. Together, homes and commercial buildings use more than one third of the energy consumed in the United States (NEED, 2011).

Green professionals have both the responsibility and the opportunity of including energy-efficient methods in their design. Because buildings have a long life cycle of 15 or more years, it is important to properly design them to prevent errors that might pose a lasting burden on society over their lifetime (Lechner, 2009). In contrast to buildings, automobiles, used for approximately 10 years, more frequently evaluated and improved, thus enabling the more rapid detection and correction of design flaws.

The building industry directly and indirectly impacts the environment in several ways. Buildings connect human beings with the past and will represent them in the future (Prowler *et. al*. 2008). They provide shelter, support productivity, symbolize culture, and play an essential role in human life on the planet. However, the role of buildings constantly changes. Currently, buildings house life support systems, communication centers, data terminals, places of education, centers of justice, communities of faith, and much more. Also, buildings and structural developments provide numerous benefits to society, such as employment. Nationally, the building sector typically provides 5 to 10 percent of employment and normally generates 5 to 15 percent of the Gross Domestic Product (UNEP, 2009). However, according to the U.S. Energy Information Administration (EIA), because buildings consume a significant portion of energy, they are responsible for the significant amounts of the greenhouse gas emissions released during the generation of energy at utility plants (US EPA, 2009).

In 2009, commercial and residential buildings consumed almost 41percent of the primary energy and approximately 72percent of the total electricity produced in the United States (NEED, 2011). Figure 1-1 provides a summary of energy consumption in the United Sates.

Electricity consumption in the United States is anticipated to rise to 75 percent by 2025 (U.S. EPA, 2009). Energy consumed by the building sector continuously increases, with approximately 40 quadrillion Btu of energy consumed per year (U.S. DOE-EERE, 2008). One accepted theory posits that these growing energy consumption rates occur because new buildings are being constructed faster than old ones are retired. Currently, 114 million households and nearly 4.9 million commercial buildings consume more energy than both the transportation and industrial sectors in the United States (U.S. EPA, 2009). In 2005, the total amount spent on energy utility bills in the United States reaches $369 billion U.S. (U.S. DOE-EERE, 2008). Increasing population, building size, and economic growth are the primary factors contributing to elevated energy consumption. The 2000 U.S. Census counted 128 million residential units (Jonas, 2003). Approximately 7.2 million new housing units were built between 2005 and 2009, and 135 million housing currently exist units in the United States (U.S. EPA, 2009). As of November 2011, the total residential population in the United States was 313 million, making it the third most highly populated country in the world (U.S. Census Bureau, 2011); however the nation U.S. has a low population density, with an average household size of 2.3 people. In comparison, the world's most populous country, China, contained in 2011 1.37 billion people, with 402 million household units, for household size of 3.4 people (NBS, 2011).

In addition to consuming a significant amount of energy buildings in the United States emitted notable amounts of carbon dioxide. In 2008, approximately 38.9 percent of the nation’s total carbon dioxide emissions, 20.8 percent from the residential sector and 18.0 percent from the commercial sector, originated from buildings (U.S. EPA, 2009).

Energy consumption affects nearly every aspect of life. People need energy to heat, cool, and light their homes, as well as to cook and refrigerate their food. An average household spends $ 2,000 U.S. per year on energy bills, over half of which goes to heating and cooling needs (U.S. EPA, 2009). Energy costs constitute one of the highest house-related expenses and are exceeded by only the home mortgage. Improperly designed structures result in wasted energy, and wasted energy means wasted fossil fuel resources that are currently being depleted at a much faster rate and are difficult to extract and refine.

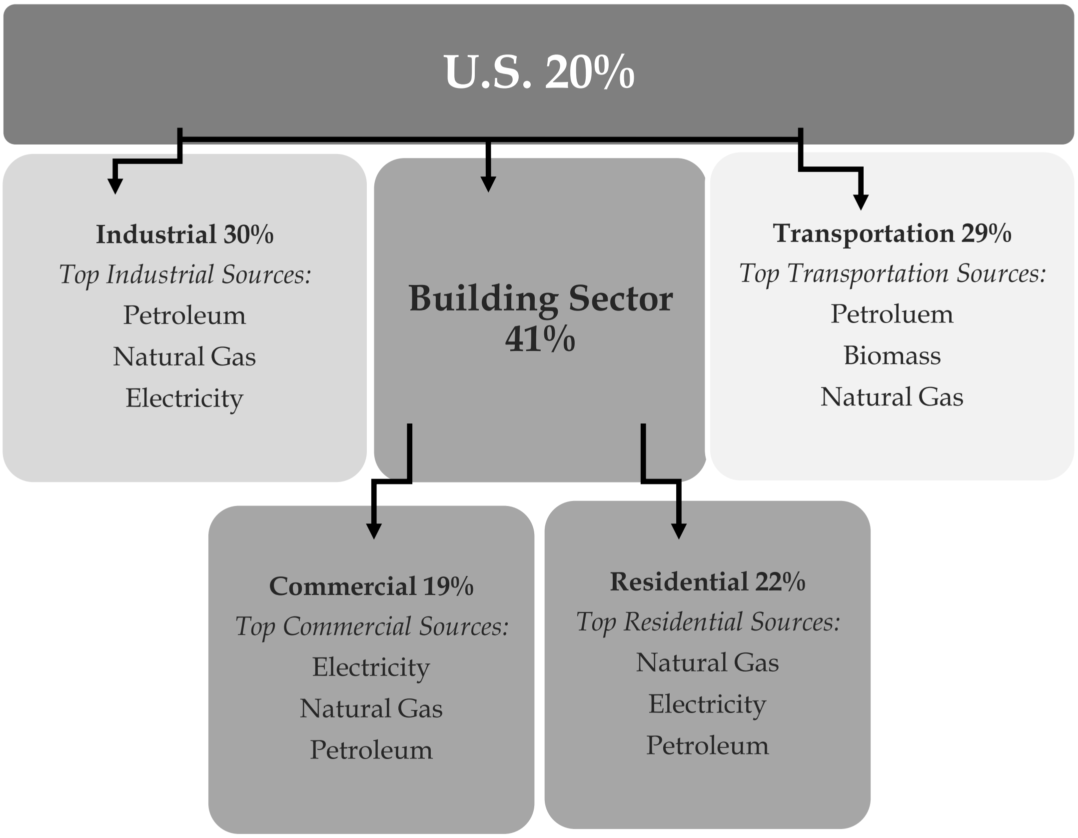


Figure 1-1U.S. energy consumption by sectors in 2009

The above figure is adapted from National Energy Education Development (NEED, 2011).

Analyzing the ways in which the average home consumes energy can help the designer identify means of saving costs on consumer's energy related utilities. Figure 1-2 provides a breakdown of the areas in which residential and commercial structures consume energy.

Reducing air leaks could cut as much as 10 percent from an average household's monthly energy bill (Allegheny Power, 2011). For example, research conducted by the U.S. Department of Energy (DOE) indicates that 31percent of energy consumed by residential structures escapes through the floor, ceiling, and walls (Melby & Cathcart, 2002). Figure 1-3 shows primary sources of heat loss occurring in a typical residential building. Thus, design professionals should consider efficient and cost-effective ways of reducing energy loss in these areas as a means of saving energy and reducing adverse environmental impacts. The option exist s for reducing emissions into the atmosphere—building fewer or building better, more energy-efficient structures.—Because, the increasing population results in increased demands for housing. Decreasing the demands is not one of the responsibilities to building design professions. In this result indicates that building energy-efficient structures are main focus for more sustainable solutions in building sectors.

Commercial

- Cooking 2%
- Computer 3%
- Refrigeration 4%
- Ventilation 6%
- Equipments 6%
- Water 7%
- Misc. 13%
- **Cooling 13%**
- **Heating 14%**
- Lights 26%

Residential

- Computer 1%
- Cooking 5%
- We Clean 5%
- Electronic 7%
- Refrigeration 8%
- Lights 11%
- Water heat 12%
- **Cooling 12%**
- **Heating 31%**

Figure 1-2 Commercial/residential building energy use

The above figure adapted from U.S. DOE Energy Efficiency and Renewable Energy (USDOE-EERE, 2008)

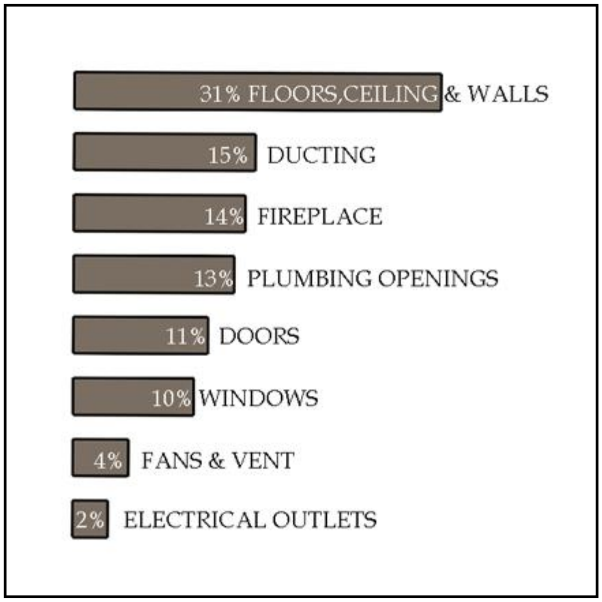


Figure 1-3 Primary sources of heat lost in a typical residential building

The above figure is adapted from US DOE-Energy Efficiency and Renewable Energy (US DOE-EERE, 2009)

2.2. Energy Consumption

The generation of energy from fossil fuels results in a devastating impact on natural ecosystems (USGBC, 2009b). Fossil fuel mining and oil production can cause and have caused irreparable damage to the environment. In the United States, most energy comes from nonrenewable energy sources such as petroleum, coal, and natural gas, which release carbon dioxide and other greenhouse gases into the atmosphere, further contributing to the greenhouse effect. Energy production not only exacerbates the emissions of greenhouse gases but contributes to global warming when energy is produced from these resources (darvill.clara.net, 2010). The negative impacts on environment and human health much effected in densely populated urban areas, where adverse environmental air quality accounts for approximately 500,000 deaths; in some developing countries poor air quality accounts for up to 5percent of the total deaths worldwide (Geller, 2003). Currently, fossil fuel energy resources and patterns of energy consumption result in unsustainable trends (Geller, 2003). These resources appear plentiful, inexpensive, and readily available; consumers make frequent use of energy without considering the means or consequences of its generation. It is estimated that the emissions from a power plant cause about 70 billion U.S. dollars' worth of harm to human health, which is equivalent to $ 0.045 U.S. per kilowatt-hour, or half the average retail electricity price (Geller, 2003). Burning fossil fuels is a major source of toxic chemicals known to be carcinogenic (Geller, 2003).

Although petroleum products used as gasoline, medicines, and fertilizers and have helped people all over the world, a trade-off exists (NEED, 2011). This trade-off consists of the fact that petroleum production, extraction, and consumption cause air and water pollution (Lechner, 2009).

Coal, another fossil fuel, formed from the remains of plants that lived and died millions of years ago, when parts of the earth were covered with massive, damp forests. Burning coal produces emissions that can pollute the air, including. It also produces carbon dioxide, the most commonly emitted greenhouse gas. When coal is burned, sulfur is also released; this element mixes with oxygen to form sulfur dioxide, a chemical that can affect the health of trees and water when it combines with moisture and produces acid rain (NEED, 2011).

Natural gas, also a fossil fuel, is trapped in pocket in underground rocks and is a mixture of gases. Methane is the main ingredient of natural gas and has no color, odor, or taste. Burning any fossil fuel, including natural gas, releases emissions such as carbon dioxide into the air. In comparison with coal and petroleum natural gas is the cleanest burning fossil fuel because, it releases much less sulfur, carbon dioxide, and ash when burned (NEED, 2011). Unfortunately, most of the obtainable gas has already been extracted from the ground. New resources come from wells as deep as 15,000 feet (4500 meters) and thereby making these supplies limited. Consequently, natural gas will in the future prove much more expensive to extract and, as a result, to consume (Lechner, 2009).

Although possessing 2 percent of the world's oil reserves, the United States consumes 25percent (Wright, 2005). This disparity leaves the nation vulnerable to fluctuations in the global oil market because it primarily depends on foreign exports to meet its demand. The Organization of Petroleum Exporting Countries (OPEC) cartel and unpredictable Persian Gulf countries hold approximately 80percent of the earth's oil reserves. Despite the potential consequences (i.e., price, shortage, and embargo), America must do business with these groups of nations in order to continue to meet its energy demands (Wright, 2005).

The amount of energy consumed by buildings remained largely ignored until the energy crisis of 1973, when leading members of OPEC suddenly increased prices and set up an embargo on oil exports to the United States. These actions resulted in energy shortages, which made Americans aware of their dependence on foreign energy sources. Green professionals began considering ways of potentially reducing energy consumption in the building sector ultimately lessening the nations' reliance on foreign energy imports (Lechner, 2009).

The unexpected collapse of Enron directly relates to the actions of these oil companies and to their effect on leaders in the government and on the world economy (Geller, 2003). The allocation and pursuit of energy resources worldwide affect global relationships and cause political discord among nations and has also provided a strong incentive for foreign powers to attempt to exert control over the oil exporter’s political, strategic, and energy policies (Pernick & O’Donnell, 2011).

The urge to control energy resources led to periodic conflicts, including two wars since 1991 and a constant U.S. military presence in Persian Gulf countries and their surrounding waters while attempting to maintain relationships with both OPEC and oil-importing nations (Geller, 2003). Energy dependence not only threatens national and international security but also damages the ecosystem (Holdren, 2007).

Conventional wisdom suggests that the Earth is so big that human beings cannot possibly significantly affect the operation of planet’s ecological system. This assumption may have been valid in the past; however, technologic innovations and trades have led to considerable grown in human consumption of energy and matching developmental planning with demography in an attempt to meet the increased demand has proved insufficient (Lechner, 2009). Concerning the environment is a worldwide phenomenon (McKinney and Scholoch, 1996); many scientists predict that carbon dioxide emissions and green house gases from human activities will raise global temperatures between 2.5^{o}F and10^{o}F over the 21st century (IPCC, 2011). The potential effects could be profound, including rising sea levels and frequent floods or droughts, and could lead to an increased spread of infectious diseases. Climate change and green-house gas emissions must be slowed or stopped. The solution will require dramatic advances in technology and a refocus on the ways in which the world economy generates and consumes energy. As concerns arise, designers are beginning to reevaluate their efforts regarding the energy consumption or buildings (darvill.clara.net, 2010). The collective approach has become known as green design or as sustainable design. In an intelligent debate, sustainable design is not an option but a necessity. The considerable impact of buildings have on the environment necessitates a shift toward a more sustainable design practice. Green buildings, one of the best strategies for meeting the challenge of climate alteration, create substantial reductions in energy consumption and carbon dioxide emissions (USGBC, 2009d).

2.3. Sustainable Design and Energy Efficiency

Building design professionals must enhance their concern for the natural environment, because the work they perform affects on ecosystems. Understanding a construction site and the impacts associated with building on it has been for several years a primary concern of green professionals (Emerald Architecture, 2008). The design and construction of buildings produce a significant impact to the environment. Because, traditional design results in adverse effects on the environmental and therefore sustainable architects are attempting to minimize the problems of the past and create a new path to follow for the future. Green buildings can reduce the amount of energy consumed over a long period and increase the quality of life while minimizing the global energy crisis.

Sustainable construction does not always require high-technology solutions; even low-technology solutions can make measureable differences. For example, installing automatic shading devices, constructing a natural ventilation system, using operable windows, and selecting energy-efficient materials provide significant energy-saving and climate-friendly technologies that can yield healthier, more comfortable, energy-efficient homes, buildings and communities. In the long term, sustainable design is not an option but a necessity. A sustainable energy future is possible through the use of energy-efficient materials and integrated green design solutions. Increased energy efficiency can potentially reduce increases in energy consumption, decrease capital investment requirements, and improve energy services for poorer households and nations.

Energy efficiency in buildings limits the adverse environmental consequences associated with energy generation, distribution, and consumption. Energy conservation and reducing utility bills are essential and require careful handling. In an integrated design process, finding a way to reduce energy consumption can be implemented in conjunction with thermal comfort and economics (USGBC, 2006).

2.4. Computer Simulation, Visual-DOE

Green professionals have begun to recognize the importance of energy efficiency on a global scale. The focus should involve the methods need to optimize the energy performance of buildings. Computer simulations models constitute one of the simplest and most reliable methods of evaluating energy performance and identifying cost-effective ways of conserving energy (Radhi, 2008).

Energy simulation software assists professionals in designing high-performance buildings that will operate with lower energy consumption. These tools help professionals make informed decisions about energy performance during the early design phases, (e.g., determining the right combination of materials, systems, and orientation) when sustainable building strategies and materials can be evaluated at a lower cost (SBIC, 2011).

Visual-DOE, one of several software tools available, is operated by the DOE-2E on an hourly simulation analysis that functions as the calculation engine. Visual-DOE requires minimal training and dramatically less time to build a functional model. Specifying the building's geometry by using standard block shapes and a built-in drawing tool or by importing DXF files provides qualifications more quickly than is possible with other comparable software. Visual-DOE is a viable tool for schematic design studies of the building envelope (US DOE, 2011c). The software has four major components: the Windows user interface, the building and HVAC database, the DOE-2 simulation engine, and simulation diagnostic and support tools. This powerful program quickly evaluates energy use, energy savings, and peak demand on an hourly basis of the building design options (Visual-DOE Manual, 2004).

Visual-DOE has been updated seven times, with the first version released in 1994 and the last update in Version 4 released in 2002. One of the newest features is the Leadership in Energy and Environmental Design (LEED) style end-use reports (Visual-DOE Manual, 2004). This feature can be used to assess energy performance and identify the most cost-effective energy efficiency measures for the LEED Green Building Rating System–Energy Atmosphere, Optimize Energy Performance credit. Energy performance is quantified and compared with a baseline building model that complies with ASHRAE/IESNA Standard 90.1-2007 (without amendments). To achieve the proposed credit, buildings and their systems need employ methods of conservation to increase the levels of energy performance above the baseline to reduce environmental and economic impacts associated with excessive energy use. The LEED, energy credit, calculation information is given in Section 4.2.1. The new feature LEED credit calculation ability, enable to determine on the amount of potential LEED points that a design can earn and is especially useful for analysis of building envelopes and HVAC design alternatives in Visual-DOE (US DOE-EERE, 2011c).

2.5. Autoclaved Aerated Concrete (AAC)

People faced with rising energy costs and emerging environmental consciousness are putting the building industry in the spotlight (Starr, n.d.). Building designers, developers, and owners are seeking efficient and innovative building solutions with which to conserve energy. One approach to improving future building performance involves the use of energy-efficient materials. Second only to durability and esthetics, energy efficiency constitutes one of the most important qualities to consider when choosing a building material. Gradually, concrete is being recognized for its environmental benefits as a creative and effective sustainable material. Greater durability, longer periods between maintenance, and longer life expectations all forms necessary parts of green design (Prokopy, 2008). In all aspects of the environmental impact of a building material over its lifetime, including extraction, production, construction, operation, demolition, and recycling, concrete proves an excellent candidate for consideration as a sustainable material. Researchers studying durable materials also look for energy-neutral products with reduced carbon footprint and reduced energy needs. According to a report from market research recently conducted by the Portland Cement Association (PCA), 77percent of design professionals agree that concrete can be a sustainable material, with a primary focus on AAC (Prokopy, 2008), which meets all of these sustainability needs (Hebel-Xella, 2009).

AAC a product of Hebel (a part of the Xella group), is made of natural materials, including Portland cement, lime, water, sand, gypsum, and aluminum paste. The dry materials are mixed with water to form slurry. Aluminum powder is added to the slurry, which reacts with the alkaline cement to form hydrogen gas. The hydrogen gas approximately triples the volume of the slurry, at this point commonly referred to as “cake”. The mixture is self-supporting after the initial set, which takes four to five hours; at this point, the molds are stripped, and the material is cut into the desired shapes with steel wires. The cut shapes are cured in an autoclave, which operates at approximately 320°F and at a pressure of 150 psi. The finished product cures in about 12 hours and, at 150 pcf weights approximately 20 to 30 percent the unit weight of regular structural concrete (Hebel-Xella, 2009).

Four times lighter than conventional block materials, AAC offers greater thermal insulation than traditional concrete masonry unit (CMU) block, provides. AAC has been used in Europe for several years and has recently been introduced into the American market (Hebel-Xella, 2009).

The use of AAC can help optimize energy performance and increase the life expectancy of a building. In this research study, Visual-DOE energy simulation software aided in the development of simulation models for AAC, traditional wood-framed, and metal-framed system, which were then compared for energy consumption. The study also involved estimating the thermal and economic benefits associated with the use of AAC in residential and commercial developments.

2.6. Problem Statements and Solution Approaches

"Lack of environmental wisdom is costly in many ways. It is costly to other species, to our quality of life, to future generations, and often to human happiness itself" (McKinney *et al.* , 1996).

AAC is considered a green building material in Europe, where the building industry has benefitted and continues to benefit from the energy-saving characteristics of this material. Little research has involved investigating the benefits of using AAC in the U.S. building industry. Previous research indicates that climate and location require consideration in the selection of a building material expected to reduce energy consumption, (Arizona State University, 2007; Coradini, E., 2009; Heathcote, 2007; Kaska & Yumrutas, 2008; Kosny, 2000; Matthys & Barnett, 2004; Memari, Grossenbacher, & Lulu, 2008; Qvaeschning & Klemm, 2006); therefore, because the climate of Europe differ from that of the United States it proves difficult to determine the same energy-savings benefits will be experienced with the use of AAC building material in the United States. A viable simulation software tool needs to accurately estimate the energy savings in different locations in order for designers to feel confident about specifying specific building materials for a project. In addition, LEED is becoming one of the most widely accepted sustainability assessment programs, and this software tool must enable designers determine way in which such material specification will allow them to earn LEED credits.

LEED green building rating systems is to measure the green performance of buildings and their impact on the environment and consist of into several categories. One evaluation category in the LEED system, the Energy and Atmosphere category, awards credits for buildings that reduce their energy consumption by a certain percentage. LEED evaluates a building as a whole instead of examining the individual components that make up that building. Previous research suggests that selecting appropriate building materials constitutes one of the most important decisions involved in achieving reducing energy consumption. LEED offers more points in the Energy and Atmosphere category than in the other categories available for achieving LEED certification. The LEED system evaluates a building with all of its components, whereas simulation software tools evaluate individual building components. The LEED process adversely affects manufacturers of individual building materials because, in the LEED evaluation process the benefits achieved from using, their products are not considered separately from those resulting from the other building material used. The software tools available today lack capabilities that will provide the confidence that designers need in order to recommend building materials that will meet the goals of reducing energy consumption, obtaining LEED credits, and maximizing building performance.

The simulation software currently available for assessing and analyzing building materials possesses several limitations that hinder its usefulness for designers seeking to specify a building material for a project. Software is required for developing green technology meeting energy criteria in the LEED rating system, via simulation tools during the design phase, when resulting cost are low. Some insufficient capabilities provided by these programs limit green building designers and require improvements to these programs that will yield viable estimations of a building material's energy performance.

The primary objective of this research involved identifying a method with which to properly select energy-efficient building materials. Approaches undertaken to achieve this goal included advance evaluation potentials to earn LEED credits when properly applied to a built structure, as well as while establishing a framework that provides suggestions for using currently available simulation software to enhance the viability of the estimates concerning energy efficiency and to achieve LEED credits.

The hypothesis that guided this research was that computer simulation modeling can be an accurate, useful tool for evaluating the capability of sustainable building to meet criteria of an established standard and has the ability to compare the energy consumption of emerging building materials. Proving hypothesis involved determining the viability of simulation software tools through analysis of different types of framed wall systems in different locations and by comparing these results to the baseline models supported by the minimum design standards suggested in by ASHRAE/IESNA Standard 90.1-2007. The three tasks included in determining a solution to this objective are discussed next.

The first task was to determine whether AAC would provide the same sustainable results in the United States that were experienced in Europe. To ascertain the energy-efficiency properties associated with AAC, I conducted a simulation analysis of the differences between building with traditional building methods and building with AAC. The analysis involved comparing the estimated energy costs of AAC used in the United States with those of a traditional building systems used in the same regions of the nation. To develop a method that includes the potential of earning LEED credits by using simulation software, I analyzed the framed and mass building systems to determine which system provides better energy-efficiency results. I evaluated each component of building system and identified energy-saving properties on each component. So application of LEED criteria in simulation software tools will allow manufacturers the opportunity to identify the areas in which they can improve the energy-saving characteristics of their building materials by estimating their energy performance based on LEED criteria. This collaboration between industry professionals and product manufacturers will create an opportunity to improve building materials that will meet and even exceed the energy-saving benefits as defined by LEED criteria. Identifying improvements that can be made to existing software tools will increase designer confidence in the analysis of these materials and in the estimated results reported for individual building materials. Evaluating commonly used software programs provides more factual data for designers and manufacturers so that, when these building materials are specified and applied in building designs, owners can expect these the same or even better results. Additionally, this research identified improvements needed to enable green building industry professionals to confidently suggest building materials that will reduce energy consumption.

2. LITERATURE REVIEW

2.7. Environmental Crises and LEED

According to the EIA, buildings constitute one of the largest consumers of natural and energy resources, because they contribute a significant portion of annual greenhouse gas emissions, which may influence climate change. In 2002, in the United States, buildings emitted approximately 38 percent of all carbon dioxide emissions and consumed 13 percent of potable water, 41 percent of total energy use, and 68 percent of electricity (U.S. EPA, 2009). Although these figures indicate that buildings significantly contribute to global climate change, such structures may also form part of the solution. Sustainable design seeks solutions to reduce and/or mitigate adverse impacts of buildings on the environment while increasing the health and comfort of building occupants by improving building performance. The basic objective of sustainability involves reducing consumption of nonrenewable sources; minimizing waste; and creating healthy, productive environments (U.S. GSA, 2008). Over the last 10 years, there has been in the U.S. market extensive growth and interest around green buildings and sustainable design principles. The United States Green Building Council (USGBC), the driving force behind this movement in America (McEnery, 2009). The council's program is the only program with a national scope that has been adopted by many private organizations, as well as by local and federal government agencies (McEnery, 2009).

Established in 1993, the USGBC is the nation’s leading non-profit organization working to advance sustainable design, construction, and operation of buildings and communities. The council developed and administers the LEED Green Building Rating System, which evaluates and measures the performance of building systems or communities and results in certification when standards are met (USGBC, 2011). The first LEED pilot program began in 1998 as Version 1.0. Because interest in LEED has increased, the rating system has been upgraded five times (current version, 3.0, adopted in April 2009) to include advantages of new technologies and progressions in building science, with a particular focus on energy efficiency and on reduction in carbon dioxide emissions from buildings (USGBC, 2011).

The USGBC has grown substantially since its founding in 1993. According to its 2008 annual summary report, the organization consists of 79 USGBC chapters representing nearly 18,000 organizational members and thousands of volunteers and includes an emerging World Green Building Council with 13 established councils (WBDG, 2011). A total of 31,000 buildings have been registered and certified, and more than 62,000 LEED Accredited Professionals who support the U.S. building industry as of August 2009 (USGBC, 2011).

The LEED rating system, an internationally recognized certification system, measures the performance of a building with respect to conservation of natural resources. USGBC’s focus on green building not only develops environmental opportunity but also supports the economy. According to the council, USGBC has announced that $ 554 billion projects contributed to the U.S. domestic product from 2009 to 2013; in addition, this revenue promises a sustainable future in energy savings through green building design methods. As the energy efficiency of buildings increases, energy consumption within the building sector potentially decreases by almost 85 percent (USGBC, 2011).

The USGBC regularly hosts visiting delegations comprising students, building professionals, government officials, and market analysts from numerous countries to discuss topics including the transformation of the building market in the United States and means through which these nations can initiate similar transformations in their own countries. The council also collaborates with several green building councils throughout the world, sharing information on achievements and failures within sustainable programs and on education. LEED has been adopted by the Canadian and Indian green building councils (GBC), with Italy and Brazil also discussing adopting the LEED program. USGBC will continue to engage with design communities, professional associations, and foreign governments to increase awareness of the concepts of sustainable design. According to McEnergy, LEED principles advocate global transformation, and USGBC will continue to focus on its capacity for development in the United States with the aforementioned principles and will continue to add more principles to meet these goals. It is apparent that the worldwide marketplace is making a connection with green buildings, sustainable design concepts, and healthier built environments (McEnery, 2009).

Larry Fisher, journalist and research director of Next-Gen Research, said, the construction industry has a big impact on the environment, so green building products are a key market within the global environmental movement. At the same time, buildings are one of the major consumers of natural resources and account for a significant portion of the greenhouse gas emissions that affect climate change. Fisher also believes that if people are forced to make a choice on which building materials to use, they are probably going toward the more environmentally responsible approach (Fisher, 2009).

Building material manufacturers benefit from staying abreast of changes within the building industry. As green building materials become more widely applied to buildings, building material manufacturers must continue research and development on more sustainable building materials. Manufacturer interest in LEED certification is increasing. Despite the facts that products and services do not directly earn projects credit points; and that the council administers and evaluates LEED certification for the building as a whole design strategy, individual materials do play a role and can help projects earn credits (USGBC, 2011). For this reason, product manufacturers want to know sustainable techniques so that they can evaluate their products in terms of the LEED rating system. This research project provides a methodology that will help manufacturers accomplish this evaluation.

Product manufacturers and service providers play an important role in advancing the USGBC mission of market transformation. Among the many product manufacturers, AAC manufacturers are particularly interested in participation in the green building industry, in increasing their involvement with LEED-accredited projects, and in learning ways in which their products can help advance green building methodologies. AAC, which offers environmentally friendly attributes with the potential of providing various advantages to building designs, may contribute to earning energy-efficiency credits within the LEED rating system. The following section contains more detailed information about AAC and research related to AAC energy efficiency.

2.8. AAC

AAC was first developed in 1923 at the Technical College in Stockholm, Sweden, after World War I. Sweden faced significant energy crises and was enduring an extreme shortage of wood as a result of deforestation, so the government desired a thermal insulation standard for building materials other than wood-framed structures (Matthys and Barnett, 2004). The Swedish architect Johan Axel Erikson designed a new building material by curing a mixture of slate, lime, and aluminum powder. The material, now known as autoclaved aerated concrete (AAC), was patented by Erikson in 1924. In 1928, Karl August Carlen first licensed and manufactured AAC under the name of Ytong. The first commercial production of AAC material began in 1930 (Aercrete-advantage LLC, 2009).

In 1943, Josef Hebel built the first AAC factory in Germany. The engineer Josef Vogele refined the production process in 1948, and the first international license was granted in the 1960s. The licensing agreement that Hebel concluded with Japan in 1966 formed the cornerstone for the successful export of Hebel technology to the growing industrial nations of Southeast Asia, (Aercrete-advantage LLC, 2009). In 1996, Hebel built the first U.S. plant for full production of AAC in Adel, Georgia; the plant closed in 2010 because of economic vondıtion in the nation.

Ytong and Hebel remained the two largest manufacturers of AAC throughout the 20th century. In 2002, Hebel and Ytong merged and now operate under the corporate umbrella of Xella, the world's largest AAC manufacturer. In 2009, Japan was one of the most important overseas markets, with an annual AAC production of more than 2 million cubic meters. In that year, AAC contributed to 80 percent of Japan's wall market for built infrastructure, 60 percent of the wall market in Germany, and 40 percent of that in the United Kingdom. During the same year, Xella reported sales of $ 1.8 billion in 2009, a 9.5 percent increase over 2008 production values (Aercrete-advantage LLC, 2009). The United States provides only a marginal fraction of the AAC wall market (Abbate, 2004).

Because of the relatively recent arrival of AAC in the United States, building industry professionals remain unfamiliar with its benefits and application. Some proponents believe that the reason that AAC is not more widely utilized is more procedural than scientific. Traditional building materials, including wood, masonry block, and metal, are typically incorporated within standard U.S. building codes (Coradini, 2009). Alternative materials, including AAC, may require additional review and, as a result, can introduce bias against their application within a construction project. According to a study conducted by Memari and Chusid (2003), the specification of AAC in design projects has remained significantly lower than the actual rate of development of the product. Although in part a result of the current downswing in the economy, this lack of increased use also reflects the slow pace and high cost of the manufacturing necessary to introducing a new building material into a different geographic market (Memari & Chusid, 2003).

As of 2005, four U.S. manufacturers and one Mexican distributor (Contec, based in Texas) supply AAC materials to the building industry. Hebel and Ytong established an AAC presence in the United States by building plants in the Southern region of the United States but were ultimately unsuccessful. They subsequently sold their plants to U.S. companies, which have continued to operate them. Ytong has become Aercon; operating in Florida; and Hebel has become Babb International, operating in Georgia. ACCO Aerated Concrete

System in Florida and E-crete in Arizona were built by the current owners (Scheffler & Colombo, 2005).

There are presently more than 300 AAC manufacturers around the world (Behrens, 2006). As AAC continues to increase in popularity for building applications in both the Middle East and China, ACC manufacturing will most likely increase globally. AAC products have been used worldwide in different climates, including cold regions such as northern Europe and northern Japan, hot and humid regions such as South America and the Far East, and hot and dry regions, such as Australia and the Middle East (Arizona State University, 2007). Therefore, AAC proves a versatile material that can provide several benefits to the building industry on a global basis.

In the environmentally-friendly manufacturing process, the ingredients used to produce AAC derive from widely available raw materials, including sand, Portland cement, lime, gypsum, and water combined with an expanding agent. Depending on the AAC formulation, the combination of these ingredients results in a finished product up to five times the volume of the raw materials. Because of its cellular structure and its 80 percent air content, AAC offers unique advantages, including fire protection, thermal conductivity, moisture-buffering capacity, and good acoustic performance (Qvaeschning & Klemm, 2006).

AAC has strong potential as a new green product because it can be effectively used and recycled and because the waste can be reused. In addition, this material is nontoxic, acoustic, and can be transported with less fuel because of its lower density (Coradini, 2009). Because AAC is produced in factories with a higher level of quality control than that associate with concrete poured in the field, the resulting products prove uniform; this uniformity provides added benefits to the construction industry. A 20-foot-wide by 2-foot-high panel increases the speed of construction because of its modular characteristics, and this property results in decreased labor costs. Like wood, AAC is an easily worked material that as can be cut, drilled, and nailed (Behrens, 2006). AAC has thermal properties that allow a building to consume less energy and, therefore, to increase its energy efficiency. The thermal insulating properties of this product also provide solid insulation without thermal bridging or cold spots. As a result, buildings using AAC tend to be cooler in the summer and warmer in the winter and often lead to lower utility bills because of the insulation benefits. Additionally, AAC is a virtually fire-resistant masonry material that can withstand a 2000 ^{0}F fire for four hours (Coradini, 2009).

2.8.1. AAC and Architecture

AAC, recognized as a green and sustainable product throughout the world, is used by building designers in residential, commercial, and industrial projects (Steel & Brock, 2009). For years, the unique attributes of AAC building systems (refer to Section 2.2) have been well-known facts in the architectural field. The material simplifies construction by minimizing the number of different building products involved in the building's envelope. AAC has been used in all types of climate conditions, as well as in earthquake and hurricane susceptible regions. Because of its structural integrity, energy efficiency, fire and termite resistance, low maintenance, acoustic quality, and various design opportunities, AAC is recognized as a viable architectural material (AerBlock, 2010). Besides having the aforementioned attributes, AAC also offers many benefits to architectural design, including those in the following list:

- AAC offers flexible design options and the opportunity for unlimited workability.
    - It can be sawn, drilled nailed and milled just like wood.
    - It can be cut with saws and rubbed to create rounded edges and arches in corner of the walls.
    - It can be easily adjusted in the field (Steel & Brock, 2009).
- AAC is manufactured in many form, including panels for exterior cladding, panels for use as firewalls and shafts, floor panels, roof panels, blocks for load-bearing walls, lintels, and blocks with cores for a reinforced application (Thompson, 2011).
- AAC blocks can be used in carve, signage, and graphics on the surface. This capability provides the opportunity to create a radius wall type (i.e., 45° walls) (Steel & Brock, 2009).
- AAC is durable; can be installed in interior and exterior applications; will not rot, warp, rust, corrode, or decompose; and has a long life cycle with a minimum amount of maintenance (Thompson, 2011).

- AAC is also more cost efficient (i.e., material cost $ 0.55/ft^2 and equipment and labor cost $ 0.25- $ 0.75/ft^2 less than traditional construction materials) when compared with a traditional frame system (Arizona State University, 2007). (See Appendix A for a more detailed comparison.)

2.9. AAC-Related Research

In a research study conducted in Gaziantep, Turkey, Kaska and Yumrutas (2008) compared experimental and theoretical results of heat gain among four wall systems commonly used in Turkey. This study analyzed briquette, brick, blockbims, and AAC wall systems. Each experimental model included two rooms, cooling units, measuring devices, and monitoring computers. The models were developed to measure transient temperature in the walls and flat roofs, and the results from the four systems were compared. To solve transient heat problems in walls and flat roofs, the investigators created theoretical (mathematical) models to perform calculations by estimating the solar radiation flux on the wall surface and the heat flow through structures. When compared the results of the theoretical and experimental models did not indicate a significant statistical difference. Results also indicated less heat gain through the exterior walls with the use of AAC and blockbims systems than with the use of brick and briquette systems (Kaska & Yumrutas, 2008).

In summer 2007, a research study conducted at the University of Technology, Sydney, Australia involved analyzing the performance of three building systems, including brick veneer, mud brick, and AAC (Heathcote, 2007). Heathcote base his research was on a prediction by the Admittance Procedure, a method developed by Loudon in 1970 for predicting summertime temperatures in buildings without air conditioning and used to predict peak temperatures in a building the basis of on repeated inputs of outside temperature. This method was chosen because it is a theoretical comparison that accommodates unconditional internal spaces and is relatively simple. The objective of the initial monitoring and evaluation consisted of providing a baseline performance of temperature controllability of these houses. A comparison of finding revealed the combined average and swing temperatures slightly lower in the model using AAC material (26.5ºC) and in the model with brick veneer (26.9ºC) than in the model with mud brick (27.6ºC). Heathcote (2007) concluded that the admittance method provides useful tool for gaining an understanding of the heat flows between the interior and exterior of a building.

In research study Matthys and Barnett results showed that because of its combination of high porosity and high thermal mass, AAC is one of the most energy-efficient building materials on the market. High thermal mass results in major cost savings for energy use for heating and cooling a building. Additionally, the investigators discovered that the properties of high porosity c and high thermal mass of AAC moderate the interior temperature of a home by significantly reducing the transmission of the exterior thermal conditions into the interior. The 6-hour time lag in the temperature flow rates between the outside and inside building walls allows the shifting of energy consumption to off-peak hours for an 8-inch-thick AAC wall.

Time lag is defined here as the delay of heat transfer between two surfaces, which allows the transfer of less heat during the day and the storage of heat in the wall, whence it will be released at night, when ambient air temperatures are cooler. Time lag offers several benefits, the primary one being that excess heat is not transferred into interior spaces during the day, when ambient air temperatures are highest; thus, buildings consume less energy by not having to maintain human comfort by coding with mechanical systems to compensate for the excess heat entering the space.

With AAC, delay in heat transfer provides more than the required thermal protection without additional insulation. A similar study was conducted by National Concrete Masonry Association. (Refer to Figure 2-1 for an illustration of thermal mass inertia of AAC, 2006). One side of a 10-inch AAC wall was painted black to maximize heat absorption from the sun and researchers used thermometer to measure temperature changes on the both exterior and interior surfaces over a 24-hour period. The exterior surface temperature increased more than 126°F, whereas the interior surface temperature increased only 3°F (SafeCrete AAC, 2006). This finding supports the reasoning that AAC provides the added benefits of energy conservation, because it limits the amount of thermal heat transferred from exterior surfaces into the interior space, thus acting as effective insulating material and allowing the specification of smaller HVAC units.

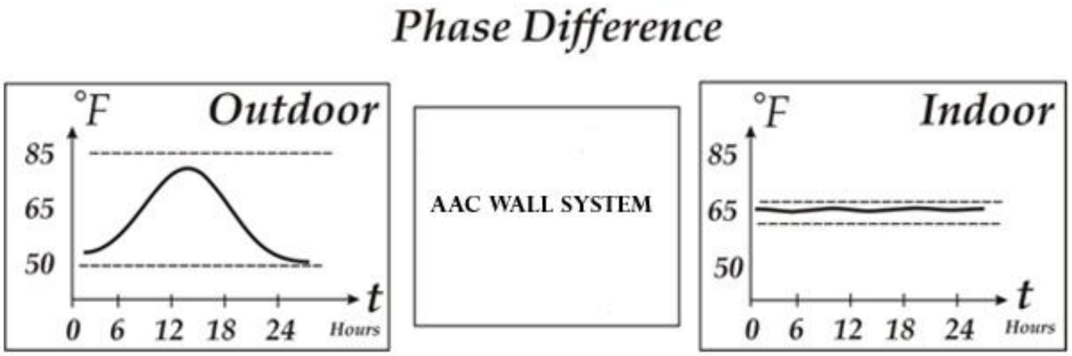


Figure 2-1 Thermal mass inertia of AAC.
The figure is adapted from SafeCrete AAC, 2006.

Although AAC use has proved successful outside of the United States application in the nation has been limited Matthys and Barnett (2004) indicated that AAC is not recognized in United States because of the lack of research data and because of nonexistent code provisions to encourage designers and contractors to specify and implement this product into their designs.

In 2008 Memari, Grossenbacher, and Lulu reported the results of their study of the structural behavior of high-thermal-mass walls among three types of masonry walls, including concrete masonry unit, adobe, and AAC. High-thermal-mass walls, when applied in residential structures, have a history of supporting the principles of sustainable design. Because, such walls have a large thermal storage capacity and the ability to absorb direct solar radiation during the day and release it at night, such walls yield significant benefits associated with reducing energy consumption with respect to heating and cooling demands from the structure. Conventional residential wall systems do not offer high-thermal-mass qualities and rely on heavy insulation for preservation of thermal properties. Walls have been used as load-bearing exterior walls to support the infrastructure of the building. As a result, using masonry walls has become attractive. To determine the structural behavior of high-thermal-mass, Memari, Grossenbacher, and Lulu (2008) chose the three wall systems (concrete masonry unit, adobe, and AAC) to analyze the different qualities offered by each system when applied to a built infrastructure. Concrete masonry units represent the typical masonry material most commonly used in construction projects. Adobe represents a masonry type of mud brick, and AAC represents a modern masonry type. The study method was called the in-plane and out-plane flexural test. At the end of the investigation, AAC walls were found to have the highest structural integrity, with about 88 percent strength capacity; the concrete masonry units and adobe types of material had a comparable flexural capacity of 650 lb, whereas the AAC material had a higher average capacity of about 1900 lb (Memari, *et al*., 2008).

In 2000, Kosny conducted a research project at Oak Ridge National Laboratory to determine the thermal performance of AAC. He used hot-box testing and computer modeling to analyze steady-state and dynamic thermal performance in the wall surfaces. A DOE 2.1E computer model enabled the comparative evaluation of thermal performance among AAC, concrete masonry units, steel studs, and wood-framed walls in five different climate locations in the United States, including Atlanta; Miami; Minneapolis; Phoenix; and Washington, D.C. Results indicated that, in comparison with a house with light framed systems, a house with AAC wall systems can significantly reduce the total consumption of space heating and cooling, even with the same steady-state R-value. It was found that the most effective application of the AAC walls was in Phoenix and that the least effective application was in Minneapolis. However, wood-framed construction would require an R-value 31 percent higher than that required by the AAC wall to generate the same total heating and cooling loads in Minneapolis. In Phoenix, wood-framed construction would require a 133 percent higher R-value for equivalent energy performance (Kosny, 2000).

A remarkable benefit provided by the AAC wall system relates to protection from heat transfer during summer months. In their study, Qvaeschning and Klemm (2006) analyzed a solid, black-coated 9.8-inch-thick wall exposed to an external temperature of 176^{0}F. After seven hours, the internal temperature of the wall increased by 35^{o}F (Qvaeschning & Klemm, 2006). This increase in internal wall temperature indicates that heat absorbed by the wall is stored and then is released when the temperature on the interior becomes cooler. This finding indicates that AAC wall systems use the properties of thermal dynamics to their advantage. The results from this study are showing that AAC possesses a unique energy-saving advantage. The material stores energy and slowly releases it, slowly thereby reducing heat transfer; this reason AAC has become recognized as a good insulator, especially in climates with large daily temperature fluctuations above and below the balance point of the building.

Another research study (Arizona State University, 2007) involved comparing a system's performance by analyzing five building systems, including AAC and frame systems, on the basis of the following parameters:

- Delivery Time
- Delivery Reliability
- Delivery Method
- Material Estimation Process
- Material Costs
- Equipment and Labor Costs
- Acoustical Performance
- Fire Rating
- Durability Potential
- Pest Resistance
- System's Components Availability
- System Complexity
- Exterior and Interior Finishes
- Workability
- Constructability in Production

The researchers evaluated the qualities of five exterior shell construction techniques, including wood-framed and AAC systems. The study results indicated that AAC is a well-rounded, flexible system with benefits similar to those of other innovative exterior shell construction systems (Arizona State University, 2007). Appendix A provides more detailed results from the aforementioned studies. The appendix also contains more comprehensive analyses from these studies.

2.10. Thermal Mass of Wall Systems

Thermal mass allows building materials to absorb, store, and release heat. Concrete and masonry building materials have unique energy-savings properties because of their inherent thermal mass. Materials with high-thermal-mass properties absorb energy and store it, typically for a longer period than that found in the use of light-framed materials (Building Green, 2007).

The thermal mass of concrete buildings consumes less energy than light-framed buildings use; this difference exits because of reduced heat transfer rate through the massive elements of concrete buildings (Grondzik *et. al*. 2010). Heating and cooling needs require consideration in most building design. Therefore, the building envelope design is a top priority for designers attempting to meet standards for energy-efficient design (Building Green, 2007).

The effect of the envelope of a mass wall system on energy consumption depends on the type and thickness of insulation, on thermal mass, and on air infiltration; in contrast, the effect of a framed wall system depends only on the amount of insulation and on air infiltration. Therefore, more insulation means less heat loss and results in lower requirement for heating and cooling purposes. Because insulation manufacturers widely publicize the characteristics of their product, consumers can easily understand its benefits. On the other hand, thermal mass also significantly affects on the amount of energy needed for heating and cooling but is a less publicized concept and therefore is poorly understood by consumers. In insulation systems, the higher the R-value of a system, the better the energy efficiency is found to be; however, this concept does not apply to the thermal mass system. Therefore, a wall system's energy efficiency cannot be rated solely on R-values. An R-value measures resistance for heat flow and determines the rate at which heat moves by conduction from the warmer side of the material to the colder side of the material under steady-state conditions. However, the mass affect results from the dynamic process of a building component's heat capacity to adapt the heat flow throughout a day (Kosny & Christian, 2001). Energy codes such as the International Energy Conservation Code (IECC) and the ASHRAE 90.1 Standard recognize the benefits of thermal mass and require less insulation for mass walls. For example, in Climate Zone 3 cities such as Atlanta, Tulsa, and Sacramento a residential structure with a wood-framed system must have R-13 insulation, whereas a residential structure with a mass system requires only R-9.5 insulation (ASHRAE 90.1, 2007).

The energy efficiency of building materials is determined by its handling of heat, its transfer of heat, and its ability to hold or store heat. Relying solely on the R-value proves problematic because, as has been demonstrated in the aforementioned research, the same R-value in similar structures with dissimilar frames may produce different impacts on energy consumption rates.

Thermal resistance (R-values) thermal transmittance (U-factors) do not in themselves take into account the effects of thermal mass and do not sufficiently describe the heat transfer properties of a system. Only computer programs such as DOE-2 hourly evaluation tools that include hourly heat transfer rates on an annual basis are sufficiently adequate to determine energy loss in buildings with mass wall systems. Heat flow through a wall depends on the material's unit weight (density), thermal conductivity, and specific heat.

Estimating energy-efficiency with the use of R-values proves reliable for framed systems but not thermal mass systems such as AAC because the effective energy efficiency of AAC construction comes from its thermal mass properties. Chapters 3 and 4 provide more detailed information on the computer simulation models and on the results. The models created for AAC have energy-saving benefits because of the inherent thermal mass of this material. Therefore, understanding the properties of heat transfer formed one focus of this research study.

2.11. Heat Transfer

This section contains a brief summary of the physics of heat transfer and includes discussions of the relationship between thermal storage and heat flow and of the essential role of thermal mass in the model used in this research study (Grondzik *et al.,* 2010). First, it is important to note that heat transfer occurs through three mechanisms: conduction, convection, and radiation. Table 2-1 provides a description of each heat transfer method.

Table 2-1 Heat transfer mechanism

Heat Transfer by	Primary Dependent upon
Conduction	Surface temperature
Convection	Air temperature, air motion, humidity
Radiation	Surface temperature, orientation to the body
Evaporation	Humidity, air motion, air temperature

In addition to understanding the transfer of heat between spaces, understanding the relationship of air and surface temperatures, air motion, and humidity to heat transfer is essential (Grondzik *et al.,* 2010). Provided next are a description and an example of each of the heat transfer type.

- Conduction is a molecule-to-molecule transfer of kinetic energy; in this transfer, one molecule becomes energized and, in turn, energizes adjacent molecules. For example, a cast-iron skillet handle heats up because of conduction through the metal (Building Green, 2007).
- Convection is the transfer of heat by physically moving the molecules from one place to another. For example, when heated, fluid moves away from the source while carrying energy with it (Lechner, 2009).

- Radiation is the transfer of heat through space via electromagnetic waves (radiant energy). For example, a camp fire can provide warmth even if in the presence of wind because air does not affected radiation (Lechner, 2009).

The heat flow of a building can be measured in several different ways. The most common reference is thermal resistance, or R-value (resistance to heat flow), which consists of the relationship between the materials and air spaces to flow of heat by conduction, convection, or radiation. The higher the R-value of a material is found to be, the better it resists heat loss (or heat gain). The U-factor (heat flow coefficient) is a measure of the flow of heat through thermal transmittance (conductance) in a material, given a difference in temperature on either side. The smaller the U-factor of the material is found to be, the better it resists heat loss or heat gain (Lechner, 2009).

An R-value, a physical property of a material, relates to resistance to heat flow when each side of a material or system is held at a constant temperature in steady-state conditions (Marceau & VanGeem, 2003). The steady-state R-value is traditionally used to measure the thermal performance of building envelope components and occurs when the temperature remains constant on each side of the material. Heat flow through the layer of material can be calculated by keeping one side of the material at a constant temperature (e.g., a summer ambient temperature of 90°F) and measuring the additional energy required to keep the other side of the material at a different constant temperature (e.g., indoor air-conditioned space of 70°F). R-value and U-factor are the inverse of one another: U = 1/R; R=1/U. Materials good at resisting the flow of heat (high R-value, low U-factor) serve well as insulation materials (Wilson, 1998).

Capturing the benefits of thermal mass in a project requires an accurate prediction of the building's energy usage. Analysis must consider the building's numerous thermal characteristics, such as the materials that make up the wall system, other materials specified in the building envelope, the size and orientation of the building, the manner in which the building is occupied and operated, and the local climate (Green in Practice, 2011). In addition, the accurate analysis of thermal mass buildings requires complex energy modeling software that can predict annual energy consumption on an hourly basis. For this reason, hourly analysis is required necessary the steady-state R-value traditionally used to measure energy performance does not accurately reflect the complex, dynamic thermal behavior of massive building envelope systems (Kosny, Yarbrough, Childs, & Syed, 2007). An alternative measurement, effective R-values, more precisely indicates actual energy performance of a mass system. Because the efficiency of thermal mass depends on the climate, building orientation, and season, therefore measuring this parameter is not a simple calculation (Green in Practice, 2011).

The mass effect, or effective R-value, generally refers the ability of high-mass materials, when used in certain ways, to achieve better energy performance than would be expected if only the steady-state R-value or U-factor parameters of that material were considered. High-thermal-mass material in a wall system causes one side of the wall to be warmer than the other side. This difference occurs because heat transferred by conduction flows from the warmer side into the material and gradually moves through it to the colder side. If both sides are at constant temperatures, conductivity will carry heat out of the building at an easily predicted rate. In result, high-thermal-mass materials can lead to smaller, less expensive mechanical systems and can thereby potentially lower electricity consumption (Wilson, 1998).

Heat capacity, another property of materials that can affect their energy performance in certain situations, measures the amount of heat required to raise the temperature of a material by 1°F. This property is most significant with heavy, high-thermal-mass materials because heavier materials have a higher heat capacity (Lechner, 2009). Typically used in energy performance computer modeling, heat capacity is determined per unit area of wall. In each layer of a wall system, the heat capacity is found by multiplying the density of that material by its thickness and by its specific heat. Specific heat consists of the amount of heat a material can hold per unit of mass. AAC possesses a specific heat of 0.25 Btu/lb. °F, while that of most building materials measures around 0.2 to 0.3 Btu/lb. °F (Wilson, 1998). If numerous layers exist in the wall, total heat capacity involves adding up the heat capacities for each layer (e.g., drywall, masonry block, and stucco).

Predicting the thermal requirements of a building necessitates considering the ways in which the heating and cooling systems of the building must respond to changing conditions in outside air temperature, in occupant and equipment activity, and in occurrence of solar energy over the course of a day. For example, the response of a thermally massive building with the same external and internal loads differs from that of a light-weight building because former structure has a greater capacity to absorb and hold heat. This function benefits thermally massive buildings by moderating indoor temperature fluctuations; reducing spikes in temperature; slowing the transfer of heat through the building envelope; storing energy; and shifting demand to off-peak periods; potentially reducing peak loads and avoiding peak utility rates (Matthys and Barnett, 2004). Figure 2-2 depicts the damping and lag effects of a high-thermal-mass building.

Figure 2-2 indicates that most energy savings occur when heat flow changes in the other side of the wall (exterior/interior) during the day, so thermal mass proves most effective in locations and during seasons with large daily temperature fluctuations above and below the balance point temperature (BPT) of the building. Therefore, thermal mass is more effective in reducing cooling loads in reducing heating loads (Lechner, 2009). The results from this dissertation research indicate similar results in different climates. Chapter 4, the Discussion of Results, provides a detailed explanation of the results from the dissertation research.

Temperature damping, a characteristic of mass construction, indicates the effect of exterior temperatures and heat on the interior of a building. Thermal mass delays by three to eight hours time of peak temperatures and heat gains on the interior. This process is also known as thermal lag.

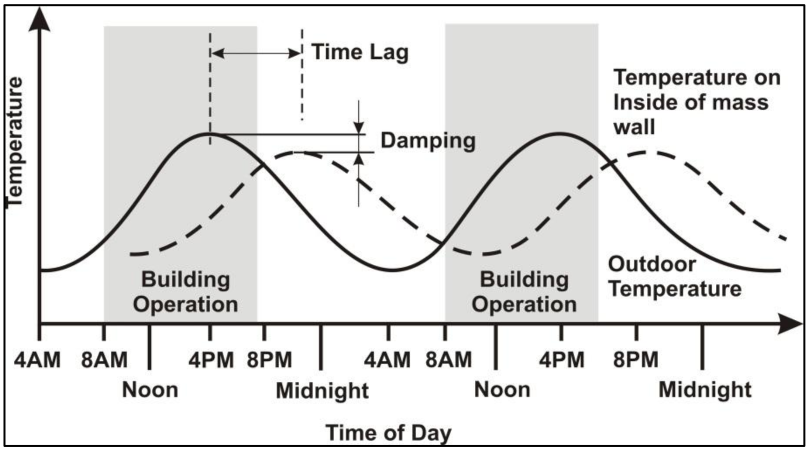


Figure 2-2 The damping and lag effects of a high thermal mass building
The above figure is adapted from Concrete Masonry Association of California and Nevada, 2006

Although thermal mass can reduce energy consumption and improve comfort in irregularly occupied interior spaces of the building, it is often more efficient to minimize the interior mass so that such spaces can warm up or cool down quickly when needed (Zhu *et al.,* 2009). Also, thermal mass materials can be expensive and space-intensive, so architects and builders tend to use them where they can also serve other functions within a structure, (e.g., as a durable interior surface such as flooring or as a heating system such as a trombe-wall) (Building Green, 2007).

2.12. Energy-Modeling Tool

Energy modeling or energy simulation predicts the energy consumption of a building. This analysis involves considering the building's numerous thermal characteristics, including the materials of the walls and the whole building envelope, the size and orientation of the building, the manner in which the building is occupied and operated, and the influences from the local climate. As mentioned earlier in this report, calculating thermal mass benefits is difficult without the use of a complex modeling software such as DOE-2, which enables hourly analysis. It is necessary to perform hourly energy use calculations and to simulate the response of the model on an hour-by-hour basis for all components, conditions, and applications of thermal mechanisms (Concrete Thinker, 2010). Energy analysis software programs have varying levels of accuracy, and each possesses different intents and phases of design processes; therefore, these programs require different levels of effort.

One task performed for this research consisted of analyzing the capabilities of currently available software. (Appendix B provides detailed information on well known software programs and on their capabilities, limitations, strengths, inputs, availabilities, etc.) Paradis (2010) stated that most energy analysis tools can be classified as being one of four generic types.

- **Screening Tools**: primarily used during budgeting and programming of retrofits. Federal Renewable Energy Screening (FRESA) and The Facility Energy Decision System (FEDS) are well known.

- **Architectural Design Tools**: primarily used during programming, schematics, and design development of new construction and major renovation. ENERGY-10, Building Design, Advisor, and Energy Scheming are well known.
- **Economic Assessment Tools**: used throughout the design process. BLCC and Quick BLCC are well known.
- **Load Calculation and HVAC Sizing Tools**: primarily used during design development and construction documentation of new construction and major renovation. HAP, TRACE, DOE-2, BLAST, Visual-DOE, and Energy-Plus are well known (Paradis, 2010).

Several building energy simulation tools expand on the capabilities of BLAST and DOE-2, both of which the U.S. government developed, maintained, and supported. The Department of Energy designed DOE-2; he Department of Defense designed BLAST, developed for the National Bureau of Standards Load Determination (NBSLD) in the early 1970s. The primary difference between the programs relates to the load calculation method. DOE-2 uses a room weighting factor approach, whereas BLAST uses a heat balance approach. Both methods are available for whole building energy use. Each is dynamic in that it accounts for the beneficial effects of the thermal mass of concrete and each requires experts to use the software and to interpret the results (Concrete Thinker, 2010). Since the late 1990s, predict consideration of merging these two government-supported programs has taken place. Selected private and government professionals joined in two workshops to discuss new ideas and fundamental issues of the energy-modeling programs. Results from the workshop were reevaluated in this research and are presented in Section 4.3 of the Framework for Software chapter.

The heat balance method (BLAST) applies of the first law of thermodynamics: Energy can only be transformed from one state to another; it can be neither created nor destroyed. Numerical concentrated the heat balance method requires significant computing power. However, a heat balance equation is written for each surface in a space. The equation provides results for simultaneous surface and air temperatures. The calculated temperatures are then used to evaluate heat flow rates. Energy-Plus, IES, and Tas software models use this method for energy simulation (Concrete Thinker and Portland Cement Association, 2010).

The weighting factor method (DOE-2), although complicated, requires much less computation. The weighting factor is first determined with the use of the heat balance method and then is applied to the transient heat flow in walls to develop weighting factors for the thermal behavior of building spaces the building systems simulated respond to these heat flows. Additional weighting factors, based on the actual properties of the room being modeled, include wall construction, furniture type, and furniture weight. The weighting factor method is used in the energy simulation software DOE-2 (Concrete Thinker, 2010). DOE-

2, the calculation engine of which simulates on an hourly basis,   is used by other programs such as Energy-10, Energy Plus, and Visual-DOE.

Energy performance simulations of a building constitute powerful tools for architects, engineers, and developers. Building simulation programs analyze the interactions between building systems and therefore can play an important role in early design analysis and decision making (LBNL, 2002). Design professionals can use these models to analyze the effect of the form, size, orientation, and type of building systems on the overall energy consumption of a building. This analysis remains crucial to the process of making informed design decisions about building systems that affect energy consumption, such as the building envelope, glazing, lighting, and HVAC systems. For the majority of projects, running simulations can lead to improved building energy performance in the early design phase (Mender *et al.,* 2006). One benefit in early adaptation consists of the opportunity to reduce cost impacts. If analyzed, accepted, and incorporated early in the process, design decisions can often have a significant impact on design time and construction cost (AIA California Council, 2007).

Energy cost estimations associated with operating a building do not prove easy in the case of a building still under design. Factors involved include the construction details and orientation of walls and windows, occupancy patterns, local climate, operating schedules, the efficiency of lighting and HVAC systems, and the characteristics of other equipment loads within the buildings. Accounting for all of these variables, as well as for their interactions, can be potentially overwhelming. Given this complexity, accurate calculations of annual building energy costs remained rarely performed until the advent of modeling software programs. Software packages that simulate building energy performance carry out these numerous and complex equations that, when combined, describe the ways in which buildings use energy. The most sophisticated of these programs can calculate a year's worth of building energy consumption on an hourly basis (LBNL, 2002).

Energy models help designers answer questions such as the effect of different wall and roof construction assemblies on a building's heating and cooling loads or the energy savings that will result from different levels of wall and roof insulation (LBNL, 2002). Building simulation can provide several advantages when design professionals start the simulation process earlier in the design phase. Early design stage models must be simple, only requiring inputs related to the thermal zoning of a building, such as its exterior and HVAC system or lighting, and not needing detailed interior layouts of the building. Adding detailed components may cause several opportunities for making mistakes, from input errors to misinterpretation of results data that go into creating a building simulation (LBNL, 2002). One other important task for the energy modeler is to avoid common input mistakes, such as facing walls the wrong direction, incorrectly assigning schedules of use, or making simple typographical errors. Therefore, the person running the simulations must already possess a relatively high awareness of the likely simulation results. The history of building simulations contains many incidents in which small errors led to unfortunate and expensive results (LBNL, 2002). To reduce the potential for error when developing a model, designers must (a) keep good notes on program inputs and document any assumptions, (b) collect and organize the correct data from design drawings and specifications, and (c) input all the data at the same time. These three tips enable a designer to focus first on accurately gathering information and then on examining the results and reviewing the outcomes to isolate extra or missing elements (LBNL, 2002).

The challenge to the energy modeler remains understanding which questions can be effectively answered with the energy model at each project phase. Just as the overall design starts with a broad focus during early design and increases in detail through the following phases, so the energy model must start as a representation and then upon conceptualization of the final project, undergo refinement as more detailed information becomes available (LBNL, 2002). The benefits of a step-by-step process include highlighting important details at each level of the project phase and elucidating design questions that can be answered appropriately at different levels of project phases.

Furthermore, incentive programs such as green building rating systems (e.g., LEED) may introduce an added level of technical and documentation requirements for the energy model. Developer of software technology need to address more of the green building sector in terms of energy management tools, which also play a vital role in support of the USGBC LEED rating system for certifying green structures. To have a building certified by the USGBC, architects and designers require tools that aid in demonstrating that the building complies with various sustainable design requirements.

The LEED rating system is consists of five major credit categories, including Energy and Atmosphere, which directly relates to this research. The Energy and Atmosphere credit category provides the opportunity for energy-efficient buildings to qualify for up to 19 of the total 100 possible LEED-2009 credit points for new construction.

Each credit category consists of mandatory prerequisites for the minimum energy performance needed for compliance with American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) Standard 90.1 and credit requirements. To achieve LEED credits, the proposed design needs to exceed the baseline design per ASHRAE 90.1-2007. In addition, energy credits can be obtained on the basis of the percentage of energy cost savings. Obtaining additional credits requires energy simulation tools.

The U.S. DOE provides a catalog for the majority of the available building simulation tools under the Building Energy Software Tools Directory. Appendix B contains this listing. Designers can use the available energy simulation software and model the proposed building and the baseline building. This research involved evaluating 20 major software programs, of which 6 can assist building designers with earning the LEED Energy and Atmosphere credit. Building simulation programs can be powerful and useful tools, but each has strengths and limitations. Appendix B provides 231 brief descriptions of software programs.

Whenever a designer selects a simulation modeling tool, the first and most important decision is centers around choosing the software tool most appropriate for the project. This decision should be based on the designer's level of familiarity with building simulation tools, the capabilities expected from the model, and the level of detail required for the project (Gundala, 2003). Visual-DOE is primarily selected for this research project because it requires less time to build an accurate DOE-2 model for schematic design studies of the building's envelope and HVAC systems.

2.13. Visual-DOE

Visual-DOE is a useful tool for evaluating building envelopes and HVAC system in early design stages (US DOE-EERE, 2011c). A 3-dimensional (3D) image of the model helps verify accuracy and allows simple management of up to 99 design alternatives (Visual-DOE Manual, 2004). A powerful program, Visual-DOE, quickly evaluates the energy savings of the building design options (U.S. DOE-EERE, 2011c). The program covers all four major components: the building envelope, lighting/day lighting, water heating/HVAC, and the central plant. The accuracy of the model originates from a DOE-2.1 engine hourly simulation of energy use and peak demand. First released in 1994 and has been updated over the years, features include such as LEED-style end-use reports and a life-cycle cost calculation. The program interfaces include the Windows user interface, the building and HVAC database, the DOE-2 simulation engine, and simulation diagnostic and support tools (Visual-DOE Manual, 2004).

Building envelope and HVAC design alternatives are common applications for Visual-DOE. The software has more than 1000 users in the United States and 34 other countries (U.S. DOE-EERE, 2011c), including mechanical, electrical, and energy engineers; consulting firms; research universities; and equipment manufacturers. Architects do not commonly use Visual-DOE because the software focuses more on engineering than on design (U.S. DOE-EERE, 2011c).

2.14. Research Related to Energy Models

In a research study conducted in the United Kingdom, Radhi (2008) used Visual-DOE to evaluate building energy performance in the Gulf States (Radhi, 2008). Radhi (2008) followed the European Energy Performance of Building Directive (EPBD), an initiative developed to help ensure energy savings and carbon dioxide emission reduction without compromising occupant comfort. The directive established the necessity of integrating the simple and reliable methodology of energy simulation tools into the process of optimizing building design approaches that meet evaluative standards for building energy performance. In his study, Radhi (2008) implemented Visual-DOE to evaluate the monthly electricity consumption in an office building in Bahrain at different times of the year. A comparison of the actual energy consumption with the simulation outcomes revealed relatively consistent result, and the analysis of the energy use patterns demonstrated that the cooling load was significant because of the heat gains through the building's skin (Radhi, 2008). Cities in Bahrain use Radhi's (2008) to study energy consumption patterns for existing buildings and to propose possible solutions for future energy performance in their buildings. In the previous section 2.7 Visual-DOE is referred to as an excellent program to analyzed energy performance in building envelops.

Gajda (2001) used Visual-DOE 2.1 E software to analyze energy consumption for a 2450-square-foot, single-family residential structure in 25 cities across the United States and Canada. Each house was modeled with 7different wall systems (traditional wood-frame walls, steel-frame walls, AAC, concrete masonry unit walls, insulating concrete form walls, insulated concrete hybrid walls with exterior insulation, and interior insulation). Wall design incorporated typical materials that met minimum energy code requirements of the 2000 International Energy Conservation Code (IECC) for U.S. locations and those of the 1997 Model National Energy Code of Canada (MNECC) for Canada. In his research, Gajda (2001) examined energy loss resulting from heat flow through exterior walls (R-value and U- value) and studied thermal mass effects. His analyses showed that, depending on the location, energy consumption for heating and cooling accounted for 20to 70 percent of the total energy cost. Results also revealed that, in comparison with houses having framed wall systems, the houses with mass walls had lower heating and cooling costs (Gajda, 2001).

According to Gajda (2001) who specializes in mass concrete structures, the properties of the exterior walls affect energy consumption in the structures. Heat loss through a framed wall depends on the amount of insulation, and more insulation, leads to less heat loss and to less energy required for heating and cooling; because widely publicize this information, consumers are familiar with the advantages of using this material. However, although thermal mass significantly affects on heating and cooling energy, the concept of thermal mass remains insufficiently publicized and is consequently inadequately understood by consumers (Gajda, 2001). Gajda (2001), remained that thermal mass is not a new concept; it has been used for centuries and its proved comfort to living environments (Gajda, 2001). For example, adobe brick has been used for centuries to construct houses throughout the Southwestern United States and Mexico.

In their research study, Iqbal & Al-Homoud (2007) used Visual-DOE 4.0 simulation software to evaluate the energy consumption of different HVAC systems in a five-story building in Damman, Saudi Arabia. Based on their research, the following recommendations were made for future projects

- Using scheduled or adjustable lighting that can be turned off during unoccupied or low-occupancy hours such as lunch breaks.
- Using dimming controls that regulate the lighting in accordance with amount of natural light present. (As a result, the luminance level, especially in the perimeter zone, remains steady and yields a reduction in electricity usage).
- Using low-emissivity double-glazed windows for energy efficiency in large glazed buildings in hot climates, as well as installing energy-efficient fluorescent light, such as 34W.
- Using a VAV variable air volume system in summer because air-conditioning systems play an important role in energy consumption in at that time (Iqbal & Mohammad, 2007).

In a research study conducted by Yezioro *et al.,* (2007), results revealed that concluded that building energy simulation models comprise an important and powerful analytical method for building energy studies in architectural design. Of the many building simulation models available in the market, four (Energy 10, Green Building Studio, e-Quest, Energy-Plus) were selected for use in a comparison of computational results ranged in detail from schematic to more advanced, with a mean absolute error of 3 percent. The comparison showed that the more detailed tools produced more accurate results (Yezioro *et al.,* 2007).

According to Mahmoud Aly Hassan's (2006) presentation at the Fourth International Energy Conversion Engineering Conference, air conditioning and lighting in buildings consume the most energy in tropical climates, and using natural light could reduce the energy consumed by artificial lighting and reduce thermal load. In his ongoing research Hassan concentrates on natural lighting in tropical office spaces and on the high energy consumption of artificial lighting because, he stated (Hassan, 2006) only modest awareness of this subject exits in the tropics. To investigate the possibility that increasing the use of natural day light instead of artificial light might reduce energy consumption in the buildings, Hassan (2006) conducted his study by using Visual-DOE software in order to establish annual energy consumption in Egypt and concluded that using day-lighting controls with or without double-tinted glazes decreased the amount of the annual lighting cost (Hassan, 2006).

Selim (2008) conducted research focused on the thermal performance and indoor air quality of the Tuskegee Healthy House, built with healthy, more efficient, and affordable housing options. The study involved examining impact of different construction materials, mechanical systems, and crawl space configurations on energy consumption and indoor air quality. This research integrated field testing and computer model simulation (Visual-DOE 4.0) and the model was used to predict the energy efficiency of the house. Model calibration took place by means of comparing the modeled data against the field test results. Visual-DOE showed results similar to those from the field tests with ± 8.5

percent (Selim, 2008), a finding indicating that the Visual-DOE program enable designers make an informed decision about design ideas and about the consequences of those designs.

2.14.1. *The validation of Visual-DOE.* This research consisted of investigating the selection of an energy-efficient building material in the early design stage by using energy modeling programs. The early stage of a building design and assessing the energy performance of the building relies on a decision making stages of a building project. Therefore, the nature of the study does not permit the calibration or validation of the simulation model used in this research. However, conducting this research required an effective and efficient tool with which to assess the energy impacts of the building material. Therefore, this study included using an energy modeling program, Visual-DOE, previously calibrated and validated by other researchers. Earlier research from Radhi, Iqbal, and Homoud, and Selim (see the remaining portion of Section 2.8.1) guided this study).

Radhi (2008), who assessed economic and environmental benefits in office buildings in Bahrain, based his methodology on building management systems, simulation tools, and other technologies. This method utilized Visual-DOE and directly collected data gained from experimental works and practical applications. The results indicated that Visual-DOE predicted fairly accurately within ± 1.4 percent the actual consumption of the structures.

Iqbal and Mohammad (2007) conducted a study to select the appropriate size and the type of HVAC system needed for a five-story building in Saudi Arabia. The method used involved collecting data from the analysis and utility bill data to calibrate the base case of the existing building and then using Visual-DOE energy modeling software as the tool to run alternative scenarios. Their results indicated that the average range of difference between the actual and modeled results was ± 7.5 percent.

Selim (2008), research focused on the thermal performance of an affordable energy-efficient single-story residential building designated as the Tuskegee Healthy House. She used a Visual-DOE energy simulation model to predict energy consumption and then compare the results with the data from a specific date. The measured and modeled results indicated an average difference between the two of ± 8.5 percent.

Reports from those studies (Radhi, 2008; Iqbal, and Homoud, 2007; and Selim, 2008) included a brief summary of the validation of Visual-DOE. The validations were determined by an analysis of the degree to which the simulations and their associated data proved accurate when compared with the field data. Those previous efforts provided evidence of the ability of Visual-DOE to accurately assess thermal mass and execute frame system evaluations in this research.

2.15. Sustainable Housing

2.15.1. *Importance of the size of a building.* In 2010, the U.S. Census Bureau reported on estimated global population of 6.8 billion (U.S. Census Bureau, 2009). Several estimates exit on the rate of population growth, which is expected to increase by 9 to 12 billion people from 2040 to 2050 (Revkin, 2009). The number of people that the earth can sustain remains unknown. However, although natural resources are limited, human beings use them as if they are unlimited; as a result, therefore an increase in population will affect the volume of consumption, thus placing a greater impact on the environment (Lechner, 2009).

The United States accounts for 5 percent of the population of the world but consumes about 20 percent of energy of the world (Lechner, 2009). The building industry alone consumes approximately one third of all energy in the United States (USGBC, 2006). It is important to determine specific areas of possible reduction in energy use. For example, decreasing the size of houses would theoretically decrease their consumption of energy.

Some environmental activists insist that house size cannot be ignored. Richard Faesy, a project manager at Vermont Energy Investment Corporation and a director of Vermont Builders for Social Responsibility, holds membership in an activist group called Deep Green. The Vermont program rewards houses designed under the benchmark size of 2300 square feet while requiring larger homes to conform to increasingly stringent standards in other categories. In contrast to the Vermont program, Built Green Colorado includes no penalties for those who live in bigger houses but it does award some points for houses smaller than 2000 square feet. The LEED Homes draft standard follows a path similar to that of the Vermont program (Energy Design Update, 2003). LEED compensates for the effect of home size on resource consumption and therefore adjusts the award thresholds for home size. The LEED Homes reference explains that the LEED Homes standard contains draft criteria based on a reference house of 1900 square feet (See Table 2-2). For every 4 percent increase in size over 1900 square feet, the project has 4 percent more environmental impact; as a result, certification of the project would require1 point more. Points needed to earn LEED certification for residential structures are on ranges 5 points less than the original point structure for commercial buildings. For example, certified LEED homes need 40 points instead of 45 points to be certified, 55 points instead of 60 points for silver certification, 70 points rather than 75 point for gold certification; the same logic applies for platinum certification. The efforts of these organizations reveal above is to show a strong consensus that size matters.

In the United States, the average affordably sized house measures approximately 1798 square feet (Lewis and Kitchen, 2006). According to Lane Kenworthy (2010), a professor of sociology and political science, the median size of new homes increased from 1500 square feet in 1973, to 2200 square feet in 2007. The Tennessee Valley Authority announced that, in the Southeastern

United States, the average size of house measures1761 square feet (Lewis & Kitchen, 2006).

Table 2-2 LEED Homes, threshold adjustment

Maximum home size (square feet) by number of bedrooms					**Adjustment to award thresholds**
1 bedroom	**2 bedroom**	**3 bedroom**	**4 bedroom**	**5 bedroom**	
610	950	1290	1770	1940	-10
640	990	1340	1840	2010	-9
660	1030	1400	1910	2090	-8
680	1070	1450	1990	2090	-7
710	1110	1500	2060	2260	-6
740	1160	1570	2140	2350	-5
770	1200	1630	2230	2440	-4
800	1250	1690	2320	2540	-3
830	1300	1760	2400	2640	-2
860	1350	1830	2500	2740	-1
900	**1400**	**1900**	**2600**	**2850**	**0 (“neutral”)**
940	1450	1970	2700	2960	+1
970	1510	2050	2810	3080	+2
1010	1570	2130	2920	3200	+3
1050	1630	2220	3030	3320	+4
1090	1700	2300	3150	3460	+5
1130	1760	2390	3280	3590	+6
1180	1830	2490	3400	3730	+7
1220	1910	2590	3540	3880	+8
1270	1980	2690	3680	4030	+9
1320	2060	2790	3820	4190	+10

(Point range: -10 to +10) Example: An adjustment -5 means that the threshold for a certified LEED Homes is 40 points rather than 45 points, and the same logic applies for silver, gold, and platinum certification (USGBC, 2009d).

A house does not need to be big to be beautiful, functional, and comfortable. According to realtors, potential buyers are often more interested in thoughtfully designed kitchens and bathrooms than in square footage (Demesne Info, 2010). Sarah Susanka, architect and author, stated that giant houses do not mean comfort (Susanka & Obolensky, 2008). However in comparison with small houses, cost more; require more resources to build; and use more heating, lighting and cooling (Susanka & Obolensky, 2008). More effort is needed to maintain them; basically, they take more and give less benefit to the homeowners. Susanka (2009) believes that sometimes having extra room burden rather than enriching the life.

Existing design standards for commercial buildings they have different functions types, and forms; standards regulate the size of commercial buildings but do not apply to residential structures. However, research indicates that the smaller size provides more benefits. A sustainable approach must be adopted in order to meet the goal of reducing carbon emissions associated with the size of a building. Appropriate building design and sizing can help reduce overall energy consumption. Because size and systems can reduce cost, the savings make it possible to allot these funds for further energy-saving materials, designs, and technologies (Nace, 2009).

2.15.2. *Sustainability in Exterior Wall Systems.* In the Southern United States, large amounts of rainfall and warm, humid temperatures create vulnerability to wood-destroying organisms such as fungi and insects. Therefore, moisture control is crucial for wood-framed structures. The most common fungi found are white rots, brown rots and water-conducting varieties. Termites, the most common insect damaging structures, annually cause millions of dollars' worth of damages (Lewis & Kitchen, 2006).

Ninety percent of American homes are constructed from wood and wood products. Results of a study by Lewis and Kitchen (2009) show that, every year, home owners spend $ 500,000,000 U.S. for wood replacement necessitate by decay and termite damages. The Formosan termite is considered one of the most destructive and aggressive termite species, and an active colony of Formosans can to eat as much as1000 lb. of wood per year (Lewis & Kitchen, 2006). According to the 2001 American Housing Survey, more than one third of all housing units constructed in the last four years were built in the Southern United States, with very little attention given to producing more durable and energy-conserving houses that would benefit an extensive percentage of the growing U.S. population (Lewis & Kitchen, 2006).

Commonly used in the construction of commercial buildings, steel remains little used in houses. The technique of constructing a steel structure almost duplicates that of a wood-framed structure. Unlike wood, steel is resists to termites; however, construction costs are about the same. Other benefits of using steel framing include added fire and earthquake resistance and new design possibilities for architects and builders because, in comparison with wooden ceiling joists, steel ones can span greater distances.

However, heat loss occurs more than 300 times more rapidly with steel than with wood. Steel studs can create thermal bridges to the outside of the house. Even the fasteners become a source point of heat loss (Energy Source Builder, 2010). Screws attached to steel studs can reduce the insulating value of foam sheathing by 39 percent (Energy Source Builder, 2010). Therefore, when selecting this framing method, designers may need to specify the use of extra insulation. In cold climates, the additional insulation required to prevent heat transfer might reduce the cost effectiveness of steel framing.

As population and energy demands continue to increase, the need for more energy-efficient building materials that help us reduce the amount of resources used to produce electricity, reduce the waste associated with the consumption of electricity in order to preserve limited resources, and increase the energy performance of buildings by maximizing the effect use of building materials incorrect. Accurate simulation software for determining the energy loads of buildings is important to building manufacturers because they need accurate estimates to develop ways of improving the performance of individual building materials. Simulation software will also help to determine the combination of specified building materials that will result in the most efficient buildings possible. As programs like LEED become more prevalent in the building industry, designers will increasingly design buildings that perform well and use that efficiently resources. Deciding the means of achieving program certification must be done before the full expense of constructing, occupying, and maintaining the buildings. This predetermination will impact the ability designers to convince building owners that their “green solution” will provide these or better results. Because buildings have a lasting impact on the environment from construction to occupancy, it is important to ensure that the buildings being designed have minimal impact throughout the life of the building.

Chapter 3 contains discussions of the research problem and the methodologies used to find an appropriate solution to the research problem. Chapter 4 contains a report of the results from the research tasks.

3. METHODOLOGY

3.1. Introduction

The primary objective of this research consisted of identifying a method of properly selecting energy-efficient building materials by evaluating their potential to earn LEED credits when applied to a built structure and of establishing a framework that provides suggestions for using currently available simulation software in a manner that enhances the viability of the estimates concerning optimizing energy efficiency and achieving LEED credits. Analysis typically involves considering buildings whole and paying little attention to the individual building materials that make up the composition. However, improving or specifying one building material can alter the performance of the whole building. Instead of a more comprehensive and more expensive solution to a problem, a change in one building material can more effective improve a certain building design and more significantly benefit the operation of the structure. Additionally, analyzing a specific building material will help material manufacturers identify ways of altering their products to advance the sustainable quality of their materials and thus cause them have a larger impact when specified for certain design projects. Specifying these innovative, recently introduced building materials remains problematic because little evidence exists of their performance in various locations around the world. As a result, building owners resist the use of these products because designers do not have viable sources to prove the performance ratings of such products in a specific area. The longer the resistance to these building materials continues the more increasingly their use will become.

This research consisted of defining a methodology that can viably estimate the sustainable characteristics of individual building materials. This methodology will ultimately help product manufacturers increase of their products recognition in the building industry and assist designers with educating builders and building owners about the innovative building materials available. Determining how to create simulation software that will meet these needs involved completing a number of tasks to answer the research question, prove the research hypothesis. And create a solution for the problem.

Several questions needed answering to find a solution to the problems associated with determining a building material's potential to reduce energy consumption and support sustainable initiatives. This research answered the following questions:

- Can AAC provide the United States with energy saving benefits comparable to the experienced in Europe?
- What are the advantages of analyzing an individual building material instead of the entire building composition?
- Can a simulation software tool accurately estimate the potential number of LEED credits achievable by specifying a specific building material?
- In what ways will an improved simulation tool that accurately estimates LEED credit potential earnings affect the building industry?

- In what ways will analyzing individual building materials improve energy-saving characteristics?

Providing accurate estimations of the energy performance of a building material fosters improvements in the building industry and reductions in the environmental impacts associated with occupant energy consumption. The hypothesis for this research was as follows: Computer simulation modeling can provide an accurate, useful tool with which evaluate sustainable building performance in terms of an established standard and can compare emerging building materials in terms of energy consumption. This hypothesis was proved by determining the viability of simulation software tools through analysis of different types of framed wall systems in different locations in the United States and by comparing these results with the baseline models supported by the minimum design standards suggested in ASHRAE/IESNA Standard 90.1-2007. The seven tasks conducted to prove the hypothesis are discussed in more detail in the 3.3.1- 3.3.7 sections.

3.2. Modeling

The two building types were used in this research enabled determine on the energy-efficient properties associated with residential and commercial models. The geometry of these model structures was developed with the use of the selected software and with a custom-designed building envelope and materials. For comparison purposes, all models have slab foundations and identical floor plans, interior finishes, windows, doors, and fixtures; this set up formed the baseline model. Site orientation, HVAC systems, and roof systems similarly remained static to allow for direct comparisons. The specifications identified electric power for cooling and ventilation needs and natural gas for heating requirements. This analysis involved evaluating the energy performance characteristics of identical structures with varying structural materials, including, wood, metal, and AAC. Figures 3.2-3.8 provide all model images. The selected building components and insulations met the current ASHRAE 90.1 Standard. Tables 3-1 and 3-2 contain code requirements; Figure 3-1 depicts International Energy Conservation Code (IECC) Climate Zones. This dissertation contains comparisons of residential structures, including both wall and building systems with the ASHRAE 90.1 standard model, with models with wood-framed and AAC systems for residential structures and with metal-framed and AAC systems for commercial structures.

Derived from research results, the IECC undergoes periodic reevaluation and modification. The IECC codes have become integral parts of the building code of almost every state and local jurisdiction. In the United States, just as the ASHRAE 90.1 standard is the most commonly applied energy code for commercial and other nonresidential buildings, IECC is the most commonly applied energy code for residential structures. The IECC also contains a commercial section that allows the use of the ASHRAE 90.1 standard for compliance. Both the 2009 IECC and ASHRAE Standard 90.1-2007 can potentially save energy by comparable levels for most building types.

Table 3-1 Residential building envelope ASHRAE 90.1 Standards

RESIDENTIAL		Houston Daytona Miami	Tulsa Sacramento Atlanta	Reno Philadelphia Richmond Springfield	Boston Chicago	Missoula Madison	Minot
		Zone2	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**
Roof	***Above deck***	R-20	R-20	R-20	R-20	R-20	R-20
	Attic	R-38	R-38	R-38	R-38	R-38	R-38
Wall	***Mass***	R-7.6	R-9.5	R-11.4	R-13.3	R-15.2	R-15.2
	Wood-frame	R-13	R-13	R-16.8	R-20.5	R-20.5	R-20.5
Floor	***Mass***	R-8.3	R-8.3	R-10.4	R-12.5	R-14.6	R-16.7
	Wood	R-30	R-30	R-30	R-30	R-30	R-30
Slab	***Both***	NR	NR	R-10	R-10	R-10	R-10

Table 3-2 Commercial building envelope ASHRAE 90.1 Standards

COMMERCIAL		Houston Daytona Miami	Tulsa Sacramento Atlanta	Reno Philadelphia Richmond Springfield	Boston Chicago	Missoula Madison	Minot
		Zone2	**Zone 3**	**Zone 4**	**Zone 5**	**Zone 6**	**Zone 7**
Roof	***Above deck***	R-20	R-20	R-20	R-20	R-20	R-20
	Metal-frame	R-13+13	R-13+13	R-13+13	R-13+13	R-13+19	R-19
Wall	***Mass***	R-5.7	R-7.6	R-9.5	R-13.3	R-13.3	R-15.2
	Metal-frame	R-16	R-13	R-19	R-13+5.6	R-13+5.6	R-19+5.6
Floor	***Mass***	R-6.3	R-6.3	R-8.3	R-12.5	R-12.5	R-12.5
	Metal-frame	R-19	R-19	R-30	R-30	R-30	R-30
Slab	***Both***	NR	NR	NR	R-10	R-10	R-15

These tables are adapted from American Society of Heating, Refrigerating and Air-Conditioning Engineers: Energy standard for buildings except low-rise residential buildings (AHSRAE 90.1, 2007).

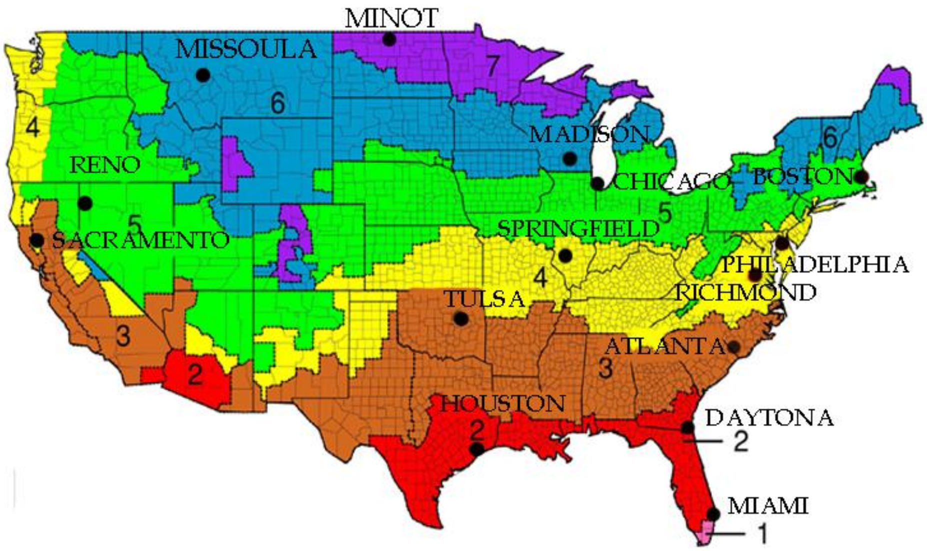


Figure 3-1 IECC Climate Zone (Adapted from ASHRAE, 2007)

This research uses both standards as reference sources for building guidelines.

In the United States, the average size of a typical residential home has doubled over the past 50 years (Selim, 2008). Environmental activists argue that the increased house size requires consideration (Energy Design Update, 2003). In comparison with the average home in other region of the world, the average American home consumes five times more energy, the use of resulting in significant amounts of energy to construct and maintain residential communities (U.S. Census Bureau, 2011). According to Kenworthy (2010) and Lewis & Kitchen (2006) the appropriate size for a residential structure ranges from 1500 to 2200-square foot. This research indicates an advocacy for smaller residential structures to reduce energy consumption; therefore, a 1615-square-foot residential modeled formed the basis for each residential model evaluation in this research.

3.2.1. Residential Model

A typical residential floor plan was modeled with the use of the Visual-DOE simulation tool. The model, 1615-square- foot structure, could house an American middle-class family of three to four people. Other specifications included roof insulation with a value of R-30, simulated slab floors with R-30 insulation, and two types of windows with 0.491 and 0.428 U-factors that depended on the size of the opening. The overall window-to-wall ratio was calculated at 2.8 percent. Figure 3-2 illustrates the residential model floor plan, and Figure 3-3 shows orientations of the model.

Walls of the simulated home were classified as either framed or mass structures. A framed wall consisted of a conventional wood frame with R-11 fiberglass batt insulation, and a mass wall contained AAC (4/500) 8-inch-thick blocks commonly used for residential structures. The simulation included an overall R-value of R-18 for a traditional wood-framed system [$\sum$Wood-frame wall R= $R_{\text{outside-air}}$ (0.17)+$R_{\text{aluminum siding}}$ (0.61)+$R_{\text{bldg paper}}$ (0.06)+R_{plywood} (0.63)+$R_{\text{2/4'' stud}}$ (4.38)+$R_{\text{2/4'' fiber glass batt}}$ (11) + $R_{\text{inside-air}}$ (0.68) +$R_{\text{gypsum-board}}$ (0.45)] and overall R-value of R-10 for an AAC system [$\sum$AAC R= $R_{\text{outside-air}}$ (0.17) +R_{stucco} (0.20) +R_{AAC} (8.33) +R_{plaster} (0.11) +$R_{\text{inside-air}}$ (0.68) +$R_{\text{gypsum-board}}$ (0.56)]. The simulation did not include metal because residential construction does not commonly involve using this material Figure 3.4 depicts residential model wall sections.

The design included the framed walls of 2x4 studs spaced 16 inches on center, with ½-inch gypsum board overlay on the interior surfaces and with ½-inch plywood with aluminum siding overlay on exterior facades. The AAC wall consisted of 8x8x24-inch blocks, with a density of 31 pounds per cubic foot (pcf). The interior surface was 7/8-inch plaster and 5/8-inch drywall, with the exterior façade consisting of 7/8-inch stucco. Figure 3-4 illustrates wall sections of the residential structure.

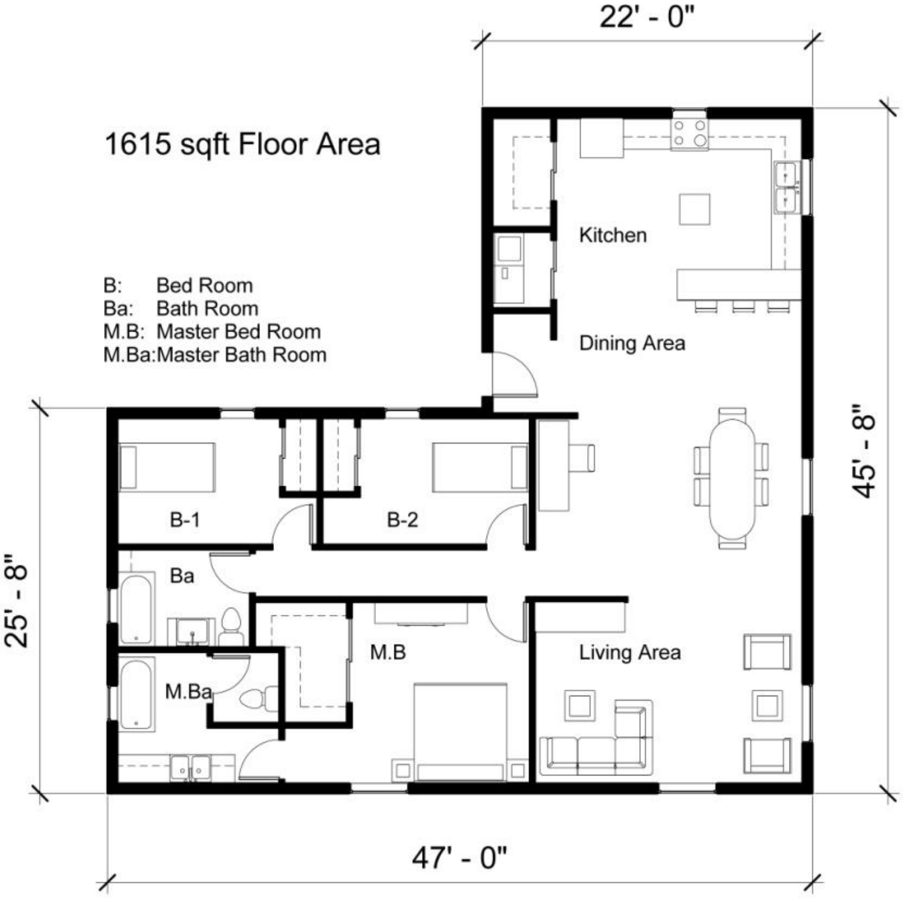


Figure 3-2 Residential model floor plan

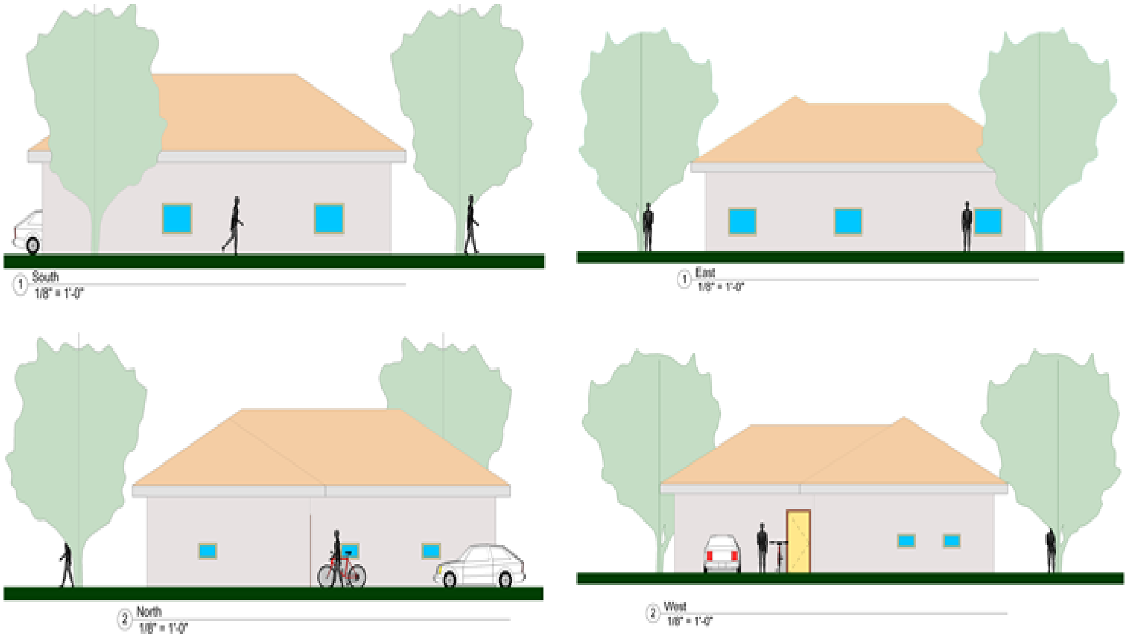


Figure 3-3 Residential model orientations

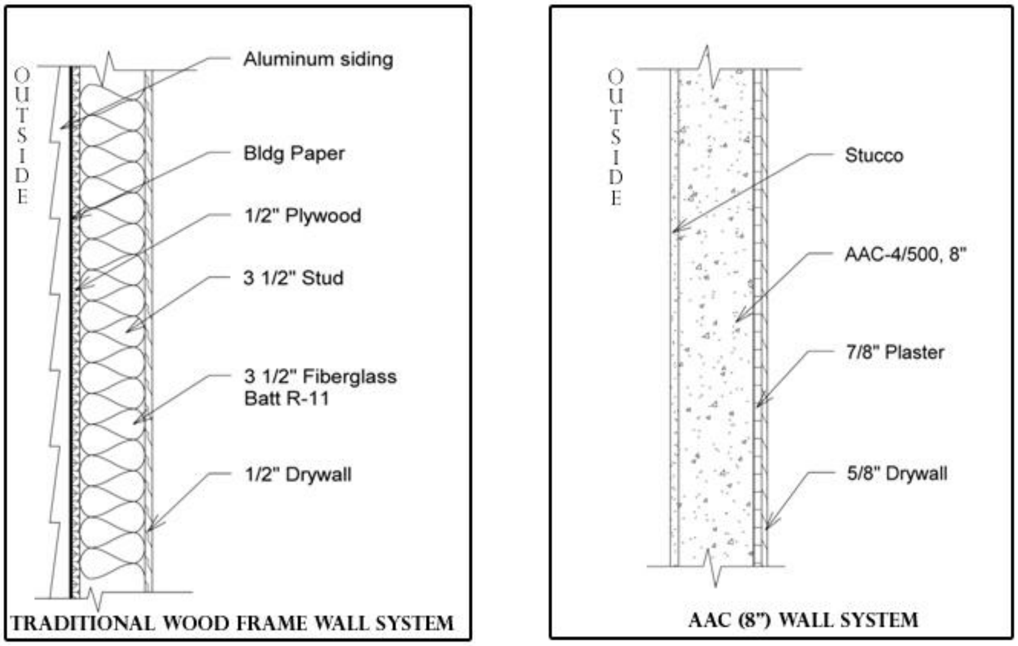
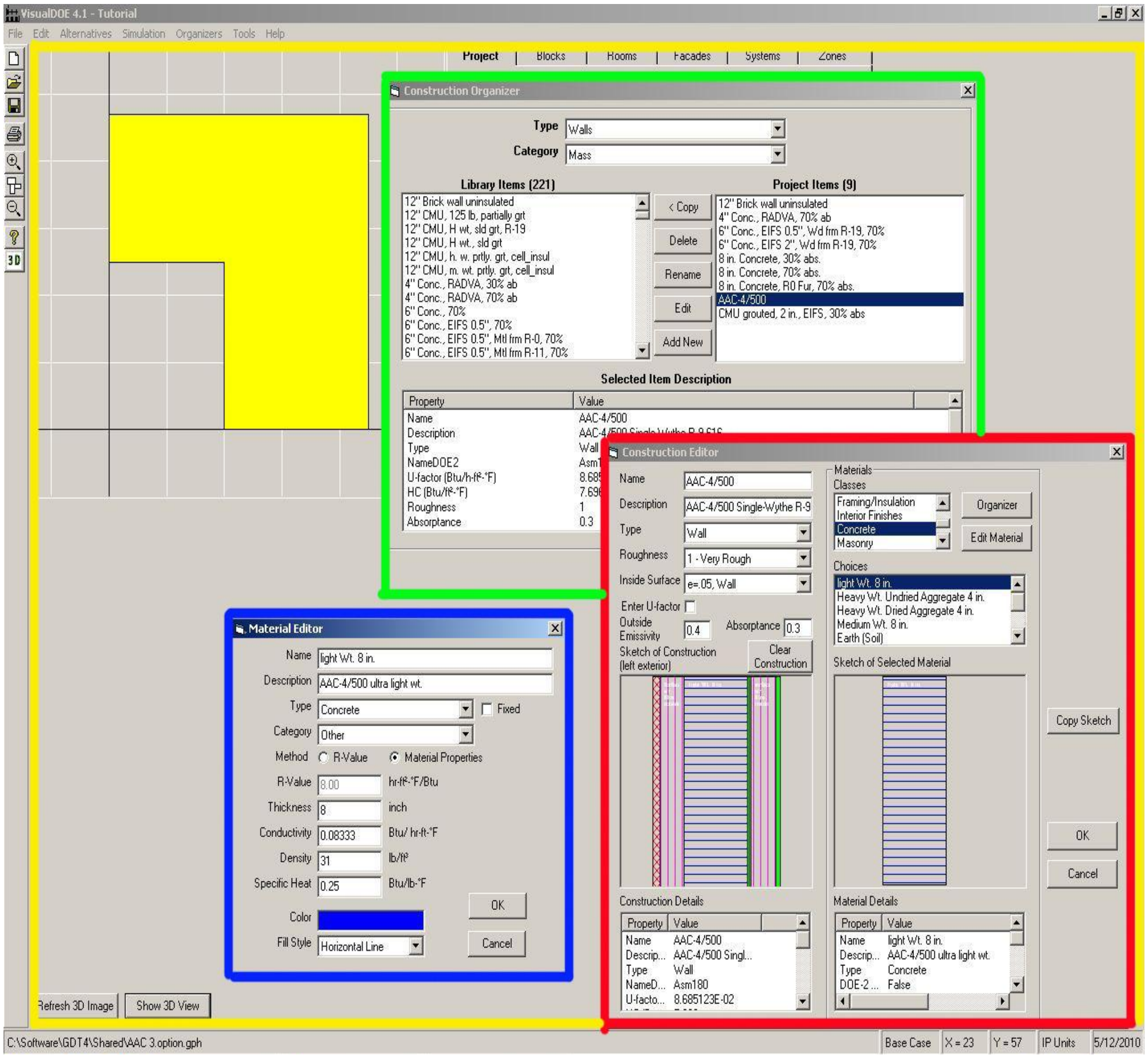


Figure 3-4 Residential model wall sections

Although containing several traditional construction materials, applicable to the models used in this research, Visual-DOE did not include AAC. If a building material is not available within the library; building materials can be amended by specifying thermal properties in “Material Editor.” Two options list for entering material properties for these materials: The first allows only two inputs such as R-value and thickness, and the second allows more detailed inputs such as thickness (inch), conductivity (Btu/hr-ft^{2}-^{0}F), density (lb/ft^{2}), and specific heat (Btu/lb-^{0}F). Attempts to accomplish accurate energy performance ratings on a thermal mass building system, which requires more than one R-value input for each material specified in the wall system. Therefore, the research study conducted at University of Alabama at Birmingham involved using the second option to customize the AAC wall system for more accurate results. Figure 3.5 for a screen shot of the Visual-DOE “Material Editor” that was used for adding a custom material to the library. The values of AAC inputs are as follows: thickness=8 inch, conductivity=0.08333 Btu/hr-ft-^{o}F, density=31 lb/ft^{3}; R-Value=8hr-ft^{2}- ^{o} F/Btu and specific heat=0.25 Btu/lb-^{o}F (Xella Aircrete N. America, Inc., 2010).



Construction Organizer

Type: Walls
Category: Mass

Library Items (221)
- 12" Brick wall uninsulated
- 12" CMU, 125 lb, partially grt
- 12" CMU, H wt, sld grt, R-19
- 12" CMU, H wt., sld grt
- 12" CMU, h. w. prtly. grt, cell_insul
- 12" CMU, m. wt. prtly. grt, cell_insul
- 4" Conc., RADVA, 30% ab
- 4" Conc., RADVA, 70% ab
- 6" Conc., 70%
- 6" Conc., EIFS 0.5", 70%
- 6" Conc., EIFS 0.5", Mtl frm R-0, 70%
- 6" Conc., EIFS 0.5", Mtl frm R-11, 70%

Project Items (9)
- 12" Brick wall uninsulated
- 4" Conc., RADVA, 70% ab
- 6" Conc., EIFS 0.5", Wd frm R-19, 70%
- 6" Conc., EIFS 2", Wd frm R-19, 70%
- 8 in. Concrete, 30% abs.
- 8 in. Concrete, 70% abs.
- 8 in. Concrete, R0 Fur, 70% abs.
- AAC-4/500
- CMU grouted, 2 in., EIFS, 30% abs

Selected Item Description

Property	Value
Name	AAC-4/500
Description	AAC-4/500 Single-Wythe R-9.616
Type	Wall
NameDOE2	Asm1
U-factor (Btu/h-ft²-°F)	8.685
HC (Btu/ft²-°F)	7.696
Roughness	1
Absorptance	0.3

Construction Editor

Name: AAC-4/500
Description: AAC-4/500 Single-Wythe R-9
Type: Wall
Roughness: 1 - Very Rough
Inside Surface: e=.05, Wall
Enter U-factor ☐
Outside Emissivity: 0.4
Absorptance: 0.3
Sketch of Construction (left exterior)

Materials
Classes
- Framing/Insulation
- Interior Finishes
- Concrete
- Masonry

Choices
- light Wt. 8 in.
- Heavy Wt. Undried Aggregate 4 in.
- Heavy Wt. Dried Aggregate 4 in.
- Medium Wt. 8 in.
- Earth (Soil)

Sketch of Selected Material

Construction Details

Property	Value
Name	AAC-4/500
Descrip...	AAC-4/500 Singl...
Type	Wall
NameD...	Asm180
U-facto...	8.685123E-02

Material Details

Property	Value
Name	light Wt. 8 in.
Descrip...	AAC-4/500 ultra light wt.
Type	Concrete
DOE-2 ...	False

Material Editor

Name: light Wt. 8 in.
Description: AAC-4/500 ultra light wt.
Type: Concrete ☐ Fixed
Category: Other
Method: ○ R-Value ● Material Properties
R-Value: 8.00 hr-ft²-°F/Btu
Thickness: 8 inch
Conductivity: 0.08333 Btu/ hr-ft-°F
Density: 31 lb/ft³
Specific Heat: 0.25 Btu/lb-°F
Color
Fill Style: Horizontal Line

C:\Software\GDT4\Shared\AAC 3.option.gph | Base Case | X = 23 | Y = 57 | IP Units | 5/12/2010

Figure 3-5 Visual-DOE screen shot for "Material Editor"

3.2.2. *Commercial Model*

The building footprint for the commercial model of 5850-square-foot and provides typical office space for 18-20 people. Figure 3-6 shows the office building floor plan, and Figure 3-7 illustrates the orientations of the model. Designed on a slab foundation, the building incorporates stucco applied to the

AAC block wall structure on all four sides of the exterior and aluminum siding applied to the metal-framed system on all four sides of its exterior.

Walls used in the commercial model were simulated and classified as either framed or mass structures. The framed wall consisted of a traditional metal frame with R-11 fiberglass batt insulation. AAC (4/500) 10-inch-thick blocks commonly prepared for commercial structures simulate a mass wall structure. Figure 3-8 illustrates wall sections of the commercial model wall section. The simulation included on the overall R-value of R-14 for the metal-framed system [$\sum$Metal-frame wall R= $R_{\text{outside-air}}$ (0.17)+$R_{\text{aluminum siding}}$ (0.68)+$R_{\text{bldg paper}}$ (0.06)+R_{plywood} (0.63)+$R_{\text{metal frame}}$ (negligible)+$R_{\text{fiber glass batt}}$ (11) + $R_{\text{inside-air}}$ (0.68) +$R_{\text{gypsum-board}}$ (0.56)] and an overall R-value of R-11 for the AAC system [$\sum$AAC R= $R_{\text{outside-air}}$ (0.17) +R_{stucco} (0.20) +R_{AAC} (10.05) +R_{plaster} (0.11) +$R_{\text{inside-air}}$ (0.68) +$R_{\text{gypsum-board}}$ (0.56)]. Because commercial construction does not commonly involve using wood, the simulation did not include this material.

Other specifications included roof insulation with a value of R-30, simulated slab floors with R-30 insulation, and two types of windows with 0.491 and 0.428 U-factors that depended on size of the window opening. The overall window-to-wall ratio was calculated as 11.5 percent.

(Left empty intentionally)

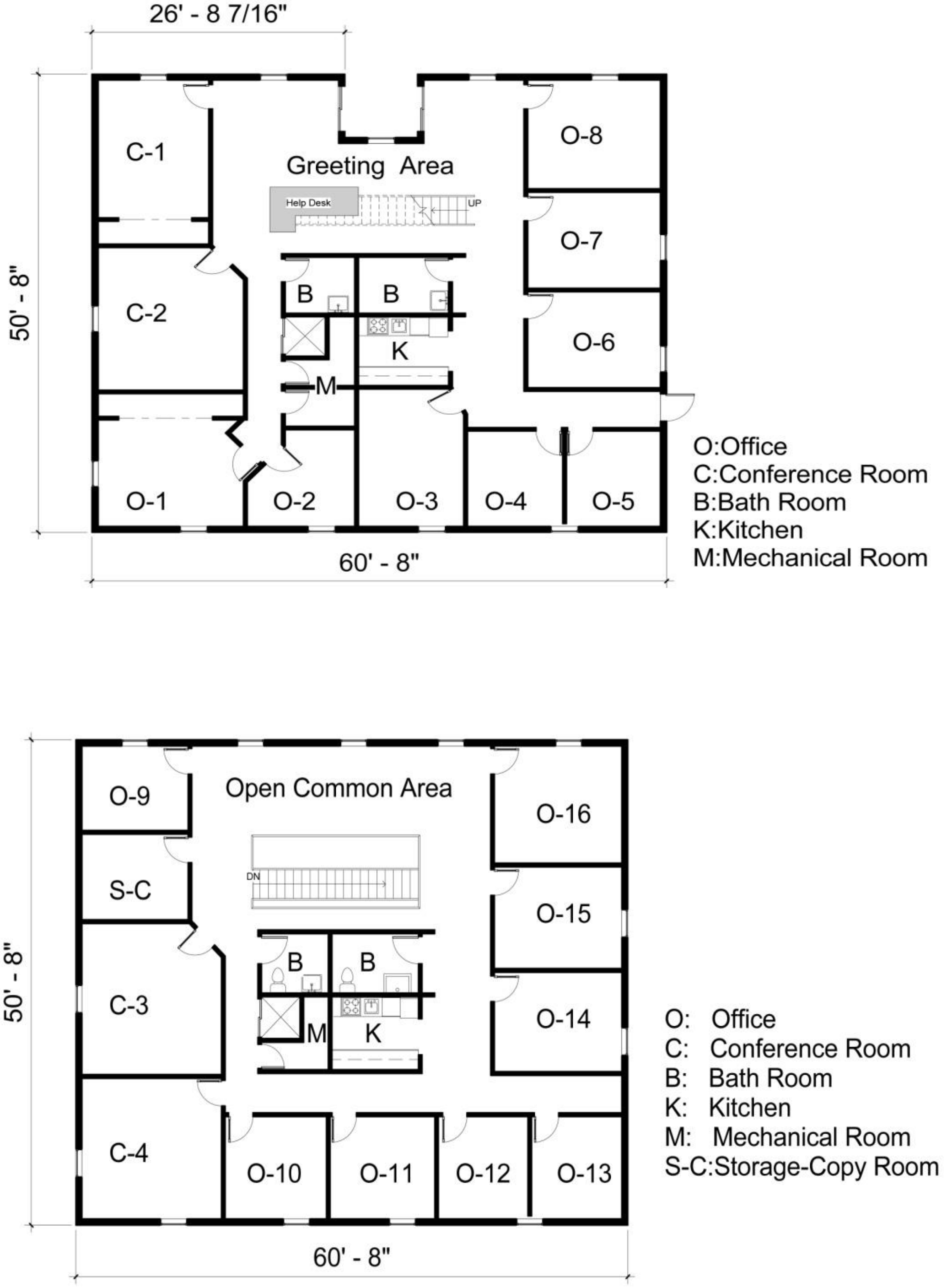


Figure 3-6 Office building model floor plan

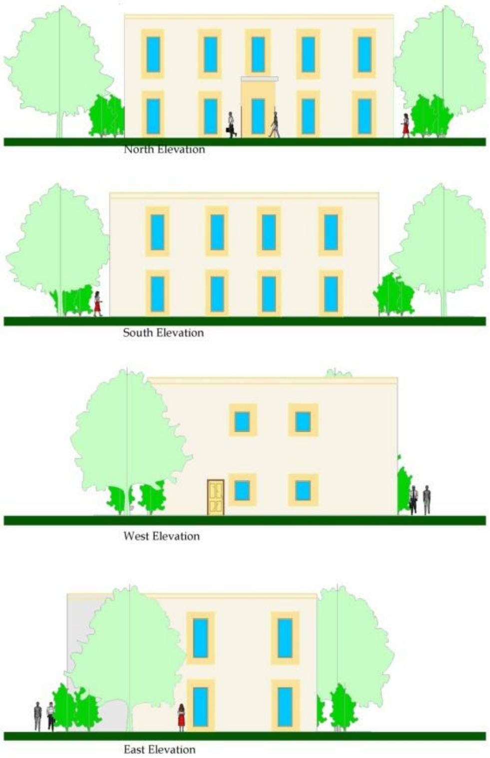


Figure 3-7 Commercial model (Office Building) orientations

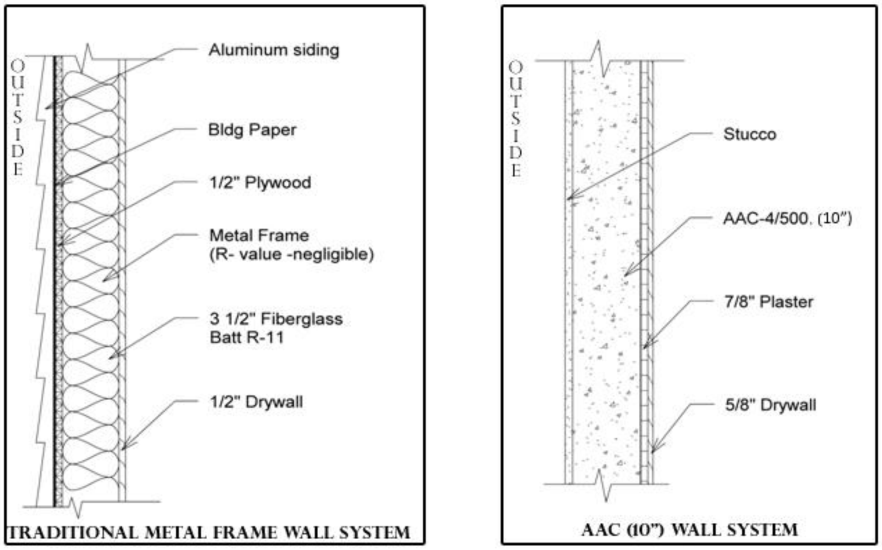


Figure 3-8 Commercial model wall sections

3.3. Data Collection and Instrumentation

The base model was compared with three (wood frame, metal frame, and AAC) models. Energy-efficiency properties for each model, discussed in section 4.1.1-4.15, were compared with the baseline model, located in Atlanta, Georgia. Additional analysis involved comparisons of the baseline model as being located in each of the 15 selected cities in the United States, as well as comparisons of each of the three models with the ASHRAE 90.1 standard. Together, these analyses enabled determination of the energy efficiency of each building construction method. Section 3.3.1 through 3.3.7 contains descriptions of the tasks included in this research.

Commercial and residential models designed in the Visual-DOE software provided the basis for determining the variations in energy savings for each of the four models (wood frame and AAC system in residential and metal frame and AAC system in commercial) described in Section 3.2.1 and 3.2.2. The purpose of simulating energy consumption for each of these models, some in different locations, consisted of ascertaining which model consumed the most energy during a one-month period and the way in which the selected material for each model affected the energy consumption for the baseline design model. HVAC energy consumption was evaluated for both residential and commercial models by month, for the traditional framed and the AAC systems. This approach contained two analyses, including:

- Evaluation of the wall system the models.
- Evaluation of building systems (wall, floor, and roof).

The first task consisted of identifying the energy-efficiency properties associated with residential and commercial structures and with different building construction methods. This task included comparing AAC building materials with traditional building materials. Elucidating the efficiency AAC was accomplished by comparing, each of the four models (residential, wood framed and AAC; commercial, metal framed and AAC) with the baseline model designed for Atlanta, Georgia.

3.3.1. Task I: Baseline model

Because the limited weather data available in the Visual-DOE program remain limited, Atlanta was selected as the representative baseline city in the region of the United States for which the Visual-DOE software uses weather data from actual recorded weather history. Simulation programs store one year's worth of weather data in order to predict how the performance of a building. Task I involved determining the energy-saving benefits by using a Visual-DOE software energy simulation model to define the most energy-efficient wall systems in the southern United States. Comparisons included the energy consumption of AAC and wood-framed construction for the residential structure, as well as the energy consumption of AAC and the metal-framed construction for the commercial structure. It was important to determine that, in comparison with traditional materials, AAC provides more energy-saving properties; once made, this determination enabled the conducting of additional analysis.

3.3.2. *Task II: Using the baseline model in 15 cities*

The second analysis involved analyzing the energy-saving properties of each of the four models located in 15 different U.S. cities. Table 3-3 lists the 15 cites selected for this task. These cities were selected on the basis of regional location and climate conditions and represent the five most populated districts of the nation. This task was consisted on assessing the impact of regional climate variations on the energy-saving benefits of using different construction methods for baseline model. Previous research (Arizona State University, 2007; Coradini, E., 2009; Heathcote, 2007; Kaska & Yumrutas, 2008; Kosny, 2000; Matthys & Barnett, 2004; Memari, Grossenbacher, & Lulu, 2008; Qvaeschning & Klemm, 2006) indicated that AAC provided significant energy savings in Europe, and might provide those same benefits in the United States. The instrumentation used to perform these simulations was the Visual DOE software.

3.3.3. *Task III: The ASHRAE 90.1 Standard model in the 15 cities*

The third analysis entailed quantifying the energy-savings benefits by comparing with the ASHRAE 90.1 Standard located in the 15 cities selected in task II. This task involved devising a method of analyzing individual building materials that provides viable estimations of the energy saving potential of a material and thereby helps manufacturers to better sell their product as a green building material. To maintain model consistency, I did not alter the required R-value for the components (wall, floor, and roof) during the execution of this task only the location varied.

Table 3-3 15 Cities selected for this study

City, State
Atlanta, Georgia
Boston, Massachusetts
Chicago, Illinois
Daytona, Florida
Houston, Texas
Madison, Wisconsin
Miami, Florida
Missoula, Montana
Minot, North Dakota
Philadelphia, Pennsylvania
Reno, Nevada
Richmond, Virginia
Sacramento, California
Springfield, Missouri
Tulsa, Oklahoma

3.3.4. *Task IV: Statistical analysis*

This section describes the statistical methods used to compare the energy consumption of the selected modeling systems via simulation results (i.e., software output analysis and paired t-test). The methodology used in this section consists of computational simulations of monthly HVAC consumption for residential and commercial structures in both the framed and the AAC systems. A two-paired t-test constituted the primary statistical tool used to determine the results for this research project. A description of this statistical analysis method follows next.

A two-paired t-test was used to analyze the statistical differences between energy performance of framed building systems and that of AAC building systems. The paired t-test proves useful when the same subject is measured twice under different conditions (often, before and after a treatment). In this case, the same model was simulated with two different materials. The paired t-test benefited this study because, at each city, only the differences between construction types were measured. This (same subject-different condition) greatly increases the power of the test over an independent samples t-test.

This section focuses on using the two-paired t-test to examine the statistical differences between the simulated energy performance of framed systems and that of AAC systems. *Lilliefors test* was used to justify the of the sample normal distribution. The following section provides the results of the statistical analysis.

The procedure for the paired t-test involved seven steps:

i. This step involved determining whether a statistically significant difference existed between the energy consumed by the simulated traditionally framed system and that consumed by the simulated AAC system.

ii. Visual-DOE software was used to calculate the average HVAC energy consumption (kWh) for the two building systems located in the 15 selected cities in United States. Excel software was used to for the paired t-test calculation.

iii. For each city, the statistical difference was calculated between the energy consumption estimates from the Visual-DOE software for the two building systems.

iv. The t-value, the average difference divided by its standard error was calculated.

v. The p-value, which corresponds to the t-value, and the degrees of freedom (degrees of freedom n-1 =14) were determined.

vi. The p-value is the probability that the observed difference between averages of the two models could have occurred by chance; if the p-value is less than or equal to 0.05, the difference between models is considered statistically significant.

vii. For each paired t-test, the Lilliefors p-value was added to justify a normal distribution. If the Lilliefors p-value (different value from the one discussed in sentences of v. and vi.) exceeds than 0.05, the sample came from a normal distribution, and the use of the parametric procedure (paired t-test) is justified.

Four tests are presented in two sections:

I. Residential and commercial wall systems
    i. Residential model: comparison of wood-frame system with AAC system
    ii. Commercial model: comparison with metal-frame system with AAC system
II. The model ASHRAE 90.1 minimum standard residential and commercial
    i. Residential model: comparison of wood-frame system with AAC system
    iii. Commercial model: comparison with metal-frame system with AAC system

For each comparison analysis, the paired-sample t-test was applied to compare the HVAC energy consumption (kWh) of the traditionally framed system with that of the AAC system.

This statistical method was applied to evaluate, by using Visual-DOE, the summer HVAC energy consumption of the framed and AAC systems in both the residential and the commercial models in 15 cities. The two-tailed hypothesis tested was as follows:

$H_0=$ the means are equal.

$H_1\neq$ the means are different.

Since the paired t-test uses the difference of values between the two treatments, the difference variable that should be approximately normally distributed. The Lilliefors test was performed to confirm the normality between the differences. Thus, a paired-t test was suited the generated data set. For each paired t-test, the p-value from the Lilliefors test was added to see whether the hypothesis was accepted or rejected.

This research was undertaken to identify the feasibility of evaluating individual building materials for their energy-saving benefits when applied to a whole building. By using four different models and comparing AAC to traditional building construction methods by testing several variables, I anticipated that the methods used would prove viable for determining the sustainable properties associated with individual building materials.

By analyzing both commercial and residential building types, each with its traditional construction methods, this study enabled the ascertainment of whether AAC is an energy-efficient building material in the United States; to accomplish this goal, I conducted several simulations located in 15 different cities in the United States. Additionally, results of this research may encourage the software industry to provide more tools to assist with the making of the proper sustainable decisions at the design phase, a point at which errors have a lower impact on cost. Through the methods described in Section3, I hope to take the green building industry to the next level by identifying a building system that maximizes energy performance and reduces costs associated with energy consumption.

3.3.5. *Task V: LEED evaluation of the material*

The fifth task conducted involved applying a performance-rating method required by the USGBC LEED Green Building Rating System to rate the energy performance and cost calculation of individual buildings. The LEED rating system awards credits based on energy performance, when energy consumption savings exceed the expectations provided by the basic requirements of the ASHRAE/ESNA 90.1-2007 code. A total of 1 to 19 points may be awarded for energy consumption reductions ranging from 12 percent to 48 percent for new buildings. Table 3-4 contains a minimum energy cost-saving chart.

Table 3-4 The minimum energy cost savings chart (USGBC, 2009b)

New Buildings (%)	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
Renovations (%)	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44
Points (#)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

I undertook this task to establish a document AAC energy performance. The documentation also presents the analysis and conclusions applicable LEED program, specifically the Energy and Atmosphere Credit 1, Optimize Energy Performance.

Two buildings were modeled with the use of the Visual-DOE program. One model followed the minimum ASHRAE 90.1-2007 standard (the baseline), and the second model exceeded the standard. Measuring the energy consumption of the baseline model led to the prediction of the annual energy consumption for a specific building design, with the intent to use the baseline model for the standard to determine which of the four construction methods exceeded the standard design model. The second model, which contained AAC wall, roof, and floor systems, was expected to exceed the current standards of the baseline model. Comparing the energy costs of the two buildings incorporated the use of the following method:

- Baseline Building Performance = BBP.
- Proposed Building Performance = PBP.
- Percent Improvement (%) = 100 × [1- (PBP)/BBP].

Whole building simulations produced data showing the total cost for electricity, gas, and other possible energy inputs. Method involved investigating the impact on LEED's Optimize Energy Performance credit of using an AAC system. For both designs, specifications included standard electricity for lighting for interior and exterior, service water heating, and equipment energy consumption. The study focused on only the potential impact of the building's envelope.

The selected LEED building type consisted of a commercial floor plan for a structure measuring 22,156 square-feet, enclosed, and suitable for an office of 80-90 people. Figure 3-8 illustrates the office building floor plan suitable for LEED credit. The building, designed on a slab foundation, included a stucco exterior applied to the AAC walls on four sides. The window type selected had

0.555 U-factors, dependent on size openings. Overall window-to-wall ratio was calculated as 9.8 percent.

Figure 3-8 The office building floor plan for LEED credit

Using the Visual-DOE program enabled the determination of the performance of proposed building. LEED requires an hourly energy load modeling tool such as Visual-DOE to verify green building materials. Adjustments of the model parameters for all loads, of the expected building occupancy profile, and of the schedule lead to identification of center system capacities and energy use by systems. Then, calculation of the baseline building performance takes place and involves adjusting the model parameters to meet the requirements listed in ASHRAE 90.1-2007. The baseline model and proposed design include the same plug and process loads, building occupancy profile, and schedule.

3.3.6. Task VI: Evaluation of future software programs

The sixth task consisted of establishing a framework that incorporates the innovations of currently available software and identifies additional needs for computational subroutines and decision pathways for green industry professionals in order to provide accurate building performance results. This framework will provide recommendations for the next generation of software that combines the best green design tools for sustainably minded design industry professionals to use to implement green designs and will also assist in LEED certification. This task was accomplished via these three subtasks:

- Identifying the components of the proposed framework for next-generation modeling programs for advanced energy simulation.
- Selecting software energy modeling programs with which to evaluate these components.

- Developing a classification scheme for comparing and ranking components on the basis of Sub-task 1 and Sub-task 2. Section 3.3.6.3 provides more details.

3.3.6.1. *Identification of the components.* The proposed framework took form based on updating viable concepts provided by U.S. DOE workshops (U.S. DOE-EERE, 1996) participants. The agenda of the workshop generated innovative ideas that potentially improve simulation software programs. In 1995 and 1996, The U.S. DOE Office of Building Technology, State and Community Programs held two workshops to improve existing energy-modeling programs and prioritize ideas for next-generation models. Energy simulation developers and expert users attended to the first workshop, called the Developer Workshop; a year later, users and other professionals attended the second one, called the User Workshop. Both groups generalized ideas and concepts about current software. A total of 1429 ideas and concepts resulted, and the participants then identified and prioritized similar topics of concern. The 86 participants, from U.S. DOE, Lawrence -Berkeley National Laboratory, U.S. Army Construction Engineering Research Laboratory, numerous U.S. and international universities, other government agencies, and private companies, agreed unanimously about the importance of using simulation programs in green design. Of the participant contributions, several hundred concepts underwent consideration as for future energy-modeling tools and comprise under the following categories:

- Applications.
- Capabilities.
- Methods and Structures.
- User Interfaces.

This task consisted of examining the 45 concepts considered of highest priority by attendees of the U.S. DOE workshop (U.S. DOE-EERE, 1996). Adding LEED compliance resulted in the inclusion of 46 concepts in the proposed framework of this research. Unfortunately, the LEED Green Building Rating System did not gain familiarity in the 1990s and therefore was not considered within U.S. DOE workshop priorities. Currently, considered one of the most prominent green building rating systems in the United States, the LEED system consists of a series of credits and includes categories in optimization of energy performance, use of daylight, on-site production of renewable energy, and heat island effect; this system warrants consideration considered in modeling tools. LEED compliances will be added to the modeling evaluated in this study.

3.3.6.2. *Selection of the evaluation tools.* Twenty of the most well known (having more than 1000 users) energy-modeling software programs were selected for use in this research task of defining a framework with which to identify the needs of designers and as a result, to enhance the accuracy of the next-generation programs developed to assess performance of future buildings. The following list contains the criteria used in selecting the software programs to evaluate.

- Must be developed to use in United States.
- Must be capable of simulating whole building energy performance.
- Must have at least 1000 users in the United States.

As of May 2011, the Building Energy Software Tools Directory provides information on 391 energy-related software programs, several of which are accessible and adaptable to differing international circumstances. Table 3-5 contains the Building Energy Software Tools Directory assemblies. Of those 391 tools, 231 (59.1%) were developed for use in the United States. A subset of 55 programs focuses on whole building analysis for energy simulation. However, because the criteria for inclusion contained a requirement that user's number 1000 or more, only 20 tools in the directory remained applicable to the evaluation. Table 3-6 contains a list of the energy software tools selected from the directory, and refer to Appendix B contains the complete list of 231 software tools.

3.3.6.3. *Evaluation of the software programs and the components.* The 20 selected energy-modeling tools were evaluated against 46 concepts utilized to identify the improvements made to the software programs from 1996 to 2011. The task consisted of determining the degree to which the software has improved during this period and estimating the direction of future improvements. After their identification, the Developer Workshop (U.S. DOE-EERE, 1996) priority vote and the User Workshop (U.S. DOE-EERE, 1996) priority vote were summed, and the total number of votes was used as a multiplier. A higher multiplier represents a higher priority, and lower multiplier signifies a lower priority. If the selected software enable the priority concept earns one point, and then it is multiplied by multiplier. The procedure yielded a ranking of the 20 software programs. Results from may encourage software designer to add the necessary improvement to their software to take the green building industry to the next level.

Table 3-5 Building Energy Software Tools Directory assembles
(Adapted from US DOE-EERE, 2011a)

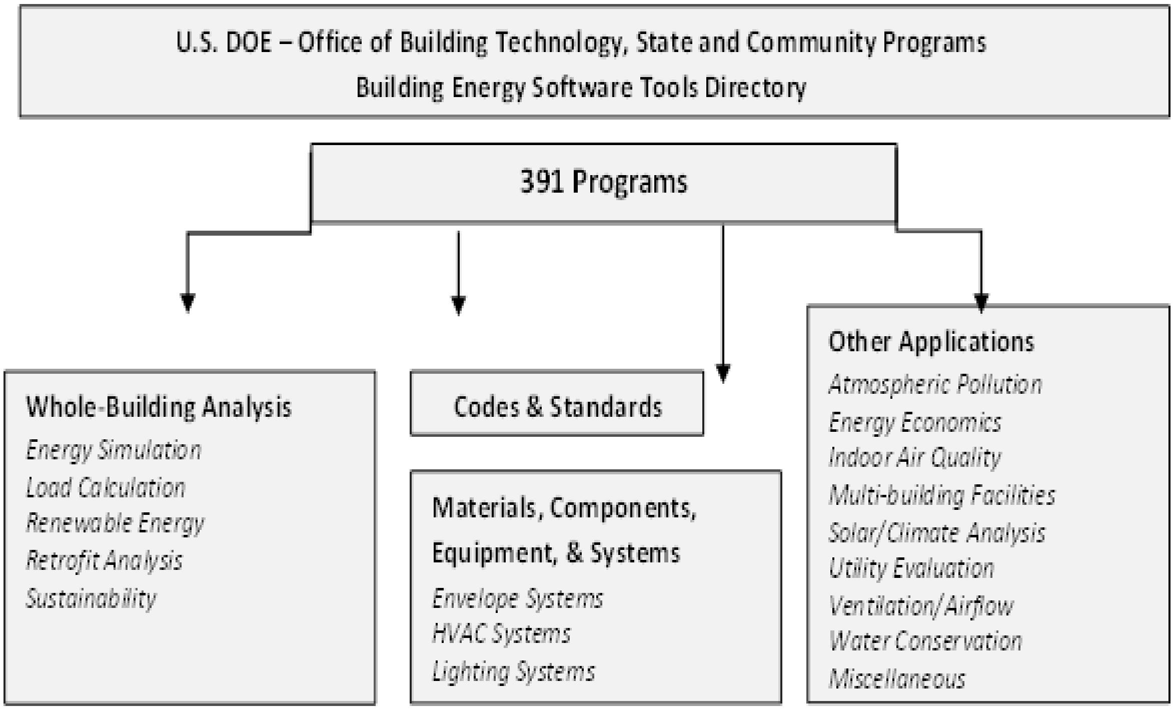


Table 3-6 Selected energy software tools from the directory

The number listed in the

Whole Building System Simulation (WBSS)

Have 1000 or more

Designed for

#	Name of the Programs	Application	USA	1000	WBSS
12	AUDIT	Operating Cost, Bin Data, Residential, Commercial	YES	YES	YES
36	COMSOL	Multi-Physics, Simulations, Modeling, Heat Transfer, Finite Element	YES	YES	YES
49	Design Advisor	Whole-Building, Energy, Comfort, Natural Ventilation	YES	YES	YES
51	DOE-2	Energy Performance, Design, Retrofit, Research, Residential & Commercial Buildings	YES	YES	YES
62	ECOTECT	Energy Data Management, Sustainable Design On-Line Data Archive, environmental analysis, conceptual design, validation; Passive design, thermal design/analysis, heating/cooling loads, natural/artificial lighting, LCA, LCC	YES	YES	YES
77	Energy-10	Conceptual Design, Residential & Small Commercial Buildings	YES	YES	YES
84	Energy Plus	Energy Simulation, Load Calculation, Building Performance, Simulation	YES	YES	YES
85	Energy Pro	California Title 24 Compliance, Commercial & Residential Energy Simulation	YES	YES	YES
86	Energy Savvy	Efficiency Calculation, Energy Rebates, Home Contractor Search	YES	YES	YES
91	e-QUEST	Energy (Performance, Simulation, Analysis, & Efficiency), LEED EA Credit Analysis, Title 24 Compliance Analysis, LCC, DOE 2, Power-DOE, Design Wizard	YES	YES	YES
97	FEDS	Single/Multi-Building Facilities, Central Energy Plants, Thermal Loops, Energy Simulation, Retrofit Opportunities, LCC, Emissions Impacts, Alternative Financing	YES	YES	YES
109	HAP	Energy Performance, Load Calculation, Energy Simulation, HVAC Equipment Sizing	YES	YES	YES
113	HEED	Building Simulation, Energy Efficient/Climate Responsive Design, Energy Costs, IAQ	YES	YES	YES
117	HOMER	Remote Power, Distributed Generation, Optimization, Off-Grid Design	YES	YES	YES
139	Market Manager	Building Energy Modeling, Design, Retrofit	YES	YES	YES
143	Micropas6	Energy Simulation, Heating- Cooling Loads, Residential units, Code Compliance	YES	YES	YES
180	Right-Suite Residential	Residential Loads Calculations, Duct Sizing, Energy Analysis, HVAC System Design	YES	YES	YES
187	SOLAR-5	Design, Residential And Small Commercial Buildings	YES	YES	YES
212	TREAT	Weatherization Auditing, BESTEST, Home Performance W/Energy Star, Retrofit, Single & Multifamily Residential, Mobile Homes, HERS Ratings, Load Sizing.	YES	YES	YES
222	Visual-DOE	Energy (Efficiency, Performance, Simulation), Design, Retrofit, Research, Residential & Commercial Buildings, HVAC, DOE-2	YES	YES	YES

The rest of programs in the Table are provided in Appendix B; these are the only 20 selected programs for the study.

3.3.7. *Task VII: Identifies the needs for the future software*

Task VII essentially consisted of providing results and identifying needs for future generations of software that evaluate a building's energy consumption. The ranking system used in the evaluation incorporated the priority voting resulting from the DOE workshops (U.S. DOE-EERE, 1996). The task included in this research study involved selecting several energy simulation programs and creating a technique with which to evaluate the proposed framework components established specify section. The two approaches are applied in this section include selecting the most commonly used energy simulation programs and reevaluating them on the basis of the proposed priority concepts established in Task VI.

3.3.8. *Selection of the Research Modeling Tool*

Visual-DOE (see Section 2.7) software was used to perform all simulations for the study, in part because this university calibrated and validated this tool in 2008 for a previous study (Selim, 2008). The Visual-DOE software uses the DOE-2 engine (see Section 2.6), which can perform an hourly assessment of the energy performance of the building. Because this engine can determine heat balance and weigh the thermal behavior of wall system construction, it can provide accurate results.

Visual-DOE 4.0 provides hourly weather data for 239 locations in the United States and for some locations in Asia, Australia, Europe, Africa, and

Canada (GARD Analytics, 2005). It is important to understand the Visual-DOE categorization of energy consumption, which the analysis report of the software divides into electricity and gas consumption.

In the Visual-DOE analytical report, the section on electricity consumption contains information concerning the annual energy consumption in kilo-watt hour (kWh) for electrical end uses (interior lights, interior equipment, cooling [chillers], tower, fans, and miscellaneous electric uses). Reports produced from such data were analyzed with the use of the DOE-2 engine. The section on fuel consumption in the Visual-DOE report provides information on the annual fuel end uses for the selected alternatives, including heating, domestic hot water, and miscellaneous uses. In comparison with the simulated models for AAC for metal and wood-framed systems have a higher R-value (wood-framed system R-18; metal-framed R-14; AAC system, R-10 for residential and R-11 for commercial). However, the unique thermal mass characteristics of AAC extend the insulating capacity of this building material. Despite having a lower initial R-value, AAC yield estimated cooling costs lower than those focused for traditional framed systems. The ability to store and release thermal energy allows AAC to effectively reduce energy consumption and to smooth the diurnal thermal profile.

The Visual-DOE software provides an option to use several building envelope types, including standard block construction as a building material, by allowing quick, customizable models for specific design analysis. Because this study required an evaluation of several unique wall systems, this software proved the best choice for the simulation evaluation needed to obtain the goals of the study. Another reason for selecting the Visual-DOE software consisted of its new feature, which includes on LEED style end-use report found to be of great assistance in accomplishing the objectives of this research. As a result, many sustainable building professionals have utilized the Visual-DOE software as a platform for their academic research (Gundala, 2003; Hassan, 2006; Iqbal and Mohammad, 2007; Radhi, 2008; and Selim, 2008). Section 2.8.1 contains validation of the Visual-DOE.

3.4. Limitations

3.4.1. Software Limits

Users of energy analysis tools should be aware that energy calculations, regardless of their sophistication, cannot precisely estimate energy consumption. Construction quality, number of occupants, and maintenance constitute some factors that could affect predicted software results (Paradis, 2010). However, this caveat does not mean that energy analyses are not imperative tools. As mentioned in the Section 2.8.1, research confirms that software simulation of energy consumption produce results close to actual level of energy consumption (range of ± 9).

3.4.2. *Insufficient Detail and Unclear Language*

Two limits identified during this research that related to energy-modeling tools include the facts that the results (1) use ambiguous language and (2) provide limited detail. Descriptions of results incorporate specific technical language difficult to understand for the wide range of users of simulation technology.

Simulated results offer improved benefits when presented by the modeling program in a language understood by even the least experienced users. Utilizing clear outputs leaves nothing to be assumed by the user. An efficacious output report includes monthly and annual energy consumption, as well providing results from the following areas:

- Heating and cooling
- Domestic hot water
- Mechanical system electrical consumption
- Lighting electrical consumption
- Plug load electrical consumption
- All other equipment that requires energy for operation.

Most important, an effective report indicates heating and cooling consumption specified by the building component type (e.g., the amount of consumption attributable to walls, roofs, windows, infiltration, and ventilation air). These detailed results help designers decide which areas will provide the largest savings. In addition, providing results in the form of a graphical illustration limits the amount of paper needed to properly convince building designers to implement recommended energy-saving strategies. Such illustrations can neatly and concisely summarize the data.

3.4.3. LEED (Commercial) Energy Credit

Visual-DOE requires minimal training to accurately use the software and properly model a structure. Specifying the geometry and materials of a building take place more quickly with Visual-DOE than with other comparable software, making it a useful tool for schematic design studies the envelope (U.S. DOE-EERE, 2011c). Overall, Visual-DOE, powerful program, quickly evaluates potential energy savings associated with incorporating design options for sustainable or green building. The latest Visual-DOE latest update, Version 4.0, contains an LEED style end-use report. However, the latest version of the LEED guideline feature of this software is insufficient; obtaining the necessary results requires on excessive length of time. Visual-DOE 4.0, a baseline design alternative created separately from the proposed design alternative, runs separately from the design alternative. After running the simulations, the user results for each of the comparisons. Another downfall consisted of that the report cannot be edited and can only be printed.

Effective software provides the baseline, as described in the ASHRAE 90.1 standard model, immediately after performing the proposed design alternative simulation. The simulated results for both design models need displaying in one report. In addition, the software user should enable a user to click on a link to access output for the possible points attained for LEED credit for optimizing energy performance. These implemented design features should allow designers (users) to accurately and quickly make important design decisions.

3.4.4. LEED (Homes) Energy Credit

One limitation associated with this study is that currently available software cannot support the parameters of the LEED Home Rating System. "The overall energy performance of a new home cannot be measured until after home is built" (USGBC, 2009d). However, energy simulation modeling enable designers to predict energy consumption and, as a result, to take necessary precautions. The nationally accepted guideline for residential structures, the Residential Energy Services Network (RESNET), developed the Home Energy Rating System (HERS) to evaluate of the energy performance of the residential structures. Evaluating energy efficiency requires optimizing energy performance credits for residential structures (USGBC, 2009d).

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3.5. Delimitations

3.5.1. Concrete versus AAC

Although many manufacturers of concrete products in deem materials energy efficient, this research only included AAC. Concrete has been a leading building material for centuries. In response to growing concern about environmental and economic impacts, green professionals seek more efficient, innovative building solutions that conserve nonrenewable resources. Concrete is known for its strong environmental benefits and effective sustainable development (NRMCA, 2010).

3.5.2. Energy-Efficiency Properties of AAC Block Systems

AAC units exist in various shapes and sizes. This research analysis involved using energy-simulated models of 8-10-and 12-inch wall, floor, and roof systems. AAC offers many benefits. The following list includes some of these benefits.

- Energy efficiency
- Fire-rating benefit
- Structural integrity
- Acoustical benefits
- Moisture resistance

The research focused on only the energy-efficiency benefits of the AAC.

3.5.3. R-value and Thermal Mass

Materials properties possess five elements that affect energy efficiency, but this research focused on only R-value and thermal mass. A typical wall system consists of a *clear wall;* corners; window and door apertures; and wall intersections with the foundation, ceiling, and interior walls and floors. Energy efficiency in advanced wall systems involves implementing a more holistic approach, or a *whole wall* system, that focuses on areas such as air tightness, thermal mass, durability, and sustainability (Kosny & Christian, 2001). This research focused on solely the energy performance of the thermal properties of the wall systems. Because software capabilities remain insufficient each component requires different software to run simulations; therefore, results of earlier research (Kosny & Christian, 2001) suggest that a need exists for developing either interoperability (combination of a group of the tools) or one tool containing all components necessary to run advance simulations.

3.5.4. LEED NC and LEED Homes

In the United States, many programs exist for evaluating green building design and construction. The construction industry has adopted the USGBC LEED Rating System, the most widely adopted standard, and as the standard for determining the degree of sustainability of a building (Morris & Matthiessen, 2007).

USGBC created several rating systems for the project types: LEED for New Construction and Major Renovations, LEED for Commercial Interiors, LEED for Existing Buildings, LEED for Core and Shell, LEED for Schools, and LEED for Homes. Several new rating systems remain under development, including LEED for Neighborhood Development, LEED for Healthcare, LEED for Retail, LEED for Retail Interiors, and LEED for Existing Schools. This document addresses only LEED 2009 NC for New Construction and Major Renovations (commercial) and LEED Homes.

The LEED 2009 NC Rating System consists of seven credit categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Quality, Innovation in Design, and Regional Priority. The study involved a concentration on Energy and Atmosphere (EA) Credit 1, Optimize Energy Performance.

4. DISCUSSION OF RESULTS

4.1. Introduction

Seven tasks were conducted for this research to identify a method of properly selecting energy-efficient building materials. These tasks, undertaken to by evaluate the potential of the material in a built structure to earn LEED credits led to the establishment to provide suggestions for improving currently available simulation software. This framework will enhance the viability of the estimates concerning energy efficiency and achieving LEED credits. Visual-DOE software was used to conduct all necessary model simulations for this research study in order to identify the energy consumption each of models used in this study.

This chapter contains a brief summary of each task and a description of the results obtained from the research analysis. Each of the seven tasks and its results are discussed and described in reference to the hypothesis. Additionally, the chapter includes answers to the questions posed before the start of this research.

The four baseline models designed for the analysis for this portion of the research included the residential model, traditional wood-framed and AAC-constructed models, and commercial traditional metal-framed and AAC-constructed models. Sections provide the results related to each of these models.

4.1.1. Model in Atlanta

According to Visual-DOE energy simulation results, the electricity consumption for the residential structure located in Atlanta, Georgia (i.e., air conditioning) measured an estimated 6114 kWh. In contrast, a wood-framed residential structure consumed an estimated 7011 kWh. Comparing traditional framed constructions with AAC construction for the four models (two residential and two commercial building types) in Atlanta, Georgia yielded results indicating that, in both residential and commercial structures, that AAC consumed less electricity but more gas. In comparison with the traditional wood-framed residential structure, the AAC residential structure used 14.7 percent less electricity; likewise, in comparison with the traditional metal-framed commercial structure, the AAC commercial structure consumed 11.6 percent less electricity. On the other hand, the AAC residential structure consumed11.0 percent more gas than the traditional wood-framed structure. This disparity occurs because, in some climates; thermal mass can actually increase winter energy consumption. In some locations, little possibility exists for solar gain on the north side of structure; therefore, the structure may require supplementary hearing to warm the mass material. In this case, insulation may be needed for the external layer in the building envelope on north-facing wall. Because this research focused on to evaluating the AAC material by itself and without added insulation, the analysis revealed that, in some cases AAC consumed more fuel in winter.

Comparing the AAC commercial structure AAC structure consumed 20 percent less gas for heating. The results from this study indicate that AAC reduces electricity consumption for cooling in both residential and commercial structures and reduces gas consumption for heating in commercial structures. Table 4-1 provides results from this simulation analysis of the residential and commercial structures modeled for Atlanta, Georgia.

Table 4-1 Visual-DOE annual energy (Location: Atlanta)

Wall Types	**Electrical (HVAC) (kWh)**	**Gas (heating) (Therm)**
	Residential	
AAC	**6,114**	**583**
Wood	**7,011 (14% > AAC)**	**525 (11%<AAC)**
	Commercial	
AAC	**45,610**	**606**
Metal	**50,889 (11%>AAC)**	**731 (20%>AAC)**

The simulated commercial model indicates that the AAC model outperforms metal-framed buildings by 11percent in cooling efficiency. In heating efficiency, the AAC model outperforms by 20 percent.

The results from this analysis support the hypothesis that computer simulation modeling can be an accurate, useful tool with which to evaluate sustainable building performance in relation to an established standard. In addition, this modeling has the ability to compare the energy consumption of emerging building materials. For these reason, energy simulation using the Visual-DOE software enable identification of the most energy-efficient building material.

It was hypothesized that, in comparison with traditional wall systems, AAC consumes less HVAC energy because AAC is considered a thermal mass product. The research findings from this study support the research hypothesis and indicate that the selected software is a potentially viable resource for evaluating differences in the energy consumption of different wall sections. Visual-DOE software results support the well known fact the thermal bridges of a metal-framed structure produce heat loss. In comparison with wood and other mass materials, metal conducts much more quickly therefore, the thermal resistance of the metal-framed structure cause adversely affects insulating properties and heat retention. Thermal mass such as AAC reduces the heat transfer rate but does not reduce heat transfer and as a result, requires additional insulation as a means of increasing heat retention.

4.1.2. Models in 15 Cities

In this section, the discussion revolves around the use of Visual-DOE software to analyze the models and compare framed and AAC wall systems for both residential and commercial structures in 15 different cities, each with different climates, in order to define the most energy-efficient wall systems. The analysis for simulation study incorporates the use of baseline models.

The annual HVAC and heating energy consumption were analyzed for both residential and commercial models. The analysis included of wood-framed and AAC systems for the residential model and comparison of metal-framed and AAC systems for the commercial model. For a graphical summary of the results for each of the 15 cities, refer to Table 4-2 for the residential structure and Table 4-3 for the commercial structure. The cities in the tables are arranged from northern latitudes to southern latitudes. Figures 4-1, 4-2, 4-3, and 4-4 depict the Visual-DOE output.

This task involved analyzing the same models without changing any components. Because structures located in the northern hemisphere require a higher R-value for insulated materials than those structures located in the southern region need, this factor remained unchanged to keep the models consistent for this analysis. The purpose of this consisted of determining the responded modeling tool to the climate conditions in different locations and understanding the performance of AAC in the northern region of the United States when the baseline model remained the same.

When compared to the baseline model in Atlanta, Georgia, the results for the residential model follow the same trends found in the previous analysis. For these structures, AAC provided better energy-efficiency properties for HVAC electrical consumption than for HVAC gas consumption. A comparison of the HVAC energy consumption of the AAC structure and the traditional wood-framed structure showed that the AAC consumed 4 to 15 percent less electricity and 4 to 21 percent more gas.

When compared with the results from the analysis of the baseline models, the results for the commercial structure also followed the same trends. AAC buildings consumed 8 t o 12 percent less HVAC energy than the traditional metal-framed building used. Because of the unique thermal properties of AAC the building constructed with this material also consumed less gas, with energy savings of 12 to 34 percent. Thermal mass can reduce peak load in an air-conditioning system and reduce heat gain during the summer but requires additional insulation in colder climates (Lechner, 2009). As Tables 4-2 and 4-3 indicate, that energy efficiency does not depend on the location or climate zone; the results show that the AAC system model consumed less HVAC energy than either of the framed systems used. The models for Task 1 and 2 indicate a pattern of energy savings with AAC-constructed buildings. This finding indicates that specify this method of determining potential energy savings is viable for estimating a building's energy performance.

Table 4-2 Residential models annual energy usage

		HVAC Energy Use (kWh)			Gas Heating (Therm)		
City, State	**Latitude**	**Wood**	**AAC**	**Progress**	**Wood**	**AAC**	**Progress**
Minot, ND	48	4336	3835	12%>AAC	828	831	0%AAC
Missoula, MT	46	4001	3221	19%>AAC	644	656	2%<AAC
Richmond, VA	44	4084	3263	20%>AAC	382	418	9%<AAC
Madison, WI	43	3897	3326	15%>AAC	638	660	3%<AAC
Boston, MA	42	3770	3119	17%>AAC	562	601	7%<AAC
Chicago, IL	41	4032	3404	16%>AAC	598	640	7%<AAC
Philadelphia, PA	39	4161	3483	16%>AAC	511	563	10%<AAC
Reno, NV	39	3976	2973	25%>AAC	436	486	11%<AAC
Sacramento, CA	38	4681	3492	25%>AAC	487	504	3%<AAC
Springfield, MO	37	4585	3765	18%>AAC	461	500	8%<AAC
Tulsa, OK	36	6084	5211	14%>AAC	635	678	7%<AAC
Atlanta, GA	33	4995	4118	18%>AAC	504	536	6%<AAC
Houston, TX	29	5392	4170	23%>AAC	278	283	2%<AAC
Daytona, FL	29	4973	3721	25%>AAC	166	161	3%>AAC
Miami, FL	25	5180	3767	27%>AAC	36	27	25%>AAC
SUM		68147	54868	24%>AAC	7166	7550	5%<AAC

Table 4-3 Commercial models annual energy usage

		HVAC Energy Use (kWh)			Gas Heating (Therm)		
City, State	**Latitude**	**Metal**	**AAC**	**Progress**	**Metal**	**AAC**	**Progress**
Minot, ND	48	40233	33251	17%>AAC	1188	1042	12%>AAC
Missoula, MT	46	37317	29631	21%>AAC	1166	1040	11%>AAC
Richmond, VA	44	47118	38486	18%>AAC	951	824	13%>AAC
Madison, WI	43	43861	36291	17%>AAC	1141	1021	11%>AAC
Boston, MA	42	43303	35653	18%>AAC	1002	876	13%>AAC
Chicago, IL	41	44755	36387	19%>AAC	1059	929	12%>AAC
Philadelphia, PA	39	45761	37592	18%>AAC	1223	1098	10%>AAC
Reno, NV	39	36577	29797	19%>AAC	1041	919	12%>AAC
Sacramento, CA	38	39824	33084	17%>AAC	831	690	17%>AAC
Springfield, MO	37	47969	38733	19%>AAC	1082	980	9%>AAC
Tulsa, OK	36	48466	38631	20%>AAC	962	843	12%>AAC
Atlanta, GA	33	48883	40453	17%>AAC	814	692	15%>AAC
Houston, TX	29	53933	44430	18%>AAC	509	398	22%>AAC
Daytona, FL	29	55444	45703	18%>AAC	355	253	29%>AAC
Miami, FL	25	56449	47153	16%>AAC	146	82	44%>AAC
SUM		689893	565275	22%>AAC	13470	11687	15%>AAC

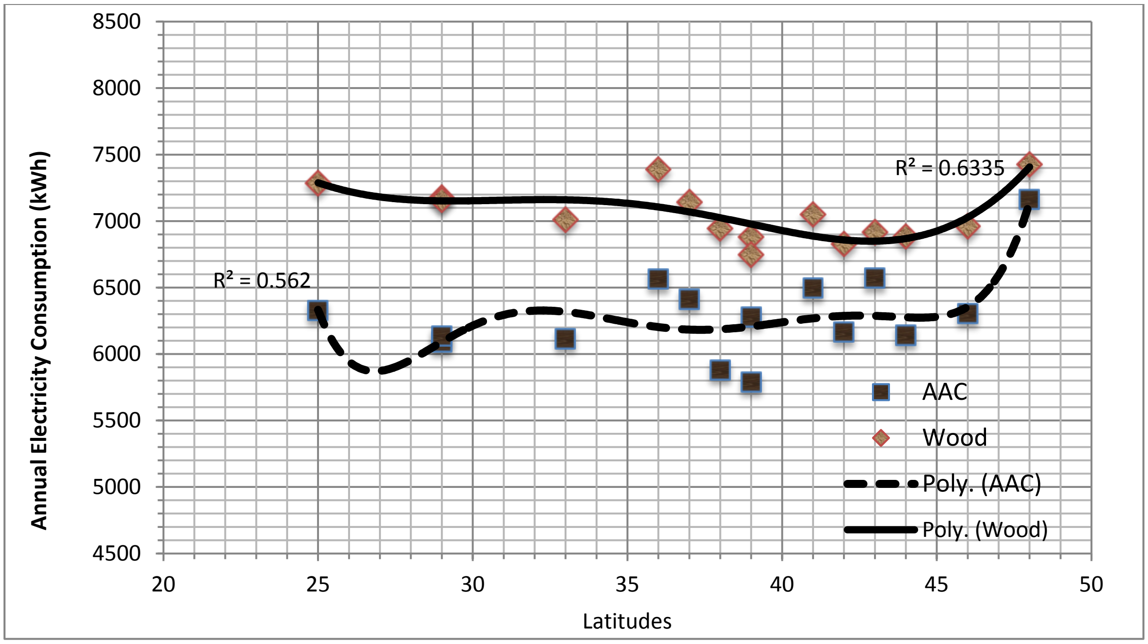

Figure 4-1 Residential models annual HVAC energy usage

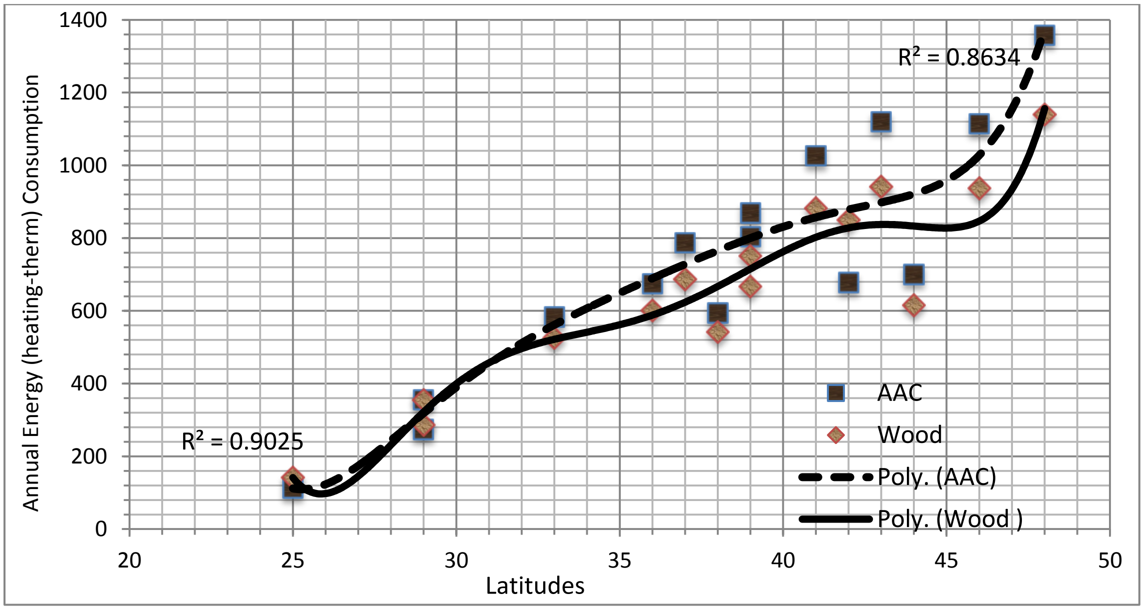

Figure 4-2 Residential models annual heating energy usage

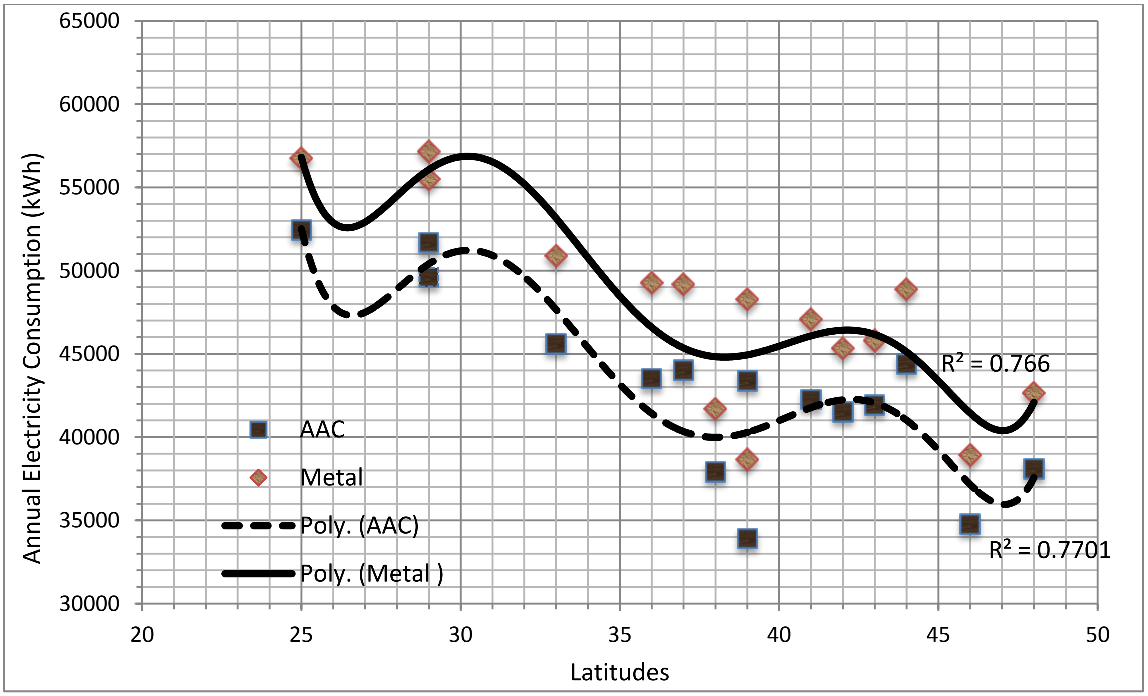

Figure 4-3 Commercial models annual HVAC energy usage

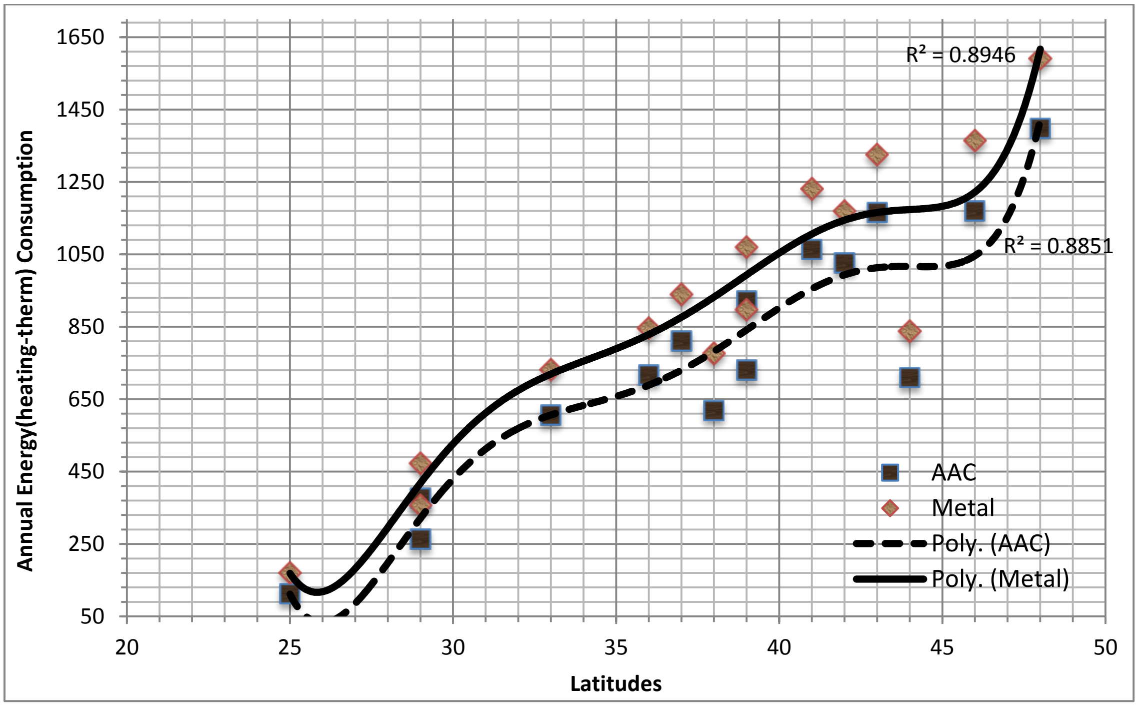

Figure 4-4 Commercial models annual heating energy usage

The results from this analysis support the hypothesis that computer simulation modeling proves an accurate, useful tool for evaluating sustainable building performance in terms of an established standard and for comparing the energy consumption of emerging building materials. Therefore, energy simulation using the Visual-DOE software identifies reliably the most energy-efficient building material.

4.1.3. Models in 15 cities compared to ASHRAE 90.1-2007 Standard

This section contains a description of the results from the framed and AAC, residential and commercial models designed with the minimum requirements from the ASHRAE 90.1 and simulated in 15 different cities. Table 3-1 and Table 3-2 provide ASHRAE 90.1 minimum standards within different climate zones for residential and commercial buildings respectively. Figure 3-1 illustrates of the IECC climatic map.

The residential model included traditional wood-framed and AAC building systems, and the commercial model consisted of traditional metal-framed and AAC building systems. Both the residential and the commercial models were to analyze the annual HVAC and heating energy consumption. Results from this analysis indicated pattern similar pattern as to that found in previous analyses. When applied to the residential structure, AAC the HVAC energy consumption was 12 to 27 percent lower than that found for the baseline model. On the other hand, application hand of AAC to the residential structure produced several different results for gas consumption. Thirteen of the 15 cities followed the same pattern seen in earlier result in the study, in which AAC proved the less efficient material for gas consumption; however, findings for Miami and Daytona, both in Florida, indicated that AAC was the more efficient material by 3 and 25 percent, respectively. Supplementary heating may be required to warm the mass material, and in some climate insulation may be needed for the external layer in the building envelope on north-facing wall. The focus of this research is to evaluate the AAC without adding insulation; therefore, in some cases in the analysis, AAC consumed more fuel in winter.

For the commercial structure, the results followed the same pattern as in previous results. In comparison with the traditional metal-framed structure, AAC proved more efficient by 17 to 21 percent for HVAC and more efficient by 9 to 17 percent for gas consumption. Table 4-4 contains results from the comparison of the residential model with the ASHRAE 90.1 standard, and Table 4-5 provides results from the comparison of the commercial model with this standard.

This analysis also involved studying a wall section for both the commercial and the residential models by comparing annual rates of energy consumption for traditional construction methods with those for AAC systems. The results for the residential AAC wall section indicated that AAC wall sections are 12 percent more energy efficient for HVAC energy consumption.

Table 4-4 Residential models (ASHRAE 90.1) annual energy usage

HVAC Energy Use (kWh)					Gas Heating (Therm)		
City, State	**Latitude**	**Wood**	**AAC**	**Progress**	**Wood**	**AAC**	**Progress**
Minot, ND	48	4336	3835	12%>AAC	828	831	0%AAC
Missoula, MT	46	4001	3221	19%>AAC	644	656	2%<AAC
Richmond, VA	44	4084	3263	20%>AAC	382	418	9%<AAC
Madison, WI	43	3897	3326	15%>AAC	638	660	3%<AAC
Boston, MA	42	3770	3119	17%>AAC	562	601	7%<AAC
Chicago, IL	41	4032	3404	16%>AAC	598	640	7%<AAC
Philadelphia, PA	39	4161	3483	16%>AAC	511	563	10%<AAC
Reno, NV	39	3976	2973	25%>AAC	436	486	11%<AAC
Sacramento, CA	38	4681	3492	25%>AAC	487	504	3%<AAC
Springfield, MO	37	4585	3765	18%>AAC	461	500	8%<AAC
Tulsa, OK	36	6084	5211	14%>AAC	635	678	7%<AAC
Atlanta, GA	33	4995	4118	18%>AAC	504	536	6%<AAC
Houston, TX	29	5392	4170	23%>AAC	278	283	2%<AAC
Daytona, FL	29	4973	3721	25%>AAC	166	161	3%>AAC
Miami, FL	25	5180	3767	27%>AAC	36	27	25%>AAC
SUM		68147	54868	24%>AAC	7166	7550	5%<AAC

Table 4-5 Commercial models (ASHRAE 90.1) annual energy usage

HVAC Energy Use (kWh)					Gas Heating (Therm)		
City, State	**Latitude**	**Metal**	**AAC**	**Progress**	**Metal**	**AAC**	**Progress**
Minot, ND	48	40233	33251	17%>AAC	1188	1042	12%>AAC
Missoula, MT	46	37317	29631	21%>AAC	1166	1040	11%>AAC
Richmond, VA	44	47118	38486	18%>AAC	951	824	13%>AAC
Madison, WI	43	43861	36291	17%>AAC	1141	1021	11%>AAC
Boston, MA	42	43303	35653	18%>AAC	1002	876	13%>AAC
Chicago, IL	41	44755	36387	19%>AAC	1059	929	12%>AAC
Philadelphia, PA	39	45761	37592	18%>AAC	1223	1098	10%>AAC
Reno, NV	39	36577	29797	19%>AAC	1041	919	12%>AAC
Sacramento, CA	38	39824	33084	17%>AAC	831	690	17%>AAC
Springfield, MO	37	47969	38733	19%>AAC	1082	980	9%>AAC
Tulsa, OK	36	48466	38631	20%>AAC	962	843	12%>AAC
Atlanta, GA	33	48883	40453	17%>AAC	814	692	15%>AAC
Houston, TX	29	53933	44430	18%>AAC	509	398	22%>AAC
Daytona, FL	29	55444	45703	18%>AAC	355	253	29%>AAC
Miami, FL	25	56449	47153	16%>AAC	146	82	44%>AAC
SUM		689893	565275	22%>AAC	13470	11687	15%>AAC

A comparison of the whole building model with to the ASHRAE 90.1-2007 standard found AAC was 24 percent more efficient for HVAC energy consumption than the traditional wood-framed construction was found to be. Likewise, for the commercial wall section and whole building model, AAC proved 11 and 22 percent more efficient respectively, than the traditional metal-framed construction method was revealed to be. This result further indicates that in comparison with the two traditional construction methods used, AAC offers greater HVAC energy efficiency for both residential and commercial models. Table 4-6 gives a summary of annual HVAC energy consumption specified for each wall system and ASHRAE 90.1 application models.

Additionally, the two models (the commercial and the residential) were simulated to enable analysis of the heating consumption by comparing AAC systems to traditional construction methods. Results were similar to those derived from the analysis run on the residential model; AAC proved less efficient for gas consumption by 13 and 5 percent for the wall section and whole building respectively. Results for the commercial models resembled those from other analyses conducted in this study; where AAC proved the more energy efficient, with results at 18 and 15 percent for the wall section and whole building simulations, respectively. Table 4-7 for provides a summary of annual heating energy consumption of wall systems and ASHRAE 90.1 application models.

Table 4-6 Annual HVAC energy consumption summary

Wall System	**Whole Building System with ASHRAE**	**AAC Improvement**
Residential –HVAC use (kWh) *Wood - AAC* *105,807 - 94,437* *12%*	**Residential- HVAC use (kWh)** *Wood - AAC* *68,147 - 54,868* *24%*	*12%*
Commercial-HVAC use (kWh) *Metal - AAC* *716,060 - 645,081* *11%*	**Commercial -HVAC use (kWh)** *Metal - AAC* *689,898 - 565,275* *22%*	*11%*

Table 4-7 Annual heating energy consumption summary

Wall System	**Whole Building System w/ ASHRAE**	**AAC Improvement**
Residential Heating use (therm) *Wood - AAC* *9,921 - 11,351* *-13%*	**Residential Heating use (therm)** *Wood - AAC* *7,166 - 7,550* *-5%*	*8%*
Commercial Heating use (therm) *Metal - AAC* *13,777 - 11,687* *18%*	**Commercial Heating use (therm)** *Metal - AAC* *13,470 - 11,687* *15%*	*-3%*

Figure 4-5 shows residential ASHRAE 90.1 model HVAC energy consumption, and Figure 4-6 shows ASHRAE 90.1 model residential heating energy consumption. Figure 4-7 illustrates ASHRAE 90.1 model commercial HVAC energy, and Figure 4-8 shows ASHRAE 90.1 model commercial heating consumption. The figures display graphical representations of the results.

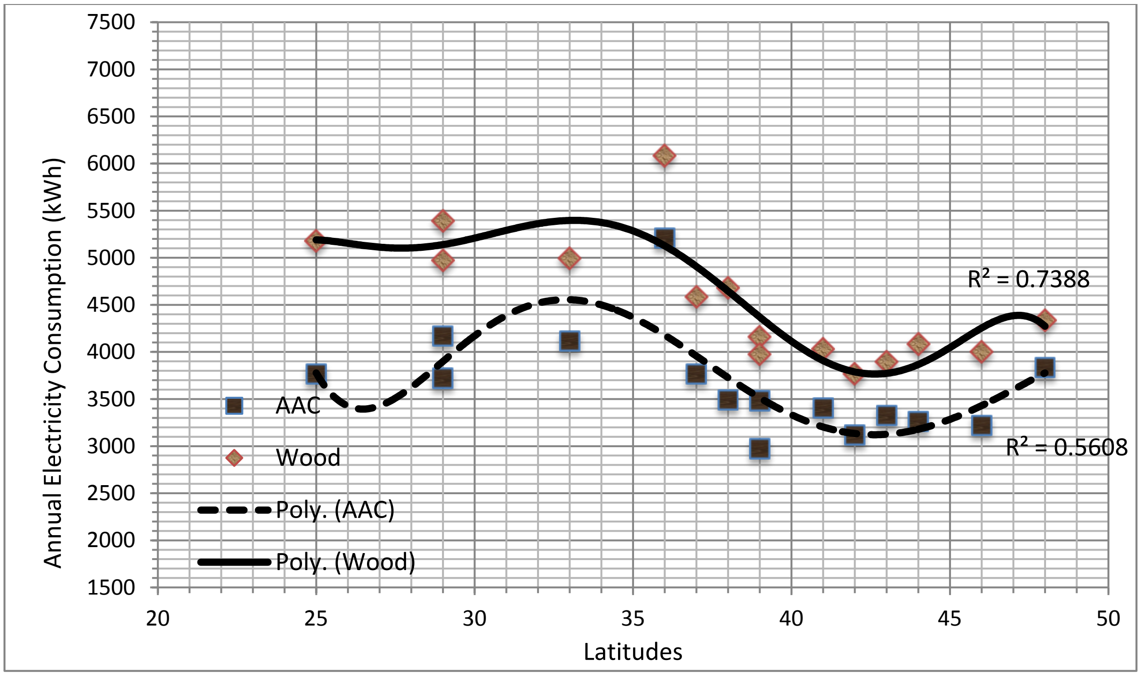

Figure 4-5 Residential models (ASHRAE 90.1) annual HVAC usage

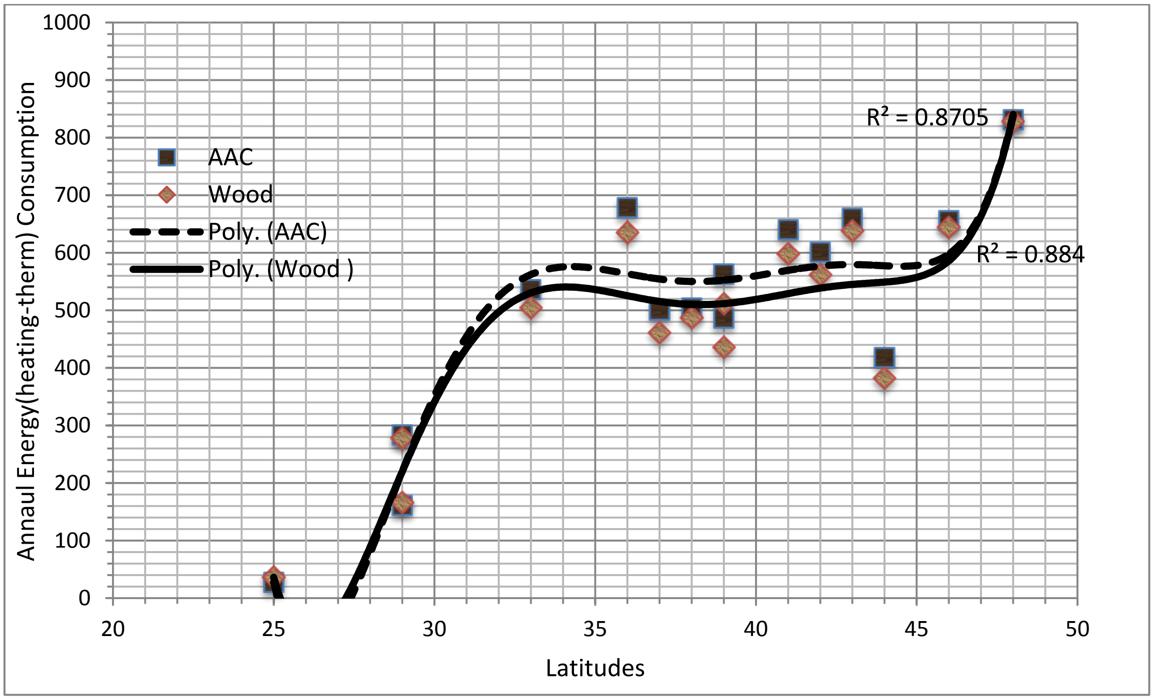

Figure 4-6 Residential models (ASHRAE 90.1) annual heating

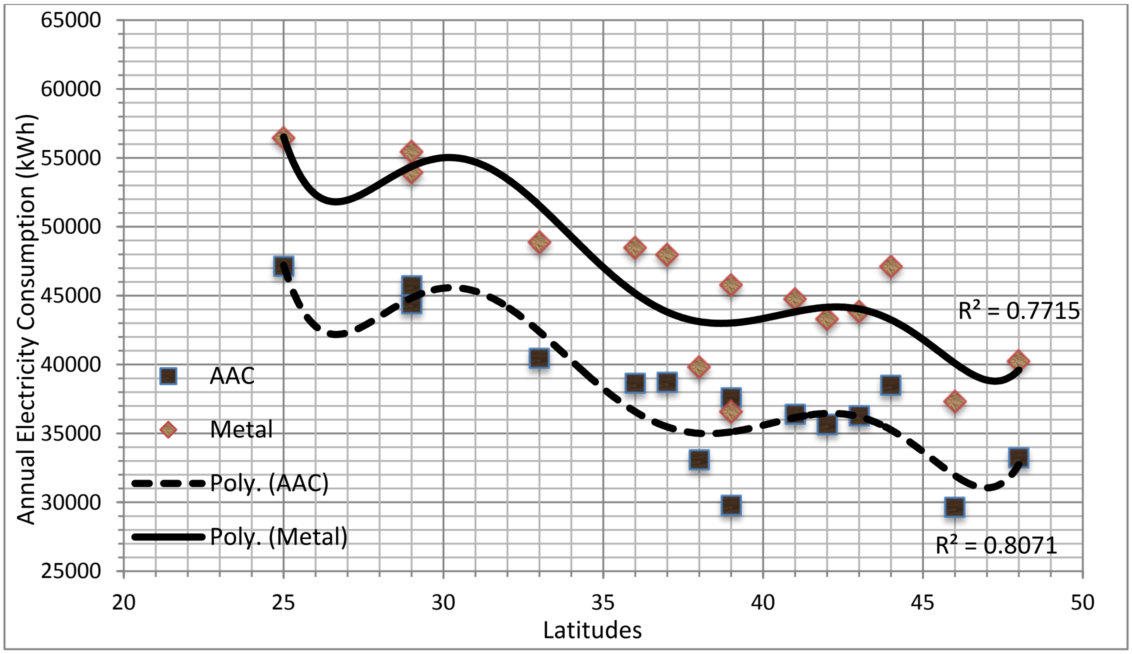

Figure 4-7 Commercial models (ASHRAE 90.1) annual HVAC usage

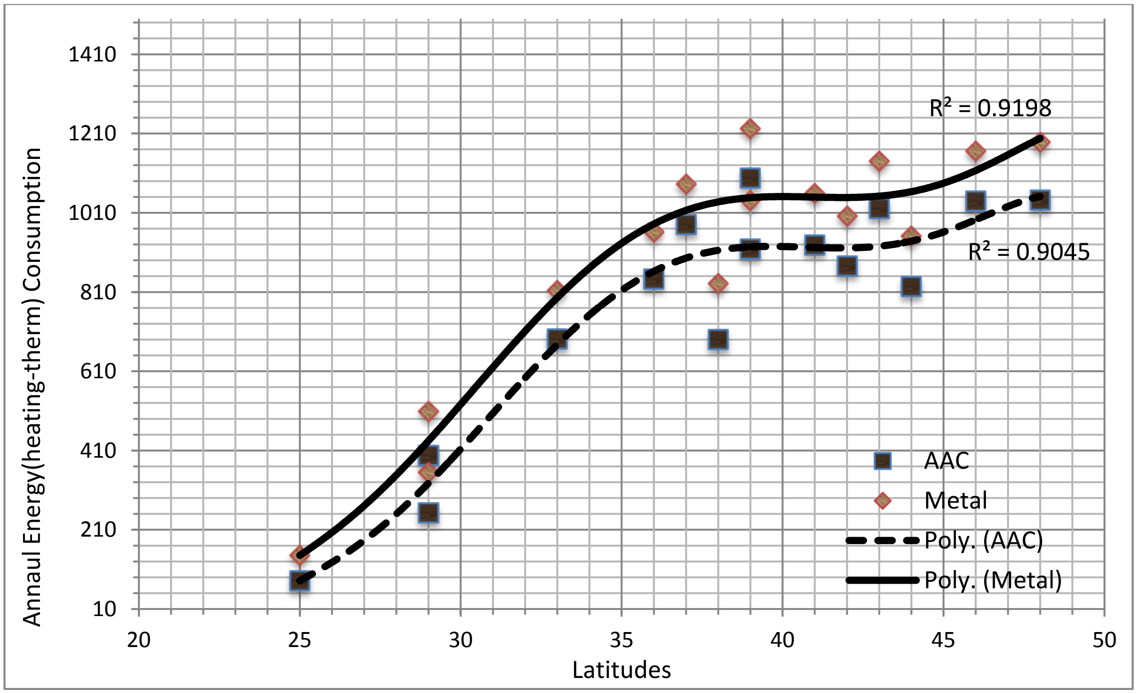

Figure 4-8 Commercial models (ASHRAE 90.1) annual heating

The results from this analysis support the hypothesis that computer simulation modeling offers an accurate, useful means of evaluating sustainable building performance in terms of established standard and enable comparison of the energy consumption of emerging building materials. Thus energy simulation using the Visual-DOE software identifies reliably the most energy-efficient building systems. The results from each task performed indicate similar patterns and remained consistent when applied to different analyses and therefore support the hypothesis that simulating energy consumption constitutes a viable of determining the impact of building materials on energy consumption.

4.1.4. Statistical Analyses

To determine whether a statistical difference exists between the outcomes for the traditional building materials and those for the AAC, I executed a two-paired t-test. This section contains a discussion of the relationship of both the wall systems model and the building systems model to the ASHRAE 90.1 standard and compares the monthly HVAC energy consumption of traditionally constructed framed and AAC systems for both residential and commercial structures. The selected cities used are grouped into five districts from north to south for this analysis as a means of evaluating the effect of climate on the energy performance of each model. Each district includes three cities simulated in this research task.

- Mideast: Minot, Madison, Chicago
- Midwest: Missoula, Springfield, Tulsa
- Northeast: Richmond, Boston, Philadelphia,
- Southwest: Reno, Sacramento, Houston
- Southeast: Atlanta, Daytona, Miami

In this section, Figures 4-9 to 4-16 display graphical representations of the results, and Table 4-8 to 4-23 provide detailed results. In the figures, cities are arranged from highest to lowest temperatures, the dashed line represents AAC structures, and the solid line represents framed structures. Residential structures, including both wall systems and building systems (wall, floor, and roof), simulated to meet the ASHRAE 90.1 standard, were compared with models wood-framed and AAC systems. The commercial models included metal-framed and AAC systems. The analysis included four tasks.

- Comparison of wall systems for residential models
- Comparison of wall systems for commercial models
- Comparison of residential building systems (wall, floor, and roof) comparison with ASHRAE 90.1 minimum standards
- Comparison of commercial building systems (wall, floor, and roof) with ASHRAE 90.1 minimum standards

4.1.4.1. *Monthly HVAC energy use by residential model wall systems.* Residential each model, simulated by using the Visual-DOE software underwent analysis to determine monthly HVAC energy consumption for wood-framed and AAC systems. The intention of the analysis involved discovering the month with the highest HVAC energy consumption.

Tables 4-8, through 4-11 indicate Visual-DOE software outputs for wood-framed and AAC models, as well as the compared results for the two systems. The highlighted cells in each table represent the most energy consumed per month. Refer to Figure 4-9 shows July HVAC energy consumption with the average July temperature indicated in the graph. In both systems models for the city of Tulsa consumed the most energy and those for the city of Reno consumed the least energy. Figure 4-10 graphically displays the average summer HVAC energy consumption, with summer average temperatures for each of the 15 cities. This figure indicates that models for the city of Tulsa consumed the most energy at 674 kWh for the wood-framed system and 598 kWh for the AAC system.

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Table 4-8 Wood-framed monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver +Std Dev	Max	Min	Max in July	Delta July-Max	Max>1 Std Dev
Minot, ND	636	653	581	618	594	618	620	654	641	601	612	598	619	23.4	642	654	581	TRUE	0	TRUE
Madison, WI	583	591	525	573	553	583	586	620	606	573	573	552	577	25.2	602	620	525	TRUE	0	TRUE
Chicago, IL	589	593	531	580	562	593	602	635	631	588	586	560	588	28.7	616	635	531	TRUE	0	TRUE
Missoula, MT	595	602	532	582	562	583	576	609	604	568	580	568	580	21.5	602	609	532	TRUE	0	TRUE
Springfield, MO	583	587	529	581	570	611	617	651	647	612	593	562	595	34.8	630	651	529	TRUE	0	TRUE
Tulsa, OK	593	596	535	599	589	635	644	699	679	629	614	577	616	44.9	661	699	535	TRUE	0	TRUE
Richmond, VA	559	562	507	561	554	586	592	632	624	585	578	546	574	34.0	608	632	507	TRUE	0	TRUE
Boston, MA	567	572	513	564	545	578	578	617	607	572	570	545	569	27.4	596	617	513	TRUE	0	TRUE
Philadelphia, PA	563	570	512	561	548	583	588	630	621	586	574	546	574	32.2	606	630	512	TRUE	0	TRUE
Reno, NV	569	568	511	563	548	569	563	594	589	560	567	546	562	21.3	584	594	511	TRUE	0	TRUE
Sacramento, CA	568	570	518	573	562	595	585	621	619	588	592	556	579	28.1	607	621	518	TRUE	0	TRUE
Houston, TX	573	578	515	584	582	625	617	658	648	613	610	571	598	38.9	637	658	515	TRUE	0	TRUE
Atlanta, GA	569	568	515	572	566	604	604	637	631	603	589	552	584	34.3	619	637	515	TRUE	0	TRUE
Daytona, FL	577	571	518	592	578	618	615	643	642	619	615	573	597	35.7	632	643	518	TRUE	0	TRUE
Miami, FL	586	591	538	601	594	631	616	652	652	614	622	587	607	31.7	639	652	538	TRUE	0	TRUE

Residential wood-frame model average HVAC energy use (kWh) is between 562-619 kWh. The dark cells indicate the most energy use by the month in 15 different climates of the United States.

Table 4-9 AAC wall system monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver. +Std Dev	Max	Min	Max in July	Delta July-Max	Max> 1 Std Dev
Minot, ND	640	665	591	605	565	577	580	612	600	561	577	588	597	30.6	627	665	561	FALSE	53	TRUE
Madison, WI	578	593	520	554	516	539	543	575	562	530	531	530	548	24.7	572	593	516	FALSE	18	TRUE
Chicago, IL	568	576	509	546	509	533	542	573	568	528	528	519	542	24.6	566	576	509	FALSE	3	TRUE
Missoula, MT	572	583	502	538	500	509	501	533	526	494	515	533	526	28.5	554	583	494	FALSE	50	TRUE
Springfield, MO	541	551	491	520	504	540	546	578	573	542	522	506	535	26.8	561	578	491	TRUE	0	TRUE
Tulsa, OK	537	550	483	528	516	557	567	622	604	552	538	510	547	38.6	586	622	483	TRUE	0	TRUE
Richmond, VA	507	517	463	500	488	516	524	561	553	517	509	486	512	27.2	539	561	463	TRUE	0	TRUE
Boston, MA	529	542	483	520	487	510	509	546	536	504	502	495	514	21.1	535	546	483	TRUE	0	TRUE
Philadelphia, PA	531	544	485	514	493	522	527	567	557	527	515	498	523	24.8	548	567	485	TRUE	0	TRUE
Reno, NV	516	512	452	488	463	477	470	499	494	468	478	475	483	19.6	502	516	452	FALSE	17	TRUE
Sacramento, CA	489	492	440	486	473	500	493	524	523	495	497	471	490	22.6	513	524	440	TRUE	0	TRUE
Houston, TX	486	493	438	492	491	529	524	565	555	521	515	481	508	34.7	542	565	438	TRUE	0	TRUE
Atlanta, GA	506	509	456	496	489	522	524	553	549	522	508	479	509	27.6	537	553	456	TRUE	0	TRUE
Daytona, FL	491	487	441	505	494	530	530	555	554	533	528	489	511	33.0	544	555	441	TRUE	0	TRUE
Miami, FL	505	509	463	518	514	548	539	575	574	537	539	507	527	31.5	559	575	463	TRUE	0	TRUE

AAC wall system model average HVAC energy use (kWh) between 483-597 kWh. The dark cells indicate the most energy use by the month in 15 different climate cities of the United States. In 10 of 15 cities, the most energy-use month is in July, four in January and one in December.

Table 4-10 Residential wall system models comparisons (kWh)

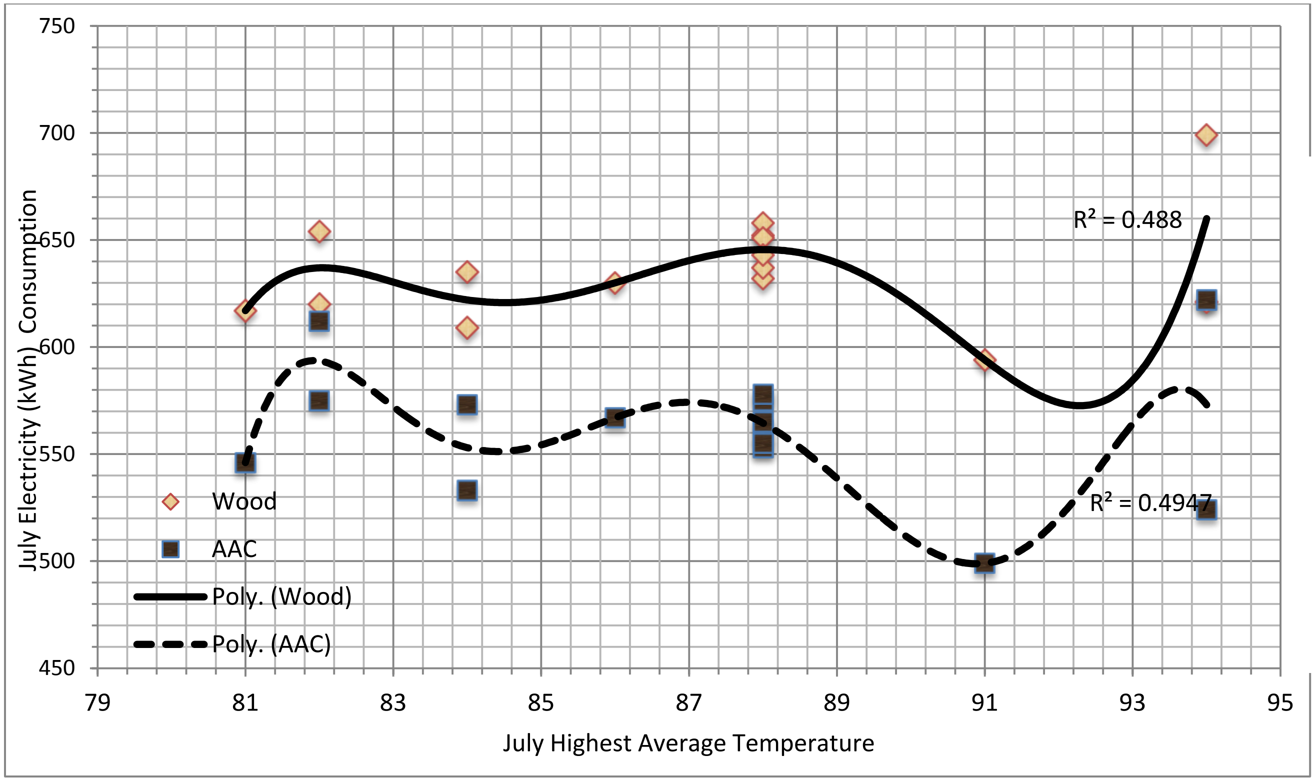
(AAC & Wood)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
US Cities	Region	Zone	Latitude													
Minot, ND	ME	7	48	-4	-12	-10	13	29	41	40	42	41	40	35	10	265
Madison, WI	ME	6	43	5	-2	5	19	37	44	43	45	44	43	42	22	347
Chicago, IL	ME	5	41	21	17	22	34	53	60	60	62	63	60	58	41	551
Missoula, MT	MW	6	46	23	19	30	44	62	74	75	76	78	74	65	35	655
Springfield, MO	MW	4	37	42	36	38	61	66	71	71	73	74	70	71	56	729
Tulsa, OK	MW	3	36	56	46	52	71	73	78	77	77	75	77	76	67	825
Richmond, VA	NE	4	44	52	45	44	61	66	70	68	71	71	68	69	60	745
Boston, MA	NE	5	42	38	30	30	44	58	68	69	71	71	68	68	50	665
Philadelphia, PA	NE	4	39	32	26	27	47	55	61	61	63	64	59	59	48	602
Reno, NV	SW	4	39	53	56	59	75	85	92	93	95	95	92	89	71	955
Sacramento, CA	SW	3	38	79	78	78	87	89	95	92	97	96	93	95	85	1064
Houston, TX	SW	2	29	87	85	77	92	91	96	93	93	93	92	95	90	1084
Atlanta, GA	SE	3	33	63	59	59	76	77	82	80	84	82	81	81	73	897
Daytona, FL	SE	2	29	86	84	77	87	84	88	85	88	88	86	87	84	1024
Miami, FL	SE	2	25	81	82	75	83	80	83	77	77	78	77	83	80	956

The HVAC energy use (kWh) comparison (AAC and wood-framed systems) between two systems is smaller in colder climates and higher in warmer climates. The smallest benefit is in Minot, ND; the city’s climate zone is 7 and requires additional insulation.

Table 4-11 Residential wall system models improvements

(AAC & Wood)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	-1%	-2%	-2%	2%	5%	7%	6%	6%	6%	7%	6%	2%	4%
Madison, WI	ME	6	43	1%	0%	1%	3%	7%	8%	7%	7%	7%	8%	7%	4%	5%
Chicago, IL	ME	5	41	4%	3%	4%	6%	9%	10%	10%	10%	10%	10%	10%	7%	8%
Missoula, MT	MW	6	46	4%	3%	6%	8%	11%	13%	13%	12%	13%	13%	11%	6%	9%
Springfield, MO	MW	4	37	7%	6%	7%	10%	12%	12%	12%	11%	11%	11%	12%	10%	10%
Tulsa, OK	MW	3	36	9%	8%	10%	12%	12%	12%	12%	11%	11%	12%	12%	12%	11%
Richmond, VA	NE	4	44	9%	8%	9%	11%	12%	12%	11%	11%	11%	12%	12%	11%	11%
Boston, MA	NE	5	42	7%	5%	6%	8%	11%	12%	12%	12%	12%	12%	12%	9%	10%
Philadelphia, PA	NE	4	39	6%	5%	5%	8%	10%	10%	10%	10%	10%	10%	10%	9%	9%
Reno, NV	SW	4	39	9%	10%	12%	13%	16%	16%	17%	16%	16%	16%	16%	13%	14%
Sacramento, CA	SW	3	38	14%	14%	15%	15%	16%	16%	16%	16%	16%	16%	16%	15%	15%
Houston, TX	SW	2	29	15%	15%	15%	16%	16%	15%	15%	14%	14%	15%	16%	16%	15%
Atlanta, GA	SE	3	33	11%	10%	11%	13%	14%	14%	13%	13%	13%	13%	14%	13%	13%
Daytona, FL	SE	2	29	15%	15%	15%	15%	15%	14%	14%	14%	14%	14%	14%	15%	14%
Miami, FL	SE	2	25	14%	14%	14%	14%	13%	13%	13%	12%	12%	13%	13%	14%	13%

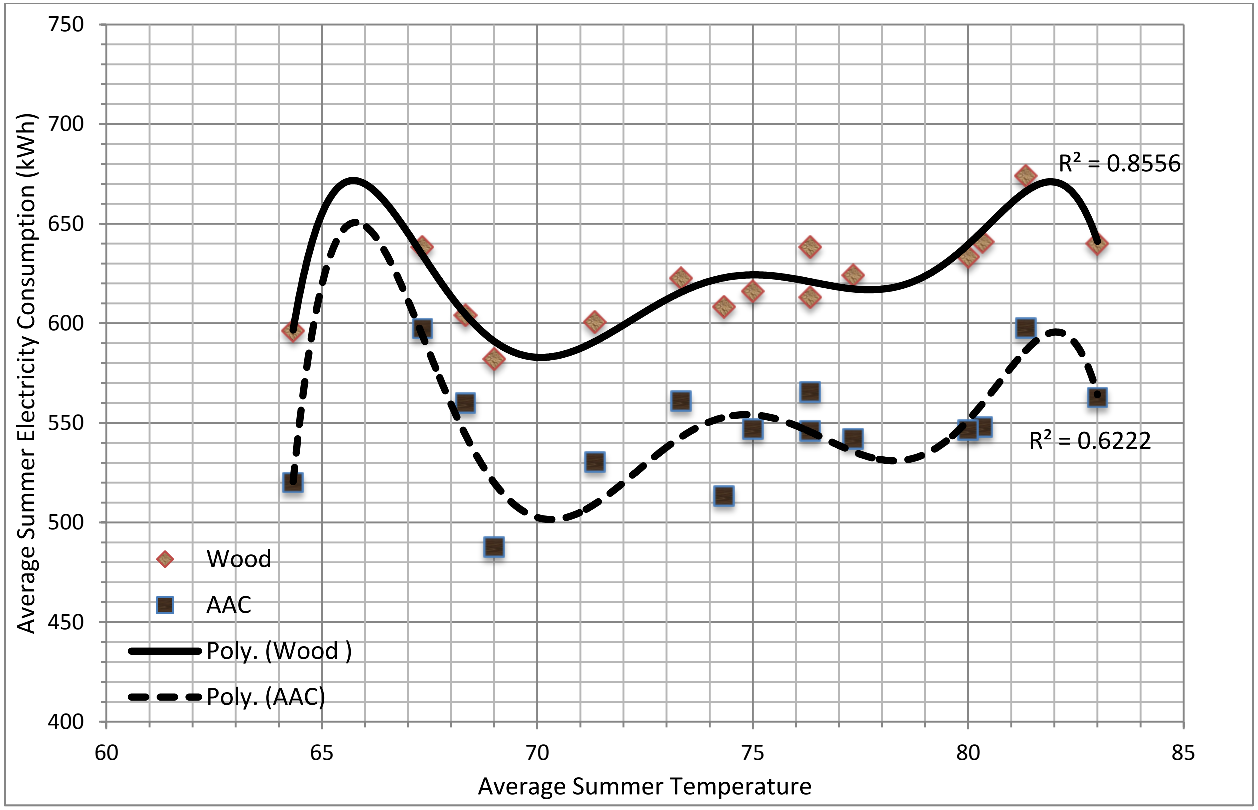
The HVAC energy use (kWh) comparison of wood-frame and AAC wall systems between models indicates that AAC uses less energy than wood-frame system. The smallest difference is in Minot, ND, with 4 percent, and the highest difference is in Houston and Sacramento with 15percent.



City, State	**F^0**	**AAC**	**Wood**
Tulsa, OK	94	622	699
Sacramento, CA	94	524	621
Reno, NV	91	499	594
Richmond, VA	88	561	632
Atlanta, GA	88	553	637
Miami, FL	88	575	652
Houston, TX	88	565	658
Springfield, MO	88	578	651
Daytona, FL	88	555	643
Philadelphia, PA	86	567	630
Missoula, MT	84	533	609
Chicago, IL	84	573	635
Minot, ND	82	612	654
Madison, WI	82	575	620
Boston, MA	81	546	617

Figure 4-9 Residential models July average HVAC use

The above figure displays July average HVAC energy use (kWh) of wood-frame and AAC wall systems. The graph set-up is July energy use by July average temperature (F^o), and it indicates that the AAC model for wall system HVAC energy use less than wood-frame model in 15 cities in the United States.



City, State	F^0	AAC	Wood
Miami, FL	83	563	640
Tulsa, OK	81	598	674
Houston, TX	80	548	641
Daytona, FL	80	546	633
Atlanta, GA	77	542	624
Springfield, MO	76	566	638
Richmond, VA	76	546	613
Philadelphia, PA	75	547	616
Sacramento, CA	74	513	608
Chicago, IL	73	561	623
Boston, MA	71	530	601
Reno, NV	69	488	582
Madison, WI	68	560	604
Minot, ND	67	597	638
Missoula, MT	64	520	596

Figure 4-10 Residential models summer average HVAC use

The above figure displays summer average (Jun-Aug) HVAC energy use (kWh) of wood-frame and AAC wall systems in residential structures. The graph set-up is summer HVAC use by summer average temperature (F^o); the figure indicates that the AAC model uses less HVAC energy than the wood-frame model.

According to the results from the Visual-DOE analysis of the wall systems for residential models, the most HVAC energy was consumed during July. The model specified with a wood-framed system consumed increased HVAC energy consumption in July for all 15 cities. On the other hand, comparing models with AAC systems revealed that only 10 of 15 cities showed increased HVAC consumption during the month of July; the other five models consumed more HVAC in December and January in the cities located in northern regions, most likely because of electrical heating systems and not because of gas-powered ones.

4.1.4.2. *Monthly HVAC energy use by commercial model wall systems.* This task involved using the Visual-DOE model to derive monthly HVAC energy consumption in commercial metal-framed and AAC systems. The task was undertaken to determine which month accounted for increased consumption of HVAC energy by commercial models. Results of the analysis of the metal-framed and the AAC commercial models indicated the highest consumption of HVAC energy occurred during August and took place in May for two cities and in March for one city.

Tables 4-12 to 4-15 display Visual-DOE data resulting from the comparison of the energy consumption of the metal-framed system with that of the AAC system. The highlighted cells in the tables represent the largest amount of energy consumed during each month. Figure 4-11 shows HVAC energy consumption during the month of August and the average August temperature.

Figure 4-12 shows summer averages of HVAC energy consumption and the summer average temperatures for each of the 15 cities. The Visual-DOE model results summarized in Figure 4-12 indicated that the model used in Daytona consumed the most energy (5096 kWh) for metal-framed systems and that Daytona also consumed the largest amount of energy 4545 kWh for AAC systems. However, the simulation results indicated that in comparison with the metal-framed systems, the AAC system proved 12 percent more efficient.

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Table 4-12 Metal-framed monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver. +Std Dev	Max	Min	Max in Aug	Delta Aug-Max	Max>1 Std Dev
Minot, ND	3081	3030	2530	4021	3150	3807	4508	4313	4870	3201	3066	3074	3554	726.3	4281	4870	2530	TRUE	0	TRUE
Madison, WI	3307	3275	2855	4161	3248	4163	4762	4361	5024	3853	3531	3260	3817	679.6	4496	5024	2855	TRUE	0	TRUE
Chicago, IL	3443	3374	2851	4172	3079	4362	4882	4301	5548	4438	3571	3063	3924	824.6	4748	5548	2851	TRUE	0	TRUE
Missoula, MT	3100	3154	2725	3492	2712	3413	3880	3423	4233	3102	2854	2835	3244	469.6	3713	4233	2712	TRUE	0	TRUE
Springfield, MO	3132	3382	2897	3940	3958	5027	5187	4486	5441	4610	4064	3051	4098	868.4	4966	5441	2897	TRUE	0	TRUE
Tulsa, OK	3178	3500	2817	4249	4135	5284	4923	4280	5274	4636	4002	3002	4107	845.9	4953	5284	2817	FALSE	10	TRUE
Richmond, VA	3189	3318	2865	3793	3685	4781	4984	4435	5426	4676	4296	3430	4073	806.8	4880	5426	2865	TRUE	0	TRUE
Boston, MA	3247	3594	2916	3796	2610	4130	4861	4421	5201	4342	3512	2701	3778	837.1	4615	5201	2610	TRUE	0	TRUE
Philadelphia, PA	3380	3427	2929	3745	3116	4757	5153	4372	5441	4753	4060	3151	4024	858.6	4882	5441	2929	TRUE	0	TRUE
Reno, NV	2848	3059	2364	3414	2926	3557	3929	3363	4109	3199	3099	2780	3221	491.5	3712	4109	2364	TRUE	0	TRUE
Sacramento, CA	2341	2697	2323	3479	3304	4235	4336	3867	4578	3827	3870	2849	3476	775.1	4251	4578	2323	TRUE	0	TRUE
Houston, TX	4038	4047	3269	5156	4819	5383	5112	4477	5364	4549	5003	4293	4626	637.9	5264	5383	3269	FALSE	19	TRUE
Atlanta, GA	3210	3187	2993	4331	4227	5064	5168	4591	5481	4996	4320	3321	4241	871.7	5113	5481	2993	TRUE	0	TRUE
Daytona, FL	4393	4285	3588	5358	4754	5406	5259	4591	5439	4592	4978	4512	4763	554.7	5318	5439	3588	TRUE	0	TRUE
Miami, FL	4669	4817	4026	5269	4571	5131	4939	4380	5171	4522	4749	4503	4729	361.7	5091	5269	4026	FALSE	19	TRUE

Commercial metal-frame model average HVAC energy use (kWh) is between 3221-4763 kWh. The dark cells indicate the most energy use by month. Twelve out of 15 cities use the most HVAC energy in August; Tulsa and Houston use the most energy in May and Miami in March.

Table 4-13 AAC system monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver. +Std Dev	Max	Min	Max in Aug	Delta Aug-Max	Max>1 Std Dev
Minot, ND	2695	2621	2153	3627	2809	3458	4083	3922	4437	2836	2735	2728	3175	706.1	3881	4437	2153	TRUE	0	TRUE
Madison, WI	2999	2930	2549	3844	2980	3858	4409	3909	4700	3550	3229	2978	3495	659.1	4154	4700	2549	TRUE	0	TRUE
Chicago, IL	3076	2994	2508	3771	2759	3967	4513	3643	5109	3983	3200	2739	3522	785.8	4308	5109	2508	TRUE	0	TRUE
Missoula, MT	2744	2771	2393	3148	2426	3109	3583	2946	3828	2769	2541	2507	2897	453.1	3350	3828	2393	TRUE	0	TRUE
Springfield, MO	2823	3026	2562	3550	3546	4595	4744	3937	4831	4081	3608	2713	3668	792.4	4460	4831	2562	TRUE	0	TRUE
Tulsa, OK	2833	3120	2489	3847	3695	4795	4262	3647	4488	4093	3577	2667	3626	731.5	4358	4795	2489	FALSE	307	TRUE
Richmond, VA	2882	3029	2592	3459	3350	4391	4623	3946	4894	4266	3883	3086	3700	743.1	4443	4894	2592	TRUE	0	TRUE
Boston, MA	2944	3284	2632	3501	2369	3797	4506	3997	4860	3968	3209	2457	3460	795.3	4256	4860	2369	TRUE	0	TRUE
Philadelphia, PA	3027	3070	2602	3405	2797	4314	4748	3779	4909	4276	3635	2822	3615	793.3	4409	4909	2602	TRUE	0	TRUE
Reno, NV	2468	2665	2043	3046	2577	3254	3543	2775	3567	2838	2722	2399	2825	459.2	3284	3567	2043	TRUE	0	TRUE
Sacramento, CA	2083	2443	2078	3181	2985	3957	4008	3497	4180	3461	3487	2556	3160	735.2	3895	4180	2078	TRUE	0	TRUE
Houston, TX	3648	3666	2933	4697	4390	4924	4374	3789	4637	4102	4553	3892	4134	569.6	4703	4924	2933	FALSE	287	TRUE
Atlanta, GA	2875	2884	2681	3941	3855	4553	4656	3961	4892	4443	3889	2980	3801	773.5	4574	4892	2681	TRUE	0	TRUE
Daytona, FL	3960	3878	3223	4930	4371	5016	4702	4048	4884	4063	4539	4080	4308	530.5	4838	5016	3223	FALSE	132	TRUE
Miami, FL	4372	4535	3747	5050	4312	4756	4421	3845	4660	4102	4405	4250	4371	366.8	4738	5050	3747	FALSE	390	TRUE

AAC wall system model average HVAC energy use (kWh) is between 2825-4371 kWh. The dark cells indicate the most energy use by month in 15 different climate cities of the United States; eleven of 15 cities use the most energy in August, three in May, and one in March.

Table 4-14 Commercial wall system comparisons (kWh)

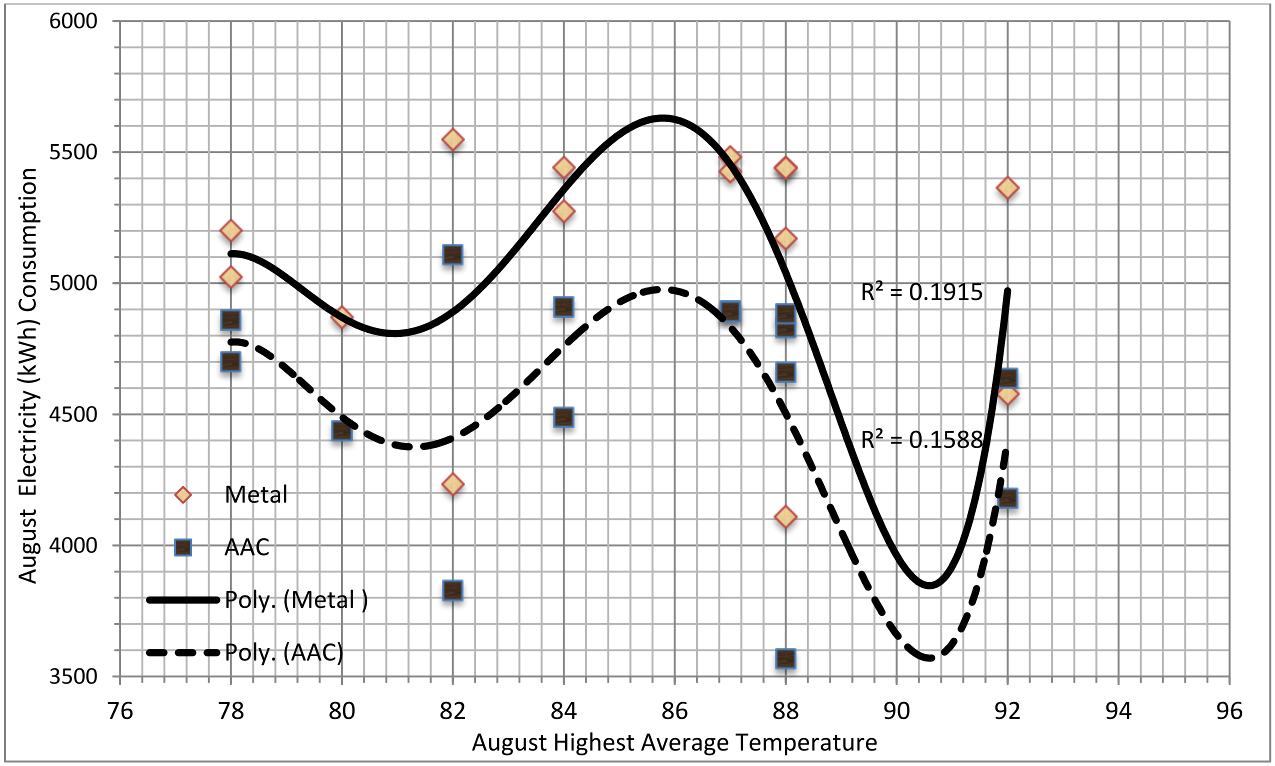
(AAC & Metal)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	386	409	377	394	341	349	425	391	433	365	331	346	4547
Madison, WI	ME	6	43	308	345	306	317	268	305	353	452	324	303	302	282	3865
Chicago, IL	ME	5	41	367	380	343	401	320	395	369	658	439	455	371	324	4822
Missoula, MT	MW	6	46	356	383	332	344	286	304	297	477	405	333	313	328	4158
Springfield, MO	MW	4	37	309	356	335	390	412	432	443	549	610	529	456	338	5159
Tulsa, OK	MW	3	36	345	380	328	402	440	489	661	633	786	543	425	335	5767
Richmond, VA	NE	4	44	307	289	273	334	335	390	361	489	532	410	413	344	4477
Boston, MA	NE	5	42	303	310	284	295	241	333	355	424	341	374	303	244	3807
Philadelphia, PA	NE	4	39	353	357	327	340	319	443	405	593	532	477	425	329	4900
Reno, NV	SW	4	39	380	394	321	368	349	303	386	588	542	361	377	381	4750
Sacramento, CA	SW	3	38	258	254	245	298	319	278	328	370	398	366	383	293	3790
Houston, TX	SW	2	29	390	381	336	459	429	459	738	688	727	447	450	401	5905
Atlanta, GA	SE	3	33	335	303	312	390	372	511	512	630	589	553	431	341	5279
Daytona, FL	SE	2	29	433	407	365	428	383	390	557	543	555	529	439	432	5461
Miami, FL	SE	2	25	297	282	279	219	259	375	518	535	511	420	344	253	4292

The table displays results of metal-frame and AAC wall systems simulation for HVAC energy use (kWh). The comparison favors the AAC model. The smallest difference is in Sacramento, with 3790 kWh, and the highest is in Houston, with 5905 kWh.

Table 4-15 Commercial wall system comparison improvements

(AAC & Metal)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Average
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	13%	13%	15%	10%	11%	9%	9%	9%	9%	11%	11%	11%	11%
Madison, WI	ME	6	43	9%	11%	11%	8%	8%	7%	7%	10%	6%	8%	9%	9%	9%
Chicago, IL	ME	5	41	11%	11%	12%	10%	10%	9%	8%	15%	8%	10%	10%	11%	10%
Missoula, MT	MW	6	46	11%	12%	12%	10%	11%	9%	8%	14%	10%	11%	11%	12%	11%
Springfield, MO	MW	4	37	10%	11%	12%	10%	10%	9%	9%	12%	11%	11%	11%	11%	11%
Tulsa, OK	MW	3	36	11%	11%	12%	9%	11%	9%	13%	15%	15%	12%	11%	11%	12%
Richmond, VA	NE	4	44	10%	9%	10%	9%	9%	8%	7%	11%	10%	9%	10%	10%	9%
Boston, MA	NE	5	42	9%	9%	10%	8%	9%	8%	7%	10%	7%	9%	9%	9%	9%
Philadelphia, PA	NE	4	39	10%	10%	11%	9%	10%	9%	8%	14%	10%	10%	10%	10%	10%
Reno, NV	SW	4	39	13%	13%	14%	11%	12%	9%	10%	17%	13%	11%	12%	14%	12%
Sacramento, CA	SW	3	38	11%	9%	11%	9%	10%	7%	8%	10%	9%	10%	10%	10%	9%
Houston, TX	SW	2	29	10%	9%	10%	9%	9%	9%	14%	15%	14%	10%	9%	9%	11%
Atlanta, GA	SE	3	33	10%	10%	10%	9%	9%	10%	10%	14%	11%	11%	10%	10%	10%
Daytona, FL	SE	2	29	10%	9%	10%	8%	8%	7%	11%	12%	10%	12%	9%	10%	10%
Miami, FL	SE	2	25	6%	6%	7%	4%	6%	7%	10%	12%	10%	9%	7%	6%	8%

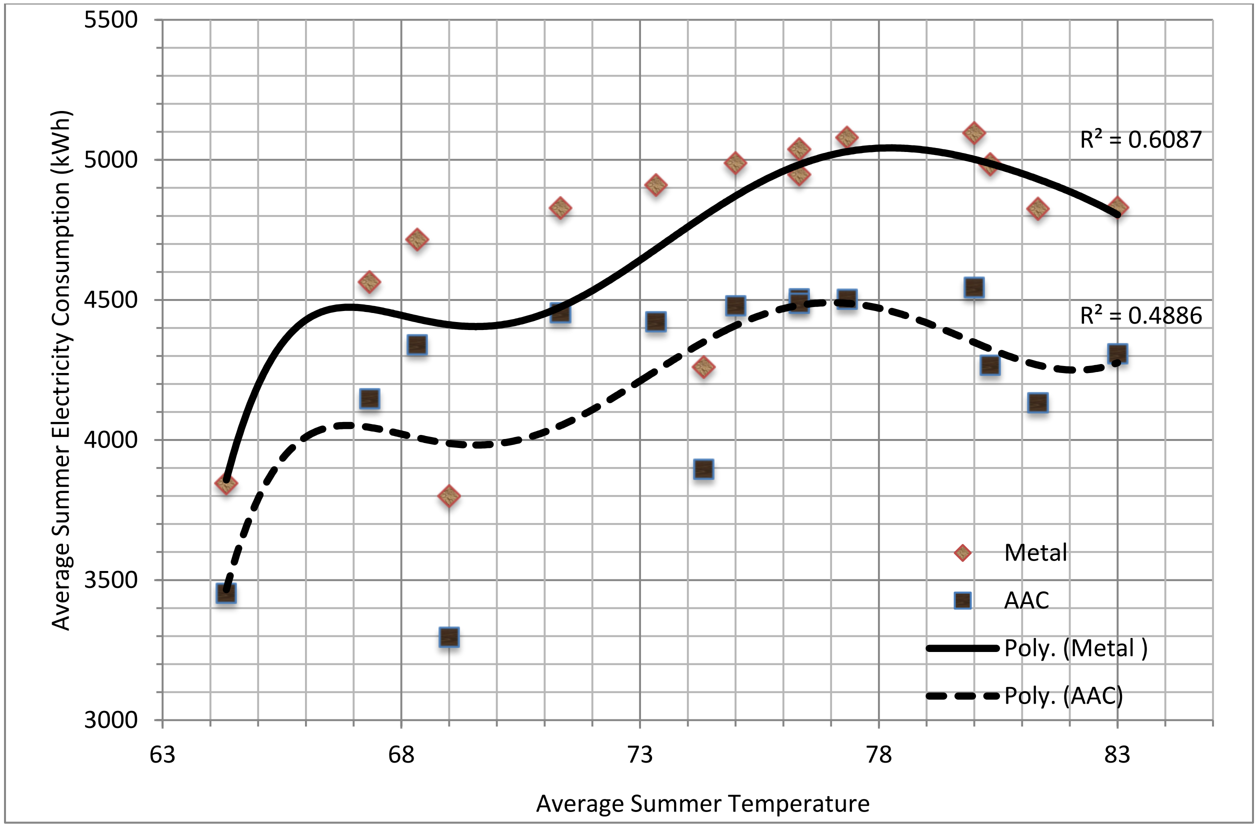
The HVAC energy use (kWh) comparison between metal-framed and AAC wall systems models indicates that the AAC outperformed than the metal-frame model. The smallest difference is in Miami, with 8 percent, and the highest difference with 12percent in Tulsa and Reno.



City, State	(F⁰)	AAC	Metal
Sacramento, CA	92	4180	4578
Houston, TX	92	4637	5364
Springfield, MO	88	4831	5441
Reno, NV	88	3567	4109
Daytona, FL	88	4884	5439
Miami, FL	88	4660	5171
Richmond, VA	87	4894	5426
Atlanta, GA	87	4892	5481
Tulsa, OK	84	4488	5274
Philadelphia, PA	84	4909	5441
Chicago, IL	82	5109	5548
Missoula, MT	82	3828	4233
Minot, ND	80	4437	4870
Madison, WI	78	4700	5024
Boston, MA	78	4860	5201

Figure 4-11 Commercial models August average HVAC use

The above figure displays August HVAC energy use (kWh) of metal-frame and AAC wall systems. The graph indicates that the AAC model for wall system uses less HVAC energy than the metal-framed model in 15 cities in the United States.



City, State	(F^{0})	AAC	Metal
Miami, FL	83	4309	4830
Tulsa, OK	81	4132	4826
Houston, TX	80	4267	4984
Daytona, FL	80	4545	5096
Atlanta, GA	77	4503	5080
Springfield, MO	76	4504	5038
Richmond, VA	76	4488	4948
Philadelphia, PA	75	4479	4989
Sacramento, CA	74	3895	4260
Chicago, IL	73	4422	4910
Boston, MA	71	4454	4828
Reno, NV	69	3295	3800
Madison, WI	68	4339	4716
Minot, ND	67	4147	4564
Missoula, MT	64	3452	3845

Figure 4-12 Commercial models summer average HVAC use

The figure displays summer average (Jun-Aug) HVAC energy use (kWh) of metal-frame and AAC wall systems in for commercial structures. The figure indicates that the AAC model uses less HVAC energy than the metal-frame model.

According to the results of the analysis using Visual-DOE for the wall systems in the commercial models, the most of the HVAC energy consumption took place during August. The model specified with a metal-framed system consumed the largest amount HVAC energy in August for 12 of 15 cities, whereas the model with the AAC system used the most HVAC energy in August for 11of 15 cities. The other four models consumed more HVAC in May and March.

4.1.4.3. *Monthly HVAC energy use by residential (ASHRAE 90.1) model.* This task incorporate the use of Visual-DOE software to analyze the residential models specified with the ASHRAE 90.1 minimum standards by comparing the monthly HVAC energy consumption of traditionally constructed wood-framed and AAC building systems. The results from this analysis indicated that like the wall systems, the residential building systems consumed the most HVAC energy during the July. The model with the wood-framed system consumed more HVAC energy in July for all 15 cities. In contrast, the model with the AAC system consumed more HVAC energy in July for 12 of 15 cities, during of August for one city, and during January for two located in the northern regions. These results because of the use of heat pumps, which heat pump move heat between an outdoor air stream and indoor stream; as a result, heat pumps can cool and heat the buildings (Grondzik et al.,, 2010). Therefore, increased consumption by this equipment increases the HVAC loads.

Tables 4-16 to 4-19 display the results from Visual-DOE analysis for wood-framed AAC systems, as well as the comparisons between the two systems. The highlighted cells in the tables represent the peak energy consumption by month. Figure 4-13 depicts HVAC energy consumption during July. Figure 4-14 graphically displays summer averages of HVAC energy consumption for each of the 15 cities. This graph also indicates that Tulsa consumed the most energy at 586 kWh and 497 kWh, respectively, for the wood-framed systems for the AAC systems; these rates represent 18 percent efficiency advantages for the AAC system.

Table 4-16 Wood-frame (ASHRAE 90.1) monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver +Std Dev	Max	Min	Max in July	Delta July-Max	Max>1 Std Dev
Minot, ND	346	361	320	347	342	369	389	417	403	359	351	332	361	28.8	390	417	320	TRUE	0	TRUE
Madison, WI	312	313	278	311	310	335	350	378	363	330	317	300	325	28.0	353	378	278	TRUE	0	TRUE
Chicago, IL	320	321	288	318	316	345	364	397	381	346	328	308	336	31.7	368	397	288	TRUE	0	TRUE
Missoula, MT	310	316	382	313	312	330	340	382	369	327	319	301	333	28.7	362	382	301	TRUE	0	TRUE
Springfield, MO	356	356	326	364	361	398	413	444	441	402	375	349	382	37.3	419	444	326	TRUE	0	TRUE
Tulsa, OK	484	498	437	479	470	508	536	624	598	503	487	460	507	54.9	562	624	437	TRUE	0	TRUE
Richmond, VA	312	313	283	322	325	351	371	408	394	358	338	309	340	37.2	378	408	283	TRUE	0	TRUE
Boston, MA	296	299	268	300	296	322	337	369	357	327	310	289	314	29.3	344	369	268	TRUE	0	TRUE
Philadelphia, PA	322	326	295	328	326	357	371	411	401	364	343	317	347	35.0	382	411	295	TRUE	0	TRUE
Reno, NV	310	311	284	319	320	340	347	388	378	343	330	306	331	30.0	361	388	284	TRUE	0	TRUE
Sacramento, CA	369	371	337	376	371	403	406	446	444	404	393	361	390	32.6	423	446	337	TRUE	0	TRUE
Houston, TX	413	417	376	421	422	462	485	543	528	469	445	411	449	50.1	499	543	376	TRUE	0	TRUE
Atlanta, GA	403	408	366	399	395	424	437	477	469	427	408	382	416	32.8	449	477	366	TRUE	0	TRUE
Daytona, FL	383	380	345	395	393	426	448	478	474	445	422	384	414	41.1	456	478	345	TRUE	0	TRUE
Miami, FL	391	392	359	402	411	449	464	506	504	461	443	398	432	46.7	478	506	359	TRUE	0	TRUE

This residential section of the model applied the ASHRAE 90.1 Standard minimum requirements. Residential wood-frame model average HVAC energy use (kWh) is between 314-507 kWh. The model with ASHRAE 90.1 Standard energy uses an average of 100 kWh less energy than the model without IECC code requirement. The dark cells are indicated the most energy use by the month in 15 different climates in the United States.

Table 4-17 AAC systems (ASHRAE 90.1) monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver +Std Dev	Max	Min	Max in July	Delta July-Max	Max>1 Std Dev
Minot, ND	333	356	313	314	295	304	317	340	331	298	301	333	320	19.0	339	356	295	FALSE	16	TRUE
Madison, WI	288	297	255	273	257	271	286	309	296	271	261	262	277	17.7	295	309	255	TRUE	0	TRUE
Chicago, IL	293	298	262	279	261	275	294	320	310	280	267	265	284	19.4	303	320	261	TRUE	0	TRUE
Missoula, MT	284	293	249	268	253	259	261	290	284	255	259	266	268	15.3	284	293	249	FALSE	3	TRUE
Springfield, MO	311	316	285	300	290	317	328	354	352	322	299	291	314	22.7	337	354	285	TRUE	0	TRUE
Tulsa, OK	433	458	388	405	392	422	448	534	509	420	407	395	434	46.4	481	534	388	TRUE	0	TRUE
Richmond, VA	259	266	237	259	254	273	290	320	311	280	266	248	272	24.8	297	320	237	TRUE	0	TRUE
Boston, MA	262	270	239	258	243	254	266	292	282	260	248	245	260	15.9	276	292	239	TRUE	0	TRUE
Philadelphia, PA	286	295	263	278	267	288	301	335	326	297	280	267	290	22.5	313	335	263	TRUE	0	TRUE
Reno, NV	254	253	223	243	237	246	248	276	271	245	242	235	248	14.7	262	276	223	TRUE	0	TRUE
Sacramento, CA	296	299	260	288	273	291	293	321	322	292	285	272	291	18.2	309	322	260	FALSE	1	TRUE
Houston, TX	325	330	299	320	317	350	372	433	417	359	336	312	348	41.7	389	433	299	TRUE	0	TRUE
Atlanta, GA	356	366	320	329	319	339	349	380	374	342	327	317	343	22.0	365	380	317	TRUE	0	TRUE
Daytona, FL	286	287	258	292	290	314	337	364	360	336	313	284	310	33.1	343	364	258	TRUE	0	TRUE
Miami, FL	275	277	253	283	291	324	346	389	387	343	318	281	314	44.8	359	389	253	TRUE	0	TRUE

AAC building system model with application of ASHARE 90.1 code requirement average HVAC energy use (kWh) is between 248-434 kWh. The above table indicates that the model uses an average of 200 kWh less energy than the model that simulated without ASHRAE code requirement. The dark cells indicate the most energy use by the month in 15 different climate cities in the U.S. In twelve of 15 cities, the most energy-use month is in July, two in January and one in August. The dark cells are indicated the most energy use by the month. Energy efficiency will increase when applied ASHRAE 90.1 standard.

Table 4-18 Residential (ASHARE 90.1) models comparisons (kWh)

(AAC & Wood)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	13	5	7	33	47	65	72	77	72	61	50	-1	501
Madison, WI	ME	6	43	24	16	23	38	53	64	64	69	67	59	56	38	571
Chicago, IL	ME	5	41	27	23	26	39	55	70	70	77	71	66	61	43	628
Missoula, MT	MW	6	46	26	23	133	45	59	71	79	92	85	72	60	35	780
Springfield, MO	MW	4	37	45	40	41	64	71	81	85	90	89	80	76	58	820
Tulsa, OK	MW	3	36	51	40	49	74	78	86	88	90	89	83	80	65	873
Richmond, VA	NE	4	44	53	47	46	63	71	78	81	88	83	78	72	61	821
Boston, MA	NE	5	42	34	29	29	42	53	68	71	77	75	67	62	44	651
Philadelphia, PA	NE	4	39	36	31	32	50	59	69	70	76	75	67	63	50	678
Reno, NV	SW	4	39	56	58	61	76	83	94	99	112	107	98	88	71	1003
Sacramento, CA	SW	3	38	73	72	77	88	98	112	113	125	122	112	108	89	1189
Houston, TX	SW	2	29	88	87	77	101	105	112	113	110	111	110	109	99	1222
Atlanta, GA	SE	3	33	47	42	46	70	76	85	88	97	95	85	81	65	877
Daytona, FL	SE	2	29	97	93	87	103	103	112	111	114	114	109	109	100	1252
Miami, FL	SE	2	25	116	115	106	119	120	125	118	117	117	118	125	117	1413

AAC building system and wood-framed system HVAC energy use between models is smaller in colder climate and higher in warmer climate cities. The smallest benefit is still in Minot, ND. The table shows Minot has the smallest and Houston has the largest benefit.

Table 4-19 Residential models (ASHRAE 90.1) improvements

(AAC & Wood)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	4%	1%	2%	10%	14%	18%	19%	18%	18%	17%	14%	0%	11%
Madison, WI	ME	6	43	8%	5%	8%	12%	17%	19%	18%	18%	18%	18%	18%	13%	14%
Chicago, IL	ME	5	41	8%	7%	9%	12%	17%	20%	19%	19%	19%	19%	19%	14%	15%
Missoula, MT	MW	6	46	8%	7%	35%	14%	19%	22%	23%	24%	23%	22%	19%	12%	19%
Springfield, MO	MW	4	37	13%	11%	13%	18%	20%	20%	21%	20%	20%	20%	20%	17%	18%
Tulsa, OK	MW	3	36	11%	8%	11%	15%	17%	17%	16%	14%	15%	17%	16%	14%	14%
Richmond, VA	NE	4	44	17%	15%	16%	20%	22%	22%	22%	22%	21%	22%	21%	20%	20%
Boston, MA	NE	5	42	11%	10%	11%	14%	18%	21%	21%	21%	21%	20%	20%	15%	17%
Philadelphia, PA	NE	4	39	11%	10%	11%	15%	18%	19%	19%	18%	19%	18%	18%	16%	16%
Reno, NV	SW	4	39	18%	19%	21%	24%	26%	28%	29%	29%	28%	29%	27%	23%	25%
Sacramento, CA	SW	3	38	20%	19%	23%	23%	26%	28%	28%	28%	27%	28%	27%	25%	25%
Houston, TX	SW	2	29	21%	21%	20%	24%	25%	24%	23%	20%	21%	23%	24%	24%	23%
Atlanta, GA	SE	3	33	12%	10%	13%	18%	19%	20%	20%	20%	20%	20%	20%	17%	17%
Daytona, FL	SE	2	29	25%	24%	25%	26%	26%	26%	25%	24%	24%	24%	26%	26%	25%
Miami, FL	SE	2	25	30%	29%	30%	30%	29%	28%	25%	23%	23%	26%	28%	29%	28%

The HVAC energy use (kWh) comparison between wood-framed and AAC building systems models indicates that AAC uses less energy than the wood-frame model. The smallest difference is in Minot, ND, with 11 percent, and the highest difference is in Miami, FL, with 28 percent.

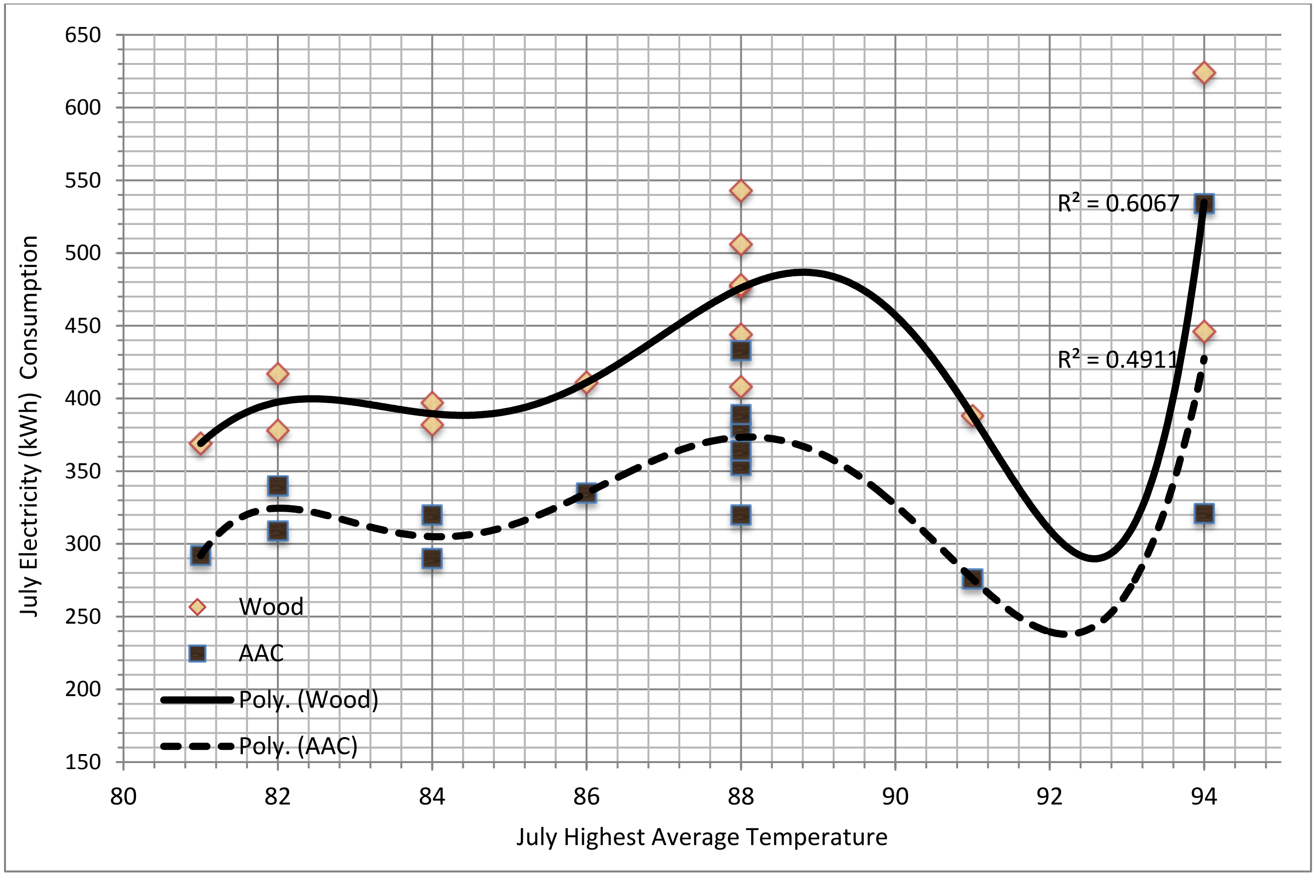
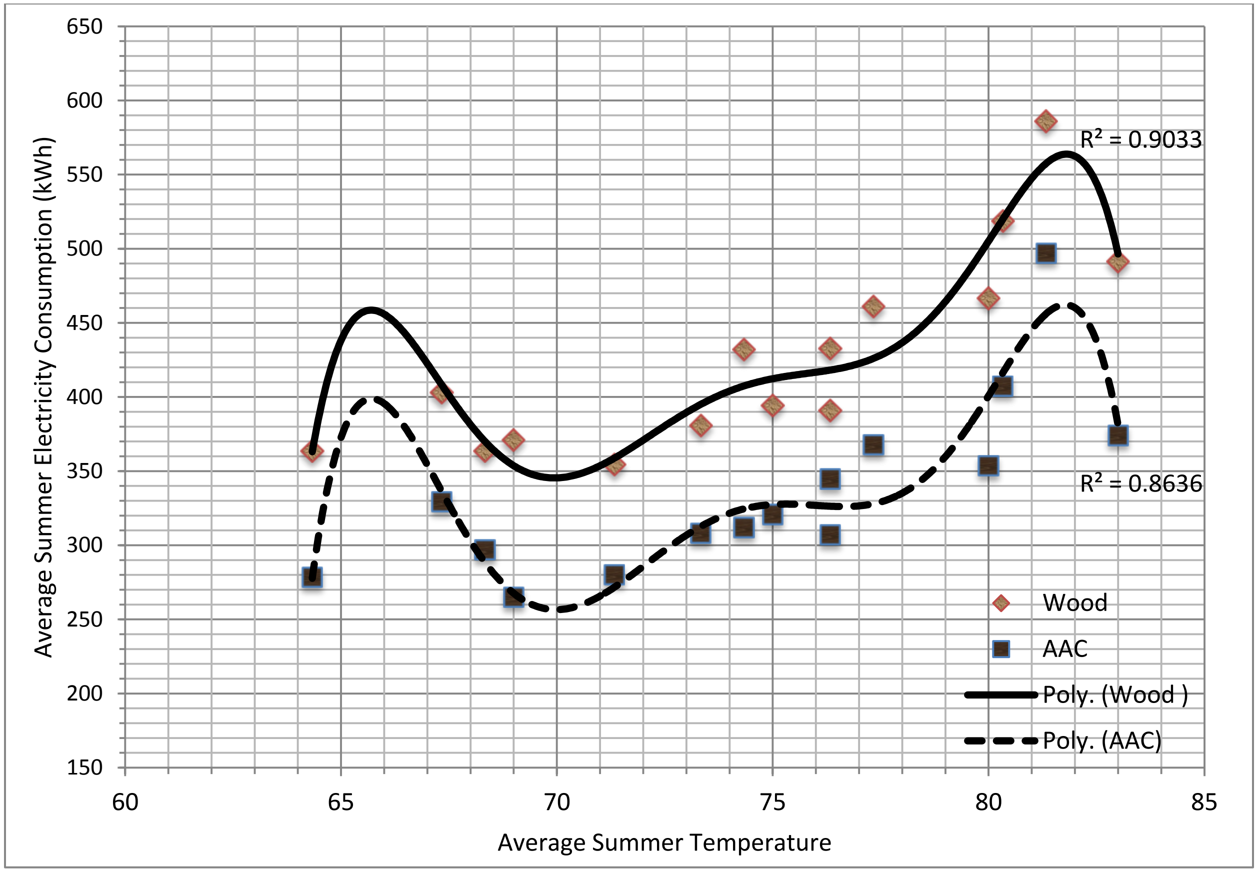


Figure 4-13 Residential models (ASHRAE 90.1) July HVAC use

City, State	**F⁰**	**AAC**	**Wood**
Tulsa, OK	94	534	624
Sacramento, CA	94	321	446
Reno, NV	91	276	388
Richmond, VA	88	320	408
Atlanta, GA	88	380	477
Miami, FL	88	389	506
Houston, TX	88	433	543
Springfield, MO	88	354	444
Daytona, FL	88	364	478
Philadelphia, PA	86	335	411
Missoula, MT	84	290	382
Chicago, IL	84	320	397
Minot, ND	82	340	417
Madison, WI	82	309	378
Boston, MA	81	292	369

The above figure displays July average HVAC energy use (kWh) in the model with ASHRAE application between wood-frame and AAC building systems. It indicates that the AAC model uses less HVAC energy than the wood-framed model in all 15 cities in the United States.



City, State	F^0	AAC	Wood
Miami, FL	83	374	491
Tulsa, OK	81	497	586
Houston, TX	80	407	519
Daytona, FL	80	354	467
Atlanta, GA	77	368	461
Springfield, MO	76	345	433
Richmond, VA	76	307	391
Philadelphia, PA	75	321	394
Sacramento, CA	74	312	432
Chicago, IL	73	308	381
Boston, MA	71	280	354
Reno, NV	69	265	371
Madison, WI	68	297	364
Minot, ND	67	329	403
Missoula, MT	64	278	364

Figure 4-14 Residential models (ASHRAE 90.1) summer HVAC use

The above figure displays summer average (June-August) HVAC energy use (kWh) in the models following ASHRAE 90.1 minimum code requirements. The figure indicates that the AAC models use less HVAC energy than the wood-frame models.

According to Visual-DOE analysis for the residential (ASHRAE 90.1) models the most HVAC energy was consumed during July. The model specified with a wood-framed system consumed peak HVAC energy in July for 15 of 15 cities. In contrast, the model with the AAC system consumed peak HVAC energy during August for 12 of 15 cities, during January for two cities located in northern region and during August for one city located also in southern region.

4.1.4.4. *Monthly HVAC energy use by commercial (ASHRAE 90.1) model.* This task involves using Visual-DOE software for commercial models with ASHRAE 90.1 minimum standard requirements to compare the monthly HVAC energy consumption of the traditionally constructed metal-framed building system with that the AAC building systems. The commercial metal-framed and AAC models consumed the most the HVAC energy during August. The model with the metal-framed system consumed peak HVAC energy during August in all 15 cities; therefore, in comparison with AAC systems, the metal-framed system yields more predictable results but is less efficient. The highest HVAC energy consumption for the model with AAC system occurred during August in 11 of 15 cities, during May in three cities, and during March in one city.

Table 4-20 to 4-23 contain the results from the Visual-DOE analysis for the metal-framed and AAC systems, as well as results from the analysis of the comparisons between the two systems. The highlighted cells in the tables represent the peak energy consumed by month. Figure 4-15 shows the average

August HVAC energy consumption and the average August temperature. Figure 4-16 graphically displays the averages of peak HVAC energy consumption during summer months and the average summer temperatures in the 15 cities; this graph also indicates that the metal-framed model in Daytona consumed the most energy at 5133 kWh and that the AAC model in that city consumed only 3269 kWh. This result reveals that, in comparison with the metal-framed model, the AAC model proved 36 percent more efficient.

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Table 4-20 Metal-frame (ASHRAE 90.1) monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver. +Std Dev	Max	Min	Max in Aug	Delta Aug-Max	Max>1 Std Dev
Minot, ND	2949	2895	2413	3771	2902	3555	4266	4143	4657	2956	2822	2904	3353	705.5	4058	4657	2413	TRUE	0	TRUE
Madison, WI	3160	3176	2708	3940	3046	3962	4643	4268	4918	3659	3315	3066	3655	695.9	4351	4918	2708	TRUE	0	TRUE
Chicago, IL	3257	3211	2684	3920	2862	4138	4777	4213	5349	4169	3322	2853	3730	832.4	4562	5349	2684	TRUE	0	TRUE
Missoula, MT	2963	3017	2579	3314	2539	3245	3776	3437	4152	2930	2680	2685	3110	498.4	3608	4152	2539	TRUE	0	TRUE
Springfield, MO	3022	3275	2780	3760	3773	4912	5313	4515	5388	4490	3845	2896	3997	920.0	4917	5388	2780	TRUE	0	TRUE
Tulsa, OK	3049	3399	2699	4084	3972	5112	5090	4437	5384	4543	3839	2858	4039	909.7	4949	5384	2699	TRUE	0	TRUE
Richmond, VA	3005	3157	2709	3584	3470	4553	5033	4479	5384	4497	4037	3210	3927	860.6	4787	5384	2709	TRUE	0	TRUE
Boston, MA	3069	3441	2751	3594	2442	3928	4688	4342	5078	4138	3304	2528	3609	848.6	4457	5078	2442	TRUE	0	TRUE
Philadelphia, PA	3157	3243	2731	3509	2895	4453	4949	4382	5307	4450	3761	2924	3813	869.5	4683	5307	2731	TRUE	0	TRUE
Reno, NV	2644	2851	2178	3186	2700	3410	3815	3319	4018	3056	2841	2559	3048	532.1	3580	4018	2178	TRUE	0	TRUE
Sacramento, CA	2161	2528	2155	3270	3087	4093	4231	3824	4548	3646	3628	2653	3319	810.2	4129	4548	2155	TRUE	0	TRUE
Houston, TX	3789	3811	3054	4852	4559	5178	5229	4609	5527	4510	4779	4036	4494	710.3	5205	5527	3054	TRUE	0	TRUE
Atlanta, GA	2997	2990	2793	4074	4002	4876	5082	4584	5508	4814	4053	3110	4074	926.1	5000	5508	2793	TRUE	0	TRUE
Daytona, FL	4114	4016	3350	5091	4571	5272	5235	4649	5514	4557	4822	4253	4620	620.9	5241	5514	3350	TRUE	0	TRUE
Miami, FL	4431	4601	3837	5106	4494	5174	5153	4680	5400	4519	4717	4337	4704	438.9	5143	5400	3837	TRUE	0	TRUE

The commercial model with ASHRAE 90.1 standard minimum requirement HVAC energy use is between 3110-4704 kWh. The model with ASHRAE application energy usage is an average of 85 kWh less energy than the model without ASHRAE application. The dark cells indicate the most energy use by the month for 15 different climates in the United States.

Table 4-21 AAC systems (ASHRAE 90.1) monthly HVAC use (kWh)

City, State	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Aver	Std Dev	Aver. +Std Dev	Max	Min	Max in Aug	Delta Aug-Max	Max>1 Std Dev
Minot, ND	2324	2276	1844	3186	2451	3055	3560	3380	3897	2513	2410	2355	2771	624.5	3396	3897	1844	TRUE	0	TRUE
Madison, WI	2513	2467	2093	3330	2580	3388	3856	3452	4146	3093	2820	2553	3024	622.6	3647	4146	2093	TRUE	0	TRUE
Chicago, IL	2585	2538	2028	3296	2393	3482	3853	3223	4382	3449	2798	2360	3032	697.1	3729	4382	2028	TRUE	0	TRUE
Missoula, MT	2256	2318	1945	2711	2059	2679	3082	2594	3326	2381	2182	2098	2469	422.9	2892	3326	1945	TRUE	0	TRUE
Springfield, MO	2451	2636	2205	3171	3110	4052	4058	3558	4367	3549	3195	2381	3228	714.4	3942	4367	2205	TRUE	0	TRUE
Tulsa, OK	2454	2675	2127	3385	3210	4213	3847	3512	4173	3579	3138	2318	3219	702.4	3922	4213	2127	FALSE	40	TRUE
Richmond, VA	2491	2602	2174	3056	2895	3833	4001	3430	4224	3703	3406	2671	3207	656.8	3864	4224	2174	TRUE	0	TRUE
Boston, MA	2509	2764	2177	3031	2042	3312	3924	3396	4192	3434	2773	2099	2971	704.7	3676	4192	2042	TRUE	0	TRUE
Philadelphia, PA	2584	2617	2184	2992	2426	3767	4122	3293	4268	3723	3178	2438	3133	708.1	3841	4268	2184	TRUE	0	TRUE
Reno, NV	2143	2331	1739	2696	2223	2863	3099	2552	3241	2445	2373	2092	2483	434.3	2917	3241	1739	TRUE	0	TRUE
Sacramento, CA	1819	2137	1774	2809	2595	3471	3493	3027	3682	3011	3047	2219	2757	652.1	3409	3682	1774	TRUE	0	TRUE
Houston, TX	3212	3235	2556	4174	3874	4466	3903	3600	4320	3614	4044	3432	3703	542.5	4245	4466	2556	FALSE	146	TRUE
Atlanta, GA	2547	2551	2340	3535	3404	4100	4007	3565	4376	3929	3467	2632	3371	693.6	4065	4376	2340	TRUE	0	TRUE
Daytona, FL	3486	3419	2809	4379	3859	4494	4183	3561	4360	3614	3941	3598	3809	491.6	4300	4494	2809	FALSE	134	TRUE
Miami, FL	3889	4009	3302	4456	3749	4303	3979	3673	4375	3779	3932	3707	3929	328.9	4258	4456	3302	FALSE	81	TRUE

The commercial model with ASHARE 90.1 code requirement HVAC energy use is between 2469-3929 kWh. The model with ASHRAE code energy usage uses an average of 400 kWh less energy than the model that simulated without ASHRAE 90.1 standard requirement. The dark cells are indicating the most energy use by the month for 15 different climates in the United States.

Table 4-22 Commercial models (ASHRAE 90.1) comparisons (kWh)

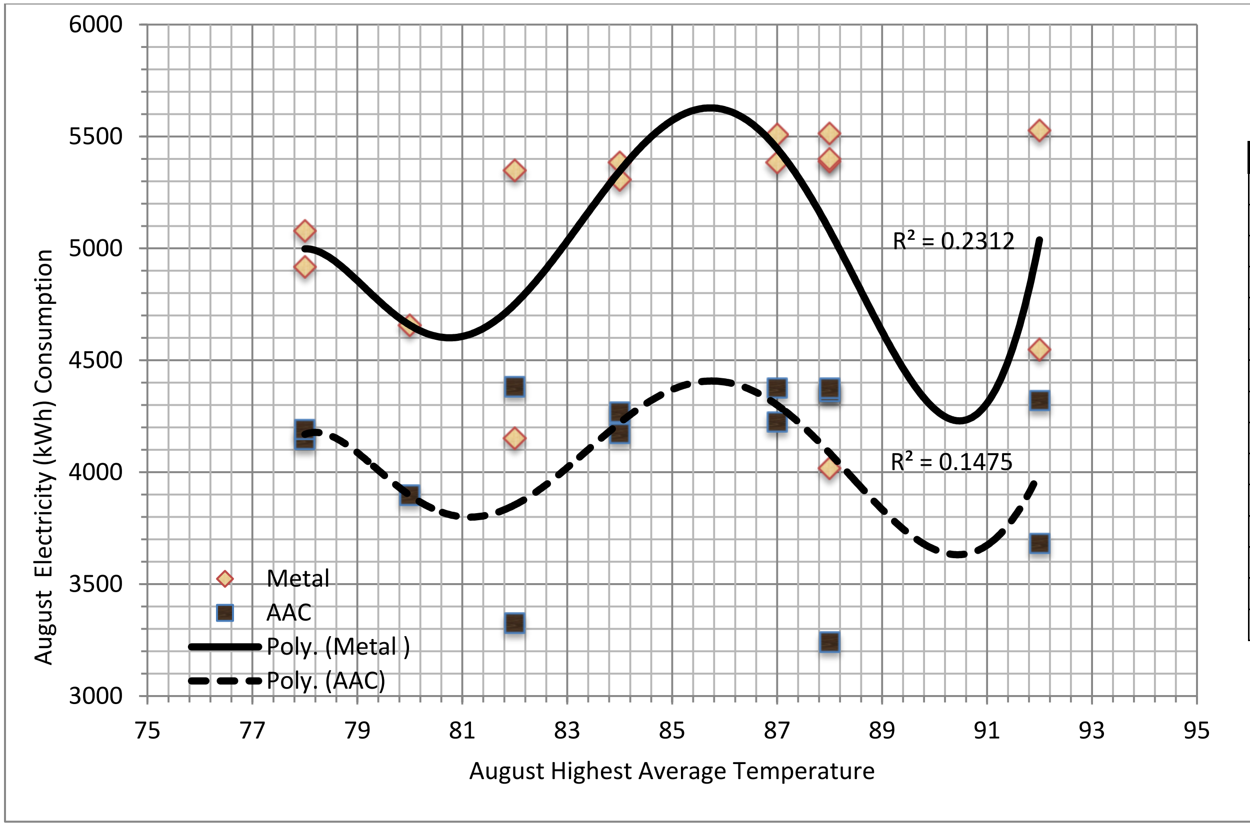
(AAC & Metal)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Sum
City, State	Region	Zone	Latitude													
Minot, ND	ME	7	48	625	619	569	585	451	500	706	763	760	443	412	549	6982
Madison, WI	ME	6	43	647	709	615	610	466	574	787	816	772	566	495	513	7570
Chicago, IL	ME	5	41	672	673	656	624	469	656	924	990	967	720	524	493	8368
Missoula, MT	MW	6	46	707	699	634	603	480	566	694	843	826	549	498	587	7686
Springfield, MO	MW	4	37	571	639	575	589	663	860	1255	957	1021	941	650	515	9236
Tulsa, OK	MW	3	36	595	724	572	699	762	899	1243	925	1211	964	701	540	9835
Richmond, VA	NE	4	44	514	555	535	528	575	720	1032	1049	1160	794	631	539	8632
Boston, MA	NE	5	42	560	677	574	563	400	616	764	946	886	704	531	429	7650
Philadelphia, PA	NE	4	39	573	626	547	517	469	686	827	1089	1039	727	583	486	8169
Reno, NV	SW	4	39	501	520	439	490	477	547	716	767	777	611	468	467	6780
Sacramento, CA	SW	3	38	342	391	381	461	492	622	738	797	866	635	581	434	6740
Houston, TX	SW	2	29	577	576	498	678	685	712	1326	1009	1207	896	735	604	9503
Atlanta, GA	SE	3	33	450	439	453	539	598	776	1075	1019	1132	885	586	478	8430
Daytona, FL	SE	2	29	628	597	541	712	712	778	1052	1088	1154	943	881	655	9741
Miami, FL	SE	2	25	542	592	535	650	745	871	1174	1007	1025	740	785	630	9296

The above table displays commercial simulation results for ASHRAE 90.1 standard models between metal-frame and AAC building systems HVAC energy use (kWh). The table indicates that the AAC model utilizes less energy than the commercial model. Lowest improvement is in Sacramento with 6740 kWh, and highest improvement in Tulsa with 9835 kWh.

Table 4-23 Commercial models (ASHRAE 90.1) improvements

(AAC & Metal)				Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Average
US Cities	Region	Zone	Latitude													
Minot, ND	ME	7	48	21%	21%	24%	16%	16%	14%	17%	18%	16%	15%	15%	19%	18%
Madison, WI	ME	6	43	20%	22%	23%	15%	15%	14%	17%	19%	16%	15%	15%	17%	17%
Chicago, IL	ME	5	41	21%	21%	24%	16%	16%	16%	19%	23%	18%	17%	16%	17%	19%
Missoula, MT	MW	6	46	24%	23%	25%	18%	19%	17%	18%	25%	20%	19%	19%	22%	21%
Springfield, MO	MW	4	37	19%	20%	21%	16%	18%	18%	24%	21%	19%	21%	17%	18%	19%
Tulsa, OK	MW	3	36	20%	21%	21%	17%	19%	18%	24%	21%	22%	21%	18%	19%	20%
Richmond, VA	NE	4	44	17%	18%	20%	15%	17%	16%	21%	23%	22%	18%	16%	17%	18%
Boston, MA	NE	5	42	18%	20%	21%	16%	16%	16%	16%	22%	17%	17%	16%	17%	18%
Philadelphia, PA	NE	4	39	18%	19%	20%	15%	16%	15%	17%	25%	20%	16%	16%	17%	18%
Reno, NV	SW	4	39	19%	18%	20%	15%	18%	16%	19%	23%	19%	20%	16%	18%	19%
Sacramento, CA	SW	3	38	16%	15%	18%	14%	16%	15%	17%	21%	19%	17%	16%	16%	17%
Houston, TX	SW	2	29	15%	15%	16%	14%	15%	14%	25%	22%	22%	20%	15%	15%	17%
Atlanta, GE	SE	3	33	15%	15%	16%	13%	15%	16%	21%	22%	21%	18%	14%	15%	17%
Daytona, FL	SE	2	29	15%	15%	16%	14%	16%	15%	20%	23%	21%	21%	18%	15%	17%
Miami, FL	SE	2	25	12%	13%	14%	13%	17%	17%	23%	22%	19%	16%	17%	15%	16%

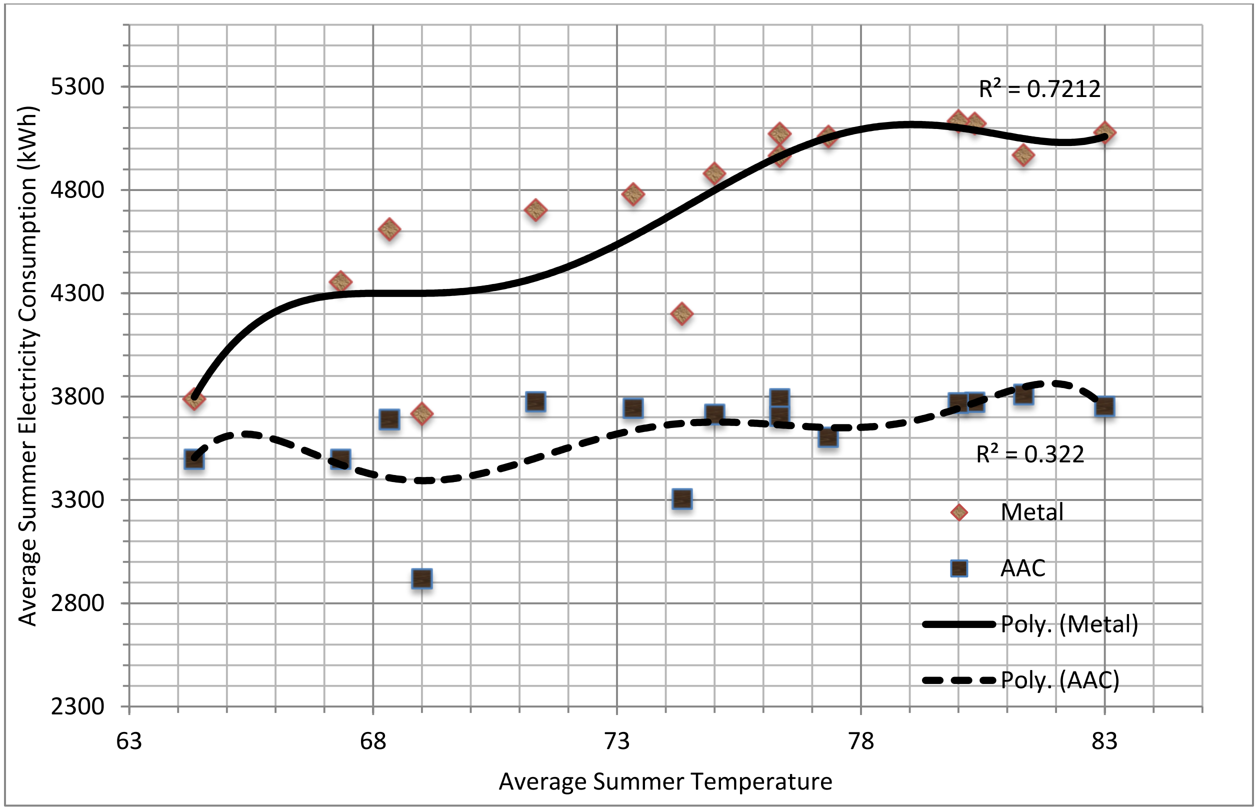
The commercial ASHRAE 90.1 standard models HVAC energy use between AAC (whole system) and metal-framed system model has the highest difference is in Missoula with 21percent, and lowest difference is in Miami with 16 percent.



City, State	(F⁰)	AAC	Metal
Sacramento, CA	92	3682	4548
Houston, TX	92	4320	5527
Springfield, MO	88	4367	5388
Reno, NV	88	3241	4018
Daytona, FL	88	4360	5514
Miami, FL	88	4375	5400
Richmond, VA	87	4224	5384
Atlanta, GA	87	4376	5508
Tulsa, OK	84	4173	5384
Philadelphia, PA	84	4268	5307
Chicago, IL	82	4382	5349
Missoula, MT	82	3326	4152
Minot, ND	80	3897	4657
Madison, WI	78	4146	4918
Boston, MA	78	4192	5078

Figure 4-15 Commercial models (ASHRAE 90.1) August HVAC use

The above figure displays August average HVAC energy use (kWh) in the model with ASHRAE application between metal-frame and AAC building systems. The figure shows clearly those metal-framed systems use more energy for HVAC than AAC systems in commercial structures for 15 United State cities in different climate zone.



City, State	(F^0)	AAC	Metal
Miami, FL	83	3753	5078
Tulsa, OK	81	3810	4970
Houston, TX	80	3772	5122
Daytona, FL	80	3769	5133
Atlanta, GA	77	3603	5058
Springfield, MO	76	3789	5072
Richmond, VA	76	3706	4965
Philadelphia, PA	75	3713	4879
Sacramento, CA	74	3304	4201
Chicago, IL	73	3744	4780
Boston, MA	71	3775	4703
Reno, NV	69	2918	3717
Madison, WI	68	3689	4610
Minot, ND	67	3498	4355
Missoula, MT	64	3498	3788

Figure 4-16 Commercial models (ASHRAE 90.1) summer HVAC use

The above figure displays summer average (Jun-Aug) HVAC energy use (kWh) between metal-frame and AAC building systems in ASHRAE 90.1 code commercial model. The figure indicates that the AAC models utilize less HVAC energy than the metal-frame models.

According to the results from the Visual-DOE analysis for the commercial (ASHRAE 90.1) models, the most HVAC energy was consumed during August. The model specified with a metal-framed system consumed HVAC energy in August for 15 of 15 cities. In contract, the model with the AAC system consumed peak rates of HVAC energy during August for 11 of 15 cities and in May or March for the other four cities.

Sections 4.1.4.1 through 4.1.4.4 contained discussions of the results from the comparative analyses of both wall systems and building systems models in traditional constructed framed and AAC systems for both residential and commercial structures. Those results support the hypothesis that computer simulation modeling constitutes a useful tool for evaluating sustainable building performance. This simulation modeling enables comparison of the energy consumption of emerging building materials and building systems. Therefore, energy simulation using the Visual-DOE software identifies reliably the most energy-efficient building material. The data analysis indicates that, in comparison with AAC building systems and regardless of climate and building type, traditional framed systems consume more HVAC energy. The results indicated that highest HVAC energy consumption by residential models occurred during July, and that peak HVAC energy consumption by commercial models took place during August.

The methods used in Section 4.1.4 support the theory that estimations of monthly energy consumption can assist designers with making decisions that lead to decreased energy use. For example, when designers in the planning phase select materials for a project, they can use a simulation model to make informed decisions that climate factors and proposed building designs. The results from this research study indicate that thermal mass materials are preferable for a project in a warmer climate.

4.1.5. Results of statistical analyses

The study involved using a paired t-test to examine the statistical differences between the Visual-DOE-simulated energy performance of framed building systems and AAC building systems. Lilliefors test was used to justify the normal distribution of the sample.

The procedure for the two-paired t-test is explained in Section 3.3.4.

The Four tests were completed in two sections:

I. Residential and commercial wall systems
    i. Residential model: comparison of wood-frame system with AAC system
    ii. Commercial model: comparison with metal-frame system with AAC system
II. The model ASHRAE 90.1 minimum standard residential and commercial
    i. Residential model: comparison of wood-frame system with AAC system

ii. Commercial model: comparison with metal-frame system with AAC system

For each comparison analysis, the paired-sample t-test was applied to compare the HVAC energy consumption (kWh) of the traditionally framed system with that of the AAC system. Results indicated a highly significant difference with $p<0.001$. Therefore, we concluded that evidence existed of a significant difference between the energy consumption of the two systems.

The results from the two-paired t-test analysis support the hypothesis that computer simulation modeling can be an accurate, useful tool with which to evaluate energy efficient-building performance and enable comparison of the energy consumption of building materials. Because p-values for Lilliefors statistical analyses exceeded 0.05, we did not reject the hypothesis that the sample came from a normal distribution. Results from the statistical analysis (two-paired t-test) led to the conclusion that evidence exists of a significant difference between the energy consumption of the two building systems, and the results from the Visual-DOE software simulations proves that, in comparison with the traditional framed systems, the AAC system is an energy-efficient building material.

Table 4-24 Paired t-test for residential wall systems

City	F^0	AAC	Wood	Improvement	Differences
Missoula	64	520	596	14.6%	-76
Minot	67	597	638	6.9%	-41
Madison	68	560	604	7.9%	-44
Reno	69	488	582	19.3%	-94
Boston	71	530	601	13.4%	-71
Chicago	73	561	623	11.1%	-62
Sacramento	74	513	608	18.5%	-95
Philadelphia	75	547	616	12.6%	-69
Springfield	76	566	638	12.7%	-72
Richmond	76	546	633	12.3%	-67
Atlanta	77	542	624	15.1%	-82
Daytona	80	546	633	15.9%	-87
Houston	80	548	641	17.0%	-93
Tulsa	81	598	674	12.7%	-76
Miami	83	563	640	13.7%	-77

t-test: Paired Two Sample for Means		
	AAC (kWh)	***Wood (kWh)***
Mean	548.333	622.067
Variance	838.524	527.210
Observations	15	
Pearson Correlation	0.8299	
Hypothesized Mean Difference	0	
df	14	
t Stat	-17.635	
P(T<=t) two-tail	$5.877\text{x}10^{-11}$	
Lilliefors test of normality of the difference variable (p>0.05)		
		p= 0.666

The table compares the output of the model between AAC wall system and wood-framed model for summer HVAC energy use (kWh).

Table 4-25 Paired t-test for commercial wall systems

City	F^0	AAC	Metal	Improvement	Differences
Missoula	64	3452	3845	11%	-393
Minot	67	4147	4564	10%	-417
Madison	68	4339	4716	9%	-377
Reno	69	3295	3800	15%	-505
Boston	71	4454	4828	8%	-373
Chicago	73	4422	4910	11%	-489
Sacramento	74	3895	4260	9%	-365
Philadelphia	75	4479	4989	11%	-510
Springfield	76	4504	5038	12%	-534
Richmond	76	4488	4948	10%	-461
Atlanta	77	4503	5080	13%	-577
Daytona	80	4545	5096	12%	-551
Houston	80	4267	4984	17%	-717
Tulsa	81	4132	4826	17%	-693
Miami	83	4309	4830	12%	-521

t-test: Paired Two Sample for Means		
	AAC (kWh)	***Metal(kWh)***
Mean	4215.378	4714.311
Variance	149126.887	177408.611
Observations	15	15
Pearson Correlation	0.968	
Hypothesized Mean Difference	0	
df	14	
t Stat	-17.817	
P(T<=t) two-tail	5.120x10^{-11}	
Lilliefors test of normality of the difference variable (p>0.05)		
		p=0.999

The table compares the output of the model between AAC wall system and metal-framed model for summer HVAC energy use (kWh).

Table 4-26 Paired t-test for residential (AHSRAE 90.1)

City	F^0	AAC	Wood	Improvement	Differences
Missoula	64	278	364	31%	-86
Minot	67	329	403	22%	-74
Madison	68	297	364	23%	-67
Reno	69	265	371	40%	-106
Boston	71	280	354	27%	-74
Chicago	73	308	381	24%	-73
Sacramento	74	312	432	38%	-120
Philadelphia	75	321	394	23%	-74
Springfield	76	345	433	26%	-88
Richmond	76	307	391	27%	-84
Atlanta	77	368	461	25%	-93
Daytona	80	354	467	32%	-113
Houston	80	407	519	28%	-112
Tulsa	81	497	586	18%	-89
Miami	83	374	491	31%	-117

t-test: Paired Two Sample for Means		
	AAC (kWh)	***Wood (kWh)***
Mean	336.111	427.333
Variance	3524.804	4438
Observations	15	15
Pearson Correlation	0.965	
Hypothesized Mean Difference	0	
df	14	
t Stat	-19.571	
P(T<=t) two-tail	$1.443x10^{-11}$	
Lilliefors test of normality of the difference variable (p>0.05)		
		p=0.335

The table compares the output of the model between AAC systems and wood-framed model for summer HVAC energy use (kWh).

Table 4-27 Paired t-test for commercial (AHSRAE 90.1)

City	F^0	AAC	Metal	Improvement	Differences
Missoula	64	3498	3788	8%	-290
Minot	67	3498	4355	25%	-857
Madison	68	3689	4610	25%	-921
Reno	69	2918	3717	27%	-799
Boston	71	3775	4703	25%	-927
Chicago	73	3744	4780	28%	-1036
Sacramento	74	3304	4201	27%	-897
Philadelphia	75	3713	4879	31%	-1166
Springfield	76	3789	5072	34%	-1283
Richmond	76	3706	4965	34%	-1260
Atlanta	77	3603	5058	40%	-1455
Daytona	80	3769	5133	36%	-1364
Houston	80	3772	5122	36%	-1350
Tulsa	81	3810	4970	30%	-1160
Miami	83	3753	5078	35%	-1324

t-test: Paired Two Sample for Means		
	AAC (kWh)	***Metal(kWh)***
Mean	3622.822	4695.4
Variance	57909.442	223470.591
Observations	15	15
Pearson Correlation	0.836	
Hypothesized Mean Difference	0	
df	14	
t Stat	-13.764	
P(T<=t) two-tail	1.578x10^{-9}	
Lilliefors test of normality of the difference variable (p>0.05)		
		p=0.549

The table compares the output of the model between AAC systems and metal-framed model for summer HVAC energy use (kWh).

4.2. LEED Analysis

This section contains a discussion the results from the task of determining the possibility of designing a method to estimating the amount of credits a building material can achieve for the LEED, Green Building Rating System Energy performance credit. The centered focus on estimating the energy cost savings and the degree to which the design exceeds the minimum requirements of the ASHRAE/ESNA 90.1-2007 code.

4.2.1. LEED Energy Credit Evaluation

I undertook this analysis to record the energy modeling performance of the AAC system and to present the results related to the LEED rating system, specifically the Energy and Atmosphere Credit 1, Optimize Energy Performance. The task involved designing two models were designed for these evaluations, one baseline model that meets the minimum ASHRAE 90.1-2007 requirements and the other a proposed model that exceeds the standards.

I undertook this task to examine the potential impact of AAC systems in building design on achieving points for the LEED Optimize Energy Performance credit. Therefore, lighting for interior and exterior, service water heating, and equipment energy consumptions remained at baseline standard for both designs. The study involved focusing on only the impact of the material on the envelope of the building. Table 4-28 and Table 4-29 summarize the baseline and proposed design input parameter. Table 4-30 contains the energy consumption results for the baseline and proposed designs, and Table 4-31 provides the percentages of expected improvement.

The results indicate that, in comparison with the baseline model, the AAC system model, designed to exceed the minimum requirements, and performed 5 percent more efficiently. Table 3-4 contains a chary of the USGBC (2006) credits guidelines for the minimum savings in energy costs; for every 2 percent increase in improved energy performance, one additional credit for LEED certification can be achieved for the project. According to Visual-DOE software results from the energy simulation analysis, AAC systems potentially can earn 3 LEED credits in the early design stage because, in comparison with the baseline model, these systems use less energy.

The results from this analysis support the hypothesis that a computer simulation modeling can be prove an accurate, useful tool with which evaluate sustainable building performance in terms of an established standard and can compare the energy consumption of promising building materials. Therefore, the method of comparing the baseline building model, which meets the ASHRAE 90.1 code, with the model that exceeds the code and uses AAC wall, roof, and floor systems, provides the results needed for improvement that earns LEED credits.

Table 4-28 The baseline design input parameters summarize

Climate Zone: 3
Gross Floor Area: 22,156 ft²
Occupancy Type: Office Building
Window Area: 1548 ft²
Overall Window-Wall-Ratio: 9.8%

Block Constructions:

Construction	**Description**	**U-Factor (Btu/h-ft²-°F)**	**HC (Btu/ft²-°F)**
Roof	Concrete 12″ R-20 insulation	0.044	28.5
Ceiling	Suspended Ceiling	0.489	0.2
Slab	Simulated Slab without Insulation	0.135	45.5
Floor	R-6.3 Mass	0.115	28.1
Wall	12″ concrete R-8	0.118	16.0

Block Dimension:

Coordinates (ft)	**Width (ft)**	**Depths (ft)**
X	130	204
Y	46	156
Z	38	190

Facade Dimension:

Orientation & #of windows	Window Construction	U-Factor (Btu/h-ft²-°F)	Bay Width (ft)	Window Height (ft)	Window Width (ft)
East - 11	Double Reflected TintIG 6/6/6 mm	.555	11	5	3
South -15	Same as above	Same as above	13	5	3
West -2	Same as above	Same as above	20	5	3
North -11	Same as above	Same as above	14	4.5	8
West - 1	Same as above	Same as above	25	4.5	8
South -11	Same as above	Same as above	16	4.5	8
West - 4	Same as above	Same as above	10	5	3
North -16	Same as above	Same as above	14.5	5	3

Table 4-29 The proposed design input parameters summarize

Climate Zone: 3
Gross Floor Area: 22,156 ft^2
Occupancy Type: Office Building
Window Area: 1548 ft^2
Overall Window-Wall-Ratio: 9.8%

Block Constructions:

Construction	**Description**	**U-Factor (Btu/h-ft²-°F)**	**HC (Btu/ft²-°F)**
Roof	AAC-Roof (R-20 Insulation)	0.030	8.3
Ceiling	Suspended Ceiling	0.489	0.2
Slab	Simulated Slab without Insulation	0.135	45.5
Floor	AAC-Floor(R-6.3 Insulation)	0.051	7.8
Wall	AAC 12''	0.064	10.2

Block Dimension:

Coordinates (ft)	**Width (ft)**	**Depths (ft)**
X	130	204
Y	46	156
Z	38	190

Facade Dimension:

Orientation & #of windows	Window Construction	U-Factor (Btu/h-ft²-°F)	Bay Width (ft)	Window Height (ft)	Window Width (ft)
East - 11	DoubleReflectedTint IG 6/6/6 mm	.555	11	5	3
South -15	Same as above	Same as above	13	5	3
West -2	Same as above	Same as above	20	5	3
North -11	Same as above	Same as above	14	4.5	8
West - 1	Same as above	Same as above	25	4.5	8
South -11	Same as above	Same as above	16	4.5	8
West - 4	Same as above	Same as above	10	5	3
North -16	Same as above	Same as above	14.5	5	3

Table 4-30: Baseline/proposed design energy use

Energy Summary for LEED	**Proposed Design Case (MBtu)**	**Baseline Design Case (MBtu)**	**Proposed/ Baseline**
Lighting –interior (Electricity)	236.4	236.4	100 %
Lighting-exterior (Electricity)	0	0	N.A.
Space heating (Electricity)	0	0	N.A.
Space heating (Fuel)	344.4	377.8	91%
Space cooling (Electricity)	33.6	37.8	89%
Pumps (Electricity)	2.8	3.2	88%
Heat rejection (Electricity)	3.1	3.6	86%
Fans (Electricity)	32.2	34.5	93%
Service Water Heating (Fuel)	4.7	4.7	100%
Misc. Equipments (Electricity)	160.5	160.5	100%
Total Building Consumption	817.7	858.5	95%

Table 4-31 Total energy percentage improvement

Percentage Improvement =	100x1-(Proposed Building Performance/Baseline Building Performance)
Percentage Improvement =	100x1-(817.7/858.5)
Percentage Improvement =	5

The results from this analysis support the hypothesis that a computer simulation modeling can be prove an accurate, useful tool with which evaluate sustainable building performance in terms of an established standard and can compare the energy consumption of promising building materials. Therefore, the method of comparing the baseline building model, which meets the ASHRAE

90.1 code, with the model that exceeds the code and uses AAC wall, roof, and floor systems, provides the results needed for improvement that earns LEED credits.

4.3. Framework for Software

This section provides results for the evaluation of currently available simulation software. The primary goal of the work discussed in this section consisted of establishing a framework that incorporates state-of-the-art software and that identifies further needs in computational subroutines and decision pathways that green industry professionals can use to derive accurate building performance results.

4.3.1. Framework Priority Concepts

I undertook this task to identify an adaptable framework based on the priorities set by the U.S. DOE workshops. Section 3.3.6 (U.S. DOE-EERE, 1996) which contains a discussion of the U.S. DOE workshops context. The proposed framework consists of 46 concepts used in the evaluation. These 46 concepts were reviewed under four categories: Applications, Capabilities, User Interface, and Methods/Structure. Appendix C lists the 46 concepts and includes detailed descriptions of each.

This section contains a description of the tasks involved in presenting approaches for next-generation energy simulation software; developing or designing a specific energy simulation tool was not the intent. The proposed framework offers several recommendations for making modeling and simulation techniques more cost effective, reducing time, improving the quality of the model, and obtaining detailed results for energy-efficiency properties throughout the life of the building and its materials. Recommendations for the proposed framework for future-generation software are represented

I. Program Application Priorities

i. Design

1- Envelope design
2- Early analysis of design
3- Analysis of advanced design
4- System design
5- Multiple building systems

ii. Performance Evaluation

6- Environmental impact
7- Energy consumption
8- Life cycle assessment
9- Economic and cost analysis
10- LEED applications
11- Comfort control
12- Indoor air quality
13- Fault detection and diagnostic procedure

iii. Information Repository

14- Electronic owner's manual

15- System and equipment sizing wizards

16- Provision of basis for simplified design options(defaults)

17- Building code compliance

II. Program Capability Priorities

i. Physical process Model

18- Lighting/day-lighting

19- Envelope/Environmental interaction

20- Moisture absorption

21- Air infiltration

22- Heat transfer models

ii. Building System

23- Passive/active solar design

24- HVAC system design

25- Advanced fenestration and natural ventilation

26- Energy storage in buildings

27- Advanced lighting system modeling

iii. Inputs and Outputs

28- Accessing of library and database information

29- Micro-and macro-weather data

30- Standardized data structures

31- Case studies database for decision-making

32- Modeling of topography

iv. Model Component

33- Comparison systems or designs

34- Design support

35- Wind pressure distribution

III. Program Interface Priorities

i. Interoperability and Integration

36- Multi platform, parallel processing
37- Emerging technologies and new processes
38- Interoperability with other tools
39- Tutorials and online support

ii. Customized Features

40- Customizable output and reports
41- 3D spatial displays
42- Adaptable interface
43- Simultaneous solution

IV. Program Method and Structure

44- Expertise requirement
45- Diversity of audience
46- Simple input options

4.3.2. Evaluation of the Tools

The section contains a discussion of the 20 most used energy modeling software programs and the evaluation of the selected energy-modeling programs in terms of the 46 proposed priority concepts. The selected software programs were suggested within the Building Technologies Program (BTP) Web Directory on the U.S. DOE (U.S. DOE-EERE, 2011a). Section 3.3.6.2 includes a list of the selected software programs, and Appendix B contains list of the other 231 programs. In addition, the Section 4.3.2.1consists of an examination of areas of improvement for the next-generation energy-modeling programs.

4.3.2.1. *Selected tools.* This section provides a comparison of software capabilities using proposed priority components to determine the current state of simulation software programs; the results from the comparison also identified the three software programs that most effectively included the priority concepts in their applications. The 20 selected energy simulation programs as the follows:

1. Audit
2. COMSOL
3. Design Advisor
4. DOE-2
5. Eco-Tect
6. Energy-10
7. Energy-Plus
8. Energy-Pro
9. Energy Savvy
10. E-Quest
11. Fed
12. Hap
13. HEED
14. Homer
15. Market Manager
16. Micropas-6
17. Right-Suite Residential
18. SOLAR-5
19. TREAT
20. Visual-DOE

4.3.2.2. *Evaluation of the 20 energy- modeling tools.* Several versions of programs simulating the energy consumed by buildings have been developed and are used throughout the building sector. As technology advances, the software requirements and expectations of users necessitate improvements. U.S. DOE (1995 and 1996) held two workshops to identify areas that most needed improving. In 2011, the research on this topic in preparation for this dissertation led to an evaluation of which of the 20 selected software tools applied U.S. DOE workshop priority concepts in their program.

Tables 4-32, through 4-36 display the results from the evaluation of the software programs. In these tables the first columns list the priority concepts, the second and the third columns represent votes for each idea by developers and users attending the workshops, and the fourth column indicates the sum of participant votes (used as multiplier). The next 20 columns indicate energy simulation software selected for evaluation. Dark cells, with a value of 0 inside them, represent software that does not apply the U.S. DOE (1995, 1996) priority concepts. A light cell with a value of 1 inside represents that does apply these concepts. The last column provides the number of software programs incorporating the concepts.

Table 4-32 The Program Application Priorities evaluation

Whole Building Analysis: Energy Simulation	User -Voting	Developer -Voting	Multiplier	AUDIT	COMSOL	DESIGN ADVISOR	DOE-2	ECOTECT	ENERGY-10	ENERGYPLUS	ENERGYPRO	ENERGYSAVVY	EQUEST	FEDS	HAP	HEED	HOMER	MARKET MANAGER	MICROPAS6	RIGHT-SUITE	SOLAR-5	TREAT	VISUAL-DOE	Sum of Raw Points
I-PROGRAM APPLICATION PRIORITIES																								
i. Design																								
Envelope design	**37**	**18**	**55**	0	0	1	1	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	1	**15**
Early analysis of design	**25**	**15**	**40**	0	0	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	1	1	**16**
Developed design analysis	**19**	**21**	**40**	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	**3**
System design	**22**	**14**	**36**	1	0	0	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	**16**
Multiple building systems	**9**	**7**	**16**	1	0	1	1	1	0	1	1	0	1	1	1	0	0	0	0	0	1	0	1	**11**
ii. Performance Evaluation																								
Environmental impact	**31**	**30**	**61**	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	1	0	1	0	0	**5**
Energy consumption	**27**	**11**	**38**	0	0	1	1	1	1	1		1	1	1	1	1	1	1	0	0	1	0	1	**15**
Life Cycle Assessment	**11**	**4**	**15**	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Economic & cost analysis	**18**	**12**	**30**	1	0	1	1	1	0	1	0	0	1	1	1	1	1	1	0	1	1	0	1	**14**
LEED applications			77	0	0	0	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	1	1	**6**
Comfort control	**64**	**21**	**85**	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**3**
Indoor Air Quality	**37**	**21**	**58**	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**2**
Fault detection & Diagnostic	**27**	**14**	**41**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	**2**
iii. Information Repository																								
Electronic owner's manual	**8**	**9**	**17**	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	**3**
System & equipment wizards	**28**	**16**	**44**	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**2**
Basis for Simplified (Defaults)	**27**	**15**	**42**	0	0	0	0	1	1	1	0	0	1	1	0	1	0	1	1	0	0	0	1	**9**
Building code compliance	**26**	**18**	**44**	0	0	0	0	0	0	1	0	0	1	0	0	0	0	1	1	0	0	0	0	**4**

Table 4-33 The Program Capability Priorities evaluation

Whole Building Analysis: Energy Simulation	User -Voting	Developer -Voting	Multiplier	AUDIT	COMSOL	DESIGN ADVISOR	DOE-2	ECOTECT	ENERGY-10	ENERGYPLUS	ENERGYPRO	ENERGYSAVVY	EQUEST	FEDS	HAP	HEED	HOMER	MARKET MANAGER	MICROPAS6	RIGHT-SUITE	SOLAR-5	TREAT	VISUAL-DOE	Sum of Raw Points
II-PROGRAM CAPABILITY PRIORITIES																								
i. Physical Process Model																								
Lighting/day-lighting	**58**	**24**	**82**	0	0	1	0	1	1	1	0	1	1	0	0	1	0	1	1	0	1	1	1	**12**
Envelope/Environment Interaction	**34**	**35**	**69**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Moisture absorption	**34**	**22**	**56**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
Air infiltration	**26**	**22**	**48**	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	**3**
Heat transfer models	**40**	**27**	**67**	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	**3**
ii. Building System																								
Passive/Active solar design	**44**	**8**	**52**	0	0	0	0	1	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0	**4**
HVAC system design	**27**	**18**	**45**	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
Fenestration & natural ventilation	**12**	**11**	**23**	0	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	**4**
Energy storage in buildings	**9**	**8**	**17**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	**1**
Advanced lighting system	**6**	**4**	**10**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
iii. Input & Output																								
Accessible library	**33**	**20**	**53**	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**3**
Micro & macro weather data	**11**	**7**	**18**	0	0	0	1	0	1	1	0	0	1	0	1	0	0	0	0	0	1	1	1	**8**
Standardized data structures	**13**	**5**	**18**	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	**3**
Case studies database	**23**	**6**	**29**	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	1	0	0	**3**
Modeling topography	**8**	**2**	**10**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
vi. Model Component																								
Comparison Systems or Designs	**9**	**3**	**12**	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	**4**
Design support	**40**	**7**	**47**	0	1	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	1	0	0	**5**
Wind pressure distribution	**7**	**3**	**10**	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**

Table 4-34 The Program Interface Priorities evaluation

Whole Building Analysis: Energy Simulation	User -Voting	Developer -Voting	Multiplier	AUDIT	COMSOL	DESIGN ADVISOR	DOE-2	ECOTECT	ENERGY-10	ENERGYPLUS	ENERGYPRO	ENERGYSAVVY	EQUEST	FEDS	HAP	HEED	HOMER	MARKET MANAGER	MICROPAS6	RIGHT-SUITE	SOLAR-5	TREAT	VISUAL-DOE	Sum of Raw Points
III. PROGRAM INTERFACE PRIORITIES																								
i. Interoperability & Integration																								
Multi-platform, parallel processing	**9**	**2**	**11**	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	**2**
Emerging technologies	**18**	**6**	**24**	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	**2**
Interoperability & collaboration	**49**	**40**	**86**	0	1	0	1	1	0	1	0	0	1	0	1	0	0	0	1	0	0	0	1	**8**
Tutorials & online support	**22**	**11**	**33**	0	1	0	0	1	0	0	0	0	1	0	1	1	0	0	0	0	0	0	1	**6**
ii. Customize Features																								
Customizable output & report	**27**	**13**	**40**	0	0	0	0	1	0	0	0	0	1	0	1	0	0	1	1	1	0	0	0	**6**
3D spatial displays	**48**	**29**	**77**	0	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	**5**
Adaptable interface	**11**	**21**	**32**	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	**3**
Simultaneous solution	**15**	**7**	**22**	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**

Table 4-35 The Program Method & Structure evaluation

Whole Building Analysis: Energy Simulation	User -Voting	Developer -Voting	Multiplier	AUDIT	COMSOL	DESIGN ADVISOR	DOE-2	ECOTECT	ENERGY-10	ENERGYPLUS	ENERGYPRO	ENERGYSAVVY	EQUEST	FEDS	HAP	HEED	HOMER	MARKET MANAGER	MICROPAS6	RIGHT-SUITE	SOLAR-5	TREAT	VISUAL-DOE	Sum of Raw Points
IV. PROGRAM METHOD & STRUCTURE																								
Expertise (Education)	**23**	**23**	**46**	0	0	1	0	0	0	0	0	1	1	0	0	1	0	0	0	0	1	0	0	**20**
Multiple audience	**6**	**5**	**11**	0	0	1	1	1	1	0	1	0	1	0	1	1	0	0	1	0	1	0	1	**11**
Simple input options	**13**	**5**	**18**	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	**8**

Table 4-36 Evaluation result summary

Whole Building Analysis: Energy Simulation	Multiplier	AUDIT	COMSOL	DESIGN ADVISOR	DOE-2	ECOTECT	ENERGY-10	ENERGYPLUS	ENERGYPRO	ENERGYSAVVY	EQUEST	FEDS	HAP	HEED	HOMER	MARKET MANAGER	MICROPAS6	RIGHT-SUITE	SOLAR-5	TREAT	VISUAL-DOE
Raw Sum	1801	114	401	489	585	721	415	860	273	301	1038	357	520	652	156	442	508	106	602	439	770
Software Licensing Cost (as of July 2011) Some of the software offers discount for Academic Area		$495	N/A	Free	$300-2000	N/A	$375	Free	$450	Free	Free	6.0v. Free	$ 1195	Free	Free	$ 2495	$795	N/A	Free	N/A	$980

The examination involved selecting 1801 point's worth of priority ideas from the U.S. DOE (1995 and 1996) workshops. Then, the current/most commonly known programs advertised in the U.S. DOE Directory were evaluated for their inclusion of each idea. The results indicated that the most inclusive program, E-Quest, received 1038 points; next came Energy Plus, with 860 points, and Visual-DOE with 770 points.

Although each of programs evaluated is a powerful tool, each has strengths and limitations. The first and perhaps most important decision remains the selection of appropriate tools for the project or the purpose. Appendix B provides detailed information on the strengths and limitations of the programs. E-Quest has applied most of the suggestions from the workshop but still needs improvements. Section 4.3.2.2 and Table 4-36 contain summaries of these findings. Refer to Table 4.37 for the priority features evaluation for E-Quest, Energy-Plus and Visual-DOE and indicates the area of possible improvements for these three software tools.

4.3.3. *Identify the Areas that Need Improvements*

This section contains a discussion of the methods used to identify needs of the future-generation energy simulation programs. The section also provides an evaluation of the framework components for the 20 selected software programs and included suggestions for improvements to these programs. Table 4-38 displays the evaluation for framework priorities. The table categorizes the framework components into highest, moderate, and lowest priority groupings. This discussion now continues with an explication of the three categories.

The category of highest priority, identified interoperability with other tools contains components that received the most votes. The components that received 58 to 86 votes by workshop participants (i.e., at least two thirds of the 86 votes) the components comprise 20 percent of the framework. Appendix C provides a detailed description of each component. LEED application also falls into this category, although the U.S. DOE workshop did not include LEED in their assessment because of the date workshop the LEED Green Building Rating System did not exist when the workshop was held. The movement toward sustainable construction can be defined as ecological design that primarily focuses on energy efficiency through the designing of energy-efficient structures. The USGBC claims that the nation's distinguished leaders from across the building industry are working to promote buildings that are environmentally responsible (Montez & Darren, 2011). Moreover, the USGBC developed the LEED rating system as a means of evaluating building performance and ratings according to the level of sustainability. One of the top credits for the LEED rating system, the Energy and Atmosphere Performance category, requires the use of energy simulation tools in order to make viable design decisions that would yield results upon occupancy of the structure; such results would lead to increased points in the research evaluation portion of LEED certification.

The moderate-priority category contains components that receive 30 to 56 votes by workshop (U.S. DOE, 1995, 1996) participant and holds 43 percent of the framework, or one third of the 86 votes with 20 components. This category includes the most components applied by the 20 selected software programs. The priority “moisture absorption” the most votes, although not all of the selected software programs used this application. Early analysis of design the most used component in this category was incorporated into 16 of 20 80 percent software tools.

The third category contains components of lowest priority. These components received 10 to 29 votes by workshop (U.S. DOE, 1995, 1996) participants. This category holds 37percent of the framework and contains 17 components. Although the priority “emerging technologies and new processes” received the most votes in this category, only 2 software tools implemented this application. The most used component in this category the “multidisciplinary user” feature, had been applied in 12 of 20 60percent software programs.

“System design” and “early design analysis” received the most focus, with 80 percent of the selected programs implementing this feature, followed by “energy consumption” and “envelope design” each of which had been incorporate into 75 percent of the programs. “Economic & cost analysis” and “lighting/day-lighting” focus a 60 percent of the selected software programs comprised the third most applied features in the list.

The data in Table 4-38 indicate that, although “envelope/environment interaction” received 69 responses from workshop (U.S. DOE, 1995, 1996) participants, this component not yet been incorporated into any current software package. This component will add a valuable attribute to building envelope design by focusing on heat, air, and moisture transport across a building envelope and on the interaction of these elements with indoor air quality and with the environment. Building envelope design affects on the surrounding (indoor and outdoor) environment and this feature will eliminate adverse impacts before completion of the structure (Bomberg & Brown, 2002). None of the selected software tools included the “moisture absorption,” “advanced lighting system”, and “individualize report” components.

The framework contains 46 suggestions for advancing the energy-modeling capacities of future generations of software programs. Results from this study indicate that E-Quest has applied most of the suggestions from the workshop but can benefit from further improvement. In Table 4-37, with plus signs indicate that the software possesses the component, and minus signs indicate that the components remains unaddressed; 17 areas that need addressing for the E-Quest, 24 for Energy Plus, and 26 for Visual-DOE.

(Left empty intentionally)

Table 4-37 The Priority evaluation of three selected software

Framework Components	Votes		E-QUEST	ENERGY PLUS	VISUAL-DOE
Interoperable with other tools	86	Highest Priorities	+	+	+
Comfort Control	85		-	-	-
Lighting/day-lighting	82		+	+	+
LEED Applications	77		+	+	+
3D spatial displays	77		+	-	-
Envelope/environment interaction	69		-	-	-
Heat transfer models	67		-	+	-
Environmental impact	61		-	-	-
Indoor Air Quality	58		-	-	-
Moisture absorption	56	Moderates Priorities	-	-	-
Envelope design	55		+	+	+
Access library and database information	53		+	-	+
Passive/Active Solar Design	52		-	+	-
Air infiltration	48		+	+	-
Design support	47		+	-	-
Expertise requirement	46		+	-	-
HVAC System Design	45		+	+	+
System & equipment sizing wizards	44		+	-	-
Building code compliance	44		+	+	-
Provide basis for simplified (defaults)	42		+	+	+
Fault detection and Diagnostic	41		+	-	+
Early analysis of design	40		+	+	+
Developed design analysis	40		+	+	-
Customizable output and reports	40		+	+	+
Energy Consumption	38		+	-	+
System design	36		+	+	+
Tutorials and Online support	33		+	-	-
Adaptable interface	32		+	-	-
Economic and cost analysis	30		+	+	+
Case studies database for decision-making	29		-	-	-
Emerging technologies and new processes	24		-	-	-
Fenestration & natural ventilation	23	Lowest Priorities	-	+	-
Simultaneous solution	22		-	-	-
Micro and macro weather data	18		+	+	+
Standardized data structures	18		-	-	-
Simple input options	18		-	-	+
Electronic owner's manual	17		+	-	+
Energy storage in buildings	17		-	-	-
Varies building type of design	16		+	+	+
Life Cycle Assessment	15		+	+	+
Comparison systems or designs	12		+	-	-
Multi-platform, parallel processing	11		-	-	-
Multidisciplinary user	11		+	+	+
Advanced lighting system modeling	10		+	+	+
Individualize report	10		-	-	-
Wind pressure distribution	10		-	+	-

Table 4-38 The priority evaluation

Framework Components	Votes	Level of the Priority	# of programs (x/20)	%(x/20)
Interoperable with other tools	86	Highest Priorities **(Average 20%)**	7	35
Comfort Control	85		3	15
Lighting/day-lighting	82		12	60
LEED Applications	77		6	30
3D spatial displays	77		5	25
Envelope/environment interaction	69		0	0
Heat transfer models	67		3	15
Environmental impact	61		5	25
Indoor Air Quality	58		2	10
Moisture absorption	56	Moderates Priorities **(Average 43%)**	0	0
Envelope design	55		15	75
Access library and database information	53		3	15
Passive/Active Solar Design	52		3	15
Air infiltration	48		3	15
Design support	47		5	25
Expertise requirement	46		5	25
HVAC System Design	45		2	10
System & equipment sizing wizards	44		2	10
Building code compliance	44		4	20
Provide basis for simplified (defaults)	42		9	45
Fault detection and Diagnostic	41		2	10
Early analysis of design	40		16	80
Developed design analysis	40		3	15
Customizable output and reports	40		6	30
Energy Consumption	38		15	75
System design	36		16	80
Tutorials and Online support	33		6	30
Adaptable interface	32		3	15
Economic and cost analysis	30		14	70
Case studies database for decision-making	29		3	15
Emerging technologies and new processes	24	Lowest Priorities **(Average 37%)**	2	10
fenestration & natural ventilation	23		4	20
Simultaneous solution	22		1	5
Micro and macro weather data	18		8	40
Standardized data structures	18		3	15
Simple input options	18		4	20
Electronic owner's manual	17		3	15
Energy storage in buildings	17		1	15
Varies building type of design	16		11	55
Life Cycle Assessment	15		1	5
Comparison systems or designs	12		4	20
Multi-platform, parallel processing	11		2	10
Multidisciplinary user	11		12	60
Advanced lighting system modeling	10		0	0
Individualize report	10		0	0
Wind pressure distribution	10		1	5

This study consisted of analyzing existing software and suggesting improvements for the next generation of software tools. Because energy-modeling tools support sustainable design, adding these suggested components will increase the quality and value of the building industry. One of the main goals of software development efforts centers creating an organized, modular program structure that allows easy additions of features and links to other programs related to green design and that allows use by all building sector professions.

Sustainable design requires determination of the environmental impact of a building, and estimating energy consumption necessitates using tools for analysis. Each building is unique and has different needs; for this reason, designers use various tools to obtain answers to their concerns. Every tool contains its own method for performing evaluations, which increases time and cost requirements. To address this problem, I suggest the creation of one tool that combines all essential functions and enables designing of an environmentally friendly building. The proposed energy-modeling tool not only will focus on the need of designers but may assist all building sector professionals, such as material manufacturers, who figure prominently in the process because the material plays an important role in energy-efficient design. Using the same modeling tool among professions will improve the construction process of buildings, selection of materials, and selection of the other necessary components and will allow collaboration among professionals, builders, and manufacturers.

4.4. Chapter Summary

The results of the seven tasks conducted in this research lead to the conclusion that simulation software programs can be used in the design phase to determine viable estimations of the ability of a material to provide energy-saving properties to a structure. The findings from Tasks 1 through 4, which consisted of comparing building material simulation with the ASHRAE (AHSRAE 90.1, 2007) standard, indicate that AAC proves a more energy-efficient building material and that Visual-DOE provides consistent results; therefore, building materials do a significantly affect the energy consumption of a structure, and simulation software can aid designers with making the proper choices when designing buildings. Additionally, with a tool that can present reliable estimations, building manufacturers can use this information to continually improve their products by developing the energy-efficiency properties of the material and as a consequence, reducing the environmental impact of the material.

The results from tasks five through seven indicate that designers and other industry professionals know what improvements need to be made to develop currently available software and how they envision these improvements to take the building industry to the next level. The validity in their comments and suggestions is based on the foundation of experience, past failures or misinterpretations of data, and their holistic knowledge of the building industry overall. Therefore these specific tasks were included in this research project to encourage software manufacturers to implement these suggestions into currently available software. These additions will enhance the performance of simulating energy consumption during the design phase, using software as a viable tool for estimating energy consumption. Improving the performance of simulation software can have a significant impact on the building industry's ability to make accurate estimations of energy consumption when specifying certain building materials, thereby allowing the ultimate goal of reducing environmental impacts associated with the built infrastructure.

The following chapter will provide a conclusion for this research project and will discuss the significance of this research project and the future work to implement the suggestions identified from this project.

5. DISSERTATION CONCLUSION

5.1. Introduction

As results from this research have shown, building materials can significantly affect energy consumption and therefore may play an important role in future energy conservation efforts. This study consisted of investigating the relationship between building materials and energy efficiency from the point of view of green building designers (architect/engineer), green product manufacturers, and energy-modeling developers.

Green building designers need a strong factual foundation when selecting building materials and require data to demonstrate that these materials will provide energy saving benefits. In addition to knowing the initial impact of building materials on energy consumption, designers must have a strong understanding of the effect of a building material on the energy consumed over the lifetime of the material. These aims need to be met without sacrificing other performance characteristics, including comfort, structural integrity, aesthetics, and/or durability.

Designers, engineers, and building owners rely on product manufacturers that understand the importance of improving the efficiency and reducing the environmental impact of their products. For the manufacturer, possessing the capability of demonstrating reliable estimations of the benefits of these building materials remains key to the commercial success of a new product.

As the green industry continues to grow and as knowledge increases about the impact of buildings on the environment it is becoming more important for designers to use simulation software to determine reliable, expected results of certain building materials, in order to give building owners confidence that investing in these green materials will reduce long-term costs while also decreasing the environmental impact of buildings. Becoming increasingly complex, designing green buildings requires equally complex evaluation tools that assist designers in making decisions that will provide benefits to both the client and the environment. Sophisticated software is the tool needed to produce these results.

The suggestions provided by industry professionals for software improvements form one step toward obtaining reliable software that will provide estimates with a small margin of error. These suggestions allow the analysis of building materials in terms of the influence of other building qualities and in terms of the climate in the location of these buildings. As a result, designers can execute a creation appropriate to a specific climate including climates that experience extreme temperature variances from season to season.

The research tasks in this study included simulations of both commercial and residential buildings and involved examining traditionally framed and AAC structures. Study results support the viability of simulation software as a tool for providing accurate design-phase estimates of the energy consumption of a building. In each task involving a simulation, the results consistently indicated that in comparison with traditionally framed structures, AAC structures proved more energy efficient in terms of HVAC consumption. Although location affected the time peak energy consumption occurred, AAC remained the more energy-efficient building material. The study methodology will allow manufacturers of their products to analyze the energy performance of a building material and to make the necessary adjustments for improvement. In addition, allowing designers to experiment with the optimization of building component to determine the maximum energy efficiency for a specific location. By enabling designers to produce viable estimations, building simulation software tools can foster the creation of buildings that operate at the most efficient levels possible.

5.2. Significance of the Study

This research provides numerous benefits to the building design industry. Most important, the study offers a method/strategy that encourages collaboration among building professionals—architects, engineers, and manufacturers—united by common tools, common principles, and the desire to achieve high-efficiency buildings. Benefits of the study will extend beyond the building sector as both the public and private sectors recognize the benefits of sustainable design. The methodology used in this research provides direct and indirect benefits to the building industry and to the environment, including improvements to existing software, a significant resource for determining ways of improving current building materials, and the identification of underutilized building materials that offer enhanced energy conservation benefits.

The results from this dissertation research reveal that the use of energy-modeling tools during the design phase of the project decreases the time and expense involved in making designs phase decisions related to high-efficiency buildings. With the use of such tools, designers can choose energy-efficient building materials and obtain accurate estimations of potential energy-saving benefits. According to findings from the research conducted in this study, simulated models indicated that AAC is energy efficient and therefore maybe considered a green building material. The United States remains unfamiliar with the benefits of using AAC, a material more commonly specified in European and Asian building markets. However, acceptance of the benefits of using this material will increase in the United States as more studies involving software simulations yield results indicating the energy-saving characteristic of AAC. Currently, little literature exists to details the benefits of the AAC building material. This study centered on the hypothesis that AAC is a energy-efficient building material and that its use in a structure will enhance the quality of the environment inside and outside the building.

This research adds to the existing research literature and to the awareness of the building industry and may lead to the initiation of more studies of AAC and its energy-saving benefits. Consequently, AAC should become more widely used in the United States as a green building product. The use of energy-efficient design applications that follow the USGBC guidelines for obtaining LEED Certification is incorporated into this research, which involved utilizing the Visual-DOE modeling tool to evaluate AAC-constructed wall systems in order to determine the number of credits toward the Optimizing Energy Performance section of LEED.

During recent years, the LEED green building rating system, certified by the USGBC, has increased in popularity. In order to obtain LEED certification, building designers require tools to assist them with demonstrating the compliance of a building with various sustainable design strategies. This research revolved around developing recommendation for possible improvements to software design. The proposed recommendations incorporate the capacity for comprehensive outputs related to energy efficiency.

The suggested recommendations combine the eligible green tools for use in creating improved green designs. In addition, the recommendation assists design professionals with obtaining LEED certification for their projects; that is understanding and responding to the guidelines specified in the LEED certification process will take less time with the recommended tool/strategy. In short, the proposed modeling tools both help the sustainable building sector with energy conservation and guide designers toward more quickly and efficiently receive certification for their green structures.

Including an interoperability feature into the existing framework of current software makes possible the achievement of the goals to which these recommendations lead. Each building is unique and requires an individual analysis to demonstrate its sustainable performance and environmental impact, in addition to identifying optimal potentials of sustainable design. Every tool has a purpose and can perform evaluations based on its purpose, and each requires training for varying ranges of time and cost. A goal of this research project was to propose an interoperability feature that will improve the productivity of the software for the green building industry.

The ideal tool includes several elements.

- quick test drive to familiarize the user with the software,
- simple use,
- easy navigation,
- interoperable with other tools, and
- collaboration with multidisciplinary users.

Regardless of the design experience of the user and regardless of the professional discipline (i.e., architects, engineers, policy makers, manufacturers, and developers) with which they are associated, user must work together and understand the design consequences in advance in order to mitigate the impacts of these consequences. This proposed tool will operate within a group of design team for more sustainable design. Interoperability provides users with the ability to capture and analyze concepts and to maintain the design vision throughout documentation and construction. In general, every modeling tool is designed with intentions of benefiting the environment and limiting influences on the global life cycle. Unfortunately, each is individually specialized in one or more areas of the design process despite the fact that eco-design requires collaboration among professions and among tools (Sullivan, 2007). In this research, I propose including interaction with other tools to significantly improve the quality of a project. For instance, life cycle analysis (LCA) one of the best ways of evaluate building sustainability, receives wide acceptance in the field of environmental research (Athena Institute, 2011b).

The building sector remains a top priority for energy conservation because buildings constitute the largest consumer of energy while also having the largest environmental impact. As efforts to reduce energy consumption focus increasingly on the building sector, for the careful choice of energy-efficient building materials will gain even more importance. Therefore, manufacturers of materials will benefit from staying current with changes in the building industry. As green building materials become more widely applied to buildings, these manufacturers must continue their research and development efforts to improve the sustainability of their materials.

The methodology used in this research indicates that materials strongly influence the process of LEED certification. An aim of this research consists of encouraging both designers and manufacturers to improve their design methods and material performance.

Last, the modeling tools recommended in this study help the design process by demonstrating the performance of a building with respect to specified building materials and components. Manufacturers can use the research method into manufactured products to guide designers seeking LEED certification and to help advance the green building industry. The proposed software framework recommendations will improve tools designed to model detailed energy performance.

5.3. Future Study

A goal of this research was to prove that energy-modeling programs reliably enable user to compare the energy efficiency of building materials as a system. Advancing current energy simulation technology to include the following features is recommended in order to improve the ability of the simulation tool to compare building materials.

- ***Building envelop/environmental interaction*** contains the analysis of building envelope design and focuses on heat, air, and moisture transport across a building envelope and on the interaction between the envelope and indoor air quality and between the envelope and the outside environment.

- ***LCA*** the technique enables assessment of environmental impacts associated with all stages of the life of a product that is evolving in concert with efforts to increase energy efficiency. Greener building design is possible when the effect of the material on the environment, is known LCA constitutes application for evaluation the environmental impact of the material, and the method involves evaluating the environmental quality of buildings. Impacts included in LCA indicate as a variety of environmental concerns such as the potential to increase global warming and such as the efficient use of resources like energy, water, and materials (Peuportier *et al.,* n.d.). These outcomes merit consideration in an evaluation of the energy efficiency of a material.
- ***Life cycle cost*** involves conducting an economic analysis to make cost-effective choices that affect the life of the buildings (in this case, choices pertaining to building materials). The analysis inputs include elements such as LCA, discount rates, growth rates, utility costs, and price of building material.

These three components will enable more accurate assessments during the decision-making process.

After implementation of these suggested software improvements takes place, anticipated improvements to software include enabling user to specify several building materials and the manner in which they work together; these capabilities allow analysis of the building as a unit. Conducting such an analysis may lead to the discover that, when working together; certain building materials have increased energy-efficiency properties that remain unnoticed when each material is analyzed separately. Additionally, as regulations become more stringent, the simulation tools will need to allow users to consider energy-efficiency on a more detailed level and may need to contain even more applications.

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APPENDIX A: EVALUATION OF FIVE WALL SYSTEMS

College of Engineering and Applied Sciences at Arizona State University conducted a research to perform a comparative evaluation of five exterior shell construction techniques among the Autoclaved Aerated Concrete (AACs), Insulated Concrete Form (ICFs), Structural Insulated Panels (SIPs), Integra block construction, and Traditional Framed walls. The research report is prepared by Anil Sawhney and Andre Mund (Arizona State University, 2007).

Information was generated using the following sources: (a) published technical literature, (b) exterior shell construction system manufacturers, (c) homebuilders and trades, (d) homeowners, and (e) public and private research institutions.

System performance comparison and findings among the five exterior shell systems are based on the category listed below:

- Delivery Time
- Delivery Reliability
- Delivery Method
- Equipment and Labor Costs
- Material Estimation Process
- Acoustical Performance
- Fire Rating
- Durability Potential
- System's components availability
- Pest Resistance
- System Complexity
- Exterior and Interior Finishes
- Workability
- System Complexity with Rating Base
- Constructability in Production

Delivery Time: The table is highlights the average delivery times from material ordering to arrival of material on the site

AAC		ICF	SIP	Integra		Frame	
Block	*Panel*			*Regular*	*Special Order*	*Lumber*	*Trusses*
1 day	1-3 weeks	~2 weeks	2-3 weeks	next day	6-8 weeks	3-4 days	~2 weeks

Delivery Reliability: The table indicates the percentage of the time that delivery takes place on the timeframe declared by manufacturer delivery responsibility.

AAC		ICF	SIP	Integra		Frame	
Block	*Panel*			*Regular*	*Special Order*	*Lumber*	*Trusses*
~100%	~80%	100%	100%	100%	~100%	~100%	~90%

Delivery Method: The table indicates the material transportation to the construction site. The precise trip variation is according to the project site. This exercise only focuses on the material amount for per trip.

AAC		ICF	SIP	Integra		Frame	
Block	*Panel*			*Regular*	*Special Order*	*Lumber*	*Trusses*
18-wheel flatbed carries 60 pallets, each w/24 (8″blocks) =approx. 1900ft^2		53-ft. van-truck 216 bundles, each w/12 (16x48″panels) =approx.6900ft^2	48-ft flatbed carries 6″ 4x8ft panel =approx.6100 ft^2	18″-wheel flatbed carries 16 pallet, each w/120 (6″block) =approx. 1700 ft^2		Flatbed, 1 trip for lumber, 1 for sheathing, & 1 for trusses.	

Material, Equipment, and Labor Cost: The cost depends on how the material is used, because all this material have different characteristic.

Item	AAC	ICF	SIP	Integra	Frame
Material Costs	~\$2.95/ft^2	\$3.25/ft^2-\$5.00/ft^2	~\$3.20/ft^2	\$3.55/ft^2-\$4.00/ft^2	~\$3.50/ft^2
Equipment & Labor Costs	~\$2.25/ft^2	~\$2.00/ft2	\$1.00/ft^2-\$1.25/ft^2	~\$4.00/ft^2	\$2.50/ft^2-\$3.00/ft^2

Note:

The wood-frame costs can change constantly, within fluctuation in the market place. Researcher pointed out the time of report the lumber costs were approximately. \$ 340.00 per 1000 board feet. With this given price the material for framed wall (2″x4″, 16″o.c., included sheathing and insulation) cost would by \$ 3.50/ft^2

Material Estimation Process: The table indicates the estimation process which displays similar for all the exterior shell construction.

AAC	take-off based on floor plans performed by installer; training is provided by manufacturer
ICF	take-off based on floor plans performed by installer
SIP	take-off based on floor plans performed by manufacturer
Integra	take-off based on floor plans performed by installer
Frame	take-off based on floor plans performed by installer

Acoustical Performance: Airborne insulation is the characterized by Sound Transmission Class (STC) ratings. The higher the STC rate is the better the wall system capability of the acoustic performance of the material.

AAC	STC=48 (8″ block finished, UL No. U924)
ICF	STC=48 (finished 84lbs/ft2 wall, National Research Council (Canada) report # 553-P)
SIP	STC=28-39 (finished, not UL listed)
Integra	STC=~48 (6″ block finished, not UL listed)
Frame	STC=30-35 (finished, not UL listed)

Fire Rating: Fire rating is measured building envelopes components such as wall, floor, and roof in hours that components can endure fire while maintain the integrity of the structure, fire tightness, and limited temperature of unexposed surfaces. The table indicates that fire rating ranges from 1hour to 4 hours among the selected systems.

AAC	4 hrs. (8″ block, UL No. U916, U917, U919, U921, X901)
ICF	2-4 hrs. (6″ concrete core, UL No. U927)
SIP	1 hr. (UL No. U532, P517, P822)
Integra	1.66 hrs. & 2 hrs. (6″ & 8″ block, not UL listed)
Frame	1 hr. (UL No. U303)

Durability Potential: The materials durability potential is considered to be the capability of the building component to maintain through the life of the structure. The according in the literature of durability or known as service life of a component depends on the deterioration rate of the component's material properties. The systems that use non-organic materials are expected to have a lower deterioration rate which it means that the material have a greater durability potential. The selected systems evaluated durability potentials in different level of curriculums in the table.

Durability Potential	***Very Low***	***Low***	***Medium***	***High***	***Very High***
Deterioration Rate	***Very Fast***	***Fast***	***Medium***	***Slow***	***Very Slow***
Material Presence	untreated, unprotected wood	treated, unprotected wood	treated wood; unprotected masonry	protected concrete; protected masonry	natural stones
Wall System			SIP, Frame	AAC, ICF, Integra	

P

Systems components availability: The table displays component availability such as wall, floor, and roof systems

AAC	All components may be built
ICF	Wall components only
SIP	All components may be built
Integra	Wall components only
Frame	All components may be built

Pest Resistance: Non-organic made materials are considered pest resistance which is less deterioration just like durability. The table for pest resistance indicates very similar results from durability evaluation output.

Pest Resistance	***Very Low***	***Low***	***Medium***	***High***	***Very High***
Material Presence	untreated, unprotected wood	treated, unprotected wood	treated, protected wood; unprotected EPS, XPS	protected EPS, XPS	natural stones; concrete masonry
Wall System			SIP, Frame	ICF, Integra	AAC
Note: ***EPS:*** synthetic, expanded polystyrene plaster that performs termite protection components. ***XPS:*** extruded polystyrene board that does not absorb water, is not a food source for mold, and moisture-related and deterioration.					

System Complexity: This is a rating based on interviews with builders (See Reference Table for the contributors) who have used the product and rated them on the complexity to work with the material. The scale is between one and ten, with one being easy and ten being difficult. Points are attributed as following table:

1 point	For the erection of the blocks, forms, frame, etc. is extremely simple (no specific training is needed) and does not require mortar joints, caulking, bracing, or similar measures.
2 points	For the erection of the blocks, forms, frame, etc. is more complicated (trained craftsmen needed) and requires mortar joints, caulking, trimming, cutting, bracing, etc.
1 point	For bond beams or other elements
2 points	For large volume concrete pouring using a concrete pump,
1 point	For additional installation of shear panels,
1 point	For separate installation of insulation material,
1 point	For post-tensioning,
1 point	For routing or cutouts for mechanical, electrical, or plumbing (MEP) installation, and
1 point	For furring for MEP or exterior or interior finishes

Exterior and interior finishes: Usually all exterior shell construction systems can use the same exterior finishes, which are mostly stucco, siding, and brick. The difference is whether or not furring strips need to be added first. Typically interior finishes are such as sheetrock and plaster. The difference is whether or not furring strips need to be added first. Following table is illustrates the differences are in furring strips.

	Exterior finishes	**Interior finishes**
AAC	No furring strips are needed.	No furring strips are needed.
ICF	Furring strips are recommended but not necessary	Furring strips are recommended but not necessary
SIP	No furring strips are needed.	No furring strips are needed.
Integra	Furring strips are needed	Furring strips are needed
Frame	No furring strips are needed.	No furring strips are needed.

Workability:

	Workability
AAC	AAC is easy to work with; it can easily cut, sawn, drilled, screwed, nailed, and shaped or sculpted using standard construction tools
ICF	ICF forms are easy to work with. EPS is easily cut. The webs can read and drilled, screwed, and nailed. ICFs cannot be shaped or sculpted.
SIP	Both the cores and the OSB skins are made of very workable materials that can be easily cut, drilled into, screwed into, and nailed. SIPs cannot be shaped or sculpted.
Integra	Integra Blocks can be cut or drilled into using appropriate power tools. Integra blocks cannot be screwed into, shaped or sculpted. Architectural or colored blocks can be used to provide different surface patterns and colors.
Frame	All wood products for frame construction are easy to work. They can be ready to cut, sawn, drilled, screwed, and nailed. A framed wall cannot be shaped or sculpted.

System Complexity with Rating Base:

	System Complexity
AAC	2 (erect blocks/panels) +1 (bond beam) +1(MEP) = 4
ICF	2 (erect forms) + 2 (concrete pump.)+1 (MEP) = 5
SIP	2 (panel erection) +1 (MEP) = 3
Integra	2 (erect blocks)+1 (insulation)+1 (post-tension) +1 (MEP)+1(furring) = 6
Frame	2 (framing) +1 (shear) +1 (MEP) +1 (insulation) = 5

Constructability: This table compares labor costs, system complexity ratings, and the number of trades involved during construction.

	Workability
AAC	Professionals and contractor worked with AAC indicated that AAC's constructability is high compared to other systems. The use of AAC panels can reduce construction duration and further improve AAC constructability.
ICF	The labor cost and system complexity rating indicates that ICF's constructability is high compared to other systems. This is mainly due to the fact that stacking of the forms is extremely easy.
SIP	SIPs combine the benefits of large panels and low weight, to simplify erection and reduce construction duration. The labor cost and system complexity ratings that indicate that the constructability of SIPs is very high compared to other systems.
Integra	Integra suffers not only from the labor intensive block construction (<1 ft2/block) that slows down construction but also from the fact that an extra trade is needed to post-tension the walls and install the polyurethane insulation. The labor cost and system complexity ratings that indicate that the constructability of the Integra wall system is only average / medium compared to other systems.
Frame	The labor-intensive and multi-stage carpentry, installation are typically indicated as a disadvantage that slows down construction. The labor cost and system complexity ratings that indicate that the constructability of framed walls is only average / medium compared to other systems.

Conclusion:

The study presented in this report performed a comparative study of five exterior shell construction techniques to evaluate the qualities of AAC as compared to the other commonly known exterior shell construction techniques. Well known AAC, a building material that has proven itself in Europe, Asia and middle-east, clearly represents a possible innovative alternative for the US building sector. Sawhney and Mund study indicates AAC is a well-rounded, flexible system that is capable of holding its own against other innovative exterior shell construction systems such as ICFs, SIPs, and Integra Block.

However, decision-maker choices can always lean on preferences.

The persons and companies who provided information for this study are listed below:

Alexander Homes (AAC)
Babb International, Inc. (AAC)
E-Crete LLC (AAC)
Mr. Doug Vogl, Pulte Homes (AAC)
Mr. Charles Popeck (AAC)
American Polysteel LLC (ICF)
Arxx Building Products Inc. (ICF)
ECO-Block LLC (ICF)
Mr. Mike O'Brien (ICF)
Mr. Bob Salars (ICF)
Premier Building Systems (SIP)
R-Control Building Systems (SIP)
Insulspan / Idaho, Inc. (SIP)
Mr. Dennis Nelson, Nelson Remodeling, (SIP)
Superlite Block, Inc. (Integra)
Mr. Ken Hogenes, Superlite Block Inc. (Integra)
Superstition Carpentry (Frame)
Mr. Vince Palozola, Superstition Carpentry (Frame)
Mr. Ron McGee, Superstition Carpentry (Frame)
Mr. Bill Washburn, Engle Homes Arizona (Frame)

APPENDIX B: US DOE DIRECTORY SOFTWARE TOOLS

Appendix B provided in two parts:

I. *Part provides US DOE Directory for 231 energy software program list.*

The US DOE Directory provides information on 391 (as of May 2011) energy-related software programs. Numerous of the tools are accessible and are adaptable to differing international circumstances. The only 231 out of 391 tools were developed for use in the United States. Subsets of 55 programs are focused on whole building analysis for energy simulation. However it was evident that the number of users (1000 or more), only 20 of whole building performance on energy simulation focused tools are considered as an evaluation tool for the research project that are indicated dark cells in tables. Appendix B provided the complete list of 231 software tools.

II. *20 selected software programs for the research.*

The directory is provided for each tool along with other information including expertise required, users, audience, input, output, computer platforms, programming language, strengths, weaknesses, technical contact, and availability.

Both section information are taken directly from US DOE Directory site at http://apps1.eere.energy.gov/buildings/tools_directory/alpha_list.cfm

I. US DOE Directory for 231 energy software program list.

	TOOL	**Application**	**USA**	**1000**	**Whole**
1	3E Plus	Insulation,	YES		
2	AAMASKY	Skylights, Day-Lighting, Commercial Buildings	YES		
3	Acoustics Program	HVAC Acoustics, Sound Level Prediction, Noise Level	YES		
4	Acuity Energy Platform	Electricity Reporting And Savings Opportunities	YES		
5	AEPS System Planning	Electrical System, Renewable Energy System, Planning And Design, Energy Usage, System Performance, Financial Analysis, Usage Profiles, Utility Rate & Plans	YES		YES
6	AFT Fathom	Pump Selection & Analysis, Duct Sizing & Design, Chilled Water & Hot Water System	YES		YES
7	AFT Mercury	Pipe Optimization, Selection, Duct Sizing, Design, Chilled Water & Hot Water Systems	YES		YES
8	AGI32	Lighting, Day Lighting, Rendering, Roadway	YES		
9	AkWarm	Residential Energy Systems, Weatherization	YES		YES
10	Analysis Platform	Heating, Cooling, And SWH Equipment, Commercial Buildings	YES		
11	Animate	Animated Visualization Of Data, XY Graphs, Energy-Use Data	YES		
12	AUDIT	Operating Cost, Bin Data, Residential, Commercial	YES	YES	YES
13	Autodesk Green Building	BIM Revit , Energy Performance, DOE-2, Energy-Plus, CAD	YES		YES
14	Awnshade	Solar Shading, Awnings, Overhangs, Side Fins, Windows	YES		
15	BEST	Electric Motors, Energy Efficiency	YES		
16	BEES	Green Buildings, LCA, LCC, Sustainable Development	YES		
17	Benchmark	Automated Benchmarking System Automation Portfolio Manager	YES		YES
18	BESTEST	Exterior Envelope Simulation Program Capability Tests	YES		
19	BinMaker Pro	Weather Data, Binned Weather Data, Weather Data Design	YES		
20	BLCC	Economic Analysis, Espcs, Federal Buildings, Life-Cycle Costing	YES		
21	BTU Analysis Plus	HVAC, Heat Load Studies	YES		
22	BTU Analysis REG	HVAC, Heat Load Studies	YES		
23	Building Design Advisor	Day-Lighting, Energy Performance, Case Studies, Commercial Bldgs	YES		YES
24	Building Energy Analyzer	Air-Conditioning, Heating, On-Site Power Generation, Heat Recovery, CHP, BCHP.	YES		YES

25	Building Performance Compass	Commercial Buildings, Multi-Family Residence, Benchmarking, Energy Tracking & Improvement, Weather Normalization	YES		
26	BuildingAdvice	Whole Building Analysis, Energy Simulation, Renewable Energy, Retrofit Analysis, Sustainability/Green Buildings	YES		YES
27	C-MAX	Pumps, Fans, Chillers, Compressors, Energy Conservation, Design	YES		
28	CHP Capacity Optimizer	CHP, Cogeneration, Capacity Optimization, Distributed Generation	YES		YES
29	CHVAC	Commercial HVAC's, Load Calculations, CLTD	YES		
30	CL4 M Commercial	Cooling Loads, Heating Loads, Commercial Buildings	YES		
31	Climate Consultant	Climate Analysis, Psychometric Chart, Bioclimatic Chart Wind Wheel	YES		
32	COMcheck	Energy Code Compliance, Commercial Bldgs, Codes Training, Energy Savings	YES		
33	COMIS	Multi-Zone Airflow, Pollution Transport	YES		
34	Commodity Server	Energy Database Server, Time Series Energy, Portfolio Management	YES		
35	CompuLyte	Lighting, Day-Lighting, Rendering	YES		
36	COMSOL	Multi-Physics, Simulations, Modeling, Heat Transfer, Finite Element	YES	YES	YES
37	CONTAM	Airflow Analysis; Contaminant Dispersal; Indoor Air Quality, Multi-Zone Analysis, Smoke Control & Management, Ventilation	YES		
38	Cool Roof Calculator	Reflective Roof, Roofing Membrane, Low-Slope Roof	YES		
39	CPF Tools	Solar (Sales, Quoting, Proposal, Financing), Leads, Auto-Populate, Rebate Form, CRM Software, Customer And Financing Dashboard	YES		
40	CtrlSpecBuilder	HVAC Controls, Specifications, CSI Section 15900 HVAC Instrumentation And Controls	YES		
41	D-Gen PRO	Distributed Power Generation, On-Site Power Generation, CHP, BCHP	YES		
42	Data Center Efficiency Savings Calculator	Energy Efficiency Calculator For Data Centers.	YES		
43	Daylight	Day-Lighting, Daylight Factor	YES		
44	DD4M Air Duct Design	Duct Design, Air-Conditioning, Heating	YES		
45	Degree Day Forecasts	Degree Days, Historical Weather, Mean Daily Temperature	YES		
46	Degree Day Reports	Degree Days, Historical Weather, Mean Daily Temperature	YES		

47	Demand Response Quick	Demand Response, Load Estimation, Energy-plus	YES		YES
48	DesiCalc	Desiccant System, Air-Conditioning, System Design, Energy Analysis, Dehumidification, Desiccant-Based Air Treatment	YES		YES
49	Design Advisor	Whole-Building, Energy, Comfort, Natural Ventilation	YES	YES	YES
50	Discount	Present Value, Discount Factors, Future Values, Life-Cycle Cost	YES		
51	DOE-2	Energy Performance, Design, Retrofit, Research, Residential And Commercial Buildings	YES	YES	YES
52	Duct Calculator	Duct-Sizing, Design, Engineering, Calculation	YES		
53	DUCTSIZE	Duct Sizing, Equal Friction, Static Regain	YES		
54	E-Z Heatloss	Heat Loss, Heat Gain, Residential Calculation	YES		
55	E.A.S.Y.	Energy Accounting, OMV System, Building Baseline Development, Energy &Emissions	YES		
56	EA-QUIP	Building Modeling, Energy Savings Analysis, Retrofit Optimization (Work Scope Development), Investment Analysis, Online Energy Analysis Tool, Multifamily Building	YES		YES
57	EASY	Energy Audit, Residential Buildings, Retrofit, Economic Evaluation	YES		
58	EBS	Utility Billing, Energy Management	YES		
59	ecasys	Energy Program Management	YES		
60	EcoAdvisor	Online Interactive & Multimedia Training, Sustainable Commercial Buildings, Lighting, HVAC	YES		
61	EcoDesigner	For Architects, Integrated In BIM Software, One Click Evaluation	YES		YES
62	ECOTECT	Energy Data Management, Environmental Design On-Line Data Archive, environmental analysis, conceptual design, validation; Passive design option, thermal design and analysis, heating and cooling loads, natural and artificial lighting, LCA, LCC analysis	YES	YES	YES
63	EEM Suite	Energy (Management, Accounting, Benchmarking, Forecasting Energy Use Analysis)	YES		
64	EffTrack	Chiller Efficiency, Chiller Performance	YES		
65	EMISS	Atmospheric Pollution, Energy-Related Pollution Emissions	YES		
66	EN4M Energy in Commercial Buildings	Energy Calculation, Commercial Buildings, Economic Analysis	YES		
67	ENER-WIN	Energy Performance, Load Calculation, Energy Simulation, Commercial Buildings, Day-Lighting, Life-Cycle Cost	YES		YES
68	EnerCop Energy	Energy Benchmarking; Carbon Benchmarking; Energy Accounting	YES		
69	Energy Estimation	Variable Frequency Drive, Energy Savings, Fans, Pumps, Carbon Footprint	YES		
70	Energy Expert	Energy Tracking, Energy Alerts, Wireless Monitoring	YES		YES

71	Energy Profiler	Load Profiles, Rate Comparisons, Data Collection	YES		YES
72	Energy Profiler Online	Online, Energy Usage, Load Profiles, Bill Estimation	YES		
73	Energy Scheming	Residential & Commercial Building Design, Energy Efficiency, Load Calculations	YES		YES
74	Energy Trainer Managers	Training, HVAC, Operation And Maintenance, Existing Buildings	YES		
75	Energy Usage Forecasts	Historical Weather, Mean Daily Temperature, Load Calculation, Energy Simulation	YES		YES
76	Energy Work Site	Energy Benchmarking, Facility Checklist, Utility Bill Manager	YES		
77	Energy-10	Conceptual Design, Residential & Small Commercial Buildings	YES	YES	YES
78	Energy Aide	Energy Audits, Home Energy Analysis, Retrofit	YES		
79	Energy CAP Enterprise	Energy (Information, Accounting, Tracking, Measurement & Efficiency), Utility Bill & Energy Management, M&V, Utility Bill Accounting, Benchmarking,	YES		
80	Energy CAP Professional	Energy Information, Energy Accounting, Energy Tracking	YES		
81	Energy Gauge Summit Premier	Building Energy Modeling Simulation & , ASHRAE & Florida Code Compliance, LEED NC 2.2 EA Credit 1, Federal Tax Deductions	YES		
82	Energy Gauge USA	Residential, Energy Calculations, Code Compliance	YES		YES
83	Energy Periscope	Renewable Energy Performance, Financial Analysis, Sales Proposals	YES		
84	Energy Plus	Energy Simulation, Load Calculation, Building Performance, Simulation, Heat Balance, Mass Balance	YES	YES	YES
85	Energy Pro	California Title 24 Compliance, Commercial & Residential Energy Simulation	YES	YES	YES
86	EnergySavvy	Efficiency Calculation, Energy Rebates, Home Contractor Search	YES	YES	YES
87	Energy Shape	Energy Load, End-Use, Energy Profile	YES		
88	ENFORMA	Data Acquisition, Energy Performance, Building Diagnostics, HVAC & Lighting Systems	YES		
89	Engineering Toolbox	Refrigerant Line Sizing, Air Properties, Fluid Properties, Power Factor Correction, Duct Sizing	YES		
90	ENVSTD and LTGSTD	Federal Commercial Building Standard, Code Compliance, Energy Savings	YES		
91	E-Quest	Energy (Performance, Simulation, Analysis, & Efficiency), LEED, Energy And Atmosphere Credit Analysis, Title 24 Compliance Analysis, LCC, DOE 2, Power-DOE, Building Design & Energy Efficiency Wizard	YES	YES	YES
92	ERATES	Electricity Costs, Electric Utility Rates Schedules	YES		

93	EXTREMES	Extreme Weather, Weather Sequences, Simulation, Energy Calculation	YES		
94	EZ Sim	Energy Accounting, Utility Bills, Calibration, Retrofit, Simulation	YES		YES
95	EZDOE	Energy Performance, Design, Retrofit, Research, Residential & Commercial Buildings	YES		YES
96	FASER	Energy Information, Resource Accounting	YES		
97	FEDS	Single & Multi-Building Facilities, Central Energy Plants, Thermal Loops, Energy Simulation, Retrofit Opportunities, Life Cycle Costing, Emissions Impacts, Alternative Financing	YES	YES	YES
98	FENSIZE	Fenestration, Solar Heat Gain Coefficient, Thermal Transmittance, Visible Transmittance, Windows, Skylights, Code Compliance	YES		
99	FENSTRUCT	Structural Performance, Fenestration, Deflection, Stress, Moment Of Inertia, Centroids,	YES		
100	Audits	Energy Audit	YES		
101	FRESA	Renewable Energy, Retrofit Opportunities	YES		
102	FSEC 3.0	Energy Performance, Research, Advanced Cooling And Dehumidification	YES		YES
103	Gas Cooling Guide PRO	Gas Cooling, Hybrid HVAC Systems	YES		YES
104	GenOpt	Parameter Identification, Nonlinear Programming, Optimization Methods, HVAC	YES		
105	GIHMS	Industrialized Housing Production Operations	YES		
106	GLASTRUCT	Structural Performance, Fenestration, Deflection, Stress, ASTM	YES		
107	GLHEPRO	Ground Heat Exchanger Design, Ground Source Heat Pump System, Geothermal Heat	YES		
108	Green Energy Compass	Low-Rise Residential, Benchmarking, Energy Tracking, Improvement Tracking, Weather Normalization	YES		
109	HAP	Energy Performance, Load Calculation, Energy Simulation, HVAC Equipment Sizing	YES	YES	YES
110	HAP System Design	HVAC, Load Calculation & Equipment Sizing, Zoning & Air Distribution	YES		
111	HBLC	Heating & Cooling Loads, Heat Balance, Residential & Commercial Energy Performance, Design, Retrofit	YES		
112	Heat Pump Design Mode	Heat Pump, Air Conditioner, Air-To-Air Heat Pump, Equipment Simulation	YES		
113	HEED	Whole Building Simulation, Energy Efficient & Climate Responsive Design, Energy Costs, IAQ	YES	YES	YES
114	Home Energy Saver	Internet-Based Energy Simulation, Residential Buildings	YES		YES
115	Home Energy Tune-up	Home Energy Audit, Energy Efficiency, Administration, Conservation, Consulting, Energy Savings, Residential Performance, Renewable Energy, Residential Retrofit, Training, Weatherization	YES		

116	Home Energy Suite	Energy Use And Savings Analysis.	YES		YES
117	HOMER	Remote Power, Distributed Generation, Optimization, Off-Grid, Grid-Connected, Stand-Alone	YES	YES	YES
118	HPSIM	Heat Pump, Research	YES		
119	HVAC 1 Toolkit	Energy Calculations, HVAC Component Algorithms, Energy Simulation, Performance Prediction	YES		
120	HVAC Solution	Boilers, Chillers, Heat Exchangers, Cooling Towers, Pumps, Fans, Expansion Tanks, Heat Pumps, Fan Coils, Louvers, Hoods, Radiant Panels, Coils, Dampers, Filters, Piping, Valves, Ductwork, Schedules	YES		
121	HVACSIM+	HVAC Equipment, Systems, Controls, EMCS, Complex Systems	YES		
122	Hydronics Design Studio	Hydraulic Heating, Radiant Heating, Simulation, Design, Piping	YES		YES
123	I-BEAM	Indoor Air Quality, IAQ Education, IAQ Management, Energy And IAQ	YES		
124	IAQ-Tools	IAQ, Ventilation Design, Contaminant Source Control Design, Tracer Gas Calculations	YES		
125	IDEAL	Electric Utility Analysis, Electricity Costs, Bill Analysis	YES		
126	Indoor Humidity Tools	Indoor Air Humidity, Dryness, Condensation	YES		
127	InterLane Power	Energy Metering, Monitoring, Power Management	YES		
128	IPSE	Solar Architecture, Passive Solar, Residential Buildings, Primer, Introduction, Reference	YES		
129	IWEC	International Weather, Weather Data, Climate Data, Energy Calculations	YES		
130	IWR-MAIN	Municipal & Industrial Water (Demand Analysis, Conservation & Resource) Planning	YES		
131	IWRAPS	Water (Planning, Management, Conservation, Rights) , Military Installations	YES		
132	J-Works	Load Calculation, Commercial & Residential Buildings	YES		
133	Load Express	Design, Low-Rise Commercial Buildings, Heating & Cooling Loads, HVAC	YES		
134	Look3D	Three-Dimensional, Full-Color Surface Plots From Columnar Data, Energy-Use Data	YES		
135	LoopDA	Airflow Analysis, Indoor Air Quality, Multi-Zone Analysis, Natural Ventilation	YES		
136	Louver Shading	Window, Overhang, Blinds, Louvers, Trellis, Shading, Solar	YES		
137	Macro-model	Indoor Air Quality, Research	YES		
138	Maintenance Edge	CMMS, Maintenance, Work Order, Maintenance, LEED, ENERGY STAR, Benchmarking, Critical Alarm	YES		
139	Market-Manager	Building Energy Modeling, Design, Retrofit	YES	YES	YES
140	MC4Suite 2009	HVAC Project Design, Sizing, Calculations, Energy Simulation, Commercial, Residential, Solar	YES		YES

141	METRIX4	Monitoring & Verification, Utility Bill Analysis, Utility Accounting	YES		
142	MHEA	Retrofit Opportunities, Audit, Mobile Homes	YES		
143	Micropas6	Energy Simulation, Heating & Cooling Loads, Residential Buildings, Code Compliance, Hourly	YES	YES	YES
144	MOIST	Combined Heat & Moisture Transfer, Envelope	YES		
145	Motor Master+	Motors, Energy Efficient Motors, Motor Database, Motor Management, Industrial Efficiency	YES		
146	myupgrades.com	HVAC Updates, HVAC Equipment Selection, Energy Savings, Up-Sell	YES		
147	National Energy Audit	Retrofit, Energy, Audit, Efficiency Measures	YES		
148	OHVAP	Venting Design, Oil-Fired Equipment	YES		
149	On-Grid Tool	Solar, Financial, Payback, Analysis, Sales, Tool, Software, Economics, Proposal	YES		
150	Opaque	Wall Thermal Transmission, U-Value	YES		
151	Opto-Mizer	Lighting Audit Retrofit Software, Lighting Retrofit Rebate Programs, Lighting Design And Analysis	YES		YES
152	Overhang Analysis	Window, Overhang, Shading, Solar	YES		
153	Overhang Design	Solar, Window, Overhang, Shading	YES		
154	Panel Shading	Solar Panels, Solar Collectors, Solar Thermal, Shading, Solar	YES		
155	PEAR	Design, Retrofit, Residential Buildings	YES		
156	Photovoltaic Calculator	Solar, Photovoltaic, Economics	YES		
157	Pipe Designer	Fluid Systems, Piping Design, Existing Systems	YES		
158	Pipe-Flo	Piping Design & Analysis, Pump Sizing, Selection, Hydraulic Analysis, Pressure Drop Calculator, Hydraulic Modeling, Steam Distribution, Chilled Water, Sprinkler System	YES		
159	Pocket Controls	PDA, Controls, Front End, Handheld	YES		
160	Polysun	Solar System Design, Simulation Software (And Heat Pump)	YES		
161	PRISM	Utility Billing Data, Demand-Side Management, Statistical Energy Savings	YES		
162	Prophet Load Profiler	Energy Budgeting & Analysis, Load Profiling, Cost Comparison, Rate Analysis, Data Collection, Real-Time Monitoring, Load Shedding	YES		
163	PsyCalc	Psychometric, Temperature, Moisture Content, Atmospheric Pressure	YES		
164	Psychrometric Analysis	Psychometric Analysis, HVAC	YES		
165	PV-Design-Pro	Photovoltaic Design, Tracking Systems, Solar, Electrical Design	YES		
166	Quick Calc	Lighting Design, 3d Drawing, Indoor Lighting	YES		

167	Quick Est	Lighting, 3d Drawing, Indoor Lighting	YES		
168	Qwick Load	Design, Residential To Large Commercial Buildings, Heating Load, Cooling Load, HVAC	YES		YES
169	Radiance	Lighting, Day-Lighting, Rendering	YES		
170	RadOnCol	Solar Radiation, Solar Collector	YES		
171	RadTherm	Convection, Conduction, Radiation, Weather, Solar, Transient	YES		
172	REEP	Energy- And Water-Efficiency Strategies, Economic Analysis, Pollution Abatement, DOD Installations	YES		
173	Rehab Advisor	High Performance Housing, Single Family, Multifamily, Housing Renovation, Energy Efficiency	YES		
174	REM/Design	Energy Simulation, Residential Buildings, Code Compliance, Design, Weatherization, Equipment Sizing, EPA Energy Star Home Analysis	YES		YES
175	REM/Rate	Residential Energy Rating Systems, Energy Simulation, Code Compliance, Design, Weatherization, EPA Energy Star Home Analysis, Equipment Sizing	YES		YES
176	REScheck	Energy Code Compliance, Residential Buildings, Codes Training, Energy Savings	YES		
177	RESEM	Retrofit, Institutional Buildings	YES		
178	RESFEN	Fenestration, Energy Performance	YES		
179	RHVAC	Residential HVAC, Residential Load Calculations, ACCA, Manual J	YES		
180	Right-Suite Residential	Residential Loads Calculations, Duct Sizing, Energy Analysis, HVAC Equipment Selection, System Design	YES	YES	YES
181	Roanakh	Photovoltaic System Design, Grid-Tie, Grid-Interactive, Solar Electric System Design	YES		
182	Conditioner Cost Estimator	Air Conditioner, Life-Cycle Cost, Energy Performance, Residential Buildings, Energy	YES		YES
183	SIP Scheming	Stressed Skin Insulating Core Panels	YES		
184	SMOC-ERS	Energy Efficiency Program, Auditing, Reporting	YES		
185	Sol Path	Solar, Sun, Sun Path	YES		
186	SOLAR-2	Windows, Shading Fins, Overhangs, Daylight	YES		
187	SOLAR-5	Design, Residential And Small Commercial Buildings	YES	YES	YES
188	SolArch	Thermal Performance Calculation, Solar Architecture, Residential Buildings, Design Checklists	YES		YES
189	Solar Design Tool	PV System Design, String Sizing, Array Layout Design	YES		
190	SolarPro 2.0	Solar Water Heating, Thermal Processes, Alternative Energy, Simulation	YES		
191	Solar Shoe Box	Direct Gain, Passive Solar	YES		YES
192	SPACER	Fenestration, Spacer, THERM, Thermal Modeling, IGU, Sealants	YES		

193	SPARK	Object-Oriented, Research, Complex Systems, Energy Performance, Short Time-Step Dynamics	YES		YES
194	SPOT	Day-Lighting, Electric Lighting, Photo-Sensor, Energy Savings	YES		
195	STREAM	Computational Fluid Dynamics, CFD, Ventilation, Airflow, Temperature Distribution, Humidity Distribution, Contaminant Distribution, Thermal Comfort, Air Quality	YES		
196	SunAngle	Solar, Sun, Angle	YES		
197	SunAngle Professional	Sun Angle, Solar Calculator	YES		
198	SUNDAY	Energy Performance, Residential And Small Commercial Buildings	YES		YES
199	SunPath	Solar Geometry, Sun Position	YES		
200	Sun Position	Solar Angle Design, Solar Altitude, Solar Design	YES		
201	SUNREL	Design, Retrofit, Residential & Small Office Buildings, Energy Simulation, Passive Solar	YES		YES
202	Sunspec	Solar Radiation, Luminance, Irradiance, Luminous Efficacies, Solar Position	YES		
203	Sun chart Solar Design	Sun-Chart, Solar Position, Sun Path, Shading	YES		
204	Super-Lite	Day-Lighting, Lighting, Residential And Commercial Buildings	YES		
205	System Analyzer	Energy Analyses, Load Calculation, Comparison Of System &Equipment Alternatives	YES		YES
206	Tariff Analysis Project	Utility Bills, Tariff, Schedules, Utility Rates, Utility Tariffs, Energy Savings Analysis, Investment Analysis	YES		
207	Therm	2-D Heat Transfer, Building Products, Fenestration	YES		
208	Thermal Comfort	Thermal Comfort Calculation, Comfort Prediction, Indoor Environment	YES		
209	Building Load Calculation	Building Loads, Energy Calculations, Heat Balance Model, Heat Transfer	YES		
210	TRACE 700	Energy Performance, Load Calculation, HVAC Sizing, Commercial-Energy Simulation	YES		YES
211	TRACE Load 700	Air Distribution Simulation, HVAC Sizing Load Calculation, Commercial Buildings	YES		
212	TREAT	Weatherization Auditing, BESTEST, Home Performance W/Energy Star, Retrofit, Single & Multifamily Residential, Mobile Homes, HERS Ratings, Load Sizing.	YES	YES	YES
213	TRNSYS	Energy (Simulation, Performance) Load Calculation, Building Performance & Simulation, Research, Renewable Energy, Emerging Technology	YES		YES
214	UM Profiler	Utility Metering, Utility Accounting	YES		
215	United Resources Group	Quantify, Lighting Conservation, Cost And Savings	YES		
216	UrbaWind	CFD, Wind Simulation, Wind Energy, Natural Ventilation, Pedestrian Comfort	YES		

217	Utility Manager	Central Capture Of Utility Data For Cost & Energy Usage Reporting & Reduction	YES		
218	UtilityTrac	Energy Tracking, LEED, ENERGY STAR, Utility Bill Management, M&V, Benchmarking	YES		
219	Varitrane Duct Designer	Duct Sizing, Static Regain, Equal Friction, Fitting Loss	YES		
220	VentAir 62	Ventilation Design, ASHRAE Standard 62	YES		
221	Visual	Lighting, Lighting Design, Roadway Lighting, Visual, Lumen Method	YES		
222	VisualDOE	Energy (Efficiency, Performance, Simulation), Design, Retrofit, Research, Residential & Commercial Buildings, HVAC, DOE-2	YES	YES	YES
223	Visualize-IT Energy	Energy Analysis, Rate Comparison, Load Profiles, Interval Data	YES		
224	WaterAide	Water Audits, Water Analysis, Water End-Sue Allocation, Retrofits, Domestic Hot Water	YES		
225	WATERGY	Water Conservation Opportunities, Energy Savings	YES		
226	Weather Data Viewer	Weather, Climate, Design (Data, Temperature), Humidity, Dew Point, Dry Bulb, Wet Bulb, Temperature, Enthalpy, Wind Speed	YES		
227	Weather Calculations 2	Weather Data, Energy Calculations, Simulation Data	YES		
228	Window	Fenestration, Thermal Performance, Solar Optical Characteristics, Windows, Glazing	YES		
229	Window Heat Gain	Solar, Window, Energy	YES		
230	WUFI-ORNL/IBP	Hydro-Thermal Model, Combined Heat & Moisture Transport, Building Envelope Performance	YES		
231	ZIP	Economic Insulation Level, Residential Buildings	YES		

II. 20 selected software programs for the research.

1- Audit

It calculates monthly and annual heating and cooling costs for residential and light commercial buildings.

Keywords

Operating cost, bin data, residential, commercial

Validation/Testing

N/A

Expertise Required

Knowledge of various types of HVAC equipment is helpful.

Users

5000 worldwide

Audience

HVAC Contractors and Engineers

Strengths

Minimal input data required for obtaining HVAC operating costs. Great sales tool for showing the benefits of using high efficiency equipment. It is not evaluating building material; it only focuses on HVAC system.

Weaknesses

The simple and easy to use monthly bin method of calculation does not allow the simulation sophistication provided by hourly energy analysis methods.

Contact

Company: Elite Software

Website: http://www.elitesoft.com

Availability

Contact Elite Software, or visit their web site for more information. Cost starts at $495. Free evaluation version available for download from their web site.

2- COMSOL

COMSOL Multi-physics slashes the metric of greatest value to computational scientists - time to solution. It is based on partial differential equations (PDEs) - the fundamental equations that describe the laws of physics. Through multi-physics and mathematical modeling, we transform any coupled PDEs into a form suitable for numerical analysis and solve it using the finite element method with high-performance solvers.

Keywords

Multi-physics, simulations, modeling, heat transfer, finite element

Validation/Testing

The software is validated to conform to all four cases of ISO 10211:2007, Annex A, for 3-D calculation programs.

Expertise Required

It needs expertise; therefore, Model Library is designed to step-by-step instructions for how to build models for all types of technical applications. Courses are also available for more advanced use of the software.

Users

Have approximately 40,000 users throughout the world.

Audience

Any scientist or engineer that is interested in simulating a device, component, or process that can be described by physics. In particular, scientists and engineers that wants to simulate phenomena that are described by two sets of coupled physics, such as fluid flow and heat transfer.

Input

Users input geometries (manually or from a CAD software) of either a component or the spatial coordinates where a process will take place. Users also input material properties directly, choose them from a material library or import them from an external source, such as in an Excel file. Users can also directly include mathematical equations that describe a material property, or even a partial differential equation, by typing them directly in the user interface.

Output

Outputs can be presented as pictures and movies, showing the simulation, or as data for further processing with other software, such as MATLAB. A report generator also allows results to be presented as an html file, along with the model set-up. Model files can also be exported as M-files as an output for further manipulation in the MATLAB software.

Computer Platform

Windows 2000, Windows XP, Windows 2003 Server, Windows Vista, Windows Server 2008, Linux, MAC OS X.

Programming Language

JAVA, C++

Strengths

COMSOL Multi-physics' strength is its ability to couple different sets of physics and solve them together, no matter what the physics. It is easy to use and intuitive to those that are familiar with the physics that describe their applications and processes. Its other strength is the ability for a user to include any arbitrary equation in their model definitions by typing such an equation directly into the user interface.

Weaknesses

For solving coupled systems of ordinary differential equations (ODEs).

Contact

Company: COMSOL, Inc.

Website: http://www.comsol.com

Availability

COMSOL is available directly from COMSOL and its global network of distributors immediately.

3- Design Advisor

This Web suite of building energy simulator is modeled energy, comfort, and day-lighting performance, and gives estimates of the long-term cost of utilities. The simulations restrict flexibility in order to offer users greater ease-of-use and speed. The tool can be quickly mastered by non-technical designers, and runs fast enough to allow them the scope to experiment with many different versions of a design during a single sitting. The immediate feedback that the site provides makes it useful in the conceptual phase of design, when architects cannot afford to invest large amounts of time to rule out any particular idea. The emphasis of the energy model is on the envelope system of the building, and includes simulations of high-technology windows such as double-skin facades. Energy-load estimates are based on a library of climate data for 30 different cities around the world.

Keywords

Whole-building, energy, comfort, natural ventilation, double-skin facade

Validation/Testing

Validated against Energy Plus with results within 15%

Expertise Required

None

Users

More than Approximately 1400 individual IP addresses logged in during the last 6 months.

Audience

Architects, planners, building contractors

Input

Using text fields and buttons only

Output

Output is in the form of graphs showing monthly and yearly energy consumption, graded color charts depicting comfort zones in a room, 3-D perspective images showing day-lighting effects, and a text-based page showing a comprehensive listing of inputs and outputs.

Computer Platform

Web-based

Programming Language

Java, HTML and JavaScript

Strengths

10-15% accuracy for comparing early building design concepts

Weaknesses

Difficult to fine-tune when a building is beyond early design concepts

Contact

Company: Massachusetts Institute of Technology

Website: http://designadvisor.mit.edu

Availability

Freely available as a real-time simulator on the web

4- DOE-2

Hourly, whole-building energy analysis program calculating energy performance and life-cycle cost of operation. Can be used to analyze energy efficiency of given designs or efficiency of new technologies. Other uses include utility demand-side management and rebate programs, development and implementation of energy efficiency standards and compliance certification, and training new corps of energy-efficiency conscious building professionals in architecture and engineering schools.

Keywords

Energy performance, design, retrofit, research, residential and commercial buildings

Validation/Testing

N/A

Expertise Required

Recommend 3 days of formal training in basic and advanced DOE-2 use.

Users

800 user organizations in U.S., 200 user organizations internationally; user organizations consist of 1 to 20 or more individuals.

Audience

Architects, engineers in private A-E firms, energy consultants, building technology researchers, utility companies, state and federal agencies, university schools of architecture and engineering

Input

Hourly weather file plus Building Description Language input describing geographic location and building orientation, building materials and envelope components (walls, windows, shading surfaces, etc.), operating schedules, HVAC equipment and controls, utility rate schedule, building component costs. Available with a range of user interfaces, from text-based to interactive/graphical windows-based environments.

Output

20 user-selectable input verification reports; 50 user-selectable monthly/annual summary reports; user-configurable hourly reports of 700 different building energy variables

Computer Platform

PC-compatible; Sun; DEC-VAX; DEC-station; IBM RS 6000; NeXT; 4 megabytes of RAM; math coprocessor; compatible with Windows, UNIX, DOS, VMS.

Programming Language

FORTRAN 77

Strengths

Detailed, hourly, whole-building energy analysis of multiple zones in buildings of complex design; widely recognized as the industry standard.

Weaknesses

High level of knowledge is needed.

Contact

Company: Lawrence Berkeley National Laboratory

Website: http://simulationresearch.lbl.gov

Availability

Cost $300 to $2000, depending upon hardware platform and software vendor.

5- ECOTECT

The complete environmental design tool with 3D modeling interface; it allows extensive solar, thermal, lighting, acoustic and cost analysis functions. It is one of the few tools perform accurate and most importantly, visually responsive simple analysis.

ECOTECT is driven by the concept that environmental design principles are most effectively addressed during the conceptual stages of design. The software responds to this by providing essential visual and analytical feedback from even the simplest sketch model, and also progressively guides the design process as more detailed. The model is handling simple shading models to full-scale cityscapes. Its extensive export facilities also make final design validation much simpler by interfacing with Radiance, Energy-Plus and many other focused analysis tools.

Keywords

Environmental design, environmental analysis, conceptual design, validation; solar control, overshadowing, thermal design and analysis, heating and cooling loads, prevailing winds, natural and artificial lighting, life cycle assessment, life cycle costing, scheduling, geometric and statistical acoustic analysis, LEED

Validation/Testing

N/A

Expertise Required

CAD and environmental design experience is useful but not necessary. ECOTECT is good tool for teaching environmental design for the beginners. It focuses many of the important concepts necessary for efficient building design. Extensive help file and tutorials is provided.

Users

Over 2000 individual licenses worldwide, taught at approximately 60 universities mainly in Australia, UK and USA.

Audience

Architects, engineers, environmental consultants, building designers, and some owner builders

Input

Intuitive 3D CAD interface allows validation of the simplest sketch design to highly complex 3D models. It can also import 3DS and DXF files.

Output

ECOTECT's own analysis functions use a wide range of informative graphing methods which can be saved as Metafiles, Bitmaps or animations. Tables of data can also be easily output. For more specific analysis or validation file could be exported to; RADIANCE, POV Ray, VRML, AutoCAD DXF, Energy-Plus, AIOLOS, HTB2, Che-NATH, ESP-r, ASCII Mod files, and XML.

Computer Platform

Windows 95, 98, NT, 2000 & XP (Can also run on Mac OS under Virtual PC)

Programming Language

C++

Strengths

It allows the user to manipulate with design ideas at the conceptual stages, providing essential analysis feedback from even the simplest sketch model. ECOTECT progressively guides the user as more detailed design information becomes available.

Weaknesses

The program can perform many different types of analysis; however user needs to be aware of the different modeling and data requirements before diving in and modeling/importing geometry. For example; for thermal analysis, weather data and modeling geometry in an appropriate manner is important; and appropriate/comprehensive material data is required for almost all other types of analysis. The ECOTECT Help File attempts to guide/educate users about this and when/how it is important. Like any analysis program it's a matter of, "garbage in, garbage out..."

Contact

Company: c/o Centre for Research in the Built Environment

Website: http://www.squ1.com

Availability

A demo version of ECOTECT can be downloaded from the website. Price List in the main menu of the site for the latest price/licensing information student license is able for US$75.

6- ENERGY-10

It is a conceptual design tool focused on making whole-building tradeoffs during early design phases for buildings that are less than 10,000 ft^2 floor area, or buildings which can be treated as one or two-zone increments. It performs whole-building energy analysis for 8760 hours/year, including dynamic thermal and day-lighting calculations. It is specifically designed to facilitate the evaluation of energy-efficient building features in the very early stages of the design process.

Keywords

Conceptual design, residential buildings, small commercial buildings

Validation/Testing

N/A

Expertise Required

Moderate level of computer literacy required; two days of training advised.

Users

It has more than 3,200 users worldwide.

Audience

Building designers especially architects; also HVAC engineers, utility companies, university schools of architecture and architectural engineering

Input

Only 4 inputs required to generate two initial generic building descriptions. Virtually everything is defaulted but modifiable. User adjusts descriptions as the design evolves, using fill-in menus, including utility-rate schedules, construction details, materials.

Output

Summary table and 20 graphical outputs are available, generally comparing current design with base case. Detailed tabular results are also available.

Computer Platform

PC-compatible, Windows 3.1/95/98/2000, Pentium processor with 32 megabytes of RAM is recommended.

Programming Language

Visual C++

Strengths

It is fast, easy-to-use, and accurate. Automatic generation of base cases and energy-efficient alternate building descriptions; automatic application of energy-efficient features and rank-ordering of results; integration of day-lighting thermal effects with thermal simulation; menu display and modification of all building-description and other data.

Weaknesses

It is limited to smaller buildings and HVAC systems.

Contact

Company: Sustainable Buildings Industry Council

Website: http://www.sbicouncil.org/energy10-soft

Availability

$375; student, private sector and academic site licenses are available; see web site for more and detailed information.

7- ENERGY-PLUS

Next generation building energy simulation program that builds on the most popular features and capabilities of BLAST and DOE-2. Energy-Plus includes innovative simulation capabilities including time steps of less than an hour, modular systems simulation modules that are integrated with a heat balance-based zone simulation and input and output data structures tailored to facilitate third party interface development. Energy-Plus modeling program enables to perform analysis to optimize building design for energy and water. Recent additions include multi zone airflow, electric power simulation including fuel cells and other distributed energy systems, and water manager that controls and report water use throughout the building systems, rainfall, groundwater, and zone water use.

Keywords

Energy simulation, load calculation, building performance, simulation, energy performance, heat balance, mass balance

Validation/Testing

Energy-Plus has been tested against the IEA BESTest building load and HVAC tests. Results are available under Testing and Validation on the Energy-Plus web site.

Expertise Required

High level of computer literacy is not required; engineering background helpful for analysis portions.

Users

Over 85,000 copies of Energy-Plus downloaded since it was first released in April 2001

Audience

Mechanical, energy, and architectural engineers, consulting firms, utilities, federal agencies, research universities, and research laboratories.

Input

Energy-Plus uses a simple ASCII input file. Private interface developers are already developing more targeted / domain specific user-friendly interfaces.

Output

Energy-Plus has a number of ASCII output files - readily adapted into spreadsheet form for further analysis.

Computer Platform

It available for Windows XP/Vista, Mac OS, and Linux

Programming Language

Fortran 2003

Strengths

It is able simulate detailed, complex model. Input is geared to the 'object' model way of thinking. It is successfully interfacing CAD program with using IFC standard architectural model to obtain geometry. Extensive testing (comparing to available test suites) is completed for each version and results are available on the web site. Weather data is available for over 2,000 locations in a file format that can be read by Energy-Plus.

Weaknesses

Text input may make it more difficult to use than graphical interfaces.

Contact

Company: U S Department of Energy

Website: http://www.energyplus.gov
http://apps1.eere.energy.gov/buildings/energyplus/

Availability

Energy-Plus Version 3.1.0 was released in April 2009. Energy-Plus and can be downloaded at no cost from the EnergyPlus Web site.

8- ENERGY-PRO

Comprehensive energy analysis program that has can be used to perform several different calculations:

- California Title 24 hourly energy analysis of low-rise residential buildings with an approved residential simulation (ResSim)
- Residential design heating and cooling load calculations (Res Loads)

California Title 24 energy analysis of nonresidential buildings, hotels/motels and high-rise residential buildings with either a prescriptive method approach which individually calculates compliance for the envelope, lighting, and mechanical building components (NR Prescriptive), or a performance simulation method using an approved version of DOE-2.1E (Win/DOE)

Nonresidential design heating and cooling load calculations (NR Loads)

DOE-2 energy analysis determines actual energy use, with or without Energy-Pro as a pre-processor.

Energy-Pro is composed of an interface, which includes a building tree, a set of libraries, and a database of state-certified equipment directories. Although Energy-Pro provides nine different types of calculations, users can purchase only the modules that pertain to the type of work they do, similar to the Microsoft Office Suites.

Keywords

California Title 24, compliance software, energy simulation, commercial, residential

Validation/Testing

N/A

Expertise Required

Users should be familiar with basic Windows operations to use the software. It is recommended that users also study the California Title-24 regulations if using the software for code compliance purposes. Knowledge of the DOE 2.1E software is optional, since the software provides a shell interface to the DOE-2.1E engine.

Users

Over 5000 copies used mostly in California, some throughout the US

Audience

Title-24 Energy Consultants (Residential & Non-residential), builders, architects, utilities, mechanical engineers.

Input

A building tree is used to describe the general building information, similar to Windows Explorer. Users can choose to display different hierarchies of information, zone level, room details, and system and plant level. Input is streamlined through the use of libraries that come pre-populated with commonly used building components such as walls, windows, mechanical systems and lighting fixtures.

Output

Energy-Pro can provide exact images of any of the 40 or more forms issued by the California Energy Commission. In addition, detailed room-by-room load calculation reports and HVAC psychometric diagrams can be produced. All available DOE-2.1E reports can be produced from within the program interface, as well as incentive calculation reporting for California's Savings By Design utility incentive program.

Computer Platform

Microsoft Windows 95, 98, 2000, NT 3.51, 4.0, IBM 486 or Pentium 75 with at least 16 MB RAM, 40 MB free disk space, SVGA monitor with minimum 800 x 600 resolution.

Programming Language

C++

Strengths

Most users are productive with Energy-Pro within a day, because of the Wizards feature to speed up the learning curve. A Building Wizard guides the user through the creation of a simple building description, the Calculation Manager sets up appropriate calculations, and an extensive Diagnostic Wizard provides detailed Errors, Warnings and Cautions to the user. Report creation takes under a minute because the Report Wizard that guides the user through the myriad of potential reports encompassed by DOE-2 and the code requirements.

Weaknesses

A number of more advanced concepts encompassed by DOE-2.1E are not handled by the Energy-Pro interface. For instants, co-generation, day lighting and off-site steam production. The user must model the basic building in Energy-Pro, generate the DOE-2 BDL file, and then manually edit the BDL file to add these features.

Contact

Company:	Gabel Dodd/Energy-Soft Inc
Website:	http://www.energysoft.com

Availability

Contact Gabel Dodd / Energy-Soft or visit the web site for an order form. Cost starts at $450, depending upon which modules are ordered.

9- ENERGY-SAVVY

The useful for homeowner who is wishing to increase the home efficiency. Homeowners can use an online energy calculator to rate the home current efficiency, search for relevant rebates and tax credits, and choose from a list of pre-screened home energy contractors in their area. They can also discuss home energy topics and get expert answers to home efficiency questions.

Keywords

Efficiency calculation, energy rebates, home contractor search

Validation/Testing

N/A

Expertise Required

None

Users

Thousand of user in the United State

Audience

The tool is directed toward homeowners who want to remodel their homes.

Input

All characteristic about home such as windows, foundation, lighting, appliances, heat, etc.

Output

The energy calculation is presented in a preformatted report that includes the home efficiency score, estimated 3-year savings, and suggested courses of action to improve efficiency.

Computer Platform

The tool is Web-based and will run on any computer that has Internet capability.

Programming Language

Python

Strengths

Energy-Savvy provides efficiency calculations with few inputs. It also allows users to investigate the home efficiency, find a contractor, and perform an energy audit.

Weaknesses

Energy-Savvy does not include information about home remodeling materials

Contact

Company: EnergySavvy.com
Website: http://www.EnergySavvy.com

Availability

All features of the site are free to use

10- E-QUEST

E-QUEST is a widely in whole building energy performance design tool. Its wizards, dynamic defaults, interactive graphics, parametric analysis, and rapid execution make E-Quest uniquely able to conduct whole-building performance simulation analysis throughout the entire design process, from the earliest conceptual stages to the final stages of design. E-Quest's simulation engine, DOE 2.2, is time-proven, well known, and widely used.

Keywords

Energy performance, simulation, energy use analysis, conceptual design performance analysis, LEED, Energy and Atmosphere Credit analysis, Title 24, compliance analysis, life cycle costing, DOE 2, Power-DOE, building design wizard, energy efficiency measure wizard

Validation/Testing

E-Quest has been tested according to ASHRAE Standard 140. Results are available at doe2.com.

Expertise Required

Due to wizard-based use, virtually no experience is necessary for energy analysis. However building technology knowledge is required in detailed model. Experience with other energy analysis simulation tools, especially DOE-2 based tools is also helpful.

Users

E-Quest is one of the most widely used building energy simulation programs in the United States. The number of full program downloads averages approximately 10,000 annually.

Audience

The primary audience consists of building designers, operators, owners, and energy/LEED consultants. E-QUEST is also widely used by regulatory professionals, universities, and researchers.

Input

Inputs can be provided at three levels: schematic design wizard, design development wizard, and detailed (DOE-2) interface. In the wizards, all inputs have defaults (based on the California Title 24 building energy code).

Output

Graphical summary reports provide a single-run results summary, a comparative results summary (compares results from multiple separate building simulation runs), and parametric tabular reports (compare annual results by endues, incremental or cumulative results). Additional output includes input/output summary reports (rule-of-thumb and other indices), non-hourly simulation results (tabular/text DOE-2 SIM file reports), hourly simulation results (text and comma-separated variable hourly listings for thousands of simulation variables), and California Title 24 compliance analysis reports.

Computer Platform

Microsoft Windows 98/NT/2000/XP/Vista

Programming Language

Interface: C++, DOE-2.2 engine: FORTRAN

Strengths

The unique strength of E-Quest is that it is an energy performance design tool that evaluates whole-building performance throughout the entire design process. Its wizards (schematic, design development, and energy efficiency measure) make it possible for any member of the design team to explore the energy performance of design concepts from the earliest design phase. Its detailed interface (a full-featured Windows front-end for DOE-2.2) supports detailed analysis throughout the construction documents, commissioning, and post-occupancy phases. Its execution speed makes it feasible to perform many evaluations of large models, capturing critical interactions between building systems at the whole-building level. Its rule-based processor provides intelligent dynamic defaults in the interface and enables automated quality control checks of simulation inputs and results and automated Title 24 compliance (certified by the California Energy Commission for use with the 2001 and 2005 Title 24 compliance analysis) and automated Savings By Design analysis (a California new construction efficiency incentive program).

Weaknesses

Defaults and automated compliance analysis has not yet been extended from California Title 24 to ASHRAE 90.1. It does not yet support SI units (I-P units only). Ground-coupling and infiltration/natural ventilation models are simplified and limited. Day-lighting can be applied only to convex spaces (all room surfaces have an unrestricted view of each surface) and cannot be transmitted (borrowed) through interior glazed surfaces. Custom functions in DOE-2.1E (allows users limited customization of source code without having to recompile the code) have not yet been made available in DOE-2.2 or E-Quest.

Contact

Company:	James J. Hirsch and Associates
Website:	http://www.doe2.com

Availability

E-Quest is supported primarily through public funding from California's Savings By Design (savingsbydesign.com) and Energy Design Resources (energydesignresources.com), and is available at no cost from www.EnergyDesignResources.com and doe2.com. Long-term average weather data (TMY, TMY2, TMY3, etc.) for 1000+ locations in North America are available via automatic download from within E-Quest (requires Internet connection).

11- FEDS

It provides a comprehensive method for quickly and objectively identifying energy improvements that offer maximum savings. FEDS (Facility Energy Decision System) makes assessments and analyzes energy efficiency of single buildings, multiple buildings, or all buildings of an entire facility. It provides an easy-to-use tool for identifying energy efficiency measures, selecting minimum life-cycle costs, determining payback, and enabling users to prioritize retrofit options and compare alternative financing options (site funding, leases, loans, ESPCs). FEDS also evaluates whether decentralization options are economically optimal for central energy plants and thermal loops.

Keywords

Single buildings, multi-building facilities, central energy plants, thermal loops, energy simulation, retrofit opportunities, life cycle costing, emissions impacts, alternative financing

Validation/Testing

N/A

Expertise Required

Default components make it easy to use there is no need knowledge. It requires two or more hours depending on number of buildings to create a model.

Users

Over 1,500

Audience

Energy and facility managers, architects-engineers, utility planners, building technology researchers, educators, federal agencies, and energy consultants

Input

Location, building types, operating hours, age, square footage, fuels used by facility and energy price data are required. Numerous detailed engineering parameters are optional.

Output

Fuel-neutral analysis is given with full life-cycle costing of retrofit options (ECMs) for the on-site buildings. Output data includes energy and cost savings, emissions reductions, and a wide range of economic measures.

Computer Platform

PC-compatible, operating Windows NT/2000/XP/Vista

Programming Language

C

Strengths

It allows but does not require input of engineering parameters; energy/economic analysis; models peak demand; optimizes retrofit opportunities; performs analysis that meets unique Federal needs; provides emissions impacts; evaluates multi-buildings; considers decentralization for central energy plants and thermal loops; engineering and economic parameters provided are user adjustable and flexible operation to meet a variety of needs.

Weaknesses

Not a building design tool

Contact

Company: Pacific Northwest National Laboratory

Website: http://www.pnl.gov/feds

Availability

Version 6.0 available free to Federal agencies through the Energy Efficiency and Renewable Energy Clearinghouse

12- HAP

HAP is focus on HVAC design and load estimating tool. Calculation rigor and integrity are provided by the ASHRAE Transfer Function Method for calculating building heat flow. A versatile (moving easily between tasks) system design tool and an energy simulation tool in one package, Hourly Analysis Program (HAP) provides the ease of use for a Windows-based graphical user interface and the computing power of modern 32-bit software.

HAP's energy analysis module performs an hour-by-hour simulation of building loads and equipment operation for all 8,760 hours in a year. This approach provides superior accuracy versus the reduced hour-by-hour method used by other software programs on the market. Such accuracy is crucial when analyzing design alternatives, energy conservation methods and details of off-design and part-load performance for equipment. HAP uses TMY weather and the ASHRAE Transfer Function to calculate dynamic heat flow.

Keywords

Energy performance, load calculation, energy simulation, HVAC equipment sizing

Validation/Testing

N/A

Expertise Required

General knowledge of HVAC engineering principles is required and also MS Windows software applications knowledge is recommended.

Users

Approximately it has 5000 worldwide users.

Audience

HVAC systems/equipment engineers, colleges and universities. Design/build contractors, HVAC contractors, facility engineers, energy service consultants and other professionals involved in the design and analysis of commercial building HVAC systems.

Input

Building geometry, envelope construction, internal heat gains and their schedules; equipment components, configurations, controls and efficiencies; utility rates are the inputs.

Output

Over 50 design, and energy analysis reports and graphs document hourly, daily, monthly and annual energy and cost performance and are available to view or print. Design reports provide system sizing information, check figures, component loads and building temperatures. Simulation reports provide hourly, daily, monthly and annual performance data. All reports can be exported for use in word processors and spreadsheets. Energy costs can be calculated using complex utility rates which consider all of the common billing mechanisms for energy use, fuel use and demand.

Computer Platform

Windows 95/98/ME/NT/2000/XP compatible computer

Strengths

HAP balances ease of use with technical sophistication. Technical features are comparable to DOE 2.1; comparison studies with DOE 2.1 have yielded good correlation. The Windows graphical user interface, report features, data management features, on-line help system and printed documentation combine to provide an efficient, easy to use tool. HAP can receive equipment performance data via electronic link from Carrier equipment selection tools.

Weaknesses

HAP has limitations for use by research scientists. Because it is designed for the practicing engineer, program features are tailored for this audience. Features such as access to the source code, often necessary in research situations, are not offered.

Contact

Company: Carrier Corporation
Website: http://www.carrier-commercial.com/software

Availability

The first year license fee is $1195; annual renewal fee is $240 for US users.

13- HEED

HEED (Home Energy Efficient Design) is tool for remodeling projects or designing new buildings. It is user-friendly; shows how much money can be saved by making changes. It also shows how much greenhouse gas (including CO2) it accounts for, and its annual total energy consumption. It has an expert system helps on the energy code, energy efficiency features. It allows users to copy designs or create its own. First draw in a proposed floor plan, rotate it to the correct orientation, then click and drag windows to the preferred location on each facade. Copy this to successive schemes and try out various passive solar and energy efficient design strategies such as window shading, thermal mass, night ventilation, and high performance glazing, etc.

For basic users the easy-to-understand bar chart shows how the energy coat, annual energy consumption, or CO2 production will change for each different design. For experienced users there are detailed data input options, plus dozens of 3D graphic outputs that reveal subtle differences in building performance. HEED's various graphics outputs clearly show the benefits of good energy efficient design.

HEED is developed for ratepayers in California; however other location local utility rates and greenhouse gas factors can be loaded. Energy-Plus climate data files for sites around the world can be read in directly.

Keywords

Whole building simulation, energy efficient design, climate responsive design, energy costs, indoor air temperature

Validation/Testing

HEED has been validated against the ASHRAE Standard 140, HERS BESTest Tier 1 and Tier 2, and in a five year experimental test cell program. It has also been validated in actual instrumented occupied low income housing units over two summers. See the result at web site.

Expertise Required

There is no expertise is required; any home owner could use it. The Advanced Design and Evaluation sections are intended for designers, builders and contractors familiar with energy efficiency issues, and for energy consultants and engineers working on smaller buildings.

Users

As of January 2008 there were 14,792 users. A survey in April 2002 showed 16 % of the users were in Southern California, 7% were elsewhere in California, 48% were elsewhere in the US, and the remaining 29% were in another country.

Audience

Homeowners and ratepayers will be comfortable with the Basic Design section of HEED which requires no special vocabulary or expertise. Designers and Energy Consultants, familiar with energy efficiency issues, will appreciate the features of the Advanced Design and Evaluation sections.

Input

To start HEED only four facts are required: location, building type, square footage, and number of stories. With this the expert system creates the two base case buildings called "Meets Energy Code" and "More Energy Efficient". The Advanced Design inputs are tabular inputs for all variables in the program including thermal characteristics, dimensions, schedules, etc.

Output

HEED is presented all data graphically, in a wide array of formats. The basic output is a bar chart of fuel and electricity annual costs using local utility rates for up to nine different schemes. This bar chart can also show comparative annual energy consumption and the CO2 production, and total annual (site) energy consumption. Advanced outputs includes 3D plots for each hour of dozens of different variables including heat gain an loss for sixteen elements of the building's total load, plus outdoor and indoor air temperatures, air change rate, furnace and air conditioner outputs, power for lights and for fans, and gas and electricity costs. There are also 3D bar charts comparing over 50 variables against up to 9 schemes. Tabular data is also available.

Computer Platform

HEED runs on all versions of Windows from 95 to Vista, and also on Mac OS 10.2 or later

Programming Language

HEED graphic user interface is written in Java and C++. The Solar-5 computation kernel is written in Fortran

Strengths

HEED's strengths are ease of use, simplicity and clarity of input data, a wide array of graphic output techniques, computational speed, and the ability to quickly compare multiple design alternatives. It can calculate the window-specific daylight reduction of electric lighting loads. It includes an intelligent whole-house fan thermostat and window-dependent operable solar controls. HEED calculates the air pollution implications of design decisions. It can automatically manage up to nine schemes which can be assembled into any number of projects. It includes context specific Help, internet based Advice, and an FAQ file. A full Spanish language version is also available.

Weaknesses

Works best for single-zone buildings, although it can aggregate up to four adiabatic zones. It has generic HVAC systems. Operating schedules in the current version are limited to residential buildings. It contains utility rates for California’s five major utilities, but they can be user-modified for most types of rate structures. HEED comes with climate data for all 16 California Climate Zones, both of which can be accessed for hundreds of California zip codes. HEED can also directly read Energy Plus climate data for over a thousand sites around the world.

Contact

Company:	Energy Design Tools Group at the UCLA Department
Website:	http://www.aud.ucla.edu/energy-design-tools

Availability

HEED can be downloaded at no cost from the web site

14- HOMER

HOMER models both conventional and renewable energy technologies. Evaluates design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed generation (DG) applications. HOMER's optimization and sensitivity analysis algorithms allow you to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability.

Keywords

Remote power, distributed generation, optimization, off-grid, grid-connected, stand-alone

Validation/Testing

Validation results are available upon E-Quest.

Expertise Required

Basic familiarity with Windows and the technology of small power systems

Users

Have 3000 users in 142 countries.

Audience

System designers, rural electrification program planners, policy, market and technology analysts for distributed and small power technologies

Input

Load profiles for the application of interest, renewable resource data (although the software makes some of that available), local installed costs for technology components.

Output

HOMER has a huge quantity of output data in tabular and graphic format, including sensitivity analyses, hourly operational data and comparative economics for competing system architectures.

Computer Platform

Windows

Programming Language

Visual C++

Strengths

It compares different technologies including hybrids. It considers storage and seasonal or daily variations in loads and resources. It designed as optimization model for sensitivity analyses and performs dozens of 8760 hour annual simulations per second. It has great graphical outputs.

Weaknesses

It does not consider intra-hour variability and does not variations in bus voltage.

Contact

Company: National Renewable Energy Laboratory
Website: http://www.nrel.gov/homer

Availability

Free download from the website. The user must fill out a survey after 6 months for continued use.

15- MARKET-MANAGER

Models any type of commercial, institutional, industrial, and residential facility and determines the energy and cost impact of virtually any type of energy conservation measure or utility rate schedule. It calculates the operating costs of any piece of equipment in the facility and determines the cost-effectiveness of improving the building envelope, HVAC controls, motors, lighting systems, heating and cooling equipment.

Keywords

Building energy modeling, design, retrofit

Validation/Testing

N/A

Expertise Required

Market-Manager is best used by energy professionals who have a good understanding of HVAC systems.

Users

Approximately 1000 users worldwide, mostly in the United States

Audience

ESCOs, performance contractors, energy consultants, utilities and energy managers

Input

Users input building envelope characteristics (windows, walls, etc.), occupancy and thermostat schedules, lighting and internal equipment data and schedules, HVAC system information (including chillers, fans, system type, etc.), HVAC controls, and rate information. Users can speed up the process by using pre-defined template projects, libraries filled with hundreds of equipment and building envelope items. Users can also use default values in the data forms for the more esoteric inputs such as thermal mass and infiltration information.

Output

Market-Manager includes over 20 standard reports formats as well as graphing capabilities. Users can also configure results output. The program also allows users to create and print lists of inputted data such as information on all fans.

Computer Platform

PC Platform, 486 and higher, Windows 3.1 and later.

Programming Language

Delphi (a derivative of PASCAL)

Strengths

Ease of use through the use of templates, libraries, defaults and drag and drop, Market-Manager users can create detailed models in a very short time. The program's calculations are based upon methods outlined in ASHRAE Fundamentals and used in DOE-2.

Weaknesses

Users must understand HVAC to correctly create models. The program doesn't run well with huge detailed models, such as 300 zone hospitals.

Contact

Company: Abraxas Energy Consulting

Website: http://www.abraxasenergy.com/marketmanager.php

Availability

Market-Manager costs $2495 per license. 30 day trial version is available at the web site.

16- MICROPAS-6

It is easy to use detailed energy simulation program which performs hourly calculations to estimate annual energy usage for heating, cooling and water heating in residential buildings. In addition to its purpose as a compliance tool for California’s Title 24 Energy Efficiency Standards, Micropas-6 can be used to demonstrate that a home meets Energy Star requirements in California (15% above Title 24). The program includes a load calculation for use in sizing heating and cooling equipment.

The current survey is showed that about 75% of the single-family homes permitted in California used Micropas-6 to determine code compliance. The program is mature, reliable and fast. I t is fully supported with top notch documentation and complete printouts. The program has a wide range of features to help automate and manage its use.

Keywords

Energy simulation, heating and cooling loads, residential buildings, code compliance

Validation/Testing

Micropas-6 tool has passed the HERS Bestest Tier 1 tests.

Expertise Required

To read building plans and an understanding of how the energy efficiency of building features such as U-factors, SHGC, R-values, SEER, etc. are specified.

Users

Over 2300 copies have been sold since 1983, mostly in California and other west coast states.

Audience

Current users include builders, architects, engineers, mechanical contractors, utilities and energy consultants.

Input

Data is required describing each building thermal zone (15 maximum); opaque surfaces (walls, roofs, floors, 100 maximum); fenestration products (doors, windows, skylights, 100 maximum); thermal mass (slabs, etc., 25 maximum); HVAC equipment (heating, cooling, venting, thermostats) and water heating systems (domestic and hydronic heating).

Output

Seven types of clearly formatted printouts are available including summary output, detailed building descriptions, HVAC sizing summary and assembly U-value calculations. For detailed oriented studies, yearly, monthly, daily and hourly table output is available including time-of-use and bin data. Annual and table outputs can be saved in delimited formats suitable for importing into other software for additional analysis and graphics. For studies including many runs, a parametric run generator and databases of run results are available.

Computer Platform

Can run on any DOS, Windows 3.1, Windows 95, 98, XP, 2000 or Windows NT based computer. Can run on Macintosh using emulation software

Programming Language

Microsoft Professional Basic

Strengths

Mature and reliable program used daily by hundreds of energy consultants in California. Good documentation and good support via toll free number. Can calculate annual energy usage and provide load (sizing) calculations at the same time. Able to manage multiple runs.

Weaknesses

No detailed modeling of heating and cooling systems is provided--seasonal performance values like AFUEs and SEERs are used.

Contact

Website: http://www.micropas.com

Availability

It is $795 for private and $500 for research option

17- RIGHT-SUITE RESIDENTIAL FOR WINDOWS

All-in-one HVAC software performs residential loads calculations, duct sizing, energy analysis, equipment selection, cost comparison calculations, and geothermal loop design. Also allows you to design your own custom proposals. Used for system design, for sales representation, and for quotation preparations.

Keywords

Residential loads calculations, duct sizing, energy analysis, HVAC equipment selection, system design

Validation/Testing

N/A

Expertise Required

Knowledge of general HVAC concepts is needed however high level of computer literacy is not required.

Users

Over 10,000 users of Right-J loads

Audience

HVAC contractors and other design and sales professionals in the industry

Input

Building description - dimensions and construction details, all data from Air Conditioning Contractors of America (ACCA)

Output

Screen representations and printouts of ACCA forms and additional printed reports, can link to Microsoft Word for custom proposals.

Computer Platform

Windows 3.1x or Windows 95, 486 or higher, minimum 8 MB RAM, 21 MB hard disk space (for all options), mouse, 3.5-inch diskette drive, any printer supported by Windows.

Programming Language

C/C++

Strengths

On-screen images of standard load forms are easy to fill in. Since loads and sizes are instantly recalculated instantly whenever input is changed, users can play "What if?" at a high level. Because Loads, Duct Sizing, and Operating Costs are all within the same program, changing any input in loads instantly updates the duct system and operating costs. Pie charts and bar charts give easy graphic display of load components and system comparisons. In addition to standard reports, users can use an OLE link to Microsoft Word, which allows custom proposals using program variables.

Weaknesses

It is only for calculations purpose

Contact

Company: Gene Palandro, SalesEric Chisholm, Marketing

Website: http://www.wrightsoft.com

Availability

Contact in the web page.

18- SOLAR-5

It displays 3-D plots of hourly energy performance for the whole building; 9 schemes and any of 40 different components. SOLAR-5 also plots heat flow into/out of thermal mass, and indoor air temperature, day-lighting, output of the HVAC system, cost of electricity and heating fuel, and the corresponding amount of air pollution. It uses hour-by-hour weather data. It contains an expert system to design an initial base case building for any climate and any building type that an architect can copy and redesign. Contains a variety of decision-making aids, including combination and comparison options, color overlays, and bar charts that show for any hour exactly where the energy flows.

Keywords

Design, residential and small commercial buildings

Validation/Testing

SOLAR-5 has been validated against DOE-2 and BLAST using the BESTEST procedure.

Expertise Required

Intended to be self-instructional, with built-in help options; requires only basic familiarity with computers and with architectural vocabulary.

Users

Estimated in the 1000’s; known to run in over a third of the schools of architecture in the U.S. and in dozens of architectural firms.

Audience

Architects, students of architecture, building managers, knowledgeable homeowners

Input

From only four pieces of data initially required—floor area, number of stories, location, and building type—the expert system designs a basic building, filling in hundreds of items of data; user can make subsequent revisions, usually beginning with overall building dimensions, window sizes, etc.

Output

It produces dozens of 3-D plots, tables, and reports. For example, displays heat gain/loss for over a dozen different building components; shows heat flow into and out of the thermal mass of the building, as well as the output of the heating and air conditioning systems; displays air temperatures (outdoors or indoors) and air change rates; predicts the cost of heating fuel and electricity; calculates the building's air pollution 'footprint' for six gasses including carbon dioxide.

Computer Platform

All Windows platforms and emulators; needs 2 megabytes of RAM

Programming Language

Visual Fortran

Strengths

It is intended for use at the very earliest stages of the design process it is user friendly; extremely rapid, calculating 8760 hours of the year using TMY data in condensed format.

Weaknesses

It is not intended for complex mechanical system design or equipment sizing.

Contact

Company: Department of Architecture and Urban Design

Website: http://www.aud.ucla.edu/energy-design-tools

Availability

SOLAR-5 has now been incorporated with HEED (Home Energy Efficient Design) a newer and more user-friendly version; it is free. HEED and SOLAR-5 can be downloaded from the web site.

19- TREAT

It performs hourly simulations for single family, multifamily, and mobile homes. Comprehensive analysis tool includes tools for retrofitting heating and cooling systems, building envelopes (insulation and infiltration), windows and doors, hot water, ventilation, lighting and appliances, and more. Weather normalizes utility bills for comparison to performance of model. Highly accurate calculations which consider waste heat (base load), solar heat gain, and fully interacted energy savings calculations. Create individual energy improvements or packages of interactive improvements. Also performs load sizing. It generates XML file for upload to online database tracking systems; complies with HERS BESTEST; approved by the U.S. Department of Energy for use in Weatherization Assistance Programs. TREAT software was created through a partnership between Taitem Engineering and Performance Systems Development Inc., under the sponsorship of the New York State Energy Research Development Authority. TREAT is currently developed and supported by Performance Systems Development. TREAT utilizes the SUNREL building physics simulation engine developed by the National Renewable Energy Laboratory.

Keywords

Weatherization auditing software, BESTEST, Home Performance with ENERGY STAR® auditing tool, retrofit, single family, multifamily residential, mobile homes, HERS ratings, load sizing, LEED Home application.

Validation/Testing

BESTested, DOE approved for weatherization (single family, multifamily, and mobile homes).

Expertise Required

Basic computer skills, knowledge of building science, building performance contracting or weatherization retrofit techniques.

Users

Over 1,000

Audience

Weatherization, Home Energy Raters, Home Performance with Energy Star Contractors, Insulation and Mechanical contractors, Mechanical or Energy Engineers whom performing multifamily building energy analysis.

Input

Building components libraries are used to input building geometry and thermal characteristics, heating and cooling equipment and system characteristics, lighting, appliances, ventilation, and hot water. It imports utility bills and daily weather data.

Output

20 user-selected, formatted reports printed directly by TREAT; generates custom program-designed reports for weatherization, home performance programs or HERS providers. Exports project data in XML format which may be uploaded to online database and tracking system.

Computer Platform

CPU: Pentium 300 or higher (600 MHz recommended); RAM: 256 MB (512 MB recommended); operating system: Windows XP and Windows Vista. Internet access required for software registration.

Programming Language

Delphi and FORTRAN

Strengths

Comprehensive and highly flexible whole building retrofit tool, easy to use graphic user interface which includes libraries of building components (walls / surfaces, windows, doors, appliances, lighting, heating and cooling, and hot water). It performs utility billing analysis including weather normalization; calculations consider solar heat gain and waste heat generated by base load and fully interacted savings from energy retrofit measures.

Weaknesses

Not recommended for commercial buildings with complex HVAC systems.

Contact

Company:	Performance Systems Development Inc.
Website:	http://www.TREATsoftware.com

Availability

Visit the web site for information and current pricing.

20- VISUAL-DOE

It interfaces with the DOE-2.1E. Through the graphical interface, users construct a model of the either building's geometry using standard block shapes, using a built-in drawing tool, or importing DXF files. Building systems are defined through a point-and-click interface. A library of constructions, fenestrations, systems and operating schedules is included, and the user can add custom elements as well.

Visual-DOE is preferred for studies of building envelope and HVAC design alternatives. Up to 99 alternatives can be defined for a single project. Summary reports and graphs can print directly from the program. Hourly reports of building parameters could also be viewed.

Keywords

Energy, energy efficiency, energy performance, energy simulation, design, retrofit, research, residential and commercial buildings, simulation, HVAC, DOE-2

Validation/Testing

N/A

Expertise Required

Basic experience with Windows programs is important. Familiarity with building systems is desirable but not absolutely necessary. One to two days of training is also desirable but not necessary for those familiar with building modeling.

Users

More than 1000 user in the US and 34 other countries

Audience

Mechanical/electrical/energy engineers and architects working for architecture/engineering firms, consulting firms, utilities, federal agencies, research universities, research laboratories, and equipment manufacturers.

Input

Required inputs include floor plan, occupancy type, and location. These are all that is required to run a simulation. Typically, however, inputs include wall, roof and floor constructions; window area and type; HVAC system type and parameters; and lighting and office equipment power. Smart defaults are available for HVAC systems based on the building vintage and size. A library and templates are provided to greatly ease user input.

Output

Produces input and output summary reports that may be viewed on-screen, stored as PDF files, or printed. A number of graphs may be viewed and printed. These graphs can compare selected alternatives and/or selected hourly variables. Standard DOE-2.1E reports and hourly reports are available.

Computer Platform

Windows 95/98/NT/ME/2000/XP; 16MB+ RAM, 50MB hard drive space.

Programming Language

Visual Basic and Visual C++

Strengths

Allows rapid development of energy simulations, dramatically reducing the time required to build a DOE-2 model. Specifying the building geometry is much faster than other comparable software, making Visual-DOE useful for schematic design studies of the building envelope or HVAC systems. Uses DOE-2 as the simulation engine--an industry standard that has been shown to be accurate; implements DOE-2's day-lighting calculations; allows input in SI or IP units; imports CADD data to define thermal zones. For advanced users, allows editing of equipment performance curves. Displaying 3D image of the model to helps verify accuracy. Experienced DOE-2 users can use Visual-DOE to create input files, modify them, and run them from within the program. The interface is designed to be able to incorporate other energy simulation engines like Energy-Plus. A live update program can be used to check and install latest updates via the internet. Responsive technical support is provided. Periodic training sessions are available.

Weaknesses

Visual-DOE implements about 95% of DOE-2.1E functionalities which is adequate for most users. Advanced users familiar with DOE-2.1E can implement the remaining 5% features by modifying the DOE-2 input files generated by Visual-DOE.

Contact

Website: http://www.archenergy.com/products/visualdoe/

Availability

Architectural Energy Corporation or visit web site for an order form. Cost is $980 + tax for a single commercial license, including 90 days phone and one year email technical support. Additional support is $300 per year. Evaluation copy is available for free download from the web site.

APPENDIX C: PRIORITY CONCEPTS

The research proposed 46 priority concepts based on US DOE workshop for development of the existing energy simulation software programs. The research evaluated 20 major software programs to identify the need for future-generation energy simulation programs. 46 priority concepts took form under four categories:

- Applications
- Capabilities
- Methods and Structures
- User Interfaces.

Appendix C provided a list of 46 concepts and brief descriptions.

I. Program Application Priorities

i. Design

Envelope Design

The design of the building that concentrates on foundation, roof, walls, doors and windows.

Early Analysis of Design

To assess alternative energy strategies and systems in the earliest phases of design. This will help teams make energy-conscious decisions early in design (e.g. compare energy potential of material) –when those decisions have greatest impact on the building’s life cycle. This capability will also help project teams make cost effective retrofit decisions (e.g. how many inches of rigid insulation to place on a roof for a re-roofing project). Compression of early design time will speed project completion time.

Developed Design Analysis

To finalize the design with all the detail in place will be given more accurate energy alternative analysis. More detail tends to add time and complexity to the model; therefore, it will use to capture highly detailed engineering effects and will improve simulation accuracy. According to research analysis, the most energy simulation tools apply early design analysis. The research recommended that the developed design analysis option is needed to link to the proposed future tool for accuracy of the simulation.

System Design

To create a technical solution that satisfies the functional requirements (e.g. HVAC)

Multiple Building Systems

To make different build design eligibility (e.g. Residential, commercial).

ii. Performance Evaluation

Environmental Impact

Possible adverse effects caused by a development.

Energy Consumption

Determination of the amount of energy requirement by the equipment.

Life Cycle Assessment

This is also known as life cycle analysis, is a technique to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave). The selection of environmentally friendly construction methods and materials are required in sustainable design. Recycling, reducing waste and minimizing production resources are all critical for making design decisions. Providing selected construction materials and technologies database will recommend cradle-to-grave energy use and environmental impact of selected construction materials and technologies. Greener building design is only possible with knowing each of the component parts–such as concrete blocks, insulation, glass, cladding materials, and roofing system–affects the environment (Athena Institute, 2011a). Life Cycle Analysis (LCA) is the application for evaluation of the material in environmental impact.

The green building movement is experiencing a fundamental shift in the way it approaches to sustainable design, which is away from a dogmatic methodology by means of which materials are assumed to have environmental benefits based on rapid renewability, recycled content or energy features toward one that emphasizes measurable performance. However 20 century sustainable design understanding was different than 20 first century; therefore, US DOE workshop didn't include LCA in the energy simulation. Matter fact even now LCA runs in different packages than the energy simulation. The research is recommended combination of these two topics; accordingly interoperability of the tools is getting more important when accuracy and detailed simulation result is been expected.

LCA is a method which is proposed to evaluate the environmental quality of buildings. LCA is a means to this end because it allows the impartial comparison of materials, assemblies and even whole buildings from cradle–to–grave, in terms of quantifiable impact indicators such as global warming potential (Athena Institute, 20011a); the issues like the protection of human health and eco-system (e.g. protection of climate, fauna, and flora), and the efficient use of resources such as energy, water, and materials (Peuportier, Kellenberger, Anink, Motzl, and Anderson, 2011). LCA is widely used among industrials as well as academics.

Economic & Cost Analysis

It will determine economic analysis to make cost-effective choice among building alternatives or building materials. The most challenging aspect of economic analysis is benefits and costs that resist quantification on such as aesthetics, safety, and environmental impact (WBDG Cost-Effective Committee, 2011). The tool will able formulate sensitivity analysis to consider when running the numbers and evaluating alternatives. Economic and Cost Analysis inputs will include life cycle impact, discount rates, growth rates, utility costs, price of building material, and etc. A rigorous sensitivity analysis could help establishing which factors are most important in the life cycle analysis and accurate impacts on the decision-making.

LEED Applications

Leadership in Energy and Environmental Design (LEED) Green Building Rating System certification advocates use of software tools for possible points of the credits. It will provide guidance on the LEED energy related credits such as Energy and Atmosphere Credits 1 and 2. It will perform in early and in developed process of the design.

The tool will be provided a matrix that links each LEED credit category which requires or suggest software use. Depends on the user preference each credit will be providing a comprehensive summary of the design strategy and includes web links to other related resources. This feature will accelerate analysis for LEED compliance.

Due to familiarly of LEED in 90's, this topic didn't mention in US DOE workshop. Yet the use of LEED ensures that sustainable strategies are considered in developments and energy simulation software is acceptable tool for evaluation in sustainable design. The research is intended to accelerate the development and adoption of advanced building simulation models for new and existed structures; so improving energy modeling tools for LEED compliance is necessary. Thus the proposed energy simulation software will provide LEED compliances for designers to clarification about their design in advanced. The tool will also target manufacturer to evaluate materials for the LEED project contribution in advance and improve them before it manufactured. Early evaluation of the material will help industry in energy consumption and make it easier for designer to take consideration of using evaluated material for green projects.

Comfort Control

The design option for the building and systems with comfort control will allow making adjustment individual needs or those of the group in shared spaces**.** This feature will assist LEED Indoor Environmental Quality credit 6.1 and 6.2 Controllability of the Systems such as Lighting and Thermal Comfort.

Indoor Air Quality (IAQ)

It will give design strategy opportunities that impact occupant health and productivity while optimizing energy efficiency (e.g. ventilation system design with exceed the minimum outdoor air ventilation rates as describe in the ASHRAE standard is optimizing energy efficiency and occupant health). To have a tool that eligible to input CO_2 and ventilation rate monitoring systems demonstrates HVAC energy use and absenteeism reduction in the output while increased occupant productivity (LEED, 2006).

Error Detection & Diagnostic

The processor will provides intelligent defaults in the interface and enables automated quality control checks of simulation inputs and results and automated building standard compliances. Diagnostic feature will provide help to assure that the results are reasonable and will help users achieve the highest levels of network availability and performance. If software system and diagnostics work together it will reduce the total number of failures. This service will perform more accurate reporting of errors; less false notifications; more information about actual errors; and early detection of conditions consequently it will lead corrective action could be taken before the failure occurs (Extreme Network Inc, 2006).

Error checking will provide after information is entered in each field. If the information is outside an acceptable range or wrong data type such as date, numeric, alpha, a warning will appears with information about how to correct the error (Visual-DOE Manual, 2004).

iii. Information Repository

Electronic Owner's Manual

The user-manual will provide for users to get step by step explanatory guide about how to use the tool and notified user about how to tool operates.

System & Equipment Sizing Wizards

Modeling tools will continually inform to the user about decision is made for proposed building. The advice (pop-up box) by sustainable design topics and building systems will make it easy for designers to identify the relevant information for their designs. Energy modeling has the potential to be highly interactive and educate about all concerned guides for designer (user) to the places where the most effect can be made. Many architects and engineers have relied upon rules of thumb, general principles and simplified calculation in order to design environmentally friendly buildings (Thoo, 2008). For instance, Nameplate data for wattage of most plug-in equipment will be higher than what the equipment uses, so actual measured data is always more accurate (in one case the mechanical, electrical, and plumbing (MEP) engineer estimated over 10 watts per square foot for plug loads for a building, yet the prospective occupants had a measured usage of one watt per square foot in their existing building). Making an error of this magnitude results in a drastically oversized cooling system, adding useless capital cost. Some rules of thumb information will be provide in this section (Rosenbaum, n.d.).

Provide Basis for Simplified (defaults)

Literally hundreds of inputs will need to be entered to build a model. The software program will be user-friendly to provide built-in industry standard defaults that speed up model creation in early stage (Rosenbaum, n.d.). It is important to consider all possible design options and evaluate their life-cycle impact. Consequently designers will be notified the design consequences in advance. The matter of default data and intelligence will available to limit environmental impacts; so, the program will start with a set of reasonable defaults coming from building standards.

Building Code Compliance

The software will develop to simplify and clarify code compliance such as the Model Energy Code (MEC) and the International Energy Conservation Code (IECC). The software will be simplifying energy code compliance by automate calculations. The approach will include state-specific energy codes for each building type (US DOE-EERE, 2011b). It will also have verification methods that provide a means of testing that a building complies with the Building Code. In addition, the compliance documents will contain the related section of the Building Code to which they relate a term of definitions, references to other documents and an index. This additional section of compliance will contains information on how the building controls regulatory frameworks, current definitions, and lists of all standards reference documents (Eggers & Maryland, 2009).

II. Program Capability Priorities

i. Physical Process Model

Lighting/Day-lighting

The tool will make eligible to evaluate interior and exterior lighting and day lighting opportunities. Day-lighting inputs are including balance heat gain, heat loss, glare control, visual quality, and variation in daylight availability. The template will add to the program to achieve demonstration that the project complies with minimum illumination levels—25 foot-candles—The input of the program will not limit requirement for day lighting potential calculation; it will allow orientation of the building, number and size of the building openings, floor plate dimensions, vertical site elements such as neighboring buildings and trees (LEED, 2009).

Building Envelope in Environment Interaction

It will contain the analysis of building envelope design that focuses heat, air and moisture transport across a building envelope interaction with the indoor air quality and its possible influences to environmental impact. Building Envelope application is an area which draws attention to building science (engineering) and indoor air quality. Building engineering is an interdisciplinary engineering discipline also known architectural engineering that offers a general engineering approach to the planning, design, construction, operation, renovation, and maintenance of buildings, as well as with their impacts on the surrounding environment. Building envelop design has impacts on the surrounding (indoor and outdoor) environment and this feature will try to eliminate negative impacts before built the structure (Bomberg & Brown, 2002).

Moisture Absorption

It will perform individual simulation model for moisture control in the design. Uncontrolled moisture in indoors could cause a major damage to the building structure and materials. It could trigger mold growth which not only damages the facility, could lead to health and unproductive performance for its user. Mold is usually not a problem indoors unless there is excess moisture.

“Controlling moisture entry into buildings and preventing condensation are critical elements of protecting buildings from mold and other moisture related problems such as pest infestation and damage to building components” (US EPA, 2011). Moisture migration in buildings is highly complex and depends on a variety of factors, including the climate conditions.

The designer must evaluate how the moisture could be drained or it could be dried out. Modeling tool will help designer to identify some of subject related questions such as: how long would the drying take; what effect would it have on materials? ; could the expanded incidence of moisture cause corrosion, mould growth or rot? “The entire process of environmental-control design must occur off-site, and never at the building site” (US EPA, 2011). In order for the building envelope to perform its role of separating the interior and exterior environments designers need advanced modeling tool for more accurate evaluation of their design (US EPA, 2011).

Air infiltration

Primarily, comfortable indoor space is possible through properly designed building envelope which required many mechanical and environmental forces. Air transport is one of the critical factors and it is related with environmental control. It is linked with all factors of environmental control because it allows both heat and moisture through the building envelope. Accommodating environmental control in building design requires repetitive analysis and changes not only minor details, but to alter the basic concept itself if information indicates that this is desirable till the design must meet all the requirements. This process, first leads with a search for suitable materials. Typical questions are asked about possible materials and their air permeability; ability to be extended; flexibility; adhesion; attachment; connection; and support. The outcome will also address the long term performance; material aging; stress; deformations during service, as well as costs of repairs; and maintenance.

After making an initial selection, the designer then specifies the architectural details such as intersections and joints between building elements such as foundations, walls, floors, windows, and doors for detail analysis in developed design stage. For satisfactory achievement location is selected for performance, and then a designer will get the rate of air leakage, location of leakage, risk of drafts and impact on condensation. Throughout the design process, the tool will help whether designer needs further consulting from the experts or not (Bomberg & Brown, 2002).

Heat Transfer Models

It will analyze the thermal behavior of components quickly and accurately with the most advanced level of technology. It will predict the full temperature distribution of the system and delivers heat rates for radiation, conduction and convection. The heat transfer model could perform either in conceptual (early) design stage or developed (detailed) design stage. Thermal representation will obtain by selecting a part of the design or whole system of the design (Thermo Analytics Inc., 2010).

ii. Building System

Passive/Active Solar Design

The program will include guidelines for techniques of passive solar design. The proposed software will encourage passive solar designs concepts in new structures. Constructing a passive solar building saves energy and creates more comfortable buildings. Passive solar building designs strategies use natural sources for heating, cooling and lighting so, it reduces consumption of non-renewable energy. The tool will provide passive solar design principles with various architectural styles and building techniques. This feature could also complement active solar energy systems such as photovoltaic arrays and solar hot water systems. The possible 'Passive Solar Building Design' categories are:

- *Passive Solar Heating (*building orientation; window selection and placement; thermal mass to moderate temperature; and heating load with an efficient back-up system)
- *Passive Cooling* (minimize direct sun exposure and heat absorption; allow for cool air to enter the building; give hot air a way out of the building)
- *Natural Lighting* (maximize natural light; special glazing and automated controls)

(Passive Solar Building Design Guidelines, 2006).

HVAC System Design

It will develop template to assist in HVAC process whether will doing a comprehensive load analysis, profiling system performance, or determining the optimal HVAC components or configurations for a given order, the package that will provide a solution for today's design demands (Trane, 2011).

Advanced Fenestration & Natural Ventilation

Substantial energy efficiencies possible when fenestration is integrated with natural ventilation system of the buildings therefore, the software will able to evaluate either in early or in developed design stages with this feature.

Energy Storage in Buildings

Sustainable buildings will need to be energy efficient beyond the current levels of energy use. Renewable and waster energy will need to take advantage to approach ultra-low energy buildings. Such buildings will need to apply thermal and electrical energy storage techniques customized for smaller loads, more distributed electrical sources and community based thermal sources. This will require that energy storage be closely integrated into sustainable building design evaluation for tool's to be considered (Morofsky, 2006).

Advanced Lighting System Modeling

Properly designed daylight reduces the need for electric lighting of the building interiors, which, if integrated into the overall approach to lighting, can result in decreased large amount of energy use. This conserves natural resources and reduces air pollution impact due to energy production and consumption. Daylight design involves a careful balance of heat gain and heat loss, glare control, visual quality, and variation in daylight availability. Shading devices, light shelves, exterior fins, louvers, and adjustable blinds, courtyard, and atriums, window glazing are all strategies employed in daylight design.

Computer modeling could be used to simulate day lighting conditions and could provide valuable, effective, and integrated day light strategy into the design.

Advanced lighting system modeling will be perform in developed design stage because it will need more and detailed input in the system such as furniture systems, wall partitions, surface color and texture which are all have the ability to reflect day light into the space. In addition, light levels, interior color schemes, direct beam penetration with the electric lighting system are need to address in design (LEED Construction, 2009).

iii. Input & Output

Accessible Library & Manufacturer's Catalog

Accessible library will allow user to create or add information to the library database. Such as colors and textures as well as commercial information such as manufacturer, price per square feet, etc. Each item is stored in the proposed software library will be accessed, edited and modified at any time. The library will have real manufacturer's products which could be dragged as objects from the browser straight into the proposed software. The customize library options and extensive collection of product information, construction specifications, material property of the product will provide to searchable option by LEED category and green topics.

Macro & Micro Weather Data

Macro-climate is a larger area such as a region or a country and Micro-climate is more localized climate around a building. The macro and micro climate has a very important effect on both the energy performance and environmental performance of buildings. The site has an effect on the building or vice versa such as prevailing wind, solar radiation, pollution levels, temperatures, and rain penetration. The orientation of the building affects solar gains and exposure to the prevailing wind.

The location of neighboring trees affects the solar gains (shading), wind patterns for buildings and also it protects buildings from driving rain. The macro climate is not affected for design changes as much as micro climate; however the building design could be developed with knowledge of the macro climate in where the building located. General climatic data will give an idea of the local climatic severity (Energy Systems Research Unit, n.d.).

Standardized Data Structures

Using standardized date format will save time and easy for the user to access the same data format in a different application (Perrin, 2011).

Case studies—Benchmark—Database

Benchmark is one of the most effective ways to vet the model accuracy for energy use in typical buildings in a similar climate. Building designers will investigate the energy use of buildings previously designed and built; this will be very productive practice, if a user informs the goal-setting process in the conceptual stages of the project. The U.S. Environmental Protection Agency's Target Finder is providing database of energy use. Building energy use databases will be available for designers (users) to ensure whether the model is on track. It will indicate if the output seems out of bounds. This feature will be helpful for early design correction. Some good benchmarks tracks are including total annual energy use per square foot; annual energy use per square foot for heating, cooling, and electricity; cubic feet per meter of ventilation air per person of expected occupancy; and square foot per ton of cooling (Rosenbaum, n.d.).

Modeling of Topography

The passive solar design such as natural ventilation has become an increasingly attractive methodology for energy efficient design. These design strategies reduce energy use and cost while increasing indoor environment quality; maintaining a healthy; productive indoor climate rather than the more prevailing approach of using mechanical ventilation. In favorable climates and buildings types, natural ventilation could be used as an alternative to air-conditioning plants, saves about 10%-30% of total energy consumption (Walker, 2010).

Designing natural ventilation and artificial cooling system is very complicated; the design needs careful interpretation of wind data. Local topography, vegetation, and surrounding buildings have an effect on the speed of wind hitting a building. Wind data collected at airports might not tell very much about local microclimate conditions that could be heavily influenced by natural and man-made obstructions. In this point tool needs modeling a topography qualification for more energy efficient design (GEMCOM Software International Inc., 2011).

iv. Model Component

Comparison Systems or Designs

This feature will accommodate few comparisons at once, the estimator will allow users to change the design, substitute materials, and make side–by–side comparisons for any possible the environmental impact indicators. This feature will not only compare material it will compare the proposed design to an existing building. It could also compare similar projects with different floor areas on a unit floor area basis. The Estimator can handle as many as three to five comparisons at a time (Allen, 2006). Having comparisons between different materials, some time whole buildings and specifications, designers could graphically demonstrate the environmental and financial credentials of different designs to clients (Boxall Sayer Construction Consultancy, n.d.).

Design Support

It will inform analysis in intellectual property, standards, and regulatory requirements. The design support will be assistance of planning, requirements, and specifications. The area of assistance in engineering and architectural will reduce time of creation a sustainable model while increases the productivity.

Wind Pressure

Wind pressure distribution has important aspect in building design. "Wind causes a positive pressure on the windward side and a negative pressure on the leeward side of buildings. Therefore the modeling tools will inform users for wind pressure impacts and prevention from negative impacts. For instances, to equalize pressure, fresh air will enter any windward opening and be exhausted from any leeward opening; in summer, wind is used to supply as much fresh air as possible while in winter, ventilation is normally reduced to levels sufficient to remove excess moisture and pollutants; the wind flow prevails parallel to a building wall rather than perpendicular to it, in this case architectural feature may induce wind ventilation by casement window opens; it is important to avoid barriers between the windward inlets and leeward exhaust openings; and avoid partitions in a room oriented perpendicular to the airflow (GEMCOM Software International Inc., 2011).

III. Program Interface Priorities

i. Interoperability & Integration

Multi-Platform, Parallel Processing

It will able to operate multi-platform, both Windows and Mac. It will integrated with other modeling tools, Excel, Word, etc.

Emerging Technologies & New Processes

Knowledge-based design manuals and some source of information that designers will be used as reference materials for design strategies, new technologies, material properties, cost data and recommended green design strategies. The knowledge-based design guides and searchable databases provide valuable information for designers to consider green design or green building rating for their projects. This feature will save time in research and assist designers toward to appropriate technology or material selection. This feature will be assist designers either in early design stage or in developed design stage.

Interoperability & Collaboration (with Other Tools & with Professions)

Proposed energy simulation software will able to operate with other design tools. For instants, Autodesk Revit Architecture software has interoperability features with the Green Building Studio (GBS) energy simulation tools which also assist designers for possible LEED points. Integration between Autodesk Revit and GBS are allowed to evaluate energy performance in preliminary design stage. Interoperability was highest priority in US DOE workshop. The proposed tool will help designers to capture and analyze concepts and maintain design vision through documentation and construction.

In general, every tool are benefiting environment some way and are attempting to limit influences on the global life cycle. Unfortunately each specialized in one area or one part of the design; but, in eco-design requires collaboration among professions including tools. (Sullivan, 2007) The tools need interact with each other in all aspects in order to improve the quality of a project in a significant way. For instance, LCA is one of the best ways to evaluate building sustainability and is widely accepted in the environmental research community. This complex and time consuming process will incorporate with energy simulation tools. Before the modeling tools LCA has been limited use and there have been only few modeling tools on this important matter in design. On the other hand some developer such as the Athena Institute are developed user-friendly tools increased LCA use (Athena Institute, 2011a). The area of LCA will be more accessible, collaborative, intergraded with design process, if the whole building analysis tools operates with them.

The collaboration feature will allow multiple designer works on the project. Work sharing will give power to the tool. Allowing teams to choose the best way to interact based on their workflow and project requirement or knowledge. For many projects that require more than one designer, each member on the team will assign a specific functional task. This involvement simultaneously will save time and each profession will sign and save different portion of the project. Regardless of design experience and area of the profession such as architects, engineers, policy makers, manufacturers and developers works together and understand design consequences in advance

Tutorials & Online support

The software will provide detailed tutorials before start using for first time user and continue support during creation of the model. It will provide responsive technical support and periodic training sessions will available for upgraded features. The program will support by an on-line help system that explains how to use the program and gives details about information needed to enter data and to perform a simulation. The help system will provide immediate information displayed on the screen.

ii. Customize Features

Customizable Output & Reports

The first, individualize report will present readable and understandable form for the user. The second, the output report will include energy use by month and by year in individual system such as heating, cooling, domestic hot water, mechanical systems, lighting, plug loads, and other sources of electrical consumption. The monthly output helps user for validation for example, If cooling energy rises in the winter, something's probably out of whack. The third, the report will show heating and cooling consumption by building component, telling how much is due to walls, roofs, windows, infiltration, ventilation air, etc. The benefit of the feature is guiding designers to look for the areas where the designs achieve the biggest savings; it will indicate the place where most attention needs it. And the last, the report will provide a table of areas for each building component such as walls, roof, windows, etc. as a quick check on the accuracy of the take-offs (Rosenbaum, n.d.).

3D Spatial Displays

The quick and accurate energy modeling is involve with capturing existing building conditions, therefore it will possible with conversion it into 3 Dimensional models. 3D will present more realistic visualization; will create easy design alternatives; will instantly check impacts; will give additional views and perspective with a rotation; will check for errors that might occur in the drawing process; and will demonstrate best possible use of materials.

Adaptable Interface

It will allow model to transfer stages in the design for instance user may ski transfer model in early design stage to in developed design stage or individual components to whole system.

Simultaneous Solution (Smart Help)

It will incorporate, immediate solution where the model need step-by-step process necessary. The Software will provide a complete end-to-end solution and will allow users to pick-and-choose the right solution for their design.

IV. Program Method & Structure

Expertise Requirement

Due to wizard-based use expertise with energy analysis will not necessary. However knowledge of building technology might helpful for time and accuracy of the evaluation. The tool will emphasize the balance between the ease-of-use and the flexibility for users with different levels of simulation skills and background. This feature will benefit research arena and future architecture and engineering students.

Audience

The primary audience concentrated in building designers, but not only focused on designer operators, manufacturer, owners, energy/LEED consultants, regulatory professionals, universities, and researchers will considered to use the proposed energy simulation tool.

Simple Input Options

Inputs will be providing at three levels: schematic design wizard, design development wizard, and portion of design interface. In the all wizards, inputs have defaults based on the standards or sustainable design guidelines.

APPENDIX D: VISUAL-DOE OUTPUTS

Appendix D contains Visual-DOE outputs results categories by following:

1- Residential model (wood-framed and AAC- wall system) designed by traditional way for southern United States. This model repeated in 15 US cities and 3 Mexican cities in different climate zone without changing any elements in the model. This folder contains 18 simulations for wood-framed and 18 simulations for AAC-wall system.

2- Residential model (wood-framed and AAC- wall, floor, and roof systems) designed by IECC minimum standards in 15 US cities and 3 Mexican cities in different climate zone with required changes in the model. This folder contains 18 simulations for wood-framed and 18 simulations for AAC-whole system.

3- Commercial model (metal-framed and AAC- wall system) designed by traditional way for southern United States. This model repeated in 15 US cities and 3 Mexican cities in different climate zone without changing any elements in the model. This folder contains 18 simulations for metal-framed and 18 simulations for AAC-wall system.

4- Commercial model (metal-framed and AAC- wall, floor, and roof systems) designed by IECC minimum standards in 15 US cities and 3 Mexican cities in different climate zone with required changes in the model. This folder contains 18 simulations for metal-framed and 18 simulations for AAC-whole system.

5- The last folder contains two simulations for LEED Energy and Atmosphere credit 1. These are proposed building performance and baseline building performance. The proposed building performance simulation for AAC whole system and baseline building performance for ASHRAE Standard base case simulation.

This Appendix is available on the UAB Civil Engineering online archive. Please contact Dr. Jason Kirby for access and download instructions.

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