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An Integrated Optimization Approach to Establish Energy Efficiency Recommendations for Residential and Commercial Buildings in Salamanca Mexico

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AN INTEGRATED OPTIMIZATION APPROACH TO ESTABLISH ENERGY EFFICIENCY RECOMMENDATIONS FOR RESIDENTIAL AND COMMERCIAL BUILDINGS IN SALAMANCA MEXICO

by

DANIELLE MARIE GRIEGO

B.S., University of Colorado, 2009

A thesis submitted to the Faculty of the Graduate School of the

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This thesis entitled:
An Integrated Optimization Approach to Establish Energy Efficiency Recommendations for Residential and Commercial Buildings in Salamanca Mexico Written by Danielle Marie Griego
Has been approved for the Department of Civil, Environmental, and Architectural Engineering

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Moncef Krarti Ph.D.

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John Zhai Ph.D.

Date________________

The final copy of this thesis has been examined by the signatories, and we
Find that both the content and the form meet acceptable presentation standards
Of scholarly work in the above mentioned discipline.

ABSTRACT

Griego, Danielle Marie (Masters of Science, Civil, Environmental and Architectural Engineering)

An Integrated Optimization Approach to Establish Energy Efficiency Recommendations for Residential and Commercial Buildings in Salamanca Mexico

Thesis directed by Professor Moncef Krarti

Energy use attributed to buildings accounts for 19% of the total energy consumption in Mexico and is estimated to rapidly increase with future building development. The existing Mexican energy efficiency standards (NOM-ENER) are primarily developed through a component based approach where energy efficiency guidelines are outlined for individual pieces of equipment with no interactions between these components taken into consideration. In this investigation, a holistic and integrative energy analysis approach is considered to improve energy efficiency in residential and commercial office building buildings. Specifically, the study investigates the interactions between various energy efficiency measures and thermal comfort measures for existing and new construction residential and commercial buildings in Salamanca, Guanajuato using detailed simulation and optimization procedures.

The results from the residential optimization analysis suggest a combination of improved appliance efficiencies, increased levels of roof and wall thermal insulation and improved water heating system efficiencies is required to achieve a minimum cost solution which results in nearly 52% annual energy savings for new homes. The commercial office building energy optimization analysis indicates that the greatest potential for energy conservation in both new and existing offices is achieved by reducing office equipment plug loads and more efficient lighting technology and controls. Over 49% annual energy savings is achieved in the retrofit and new construction commercial office building analysis.

DEDICATION PAGE

I would like to extend my gratitude to my mentors who have helped encourage and guide me through my academic and personal endeavors: my mother, sister, grandmother and step-father.

ACKNOWLEGEMENTS

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CHAPTERS

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1 INTRODUCTION

The building energy use in Mexico makes up nearly 19% of the nation's total demand where 16% is from residential energy consumption while only 3% is reported for commercial building energy consumption (SENER, 2010). This makes domestic energy consumption the third largest in the country only behind the transportation and industrial sectors. However, various sources identify that a portion of the industrial energy consumption is actually from commercial building end use because the national utility company, Comision Federal de Electricidad (CFE) categorizes non-residential customers by voltage. Commercial buildings are categorized as low voltage consumers, however many of the service-sector facilities including hospitals, hotels, schools, retail and restaurants are included in the medium industry. Therefore the energy consumption attributed to the commercial building sector is greatly underestimated.

Overall there is a lack of accounting for commercial buildings and building energy consumption in Mexico. Therefore there is less urgency for energy reduction in commercial buildings when compared to residential buildings. This is observed through literature, where there are few rigorous commercial building energy studies. Thus, part of this study aims to open this discussion, which is particularly important for emerging industrialized countries where commercial building development occurs rapidly.

The residential energy consumption in Mexico is steadily increasing. Similarly, the number of homes in Mexico is also rising, between 1996 and 2006 housing units increased from 20.4 million to 26 million where nearly 78% were urban homes as of 2006 (Jorge Alberto Rosas-Flores, 2011). Urban homes also have greater quantities of equipment such as refrigerators, washing machines, televisions, etc. and have subsequently higher annual energy consumption per household (Jorge Alberto Rosas-Flores, 2011). Furthermore it is estimated that the number of housing units will reach nearly 50 million by 2030 (Feng Lui, 2010), emphasizing the importance of implementing energy efficiency measures in both new and existing homes.

Furthermore, the government is also interested in sustainable development and one of their methods of reaching this goal is by improving the standard of living for the lower income bracket in

Mexico. This movement was first initiated by President Vicente Fox in 2000 (Dieck-Assad, 2005). Improving the quality of life for people involves improving access to electricity and natural gas for cooking and heating water in the home. In efforts to increase access to electricity throughout the country, the government assists domestic users by heavily subsidizing electricity costs. In fact nearly US$10 billion was supplied by the government for domestic electricity subsidies in 2006 (Feng Lui, 2010). Although this improves the standard of living for families, such government subsidies do not motivate homeowners to invest in energy efficient equipment. Therefore it is important that this switch to a better quality of life is done efficiently and sustainably.

1.1 Purpose of the Study

The primary objective of this investigation is to apply an integrative optimization methodology to determine the best set of energy efficiency recommendations for residential and commercial buildings in one specific region in Mexico: Salamanca, Guanajuato. The integrative approach used in this study is outlined in Figure 1-1. This investigation aims to address each of the essential components to develop building energy efficiency codes: energy efficiency, market variability, available technology, construction costs, and policy enforcement (DOE Building Energy Code Program, 2010). The energy efficiency component is covered through the energy analysis, while construction costs and market variability are incorporated through the life cycle cost (LCC) analysis and associated sensitivity analyses. Available technology in Mexico is incorporated in the optimization analysis through the selection of appropriate energy efficiency measures (EEMs). Finally, the policy enforcement element is considered by selecting a prescriptive based approach for energy efficiency recommendations.

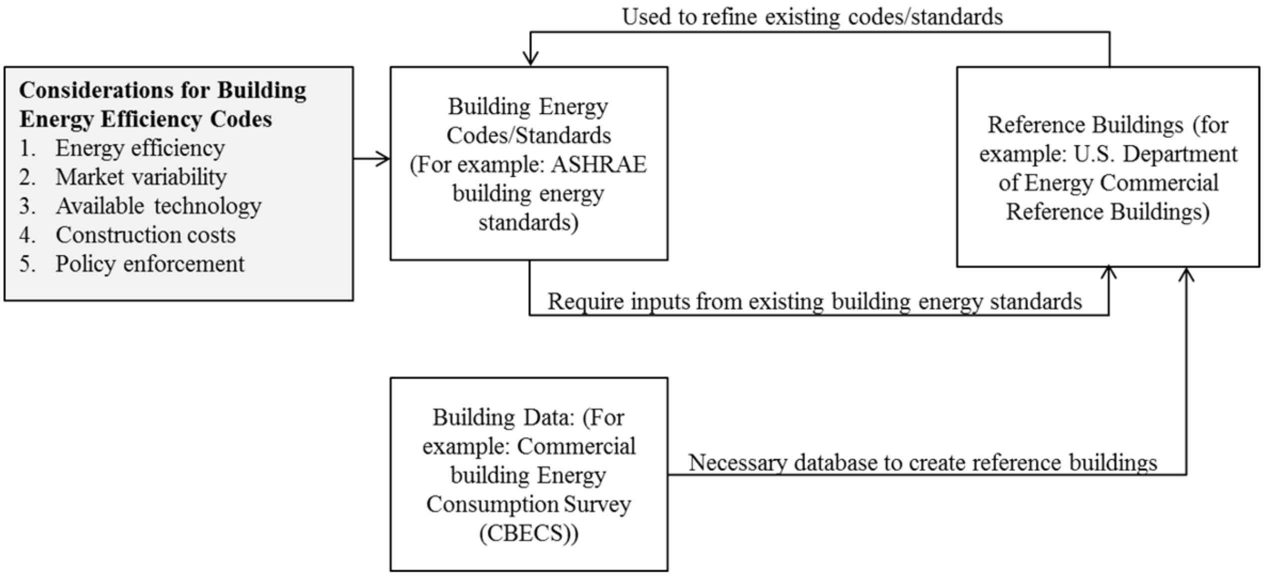


Figure 1-1: Organization of primary goals and objects

The current building energy efficiency codes and standards are mixed between prescriptive and performance based approach. The prescriptive codes are primarily for equipment while the performance based approach is for thermal insulation for commercial buildings. The Prescriptive based approach for equipment and appliances have been very successful (Michael McNeil, 2006). On the other hand, the performance based standards for thermal insulation in commercial buildings has not been widely adopted or enforced (Feng Lui, 2010).

The schematic also illustrates how the primary objectives of this research relate to the broader context of building energy efficiency codes and standards, reference buildings, and building energy data. The development of building energy standards and codes are the first step in addressing energy reduction, for example the first American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) building codes were developed in 1975 and have been updated multiple times since then. The next step is the development of reference buildings which are extremely useful for refining and improving upon the existing building energy codes and standards. The U.S. Department of Energy in collaboration with other national laboratories has developed a series of U.S. reference buildings that represent over 62% of the total U.S. commercial building stock (Michael Deru, 2011). However comprehensive building data is necessary to determine the most representative buildings and their characteristics. The U.S. Department of Energy (DOE) used the Commercial Building Energy Consumption Survey (CBECS) to develop the U.S. reference buildings.

1.2 Scope of the Study

Two different building types are included in the scope of work for this investigation, residential buildings and commercial office buildings. Additionally, each building type is evaluated as a retrofit project and new construction. An optimization analysis is performed for each building type and class of construction to explore the greatest potential for energy savings in each case: retrofit-office building, new construction-office building, retrofit-residential and new construction-residential. Building design recommendations from the current Mexican building energy standards are included in the analysis to verify if they are appropriate for this region of the country. Furthermore this study aims to identify the most common and the most cost effective solutions for energy reduction.

1.2.1 Limitations

There are various limitations encountered throughout the course of this investigation. To begin, here is limited building energy data for the commercial building sector in Mexico and also in Salamanca. This made it challenging to verify if the baseline building energy data is representative of similar buildings. Additionally, the commercial buildings included in the study were selected based on the owners interest to participate and therefore may not be the most representative buildings from Salamanca. However a comprehensive commercial building energy survey for Salamanca is not feasible for the scope of this investigation.

Another challenge encountered for the commercial building study was the limited access to optimization analysis tools specific for commercial buildings. Various optimization tools are currently being developed for commercial buildings but are not yet publicly available. Therefore a manual optimization approach was used for the commercial building study which limits the number of parameters and level of detail. This is in contrast with the residential building optimization analysis which was performed using the supported Building Energy Optimization tool (BEOpt).

There are also limitations surrounding the construction cost estimates because there isn’t a statistically verifiable construction cost estimation database in Mexico.   A reasonable amount of time was dedicated to estimating the capital construction costs for the energy efficiency measures in Mexico. However, greater scrutiny could be dedicated to verifying these costs estimates. Finally, the weather data used in this analysis was not specific for the city of Salamanca because it was not available. Instead the weather data used in the analysis is for the city of Leon.

2 REVIEW OF THE LITERATURE

2.1 National Energy Data

It is important to understand the broad context of the energy resources throughout Mexico because it can greatly affect the country’s political and economic climate. This can also impact the overall government support for energy efficiency, conservation measures and renewable energy production. Mexico relies heavily upon fossil fuel resources to meet their domestic energy needs and also to support a substantial portion of their gross domestic product through oil exports. The two primary fossil fuels found throughout Mexico are oil and natural gas.

The country produces 2.56 million barrels a day (Mbd) of crude oil and exports nearly 1.35 Mbd as of August 2010 (SENER, 2010). However when compared to the last four years, there is a steady decline in the countries oil production and oil exports. In January of 2006, the total oil production was 3.37 Mbd and the total exports were up to 2.05 Mbd (SENER, 2010). When comparing data from 2006 to the present condition, there is a 34% decrease in oil exports and a 24% decrease in oil production.

The remaining oil production is used for domestic consumption, however this should not be used as an indication of the overall National energy consumption. In fact the nation’s energy consumption is rising by nearly 5% each year from 2005 to 2008 (SENER, 2010). Figure 2-1 illustrates that the greatest energy demand is for transportation followed by industrial and residential energy consumption. The transportation energy use is increasing faster than the other sectors. However it should be noted that from 2005 to 2008 the energy consumption in the commercial and residential sectors has risen by 8% and 6% respectively.

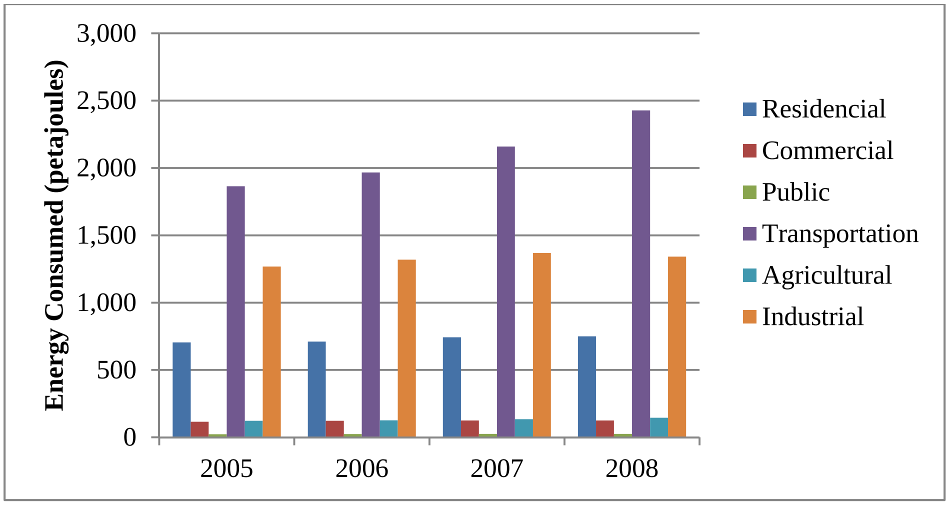


Figure 2-1: Total energy consumption in Mexico by sector (SENER, 2010)

As mentioned previously, the two primary energy sources in Mexico are natural gas and oil. Unlike Oil, only a small fraction of natural gas is exported and in order to meet the energy demand for this source, a large fraction of Natural gas is imported. National natural gas production has had a substantial increase from 2006 to 2009 because the government is increasing the use of natural gas for electricity combustion instead of oil to decrease greenhouse gas emissions related to electricity production with oil combustion (Dieck-Assad, 2005).

As of 2004, the greatest sources of fuel for thermoelectric power generation were fossil fuels which account for nearly 90% of all energy sources (Figure 2-2). Oil accounts for 60% of the total and natural gas accounts for 29% of the total. Taking it a step further it is equally important to understand what process is used for electricity generation. Figure 2-3 gives an overview of the types of electricity power plants used throughout Mexico. It can be seen that combined cycle plants are most prevalent with vapor and hydroelectric following. This figure also shows the renewable energy contribution for electricity generation. Including wind, hydro and geothermal power the total renewable energy amounts to a little over 15% of the total energy generation.

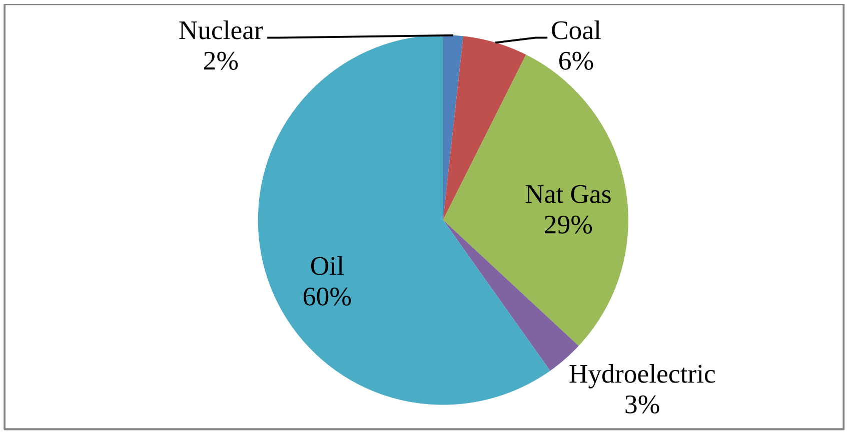


Figure 2-2: Electric consumption by fuel type (BP Statistical Review of World Energy 2004)

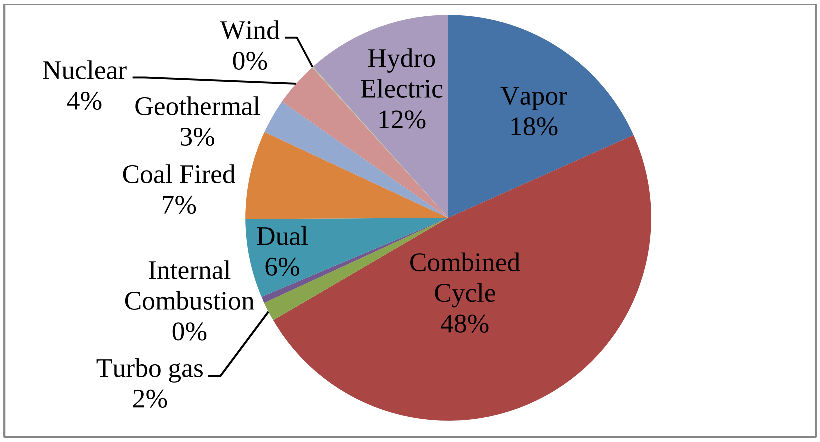


Figure 2-3: Electricity production by process (SENER, 2010)

2.1.1 National Building Energy Information

The building energy consumption in Mexico makes up 19% of the total energy demand as of 2008. It is also useful to understand the energy use by source for each building sector. The total residential and commercial energy consumption by source, from 2008, is illustrated in Figure 2-4 and Figure 2-5 respectively. The quantity of energy used is compared in petajoules (PJ). The dominant energy source in the residential sector is liquid petroleum gas (LPG) followed by wood, electricity and natural gas. LPG is also the largest energy source in commercial buildings and closely followed by electricity use of 39%.

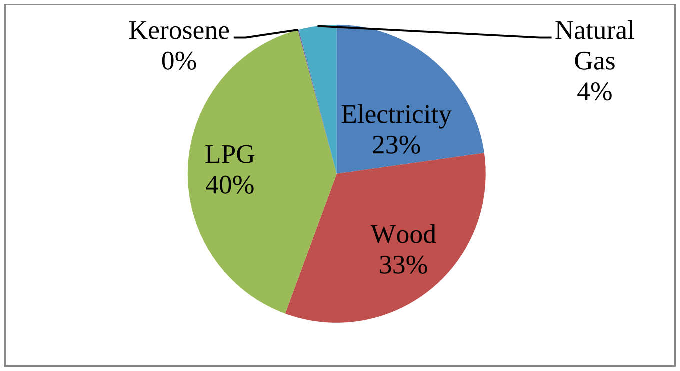


Figure 2-4: Residential Energy End-Use by Source in 2008, measured in PJ (SENER, 2010)

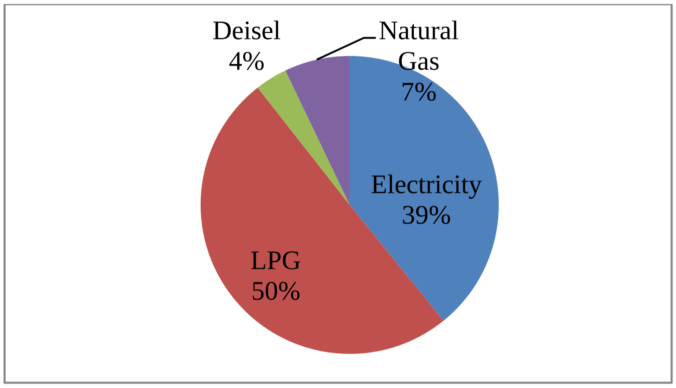


Figure 2-5: Commercial Energy End-Use by Source in 2008, measured in PJ (SENER, 2010)

2.2 Energy Efficiency and Energy Conservation Efforts in Mexico

Along with understanding the current national energy scenario, it is also important to know what organizations are involved in energy efficiency and conservation efforts throughout Mexico. Energy conservation became a focus in the early 1980s when the Universidad Nacional Autonoma de Mexico (UNAM) initiated a graduate energy program with a Permanent Advisory Forum focused on energy efficiency and conservation. The program and advisory forum started with the intent of synthesizing all of the energy related topics throughout the country and developing open communication and collaboration for conservation efforts. Through the development of the forum, other universities began expanding their efforts to address energy efficiency. (Dieck-Assad, 2005)

Today, the federal branch actively involved in national energy topics is the Secretaria de Energia (SENER). This government branch oversees all of the energy policies and regulations in Mexico and has the mission to “ensure energy sources are efficient, of high quality, safe, profitable and environmentally friendly” (SENER, 2010). SENER focuses on the big picture of energy use throughout the country including the sources of energy, means of production, total imports, total exports, domestic sales, etc. This information is organized and regularly updated on the website, Sistema de informacion Energetica (SIE). National energy conservation activities are also catalogued in the database.

2.2.1 Mexican Official Standards for Energy Efficiency (NOM-ENER)

By 1989, the first publicly organized association for energy conservation was developed, the Comisión Nacional de Ahorro de Energía (CONAE, for its acronym in Spanish, National Commission on Energy Savings). As of 2008, CONAE is now referred to as the Comisión Nacional Para el Uso Eficiente de la Energía (CONUEE, for its acronym in Spanish, National Commission for the Efficient Use of Energy) and is now an administrative branch within the Ministry of Energy. This organization has played a substantial role in addressing energy conservation issues nationwide by initiating energy guidelines and restrictions on equipment and appliances, publishing best practice methods for different energy sectors as well as sustaining collaboration between the private and public organizations interested in energy efficiency.

Most notably, CONUEE has developed the Mexican Official Standards for Energy, Norma Oficiales Mexicanas (NOM-ENER), which apply to the public, commercial, residential, industrial and agriculture energy sectors. There are two different energy efficiency standards used throughout Mexico, one is a mandatory standard which are through the NOMs, the Official Mexican Standards. There are also voluntary standards which are called Normas Mexicanas (NMXs), Mexican Standards. Table 2-1 includes a list of the current versions of the mandatory Mexican Official Standards for Energy. The standards highlighted in grey apply to the residential and commercial building energy sectors. Many of the standards address equipment power ratings, lighting standards and construction materials.

Table 2-1: The Mexican Official Standards for Energy use (NOM-ENER in Mexico) (CONUEE, 2010)

Standard	**Description**
NOM-001-ENER-2000	Energy efficiency of vertical turbine pumps with vertical electric outboard motor.
NOM-003-ENER-2000	Thermal efficiency water heaters for domestic and commercial use
NOM-004-ENER-2008	Energy efficient pumps and motors for potable water, power of 0.187 kW to 0.746 kW
NOM-005-ENER-2010	Energy efficiency of household electric clothes washing machines
NOM-006-ENER-1995	Energy efficiency of pumping systems for deep wells
NOM-007-ENER-2004	Energy efficiency of lighting systems in commercial buildings
NOM-008-ENER-2001	Non-residential building envelope R-value recommendations
NOM-009-ENER-1995	Energy efficiency in industrial thermal insulation
NOM-010-ENER-2004	Energy efficiency of submersible deep well motors and pumps
NOM-011-ENER-2006	Energy efficiency of central air conditioners, package or split
NOM-013-ENER-2004	Energy efficiency of roadway lighting systems and public outdoor areas
NOM-014-ENER-2004	Energy efficiency of AC motors, single phase induction squirrel-cage, rated output of 0.180 to 1.500 kW
NOM-015-ENER-2002	Energy efficiency of refrigerators and freezers
NOM-016-ENER-2002	Energy efficiency of AC motors, three phase, induction, squirrel cage type, rated output of 0.746 kW to 373 kW
NOM-017-ENER/SCFI-2008	Energy efficiency guidelines for compact fluorescent lamps
NOM-018-ENER-1997	Characteristics of thermal insulation for buildings
NOM-019-ENER-2009	Thermal and electrical efficiency of mechanical tortilla machines
NOM-021-ENER/SCFI-2008	Energy efficiency of packaged terminal and window AC units
NOM-022-ENER/SCFI-2008	Energy efficiency of commercial refrigeration units
NOM-028-ENER-2010	Phase out incandescent lamps
NMX-C-460-ONNCCE-2009	Residential assembly R-value recommendations

The most recent NOM-ENER will enforce a reduction of incandescent lamps on the market and ultimately eliminate lamps of 40 Watts and higher by 2013. NOM028-ENER-2010 aims to discontinue marketing incandescent lamps of 100 watts or higher by December 2011, 75 watt incandescent lamps by December 2012 and 60-40 watt incandescent lamps by December 2013. (CONUEE, 2010) Another lighting NOM-ENER is the NOM-007-ENER-2004 which provides lighting power density (LPD) recommendations using the building type method or the space by space method similar to the ASHRAE 90.1 lighting standards. This code applies to all non-residential building types for new construction and also to new additions and modifications to existing buildings. The NOM-007-ENER-2004 building area method for LPD recommendations is included in Table 9-5 of Appendix 9.1.

The first building energy efficiency NOM-ENER for construction materials was developed in the late 1990’s through the collaboration between Lawrence Berkeley National Laboratory and CONAE (Yu Joe Huang, 1998). NOM-008-ENER-2001, the building envelope energy efficiency standard for non-residential buildings provides baseline heat transfer coefficients for the walls and roofs, average equivalent temperature (T_{eq}) for all exterior surfaces, along with the solar heat gain factor (FG, for the Spanish acronym, factor de ganancia solar) for windows and skylights for 61 cities in Mexico. The recommendations are based on a performance path compliance method where the conduction heat transfer through all exterior surfaces plus the solar radiation through all exterior windows must be less than the equivalent reference building. The average equivalent temperature (T_{eq}) for each exterior surface and the fenestration solar heat gain factors (FG) are provided for all cities as inputs for the simplified calculation method. Assembly R-values for each of the 61 locations are also provided as part of the optional prescriptive path method. A sample of the NOM-008-ENER-2001 standard is included in Table 9-6 of Appendix 9.2.

The report (Yu Joe Huang, 1998), does not provide specific recommendations for glazing properties for each location. However specific glazing and window properties were used to calculate the fenestration solar heat gain factors (FG). These inputs include fixed 40% total window to wall ratio (WWR), a shading heat gain coefficient (SHGC) of 0.87 and a U-value of 5.319 W/m^2-K (0.94 Btu/h-ft^2-F). The fenestration solar heat gain factors are not specific to each of the 61 cities included in the study due to limited solar radiation weather data. Therefore this data is very limited and non-specific and has a lot of potential for improvement.

Another study (Itha Sánchez Ramos, 2006) reports on the impact of the standards and labeling program in Mexico that first began in 1995 for many appliances and equipment. Four specific products are included in the study: refrigerators, washing machines, motors, and packaged air conditioning units. The study indicates that minimum energy efficiency standards in Mexico have been a great success, significantly reducing energy consumption and related costs. Of the four types of equipment included in the study, the refrigerator standard has the largest total energy savings. From 1995 through 2005 it is estimated that over 29 TWh, 15 TWh, 12.8 TWh and 1.8 TWh was avoided from the refrigerator, air conditioner, motor and clothes washer minimum efficiency standards. The evolution of the NOM-ENER standards for refrigerators and washing machines are included in Table 9-4 of Appendix 9.1.

Furthermore, there are various minimum efficiency performance standards (MEPS) for different cooling and heating equipment types. NOM-011-ENER-2006 states that the minimum SEER value is 13 for all central air conditioning systems including packaged systems and split systems with a nominal cooling capacity of 8,800 W (30,000 Btu/h) to 19,050 W (65,000 Btu/h) (Table 9-7 in Appendix 9.2). NOM-021-ENER/SCFI-2008 provides efficiency standards for packaged terminal and room air conditioning units as shown in Table 9-8 in Appendix 9.2. Finally, the Sello FIDE mandatory labeling efficiency program provides standards for unitary packaged or split-system AC units as shown in Table 9-9 and

Table 9-10 in Appendix 9.2. Many of the equipment efficiency standards are comparable to the ASHRAE 90.1-2007 efficiency levels. However there is limited information on standards for larger central equipment and for operation and control standards for various equipment types and climate regions.

2.2.2 The Federation for Electric Energy Efficiency and Savings (FIDE)

Another important program aimed at encouraging energy efficiency is a joint collaboration between the national electric utility company, CFE and the Fideicomisco para el Ahorro de Energia Electrica (FIDE). FIDE is a voluntary energy labeling program similar to the U.S. Energy Star Program. The program also provides financial assistance and incentives for building owners to invest in energy efficient technology. There have separate assistance methods and requirements for residential and commercial buildings In the commercial sector they support hotels, restaurants, offices, hospitals, department stores, warehouses and schools. They provide financial assistance on the following investments: new air conditioning equipment, T-5 and T-8 fluorescent lamps, high intensity discharge lamps, CFLs, electronic ballasts, occupancy sensors, specular reflector luminaires, demand control systems, automated control systems, chillers, refrigeration equipment, variable frequency drive (VFD) motors and pumps, transformers, thermal insulation and new technologies such as photovoltaic (PV) and light emitting diode (LED) lighting. (FIDE, 2010)

One of the most notable FIDE/CFE conservation efforts is the ILUMEX project started in 1993 where they solicited government funding and additional grants to distribute 1.7 million compact fluorescent lamps in households located within Guadalajara and Monterrey. (Jaime Klapp, 2007) This type of organized financial assistances is imperative for sustainable energy development and provides a realistic opportunity for people to make investments in their homes and in their businesses.

2.2.3 National Housing Commission (CONAVI) and the Residential Building Code (CEV)

Another stakeholder involved in sustainable building development and efficient energy in Mexico is the Comisión Nacional de Vivienda (CONAVI, for its acronym in Spanish, National Commission on Housing), a federal organization responsible for overseeing issues related to the housing sector in Mexico. They are also responsible for issuing the Mexican Official Standards on topics that directly impact housing (CONAVI, 2010). In 2007 CONAVI developed the first edition of a voluntary regulation for residential construction, Código de Edificación de Vivienda (CEV, for its acronym in Spanish, Housing Building Code) and has since been updated in 2010. CONAVI has recently established a system of subsidies for energy conservation where developers are eligible to receive the subsidy if they follow the CEV guidelines (Feng Lui, 2010). Linking financial incentives to residential energy efficiency guidelines is an effective way to mainstream implementation.

The CEV covers all areas of residential construction including water, sewer, structural design, space layout, electrical installation, as well as energy and sustainability (Comisíon Federal de Electricidad, 2010). Many of the energy requirements outlined in the CEV are linked to the corresponding NOM-ENERs and other official standards. These include guidelines for domestic hot water heater minimum efficiencies, solar hot water heaters, minimum air conditioning unit efficiencies when applicable and allowable lighting power densities specific for each building space.

Regarding envelope requirements, the CEV refers to NMX-C-460-ONNCCE-2009 (CONAVI, 2010), a code which specifies recommended thermal resistance values of exterior envelope assemblies for eight climate regions. The climate zone classification, exterior roof and wall insulation recommendations and the window and skylight glazing recommendations from NMX-C460-ONNCCE-2009 are included in Table 9-1, Table 9-2 and Table 9-3 respectively in Appendix 9.1. The CEV also provides general building design recommendations for different climate zones in Mexico; however these climate regions do not correspond with those in the NMX-C-460-ONNCCE-2009. Instead there are ten different climate regions: warm-dry, extreme warm-dry, warm-semi humid, warm-humid, temperate-humid, temperate, temperate-dry, cold-dry, cold and cold-humid.

For each climate region a few examples of cities are specified, but there isn’t a comprehensive list of Mexican cities with their appropriate climate zones. Each zone has a given set of recommendations for building orientation, vegetation, building geometry, type of roof (flat versus inclined), ceiling height, general description of building materials, and if heating, ventilation and air conditioning (HVAC) equipment is required. Although a general set of guidelines exists for different climate zones, a greater level of detail and consistency between the NMX-C-460-ONNCCE-2009 recommendations should be established to ensure better results.

2.2.4 Building Energy Efficiency Case Studies in Mexico

There are also several case studies of energy efficiency projects implemented throughout Mexico. One such program is a lighting retrofit project at UNAM and another is a nationwide effort to encourage the use of CFLs over incandescent lamps. The initiative undertaken at UNAM to replace the existing lighting equipment with new technology was carried out through a collaborative effort between a German consulting firm for economic and ecologic studies, Buro O-quadrat, UNEP/Wuppertal Institute Collaborating Center on Sustainable Consumption and Production, a Mexican consulting firm called Generteck S.A. lead by Professor Alex Ramirez and a group of UNAM students working under Professor Ramirez. It was first observed that nearly 70,000 MWh of electricity is consumed annually for the entire campus. Since the majority of the buildings do not have heating or cooling equipment a substantial portion of the electricity used is assumed to be dedicated to lighting. Therefore this is where the team focused their efforts to reduce energy. (Seifried, 2009)

Four spaces throughout the campus were used as case studies to represent the typical library, classroom, laboratory and foyer. The classroom, laboratory and the foyer were originally using T12 lamps with magnetic ballasts and only utilized very basic on/off control systems. The library used T8 lamps and electronic ballasts and also did not have an advanced form of light control. Each space was retrofitted with high output T5 lamps (T5HO) and dimmable electronic ballasts and compatible daylight control and occupancy sensors.

After testing each of the installed systems compared to the initial energy use, it was reported that the foyer has the greatest electricity savings for lighting of up to 90%, the laboratory saved 65%-75%, the classroom saved 72% and the library saved up to 59%. Since the annual electricity savings are substantially high the payback periods are also relatively short, especially when compared to the life of the establishment and the life of the equipment. The greatest payback period is for the library with a little over 12 years, however the payback period for the foyer is only 1 year and the overall average payback period is 2.5 years. When the team scaled these investments and savings to represent all campus buildings there was a reported investment cost of nearly 14 million US$ but has the potential to save the campus 68 million US$ over the 20 year lifecycle of the equipment. (Seifried, 2009) Although this study indicates the potential energy savings from lighting retrofit measures, the team did not perform a detailed energy audit of the buildings before the assessment. Therefore the annual energy consumption from plug loads may be underestimated while the lighting energy consumption may be overestimated.

Improved lighting efficiency is typically the most economic retrofit measure and can be marketed to a relatively large audience. Thus there is generally greater attention to reduce electricity use related to lighting. For example, a high efficiency lighting program was initiated in 1995 throughout Mexico, the project is commonly referrerd to as the Mexico-Ilumex Project. The project first started in the cities of Guadalajara and Monterray to promote the use and sale of high quality CFLs in the residential sector. By the end of the project in 1998 nearly 2.6 million CFLs were sold in the sates of Jalisco, Nuevo Leon, Colima, Nayarit, Coahuila and Tamaulipas. (Marbek Resource Consultants and Lightstream Energy, 2006)

The project was initiated by CFE with economic support from the Wrold Bank through a Global Environmental Facility (GEF) grant, as well as substantial funds from the Mexican Government and some support from Norway. This became a nationwide initiative which was also successful in raising genergal awarness of the importance of energy efficiency. At the beginning of the project it was very difficult to find CFLs in stores and they were also very expensive, almost 15 US$ in 1995. They now make up much of the available lamp selection in stores and now cost less than $3 USD. Furthermore it is estimated that as of 2004, the Illumex Project contributed a National savings of 1.4 TWh. This case study indicates that in general people are aware of the advantages of conserving energy and know that CFLs are a good way to conserve energy in the home. This also indicates that this technology is readily available in local stores and have a competitive price to conventional incandescent lamps. (Marbek Resource Consultants and Lightstream Energy, 2006)

Furthermore, a series of case studies were performed as part of an energy efficiency campaign established by FIDE and CFE. This information is primarily used as a general guide to see what EEMs have been implemented in existing buildings in Mexico. The document vaguely states the cost and energy savings and does not provide any detailed information on how they arrive at the final savings. Nor do they show the initial annual energy consumption for comparison. One of the case studies is a hotel located in Ensenada, Hotel Paraiso La Palmas. They replaced the low efficiency freezers and refrigerators in the restaurant area with high efficiency appliances. They also replaced the older packaged AC units with high efficiency mini-split air conditioning units. The study estimates energy reduction of 23 kW demand and 79.7 MWh/year for a total annual cost savings of $6,812 USD. The total investment cost for these measures is $25,696 USD. (Esquivel, 2008)

There is limited information from literature that covers energy efficiency in commercial buildings in Mexico. One of the only journal articles related to building energy consumption and energy efficiency in commercial office buildings is titled *Appraisal of thermal performance of a glazed office with a solar control coating: Cases in Mexico and Canada* (M. Gijón-Rivera, 2011). Although this study does not perform an integrated building energy analysis, it provides a recommendation for the most efficient window glazing types for office buildings with large window glazing area in Mexico City. The article also serves as a reference for the energy use intensity (EUI) for an office space. The study considers a 12m x 4m office space and predicts the annual energy consumption of the cooling and heating equipment for that space in response to various glazing types.

The four glazing types investigated in the office glazing study are single pane (transmission=0.78, absorbance=0.15, reflectance=0.07), single pane, low transmissive glazing (transmission=0.15, absorbance=0.69, reflectance=0.16), clear double pane glazing (transmission=0.15, absorbance=0.69, reflectance=0.16) and double pane low transmissive glazing (transmission=0.12, absorbance=0.72, reflectance=0.16). The results of the study indicate that the double pane glazing provides the greatest heating and cooling energy savings. The annual energy consumption for a 516 ft^2 office space is approximately 25 MWh/year for the double pane glazing compared to 41 MWh/year for the single pane glazing. (M. Gijón-Rivera, 2011)

After reviewing numerous sources for energy use in Mexico, no source provides information on reference commercial buildings with an estimated square footage, energy use intensity (EUI), or an approximate number or percentage of buildings in the country. A document written as part of the United Nations Environment Program Sustainable Buildings and Climate Initiative (UNEP SBCI) confirmed that "energy use and built space data on commercial buildings in Mexico is scarce and dispersed" (Odón de Buen R., 2009). None the less, this document attempts to fill in the gaps of information regarding total square footage, EUI, and a breakdown of energy used by source for each of the commercial sectors in Mexico including warehouses, hotels and restaurants, office buildings, wholesale and retail, hospitals, schools, theaters and recreational facilities and other buildings.

Various assumptions were made when developing these values. Since no data exists for energy use intensity for the various building types in Mexico the authors used the building energy consumption from buildings in Canada as a reference for lighting and water heating consumption. The energy use for heating was then assumed to be zero for all buildings in Mexico and the value for space cooling is doubled in all buildings except for schools. Table 2-2 summarizes the information gathered from this report along with their assumptions. Although this source is a good initial reference for commercial building energy use in Mexico it clearly shows the lack of accounting for essential statistical information for research analysis.

Table 2-2: Summary of limited building energy use intensity information

Building Type	Total area (m^2)	m^2/ building	EUI (MJ/ m^2/year)	Total PJ/year	Assumptions
Warehouses	5,000,000	5,000	576	2.88	Only a portion of the total warehouse area is considered for the commercial sector. The total built space for warehouses is 25,500,000 m^2
Hotels and restaurants	12,000,000 (hotels) 2,000,000 (restaurants)	14,000	1373	19.22	Each hotel is estimated to have 39 rooms each with roughly 30m^2 per room including area for the lobby and public spaces
Office buildings	4,600,000	4,600	663	3.05	
Wholesale and retail	15,200,000	15,200	792	12.04	Total area accounts for total sales space from stores, retail, department stores and specialty stores
Theaters and recreational facilities	2,800,000	3,000	1013	2.84	Total area is estimated as 10% of total mall area for movie theaters
Hospitals	6,000,000	6,000	1483	8.90	There are 4300 hospitals in Mexico and a total of 120,000 beds; its assumed that 50 m^2/bed
Schools	121,000,000	121,000	660	79.86	The Ministry of Education estimate 242,000 schools in Mexico, 500 m^2 is assumed for each school
Other buildings	110,000	No Data	768	0.08	Considers all small businesses

Overall, this article illustrates that there is an interest to improve the current building energy standards and codes in Mexico. They are also aware of the issues that need to be addressed in order to overcome such barriers. The author states that one of the medium term goals should be to

> implement surveys and detailed audits by building types and climatic regions in order to identify energy end-use by technology and intensities. This work is to supplement the efforts done in the short term and would help to improve the design of programs in the sector and should be done for both the residential and commercial sectors. (Odón de Buen R., 2009)

Although this source is a good initial reference for commercial and residential buildings in Mexico it clearly shows the lack of accounting for essential statistical information for research analysis. It further emphasizes the importance of using actual building data for the case studies in this research. Therefore the intention of this investigation is to increase the body of knowledge for building energy use through detailed energy assessments in one specific climate region in Mexico

3 METHODOLOGY

The methodologies used in this study are tailored to each building type and should be considered as independent studies. Also note that the intent is not to compare the commercial building methodology to the residential methodology. Each methodology is adapted to the available building data and available building energy optimization tools. Since there is limited commercial building energy data available in Mexico and even less information specific to Salamanca, the first step in this investigation is to collect information from various commercial building types in Salamanca. Although there is more building energy data available for residential buildings in Mexico it is also important to collect residential building data to verify the building characteristics and annual energy consumption for homes in Salamanca.

In order to collect this data, two site visits were made to Salamanca Mexico. The first trip was from November 21, 2011 through November 27, 2010 and the second was from February 20, 2011 through March 3, 2011. Building energy data from three buildings was collected during the first site visit, one home, the existing Mayor´s office building and the new city hall office building which was in the final stages of construction. Several building energy assessments were performed during the second trip to Salamanca including four residential buildings, a bakery-café, a middle school, a small automotive manufacturing site, and multiple administration buildings located within the thermoelectric plant CFE. A summary of information from each commercial building is included in Table 9-17 of Appendix 9.4.

As a brief background, Salamanca is located in the southwest region of the state of Guanajuato. The state of Guanajuato is centrally located in the country. The elevation in the city is 1720 m above sea level and is considered to have a temperate climate where the temperatures reach highs of 30-35°C in May and reach a low of 0-5°C in the winter months. The average temperature is however maintained between 15-20°C.

3.1 Selecting Appropriate Baseline Buildings

The baseline for the commercial building is selected differently from the residential building based on available data. The residential baseline is developed for a typical home using data collected from five residential energy audits performed throughout Salamanca. This methodology provides an average for building schedules, loads, occupancy and annual energy use instead of using one specific home as the baseline. Other building characteristics are consistent for nearly all homes in Salamanca including the construction materials, most are not conditioned and they use both electricity and LPG as energy sources.

Selecting the baseline commercial building is slightly more challenging. It is highlighted in the literature review that one of the greatest limitations for commercial sector is the limited building data. This made it particularly challenging to determine the area of greatest need within the commercial building sector. Therefore building energy data was collected from several different building types during the site visits to Salamanca Mexico. The building types include administrative offices, a small mechanical industrial site, a middle school and a café/bakery. Table 3-1 summarizes the annual energy use for each building.

The building with the highest annual energy use intensity (EUI) is the Mayor’s office building with 31.3kBtu/ft^2/year. The café has the second greatest EUI of 28.0Btu/ft^2/year however the natural gas utility data was not available. Therefore the EUI is likely an underestimate since the large stoves in the bakery use natural gas. The middle school has the smallest EUI of a meager 1.8Btu/ft^2/year. Additionally, the new mayor’s office building just opened and did not have annual utility data so it was not considered for the reference building. Similarly, the administrative office buildings at the thermoelectric plant CFE were not used as baseline buildings because CFE does not meter on-site building electricity consumption. This comparison shows that the greatest potential for improvement is in the Mayor’s office building and therefore it was decided to focus on office buildings, using the Mayor’s office as a baseline.

Table 3-1: Commercial building energy data from Salamanca, Mexico

Building	Mayor's Office	Middle School	Café and Bakery	10 CFE Office Buildings	New City Hall	Mechanic Shop
Building area (ft^2)	13,730	5,035	4,626	600 ft^2 -6000 ft^2	31,375	12,146 (enclosed)
Energy sources	Electricity	Electricity, LPG	Electricity, natural gas	Electricity	Electricity	Electricity, LPG
Electric tariff	Low voltage Commercial	Low voltage Commercial	Low voltage Commercial	NA; do not meter electricity	Low voltage Commercial	High voltage industrial
Annual electricity use, 2010 (kWh)	126,080	1,912	37,987	NA	NA, not occupied yet	79,360
Annual gas use, 2010 (kBtu)	0	2,693	No data	NA	NA	3,078
Energy use intensity (kBtu/ft^2/year)	31.3	1.8	28.0	NA	NA	22.5

Reference buildings are typically developed with much greater stringency due to better availability of data and through collaboration between experts in the building energy field. For example, the U.S. Department of Energy partnered with the National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL), and Pacific Northwest National Laboratory (PNNL) to create a set of reference buildings to represent the most common commercial building types throughout the United States. These buildings include 16 different building types in 16 different locations to cover the most standard climate types in the U.S. Data from the Commercial Building Energy Consumption Survey (CBECS) was used to select the building types and characteristics. Additional information from ASHRAE 90.1, ASHRAE 62.1 and other building energy literature was used to help define the standard building characteristics, system types, schedules, etc. (Michael Deru, 2011)

3.1.1 Existing Buildings and New Construction

This investigation explores the potential energy savings for existing buildings and new construction. A detailed assessment of existing building energy consumption and typical building characteristics are applied to the new construction building as applicable. This is particularly useful for the commercial office building where there is limited available data. The information from the baseline buildings are also used to develop the new construction reference buildings. Furthermore, this study aims to expand upon the recommendations in the existing NOM-ENER standards for new construction along with existing buildings. This is similar to the standards in ASHRAE 90.01 which includes new construction, additions to existing buildings and alterations of existing buildings.

3.2 Analysis Tools and Optimization Procedures

The most effective way of determining the best set of energy efficiency recommendations is through optimization analysis because it explores numerous combinations of EEMs. This methodology also considers the life cycle cost of implementing each measure, which is critical when evaluating appropriate technology for a given application.

3.2.1 Residential Building Optimization Analysis

A detailed optimization tool developed through NREL, Building Energy Optimization (BEOptE+) with Energyplus is used to estimate the annual energy savings from various combinations of energy efficiency measures and thermal comfort measures. Thousands of combinations of measures are evaluated through a sequential search method in order to arrive at the optimum set of recommendations based on the greatest percent source energy savings per year and the minimum annualized energy related costs. The Energyplus version of BEOpt is used in this analysis because of the capabilities of including thermal comfort in the final assessment, which is critical when considering unconditioned buildings.

As part of the residential analysis, thermal comfort is assessed for specific combinations of measures using the Fanger comfort model to estimate the predicted mean vote (PMV) for each hour of the year. Along with the PMV thermal comfort analysis, a parallel energy analysis is performed on the reference home with a heating and air conditioning system. The concomitant studies correlate thermal comfort improvements with cost savings and energy savings. This methodology associates improved thermal comfort in the unconditioned reference home with the cost savings in the conditioned reference home. The ultimate goal is to find an optimum set of recommendations which passively improves the thermal comfort level of the unconditioned case to match the acceptable thermal comfort levels of the conditioned case.

The Fanger Comfort model is used in this analysis to estimate the PMV for each hour of the year. PMV is calculated using an energy balance equation which accounts for various energy losses from the human body. Such means of heat transfer include the body's convective heat loss and radiation heat loss as it varies with clothing level, the heat transfer between the outer surface of the clothing and the surface of the skin, heat losses induced by sweat evaporation and respiration heat losses. The surface temperature of the skin is estimated by applying all associated heat losses, which require hourly input information for the activity level of the people, the ambient air temperature, the clothing level, the space air velocity and the work efficiency of the body (ASHRAE, 2009). Table 3-2 includes a list of model inputs for the PMV thermal comfort model used in this study.

Table 3-2: Thermal comfort model inputs

Model	Activity level	Work efficiency	Clothing insulation level	Space air velocity
Fanger PMV	112 W/person (low-medium activity level)	0 (all of the energy produced in the body is converted to heat)	Sept 1-Feb 15, clo=1 Feb 16-Aug 31, clo=0.75	0.0034 m/s

Other thermal comfort models exist, however the Fanger Comfort model is used in this study because it is the most widely adopted. The activity level affects the bodies calculated metabolic rate where the lower the number, the lower the activity level. For example an activity level of 72 W/person corresponds with the metabolic activity of sleeping while 171-207 W/person corresponds with cooking (ASHRAE, 2009). In order to cover a wide range of activities a low to medium activity level of 112 W/person is used for this analysis. Next the work efficiency of the body was chosen to be zero, to represent that all of the energy produced by the body is converted to heat. The clothing level is scheduled to vary seasonally with a clothing (clo) value of 1 for the cooler season to represent pants and a long sleeve shirt. The clothing level during the warmer months is 0.75 which represents pants and a short sleeve shirt. Finally the interior space velocity is estimated to be relatively low with a value 0.0034 m/s.

The scale for the PMV Fanger Comfort model used in this study is based on a scale from -4 to 4. Values between -1 and 1 correspond with good thermal comfort, while values below -1 correspond with feeling cold and values above 1 are associated with feeling warm. (LBNL, 2010) A PMV rating is given for every hour of the year, where it is recommended in Appendix G of the ASHRAE 90.1 guidelines to maintain less than 300 hours outside of the comfort range ±1 PMV.

3.2.2 Manual Optimization Approach for Commercial Office Buildings

The building energy analysis tool used for the commercial office application is the DOE-2 software, eQUEST 3-64. An eQUEST based batch processing tool is used to organize and run the numerous simulations required for the manual optimization. This tool is called Model Manager and was developed by Ellen Franconi at Rocky Mountain Institute (RMI). eQUEST was also selected as the simulation tool for the commercial buildings because the existing office building and new construction buildings are both conditioned and therefore do not require the thermal comfort PMV analysis used in the residential case.

All necessary analysis features needed for the optimization analysis are available in eQUEST including delayed thermal conduction for thermal mass buildings. Furthermore, there are no readily available optimization tools for commercial building applications. Therefore a manual optimization using simplified building energy software was the most appropriate method to estimate cost and energy savings in the commercial buildings. The manual optimization considers the same sequential search technique used in BEOpt. Other optimization methods such as the brute force method, genetic algorithm method and particle swarm were not feasible for the scope of work.

The manual optimization used for the commercial buildings follows the basic principle of the sequential search technique from BEOpt. First, each measure is evaluated from the baseline condition. The EEM with the steepest negative slope relative to the baseline is selected, where the life cycle cost is on the y-axis and percent annual energy savings on the x-axis. That selected point becomes the next reference value, where each EEM is applied individually to that case to find the next EEM with the steepest slope relative to that point. This process is repeated until no further energy savings are accomplished through the various combinations of EEMs. Note also that during the manual optimization, if a preceding iteration has a larger slope than the new combination of measures, it is selected as the new reference point. The two primary sequential search techniques used in the manual optimization are illustrated in Figure 3-1 below (Images from BEOpt 1.1 Help guide).

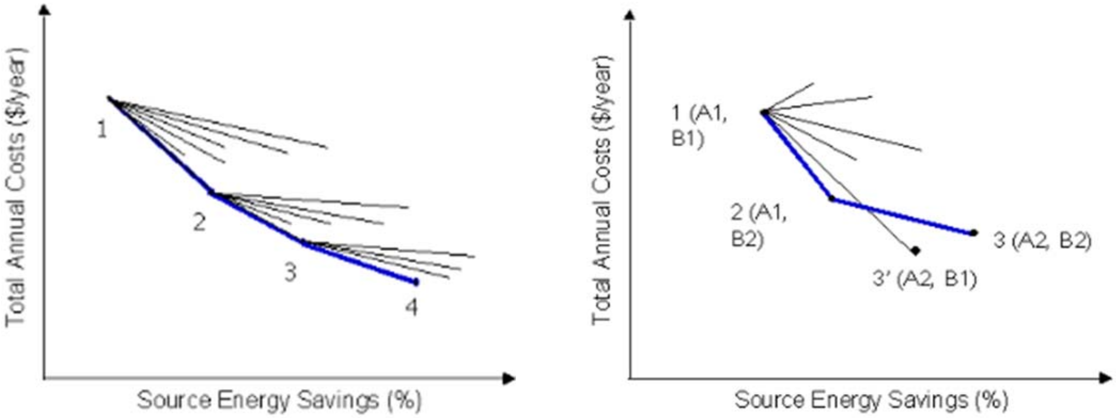


Figure 3-1: Sequential search methods from BEOpt used in the manual optimization

Additionally, each point represents a unique combination of EEMs and a manual optimization allows for greater control and evaluation at each point. There are however limitations when performing a manual optimization when compared to the actual BEOpt tool. The first assumption for the manual optimization is that once a measure is selected at each incremental step, those measures are assumed to stay in the building unless the scenario represented by Figure 3-1 (right) occurs.

3.3 Life Cycle Cost Analysis

An important component of the optimization analysis is the life cycle cost analysis which considers the energy associated with operation as well as the initial cost of the measure(s). The residential building and the commercial building both incorporate the LCC outlined in Equation 1 through Equation 3. The residential buildings present the LCC as an annualized energy cost which also includes the incremental cost of replacement and maintenance within the lifetime of the project.

$$LCC = IC + AC * USPW(r_d, N) \qquad \text{(Equation 1)}$$

$$USPW = \frac{1-(1+r_d)^{-N}}{r_d} \qquad \text{(Equation 2)}$$

$$r_d = \frac{r_{int}-r_{inf}}{1+r_{inf}} \qquad \text{(Equation 3)}$$

The lifetime of the project (N) for the office buildings and residential building analysis is initially estimated at 20 years and 30 years respectively. The inflation rate (r_{inf}) and the interest rate (r_{int}) in Mexico are estimated at 4.2% and 4.9% respectively for 2010 (OECD, 2010). This yields a discount rate (r_d) of 0.67%. Although these values are considered for the base case, additional sensitivity analysis for the discount rate and project life are included to estimate the impact of varying these parameters. Additionally, note that the exchange rate used throughout this study is 12.12 Mexican pesos to 1 U.S. dollar (Department of the Treasury, 2011).

The residential electricity sales are subsidized by the government using a three tier price adjustment where the utility costs also vary by location and by season. BEOpt considers the cost of electricity using a single utility rate and therefore the average utility cost was estimated utility data from each home included in the study. The three tier utility structure used in this analysis is shown below in Table 3-3 using data from the national electric utility company (Comisíon Federal de Electricidad, 2010). The base rate average costs per billing term in 2010 are 0.058 US$/kWh for the first 150 kWh the second tier is 0.096 US$/kWh for the next 100 kWh and the final price nearly doubles to 0.20 US$/kWh for additional consumption. Note that each billing term for the residential sector in Mexico is two months. The utility rate is approximated at 0.10 US$/kWh using this tree-tier scale for each of the five homes included in the residential study.

Table 3-3: Residential electricity 3-tier utility costs

	Average cost in 2010 (US$/kWh)
Base rate (first 150 kWh/bill)	0.058
Intermediate rate (next 100 kWh/bill)	0.096
Additional (above 250 kWh/bill)	0.203

The most common fuel source used in residential buildings in Mexico and in Salamanca is liquid petroleum gas. It is most common for families to purchase 30 kg tanks of gas as needed. Since LPG is sold by weight and volume, the energy content is estimated using the heating value of 84950 Btu/gal (22441 Btu/L) (DOE, 2010). The density of LPG is also approximated at 0.6 kg/L (Turner, 2005). The price of LPG is extracted from the receipts saved by several of the home owners in Salamanca. The average cost of LPG sold in 30 kg tanks is 0.47US$/L. This price is validated using the cost of LPG sold by the liter. One of the homes has a 300 liter permanent tank and the receipts show a price per liter, which is averaged at 0.43 US$/L. The commercial office building evaluated in this study does not use LPG or any other gas source.

The cost of electricity in the commercial sector is typically not subsidized by the government and is billed monthly rather than every two months for residential customers. The Mayor’s office building is in Tariff 2- Commercial and also follows a three-tier utility rate structure. The prices in each tier vary slightly from month to month, depending on the season where the summer months typically have a higher cost. The average cost for 2010 are 0.16 US$/kwh in the first tier (the first 50 kWh), 0.196 US$/kWh in the second tier for consumption above 50 kWh and up to 100 kWh and the third tier is 0.215 US$/kWh for consumption above 100 kWh. There is also a monthly fixed charge of $3.97 for this tariff. These rates are averaged based on data from the national utility company (Comisíon Federal de Electricidad, 2010).

The commercial utility rates provided by Comisíon Federal de Electricidad online were not consistent with the monthly costs provided by the facilities manager from the Mayor´s office building. The utility data for the Mayor’s office building shows an average rate of 0.165 US$/kWh. This utility rate is used in the commercial building analysis for consistency. However future work may include a comparison between the two, because clearly the three tier utility rate structure will yield greater potential for return on investment.

3.3.1 Capital Construction Cost Estimates

Since the life cycle cost analysis is such an integral part of the optimization analysis it is critical to use capital cost estimates that represent the prices of goods and services specific to Mexico. Therefore original cost estimates were obtained from a Mexican construction cost estimation company, Varela. The database of cost estimates is from a software program M2 which was developed and regularly updated by the consulting firm Varela (Varela Ingenieria de Costos, 2011). Although the construction cost estimate database initially seemed useful it lacks a significant level of detail to determine the estimates for high efficiency equipment. Furthermore, the cost estimates given in the database are not disaggregated by material costs and labor costs, where it is unclear if the total cost includes labor or just material costs. Some descriptions state that labor is included in the cost estimate, but not all. Overall the data given in the software is highly unorganized and the descriptions lack a sufficient level of detail to confidently estimate costs for the energy efficiency measures recommended in the analysis. Additionally, the database does not provide information on more advanced energy conservation technology such as dimming ballasts, high efficiency appliances and equipment and occupancy sensors.

For consistency and accuracy, construction cost estimates from RSMeans (R.S. Means Company, Philip Waier, 2011) are used in the economic analysis with several adjustment factors to make it more appropriate for the Mexican construction industry. This eliminates the confusion and potential error of using cost estimates from the M2 construction database for some measures and RSMeans for others. First, an adjustment factor to account for the different construction labor rates is applied to the RSMeans labor cost estimate. Table 3-4 indicates that the labor compensation per employee per hour for construction in Mexico is only 19% of the American construction hourly wage in 2009 when compared in US$ purchasing power parity (OECD, 2009).

Table 3-4: Labor rates in Mexico and the U.S.

Country	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Mexico	5.1	5.2	4.9	5.0	5.6	5.9	6.1	6.1	6.4	6.1
US	22.3	23.2	23.7	24.6	24.9	25.9	26.6	28.6	30.3	31.6
% of US labor rate	23%	22%	21%	20%	22%	23%	23%	21%	21%	19%

The construction material costs are assumed to be the same as in Mexico as in the US and the labor cost are adjusted at 19% of the US labor cost indicated in RSMeans. This is supported by comparing some of the known prices for basic materials from the available data from the M2 database and cost estimate from RSMeans. Most of the material price estimates from the M2 database and RSMeans are within ±12% with the exception of the thermal insulation material cost estimate (Table 3-5). It should however be noted that the M2 database has very limited information on thermal insulation materials and it is likely that this is not representative.

Table 3-5: Material cost comparison between US and Mexican estimates

Description	**Unit**	**M2 Material cost per unit (US$)**	**RSMeans Material cost per unit (US$)**	**% difference**
Glass skylight with aluminum frame	m^2	532.72	602.4704	12%
Acrylic lens 2'x2', 2-U32Watt T8 lamps	ea	85.56	80	-7%
Troffer parabolic lay-in, 2'x4', 3-32W T8 lamps	ea	120.56	125	4%
Fiberglass, 2" thick, R-8.3	m^2	3.90	6.885376	43%
Packaged Terminal Air-conditioners, 12,000 Btu/h cooling	ea	855.43	895	4%
Single hung 2'-8"x 6'-8" opening, standard glazing	ea	314.99	350	10%
Refrigerator, no frost, 10 CF to 12 CF	ea	436.25	415	-5%
Gas fired residential	ea	587.29	635	8%
Reinforced Brick Walls, 4", 1 Wythe, #4@48" reinforcement	m^2	51.93	52.71616	1%

The RSMeans Costworks Repair and Remodeling book (R.S. Means Company, Edward Wetherill, 2002) was referenced to find adjustments factors to apply to the new construction cost estimates in the reference books. Four primary cost adjustment factors for retrofit construction were used in the analysis including the cut and patch work, additional equipment usage, protection of existing work, and temporary shoring and bracing for masonry retrofit projects. The average between the minimum and the maximum cost adjustment factors were used for the adjustment factors in this study and are shown below in Table 3-6.

Table 3-6: Repair and remodeling cost adjustment factors

Cost adjustment factors	**Material**	**Labor**
Cut & Patch to match existing construction, add	4%	6%
Equipment usage curtailment, add	2%	6%
Protection of existing work, add	4%	5%
Temporary shoring and bracing, add (For masonry)	4%	9%

4 RESIDENTIAL BUILDING ANALYSIS

The residential optimization analysis is performed on an existing home and new construction prototype. The reference home is established using data collected from five residential energy audits performed throughout Salamanca. Energy consumption, construction materials, occupancy, building geometry and building area are compared to previous residential energy studies performed in Mexico to validate the model inputs and annual energy end-use consumption. The indoor air temperature of the model is also validated using measured indoor air temperature data monitored in representative homes included in the study.

4.1 Reference Home Building Energy Model

The building characteristics for the existing building analysis and the new construction residential analysis are identical. However the two cases are evaluated separately because the EEMs and the associated costs differ between the two scenarios. This is also done in order to provide two sets of recommendations, for current home owners and for new development. Furthermore, each case is evaluated as an unconditioned home and a conditioned home. Aside from the use of a unit heat pump, the building characteristics for the conditioned model are the same as the unconditioned model.

4.1.1 Reference Home Characteristics: Model Inputs and Assumptions

Characteristics of a representative home in Salamanca are defined using data collected during site visits to five homes in the region. During the site visits a wide range of information was collected including, building construction materials, building area, two years of utility data, occupancy schedules, appliance information, and reported thermal comfort levels. A summary of the data collected from the five homes is outlined in Table 4-1.

Table 4-1. Housing characteristic for collected data and Toluca reference home

Home characteristic	**Home 1**	**Home 2**	**Home 3**	**Home 4**	**Home 5**	**Salamanca reference home**	**Toluca social housing**	**Toluca medium housing**
Occupants per home	4	2	5	3	3	4.1	4.2	4.2
Building area (m^2)	128	71	132	211	400	110	68	108
Number of bedrooms/ bathrooms	3/1	2/1	3/2	3/2	3/3	3/2	3/1	3/2
Average annual LPG consumption (MJ)	6010	14423	21634	21634	24411	17622	10500	22300
Annual electricity consumption (kWh)	1807	1269	2587	2085	3347	1962	611	2166
Refrigerator (kWh/year)	429	473	487	360	578	465	222	764
Washing machine (kWh/year)	110	115	200	120	118	133		
Plug load (kWh/year)	515	276	1026	328	1205	536		
Lighting (kWh/year)	753	405	874	1278	1446	827	333	1402

The data in Table 4-1 related to annual energy consumption for homes 1 through 5 is estimated based on utility data, the rated annual energy use given on the NOM appliance plaque and reported occupancy consumption. Liquid petroleum gas is the most common gas fuel source used for domestic hot water and cooking needs in Salamanca. Typically, families have 30 kg tanks delivered to their homes as needed. Some families also have larger, permanent, LPG tanks that are filled as needed. The annual LPG consumption for home 1 is taken directly from the receipts provided by the family; this family was very conservative with their resources and purchases one 30 kg tank of LPG every other month. The family from home 2 reported buying one 30 kg tank every month while the families from home 3 and 4 noted that they use approximately one and a half 30 kg tanks of LPG every month. The family from home 5 has 300 liter tank of LPG that they fill as needed; the receipts from the last two years are used as a baseline for annual energy consumption.

The annual electricity consumption is an average of the two year utility data specific to each home. The refrigerator annual electricity consumption is directly from each homes refrigerator NOM-015-NER-2002 energy rating. Homes 1 and 2 have washing machine NOM-005-ENER-2010 energy rating data which specifically provides the estimated annual energy consumption, while the consumption in the other homes are estimated based on reported loads/week from site visits. The lighting energy use is specific to each home, where the number and wattage of regularly used lamps were recorded during each residential site. The annual energy consumption is calculated based on 6 hours a day usage. Finally, the plug load is calculated as the difference between all known loads and the total annual energy use.

The Salamanca reference home annual energy consumption for large appliance loads and annual gas use are estimated by averaging the data from homes 1-5 in order to get a large range of equipment types and operational schedules. The plug loads and the lighting loads from homes 1-4 are averaged to estimate these loads in the reference home. Home 5 is from an upper income family and therefore the lighting and miscellaneous equipment consumption is not included in the average for the reference home consumption.

The Salamanca reference home developed for this study is compared to reference homes defined in a previous residential energy study, which quantifies the total embodied energy of residential homes in Toluca Mexico. The study includes three types of homes found in Toluca, social housing for low income families, medium income level housing and traditional style homes. The traditional style home is much different than the medium and low level homes and was therefore excluded from the comparison for this study. Table 4-1 also includes the characteristics of the typical social and medium level homes in Toluca. It can be seen that the Salamanca reference home is most similar to the Toluca medium level housing regarding building area, number of occupants, number of bedrooms and bathrooms, as well as annual electricity and LPG consumption. Additionally, it is common that homes in Salamanca and Toluca do not have heating or cooling equipment. Thus the total electricity consumption is from large appliances, plug loads and lighting while the total LPG use is from domestic hot water (DHW) and cooking. It is also relevant to note that Toluca is located approximately 300 km southeast of Salamanca and sits at an altitude of 2,680 m above sea level. The higher elevation brings cooler annual average temperatures, characterizing Toluca as cool climate (Comisíon Federal de Electricidad, 2010).

During the site visits it was observed that the construction materials for all five homes are nearly identical. Figure 4-1 shows the construction details from several houses included in the study to show the construction materials of the typical home in Salamanca. It should be noted that the construction materials for the homes in Salamanca are also very similar to those found in Toluca study.

(a) (b)

(c) (d)

Figure 4-1: Construction materials observed during residential site visits

The windows are clear, single pane glazing with an aluminum frame. Walls are comprised of reinforced concrete columns, single wythe red clay brick with a stucco/concrete exterior finish and a cement plaster interior finish as seen in images (b), (c) and (d) of Figure 4-1. Roofs are reinforced concrete slabs with a medium or light color impermeable asphalt finish while floors are typically slab on grade concrete with a tile finish. Table 4-2 shows the material properties used as inputs for the reference home model along with the final assembly R-values.

Table 4-2: Construction material properties (ASHRAE, 2009)

Construction	Layer	Density (lbm/ft^3)	Specific heat (Btu /lbm-F)	Conductivity (Btu-in/hr-ft-F)	Thickness (in)	R-value (hr-ft-F/Btu)	Additional information
Wall	Fire clay brick	120	0.2	6	4	1.09	
	Cement plaster interior finish	116	0.2	5	1		
	Stucco exterior finish	80	0.2	4.5	1		a=0.75, e=0.9
Roof	Concrete slab	140	0.2	9	6	0.989	
	Cement plaster ceiling finish	116	0.2	5	1		
	Asphalt exterior finish	70	0.4	1.128	0.37		a=0.8, e=0.91
Ground floor	Exterior layer	2.5	0.3	0.286	1	6.6	
	Soil layer	115	0.1	12	12		
	Concrete slab	140	0.2	9	6		
Second floor	Concrete slab	140	0.2	9	6	946.3	Modelled as adiabatic
	Cement plaster ceiling finish	116	0.2	5	1		

The construction materials observed during the site visit are supported by a regional database, Instituto Nacional de Estadística y Geografía (INEGI for its acronym in Spanish, National Institute for Statistics and Geography), which states that as of 2000, 88% homes in Guanajuato have brick and concrete walls, 71% of homes have a concrete slab or flat brick roof and 53% of the homes have a concrete foundation (INEGI, 2010). The Codigo de Edificacion de Vivienda (CEV for its acronym in Spanish, Residential Building Code) confirms that the most common residential construction type throughout Mexico is structural brick construction as illustrated in Figure 4-2 below.

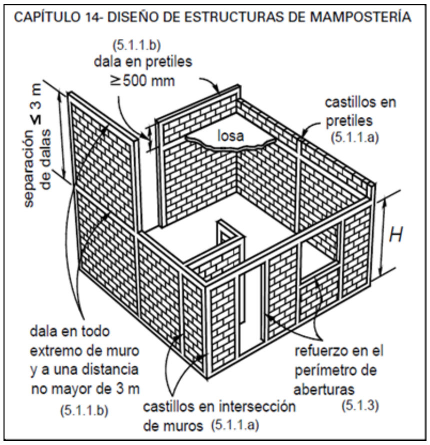


Figure 4-2: Brick construction design (Comisión Nacional de Vivienda, 2010)

Along with the basic building characteristics outlined above, additional details were required to create the baseline residential energy model. Refer to Table 9-11 Appendix 9.3 for a comprehensive list of model inputs used for the conditioned and the unconditioned baseline building energy models. The home is two stories tall where each level is 20 feet by 30 feet. An image of the building model used for each of the four cases is shown below in Figure 4-3.

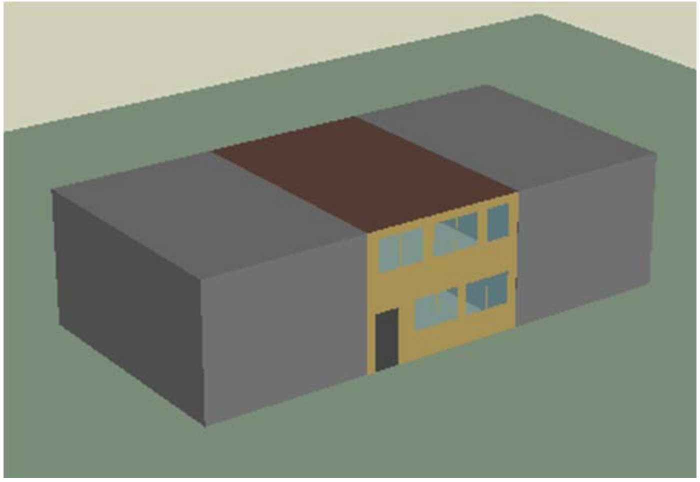


Figure 4-3: Residential building energy model

The validated reference home is modeled as unconditioned and is used as the baseline for the conditioned reference home where the only difference between the two models is the HVAC equipment and associated thermostat temperature set points. A previous residential energy study for Mexican homes (Jorge Alberto Rosas-Flores, 2011) indicates that electricity is used as the source for both heating and cooling systems. Therefore the conditioned models use a heat pump to supply both heating and cooling. NOM-011-ENER-2006, the official standard for air conditioning units specifies a minimum seasonal energy efficiency ratio (SEER) of 13. The corresponding heating seasonal performance factor (HSPF) for this system in BEOptE+ is given at 8.1. Additionally, the heating and cooling temperature setpoints are modeled conservatively as to not overestimate the annual energy costs associated with the heating and cooling system. The heating setpoint is modeled at 20°C (68°F) and the cooling setpoint is 24°C (75°F).

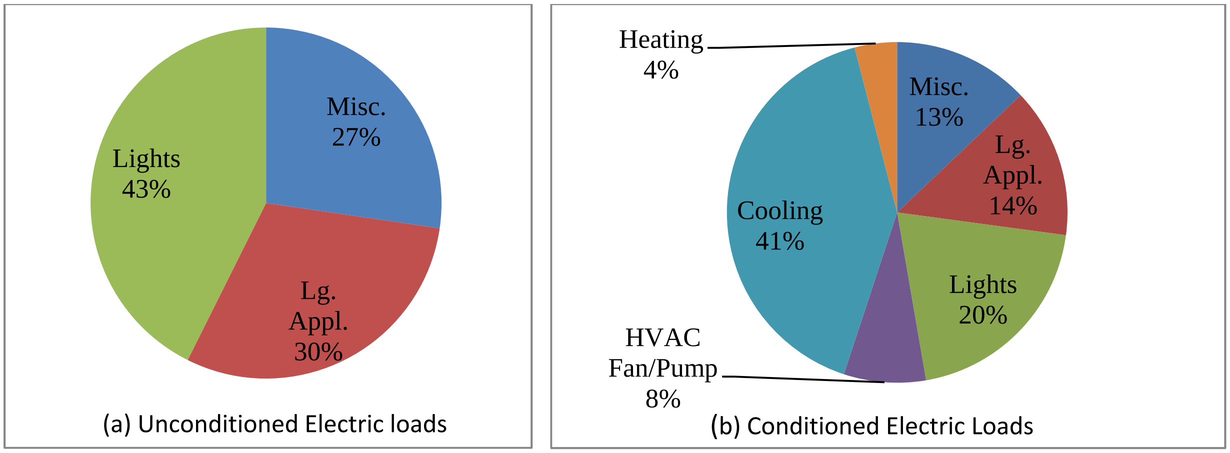
4.1.2 Energy Use Verification

In order to most accurately model the reference home, the disaggregated annual energy consumption of the Salamanca reference home outlined in Table 4-1, are used to validate the annual energy end-uses of the baseline, retrofit-unconditioned residential energy model. Table 4-3 shows a direct comparison of the annual energy consumption for various end uses between the Salamanca reference home and the baseline unconditioned energy model. The percent differences between the reference home and the baseline energy model are less than 5% for each end-use.

Table 4-3: Annual Energy Use Verification

	Salamanca reference home	**Baseline Energy Model**	**Difference between model and reference home**
Refrigerator (kwh/year)	465	470	-1%
Washing machine (kwh/year)	133	130	2%
Plug load equipment (kwh/year)	536	545	-2%
Lighting (kwh/year)	827	851	-3%
Total electricity use (kwh/year)	1962	1996	-2%
Total LP Gas use (MJ/year)	17622	16914	4%

The annual electricity end-use consumption from the baseline retrofit-unconditioned model is illustrated below in Figure 4-4 (a). It can be seen that the greatest electricity consumption is from lighting, followed by large appliances and plug loads. When the same baseline-retrofit home is conditioned 53% of the electric annual energy use is dedicated to heating and cooling (Figure 4-4 (b)). In the conditioned case, cooling is clearly the greatest end-use demand.



(a) Unconditioned Electric loads

(b) Conditioned Electric Loads

Figure 4-4: Retrofit baseline model annual electric end-uses (a) unconditioned (b) conditioned

It is also important to validate the annual energy consumption of the baseline retrofit-conditioned home. A Mexican residential energy study (Jorge Alberto Rosas-Flores, 2011) provides a rough estimate for annual electricity use for a residential air conditioning unit of 2042 kWh per year and for electric heating of 278 kWh per year. The estimates given in this previous study are based on a national average and may vary by location; therefore these estimates are only used as a general guideline rather than a strict validation point. The retrofit-conditioned home energy model estimates an annual energy consumption of 1726 kWh per year for cooling, 328 kWh per year for HVAC fans and pumps and 169 kWh per year for heating as indicated in Table 4-4. The conditioned baseline energy model is relatively consistent with the general estimates provided in the previous study.

Table 4-4: Annual energy end-use for each of the four residential energy cases

	Retrofit		**New Construction**	
	Unconditioned	**Conditioned**	**Unconditioned**	**Conditioned**
Site Electricity Use (kWh/year)				
Misc.	544.8	544.8	544.8	544.8
Lg. Appl.	600.28	600.28	1020.58	1020.58
Lights	850.51	850.51	850.51	850.51
HVAC Fan/Pump	-	328.11	-	351.73
Cooling	-	1726.27	-	1862.71
Heating	-	169.56	-	152.83
Total	1995.59	4219.53	2415.89	4783.16
Site gas Use (Therms/year)				
Misc.	6.7	6.7	6.7	6.7
Lg. Appl.	50.5	50.5	-	-
Hot Water	103.11	103.11	103.11	109.25
Total	160.31	160.31	109.81	115.95

Table 4-4 includes the annual site electricity use as well as the site liquid petroleum gas use. The LPG end-use consumption is driven by domestic hot water needs followed by the large appliance load which is typically used for cooking. This is consistent with the Toluca study where it is estimated that that roughly 20 percent of the LPG consumption is for cooking appliances while the remaining portion is for domestic hot water. Furthermore it should be noted that the annual energy end-use for the new construction and the retrofit cases are nearly identical with the only difference is seen for the gas use. The retrofit building case uses a LPG stove while the new construction case uses an electric cooking stove.

4.1.3 Temperature Verification

Typical existing residential buildings in Salamanca do not use heating or air conditioning systems, thus it is important to verify that the energy models accurately reflects the actual homes regarding indoor thermal conditions. Therefore hourly indoor temperature was measured in one of the homes for roughly two weeks, April 26th, 2011 through May 11, 2011. Indoor temperature and relative humidity was measured in the first and second floors in the home. It can be seen in Figure 4-5 that the second floor indoor temperatures are greater than the temperatures on the first floor during the day, but reach a relatively similar temperature during the evening hours. The relative humidity for the first and second floor are roughly the same.

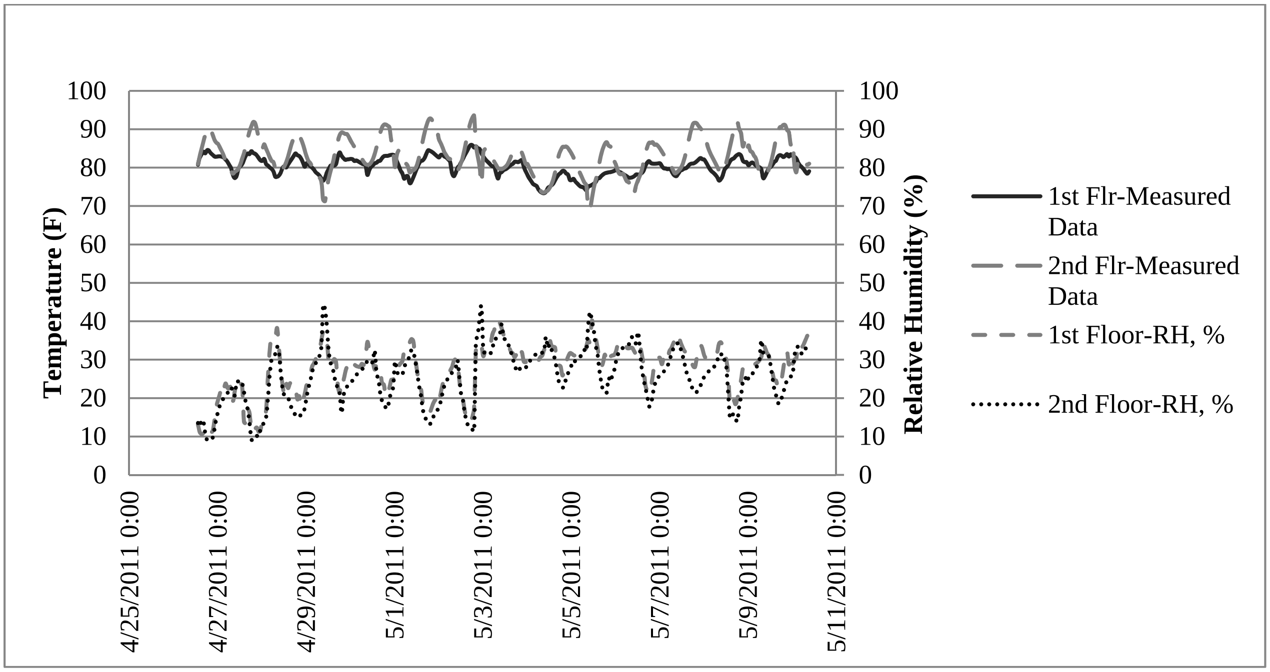


Figure 4-5: Two-week indoor temperature and relative humidity measurements

In order to accurately model the indoor thermal conditions, the measured hourly indoor temperatures for the first and second floor are compared to the modeled hourly indoor temperatures for the first and second floor respectively. BEOpt only considers homes as a single zone, therefore a two zone temperature verification was performed by modifying the Energyplus input file (.idf) created by BEOptE+. The two zone Energyplus model is identical to the baseline BEOpt model in all aspects except for the zoning. The building loads were split appropriately between the first floor and the second floor zones, natural ventilation was applied to both zones, the dimensions of the building are equivalent and the material properties for constructions are the same. The inter-zone heat transfer between the first and the second floor zones are also accounted for in the two zone Energyplus model. Figure 4-6 and Figure 4-7 show the resulting temperature validation for the first floor and the second floor respectively.

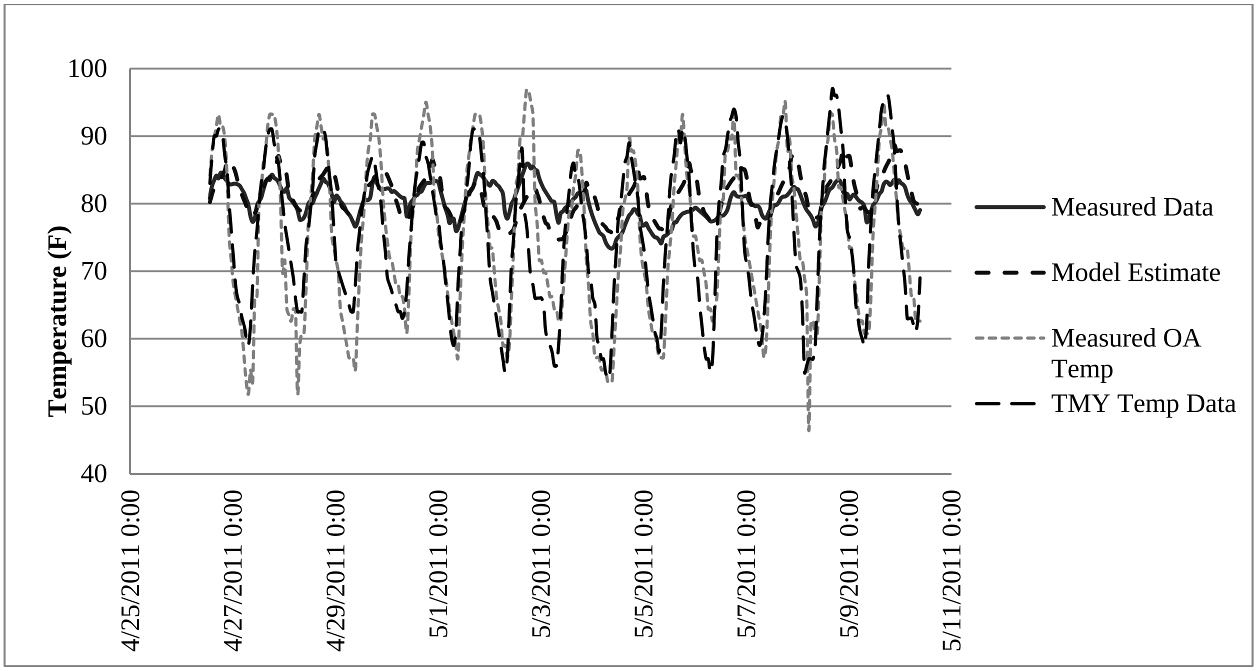


Figure 4-6: First floor temperature validation

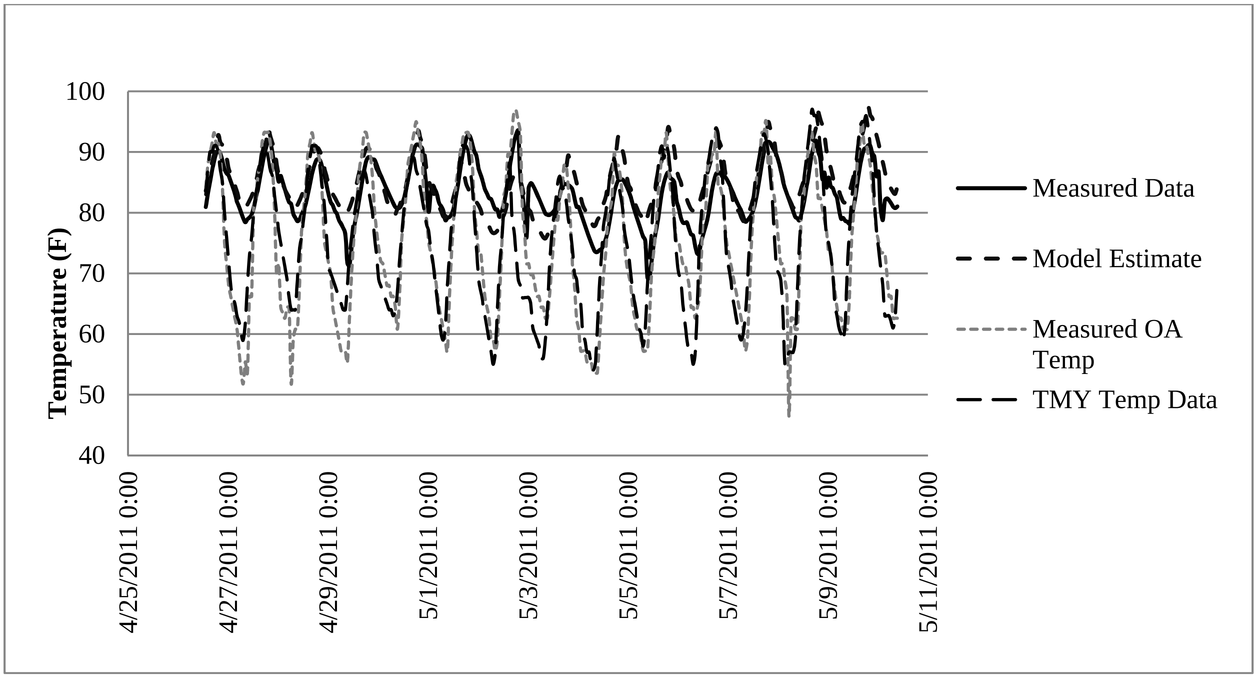


Figure 4-7: Second floor temperature validation

It can be seen that the modeled indoor temperature on both the first and second floor closely match the measured hourly indoor temperatures. The measured outdoor temperature and the typical meteorological year (TMY) outdoor temperatures are also included in the figures to show that there no significant outdoor temperature variations for this time period. It should also be noted that the temperature comparison is used as a means of verification rather than calibration.

The temperature verification was also used to refine the building material characteristics used in the final model. Upon completion of the two zone temperature verification, the single zone averaged indoor temperature from the BEOptE+ model was compared to the two zone temperatures as seen in Figure 4-8 below. It can be seen that the BEOptE+ single zone temperatures closely match the second floor zone indoor temperatures from the two-zone model. This trend can be explained by the significantly greater conduction heat transfer and convective heat transfer of the roof surface compared to the ground floor slab.

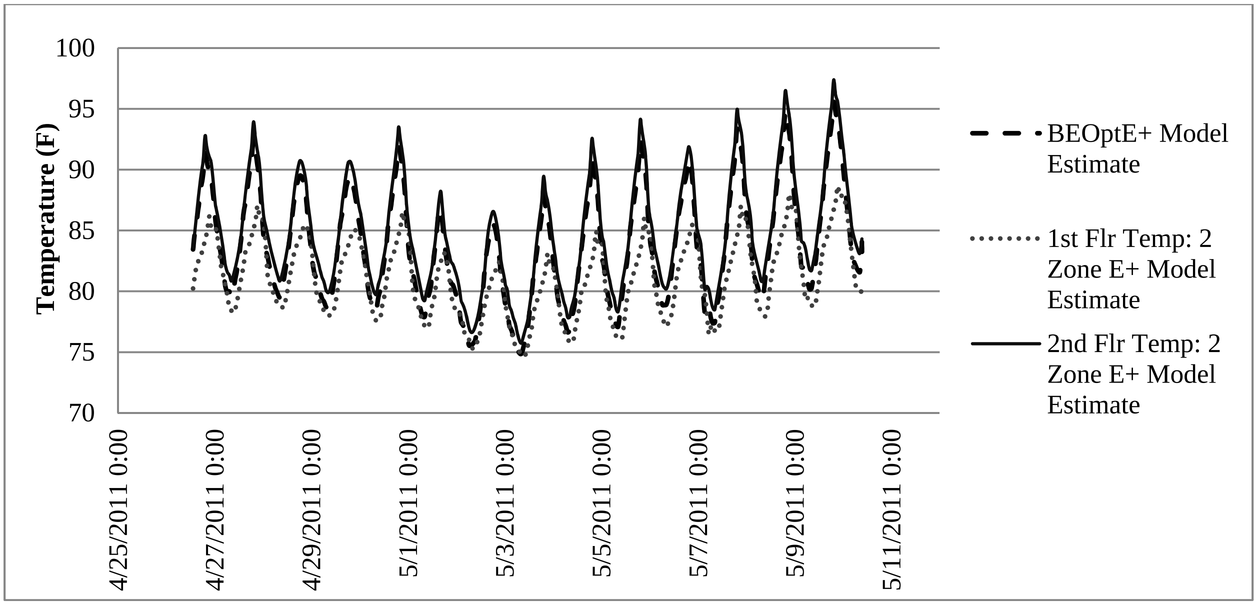


Figure 4-8: Verification of BEOpt model and two-zone E+ model: indoor air temperature

The primary modes of heat transfer through exterior surfaces are convection and conduction (Krarti, 2011). Therefore the conduction and convection heat transfer through the roof and the ground slab are compared in order to explain the strong temperature correlation between the second floor zone temperature and the estimated single zone temperature observed in the BEOptE+ model. The hourly interior surface convective heat transfer rate and the hourly inside surface conduction heat transfer rate are plotted below in Figure 4-9 and Figure 4-10 respectively for the roof surface and the ground floor slab for the same time period as the two zone indoor temperature verification.

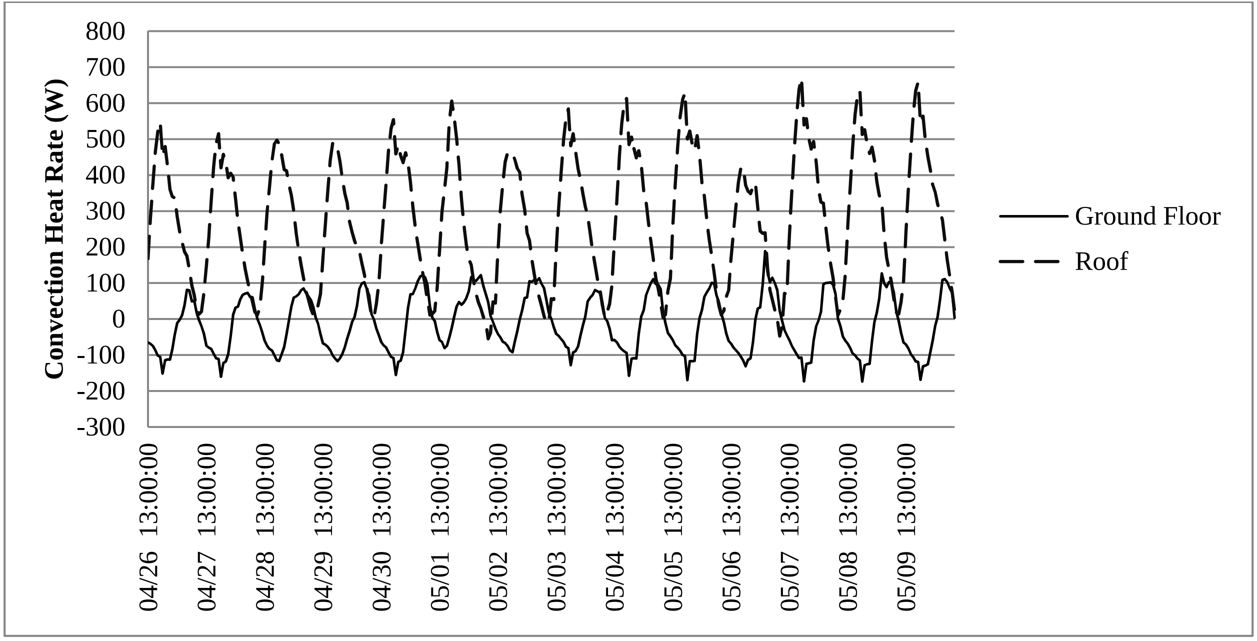


Figure 4-9: Hourly interior surface convection heat transfer rate

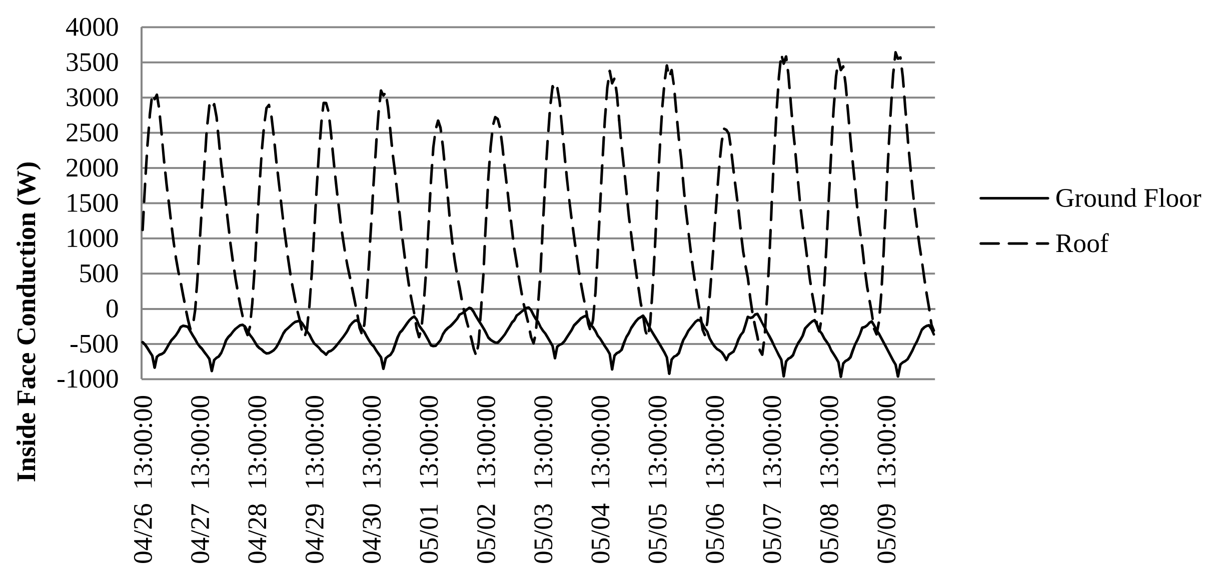


Figure 4-10: Hourly inside surface conduction

During the day, the direction of heat transfer for the roof is from the outside in. The floor slab acts oppositely during the day where the heat transfer moves from inside, outward. Furthermore the roof convection heat transfer is four orders of magnitude greater than the floor during the daytime hours. The roof conduction heat transfer is up to five orders of magnitude greater than the floor surface during the day. This illustrates that the indoor temperatures are strongly influenced by the heat transfer from the roof surface.

4.2 EEM Selection for Residential Buildings in Salamanca Mexico

Since one of the primary objectives of this study is to provide an optimal package of energy conservation measures for new and existing residential buildings, it is critical to select appropriate measures. Furthermore, this study includes the existing component based residential energy efficiency standards in the optimization in order to assess if these measures are appropriately recommended or if they can be improved. The existing residential building codes are first identified and evaluated to see where they could be further developed. This requires a thorough review of the existing efficiency standards and codes related to residential buildings as well as an evaluation of other appropriate measures.

Before discussing the existing CEV Mexican residential energy efficiency standards, it is important to first identify the general residential demographics in Salamanca. This provides contextual information for residential units in Salamanca and how they compare to homes in the state (Guanajuato) and the country (Mexico). Table 4-5 shows a basic overview of the population, number of housing units, number of occupants per home, the total domestic electricity consumption, number of homes with electricity and the percentage of homes with certain types of appliances and equipment from the Instituto Nacional de Estadistica y Geografia (INEGI for its acronym in Spanish, National Institute for Statistics and Geography) from 2010.

Table 4-5: Demographics for Salamanca, Guanajuato and Mexico (INEGI, 2010)

Data	**Mexico (Country)**	**Guanajuato (State)**	**Salamanca (City)**
Population	112,336,538	5,486,372	260,732
Housing units	28,607,568	1,276,584	64,073
Average number of occupants/home	3.9	4.3	4.1
Total domestic electricity consumption (MWh/year)	48,700,400 (SENER, 2010)	177,484,872 (SIEG, 2003)	79,865 (SIEG, 2003)
Estimated consumption/home (kWh/year)	1702	1161	1246
Homes with electricity	96%	97%	99%
Homes with refrigerators	81%	85%	91%
Homes with washer machine	65%	72%	82%
Homes with a TV	91%	95%	97%
Homes with a computer	29%	24%	29%

It can be seen that 99% of homes in Salamanca have electricity and of those homes, 91% have refrigerators, 82% have washer machines, 97% have a television, and only 29% have a computer in the home. The saturation of electric appliances in Salamanca is slightly higher for each category when compared the state and national level. This information indicates the relevance of electric appliance and plug load energy efficiency measures for the city of Salamanca.

The annual electricity consumption per home is estimated by dividing the total domestic consumption by the number of housing units. The total domestic electricity consumption for Salamanca and the state of Guanajuato is collected from the Sistema de Información Energética de Guanajuato (SIEG, for its acronym in Spanish, Energy Information System of Guanajuato) from 2003 which is the most recent set of data (SIEG, 2003). Therefore the estimated electricity consumption per housing unit may be a slight underestimate when compared to the Salamanca reference home.

The existing energy and sustainability guideline from the CEV, for homes in Salamanca, is referenced before developing the list of applicable energy efficiency measures. The residential code covers all aspects of residential building construction, however only the relevant energy related codes are considered when selecting the EEMs. Also, as described in the literature review, the climate zones outlined in the CEV are loosely described and not specific to all Mexican Cities. Furthermore they contradict the climate zones outlined in the NMX-C-460-ONNCCE-2009: Building industry-insulation R-value for housing envelope by thermal zone for Mexican Republic.

The standard NMX-C-460-ONNCCE-2009, defines Salamanca as being in climate zone 2 which is categorized by having between 3500 and 5000 cooling degree days (CDD) and less than 3000 heating degree days (HDD) where Salamanca has 3140.6 CDD. The cities of Guadalajara and Chilpancingo are also categorized under climate zone 2 by the NMX-C-460-ONNCCE-2009. Guadalajara and Chilpancingo are given as example cities located in the temperate climate zone in the CEV code therefore it is assumed that Salamanca is within the temperate climate region as well. The building design recommendations for the temperate climate region from the CEV are outlined in Table 4-6 below.

Table 4-6: Residential building design recommendations for temperate climates

Category	**Recommendation**
Grouping/Spacing	Place taller buildings north of smaller neighbouring buildings Optimum spacing between buildings is 1.7 times the height, but minimum spacing is at least once the building height
Building Orientation	Southeast, northeast or southwest orientation with solar control during the spring in the afternoon
Building Shape	Compact, cube-geometry with a patio
Location of activities	Bedrooms, living room, dining room in the SE, kitchen in the N and circulation in the NW or W
Type of roof	Flat
Floor to ceiling height	Minimum of 2.4 m
Eaves	Eaves on the south façade to avoid thermal gains in the summer and spring On other orientations, use mullions and vegetation
Skylights	Control solar gains in the summer and spring
Mullions	Combine with eaves and vegetation on the NE, E, NW and W facades
Ventilation	Well sealed and operable windows Windows located at the level of occupancy
Windows	Less than 80% window to wall ratio Place the largest percentage on the south, east, and southeast facades Place the smallest percentage on the north, northeast, northwest, west and southwest facades Well sealed and operable windows Blinds are not recommended
Roofing	Materials that promote heat storage and act as a thermal barrier from the outdoor environment low conductivity
Wall	Materials that promote heat storage and act as a thermal barrier from the outdoor environment
Exterior finishes	Roofs and exterior walls surfaces located on the east, south and west facades should have a low reflectance, dark and rough finish
Auxiliary AC equipment	Not required

The CEV also directs the users to many other voluntary and mandatory energy standards including the NMX-C-460-ONNCCE-2009. The minimum recommended construction assembly R-values for climate region 2 from this standard for the roof and wall are R-1.4 m^2-K/W (R-8 ft^2-h-°F/Btu) and R-1 m^2-K/W (R-5.7 ft^2-h-°F/Btu) respectively. This code also recommends increased R-value assembly levels for improved thermal comfort and greater energy efficiency as seen in the original code specification in Appendix 9.1. The thermal performance recommendations for the roof and wall are R-2.1 m^2-K/W (R-12 ft^2-h-°F/Btu) and R-1.2 m^2-K/W (R-7 ft^2-h-°F/Btu) respectively. Lastly the energy saving thermal insulation levels are recommended at R-2.65 m^2-K/W (R-15 ft^2-h-°F/Btu) and R-1.4 m^2-K/W (R-8 ft^2-h-°F/Btu) for the roof and wall respectively. Finally this voluntary standard recommends a U-value of 4.25 W/m^2-K (U-0.75 Btu/ ft^2-h-°F) for both windows and skylights.

Along with the construction assembly R-value recommendations and the general energy efficiency guidelines provided in the CEV, efficient electric equipment and appliances were also considered in the optimization analysis. This is of particular interest because it is reported that the:

> Mexican Minimum Efficiency Performance Standards (MEPS) for refrigerators, air conditioners and motors are now fully harmonized with the U.S. Department of Energy (DOE) standards. Stringency varies with product but these standards are among the most stringent in the world, making the Mexican program among the world’s most aggressive in therms of energy efficiency. (Itha Sánchez Ramos, 2006)

Therefore efficient appliances are confidently recommended for the residential sector since they are already available in the Mexican market. The annual energy consumption and equipment costs associated with equipment size and efficiency level from this study are used as a reference in the optimization analysis.

4.2.1 EEMs Evaluated in the Residential Energy Analysis.

A wide range of information is considered when selecting the appropriate energy efficiency measures for the retrofit residential energy optimization analysis. It is important to first evaluate the disaggregated annual energy consumption for both electricity and gas to determine the greatest potential for energy savings. For this study it is also critical to consider the available technology and cultural acceptance of EEMs in the Mexican residential sector.

The electricity energy consumption in the unconditioned retrofit baseline building is 43 percent lighting, 30 percent large appliances and 27 percent plug load equipment. However, when the cooling and heating system is added to the building, cooling is the dominant energy consumer with 41 percent of the total annual electricity (Figure 4-4). By including the conditioned case in the analysis it indicates that there is a great need to reduce the heat gains from the exterior environment, therefore various thermal comfort measures are included in the analysis along with energy efficiency measure for appliances¸ lighting and plug load equipment. Table 4-4 indicates that the annual energy end-uses for the new construction case are similar to the retrofit case for both the unconditioned and conditioned cases respectively. Therefore the energy efficiency measures appropriate for the retrofit case are also appropriate for the new construction case. However the new construction case includes additional energy design measures since there is greater flexibility to make recommendations for new construction.

Since a large percentage of the annual energy consumption is allocated to lighting, appliances and plug loads, a wide range of appropriate EEMs are evaluated in this study. These include reduced miscellaneous equipment loads using surge protector power strips and purchasing more efficient plug load equipment as needed. During the site visits it was observed that many families use power strips to accommodate for the limited number of outlets in the home, therefore this can be an easily adaptable technology. More efficient appliances that comply with and go beyond the NOM-ENER standards and labeling program are also included in the study. A condensing tank-less domestic hot water heater and R-2 (ft^2-h-°F/Btu) trunk-branch DHW pipe insulation are evaluated in efforts to reduce the gas loads. The renewable energy technologies included in the optimization are a solar domestic hot water (SDHW) system and a photovoltaic system.

The thermal comfort measures included in the retrofit and new construction studies are adding insulation to the walls and roof constructions to reach the recommended assembly R-values provided in NMX-C-460-ONNCCE-2009. The additional insulation added to the single wythe brick walls correspond with the NMX-C-460-ONNCCE-2009 recommendations are R-4.6 (ft^2-h-°F/Btu), R-6 (ft^2-h-°F/ Btu) and R-7 (ft^2-h-°F/ Btu). Additional R-10 (ft^2-h-°F/ Btu) insulation is included in the study because it is recommended in ASHRAE 90.1-2007 from Table 5.5-3 for mass residential buildings in a similar climate zone. The new construction case also evaluates double wythe brick construction to increase the thermal mass of the building.

The additional insulation levels added to the concrete roof slab that correspond with the NMX-C-460-ONNCCE-2009 recommendations are R-7(ft^2-h-°F/ Btu), R-11(ft^2-h-°F/ Btu) and R-14(ft^2-h-°F/ Btu). R-18 (ft^2-h-°F/ Btu) insulation is also included in the study because it is recommended in ASHRAE 90.1-2007, Table 5.5-3 for mass residential buildings in a similar climate zone. Other roof thermal comfort measures included in the optimization are dark roof asphalt shingles (absorptivity 0.92) and dark tile (absorptivity 0.9) because dark roofs are recommended in the CEV for temperate climates as indicated in Table 4-6 above. Medium colored asphalt roof shingles (absorptivity 0.85), white or cool colored asphalt roof shingles (absorptivity 0.75) are also included in the optimization. Additionally, double pane windows, 1 foot eaves and reduced infiltration are also considered in the thermal comfort measures. A comprehensive list of all EEMs included in the optimization analysis for the retrofit and the new construction cases is outlined in Table 9-12 of Appendix 9.3. The retrofit costs, new construction costs and input assumptions for each measure are also detailed in Table 9-12 of Appendix 9.3. Also note that many of the thermal comfort measures are recommended in the CEV for a temperate climate.

5 COMMERCIAL OFFICE BUILDING ANAYLSIS

The optimization analysis is performed on two different commercial office building types, an existing building and a new construction prototype. The characteristics of the existing office building are defined using specific information gathered during a walk-through of one specific building. This information includes building operation schedules, seasonal occupancy variations, a detailed accounting of all cooling equipment, construction materials, a set of building plans, a list of specific office equipment, miscellaneous equipment and lighting fixtures along with two year electric utility data. The new construction office building implements modern building materials and also has a square floor plan compared to the traditional open courtyard style of the existing building. The internal loads and schedules from the existing building are used in the new construction case assuming similar building use.

5.1 Existing Office Building Analysis

The evaluation of a specific existing office building is particularly important for this study due to the limited available data for office buildings in Mexico. There is little verifiable information on existing building characteristics including equipment loads, occupancy, lighting power density and HVAC system types. Therefore the Salamanca City Hall, also referred to as the Mayor's office building was chosen as the baseline office building in Salamanca. A detailed energy audit was performed on this building to ensure greater accuracy and reliability of the optimization analysis. Therefore a baseline model for building energy use was created using detail building information collected during the site visit and two year electric utility data. The model is calibrated within 10% for each month when compared to the given utility data.

5.1.1 Building Characteristics and Energy Model Inputs

The two-story City Hall office building is located in the historic downtown area of Salamanca, Guanajuato and was constructed in 1904 with the traditional open courtyard layout. The building has a thin shell, rectangular shaped building footprint as seen in the building first floor building plans (Figure 5-1). A series of images of the Mayor's office building is shown in Figure 9-1 of Appendix 9.4. The total constructed is area approximately 13,730 ft^2 and 19,160 ft^2 including the covered lobby area on the north end of the courtyard.

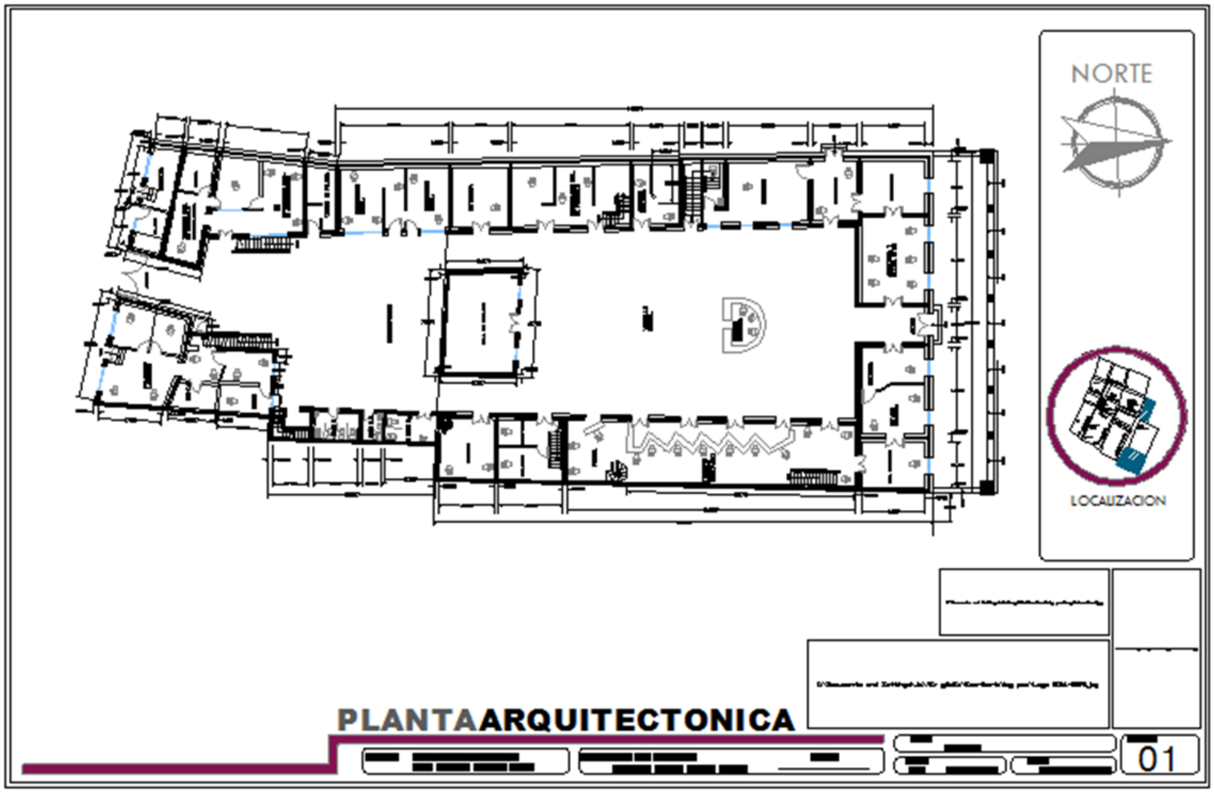


Figure 5-1: Mayor’s office first floor building plan

The open courtyard building style promotes a relatively high level of air infiltration and therefore an ACH of 1 is assumed for the buildings. The first floor has an estimated floor to ceiling height of 11 feet while the second floor has an estimated floor to ceiling height of 9 feet. The front entrance of the building is oriented north. A church and another historic building are directly adjacent on the east and west sides of the building. The building also has an arched roof structure above the north half of the building therefore reducing direct solar gains on this half of the building. The building is constructed of large thermal mass walls and roofs and has a total window to wall ratio of 3%. The material layers and material properties used in the building energy model are shown in Table 5-1 below. An image of the building energy model used for this analysis is shown in Figure 5-2.

Table 5-1: Mayor’s office construction material properties

Component	**Assembly U-value (Btu-in/hr-ft^2-F)**	**Total Thickness (ft)**	**Material description**	**Thickness (ft)**	**Density (lbm/ft3)**	**Specific Heat (Btu/lbm-F)**	**Conductivity (Btu-in/hr-ft2-F)**
Ext Wall	0.352	1.5	Interior/exterior cement plaster finish	0.083	116	0.2	5
			Fire clay brick	0.333	120	0.19	6
			HW concrete	1	140	0.2	9.1
Interior Wall	0.633	0.667	Interior/exterior cement plaster finish	0.083	116	0.2	5
			HW concrete	0.5	140	0.2	12
Roof	0.595	0.698	Built up roofing	0.031	70	0.35	1.1
			HW concrete	0.6667	140	0.2	12
Floors	0.813	0.5	HW concrete	0.5	140	0.2	12
Ceilings	4.999	0.083	Interior/exterior cement plaster finish	0.083	116	0.2	5

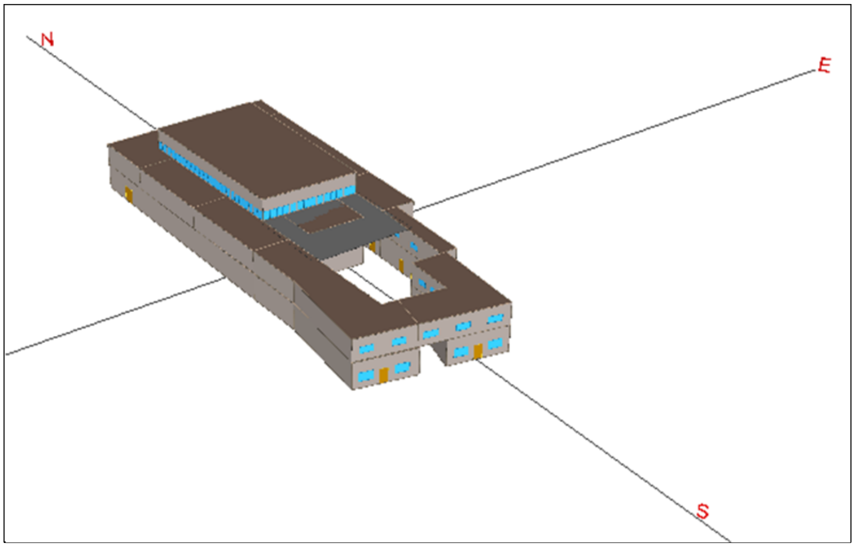


Figure 5-2: Mayor’s office building energy model

The commercial office building only uses electricity as an energy source and does not use natural gas or liquid petroleum gas. Therefore only electric loads are considered in this evaluation. A little over two years of utility data was obtained from the City Hall facilities manager during the site visit. Table 5-2 and Figure 5-3 show the electric utility data used as a reference for the building energy assessment. The building base-load is 9233 kWh per month, which is the average energy consumption for the winter months of October through February where there is very little to no cooling demand. The energy use intensity (EUI) of the existing building is 9.2 kWh/ft^2/year (31.3 kBtu/ft^2/year). The EUI for small and medium U.S. office buildings constructed before 1980 and located in a relatively similar climate, (climate zone 3C) are 66 kBtu/ft^2/year and 53 kBtu/ft^2/year respectively (DOE, 2011).

Table 5-2: Monthly electric utility data

	2009			2010			2011			Average	
Month	Use (kWh)	Cost (Peso)	Cost (US$)	Use (kWh)	Cost (Peso)	Cost (US$)	Use (kWh)	Cost (Peso)	Cost (US$)	Use (kWh)	Cost (US$)
Jan	10480	18946	1563	8800	16954	1399	9280	17778	1467	9520	1476
Feb	9280	16780	1385	8880	18037	1488	8880	18117	1495	9013	1456
Mar	10400	17939	1480	9520	19795	1633	11040	23625	1949	10320	1688
Apr	10560	20850	1720	10720	23586	1946				10640	1833
May	10640	19434	1603	12960	25934	2140	-	-	-	11800	1872
Jun	12400	22657	1869	13280	26893	2219	-	-	-	12840	2044
Jul	12000	21540	1777	12160	25287	2086	-	-	-	12080	1932
Aug	11040	20377	1681	9600	25975	2143	-	-	-	10320	1912
Sep	10160	19048	1572	11520	23949	1976	-	-	-	10840	1774
Oct	9920	19284	1591	10640	20598	1700	-	-	-	10280	1645
Nov	9200	17147	1415	9520	18097	1493	-	-	-	9360	1454
Dec	8480	17425	1438	9600	18776	1549				9040	1493
Total	124560	214001	17657	127200	245106	20223	29200	59520	4911	126053	18940
Monthly Avg.	10553	19455	1605	10691	22282	1838	9733	19840	1637	10638	1694
US$/ kWh			0.142			0.159			0.168		0.150

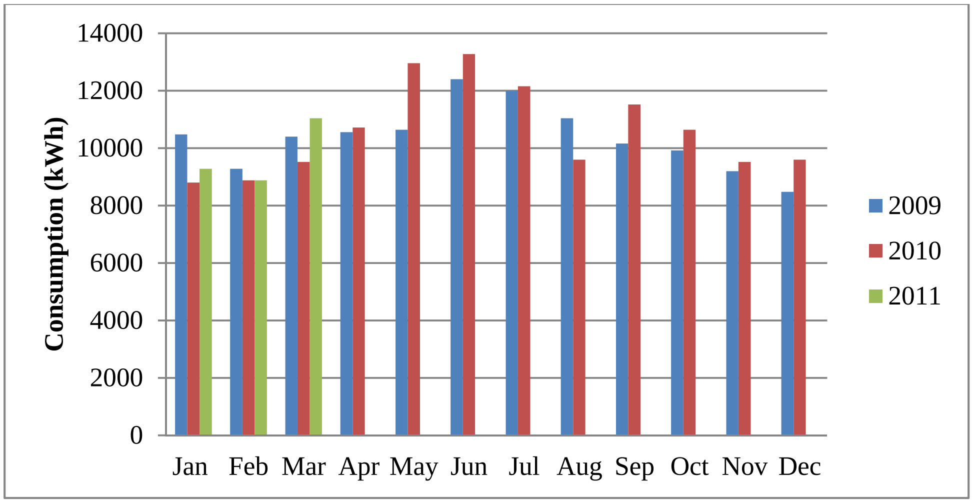


Figure 5-3: Monthly electricity consumption for 2009-2010 and part of 2011

There are 134 people who work in the City Hall and there are regular office visitors. The typical work week is Monday through Friday 8am to 4pm. However the communications office is occupied 24 hours a day, 7 days a week with 2 to 3 people outside of business hours. Figure 5-4 shows the weekday hourly schedules for occupancy, general lighting, and exterior lighting used in the building energy model. Figure 5-5 shows the seasonal variation of the office and plug load equipment, which corresponds with the varied use of plug load equipment reported by some of the building occupants. June and July have a higher use fraction because it is common for many of the occupants to use portable fans during the hotter season compared to other times of the year. December also has a lower demand than the general schedule due to the reported higher levels of vacation during this time of the year. Separate operational schedules were created for the communications office since space is always occupied (Figure 5-6).

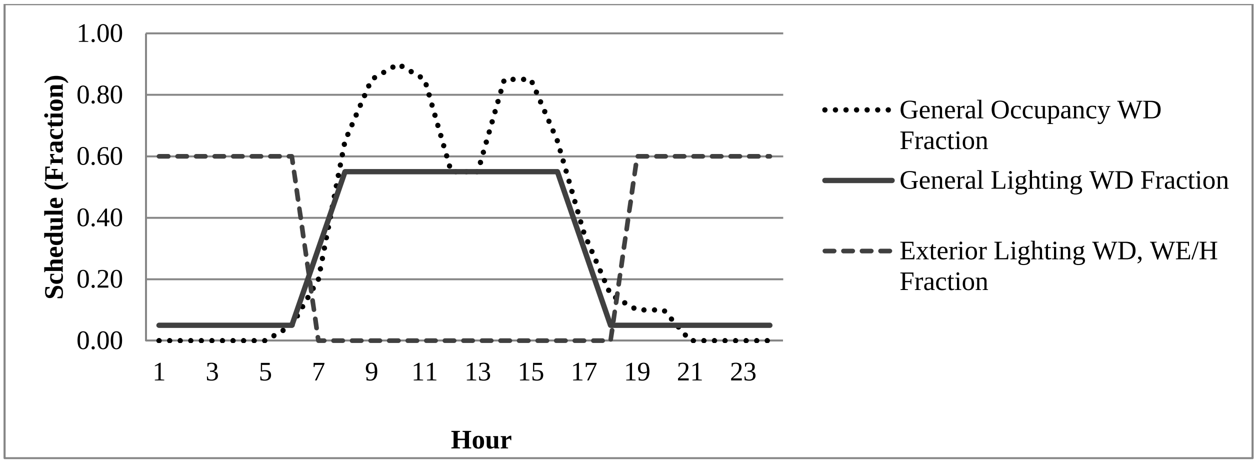


Figure 5-4: General lighting and occupancy weekday hourly schedules

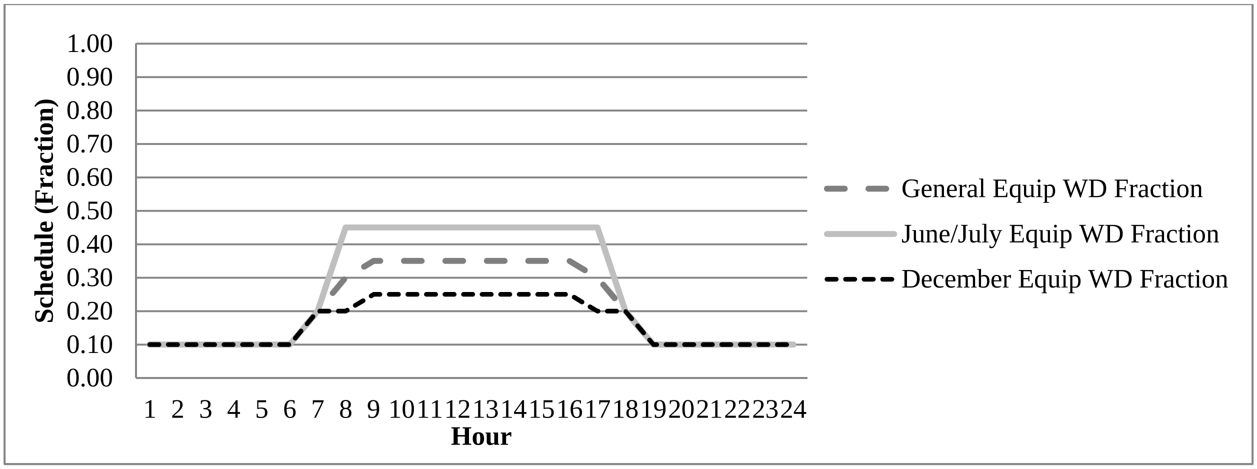


Figure 5-5: Seasonal equipment weekday hourly schedules

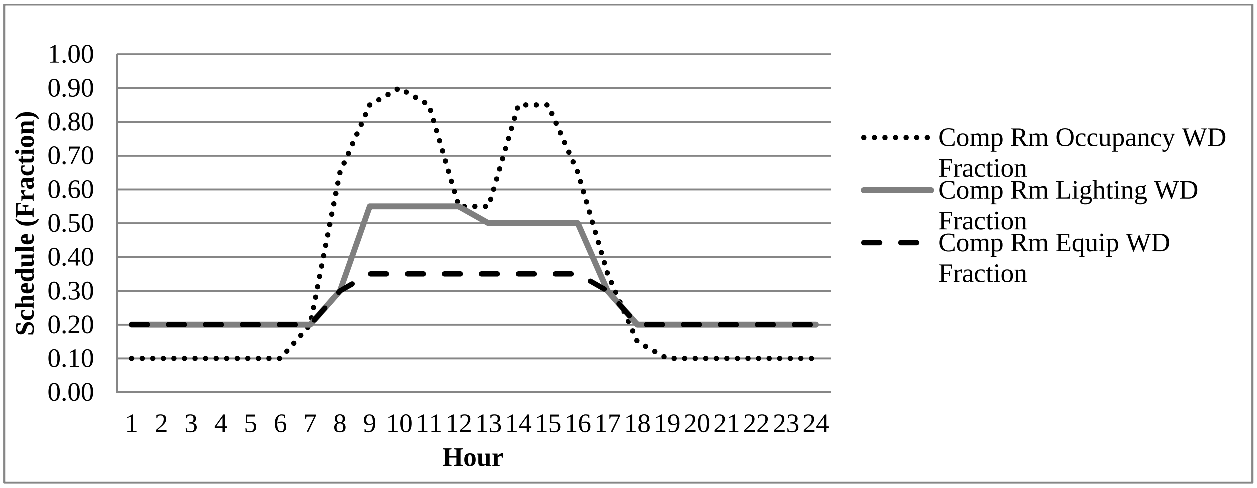


Figure 5-6: Computer room weekday hourly schedules

Next the equipment power density (EPD) and the lighting power density (LPD) are defined using a detailed list of office equipment, miscellaneous plug loads and lighting types used throughout the building. This list of equipment was provided by the facilities manager on site to use as a guide for the type and approximate number of equipment. The equipment wattage is not specified in the list of equipment provided by the facility manager and is therefore estimated using a variety of sources listed next to each equipment type in Table 5-3. When considering all of the equipment in the given list and the approximated equipment wattages, the EPD is 3.06 watts/ft^2. This value is significantly higher than the 0.75 watts/ft^2 used in a previous Mexican office building study done in the late 1990's (Yu Joe Huang, 1998). The difference between the two EPDs shows the importance of reducing the office equipment power densities in Mexican office buildings particularly as technology evolves and as the demand for more equipment increases.

Table 5-3: List of equipment type, quantity and approximate wattage

Equipment Type		Basecase		
	Type	**Quantity**	**W/ Equip (Source)**	**Total W**
Office Equipment	Inkjet Printers	89	64 (Laura Moorefield, 2008)	5717
	Computers	138	33 (Krarti, 2011)	4554
	CRT Display	46	71 (Laura Moorefield, 2008)	3246
	LCD Display	92	34 (Laura Moorefield, 2008)	3150
	Laptops	4	26 (Laura Moorefield, 2008)	104
	Copiers/Laser printer	6	130 (Laura Moorefield, 2008)	781
	Adding machines	18	4 (Laura Moorefield, 2008)	64
	Telephones	15	5 (Laura Moorefield, 2008)	72
	Recorders	5	40 (CFE, Comision Federal de Electricidad, 2010)	200
	Modem	1	5 33 (Krarti, 2011)	5
	Televisions	4	250 (CFE, Comision Federal de Electricidad, 2010)	1000
	Plotter	1	130 (Laura Moorefield, 2008)	130
	Laminator	1	50 (Estimate)	50
	Scanner	2	10 (Laura Moorefield, 2008)	20
	Fax machine	2	32 (Laura Moorefield, 2008)	65
	Fans	33	65 (CFE, Comision Federal de Electricidad, 2010)	2129
	Coffee machine	12	464 (Laura Moorefield, 2008)	5568
	Microwave	9	1200 (CFE, Comision Federal de Electricidad, 2010)	10800
Other Equipment	Security Cameras	2	30 (Estimate)	60
	Water coolers	15	85 (From nameplate)	1275
	Mini-Refrigerator	3	250 (CFE, Comision Federal de Electricidad, 2010)	750
	Large Refrigerator	4	375 (CFE, Comision Federal de Electricidad, 2010)	1500
	Vending Machines	2	400 (Estimate)	800
			Total	42040.3
			W/ft^2	3.06
			W/m^2	32.94

Similar to the equipment, the type and number of luminaires were provided by the facility manager. The lamp wattages were provided in the list however the system wattage was not given and are therefore used instead of the lamp wattages for greater accuracy. Table 5-4 shows the indoor lighting type, quantity of lamps, quantity of luminaires and system wattage. The LPD for the indoor lighting is 2.35 watts/ft^2, which is also greater than the values used in the previous Mexican office building study of 1.5 watts/ft^2. The previous study does not indicate the lamp technology, but the lamps used in the Mayor's office building are old technology, T12 lamps with magnetic ballasts therefore it is expected that the lighting power densities are so high.

Table 5-4: Indoor lighting types, quantity and system wattage

Lamps	**Ballast type**	**Qty Fixt**	**Lamps/ Fixt**	**System W**	**Total W**
Metal Halides	magnetic	8	1	450 (Krarti, 2011)	3600
Metal Halides	magnetic	1	1	1103 (Lindsey, 1997)	1103
48" 40 W T12s	magnetic	322	2	96 (Lindsey, 1997)	30912
96" 75 W T12s	magnetic	30	2	173 (Lindsey, 1997)	5190
Fluorescent U-lamp	electronic	12	2	63 (Krarti, 2011)	756
100 W Incandescent	NA	10	1	101 (Krarti, 2011)	1010
				Total	42571
				W/ft^2	2.35
				W/m^2	25.26

The outdoor lighting for this facility is primarily used for safety and security purposes and located along the exterior facades. The facilities manager is replacing old incandescent lamps with LED fixtures as the incandescent lamps burn out. Table 5-5 shows the outdoor lighting type, quantity of fixates and total wattage used as inputs for the building energy model.

Table 5-5: Outdoor lighting type and, quantity and wattage

Lamps	**Qty Fixt**	**Lamps/Fixt**	**W/Lamp**	**Total W**
LEDs	13	1	15	195
Incandescent lamps	22	1	45	990
			Total	1185
			W/ft^2	0.09
			W/m^2	0.93

Next the HVAC equipment is defined based on observations and data collected during the site. Since the building was constructed in 1904, the original design does not account for mechanical cooling or heating equipment. The first system installed in the building was a small rooftop unit that only served two zones within the building however the system is no longer in use. In order to serve more zones throughout the building numerous 1-2 ton split-system packaged air conditioning units are installed throughout the building. A summary of the AC zoning is shown below in Table 5-6. Additionally, it should also be noted that there is no heating equipment that serves the buildings, only cooling.

Table 5-6: HVAC zoning and equipment capacities

	General Information		**Mechanical Equip**		
	Zone	**Occupants**	**AC Units**	**Total Tons**	**Total Capacity (Btu/h)**
First Floor	Z0	3	0	0	0
	Z1	12	2	2	24000
	Z2	13	0	0	0
	Z3	4	2	3	36000
	Z4	20	4	4.75	57000
	Z5	2	0	0	0
	Z6-RR		0	0	0
	Z7	20	0	0	0
Second Floor	Z8	17	2	2	24000
	Z9	8	1	2	24000
	Z10	3	2	2	24000
	Z11	5	3	3	36000
	Z12	13	4	4.42	53000
	Z13	5	1	1	12000
	Z14	2	0	0	0
	Z15	7	0	0	0
Totals		134	21	24.2	290000

Table 5-6 shows which zones currently have cooling equipment and what the total capacity is for each zone. Instead of modeling each packaged split system AC unit, the model considers the total capacity in each zone as if it were served by that single system since eQuest cannot model a single zone served by more than one system as specified in the eQuest Energy Design Resource Guide. When simulating the existing cooling system, the two zones located in the southwest corner of the building, Z1 and Z8 have between 10 and 140 undercooled hours during the three hottest months: April, May and June.

The split system AC units are modeled as packaged single zone units with DX cooling and air-cooled condensing units. The supply fan control type is two-speed and the systems have a zone entering minimum supply temperature of 55 °F. The cooling electric input ratio (EIR) is modeled as 0.43 Btu/Btu (8.0 EER), which corresponds with older equipment which was observed during the site visit. This is also consistent with the 8.5 EER used for the cooling equipment in a previous commercial building energy study (Yu Joe Huang, 1998) from the late 1990's. The minimum design flow rate is specified at 0.5 cfm and the outside air flow rate per person is 20 cfm.

The cooling temperature set-points are based on measured hourly temperature data recorded for two zones in the building, an unconditioned space located on the first floor (zone 7) and a conditioned space located on the second floor (zone12) as shown in Figure 5-7 below. The indoor air temperature data was also collected for two weeks during the end of April and beginning of May, which was during the hottest season in this region of Mexico. The measured data is used to determine a reasonable thermostat set point for occupied and unoccupied hours in conditioned zones which is particularly useful because the actual systems are manually operated by occupants. During business hours the temperature set-points are modeled as 76°F from 8am to 12pm and 75°F from 1pm to 5pm and set-up to float up to 90°F during non-business hours.

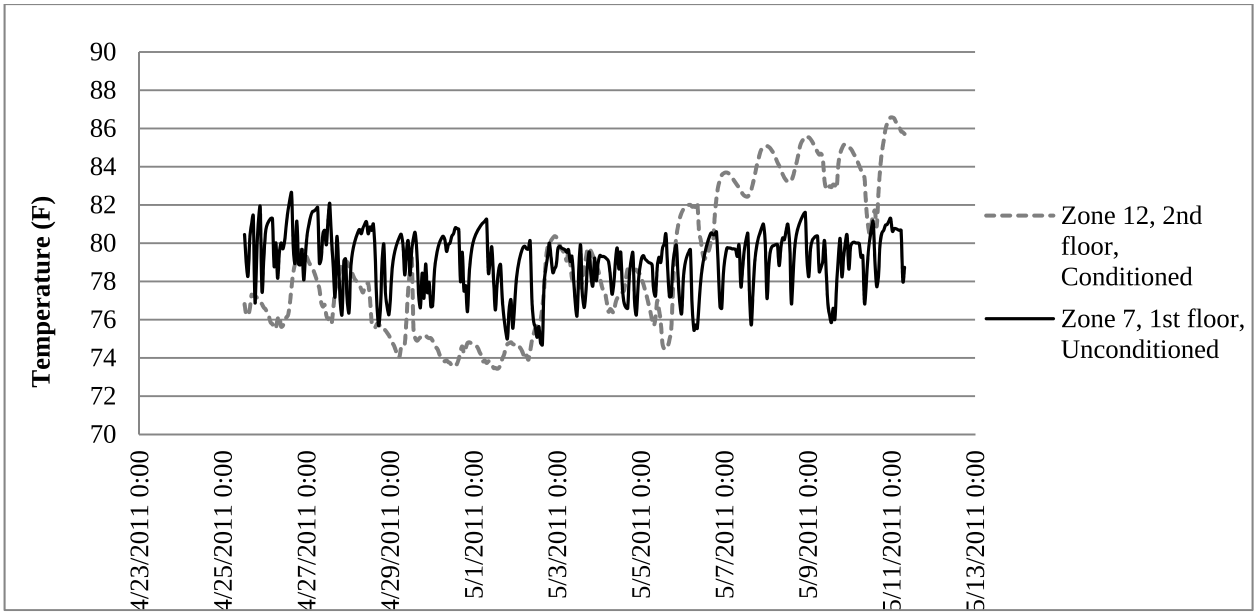


Figure 5-7: Measured indoor temperature April 25th through May 11th

5.1.2 *Calibration*

Next, the model is calibrated within 10% for each month with annual averages less than 1% compared to the two year utility data. This involved a series of changes to the original building energy model. First, the equipment and lighting schedules are modified to roughly match the building base-load of 9233 kWh per month. Then, to calibrate the remaining cooling load in the building to the utility data, the EER of the packaged single zone AC units is adjusted until a reasonable value is obtained within the minimum calibration limit of less than 10% difference per month. Table 5-7 and Figure 5-8 show the final monthly calibration data.

Table 5-7: Mayor's office monthly electric utility

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Utility Data (kWh)	9520	9013	10320	10640	11800	12840	12080	10320	10840	10280	9360	9040	126053
equest estimate (kWh)	9723	9132	9875	10882	12609	12674	12155	10892	9916	9878	9528	8879	126143
% Difference	-2%	-1%	4%	-2%	-7%	1%	-1%	-6%	9%	4%	-2%	2%	-0.1%

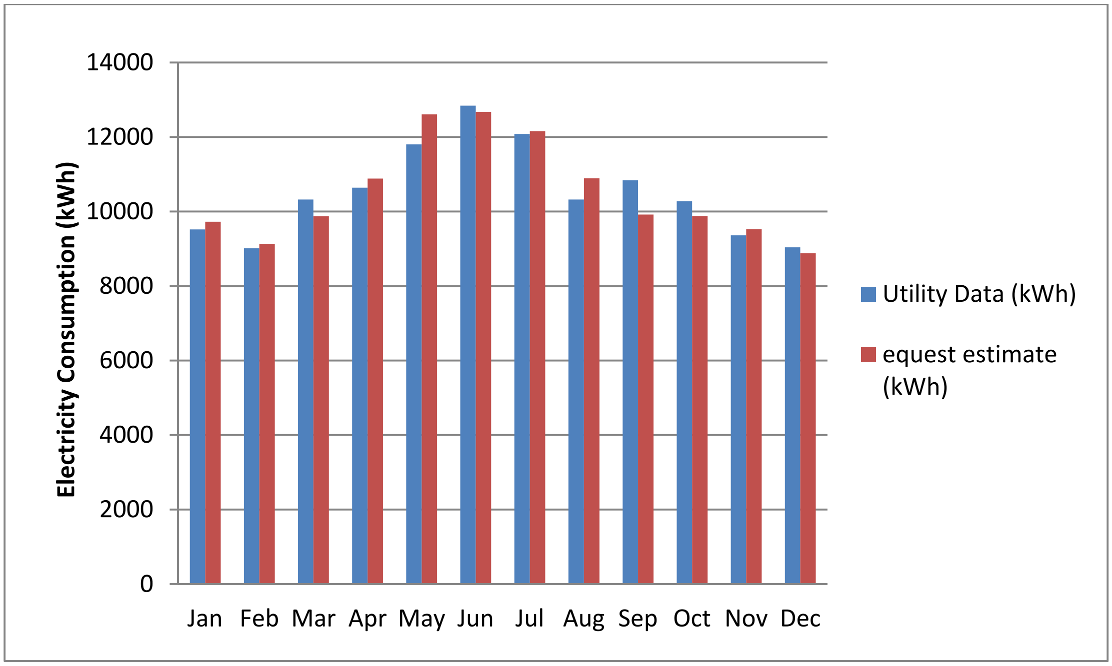


Figure 5-8: Mayor's office monthly electric utility calibration

The current Mexican minimum efficiency performance standard (MEPS) for packaged terminal AC systems is referenced in order to find a reasonable EER for the packaged single zone split system AC units. The most current version of the standard is NOM-021-ENER/SCFI-2008. The EER limits are based on the cooling capacity of the system and also depend on if the system includes a reverse cycle for heating capabilities. The current standards suggest a minimum EER as low as 8.5 (Btu/h)/W for packaged units between 20,000 Btu/h and 36,000 Btu/h and as high as 9.8 (Btu/h)/W for packaged units between 8,000 Btu/h and 14,000 Btu/h. Therefore the assumption of an EER for 8.0 for the existing units is reasonable, particularly since they are older units.

The final annual electricity end-us consumption is illustrated in Figure 5-9 and Figure 5-10. This analysis indicated that office equipment and plug loads are the highest end-uses with 49% of the total annual electricity consumption. Lighting is the second greatest area of energy consumption with 41% of the total annual energy use. Finally it is important to note that the cooling equipment only makes up 10% of the total annual electricity consumption in the building. Many studies performed on U.S. office equipment end use indicate that as the lighting and HVAC efficiency standards have been increasing strict, the equipment loads have become a greater percentage of the total energy consumption, of up to 40% in many U.S. buildings (David Kaneda, 2010). The retrofit building does not have significant HVAC loads, therefore it is reasonable for the equipment loads and the area lighting loads dominate the annual energy consumption.

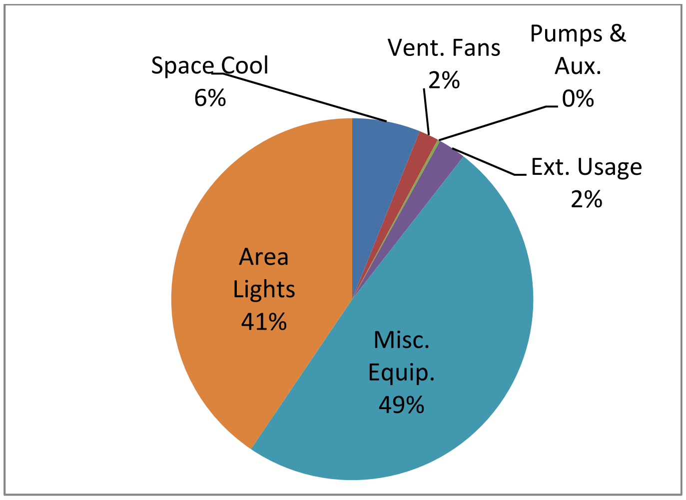


Figure 5-9: Mayor’s office annual electric consumption by end-use

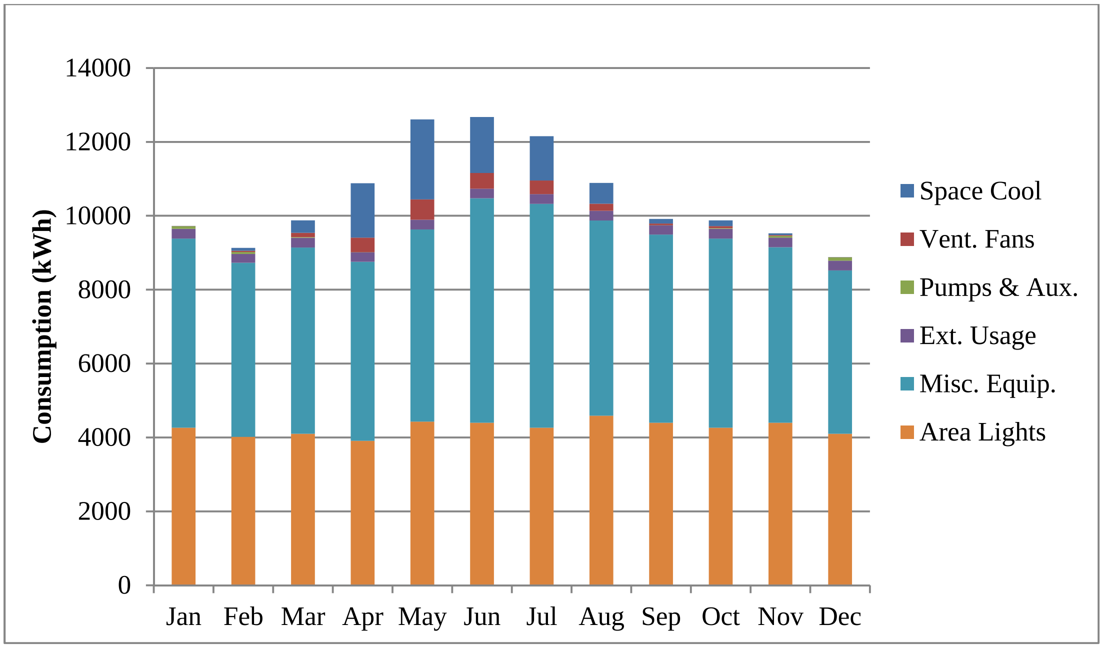


Figure 5-10: Mayor’s office monthly electric consumption by end-use

5.2 New Construction Office Building Analysis

The new construction office building case differs from the retrofit construction energy model because it does not use specific information from one building and it cannot be calibrated against utility data. Therefore the characteristics of the new construction office building are developed using information from various sources. The annual energy consumption is expected to be higher than the existing construction case, particularly for cooling since it is assumed that the entire building is conditioned instead of isolated zones as seen in the retrofit office building case.

5.2.1 Building Energy Model Characteristics and Assumptions

The model inputs for the new construction office building are developed from information gathered from literature, NOM-ENER standards for commercial buildings, site visits to newer commercial buildings in Mexico, and applicable inputs used in the retrofit building. The new construction case uses relatively modern construction methods compared to the existing building case. One study (M. Gijón-Rivera, 2011) indicates that red brick walls, concrete roofs and clear-single pane glazing are typical construction types for office buildings in Mexico.

Additionally, the report from the development of the first building envelope standard in Mexico, (Yu Joe Huang, 1998), provides basic information for the prototypical office building used in the study This study classifies common office buildings in Mexico as either masonry or steel-frame construction. It is observed that the most common construction type for newer commercial buildings in Salamanca is masonry and concrete. Therefore the construction types for the new office building baseline used in this study are brick masonry walls, concrete floor slabs, concrete roof slabs and single pane glazing. Although the materials in the new construction case are very similar to the existing building case, the walls and roof are much thinner. The new office building is modeled with an aspect ratio of 1:1 (Yu Joe Huang, 1998) and maintains the same constructed square footage as the existing building, 13,730 square feet. It is also two stories high and has a floor to ceiling height of 10 feet and floor to floor height of 12ft. An image of the new construction building energy model is shown in Figure 5-11 below.

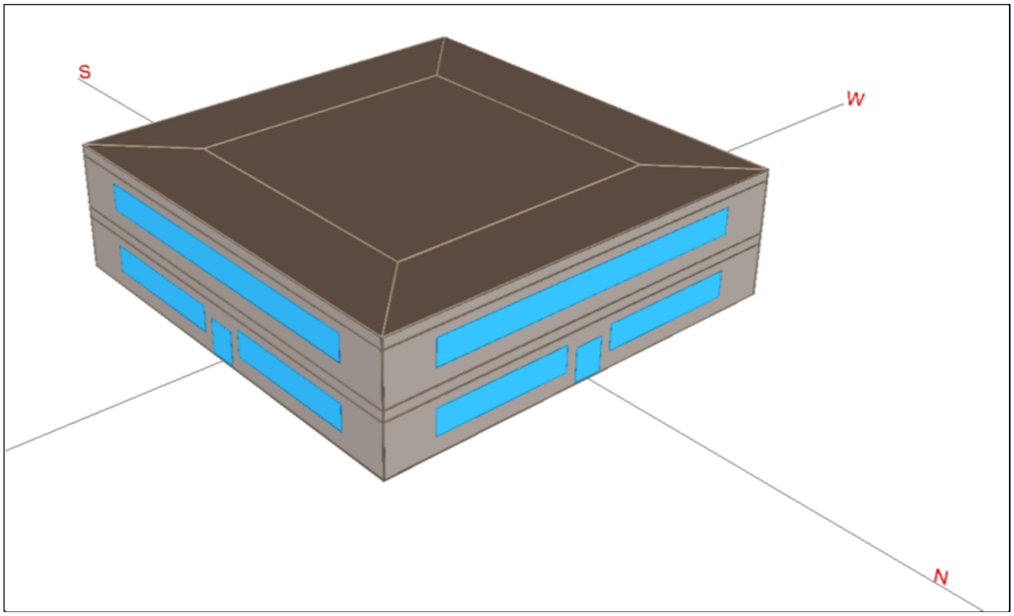


Figure 5-11: New construction commercial office building energy model

The equipment and occupancy loads and schedules from the existing building are used in the new construction case assuming similar building use. Therefore the baseline building has en EPD of 3.06 watts/ft^2 and the total occupancy is 334 people and uses the general equipment and occupancy schedules used in the retrofit office building energy model outlined in Figure 5-4 and Figure 5-5. The LPD used in the new construction building model is less than the retrofit office model because it was observed that in the newer facilities that they used newer lighting technology such as T8 lamps and T5 lamps with electronic ballasts. Therefore the LPD used in the model is 1.3 watts/ft^2 as recommended in NOM-007-ENER-2004 for the building area method for lighting power density.

It is assumed that all zones in the new construction case are conditioned, as it is becoming very common for commercial office buildings to use cooling in Mexico (Michael McNeil, 2006). Single zone, split system AC units will also be used in the baseline new construction building as they are very common for small to medium buildings in Mexico. The systems are auto-sized to meet the building loads for each individual zone. Standard perimeter core zoning is allocated to the building and each zone is served by a single split system AC unit. The EER used for these systems follows the more aggressive Sello FIDE labeling program efficiency standards for split system AC units which is EER 10.5 for systems having a cooling capacity between 18,000 Btu/h and 65,000 Btu/h. Also note that the same temperature set-points from the existing building model are also used in the new construction case, except with a constant 75 °F occupied temperature set-point.

5.2.2 Annual Energy End-Use

There is no existing data or standard reference buildings for Mexico to compare annual energy consumption of the baseline new construction model to typical annual energy consumption in this region. The office glazing study (M. Gijón-Rivera, 2011) is the only available source that provides any sort of annual energy use data. However the annual energy consumption from the glazing study is only based on the heating and cooling loads and does not consider electric consumption of lamps and equipment. The annual cooling and heating loads for the baseline building from the glazing study are roughly 38,000kWh/year and 2,500kWh/year respectively. These results are from a small office space of 516 ft^2 giving some sort of reference point of 73.6 $kWh/ft^2/year$ for new construction office buildings. It is however important to note that the system type used in the glazing study model is never described in the report, they only include the indoor temperature set points as floating between 20°C and 24°C.

The estimated annual and monthly electric consumption by end-use for the new construction prototype are included in Figure 5-12 and Figure 5-13. A larger portion of annual energy consumption is allocated to space cooling, 22%, when compared to the retrofit office building at 6%. The miscellaneous and lighting equipment make up 43% and 27% of the total annual energy consumption. Furthermore less than 1% of the total annual energy consumption is needed for space heating.

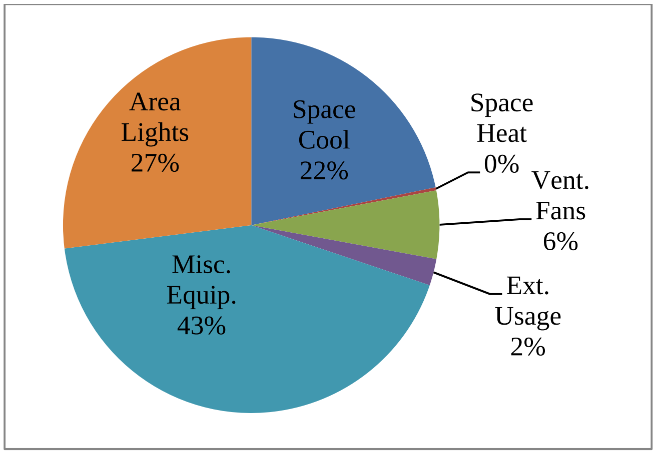


Figure 5-12: New construction office building annual electric consumption by end-use

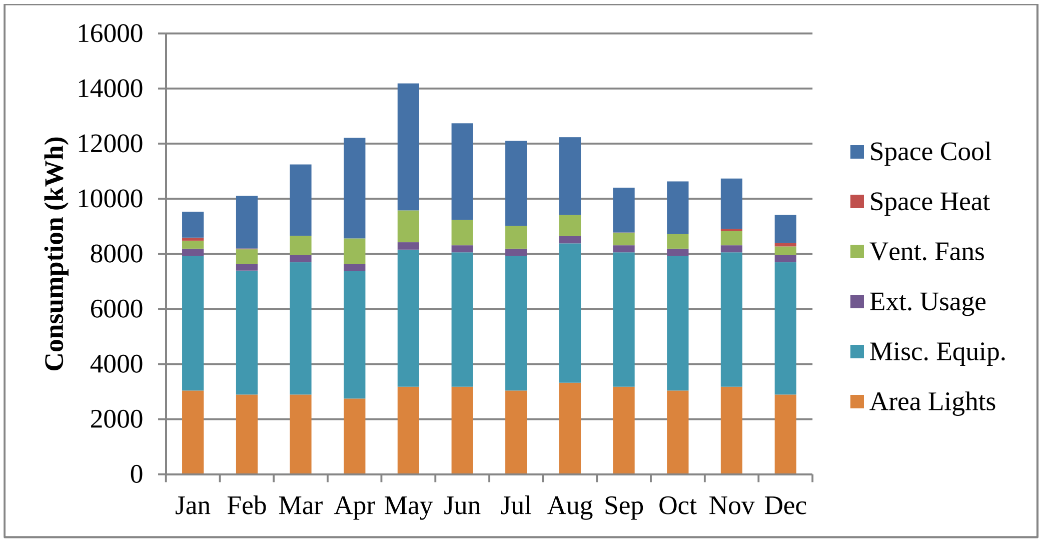


Figure 5-13: New construction office building monthly electric consumption by end-use

5.3 EEM Selection for Commercial Office Buildings in Salamanca Mexico

The energy efficiency case studies, Mexican Official Standards for energy efficiency (NOM-ENER), and minimum efficiency performance standards establish through the Sello FIDE program are used as a guideline in selecting appropriate energy efficiency measures for commercial buildings in Mexico. The ASHRAE 90.1 standard recommendations for a similar climate zone as Salamanca Mexico are also used as a reference point for selecting applicable energy efficiency measures. Overall, not only is it important to suggest EEMs that have the greatest potential for energy savings, it is equally important to suggest measures that could be adoptable in Mexican.

First, Table B-4-International Climate Zone Definitions in ASHRAE-90.1-2007 was used to determine an equivalent ASHRAE climate zone for Salamanca Mexico, as recommended for international cities that are not outlined in Table B-2 and B-3 in the standard. The standard, NMX-C-460-ONNCCE-2007 states that the cooling degree day for Salamanca is 3984 CDD50°F. The document doesn't however provide information on heating degree day, therefore it is assumed that there are fewer than 3600 HDD65°F in Salamanca and is therefore considered climate zone 3C (Warm Marine).

Table 5-7: NOM-ENER standards versus ASHRAE 90.1-2007 prescriptive standards

	Units	**ASHRAE 90.1-2007**	**NOM-ENER**
Assembly Roof U-value (insulation above deck)	(Btu/ft^2-hr-F)	0.048	0.069
Assembly Wall U-value (mass wall)	(Btu/ft^2-hr-F)	0.123	0.387
Maximum WWR	%	40%	40%
Window U-Value	(Btu/ft^2-hr-F)	0.6	0.94
Window SHGC	fraction	0.25	0.87
LPD Building area method	W/ft^2	1	1.30
Split System AC EER (18,000 Btu/h- 65Btu/h)	(Btu/h)/W	10.3	10.5

The recommended thermal insulation levels are all for continuous insulation in the ASHRAE recommendations. Also slab on grade floors for unheated spaces insulation not required. Both standards provide minimum HVAC equipment efficiency based on size and equipment type; however the NOM standards do not provide climate specific operation recommendations. There are no standards for the use of economizers, minimum outdoor air, or controls for HVAC equipment in the NOM-ENER standards as there are in ASHRAE 90.1.

5.3.1 EEMs Evaluated in the Commercial Office Building Analysis

A considerable effort was delegated toward selecting appropriate and meaningful energy conservation measures to be used in this investigation. Particularly, because the results of the optimization analysis are intended to verify or improve upon the existing NOM-ENER standard and also provide new recommendations where there is no previous guideline. Many of the same EEMs are evaluated in the retrofit case and the new construction buildings including assembly wall and roof R-values, glazing types, plug load reduction, daylighting and improved HVAC equipment efficiency.

The plug load and miscellaneous equipment EEMs are specific to the retrofit building case since there was detailed information about equipment types and numbers. The same equipment measures are used for the new construction case as the retrofit building since the EPD from the existing case was in the new construction case. The retrofit case considers new lamp technology (T8/T5 lamps with magnetic ballasts) in the optimization since most of the existing lamps are old T12s with magnetic ballasts. The new construction case on the other hand already incorporates newer lighting technology and has fewer lighting measures. The new construction case also investigates the variation of window to wall ratio from 60%-10%.

The glazing types included in this study are single pane glazing as the base-case for both office buildings, double pane glazing, double pane-low transmissive glazing, single pane low transmissive glazing, low emissive glazing and low solar gain-low emissive glazing. The double pane, low transmissive glazing meets the glazing properties in ASHRAE 90.1 for climate zone 3C. Low solar gain-low emissive glazing is also included in the optimization analysis. The ASHRAE Handbook of Fundamentals suggest that warmer climate regions utilize higher transmission levels in the visible portion of the solar spectrum and low transmission levels in all other sections of the solar spectrum to reduce heat gain. This can be done through using spectrally selective, low solar gain, low-emissive glazing. The material properties of each glazing material are shown in Table 5-8.

Table 5-8: Glazing material properties for window EEMs

Glazing type	**U-value Btu/ft^{2}-h-F**	**SHGC**	**Solar T**	**Solar A**	**Solar R**
Single pane	0.81	0.81	0.77	0.16	0.07
Solar E	0.65	0.55	0.48	0.45	0.07
Double pane	0.55	0.76	0.7	0.1	0.2
Low e	0.75	0.72	0.75	0.15	0.1
Low transmissive glazing	0.88	0.25	0.11	0.64	0.15
Double pane low transmissive	0.51	0.24	0.14	0.64	0.22

The EEMs for construction assembly R-values are from the prescriptive values provided in the NOM-800-ENER-2001 standard along with the recommendations from climate zone 3C from ASHRAE 90.1. The assembly R-values from NOM-008-ENER-2001 are specific to the cities of Guanajuato and Leon, the only two cities listed in the code that are located within the state of Guanajuato. The roof and wall assembly R-values are 14.55 h-ft^2-F/Btu and 2.58 h-ft^2-F/Btu respectively. A summary of the EEMs used in the retrofit and new construction building optimization analysis are included below in

Table 5-9 and Table 5-10 respectively. The associated cost estimates and additional details and assumptions are shown in Table 9-18 and Table 9-19 in Appendix 9.4.

The reduction of phantom loads is through the use of individual surge protectors at each office station. This is modeled where the unoccupied use fraction is 1% compared to the current 10%. Over 93% of the EPD is from plug loads that can be connected to surge protectors to reduce unoccupied energy consumption. Occupancy sensors are accounted for by reducing the connected lighting power density by 15% as recommended in Appendix G Table G3.2 of ASHRAE 90.1 for spaces less than or equal to 5,000 ft^2 and for non-24 hour building use. Finally, the minimum NOM energy efficiency standards for split system air conditioning units (EER 10.5) are used in the optimization analysis along with more efficient (EER 13.7) split system air conditioning units.

Table 5-9: List of EEMs and input values for the retrofit office building analysis

EEM	EEM Description	New Values	Basecase Values
A	Replace all incandescent lamps with CFLs	New LPD=2.3	LPD=2.35
B	Replace T12s with T8s, & magnetic ballasts for electronic ballasts	New LPD=1.58	LPD=2.35
C	Replace ceiling tiles w/ transparent material	New LPD=2.19	LPD=2.35
D	Daylighting	Open loop sensors, continuous dimming, 50 fc	No Daylight
E	Occupancy sensors in private offices	LPD=1.99	LPD=2.35
F	Replace CRT computer screens with LCD	New EPD= 2.96	EPD=3.06
G	Reduce Number of inkjet printers	New EPD= 2.75	EPD=3.06
H	High efficiency refrigerators	New EPD= 3.04	EPD=3.06
I	New televisions	New EPD= 3.03	EPD=3.06
J	Reduce Phantom plug loads	Unoccupied use fraction=0.01 schedule	Unoccupied use fraction=0.1 schedule
K	More efficient Split system AC units	EER=10.25(EIR=0.333)	EER=8 (EIR=0.43)
L	More efficient Split system AC units	EER=10.5 (EIR=0.325)	EER=8 (EIR=0.43)
M	Add exterior wall insulation R-2	Assembly U-Value=0.2	Assembly U-Value= 0.352
N	Add exterior wall insulation R-7	Assembly U-Value=0.05	Assembly U-Value= 0.352
O	Add exterior wall insulation R-12	Assembly U-Value=0.1	Assembly U-Value= 0.352
P	Add exterior roof insulation R-8	Assembly U-Value=0.1	Assembly U-Value= 0.595
Q	Add exterior roof insulation R-13	Assembly U-Value= 0.068	Assembly U-Value= 0.595
R	Add exterior roof insulation R-19	Assembly U-Value= 0.05	Assembly U-Value= 0.595
S	Improved glazing	Double pane, clear	Single pane, clear
T	Improved glazing	Single pane, low transmissive glazing=0.1	Single pane, clear
U	Improved glazing	Low-e for hot climates	Single pane, clear
V	More efficient Split system AC units	EER=13.7 (EIR=0.25)	EER=8 (EIR=0.43)

Table 5-10: List of EEMs and input values for the new construction office building analysis

ECM	**ECM Description**	**New Values**	**Basecase Values**
A	Daylighting Sensors in perimeter zones	Open loop sensors, continuous dimming, 50 fc level	No Daylight
B	Occupancy sensors in private offices	New LPD=1.105	LPD=1.3
C	Replace all CRT computer screens with LCD screens	New EPD= 2.96	EPD=3.06
D	Reduce Number of inkjet printers	New EPD= 2.75	EPD=3.06
E	High efficiency refrigerators	New EPD= 3.04	EPD=3.06
F	New televisions	New EPD= 3.03	EPD=3.06
G	Reduce Phantom plug loads	Unoccupied use fraction=0.01 schedule	Unoccupied use fraction=0.1 schedule
H	More efficient split system AC units	EER=13.7 (EIR=0.25)	EER=10.5 (EIR=0.325)
I	Add exterior wall insulation R-1	Assembly U-Value=0.384	Assembly U-Value= 0.566
J	Add exterior wall insulation R-6	Assembly U-Value=0.0.125	Assembly U-Value= 0.566
K	Add exterior wall insulation R-13	Assembly U-Value=0.0667	Assembly U-Value= 0.566
L	Add exterior roof insulation R-8	Assembly U-Value=0.1	Assembly U-Value= 0.577
M	Add exterior roof insulation R-13	Assembly U-Value= 0.068	Assembly U-Value= 0.577
N	Add exterior roof insulation R-19	Assembly U-Value= 0.05	Assembly U-Value= 0.577
O	Improved glazing	Double pane, low transmissive	Single pane, clear
P	Improved glazing	Single pane, low transmissive glazing	Single pane, clear
Q	Improved glazing	Low-e glazing for hot climates	Single pane, clear
R	Reduce WWR	30% WWR	40% WWR
S	Reduce WWR	20% WWR	40% WWR
T	Reduce WWR	10% WWR	40% WWR

6 OPTIMIZATION RESULTS AND FINAL RECOMMENDATIONS

This section presents the results and recommendations for retrofit and new construction residential buildings and commercial office buildings respectively.

6.1 Residential Buildings

The residential study includes an evaluation of various combinations of energy efficiency and thermal comfort measures to arrive at an optimum set of recommendations for existing and new construction residential buildings. The optimum point is the minimum annualized energy related costs and the corresponding percent annual source energy savings. Four separate optimizations are performed, the existing-unconditioned home, the existing-conditioned home, the new construction-unconditioned home and the new construction-conditioned home. Also, as a summation, a qualitative market analysis is included to highlight the potential benefits of large scale adoption.

6.1.1 Retrofit Residential Building Optimization Analysis Results

The baseline annualized energy related cost for the conditioned and unconditioned homes are 797 US$ and 557 US$ respectively. These costs are obtained before any of the energy efficiency and thermal comfort measures are applied. Therefore, it is determined that the cost of improved thermal comfort for a typical home in Salamanca is roughly 240 US$ per year. The optimum point for the unconditioned case occurs at 17.2% annual energy savings and a corresponding minimum cost of 433 US$ as shown in Figure 6-1. The conditioned case on the other hand has a greater opportunity for energy savings and achieves a minimum cost of 542 US$ at 35.0% energy savings as indicated in Figure 6-2.

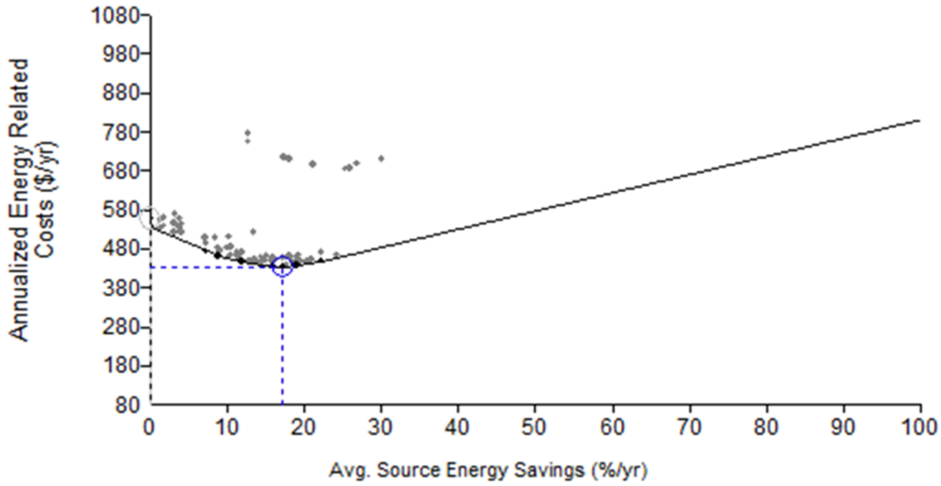


Figure 6-1: Retrofit unconditioned optimization curve

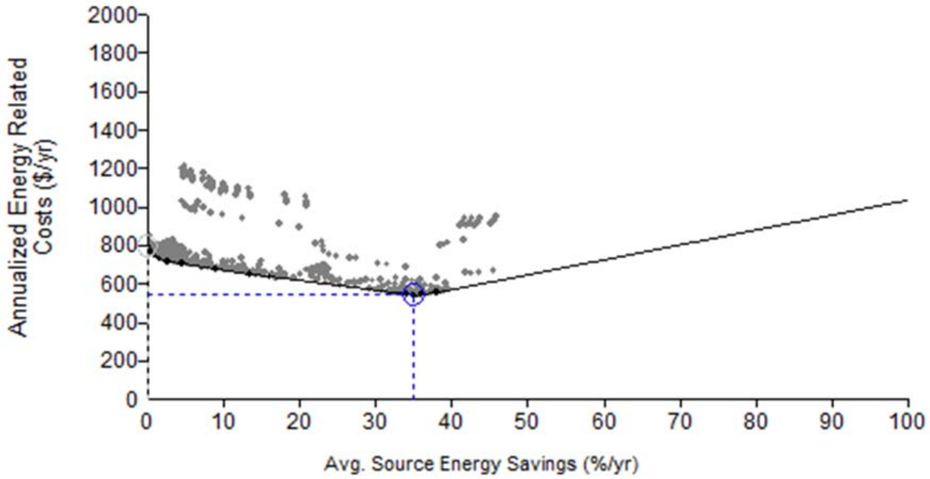


Figure 6-2: Retrofit conditioned optimization curve

The optimum point for the conditioned case includes implementing methods to reduce miscellaneous plug loads, R-1.4 m^{2-}K/W roof assembly, low-flow shower heads and sinks, an electric stove, 100% compact fluorescent lamps (CFLs), and R-0.35 m^{2-}K/W trunk-branch DHW pipe distribution. The optimum point for the unconditioned case includes all of the same measures as the conditioned model with the exception of the added roof insulation. A summary of the percent source energy savings and annualized energy related costs at the baseline, minimum cost, PV start and at the net zero energy option is also outlined in Table 6-1 for the unconditioned and the conditioned models. A detailed summary of the results for the optimum point are included in Table 9-13 and Table 9-14 of Appendix 9.3.

Table 6-1: Retrofit residential optimization summary

Point of evaluation	**Retrofit unconditioned**	**Retrofit conditioned**
Baseline (%savings, $ annual)	(0%, $557)	(0%, $797)
Optimum (%savings, $ annual)	(17.2%, $433)	(35%, $542)
PV start (%savings, $ annual)	(22.2%, $449)	(38.1%, $557)
NZE (%savings, $ annual)	(100%, $920)	(100%, $1185)

The comparison between the unconditioned and the conditioned optimization results, illustrated in Figure 6-3, reveal that the optimum point for the conditioned case (542 US$) is roughly the cost neutral point for the unconditioned case (557 US$). It is also useful to look at the end uses to gauge measures with highest potential of the energy savings. Figure 6-4 and Figure 6-5 include a summary of the total annual source energy consumption by end-use for the unconditioned and conditioned home models, respectively. The minimum cost option and the PV start options are compared with the baseline model. In the unconditioned case, the largest energy savings are obtained for domestic hot water, miscellaneous equipment and lighting. The conditioned case has similar energy savings as the unconditioned case for miscellaneous equipment, and domestic hot water, however the greatest area for energy savings is for cooling, which is primarily attributed to the use of roof insulation.

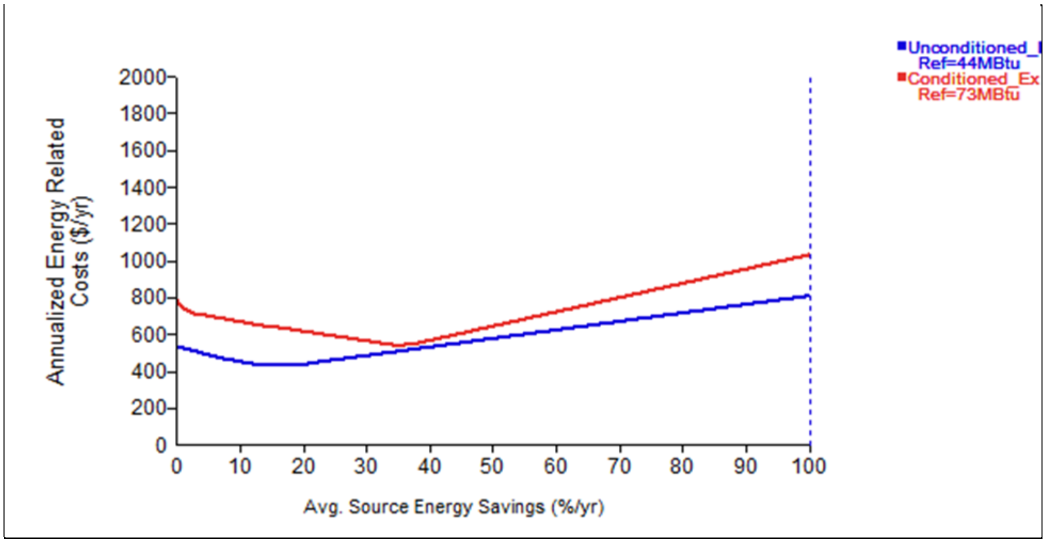


Figure 6-3: Retrofit optimization curve comparison between the unconditioned and conditioned cases

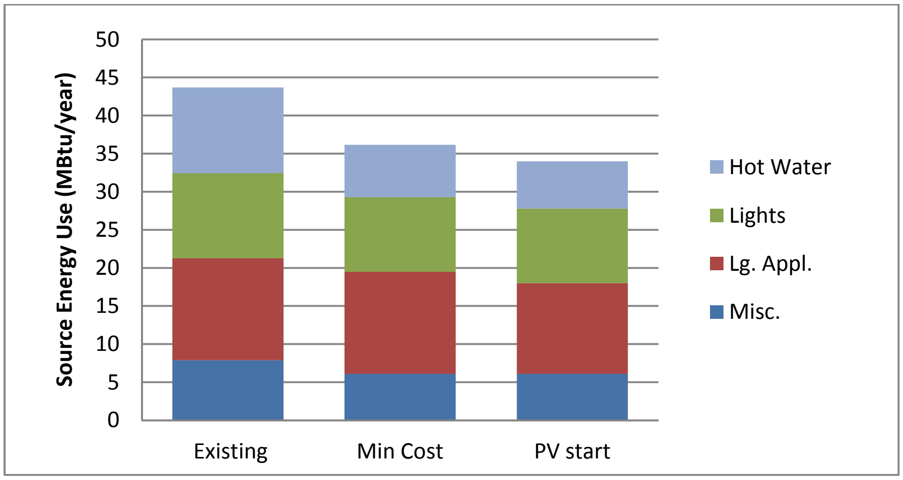


Figure 6-4: Retrofit-unconditioned annual source energy by end use

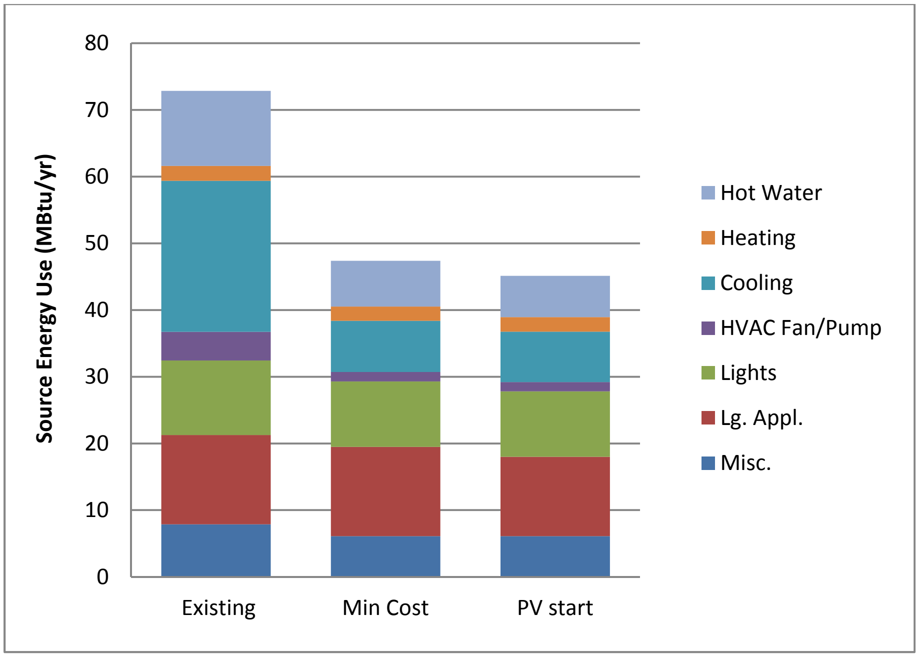


Figure 6-5: Retrofit-conditioned annual source energy by end use

The two renewable energy technologies included in this study are solar domestic hot water systems and photovoltaic systems. Although solar DHW has potential energy savings, the high implementation cost make it unfeasible. Similar overall annual energy savings are obtained with other energy conservation measures. Figure 6-1 and Figure 6-2 show simulation points hovering above the optimization curve, those points are the options including solar domestic hot water. Note that the cost for labor and materials are assumed to be comparable to those in the U.S.

The results for the photovoltaic system are shown by the sloped line leading to 100% energy savings. The size of PV to arrive at a zero net energy (ZNE) solution for the unconditioned home model is a 3kW system and the conditioned home model is a 4 kW system. Both systems are south facing and installed in inclined panels to match the latitude in Salamanca. The slope of the line toward ZNE is relatively shallow where the annualized energy cost for 100% annual energy savings is 920 US$ for the unconditioned and 1185 US$ for the conditioned cases. Similar to the solar DHW system, U.S. costs are assumed for PV material and labor cost. The results indicate that PV technology may be desirable with the appropriate subsidies for implementation costs.

The PMV thermal comfort analysis is used as verification for the optimization results by evaluating the improved indoor thermal comfort after implementing the recommended energy efficiency measures. First, the PMV ratings above and below the acceptable comfort range (i.e., PMV values between -1 and 1) are determined for the baseline and optimal cases for both conditioned and unconditioned building models. The unconditioned building model shows roughly 1550 hours above 1 PMV and 150 hours below 1 PMV annually. This is in contrast to the conditioned building models, where thermal comfort is maintained throughout the year, as expected.

The thermal comfort analysis is also applied at the optimum building models to show the impact of the final recommendations. The annual energy consumption in the conditioned new construction and existing building models decreases relative to the baseline when thermal insulation is added to the building and as predicted, the annual PMV ratings remain relatively constant. However, when the optimum set of EEMs from the conditioned case are applied to the unconditioned baseline home model, the number of hours outside of the thermal comfort zone decreases significantly shown in Figure 6-6.

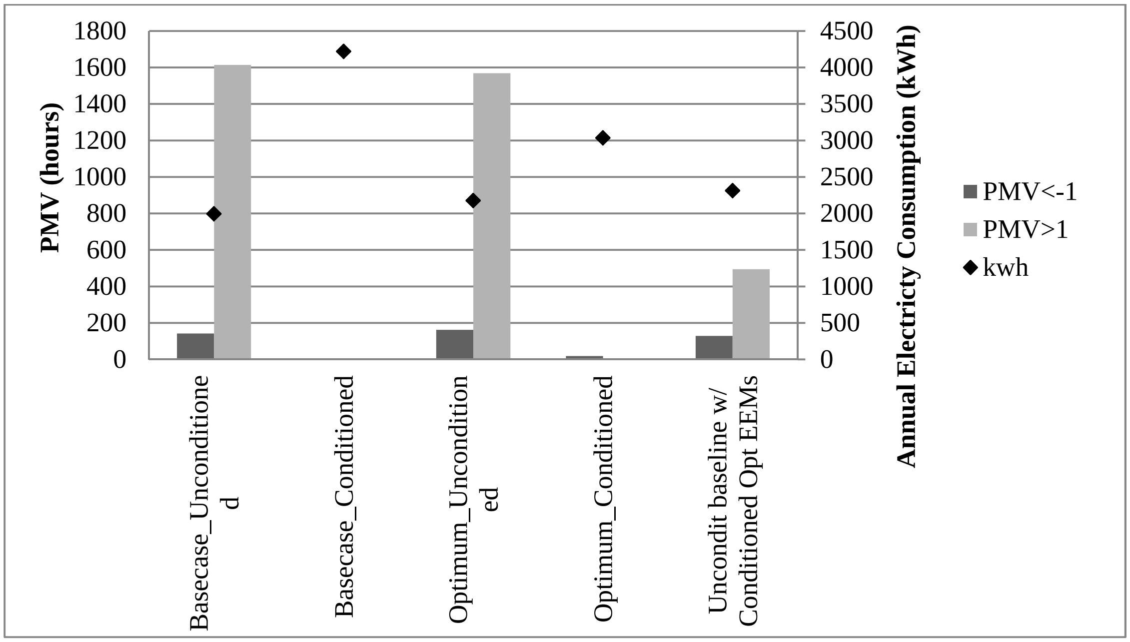


Figure 6-6: Retrofit construction case- PMV thermal comfort analysis

In the conditioned baseline retrofit case, the cost of installing an electric heat pump is estimated at $4394 US$ for a 3.5 ton unit. However when roof insulation is added to the unconditioned retrofit building the number of hours outside of the thermal comfort zone decreases by almost 60% for a much lower initial cost of roughly 426 US$.

6.1.2 New Construction Residential Building Optimization Analysis Results

The results for the new construction case have a higher potential for cost and energy savings due to the reduced implementation costs and larger flexibility in selecting measures specially those related to the building envelope. Similarly, the new construction baseline annualized energy costs are also lower than when compared to the retrofit baseline case. The annualized energy related costs for the conditioned and unconditioned new construction baseline homes are 764 US$ and 495 US$ dollars respectively. Thus, without applying energy efficiency measures, the cost of improved thermal comfort for new homes in this part of Mexico is almost 270 US$ per year. In the new construction homes, the optimum energy efficiency combination for the unconditioned case occurs at 19.0% annual energy savings and a corresponding minimum annual cost of 381 US$ as shown in Figure 6-7. The conditioned case on the other hand has a higher opportunity for energy savings and achieves a minimum cost of 315 US$ at 50.6% annual energy savings as outlined in Figure 6-8.

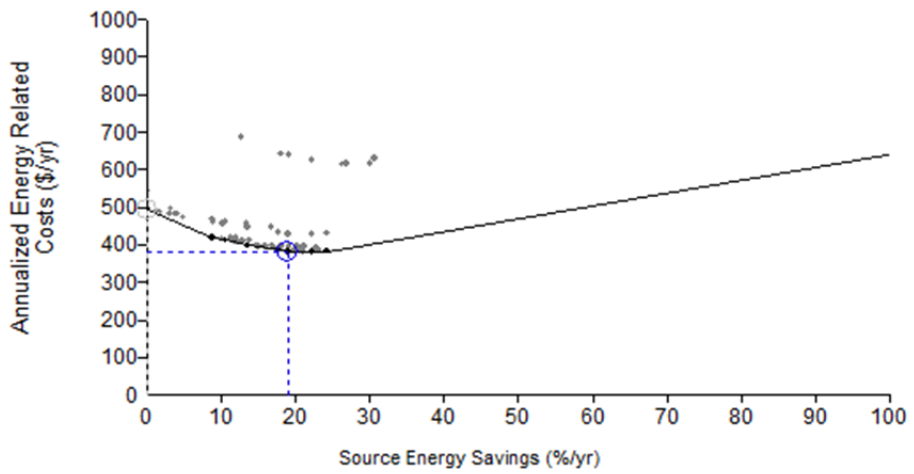


Figure 6-7: New construction unconditioned optimization curve

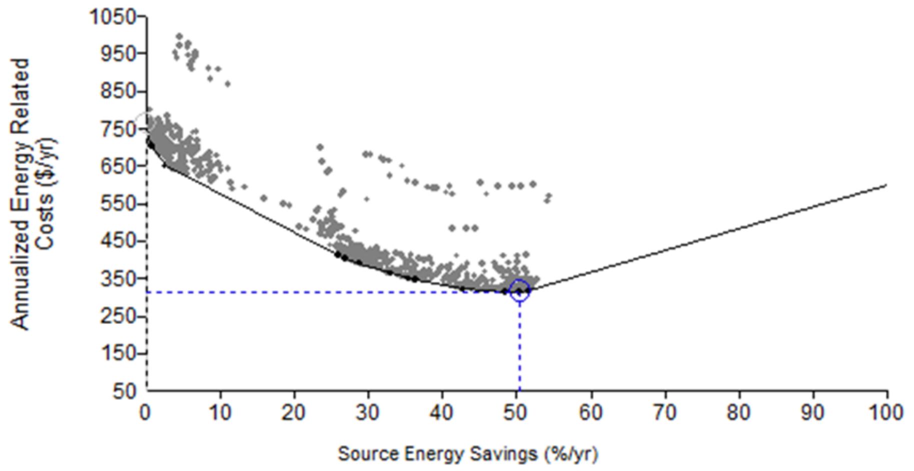


Figure 6-8: New construction conditioned optimization curve

The optimum point for the conditioned case includes reducing miscellaneous plug loads, R-1.4 m^{2}·K/W roof assembly, R-1 m^{2}·K/W wall assembly, white or cool white asphalt shingle roof finish, 15% window to wall ratio, high efficiency refrigerator and washing machine, low-flow shower heads and sinks, an electric stove, 100% CFLs, SEER 17 AC unit, and R-0.35 m^{2}·K/W trunk-branch DHW pipe distribution. The optimum combination of energy efficiency measures for the unconditioned analysis include an electric stove, 100% CFLs, reduced miscellaneous equipment loads, a high efficiency clothes washing machine, low-flow showers and sinks, and R-0.35 m^{2}·K/W trunk-branch DHW pipe distribution.

Additionally, the summary of the annual percent energy savings and the annualized energy related costs for the new construction building models at the baseline, minimum cost, PV start points and net zero energy (NZE) point are included in Table 6-2. Additionally, a detailed summary of the results for the optimum point are included in Table 9-15 and Table 9-16 of Appendix 9.3.

Table 6-2: New construction residential optimization summary

Point of evaluation	**New construction unconditioned**	**New construction conditioned**
Baseline (%savings, $ annual)	(0%, $495)	(0%, $764)
Optimum (%savings, $ annual)	(19%, $381)	(50.6%, $315)
PV start (%savings, $ annual)	(24.2%, $383)	(51.8%, $316)
NZE (%savings, $ annual)	(100%, $726)	(100%, $773)

When comparing the unconditioned and the conditioned new construction buildings as shown in Figure 6-9, the optimum point for the conditioned case (315 US$) has lower annualized energy cost than the optimum point for the unconditioned case (381 US$). Therefore, higher energy savings can be obtained for new construction at a low cost when the total implementation costs are included in the 30 year mortgage.

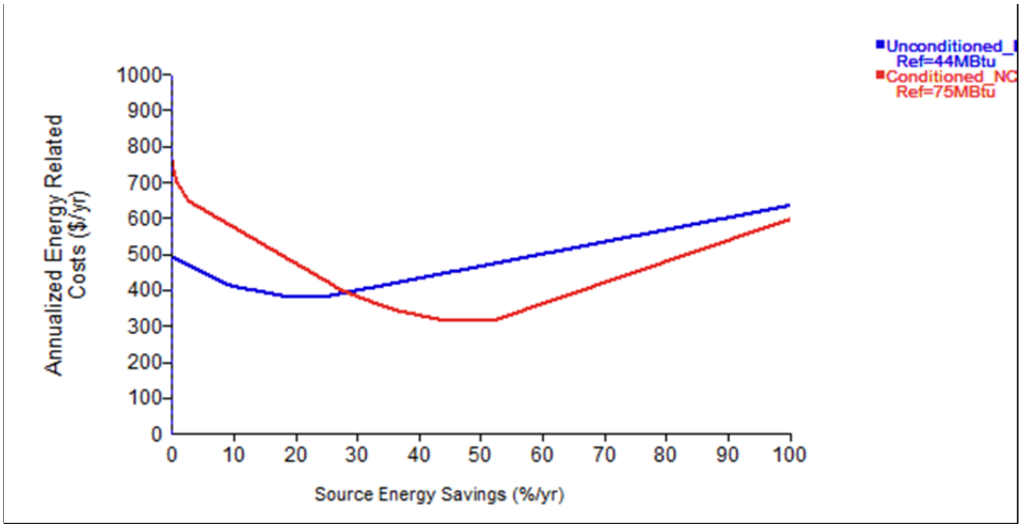


Figure 6-9: New construction optimization curve comparison: unconditioned and conditioned cases

Figure 6-10 and Figure 6-11 provide a summary of the total annual source energy consumption by end-use for the unconditioned and conditioned home models, respectively. The results indicate that a significant reduction can be achieved in annual cooling energy for the conditioned case when compared to the baseline building. Similar to the retrofit study, the unconditioned building shows the largest energy savings related to hot water, miscellaneous equipment and lighting. The minimum cost option in the conditioned case has a lower annual energy consumption than the unconditioned case because it is cost effective to install more efficient appliances and use condensing tank-less domestic hot water heater. The cooling loads are primarily reduced by including roof and wall insulation to achieve assembly R-values of 1.4 m^2-K/W and 1 m^2-K/W respectively.

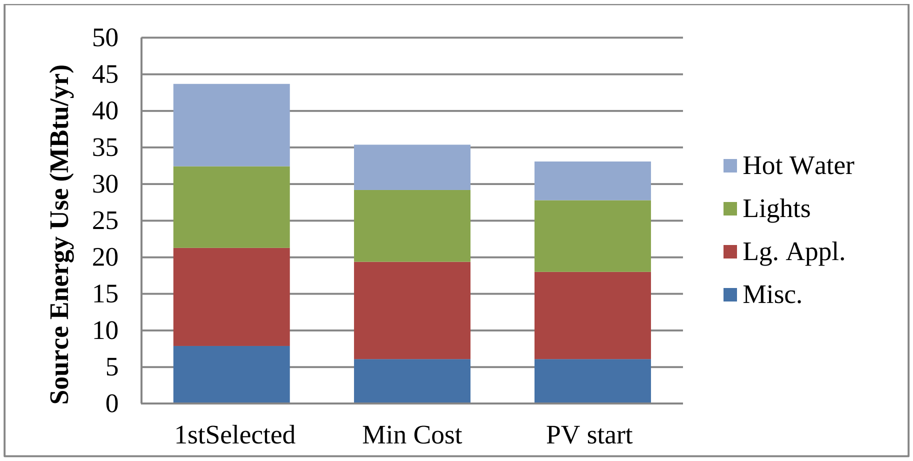


Figure 6-10: New construction-unconditioned annual source energy by end use

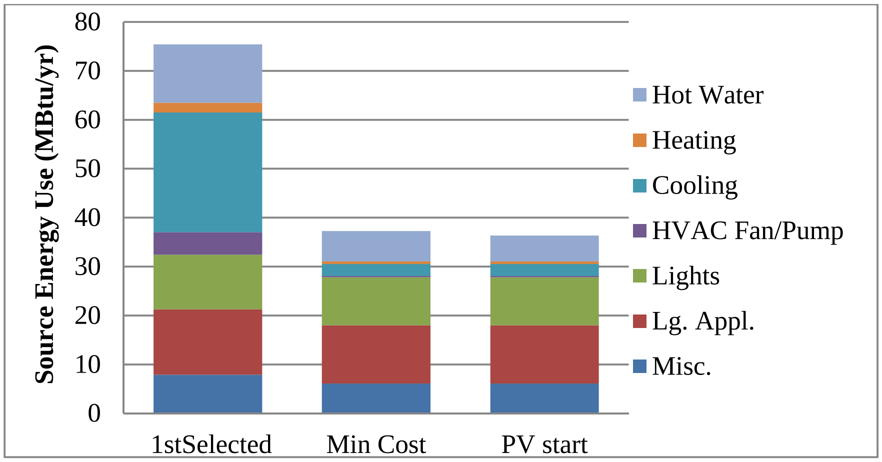


Figure 6-11: New construction-conditioned annual source energy by end use

Similar to the retrofit case, installing a solar domestic hot water system is not cost-effective. The size of PV to achieve a ZNE home for the unconditioned case is a 3kW system and a 4 kW system for the conditioned case. When implementing the PV system in the conditioned building, the annualized energy related cost for the 30 year period is only 773 US$, which is roughly the same annual cost when compared to the baseline. The annualized energy related cost of implementing PV in the unconditioned home is 726 US$.

The annual energy consumption in the new construction conditioned model decreases relative to the baseline when thermal insulation is added to the exterior walls and roof and as anticipated. However the annual PMV ratings remain relatively constant. The hours outside of the thermal comfort zone decrease significantly when the thermal comfort measures from the conditioned case are applied to the unconditioned baseline model, as indicated in Figure 6-12.

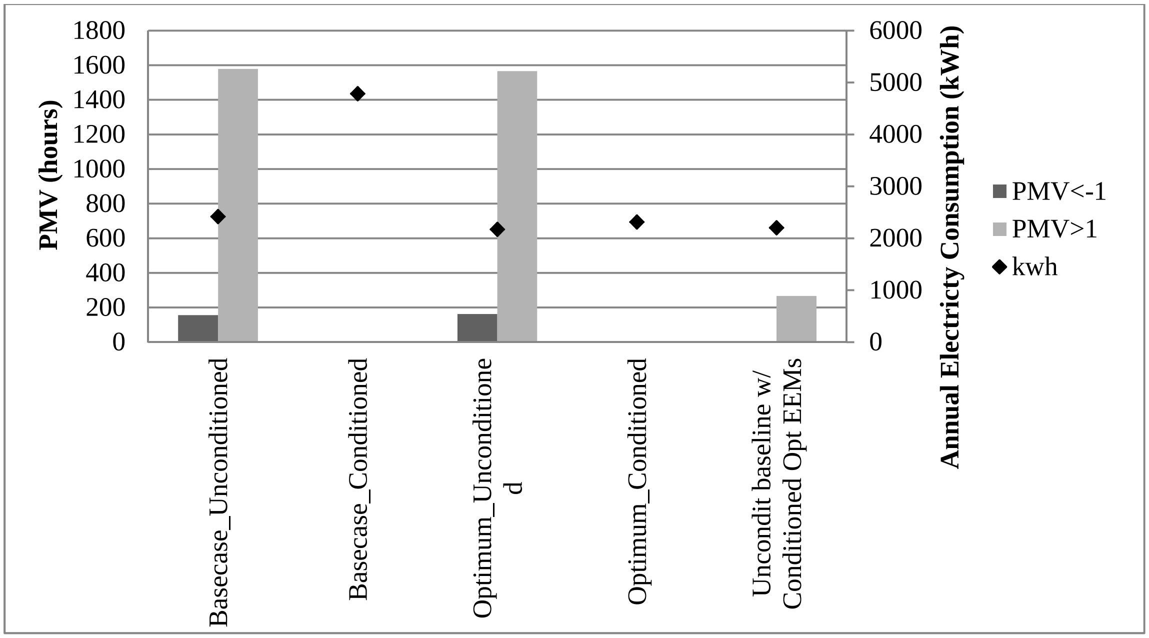


Figure 6-12: New construction case-PMV thermal comfort analysis

The cost of installing an electric heat pump in the new construction baseline conditioned model is approximately $4622 for a 4 ton unit and only costs $1952 to install roof and wall insulation. Furthermore the annual electricity consumption in the optimized new construction building is almost the same as the unconditioned baseline building with the optimum combination of EEMs from the conditioned case. The analysis results indicate that there is a strong correlation between the use of thermal insulation and improved thermal comfort in unconditioned homes. Implementing thermal insulation also proves to be a cost effective way of improving thermal comfort when compared to the cost of installing a unit air conditioner.

6.1.3 Residential Market Analysis

If the optimum annual energy savings for the existing, unconditioned home is applied to all existing residential buildings in the city of Salamanca, the city has the potential of saving 13,817 MWh of electricity annually, or nearly 17% of the total domestic energy consumption. Similarly, if the same energy savings is applied to the existing housing stock nationally, nearly 8,425,170 MWh is saved per year. This equates to avoiding 1.5 MW of power production in Salamanca annually and almost 914 MW per year nationally, when assuming a power plant capacity factor of 95%.

Since it is unlikely for the entire country to adopt all of the recommended EEMs, estimates for 10% and 50% of market penetration is also in included in Table 3. Estimated annual energy savings are also included for the new construction housing units predicted by 2030. It is assumed that 50% of the new construction homes have air conditioning units, while the other half are unconditioned. Table 2-1 also outlines pertinent data used for the market analysis along with other general characteristics for the city of Salamanca, the state of Guanajuato and the country of Mexico. Such data includes the population, number of housing units, number of occupants per home and the total domestic annual energy consumption.

Table 6-3: Characteristics for the city of Salamanca, state of Guanajuato and country of Mexico

Data	**Mexico**	**Guanajuato**	**Salamanca**
Population	112,336,538	5,486,372	260,732
Housing units	28,607,568	1,276,584	64,073
Average number of occupants/home	3.9	4.3	4.1
Total domestic consumption (MWh/year)	48,700,400[a]	1,481,564[b]	79,865[b]
Estimated number of homes by 2030	50,000,000	2,231,200	111,986
Estimated domestic consumption 2030 (MWh/year)	85,118,036	2,589,462	139,587
Existing buildings unconditioned			
Savings for 10% adoption (MWh/year)	842,517	25,631	1,382
Savings for 50% adoption (MWh/year)	4,212,585	128,155	6,908
Savings for 100% adoption (MWh/year)	8,425,169	256,311	13,817
New construction by 2030[c]			
Savings for 10% adoption (MWh/year)	1,267,334	38,555	2,078
Savings for 50% adoption (MWh/year)	6,336,669	192,774	10,392
Savings for 100% adoption (MWh/year)	12,673,337	385,548	20,783

Source (INEGI, 2010) a.) Total domestic consumption in the country (Jorge Alberto Rosas-Flores, 2011) b.) Total domestic consumption in the state of Guanajuato and the city of Salamanca (SIEG, 2003) c.) Only new construction buildings are included in this estimate, 50% are conditioned and 50% are unconditioned

6.1.4 Thermal insulation construction detail

The voluntary residential building thermal insulation standard, NMX-C-460-ONNCCE-2009 provides recommendations for construction assembly R-values instead of specific levels of insulation for different types of construction. The exterior brick walls and concrete roof slab cannot achieve the desired thermal insulation without the addition of an insulating material. Board insulation is recommended for its ease of installation because it is common practice to apply board thermal insulation to exterior building surfaces in many different parts of the world. Furthermore, multiple studies recommend exterior thermal insulation over interior thermal insulation.

Figure 6-13 is an image of board insulation installed on an exterior brick wall while Figure 6-14 shows a cross section of a typical home with exterior board insulation applied to the wall and roof. In order to apply the exterior wall insulation, a smoothing concrete layer is applied to the brick wall. Then an adhesive is applied to the smoothing surface where the exterior board insulation is attached to the adhesive. Finally, a concrete plaster finish is applied to the exterior surface of the insulation. A reinforcing fiberglass mesh is placed between layers of concrete plaster finish. Anchors are also recommended to secure the insulation board, especially when the structural integrity of the smoothing layer (between the brick and the insulation) is unknown or when little or no smoothing layer is used. (MAPEI, 2011) The exterior roof insulation is installed on top of the vapor control layer and should be attached using adhesive. Then an exterior roof sheathing material is applied upon the exterior insulation and secured using anchor bolts. (Quinn Therm , 2011)

Figure 6-13: Exterior wall board insulation (CommonWealth LLC, 2009)

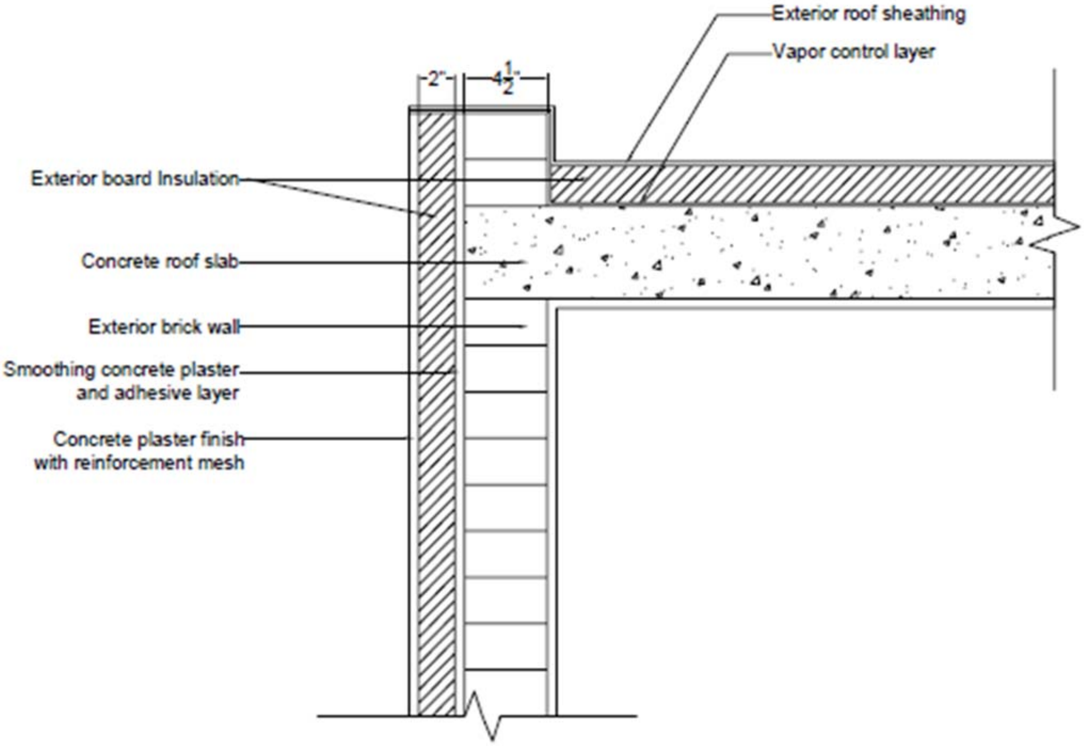


Figure 6-14: Roof and exterior wall construction detail

6.2 Commercial Office Buildings

This section includes the results of the manual optimization analysis for an existing office building and new construction office building prototype in Salamanca Mexico. The optimum point is the group of measures with the minimum life cycle cost. Note that throughout the commercial building optimization analysis, the LCC savings are presented as a fraction of the baseline building LCC.

6.2.1 Retrofit Office Building Optimization Analysis Results

The optimum point occurs at 47% annual energy savings and a corresponding minimum life cycle cost of 245,486 US$ where the baseline LCC is estimated at 388,346 US$. The minimum cost optimum includes various lighting EEMs such as 100% CFLs used throughout the building, occupancy sensors in private offices and conference rooms, daylighting control and replace 5% of the ceiling tiles in the lobby area with skylights. The equipment measures included in the optimum point are surge protector power strips for each work station to reduce phantom loads and reduce the number of individual inkjet printers and have one multi-function copy machine in common office spaces.

The combination of measures which achieves the greatest percent annual energy savings (49%) before considering PV includes replacing the old CRT computer monitors with LCD computer monitors. The most cost effective measures for this building are geared toward reducing equipment and lighting loads since they have the greatest annual energy consumption. The existing building optimization analysis is shown in Figure 6-15 while a summary of the results for the baseline, optimum point, PV start and the net zero energy points are included in Table 6-4.

Table 6-4: Retrofit office building optimization summary

Point of evaluation	**Energy savings**	**LCC (US$)**
Baseline	0%	388,346
Optimum	47%	245,486
PV Start	49%	248,887
NZE	100%	438,601

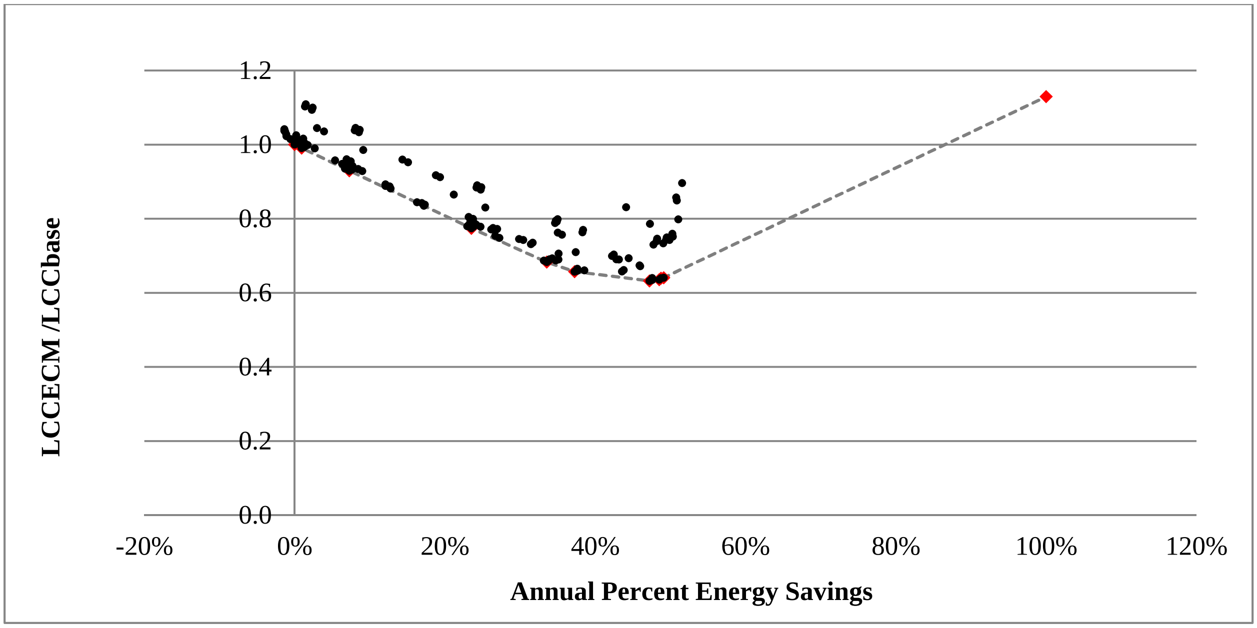


Figure 6-15: Retrofit commercial office building optimization curve

The annual energy end use for the baseline, optimum and the PV start option are depicted in Figure 6-16. Not only are the lighting and equipment loads reduced, the annual cooling energy is also reduced by 31% at the optimum point, indicating the additional benefit of reducing these internal loads.

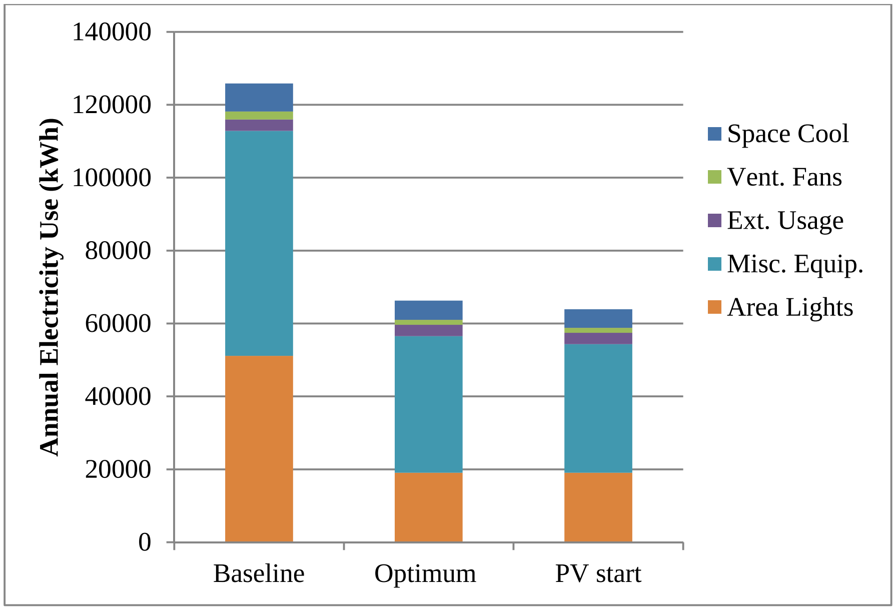


Figure 6-16: Retrofit office building annual energy by end use

Thermal comfort measures such as thermal insulation and different glazing types were include in the optimization analysis to see the impact of implementation. However since the cooling load is such a small part of the annual energy consumption, it was quickly seen that they were not cost effective measures. This is especially true when adding thermal insulation to the roof and walls, because it increases the annual energy consumption. When looking into this further, it is concluded that the primary cooling load is from internal gains and the use of thermal insulation does not allow for the heat to escape outward. This is verified by looking at the hourly indoor air temperature and the outdoor air temperature for the cooling design day, May 9th (Figure 6-17). The average daily temperature is roughly 80 F with a minimum temperature at night of 64 F and a maximum temperature of 97 F for only a few hours in the late afternoon.

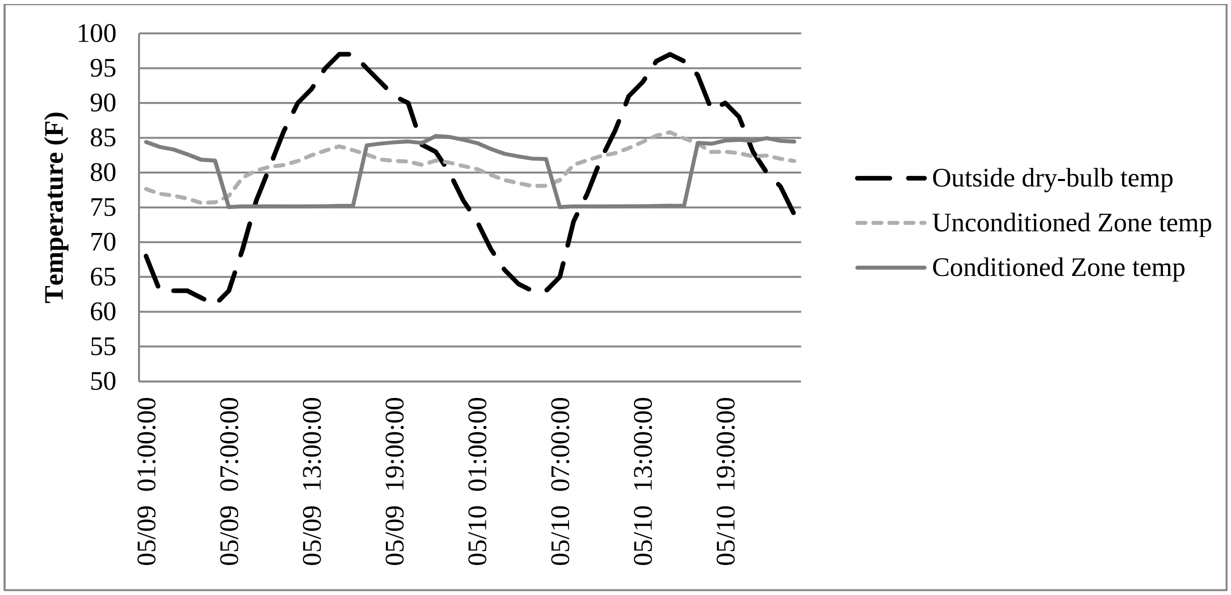


Figure 6-17: Modeled indoor air temperature and TMY outdoor air temperature

Furthermore, the benefits of double pane, low transmissive and low solar gain low-emissive glazing types are very small for the retrofit commercial office building, less than 0.5% annual energy savings from the baseline for any one of the improved glazing types. There are various reasons supporting the low annual energy savings from improved glazing. The building is also very old where the building has a total of 3% WWR. The covered courtyard architectural also limits direct solar gains. Furthermore, the annual energy consumption from cooling is less than 8%. Therefore there is very little room for improvement for EEMs related to reducing cooling energy consumption. Also, when looking at the disaggregated building loads in Figure 6-18, a large majority of the load throughout the year is from the internal gains, not from exterior building envelope elements. Furthermore, a comparison is made in the baseline building for the annual cooling energy consumption with and without internal loads (people, lighting and equipment) as shown in Figure 6-19. The annual cooling energy decreases by 83% when the internal loads are absent.

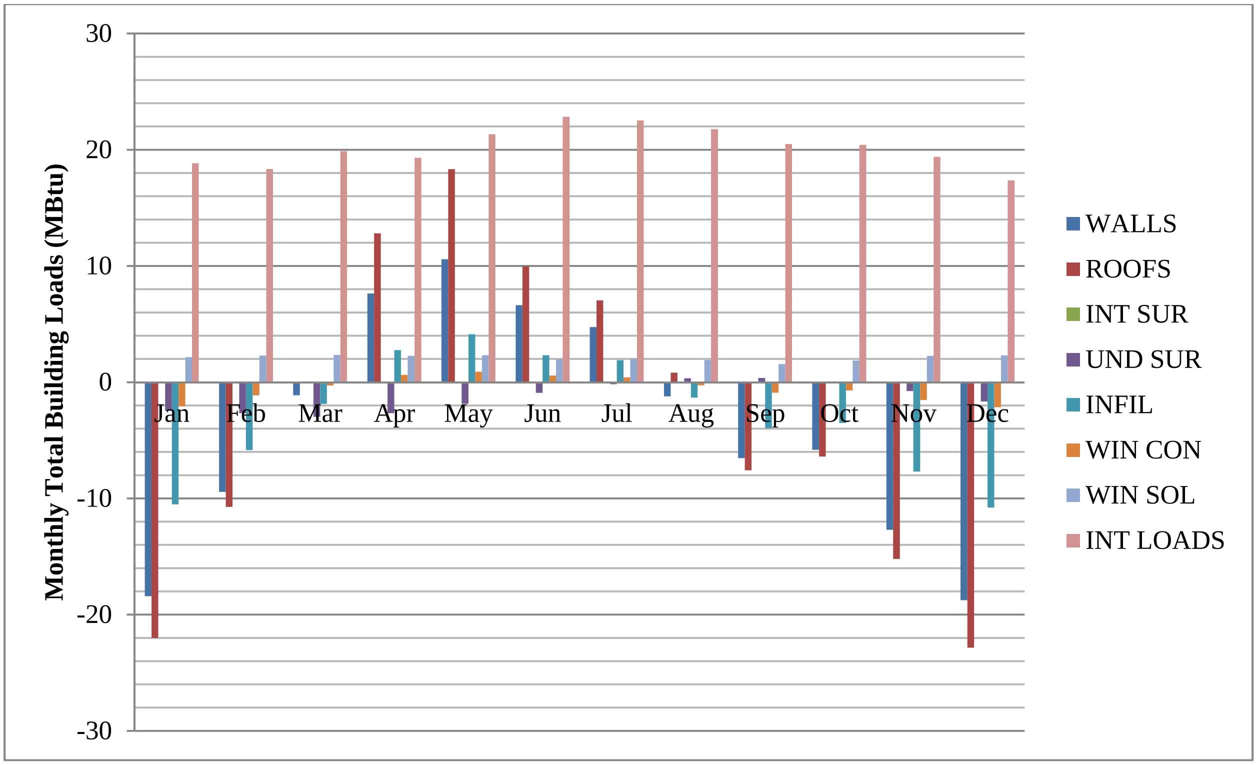


Figure 6-18: Baseline model disaggregated monthly building loads

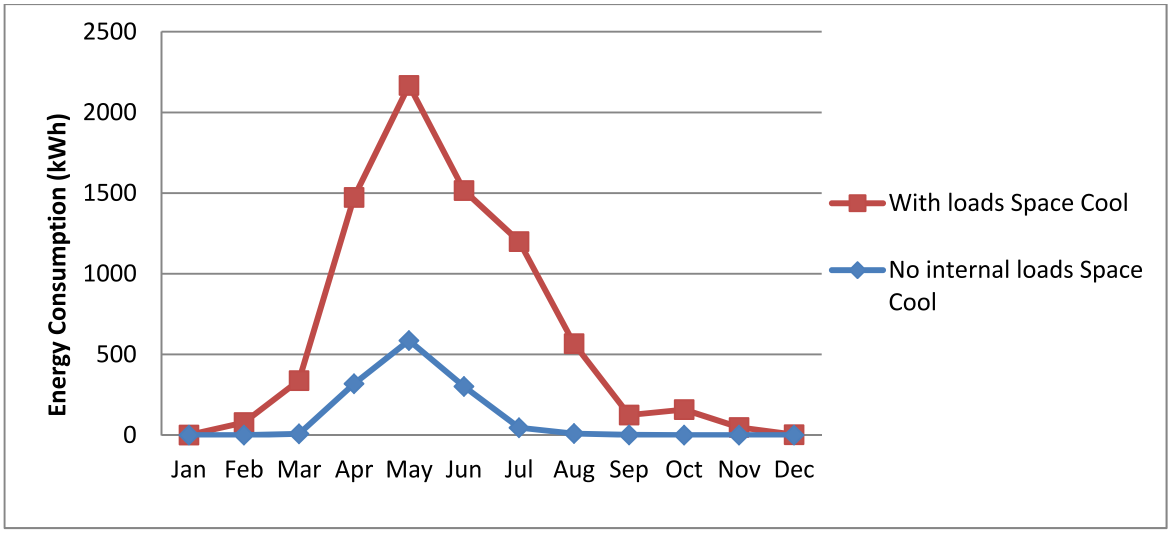


Figure 6-19: Cooling energy use with and without internal loads

Although improved glazing types are not economically feasible for the retrofit building application, a parametric analysis was performed for various types of improved glazing. The parametric study indicates that the most important glazing property is the solar heat gain coefficient. For example Figure 6-20 includes single pane and double pane low transmissive glazing where the double pane glazing has a lower U-value. Both glazing types have roughly the same energy reduction potential.

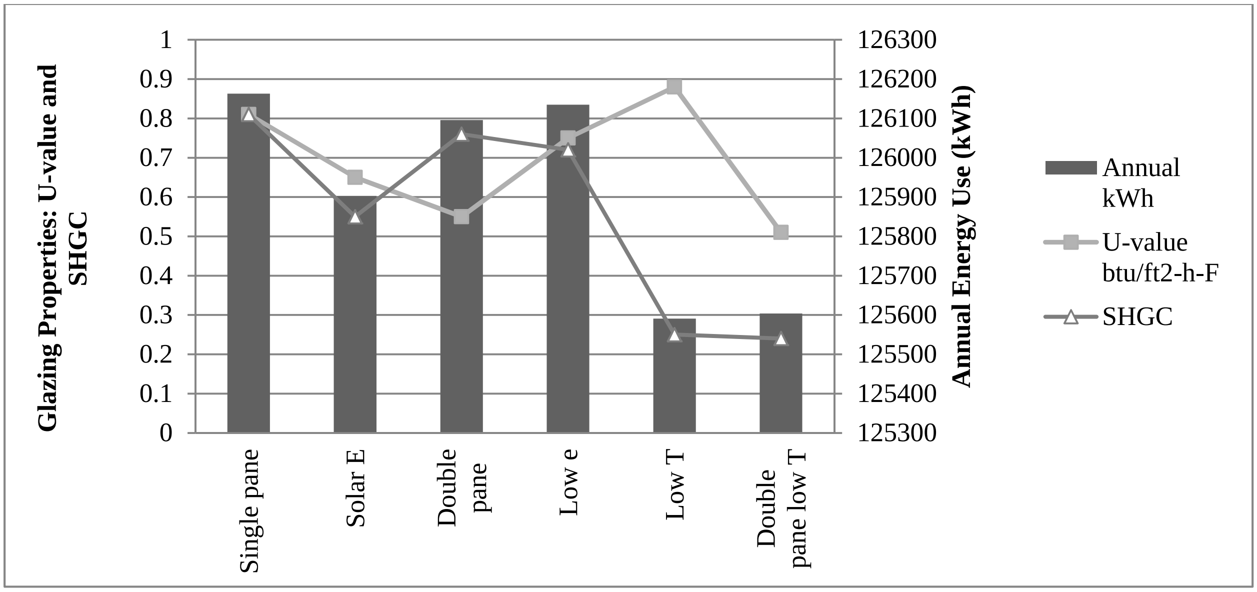


Figure 6-20: Glazing type parametric analysis in the retrofit office building

Next, a sensitivity analysis is performed to observe the impact of modifying the labor rates for the capital construction costs. The original optimization analysis considers only 19% of the US labor rates estimated from the RSmeans database in effort to more accurately represent the labor rates in Mexico. The optimization analysis with and without the 19% labor rate adjustment is shown in Figure 6-21. There is a minimal impact on the optimization curve illustrating that the reduced labor rates in Mexico have a relatively small impact on the life cycle costs. Therefore the effects of various LCC parameters are compared in two separate sensitivity analyses to observe the impact of the life of the project (N) shown in Figure 6-22 and the discount rate (r_d) shown in Figure 6-23. The discount rate is held constant at the original value of 0.67% in Figure 6-22, while the project life (N) varies between 15 and 30 years. This analysis is particularly meaningful, because it indicates that PV is cost effective for projects estimated at longer than 25 years. In this analysis the life of the project is held constant at 20 years and the discount rate is varied between 5% and -2% to test the potential variability in the discount rate. The higher the discount rate, the higher the LCC fraction will be as a result of the estimated increase of future costs of electricity.

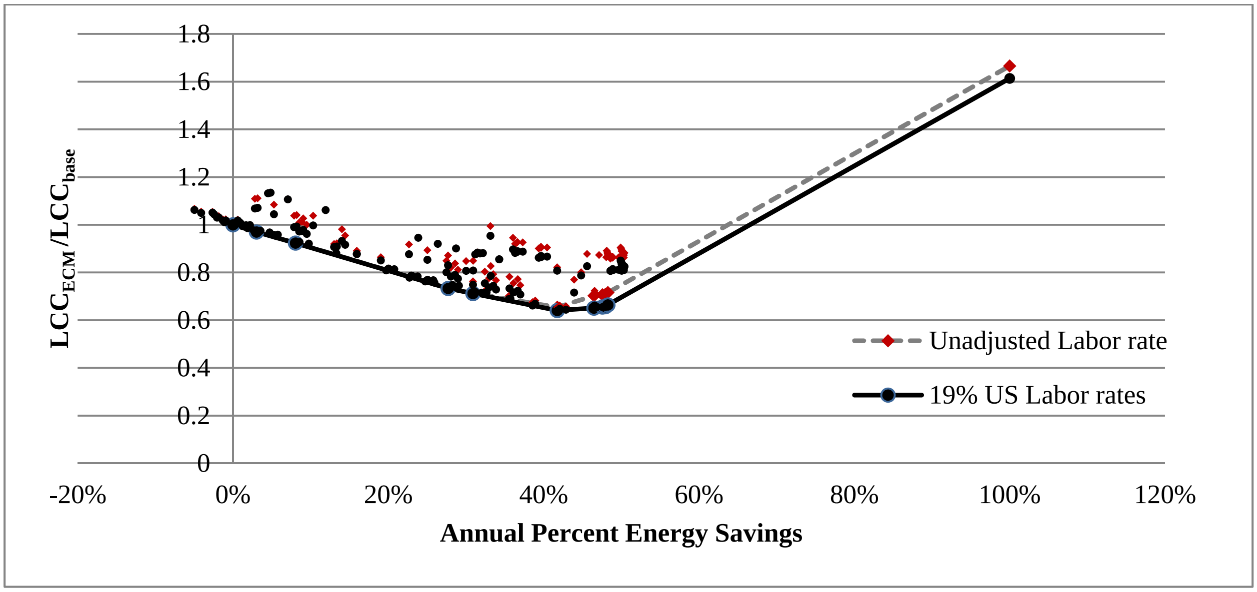


Figure 6-21: Retrofit office building- sensitivity analysis for capital construction labor rates

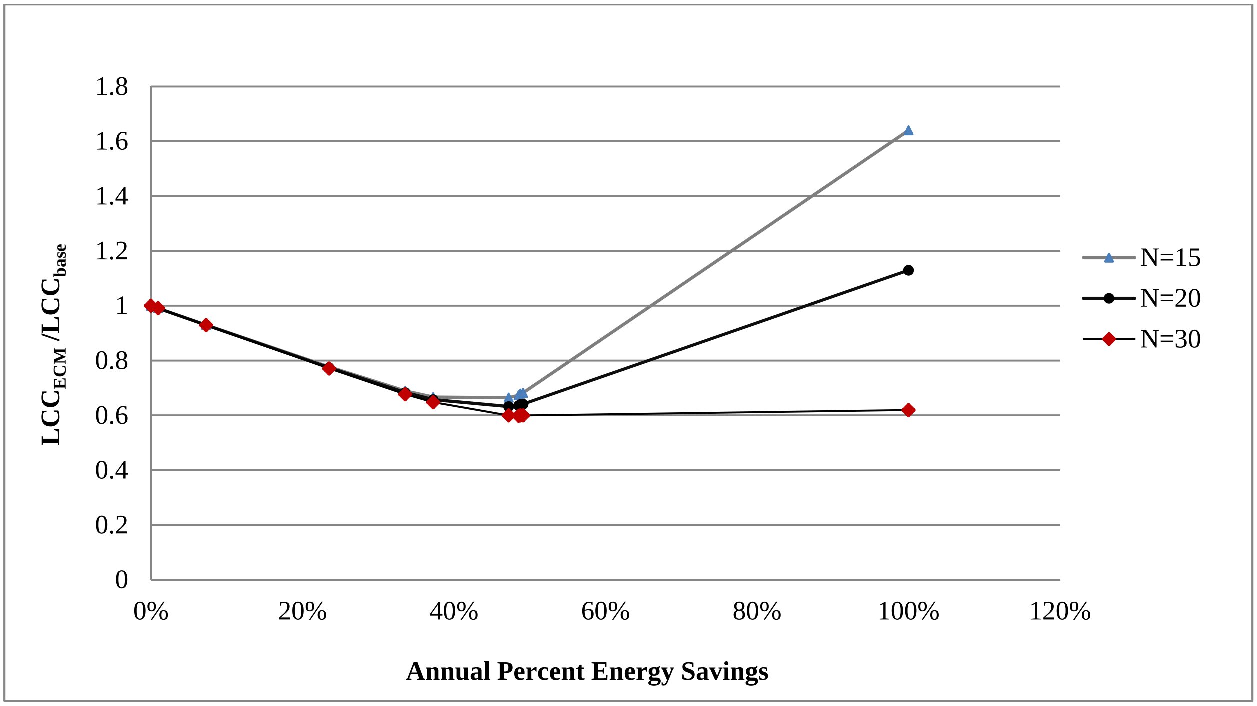


Figure 6-22: Retrofit office building- sensitivity analysis for project life (N)

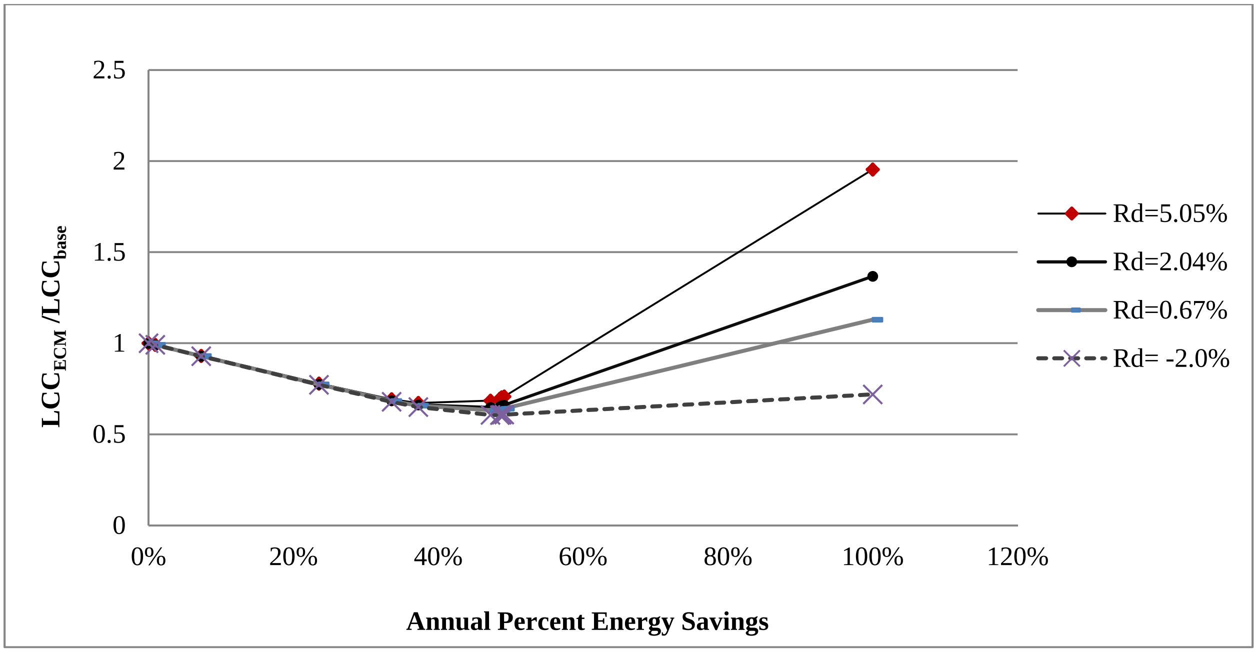


Figure 6-23: Retrofit office building- sensitivity analysis for discount rate (r_d)

6.2.2 New Construction Office Building Optimization Analysis Results

The optimization analysis results for the new construction commercial office building in Salamanca Mexico show an optimum point of 42% annual energy savings with a corresponding LCC of

273,073 US$ when compared to the baseline model which has a total LCC of 417,300 US$. The optimum point includes both lighting EEMs, occupancy sensors in private offices and conference rooms and daylighting control. The equipment measures included in the optimum point are surge protector power strips for each work station to reduce phantom loads and reducing the number of individual inkjet printers and have one multi-function copy machine in common office spaces. The additional EEMs in the optimum case include single-pane low-transmissive glazing, high efficiency refrigerators and LCD computer monitors and televisions. The optimization is shown in Figure 6-24 while several points along the optimization curve are included in Table 6-5.

Table 6-5: New construction office building optimization summary

Point of evaluation	**Energy savings (%)**	**LCC (US$)**
Baseline	0	417,300
Optimum	42%	273,073
PV start	48%	298,832
NZE	100%	479,129

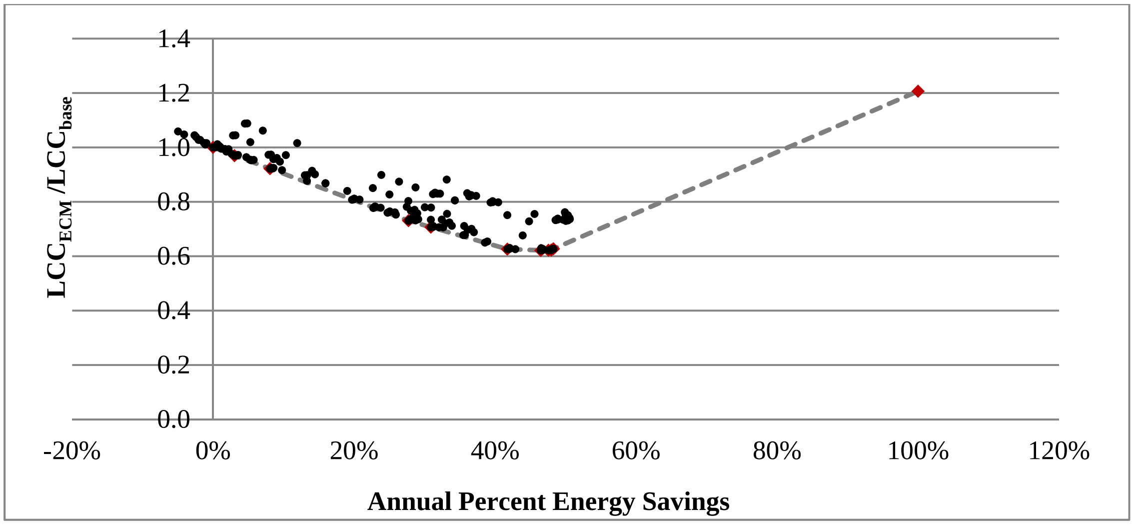


Figure 6-24: New construction commercial office building optimization curve

The annual energy consumption by end use for the baseline building, the optimum point and the PV starting point are shown in Figure 6-25. The optimum point shows the greatest energy reduction for miscellaneous and lighting equipment and also has a reduced space cooling load. Subsequently, the heating demand increases from 350 kWh/year in the baseline compared to 876 kWh/year and 1427 kWh/year in the optimum and PV start points respectively. Although the reduced internal gains increase the need for heating, the benefit for reduced cooling is much greater.

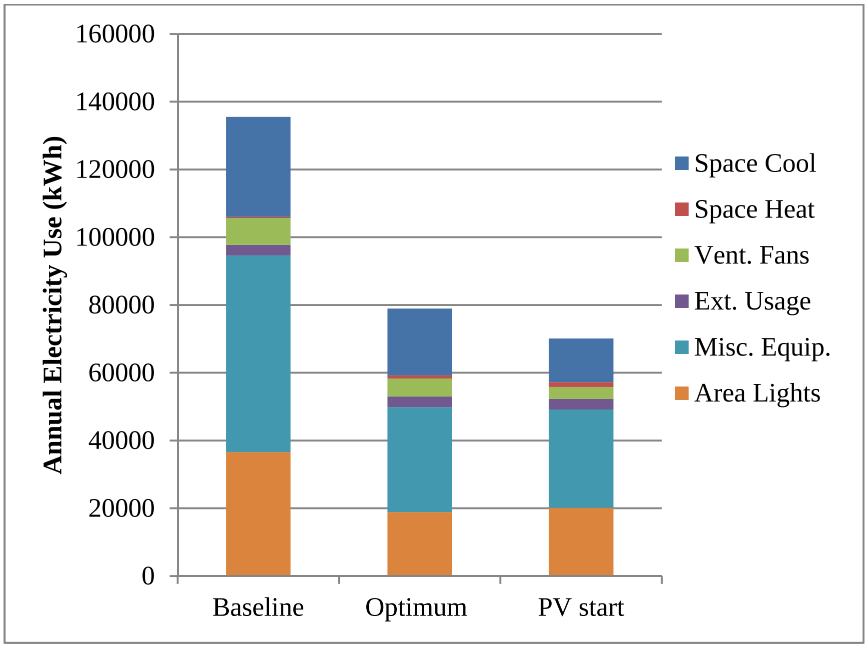


Figure 6-25: New construction office building annual energy by end use

Similar to the retrofit building energy analysis, thermal insulation proved to negatively impact annual energy consumption. Again most of the cooling load is from internal gains and in the new construction building case, solar gains through fenestration. The annual cooling energy consumption in the new construction building is significantly reduced when all internal loads are taken out of the building energy model and reduced again when the WWR is set to 0% as shown in Figure 6-26. Therefore only a small fraction of the cooling load is from conduction heat transfer through the roof and exterior walls.

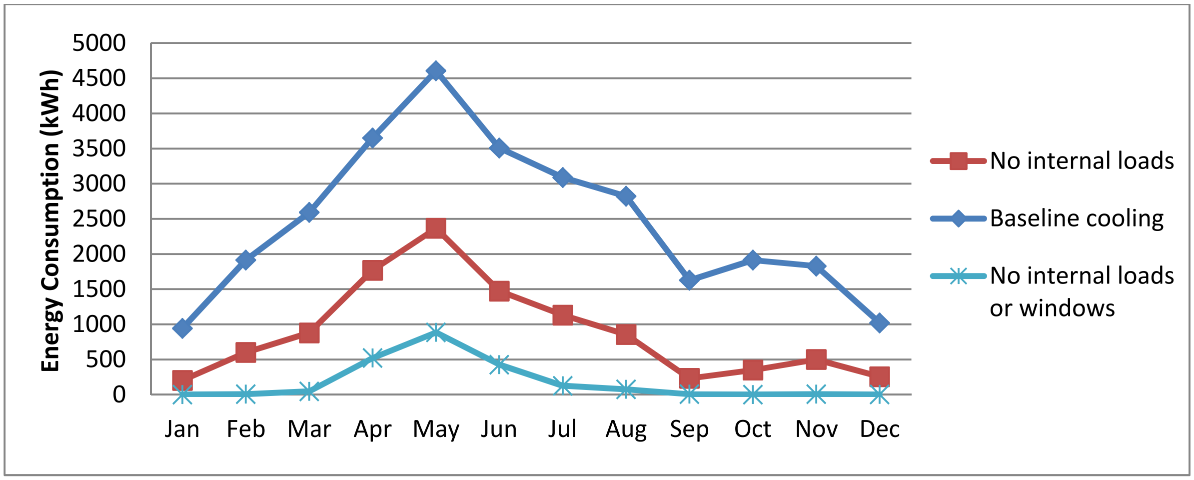


Figure 6-26: New construction office annual cooling energy use without internal loads and windows

A separate analysis is included for the various combinations of glazing types and a range of window to wall ratios between 10% and 60% as shown in Figure 6-27. This study is performed at the PV starting point and concludes that the optimum WWR is around 30% with single pan low transmissive glazing. Although, the performance of the double pane low transmissive glazing is slightly better than the single pane low transmissive glazing below 30% WWR, the benefits do not outweigh the substantially higher initial costs. Furthermore, clear single pane glazing is recommended for buildings with a WWR below 20% and single pane low transmissive is recommended for all WWRs above 20%.

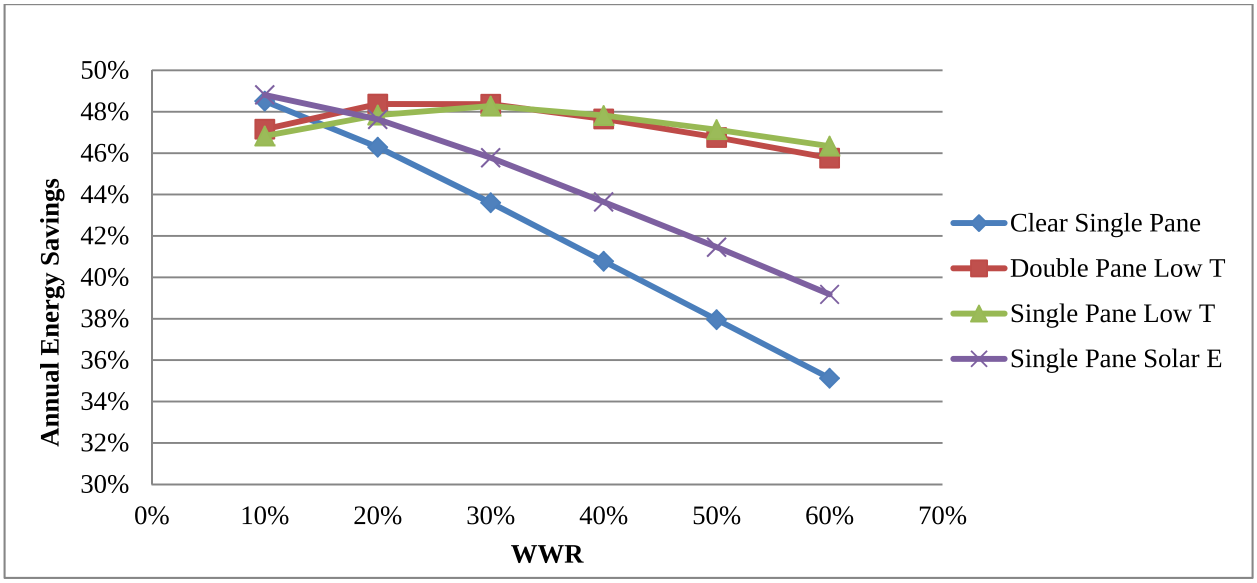


Figure 6-27: New construction WWR and glazing type sensitivity analysis

Like the retrofit commercial building study a series of sensitivity analyses are performed to observe the impact of modifying the labor rates for the capital construction costs (Figure 6-28), the project life (N) (Figure 6-29) and the discount rate (r_d) (Figure 6-30). The new construction office study includes more measures that require a higher degree of labor, such as improved glazing, therefore the impact of the increased labor rate is slightly more than the retrofit case. This is of particular interest for the PV start option with includes the single pane low transmissive glazing.

Similar to the retrofit construction office building analysis, the economic feasibility of PV and other higher cost measures near the optimum point improve as the project life increases and as the discount rate decreases. With the estimated 0.67% discount rate, the best project life for the greatest return on investment is just above 30 years, particularly for PV. Although, the discount rate is one of the most variable factors in the economic analysis, it only has a significant impact for implementing PV. Figure 6-30 shows the impact of discount rate when the project life is held constant at 20 years.

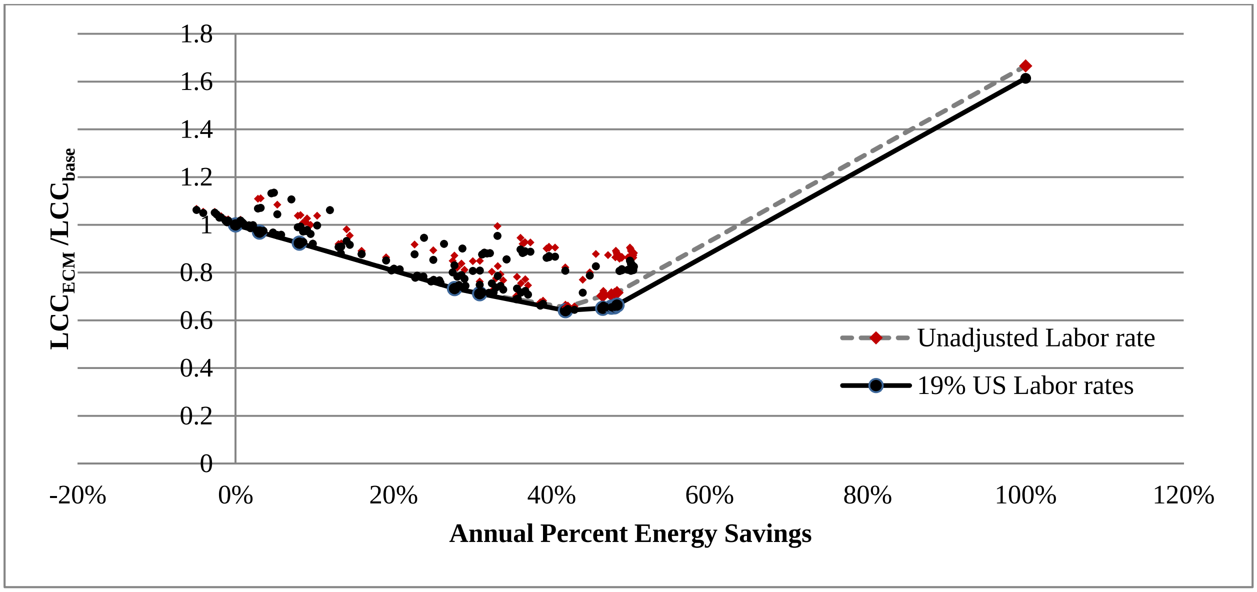


Figure 6-28: New construction office building sensitivity analysis for capital construction labor rates

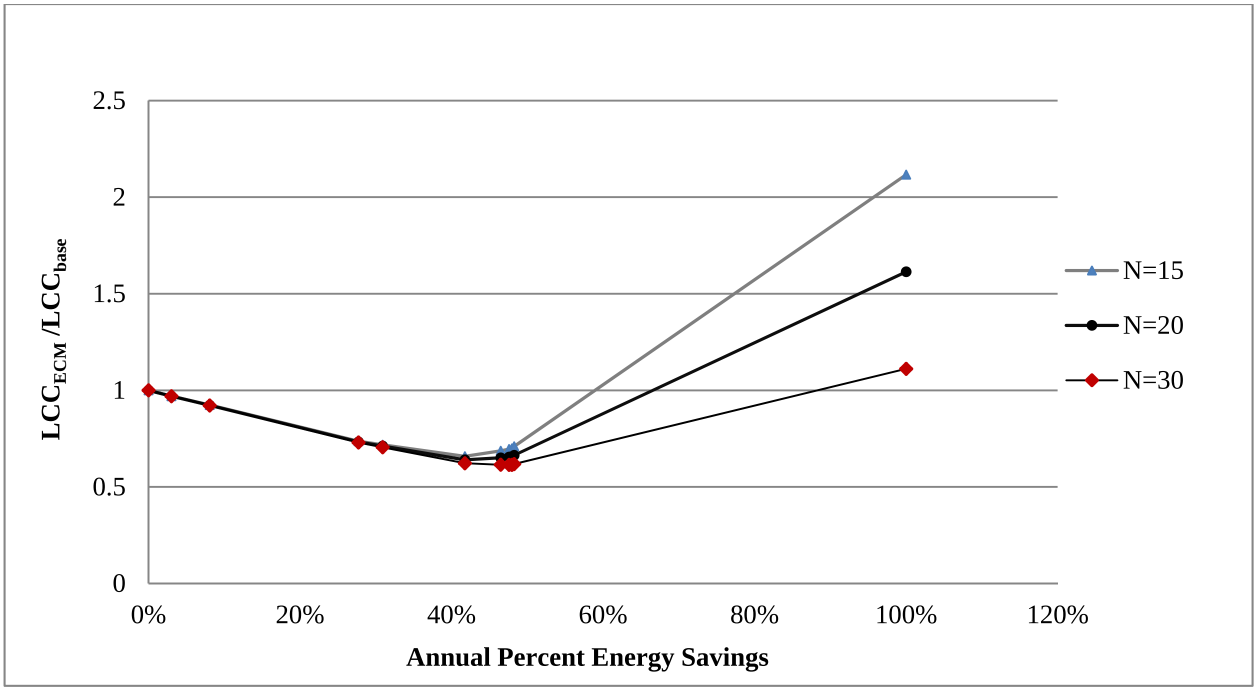


Figure 6-29: New construction office building- sensitivity analysis for project life (N)

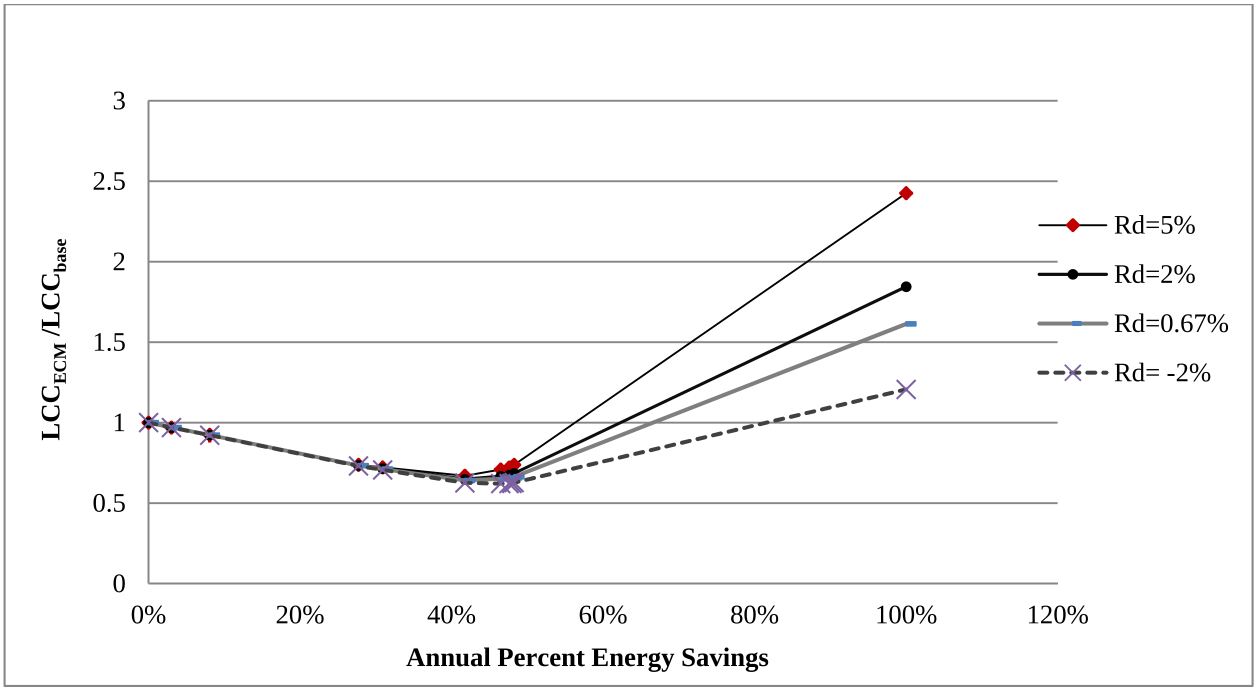


Figure 6-30: New construction office building sensitivity analysis for discount rate (r_d)

7 CONCLUDING REMARKS AND FUTURE WORK

The optimization analysis from this study highlights the importance of utilizing a holistic approach to evaluate EEMs. The interactions between various parameters are considered for a more meaningful set of recommendations. The residential building investigation indicates that although most existing homes in Salamanca, Mexico do not currently have a HVAC system, there is a need for better thermal comfort, particularly during the cooling season. This is an important finding because as the standard of living and expectation for improved thermal comfort increases, families will potentially invest more of their disposable income on a HVAC system. This investigation illustrated that the minimum thermal insulation measures are more cost effective than high efficiency air conditioning equipment. The minimum recommended roof thermal insulation (R-7 ft^2-h-°F/ Btu) significantly improves indoor thermal comfort. The new construction case has even greater potential for improved thermal comfort nearly eliminating the need for mechanical cooling and heating with the implantation of R-7 ft^2-h-°F/ Btu roof insulation and R-4.6 ft^2-h-°F/ Btu exterior wall insulation. Therefore the most important energy standard that should be enforced for residential buildings in Salamanca is the use of the minimum thermal insulation.

Future work for the residential building sector should include a comprehensive study of the impact of the voluntary NMX-C-460-ONNCCE-2009 thermal insulation standards for various climate regions throughout Mexico. The indoor thermal conditions and potential energy savings associated with different masonry configurations and construction types should also be included in future work. The study should consider a greater level of detail to the geometry, thermal properties and means of construction specific to Mexico. The paper *Concrete blocks for thermal insulation in hot climate* (K.S. Al-Jabri, 2004) focuses on local construction techniques and materials that will improve indoor thermal comfort for residential units and other smaller buildings in Oman. A similar study for different climate types throughout Mexico could potentially be more useful than using the conventional assembly R-value recommendations for wall and roof insulation, which is currently in place.

Further investigate could also include different system types for residential buildings along with the thermal insulation study. As part of the existing Mexican building construction standard (CEV), only the extreme warm-dry climate zone has a requirement for heating and cooling but does not suggest a specific system. Climate zones warm-semi humid, warm-humid and temperate-humid have a certain level of ventilation recommended, while the remaining zones do not require any means of HVAC (Comisión Nacional de Vivienda, 2010). The HVAC recommendations for the various climate zones throughout the country do not seem adequate to meet the thermal comfort needs of building occupants.

The commercial building energy analysis indicates that a significant portion of the annual energy consumption in new construction and existing office buildings is attributed to equipment loads. The existing building has older lighting technology which is not energy efficient, while it is typical for new construction to implement energy efficient lighting systems. The new construction office building also has a greater demand for cooling energy when compared to the existing building. In both studies, the reduction in office equipment and lighting energy also reduces the annual energy consumption from cooling. This indicates that for this particular climate, internal gains have a greater impact on cooling than conduction heat transfer through the opaque exterior envelope. The new construction office building study indicates that single pane low-transmissive glazing at 30% WWR is the optimum fenestration configuration. Furthermore, the low-transmissive glazing recommendation is more cost effective than high efficiency HVAC equipment to reduce cooling energy consumption in the new construction case. However the most effective way of reducing the cooling load is by reducing the internal gains in the new construction and retrofit case.

Another interesting finding from this study is the negative impact on cooling energy consumption for exterior wall and roof thermal insulation in both new and existing construction office buildings. This contradicts the existing commercial building energy efficiency standard for thermal insulation, NOM-008-ENER-2001. It is assumed that the difference is partially due to the lower equipment power density used for developing the standard from 1999. This finding further emphasizes the importance of regularly updating the existing standards with up-to-date building energy information. However in order to do this more effectively, a means of building energy accounting needs to be developed for the commercial building stock throughout Mexico. Therefore, on a long-term basis, future work should include the development of representative reference buildings for various climate regions throughout Mexico.

The national utility company, CFE is currently in the process of defining the building types for each of their customers in effort to count the number of offices, retail buildings, grocery stores, schools, etc. throughout the country (Patino, 2100). The electricity consumption from each building type will also be available through the new accounting system. As mentioned earlier, currently electricity is billed by voltage level where a large portion of the commercial building consumption is grouped with the industrial sector low or medium voltage tariff. Future work could be to encourage CFE to collect square footage data for each of their customers to create a database of typical EUI for each building type per region in Mexico.

Additional future work related to the commercial building energy optimization should include a more rigorous analysis of different HVAC system types, HVAC controls, and HVAC operation to determine the most efficient system for different climate regions in Mexico. Furthermore, when available, future work can include the use of an optimization tool for the commercial buildings to see what ECM packages are recommended compared to the manual optimization approach performed in this study. It is also recommended that the future energy analysis are performed using Energyplus as the simulation tool for the commercial building applications to explore the potential for natural ventilation and advanced HVAC system types.

Finally, further investigation should also factor in the purchasing power in Mexico is may be lower than here in the US. For the residential building study, it is potentially important to look at the disposable income of typical families throughout different regions in Mexico and compare that to the cost of implementing EEMs. The FIDE financial incentives could also be included in the life cycle cost analysis for future commercial and residential building energy optimization studies to provide greater incentive for more expensive measures.

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9 APPENDICES

9.1 *Residential Building Energy Efficiency Standards and Codes*

Table 9-1: NMX-C-460-ONNCCE-2009 Climate zone classification

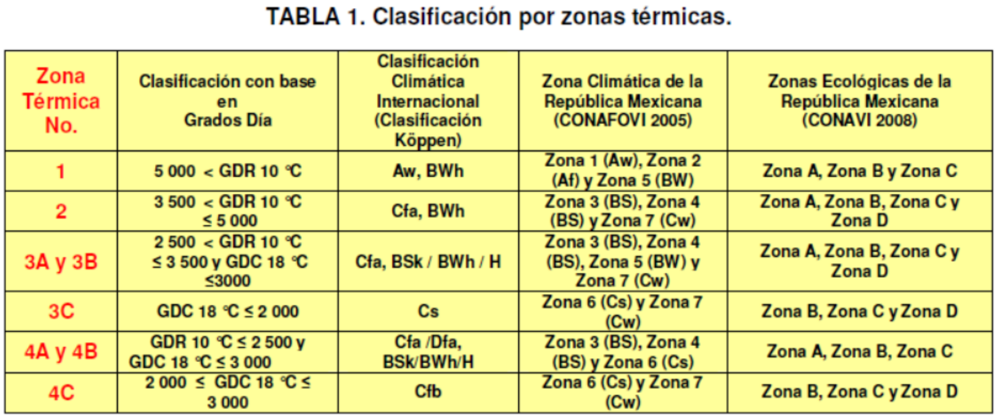


TABLA 1. Clasificación por zonas térmicas.

Zona Térmica No.	Clasificación con base en Grados Día	Clasificación Climática Internacional (Clasificación Köppen)	Zona Climática de la República Mexicana (CONAFOVI 2005)	Zonas Ecológicas de la República Mexicana (CONAVI 2008)
1	5 000 < GDR 10 °C	Aw, BWh	Zona 1 (Aw), Zona 2 (Af) y Zona 5 (BW)	Zona A, Zona B y Zona C
2	3 500 < GDR 10 °C ≤ 5 000	Cfa, BWh	Zona 3 (BS), Zona 4 (BS) y Zona 7 (Cw)	Zona A, Zona B, Zona C y Zona D
3A y 3B	2 500 < GDR 10 °C ≤ 3 500 y GDC 18 °C ≤3000	Cfa, BSk / BWh / H	Zona 3 (BS), Zona 4 (BS), Zona 5 (BW) y Zona 7 (Cw)	Zona A, Zona B, Zona C y Zona D
3C	GDC 18 °C ≤ 2 000	Cs	Zona 6 (Cs) y Zona 7 (Cw)	Zona B, Zona C y Zona D
4A y 4B	GDR 10 °C ≤ 2 500 y GDC 18 °C ≤ 3 000	Cfa /Dfa, BSk/BWh/H	Zona 3 (BS), Zona 4 (BS) y Zona 6 (Cs)	Zona A, Zona B, Zona C
4C	2 000 ≤ GDC 18 °C ≤ 3 000	Cfb	Zona 6 (Cs) y Zona 7 (Cw)	Zona B, Zona C y Zona D

Table 9-2: NMX-C-460-ONNCCE-2009 Thermal insulation recommendations

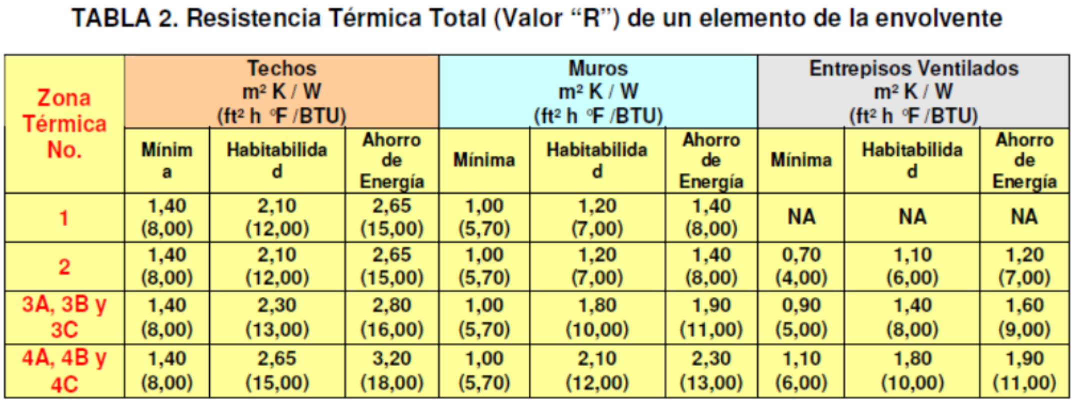


TABLA 2. Resistencia Térmica Total (Valor "R") de un elemento de la envolvente

Zona Térmica No.	Techos m^2 K / W (ft^2 h °F /BTU)			Muros m^2 K / W (ft^2 h °F /BTU)			Entrepisos Ventilados m^2 K / W (ft^2 h °F /BTU)		
	Mínima	Habitabilidad	Ahorro de Energía	Mínima	Habitabilidad	Ahorro de Energía	Mínima	Habitabilidad	Ahorro de Energía
1	1,40 (8,00)	2,10 (12,00)	2,65 (15,00)	1,00 (5,70)	1,20 (7,00)	1,40 (8,00)	NA	NA	NA
2	1,40 (8,00)	2,10 (12,00)	2,65 (15,00)	1,00 (5,70)	1,20 (7,00)	1,40 (8,00)	0,70 (4,00)	1,10 (6,00)	1,20 (7,00)
3A, 3B y 3C	1,40 (8,00)	2,30 (13,00)	2,80 (16,00)	1,00 (5,70)	1,80 (10,00)	1,90 (11,00)	0,90 (5,00)	1,40 (8,00)	1,60 (9,00)
4A, 4B y 4C	1,40 (8,00)	2,65 (15,00)	3,20 (18,00)	1,00 (5,70)	2,10 (12,00)	2,30 (13,00)	1,10 (6,00)	1,80 (10,00)	1,90 (11,00)

Table 9-3: NMX-C-460-ONNCCE-2009 Window and skylight glazing U-value specifications

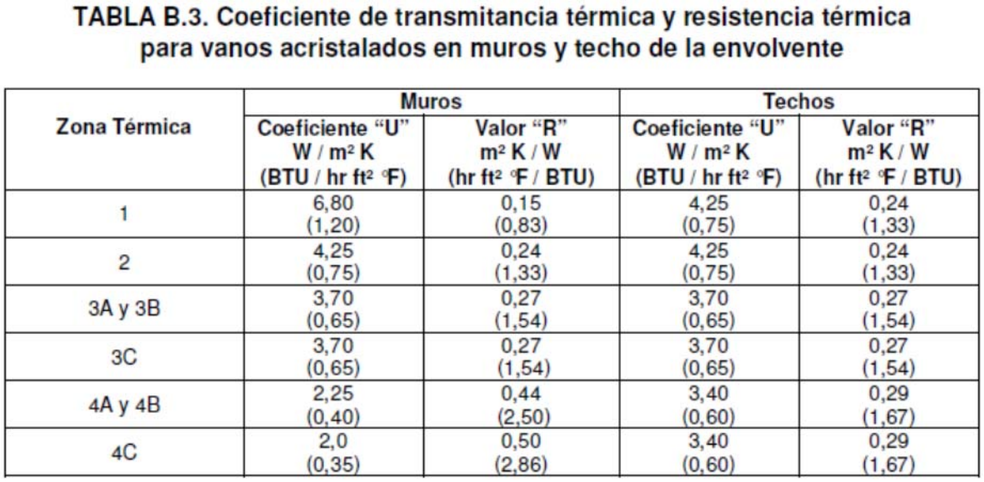


TABLA B.3. Coeficiente de transmitancia térmica y resistencia térmica para vanos acristalados en muros y techo de la envolvente

Zona Térmica	Muros		Techos	
	Coeficiente "U" W / m^2 K (BTU / hr ft^2 °F)	Valor "R" m^2 K / W (hr ft^2 °F / BTU)	Coeficiente "U" W / m^2 K (BTU / hr ft^2 °F)	Valor "R" m^2 K / W (hr ft^2 °F / BTU)
1	6,80 (1,20)	0,15 (0,83)	4,25 (0,75)	0,24 (1,33)
2	4,25 (0,75)	0,24 (1,33)	4,25 (0,75)	0,24 (1,33)
3A y 3B	3,70 (0,65)	0,27 (1,54)	3,70 (0,65)	0,27 (1,54)
3C	3,70 (0,65)	0,27 (1,54)	3,70 (0,65)	0,27 (1,54)
4A y 4B	2,25 (0,40)	0,44 (2,50)	3,40 (0,60)	0,29 (1,67)
4C	2,0 (0,35)	0,50 (2,86)	3,40 (0,60)	0,29 (1,67)

Table 9-4: Appliance efficiency standards and labeling program (Itha Sánchez Ramos, 2006)

Appliance	Description	kWh/ year	Cost (USD)	Note
Old Refrigerators from 1994	3.7 to 5 cf (manual defrost)	483	218	Cost estimate from 2005, energy use from 1994 model
	6.5 to 9.8 cf (manual and semi-automatic defrost)	579	265	
	6.5 to 9.8 cf (Ref/Frz automatic defrost)	812	525	
	12.5 to 14 cf (Ref/Frz automatic defrost)	1050	552	
	14.5 to 29.7 cf (Ref/Frz automatic defrost)	1178	1126	
NOM rated Refrigerators	3.7 to 5 cf (manual defrost)	273	236	Cost estimate from 2002, energy use from 2005 model
	6.5 to 9.8 cf (manual and semi-automatic defrost)	296	332	
	6.5 to 9.8 cf (Ref/Frz automatic defrost)	334	430	
	12.5 to 14 cf (Ref/Frz automatic defrost)	396	506	
	14.5 to 29.7 cf (Ref/Frz automatic defrost)	502	1240	
Old Clothes washers	Clothes washers compacts manual	30	188	Cost estimate from 2005
	Clothes washers manual	67	323	
	Clothes washers semiautomatics	125	375	
	Clothes washers automatics	150	736	
NOM rated clothes washers	Clothes washers compacts manuals	15	190	Cost estimate from 2004, energy use from 2005 model
	Clothes washers manuals	27	330	
	Clothes washers semiautomatics	79	440	
	Clothes washers automatics	127	743	

9.2 Commercial Building Energy Standards

Table 9-5: NOM-007-ENER-2004 Building area commercial lighting LPD recommendations

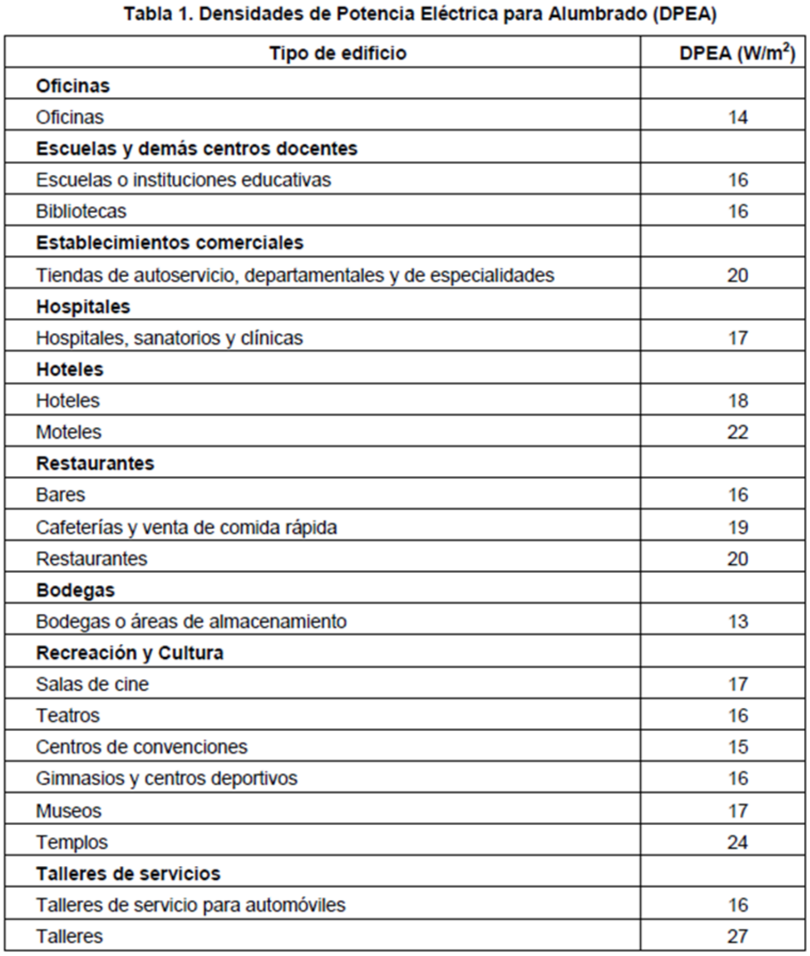


Tabla 1. Densidades de Potencia Eléctrica para Alumbrado (DPEA)

Tipo de edificio	DPEA (W/m^2)
Oficinas	
Oficinas	14
Escuelas y demás centros docentes	
Escuelas o instituciones educativas	16
Bibliotecas	16
Establecimientos comerciales	
Tiendas de autoservicio, departamentales y de especialidades	20
Hospitales	
Hospitales, sanatorios y clínicas	17
Hoteles	
Hoteles	18
Moteles	22
Restaurantes	
Bares	16
Cafeterías y venta de comida rápida	19
Restaurantes	20
Bodegas	
Bodegas o áreas de almacenamiento	13
Recreación y Cultura	
Salas de cine	17
Teatros	16
Centros de convenciones	15
Gimnasios y centros deportivos	16
Museos	17
Templos	24
Talleres de servicios	
Talleres de servicio para automóviles	16
Talleres	27

Table 9-6: NOM-008-ENER-2001 Non-residential building envelope energy efficiency recommendations

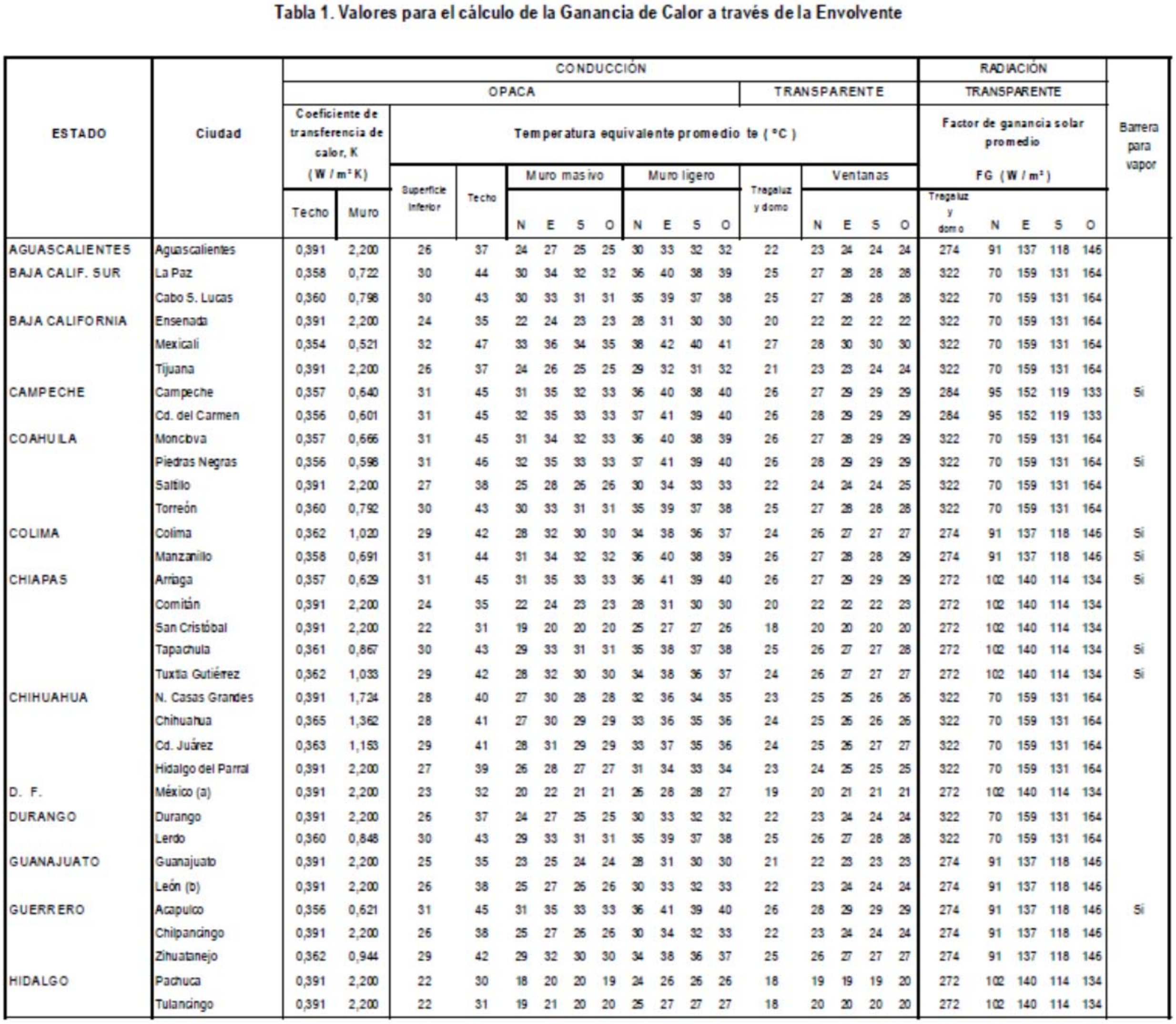


Tabla 1. Valores para el cálculo de la Ganancia de Calor a través de la Envolvente

ESTADO	Ciudad	CONDUCCIÓN																		RADIACIÓN					Barrera para vapor
		OPACA													TRANSPARENTE					TRANSPARENTE					
		Coeficiente de transferencia de calor, K (W / m² K)		Temperatura equivalente promedio te (°C)																Factor de ganancia solar promedio FG (W / m²)					
				Superficie inferior	Techo	Muro masivo				Muro ligero				Tragaluz y domo	Ventanas									
		Techo	Muro			N	E	S	O	N	E	S	O		N	E	S	O	Tragaluz y domo	N	E	S	O	
AGUASCALIENTES	Aguascalientes	0,391	2,200	26	37	24	27	25	25	30	33	32	32	22	23	24	24	24	274	91	137	118	146	
BAJA CALIF. SUR	La Paz	0,358	0,722	30	44	30	34	32	32	36	40	38	39	25	27	28	28	28	322	70	159	131	164	
	Cabo S. Lucas	0,360	0,798	30	43	30	33	31	31	35	39	37	38	25	27	28	28	28	322	70	159	131	164	
BAJA CALIFORNIA	Ensenada	0,391	2,200	24	35	22	24	23	23	28	31	30	30	20	22	22	22	22	322	70	159	131	164	
	Mexicali	0,354	0,521	32	47	33	36	34	35	38	42	40	41	27	28	30	30	30	322	70	159	131	164	
	Tijuana	0,391	2,200	26	37	24	26	25	25	29	32	31	32	21	23	23	24	24	322	70	159	131	164	
CAMPECHE	Campeche	0,357	0,640	31	45	31	35	32	33	36	40	38	40	26	27	29	29	29	284	95	152	119	133	Si
	Cd. del Carmen	0,356	0,601	31	45	32	35	33	33	37	41	39	40	26	28	29	29	29	284	95	152	119	133	
COAHUILA	Monclova	0,357	0,666	31	45	31	34	32	33	36	40	38	39	26	27	28	29	29	322	70	159	131	164	
	Piedras Negras	0,356	0,598	31	46	32	35	33	33	37	41	39	40	26	28	29	29	29	322	70	159	131	164	Si
	Saltillo	0,391	2,200	27	38	25	28	26	26	30	34	33	33	22	24	24	24	25	322	70	159	131	164	
	Torreón	0,360	0,792	30	43	30	33	31	31	35	39	37	38	25	27	28	28	28	322	70	159	131	164	
COLIMA	Colima	0,362	1,020	29	42	28	32	30	30	34	38	36	37	24	26	27	27	27	274	91	137	118	146	Si
	Manzanillo	0,358	0,691	31	44	31	34	32	32	36	40	38	39	26	27	28	28	29	274	91	137	118	146	Si
CHIAPAS	Arriaga	0,357	0,629	31	45	31	35	33	33	36	41	39	40	26	27	29	29	29	272	102	140	114	134	Si
	Comitán	0,391	2,200	24	35	22	24	23	23	28	31	30	30	20	22	22	22	23	272	102	140	114	134	
	San Cristóbal	0,391	2,200	22	31	19	20	20	20	25	27	27	26	18	20	20	20	20	272	102	140	114	134	
	Tapachula	0,361	0,867	30	43	29	33	31	31	35	38	37	38	25	26	27	27	28	272	102	140	114	134	Si
	Tuxtla Gutiérrez	0,362	1,033	29	42	28	32	30	30	34	38	36	37	24	26	27	27	27	272	102	140	114	134	Si
CHIHUAHUA	N. Casas Grandes	0,391	1,724	28	40	27	30	28	28	32	36	34	35	23	25	25	26	26	322	70	159	131	164	
	Chihuahua	0,365	1,362	28	41	27	30	29	29	33	36	35	36	24	25	26	26	26	322	70	159	131	164	
	Cd. Juárez	0,363	1,153	29	41	28	31	29	29	33	37	35	36	24	25	26	27	27	322	70	159	131	164	
	Hidalgo del Parral	0,391	2,200	27	39	26	28	27	27	31	34	33	34	23	24	25	25	25	322	70	159	131	164	
D. F.	México (a)	0,391	2,200	23	32	20	22	21	21	26	28	28	27	19	20	21	21	21	272	102	140	114	134	
DURANGO	Durango	0,391	2,200	26	37	24	27	25	25	30	33	32	32	22	23	24	24	24	322	70	159	131	164	
	Lerdo	0,360	0,848	30	43	29	33	31	31	35	39	37	38	25	26	27	28	28	322	70	159	131	164	
GUANAJUATO	Guanajuato	0,391	2,200	25	35	23	25	24	24	28	31	30	30	21	22	23	23	23	274	91	137	118	146	
	León (b)	0,391	2,200	26	38	25	27	26	26	30	33	32	33	22	23	24	24	24	274	91	137	118	146	
GUERRERO	Acapulco	0,356	0,621	31	45	31	35	33	33	36	41	39	40	26	28	29	29	29	274	91	137	118	146	Si
	Chilpancingo	0,391	2,200	26	38	25	27	26	26	30	34	32	33	22	23	24	24	24	274	91	137	118	146	
	Zihuatanejo	0,362	0,944	29	42	29	32	30	30	34	38	36	37	25	26	27	27	27	274	91	137	118	146	
HIDALGO	Pachuca	0,391	2,200	22	30	18	20	20	19	24	26	26	26	18	19	19	19	20	272	102	140	114	134	
	Tulancingo	0,391	2,200	22	31	19	21	20	20	25	27	27	27	18	20	20	20	20	272	102	140	114	134	

Table 9-7: NOM-011-ENER-2006 Minimum SEER value for central type AC systems

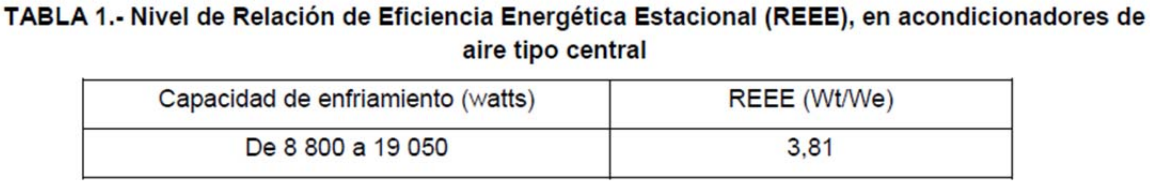
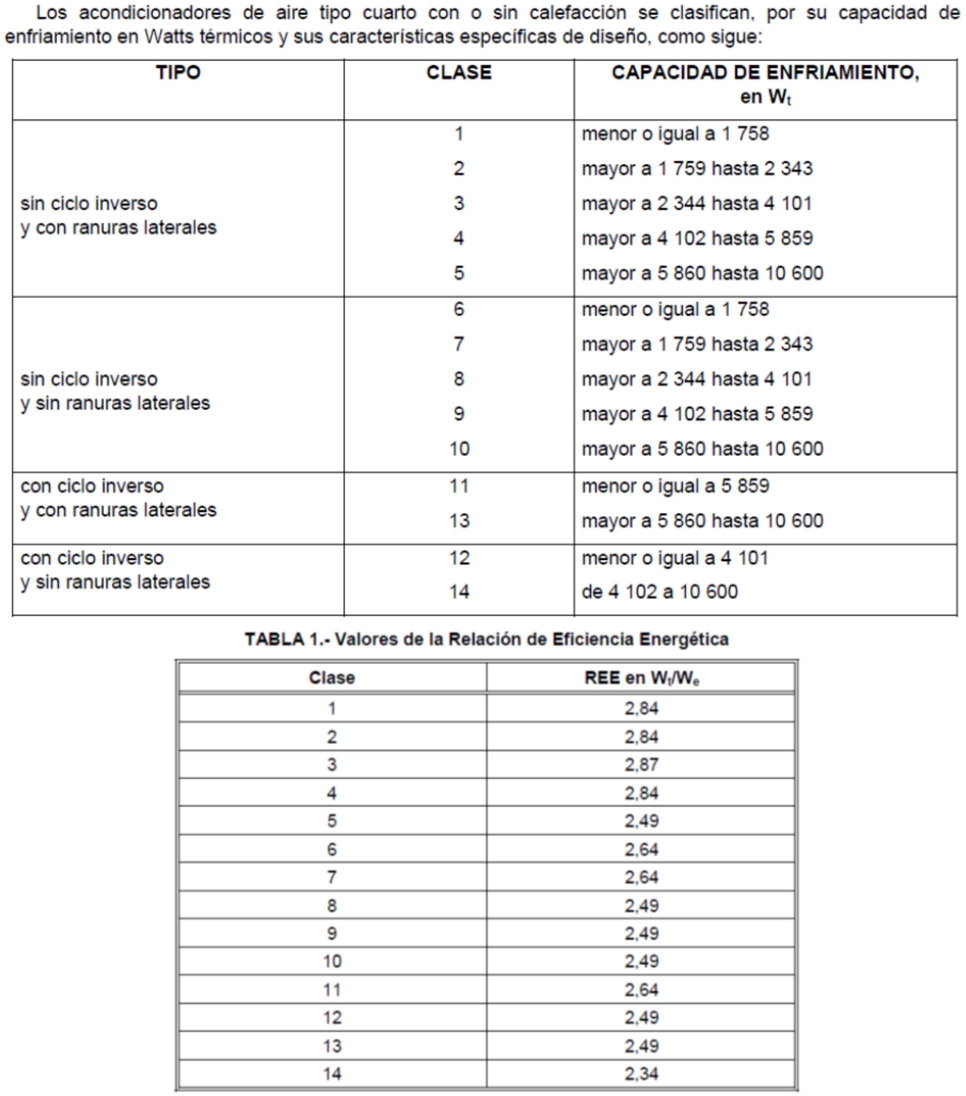


TABLA 1.- Nivel de Relación de Eficiencia Energética Estacional (REEE), en acondicionadores de aire tipo central

Capacidad de enfriamiento (watts)	REEE (Wt/We)
De 8 800 a 19 050	3,81

Table 9-8: NOM-021-ENER/SCFI-2008 Packaged terminal room air conditioners and heat pumps



Los acondicionadores de aire tipo cuarto con o sin calefacción se clasifican, por su capacidad de enfriamiento en Watts térmicos y sus características específicas de diseño, como sigue:

TIPO	CLASE	CAPACIDAD DE ENFRIAMIENTO, en W_t
sin ciclo inverso y con ranuras laterales	1	menor o igual a 1 758
	2	mayor a 1 759 hasta 2 343
	3	mayor a 2 344 hasta 4 101
	4	mayor a 4 102 hasta 5 859
	5	mayor a 5 860 hasta 10 600
sin ciclo inverso y sin ranuras laterales	6	menor o igual a 1 758
	7	mayor a 1 759 hasta 2 343
	8	mayor a 2 344 hasta 4 101
	9	mayor a 4 102 hasta 5 859
	10	mayor a 5 860 hasta 10 600
con ciclo inverso y con ranuras laterales	11	menor o igual a 5 859
	13	mayor a 5 860 hasta 10 600
con ciclo inverso y sin ranuras laterales	12	menor o igual a 4 101
	14	de 4 102 a 10 600

TABLA 1.- Valores de la Relación de Eficiencia Energética

Clase	REE en W_t/W_e
1	2,84
2	2,84
3	2,87
4	2,84
5	2,49
6	2,64
7	2,64
8	2,49
9	2,49
10	2,49
11	2,64
12	2,49
13	2,49
14	2,34

Table 9-9: Sello FIDE mandatory labeling efficiency standards for split system AC units

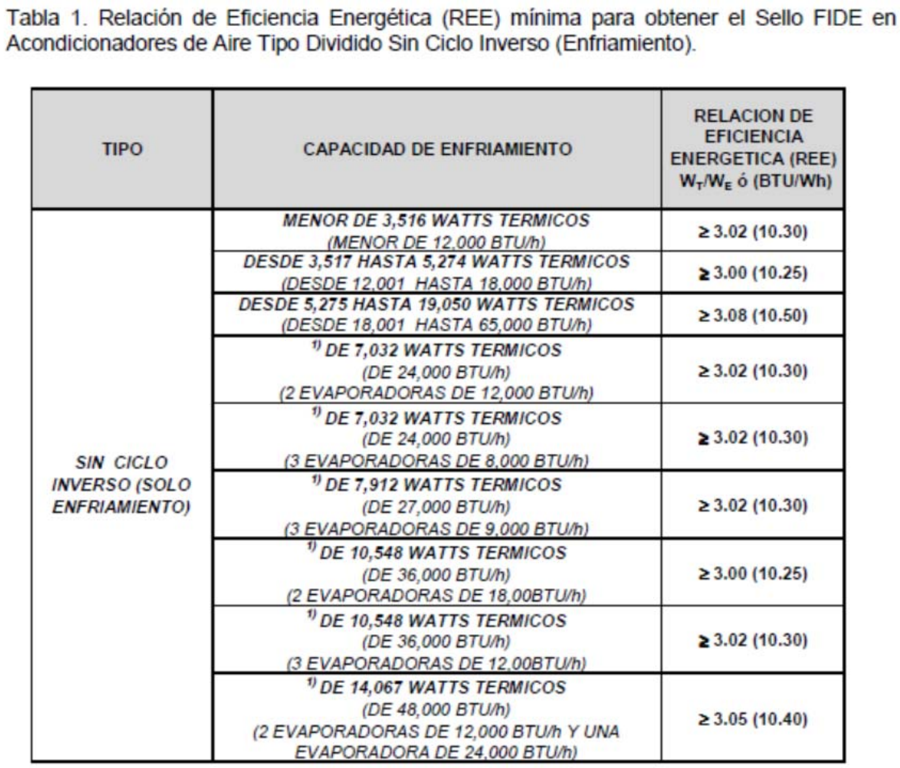


Tabla 1. Relación de Eficiencia Energética (REE) mínima para obtener el Sello FIDE en Acondicionadores de Aire Tipo Dividido Sin Ciclo Inverso (Enfriamiento).

TIPO	CAPACIDAD DE ENFRIAMIENTO	RELACION DE EFICIENCIA ENERGETICA (REE) W_T/W_E ó (BTU/Wh)
SIN CICLO INVERSO (SOLO ENFRIAMIENTO)	*MENOR DE 3,516 WATTS TERMICOS* *(MENOR DE 12,000 BTU/h)*	≥ 3.02 (10.30)
	DESDE 3,517 HASTA 5,274 WATTS TERMICOS *(DESDE 12,001 HASTA 18,000 BTU/h)*	≥ 3.00 (10.25)
	DESDE 5,275 HASTA 19,050 WATTS TERMICOS *(DESDE 18,001 HASTA 65,000 BTU/h)*	≥ 3.08 (10.50)
	1) DE 7,032 WATTS TERMICOS *(DE 24,000 BTU/h)* *(2 EVAPORADORAS DE 12,000 BTU/h)*	≥ 3.02 (10.30)
	1) DE 7,032 WATTS TERMICOS *(DE 24,000 BTU/h)* *(3 EVAPORADORAS DE 8,000 BTU/h)*	≥ 3.02 (10.30)
	1) DE 7,912 WATTS TERMICOS *(DE 27,000 BTU/h)* *(3 EVAPORADORAS DE 9,000 BTU/h)*	≥ 3.02 (10.30)
	1) DE 10,548 WATTS TERMICOS *(DE 36,000 BTU/h)* *(2 EVAPORADORAS DE 18,00BTU/h)*	≥ 3.00 (10.25)
	1) DE 10,548 WATTS TERMICOS *(DE 36,000 BTU/h)* *(3 EVAPORADORAS DE 12,00BTU/h)*	≥ 3.02 (10.30)
	1) DE 14,067 WATTS TERMICOS *(DE 48,000 BTU/h)* *(2 EVAPORADORAS DE 12,000 BTU/h Y UNA EVAPORADORA DE 24,000 BTU/h)*	≥ 3.05 (10.40)

Table 9-10: Sello FIDE mandatory labeling efficiency standards for heat pumps

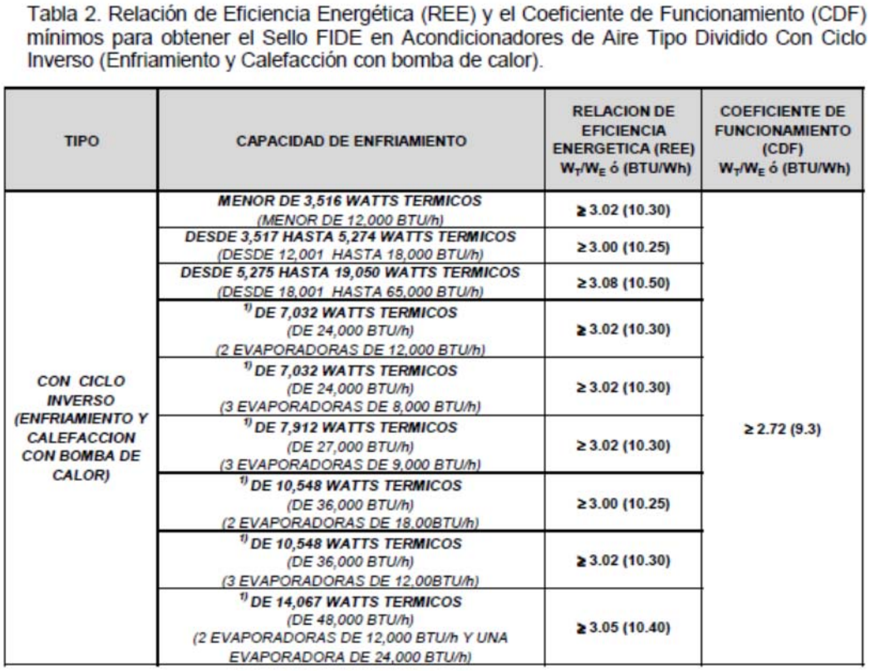


Tabla 2. Relación de Eficiencia Energética (REE) y el Coeficiente de Funcionamiento (CDF) mínimos para obtener el Sello FIDE en Acondicionadores de Aire Tipo Dividido Con Ciclo Inverso (Enfriamiento y Calefacción con bomba de calor).

TIPO	CAPACIDAD DE ENFRIAMIENTO	RELACION DE EFICIENCIA ENERGETICA (REE) W_T/W_E ó (BTU/Wh)	COEFICIENTE DE FUNCIONAMIENTO (CDF) W_T/W_E ó (BTU/Wh)
CON CICLO INVERSO (ENFRIAMIENTO Y CALEFACCION CON BOMBA DE CALOR)	*MENOR DE 3,516 WATTS TERMICOS* *(MENOR DE 12,000 BTU/h)*	≥ 3.02 (10.30)	≥ 2.72 (9.3)
	DESDE 3,517 HASTA 5,274 WATTS TERMICOS *(DESDE 12,001 HASTA 18,000 BTU/h)*	≥ 3.00 (10.25)	
	DESDE 5,275 HASTA 19,050 WATTS TERMICOS *(DESDE 18,001 HASTA 65,000 BTU/h)*	≥ 3.08 (10.50)	
	1) DE 7,032 WATTS TERMICOS *(DE 24,000 BTU/h)* *(2 EVAPORADORAS DE 12,000 BTU/h)*	≥ 3.02 (10.30)	
	1) DE 7,032 WATTS TERMICOS *(DE 24,000 BTU/h)* *(3 EVAPORADORAS DE 8,000 BTU/h)*	≥ 3.02 (10.30)	
	1) DE 7,912 WATTS TERMICOS *(DE 27,000 BTU/h)* *(3 EVAPORADORAS DE 9,000 BTU/h)*	≥ 3.02 (10.30)	
	1) DE 10,548 WATTS TERMICOS *(DE 36,000 BTU/h)* *(2 EVAPORADORAS DE 18,00BTU/h)*	≥ 3.00 (10.25)	
	1) DE 10,548 WATTS TERMICOS *(DE 36,000 BTU/h)* *(3 EVAPORADORAS DE 12,00BTU/h)*	≥ 3.02 (10.30)	
	1) DE 14,067 WATTS TERMICOS *(DE 48,000 BTU/h)* *(2 EVAPORADORAS DE 12,000 BTU/h Y UNA EVAPORADORA DE 24,000 BTU/h)*	≥ 3.05 (10.40)	

9.3 Additional Residential Building Information

Table 9-11: Baseline residential energy model inputs and assumptions

Category	Unconditioned Reference	Conditioned Reference
Building orientation	N facing entrance	N facing entrance
Neighbours	0 feet between neighbors on the east and west sides	0 feet between neighbors on the east and west sides
Heating set point	N/A	68 F
Cooling set point	N/A	76 F
Miscellaneous gas loads (therms)	6.7	6.7
Miscellaneous hot water loads	1.14 gpm sink, 2.25 gpm shower	1.14 gpm sink, 2.25 gpm shower
Natural ventilation	Year Round, assume occupants open windows when humidity ratio of OA<humidity ratio of Tin; windows close when Tin<T setpoint heating or if natural vent cannot meet cooling load	Year Round, assume occupants open windows when humidity ratio of OA<humidity ratio of Tin; windows close when Tin<T setpoint heating or if natural vent cannot meet cooling load
Exterior walls assembly	Single Wythe Brick wall	Single Wythe Brick wall
Exterior wall finish	Stucco, absorptivity 0.75, emissivity 0.9	Stucco, absorptivity 0.75, emissivity 0.9
Exterior wall mass	Cement plaster wall finish	Cement plaster wall finish
Finished roof	Flat, uninsulated	Flat, uninsulated
Roofing material	Asphalt shingles, absorptivity 0.8, emissivity 0.91	Asphalt shingles, absorptivity 0.8, emissivity 0.91
Roof/ceiling mass	6 inch concrete slab	6 inch concrete slab
Floor slab	Uninsulated	Uninsulated
Exposed floor	100% uncarpeted floors	100% uncarpeted floors
Floor Mass	Concrete	Concrete
Window area	12.5% total, 100ft2 on S wall, 100 ft2 on N wall	12.5% total, 100ft2 on S wall, 100 ft2 on N wall
Window type	Single pane; U-value 0.869 Btu/F-ft2-hr; SHGC 0.619	Single pane; U-value 0.869 Btu/F-ft2-hr; SHGC 0.619
Eaves	None	None
Infiltration	Typical , Annual average ACH=0.36	Typical , Annual average ACH=0.36
Refrigerator	Standard, top mount freezer; 480 kWh/year	Standard, top mount freezer; 480 kWh/year
Cooking range	Gas stove; 68 therms/year	Gas stove; 68 therms/year
Clothes Washer	Standard, 3.5 ft3	Standard, 3.5 ft3
Lighting	80% CFLs, 780 kWh/year	80% CFLs, 780 kWh/year
Heat pump	N/A	SEER 13, HSPF 8.1, one speed
Water heater	Gas, tankless	Gas, tankless
DHW distribution	R-0 Trunkbranch, pex	R-0 Trunkbranch, pex
Solar domestic hot water (SDHW)	N/A	N/A
SDHW azimuth	N/A	N/A
SDHW tilt	N/A	N/A

Table 9-12: Energy efficiency measures for retrofit and new construction residential units

	Case	EEMs	Unit	Material cost	Adjusted Labor cost (19%)	Construction cost ($US)	Retrofit Cost ($US)
Equipment	New & Retrofit	Reduce plug loads with power strips/more efficient appliances from 570 kWh/yr to 420 kWh/yr	ea	39.94	NA	39.94	39.94
	New & Retrofit	Energy Star, Top Mount Frezer, refrigerator type 374 kWh/yr	ea	780.00	NA	780.00	780.00
	New & Retrofit	Energy Star, cold only, clothing washing machine	ea	670.00	NA	670.00	670.00
	New & Retrofit	Electric stove	ea	1367.00	NA	1367.00	1367.00
Lighting	New & Retrofit	100% CFL use	sf	0.08	NA	0.08	0.08
Wall constructions	New	Double Wyth Brick wall construction	sf	9.05	4.09	13.14	13.14
	New & Retrofit	Apply polystyrene board insulation to exterior face of brick walls, then cover with stucco R- 4.6	sf	5.44	1.32	6.76	7.76
	New & Retrofit	Apply polystyrene board insulation to exterior face of brick walls, then cover with stucco R- 6	sf	5.65	1.32	6.97	8.00
	New & Retrofit	Apply polystyrene board insulation to exterior face of brick walls, then cover with stucco R- 7	sf	5.73	1.32	7.05	8.10
	New & Retrofit	Apply polystyrene board insulation to exterior face of brick walls, then cover with stucco R- 10	sf	6.15	1.32	7.47	8.57
Roof constructions	New & Retrofit	Apply polystyrene board insulation R- 7	sf	0.58	0.04	0.62	0.71
	New & Retrofit	Apply polystyrene board insulation R- 11	sf	0.87	0.23	1.10	1.27
	New & Retrofit	Apply polystyrene board insulation R- 14	sf	1.16	0.24	1.40	1.60
	New & Retrofit	Apply polystyrene board insulation R- 18	sf	1.45	0.25	1.70	1.94
Roof Finishes	New & Retrofit	Asphalt shingles, dark, abs=0.92, emiss=0.91	sf	0.74	0.10	0.84	0.96
	New & Retrofit	Asphalt shingles, medium, abs=0.85, emiss=0.91	sf	0.74	0.10	0.84	0.96
	New & Retrofit	Asphalt shingles, light, abs=0.8, emiss=0.91	sf	0.74	0.10	0.84	0.96
	New & Retrofit	Asphalt shingles, white or cool colors, abs=0.7, emis=0.91	sf	0.74	0.10	0.84	0.96
	New & Retrofit	Clay Tile, red	sf	3.25	0.31	3.56	4.04
Radiant Barrier	New & Retrofit	Has external radiant Barrier	sf	0.14	0.03	0.18	0.20
Windows	New & Retrofit	Double pane, clear	sf	10.35	2.02	12.37	14.16
	New & Retrofit	Single pane, clear	NA	5.95	1.60	7.55	8.68
	New	12% WWR	NA	NA	NA	NA	NA
	New	15% WWR	NA	NA	NA	NA	NA
	New	18% WWR	NA	NA	NA	NA	NA
Eaves	New & Retrofit	Eaves	sf	12.50	1.13	13.63	15.47
Overhangs	New & Retrofit	Overhangs	sf	12.50	1.13	13.63	15.47
Infiltration	New & Retrofit	Reduced infiltration, tight construction 0.26 annual Avg ACH	sf	0.10	0.18	0.28	0.28
Mechanical Ventilation	New & Retrofit	Spot Vent Only	ea	227.56	4.26	231.82	261.31
	New & Retrofit	Exhaust, 50% of A-62.2	ea	421.43	7.90	429.33	483.94
	New & Retrofit	Supply 50% of A-62.2	ea	421.43	7.90	429.33	483.94
Heat Pump	New & Retrofit	SEER 17, HSPF 8 varies by size	ea	2829.91	138	2967.49	3167.88
Ceiling Fans	New & Retrofit	3 Fans, Std, Typical	ea	115.00	7.60	122.60	138.84
Domestic HW	New & Retrofit	Gas Tankless, condensing	ea	1056.00	133.76	1189.76	1229.76
DHW distribution	New & Retrofit	Piping insulation, R-2 Trunk branch, pex	sf	1.70	0.23	1.93	2.20
	New & Retrofit	Solar DHW System 40 sq. ft closed loop	ea	4850.00		4850.00	4850.00

Table 9-13: Residential retrofit-unconditioned building optimization results

Retrofit Case				
Unconditioned_Min Cost Option				
% Source Energy Savings	17.2%			
Annualized Energy Related Costs	$433			
Simulation	Iteration 8, point 0			
Initial Cost	$1,285			

Group Name	**Category Name**	**Incremental Present Value**	**Current Option Name**	**Ref Option Name**
Building				
	Orientation	$0	North	
	Neighbors	$0	at 0 ft	
Operation				
	Heating Set Point	$0	68 F	
	Cooling Set Point	$0	76 F	
	Misc Electric Loads	$40	0.15	0.2
	Misc Gas Loads	$0	1	
	Misc Hot Water Loads	$0	Low-Flow Showers & Sinks	Benchmark
	Natural Ventilation	$0	Year-round	
Walls				
	CMU	$0	Single Wyth Brick wall	
	Exterior Finish	$0	Stucco	
Ceilings/Roofs				
	Finished Roof	$0	Uninsulated/ pseudo roof	
	Roofing Material	$0	Asphalt Shingles Medium	
Foundation/Floors				
	Slab	$0	6 inch slab	
	Exposed Floor	$0	100% Exposed	
Thermal Mass				
	Floor Mass	$0	2" Gypsum Concrete	
	Ext Wall Mass	$0	1in "Drywall"	
	Partition Wall Mass	$0	Brick	
	Ceiling Mass	$0	Concrete Slab	
Windows & Shading				
	Window Areas	$0	12.0% F50 B50 L0 R0	
	Window Type	$0	Single Pane	
	Interior Shading	$0	Summer = 0.5	
	Eaves	$0	None	
	Overhangs	$0	None	
Airflow				
	Infiltration	$0	Typical	
	Mechanical Ventilation	$0	None	
Major Appliances				
	Refrigerator	$0	Standard Top Mount Freezer	
	Cooking Range	$1,025	Electric Conventional	LPG gas stove
	Dishwasher	$0	None	
	Clothes Washer	$0	Standard	
	Clothes Dryer	$0	None (Clothes Line)	
Lighting				
	Lighting	($27)	100% Fluorescent Hardwired & Plugin	80% Fluorescent Hardwired & Plugin
Space Conditioning				
	Ducts	$0	None	
	Ceiling Fans	$0	None	
Water Heating				
	Water Heater	0	Gas Tankless	
	Distribution	$247	R-2 TrunkBranch PEX	R-0 TrunkBranch PEX
	Solar DHW	$0	None	
	SDHW Azimuth	$0	Back Roof	
	SDHW Tilt	$0	Latitude	
Power Generation				
	PV System	0	0 kW	
	PV Azimuth	$0	Back Roof	
	PV Tilt	$0	Latitude	
HVAC Sizing				
	Cooling Capacity	0	0.0 tons	
	Heating Capacity	$0	0 kBtu/hr	
Total Incremental Present Value		1285		

Table 9-14: Residential retrofit-conditioned building optimization results

Retrofit Case				
Conditioned_Min Cost Option				
% Source Energy Savings	35.0%			
Annualized Energy Related Costs	$542			
Simulation	Iteration 16, point 0			
Initial Cost	$1,711			

Group Name	**Category Name**	**Incremental Present Value**	**Current Option Name**	**Ref Option Name**
Building				
	Orientation	$0	North	
	Neighbors	$0	at 0 ft	
Operation				
	Heating Set Point	$0	68 F	
	Cooling Set Point	$0	76 F w/ setup 81 F	76 F
	Misc Electric Loads	$40	0.15	0.2
	Misc Gas Loads	$0	1	
	Misc Hot Water Loads	$0	Low-Flow Showers & Sinks	Benchmark
	Natural Ventilation	$0	Year-round	
Walls				
	CMU	$0	Single Wyth Brick wall	
	Exterior Finish	$0	Stucco	
Ceilings/Roofs				
	Finished Roof	$426	R-7	Uninsulated/ pseudo roof
	Roofing Material	$0	Asphalt Shingles Medium	
Foundation/Floors				
	Slab	$0	6 inch slab	
	Exposed Floor	$0	100% Exposed	
Thermal Mass				
	Floor Mass	$0	2" Gypsum Concrete	
	Ext Wall Mass	$0	1in "Drywall"	
	Partition Wall Mass	$0	Brick	
	Ceiling Mass	$0	Concrete Slab	
Windows & Shading				
	Window Areas	$0	12.0% F50 B50 L0 R0	
	Window Type	$0	Single Pane	
	Interior Shading	$0	Summer = 0.5	
	Eaves	$0	None	
	Overhangs	$0	None	
Airflow				
	Infiltration	$0	Typical	
	Mechanical Ventilation	$0	None	
Major Appliances				
	Refrigerator	$0	Standard Top Mount Freezer	
	Cooking Range	$1,025	Electric Conventional	LPG gas stove
	Dishwasher	$0	None	
	Clothes Washer	$0	Standard	
	Clothes Dryer	$0	None (Clothes Line)	
Lighting				
	Lighting	($27)	100% Fluorescent Hardwired & Plugin	80% Fluorescent Hardwired & Plugin
Space Conditioning				
	Heat Pump	$0	SEER 13. HSPF 8.1	
	Ducts	$0	None	
	Ceiling Fans	$0	None	
Water Heating				
	Water Heater	$0	Gas Tankless	
	Distribution	$247	R-2 TrunkBranch PEX	R-0 TrunkBranch PEX
	Solar DHW	$0	None	
	SDHW Azimuth	$0	Back Roof	
	SDHW Tilt	$0	Latitude	
Power Generation				
	PV System	$0	0 kW	
	PV Azimuth	$0	Back Roof	
	PV Tilt	$0	Latitude	
HVAC Sizing				
	Cooling Capacity	$0	3.5 tons	
	Heating Capacity	$0	30 kBtu/hr	
Total Incremental Present Value		1711		

Table 9-15: Residential new construction-unconditioned building optimization results

New Construction Case				
Unconditioned_Min Cost Option				
% Source Energy Savings	19.0%			
Annualized Energy Related Costs	$381			
Simulation	Iteration 6, point 0			
Initial Cost relative to baseline	$381			
Group Name	**Category Name**	**Incremental Present Value**	**Current Option Name**	**Ref Option Name**
Building				
	Orientation	$0	North	
	Neighbors	$0	at 0 ft	
Operation				
	Heating Set Point	$0	68 F	
	Cooling Set Point	$0	76 F	
	Misc Electric Loads	$40	0.15	0.2
	Misc Gas Loads	$0	1	
	Misc Hot Water Loads	$0	Low-Flow Showers & Sinks	Benchmark
	Natural Ventilation	$0	Year-round	
Walls				
	CMU	$0	Single Wyth Brick wall	
	Exterior Finish	$0	Stucco	
Ceilings/Roofs				
	Finished Roof	$0	Uninsulated/ pseudo roof	
	Roofing Material	$0	Asphalt Shingles Medium	
Foundation/Floors				
	Slab	$0	6 inch slab	
	Exposed Floor	$0	100% Exposed	
Thermal Mass				
	Floor Mass	$0	2" Gypsum Concrete	
	Ext Wall Mass	$0	1in "Drywall"	
	Partition Wall Mass	$0	Brick	
	Ceiling Mass	$0	Concrete Slab	
Windows & Shading				
	Window Areas	$0	12.0% F50 B50 L0 R0	
	Window Type	$0	Single Pane	
	Interior Shading	$0	Summer = 0.5	
	Eaves	$0	None	
	Overhangs	$0	None	
Airflow				
	Infiltration	$0	Typical	
	Mechanical Ventilation	$0	None	
Major Appliances				
	Refrigerator	$0	Standard Top Mount Freezer	
	Cooking Range	$0	Electric Conventional	
	Dishwasher	$0	None	
	Clothes Washer	$163	EnergyStar - Cold Only	Standard
	Clothes Dryer	$0	None (Clothes Line)	
Lighting				
	Lighting	($69)	100% Fluorescent Hardwired & Plugin	80% Fluorescent Hardwired & Plugin
Space Conditioning				
	Ducts	$0	None	
	Ceiling Fans	$0	None	
Water Heating				
	Water Heater	0	Gas Tankless	
	Distribution	$247	R-2 TrunkBranch PEX	R-0 TrunkBranch PEX
	Solar DHW	$0	None	
	SDHW Azimuth	$0	Back Roof	
	SDHW Tilt	$0	Latitude	
Power Generation				
	PV System	0	0 kW	
	PV Azimuth	$0	Back Roof	
	PV Tilt	$0	Latitude	
HVAC Sizing				
	Cooling Capacity	0	0.0 tons	
	Heating Capacity	$0	0 kBtu/hr	
Total Incremental Present Value		381		

Table 9-16: Residential new construction-conditioned building optimization results

New Construction Case				
Conditioned_Min Cost Option				
% Source Energy Savings	50.60%			
Annualized Energy Related Costs	$315			
Simulation	Iteration 20, point 0			
Initial Cost relative to baseline	($1,904)			

Group Name	**Category Name**	**Incremental Present Value**	**Minimum Cost**	**Ref Option**
Building				
	Orientation	$0	North	
	Neighbors	$0	at 0 ft	
Operation				
	Heating Set Point	$0	68 F	
	Cooling Set Point	$0	76 F	
	Misc Electric Loads	$40	0.15	0.2
	Misc Gas Loads	$0	1	
	Misc Hot Water Loads	$0	Low-Flow Showers & Sinks	Benchmark
	Natural Ventilation	$0	Year-round	
Walls				
	CMU	$1,526	Single Wyth Brick + R-4.6	Single Wyth Brick wall
	Exterior Finish	($265)	Stucco	
Ceilings/Roofs				
	Finished Roof	$426	R-7	Uninsulated/ pseudo roof
	Roofing Material	$0	Asphalt Shingles White or cool colors	Asphalt Shingles Dark
Foundation/Floors				
	Slab	$0	6 inch slab	
	Exposed Floor	$0	100% Exposed	
Thermal Mass				
	Floor Mass	$0	2" Gypsum Concrete	
	Ext Wall Mass	($36)	1in "Drywall"	
	Partition Wall Mass	$0	Brick	
	Ceiling Mass	$0	Concrete Slab	
Windows & Shading				
	Window Areas	$0	15.0% F50 B50 L0 R0	12.0% F50 B50 L0 R0
	Window Type	$375	Single Pane	
	Interior Shading	$0	Summer = 0.5	
	Eaves	$0	None	
	Overhangs	$0	None	
Airflow				
	Infiltration	$0	Typical	
	Mechanical Ventilation	$0	None	
Major Appliances				
	Refrigerator	$353	EnergyStar Top Mount Freezer	Standard Top Mount Freezer
	Cooking Range	$0	Electric Conventional	
	Dishwasher	$0	None	
	Clothes Washer	$163	EnergyStar - Cold Only	Standard
	Clothes Dryer	$0	None (Clothes Line)	
Lighting				
	Lighting	($69)	100% Fluorescent Hardwired & Plugin	80% Fluorescent Hardwired & Plugin
Space Conditioning				
	Heat Pump	($4,296)	SEER 17. HSPF 8.6	SEER 13. HSPF 8.1
	Ducts	$0	None	
	Ceiling Fans	$0	None	
Water Heating				
	Water Heater	$0	Gas Tankless	
	Distribution	($121)	R-2 TrunkBranch PEX	R-0 TrunkBranch Copper
	Solar DHW	$0	None	
	SDHW Azimuth	$0	Back Roof	
	SDHW Tilt	$0	Latitude	
Power Generation				
	PV System	$0	0 kW	
	PV Azimuth	$0	Back Roof	
	PV Tilt	$0	Latitude	
HVAC Sizing				
	Cooling Capacity	$0	1.5 tons	4.0 tons
	Heating Capacity	$0	30 kBtu/hr	
Total Incremental Present Value		-1904		

9.4 Additional Commercial Office Building Information

Table 9-17: Summary of data collected from all commercial building site visits

Building	**Mayor's Office**	**OTMMH**	**Middle School**	**Café and Bakery**	**10 CFE Administration Buildings**	**New city hall**
Building area (m2)	1276	1129	468	430	From 55m^2 to 550m^2	2916
Energy sources	Electricity	Electricity, LPG	Electricity, LPG	Electricity, natural gas	Electricity	Electricity
Electric tariff	02-Commercial	High voltage industrial	02-Commercial	02-Commercial	NA; they do not meter electricity	02-Commercial
Annual electricity use, 2010 (kWh)	126,080	79,360	1,912	37,987	NA	NA, not occupied yet
Annual gas use, 2010 (kBtu)	None	3,078	2,693	No data	NA	NA
Energy use intensity (kBtu/m^2/year)	337.1	242.6	19.7	301.4	NA	NA
Occupancy	134	40-45 machine operators, 9 admin employees	74 Students, 18 teachers, 3 staff	23 employees; 30 clients max	Between 4-30	NA
Schedule	M-F 8am-4pm; Sat-Sun closed	M-F 8am - 6pm, Sat. 8am-2pm, Sun. closed	M-F 7am - 2:30pm, Sat-Sun closed	M-Sat 9am - 11:00pm, Sun 9:30am-5:30pm	M-F 8am - 3:30pm, Sat. - Sun. closed	M-F 8am-4pm; Sat-Sun closed
Year of construction	1904	1991	2005	1987	Varies; 1970 to 2000	2010
Primary equipment loads	Office equipment, lighting	Large machinery	Office equipment, lighting	Refrigerators; ovens	Office equipment and AC units	Office equipment, lighting
Lighting type	T12s; magnetic ballasts	T12s; magnetic ballasts	T12s; magnetic ballasts	T12s; magnetic ballasts; MR16s; CFLs	Mostly T12s; magnetic ballasts	T5s; electronic ballasts
Construction materials	Concrete and brick	Reinforced concrete; brick	Reinforced concrete; brick	Reinforced concrete; brick	Reinforced concrete; brick	CMU walls, corrugated sheet metal roof
Comfort issues	Hot in the summer months	Hot in open machinery area	A little cold in the winter months	Gets very hot in the summer	Most offices hot in summer, even with AC	NA

Figure 9-1: Images of the Mayor’s office building

Table 9-18: EEM cost estimates for retrofit office building analysis

	Cost description	Unit	Material Cost ($US)	Labor Cost ($US)	Number of units	NC Capital Costs ($US)	Retrofit Costs ($US)	Source/Notes
ECM A	Energy Star 25-Watt CFL	ea	3.40	0.00	10	34	34	www.energysavers.gov
ECM B	2'Wx4'L, two 40 Watt, RS (rapidstart)	ea	91.00	12.55	352	36449	40038	RSMeans
ECM C	plastic domes 10 sf to 20 sf, single glazing	m2	290.48	11.01	80	24119	28986	RSMeans
	Dimming control module and photocell sensor	ea	260.00	10.23	12	3243	3543	Labor from Rsmeans for installing dimming ballasts; material cost estimate from www.reedconstructiondata.com
	Dimming ballast	ea	102.00	10.23	281.60	31604	34650	RSMeans
ECM D	Total cost	ea				34847	38194	
ECM E	Leviton Decora Wall Switch Occupancy Sensor	ea	49.99	1.94	15	779	851	Labor estimate from RSMeans for electrical installationof low voltage switching; www.westsidewholesale.com
ECM F	Dell E Series E1911 19-inch widescreen monitor, 28W typical/28W maximum	ea	139.00	0.00	46	6394	6394	www.nextag.com
ECM G	Panasonic Panafax UF-7200 high-volume workstation, 100 W max	ea	1089.95	0.00	4	4360	4360	www.officegrabs.com
ECM H	Energy-Star qualified, 18 CF minimum	ea	600.00	0.00	4	2400	2400	RSMeans
ECM I	Energy Star, Sony KDL-40EX720 40" BRVIA 1080p LED-LCD HDTB, 64W	ea	1079.99	0.00	4	4320	4320	www.crutchfield.com
ECM J	Ultra Smart 8-outlet 6' green surge protector- 3600 Joules	ea	19.97	0.00	138	2756	2756	www.tigerdirect.com
ECM K	1.5 ton AC Unit, EER=10.25 (EIR=0.333)	ea	1978.00		21	41538	45276	NREL database
ECM L	1.5 ton AC Unit, EER=10.5 (EIR=0.325)	ea	2103.00		21	44163	48138	
ECM M	Expanded polystrene, 1"thick, R3.85	m2	3.12	0.89	815	3271	3616	Rsmeans
ECM N	Expanded polystrene, 1"thick, R7.69	m2	6.24	0.98	815	5881	6466	Rsmeans
ECM O	Expanded polystrene, 1"thick, R11.49	m2	9.36	0.98	815	8424	9238	Rsmeans
ECM P	Expanded Polystrene, 1#/CF density 2" thick R7.69	m2	6.24	0.48	611	4104	4494	Rsmeans
ECM Q	Expanded Polystrene, 1#/CF density 2" thick R15.38	m2	12.48	0.50	611	7930	8665	Rsmeans
ECM R	Expanded Polystrene, 1#/CF density 2" thick R19.23	m2	15.60	0.52	611	9849	10757	Rsmeans
ECM S	Glazing panel (dbl pane) , insul, 1/2" thick clear	m2	111.35	22.12	45	6006	6616	Rsmeans
ECM T	Plate glass (sgl pane) 1/4" think, tem	m2	93.06	17.44	45	4973	5475	Rsmeans
ECM U	Reduced heat transfer glazing, heat reflective, film ion weather side, 1/2" thick unit, clear	m2	200.11	14.75	45	9668	10585	Rsmeans
ECM V	1.5 ton AC Unit SEER 18	ea	2891.00		21	60711	66175	NREL database

Table 9-19: EEM cost estimates for the new construction office building analysis

	Cost description	Unit	Material Cost ($US)	Labor Cost ($US)	Number of units	Capital Costs ($US)	Source/Notes
Baseline	EER 10.5, 5 ton Heat pumps	ea	5509	268	10	57772	BEOpt Estimates, they consider efficiency
	Plate glass (sgl pane) 1/4" think, clear	m2	64	17	638	51797	RSMeans
ECM A	Includes dimming control module and photocell sensor	ea	260	10	8	2161	Labor from RSMeans for installing dimming ballasts; material cost estimate from www.reedconstructiondata.com
	Dimming ballast	ea	102	10	120	13448	RSMeans
	Cost of dimming control module, photocell sensors & dimming ballasts	ea				15609	
ECM B	Leviton Decora Wall Switch Occupancy Sensor	ea	50	2	30	1557	Labor estimate from RSMeans for electrical installationof low voltage switching; www.westsidewholesale.com
ECM C	Dell E Series E1911 19-inch widescreen monitor, 28W typical/28W maximum	ea	139	0	46	6394	www.nextag.com
ECM D	Panasonic Panafax UF-7200 high-volume workstation, 100 W max	ea	1090	0	4	4360	www.officegrabs.com
ECM E	Energy-Star qualified, 18 CF minimum	ea	600	0	4	2400	RSMeans
ECM F	Energy Star, Sony KDL-40EX720 40" BRVIA 1080p LED-LCD HDTB, 64W	ea	1080	0	4	4320	www.crutchfield.com
ECM G	Ultra Smart 8-outlet 6' green surge protector- 3600 Joules	ea	20	0	138	2756	www.tigerdirect.com
ECM H	5 ton Heat pump, (SEER 18)	ea	7076	344	10	74196	NREL database
ECM I	Expanded polystrene, 1"thick, R3.85	m2	3	1	522	2088	
ECM J	Expanded polystrene, 1"thick, R7.69	m2	6	1	522	3759	RSMeans
ECM K	Expanded polystrene, 1"thick, R11.49	m2	9	1	522	5388	RSMeans
ECM L	Expanded Polystrene, 1#/CF density 2" thick R7.69	m2	6	0	638	4281	RSMeans
ECM M	Expanded Polystrene, 1#/CF density 2" thick R15.38	m2	12	0	638	8275	RSMeans
ECM N	Expanded Polystrene, 1#/CF density 2" thick R19.23	m2	16	1	638	10279	RSMeans
ECM O	Glazing panel (dbl pane) , insul, 1/2" thick clear	m2	111	22	217	28917	RSMeans
ECM P	Plate glass (sgl pane) 1/4" think, tempered	m2	93	17	217	23945	RSMeans
ECM Q	Reduce heat transfer glazing, 1" thick, double glazed, 1/4" float, 30-70 SF, clear	m2	168	18	217	40548	RSMeans
ECM R	WWR 30%		NA	NA	NA	NA	NA
ECM S	WWR 20%		NA	NA	NA	NA	NA
ECM T	WWR 10%		NA	NA	NA	NA	NA