AN ANALYSIS OF A LOW-ENERGY, LOW-WATER USE COMMUNITY IN MEXICO CITY

A Dissertation

by

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ABSTRACT

This study investigated how to determine a potential scenario to reduce energy, water and transportation use in Mexico City by implementing low-energy, low-water use communities. The proposed mixed-use community has multi-family apartments and a small grocery store. The research included the analysis of: case studies, energy simulation, and hand calculations for water, transportation and cost analysis. The previous case studies reviewed include: communities in Mexico City, Mexico, Austin, Texas, Phoenix, Arizona, New York City, New York and San Diego, California in terms of succesful low-energy, low-water use projects. The analysis and comparison of these centers showed that the *Multifamiliar Miguel Aleman* is an excellent candidate to be examined for Mexico City. This technical potential study evaluated energy conserving measures such as low-energy appliances and efficient lighting that could be applied to the apartments in Mexico City to reduce energy-use. The use of the simulations and manual calculations showed that the application of the mixed-use concept was successful in reducing the energy and water use and the corresponding carbon footprint. Finally, this technical potential study showed taking people out of their cars as a result of the presence of the on-site grocery store, small recreation center and park on the ground floor also reduced their overall transportation energy-use.

The improvement of the whole community (i.e., apartments plus grocery store) using energy-efficient measures provided a reduction of 70 percent of energy from the base-case. In addition a 69 percent reduction in water-use was achieved by using water-saving fixtures and greywater reuse technologies for the complex. The combination of high-efficiency automobiles and the presence of the on-site grocery store, small recreation center and park potentially reduced the transportation energy-use by 65 percent. The analysis showed an energy cost reduction of 82 percent reduction for apartments and a 22 percent reduction for the store. In addition, for water cost there was a 70 percent reduction for apartments and a 16 percent reduction for the store. Overall, a 64 total percent reduction in carbon dioxide (CO_2) was accomplished by saving energy-use in the apartments, the grocery store and transportation.

Finally, a guide has been created for Mexico City to establish strategies and actions based on the results of this work in order to reduce overall energy and water-use in Mexico City. The guide is expected to be useful in the short term in Mexico City, and could be potentially adopted in the long term in other countries in the same manner as which Brazil and Colombia adopted the Mexican *CONAVI's 2010 Housing Building Code*.

DEDICATION

To my parents Jacqueline and Jose Luis

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

1.1. Background

Fossil fuels have supported the development of human life for thousands of years. The use of fossil fuels made possible the existence of the steam engine created by James Watt, the Industrial Revolution, the growth of the cities, and the development of the Internet Age (Lovins, 2011). Unfortunately, the over-use of the coal, oil and natural gas from industrialized countries is depleting non-renewable resources, increasing the greenhouse gas emissions, accelerating the resultant climate change from increasing CO_2, and threatening life in the world. In addition, although much has been published about how to reduce energy-use in industrialized nations, few articles have been published about how to reduce energy-use in developing countries such as Mexico, while at the same time improving living standards.

One of the few studies is the study by Bermudez-Alcocer and Haberl (2010) who published a comparative study of the energy-use of Mexico versus United States. In their study they found that the cities in the south-central area that surrounds Mexico City Metropolitan Area have 50 percent of the total population in Mexico in comparison with the more spread-out population throughout the U.S. Therefore, they concluded that if changes in the energy consumption could be made to the future building stock of Mexico City, it would impact much of Mexico.

The main problem in Mexican cities is that they are horizontal cities with two or three-floor buildings. Other issues include the increasing need for energy and water-efficient housing close to different activites (e.g., school, office, etc.), as well as the gasoline consumed and the pollution generated by people driving private vehicles due to the cities' sprawl. One of the potential solutions for Mexico City is the concept of a low-energy, low-water-use community. The analysis of such centers requires a community-wide energy and water-use analysis, including: residential, commercial and transportation.[1] Figure 1 shows

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[1] The industrial sector is not considered for this study due to its absence in the selected base-case community in Mexico City.

the *Multifamiliar Miguel Aleman* community in Mexico City. This community currently has mixed-use (i.e., apartments, retail, recreation center, parks, etc.), is close to alternative transportation (underground and buslines), has 13 floors, and already has a good potential to be a low-energy, low-water use center. The site of this complex has 430,556 square feet (ft^2) and has 1,080 apartments.

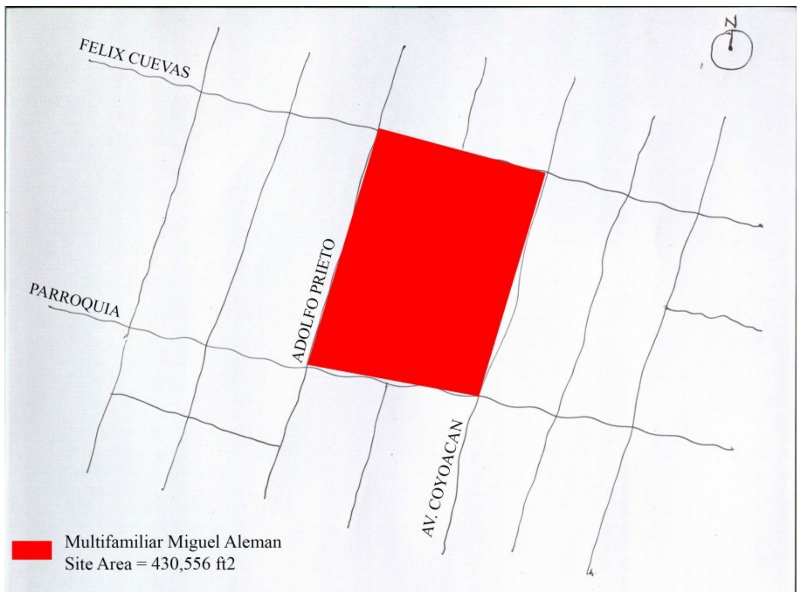

Figure 1. *Multifamiliar Miguel Aleman's* Site Area.

Figure 2 shows a comparison of a equivalent site area of the mixed-use, mid-rise *Multifamiliar Miguel Aleman* community with 1,080 apartments, retail area, recreation center and parks, and a two-storey complex with the same building area. This two-storey complex would need 3.5 times the site area of the *Multifamiliar Miguel Aleman* complex. The presence of low-rise and low-density buildings and the use of the automobiles[2] are

[2] Gabriel Quadri-De la Torre (2009) explained that Mexico City's cars contributed 82 percent of the NO_x emissions in the City. In addition to the purchase and use of more fuel-efficient cars, the increase use of mixed-use buildings to reduce the need to use the automobile, mainly in Mexico City, and the increased use of high-efficiency transportation could start an important trend in Mexico in terms of energy efficiency, air pollution reduction and urban welfare.

contributing to the sprawl of Mexico City. In contrast, a mixed-use, vertical, mid-rise, low-energy, low-water use community would reduce the urban sprawl by allowing more residents to be comfortably housed in less area. This would also reduce the need of the private cars and the accompanying pollution produced by burning fossil fuels, because of the mixed-use community that lessens the need for private automobiles.

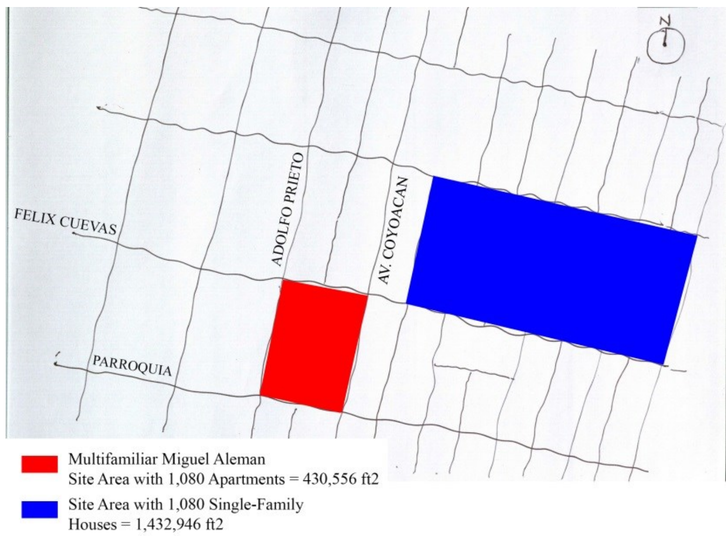

Figure 2. *Multifamiliar Miguel Aleman's* Site Area versus Two-Storey Building Site Area.

Recently, Mexico has hosted three important international conferences: the Cancun 2010 United Nations Climate Change Conference (CC2010, 2011a; UNFCCC, 2011); the Mexico City 2010 World Mayors Summit on Climate (WMSC, 2010); and the Aguascalientes 2011 United Nations Human Settlements Programme Global Observance of World Habitat Day to begin to address these issues (UN-Habitat, 2011a, b).

These conferences discussed a number of related topics including: the climate issues and the commitment to reduce the CO_2 emissions, the commitment to develop strategies, measures, public policies, laws, plans and campaigns to reduce greenhouse gas emissions, the problems with population and urban growth, and the importance of cities in the mitigation of climate change. In light of these efforts it is clear that Mexico City must address community-wide energy-use and water-use in order to reduce the total energy and water consumption and the associated greenhouse gas emissions.

During the last few years, Mexico has made progress toward these goals. For example, Mexico has developed the *2007 Housing Building Code* (*CONAVI,* 2007)[3] with the help of the International Code Council (ICC, 2012). This is the first building code in Mexico with a chapter related to sustainability, which is setting an important trend for other countries. Furthermore, Hirata-Nagasako (Ortigoza, 2010) stated that countries like Colombia and Brazil are adopting the Mexican *2010 Housing Building Code.*[4] This shows that not only is Mexico benefitting from these efforts but other countries are following the example of Mexico in terms of energy-efficiency, energy renewable technology and sustainability, and its application to the housing sector. Therefore, the guide from this technical potential study of mixed-use communities could be adopted by other countries.

This technical potential study intends to analyze a low-energy, low-water use community in Mexico City to help fill the knowledge gap that exists for the analysis of community-wide energy-use and water savings use in Mexico City. It will address parameters in the accompanying guide that will impact the energy and water consumption by implementing energy and water-efficiency measures, on-site energy generation, water savings and transportation use reduction. Finally, this technical potential study will quantify the potential total energy and water use reduction of a low-energy, low-water use community in Mexico, and estimate the reduction in private automobile use due to the incorporation of mixed-use buildings.

1.2. Purpose

The purpose of this study was to determine and investigate a potential scenario to reduce energy, water and transportation use in Mexico City by implementing low-energy, low-water use communities. Such an analysis would include the application of energy-efficient measures; the use of on-site energy generation (i.e., passive solar, solar thermal, solar domestic hot water, and solar photovoltaic systems among others) applied to the

[3] Translated from *Codigo de Edificacion de Vivienda 2007* (*CONAVI,* 2007).
[4] The *2010 Housing Building Code* is the version 2 from the *2007 Housing Building Code.*

buildings in a case-study community; the implementation of low-water use strategies; and the reduction of transportation use.

1.3. Objectives

In order to achieve this purpose, the following objectives must be fulfilled:

1) Review the previous literature concerning the population and energy consumption for Mexico and the US, regarding low-energy, low-water use communities.
2) Investigate building characteristics and urban patterns in Mexico City to select a base-case community for analysis.
3) Model the baseline of the existing base-case community in Mexico City.
4) Identify potential energy and water-efficiency measures to minimize consumption for low-energy, low-water use communities in Mexico City.
5) Investigate methodologies and tools to analyze community-wide energy and water use, including a combined analysis that uses energy simulation software for whole-building energy analysis; size renewable energy systems; analyze the annual savings from the generation and use of on-site renewable energy; and analyze the water-saving and transportation savings potential of the mixed-use facility.
6) Apply the procedures above to the base-case community to achieve the low-energy, low-water use of the new facility. 7) Develop an overall guide based on the results of procedures one to six.

1.4. Organization of the Dissertation

This dissertation is divided into the following six chapters with supporting appendixes: Introduction; Literature Review; Significance and Limitations of the Technical Potential Study; Methodology; Application of the Methodology and Summary and Conclusions.

Chapter I is the introduction of the technical potential study. This chapter shows the background of the study; the problem statement and the purpose of the research; as well as and the objectives to be fulfilled during the study.

Chapter II is the literature review. The chapter presents a review of the literature related to the objectives of the technical potential study. The literature review covers the following areas: population and energy consumption in Mexico compared to the US; the concept and application of low-energy, low-water use communities in Mexico; urban patterns and building characteristics in Mexico City; potential renewable energy and energy and water-efficiency technologies for mixed-use buildings to create low-energy, low-water use communities for Mexico City; and simulation tools to analyze energy consumption. This review is intended to build up a basis for conducting the research.

Chapter III is the significance and limitations of the technical potential study. This chapter explains the expected contributions to this area of study; and the significance and the limitations of the study.

Chapter IV is the methodology and the application of the methodology. This chapter shows the step-by-step procedure to build up the framework to estimate a low-energy, low-water use community in Mexico City. It also applies the step-by-step procedure to a case-study community in Mexico City and presents the findings in terms of: the selection of energy and water-efficiency strategies, and their final reduced energy and water use; and provides an analysis of the potential on-site energy generation through renewable energy-use systems.

Chapter V presents the results. This chapter shows the final results of the analysis and provides an overall guide based on the results of the step-by-step procedure.

Chapter VI is the summary and conclusions. This chapter summarizes the technical potential study, and presents the study's conclusion and recommendations for future research.

Additional information to support the technical potential study is included in the appendixes.

CHAPTER II
LITERATURE REVIEW

The categories of the literature review for this study are: 1) population and energy consumption in Mexico compared to the US; 2) the concept and previous applications of low-energy, low-water use communities in Mexico; 3) urban patterns in Mexico City; 4) building characteristics in Mexico City; 5) potential energy and water-efficiency measures to minimize the consumption in a Mexican use community and 6) energy simulation tools to analyze selected building types in the Mexican case-study community.

2.1. The Population and Energy Consumption in Mexico Compared to the US

In a previous study by Bermudez-Alcocer and Haberl (2010), a comparative analysis was presented on low-impact, low-income housing for Mexico and the US. The analysis included a comparison between Mexico and the US on population density by state, total population by state, population by cities and energy consumption. The study concluded that Mexico and the US differ significantly in population and energy consumption. Mexico had 103.2 million people in 2005, and the US had 304 million people in 2008 (*INEGI,* 2008a; US Census Bureau, 2010a). In addition to the three-to-one difference in population, 50 percent of the population in Mexico is concentrated in the south-central states in comparison with the more spread-out population throughout the US.

Any study of housing in Mexico needs to consider that there is an average of four members in each family in Mexico, which is twice the US average (*INEGI,* 2008a; US Census Bureau, 2010b). The number of people living in a dwelling in Mexico seems to consume more energy than the number of people living in a dwelling in the US. However, the air-conditioning systems used in the American houses consume more energy to keep thermal comfort than the Mexican houses without air-conditioning.

Comision Nacional de Vivienda (*CONAVI,* 2006) showed that the highest energy consumption end-use in the Mexican housing sector (i.e. single-family and multi-family) are: cooking, hot water, lighting and appliances. In 2011, the appliances' purchase in Mexico reached US$1,985 million (ProMexico, 2013). Trends show that the purchase of electric appliances for Mexican residences will increase an 8.9 percent from 2012 to 2020. This will raise the energy consumption per household.

Bermudez-Alcocer and Haberl (2010) also showed a comparison of the energy consumption in the housing sectors in Mexico and in the US and found that an energy consumption of 6.8 MMBtu/person for Mexico (in 2005) and 71.1 MMBtu/person for the US (in 2008). Mexico must be careful to assure that the new housing buildings in Mexico are designed to be environmentally adapted, more energy-efficient, and use renewable energy, or they face becoming as energy-consumptive in the long run as those in the US.

In addition, there is an urgent need for new housing in Mexico. However, new areas to build in the most populated areas, like in Mexico City, are scarce (Horbath-Corredor, 2003). Therefore, this technical potential study will focus on multi-family housing, instead of single-family housing. The technical potential study will focus in Mexico City due to its high density population, and the impact that the multi-family buildings in Mexico City will bring to the rest of the country in terms of housing and energy consumption.

Mexico City has a unique climatic condition due to its altitude [7,559 feet (ft.) (2,304 meter (m))]. By comparison Denver, Colorado has an altitude of 5,470 ft. (1,667 m), which makes it the largest American city with an elevation closest to Mexico City's elevation. Heating Degree Days (HDD) and Cooling Degree Days (CDD) in Table 1 can be used to find a major U.S. city similar to Mexico City in terms of climate.

Figure 3 shows that Mexico City, San Diego and Burbank are close to 1,203 HDD65ºF, and that Mexico City and Los Angeles are close to 4,762 CDD50ºF. Denver is far away from Mexico City, Burbank, Los Angeles and San Diego in terms of HDD and CDD. Therefore, the only American cities with similar climate compared to Mexico City are Burbank, Los Angeles and San Diego. However, neither Burbank, Los Angeles nor San Diego are near to the 7,559 ft. altitude of Mexico City, which impacts the heating and cooling. Burbank, Los Angeles and San Diego are also influenced by the nearby ocean which provides sea breezes to help cool the land. To conclude, in comparison to US cities, Mexico City could apply energy-efficiency solutions from San Diego or Burbank for the summer season, and energy-efficiency solutions from Los Angeles for the winter season.[5]

Table 1. Heating and Cooling Degree Days in Analyzed Cities.

Cities	Heating Degree Days (HDD65°F)	Cooling Degree Days (CDD50°F)
Burbank	1,204	5,849
Denver	6,020	2,732
Los Angeles	1,458	4,777
Mexico City	1,203	4,762
San Diego	1,256	5,223

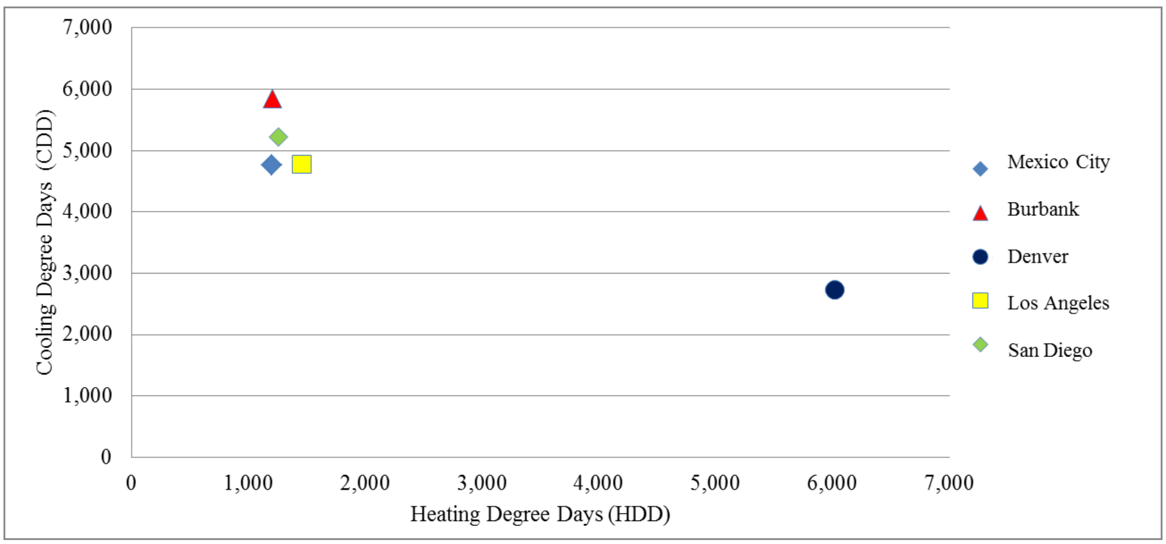

Figure 3. Heating Degree Days (HDD) and Cooling Degree Days (CDD) for Mexico City, Burbank, Denver, Los Angeles and San Diego.

[5] Use natural ventilation and thermal mass during the summer and let solar access during the winter (Lechner, 2001).

2.2. The Concept and Application of Low-Energy, Low-Water Use Communities in Mexico

The most significant literature discusses the concepts and reasons for low-energy, low-water use communities, and the applications of the low-energy, low-water use communities for case studies in Mexico and the US.

2.2.1. Concepts and Reasons for the Low-Energy, Low-Water Use Communities.

Although the low-energy, low-water use community is not commonly used, the concept of a low-energy community, the relationship between the people and its environment, and the spatial characteristics of the cities has been subtly mentioned by several authors, including Brand (2009), Glaeser (2011), Owen (2009), Register (2006), Rybczynski (2010) and Van der Ryn and Calthorpe (1986), Yeang (2009), and Vittori and Fisk (2010). The concept of a low-water community has also been subtly mentioned by several authors, including Kemp (2009) and Novotny et al. (2010). Many of the communities inside the cities in these previous studies about low-energy or low-water use communities have a high concentration of poverty, yet these communities in the cities represent the best hope of escaping this poverty (Brand, 2009).

In the early 1980s, Calthorpe, Duany and Plater-Zyberk looked at the characteristics of the New Urbanism Theory, which contain: high density, walkability, mixed-use buildings and mass transportation among others (Brand, 2009). Calthorpe mentioned that these characteristics could even be seen in squatter communities. Squatter communities found in cities are most often a mosaic of the inhabitants' different social backgrounds. These communities have high density and mixed-use spaces (i.e., housing and retail) where people can walk, use a bike or utilize other mass transportation.

The low-energy, low-water use community is an essential concept in order to understand the interaction between people and their cities. The concept of a low-energy, low-water use community has been present in many previous theories or methodologies. Register (2006) referred to Paolo Soleri who began with the idea of the Mesa City, while living in Paradise Valley, outside Phoenix, Arizona. He hypothesized about a vertical three-dimensional city, Mesa City, with different parts that he called "housing," "industry," "civic center” and “education.” He realized that this hypothetical vertical city could cover 1/10 of the site and consume 1/20 of the energy apparently linked to transportation. In relation to the low-energy, low-water use community guide, the strongest idea about his theory was to build cities with vertical and compact areas, which would allow for increased proximity; and thus reduce energy losses and pollution emissions associated with horizontal transportation. Also, Soleri stated that the city is like a living system to encourage people to use pedestrian areas instead of cars and buses. This pedestrian concept will also reduce energy.

Yeang (2009) showed the EcoMasteringPlanning process that involves a series of layers that are integrated onto a final map. These layers are the following:

- A “green-colored” infrastructure that is nature’s infrastructure;
- A “blue-colored” infrastructure that is overall water system (drainage and hydrology of the site);
- A “grey-colored” infrastructure that is composed of roads, sewage system and utilities; and
- The “red-colored” infrastructure that includes the built environment and the areas of social, economic and legislative activities.

Yeang recommended such a site analysis should be done before designing any building. The EcoMasteringPlanning final map would help to identify and understand the properties of each layer (green, blue, grey and red infrastructure), and the interaction of these layers once they are superpositioned within the site. This is an interesting approach from a site analysis point of view. However, the study was not used to create a community from scratch. Since the targeted community currently exists in Mexico City, the goal is to improve its energy-efficiency, reduce its energy consumption, maintain or improve its livability and use on-site energy power generation to better utilize non-renewable resources.

Vittori and Fisk from the Center for Maximum Potential Building Systems (CMPBS, 2010) showed the EcoBalance planning process which determines and analyzes footprints to supply requirements such as air, water, food, energy, and materials. The idea of this methodology is to establish an eco-balance. This balance could be obtained within its analyzed limit. However, if this balance is not obtained within its analyzed limit, the analysis goes up the hierarchical level and achieves the required footprint. The hierarchical level, used by CMPBS, goes from the smallest to the biggest element as shown in Figure 4: building, lot, site, neighborhood, city and state.

This source was useful to identify and understand the properties of each requirement (i.e., air, water, food, energy, and materials), and the quantification of the areas of each requirement in order to achieve an ecological balance. Also, the EcoBalance allowed for the interaction of the areas of the requirements once they are superpositioned within the analyzed building, lot, site, neighborhood, city or state. The guide will be used to size the energy-use and water-use systems due to the requirements of the people in the community. It is remarkable how Vittori and Fisk group the requirements (e.g., air, water, food, energy and materials) around hierarchical levels (building, lot, site, neighborhood, city and state in Figure 4).

The Mexican and the American government agencies have made significant progress in terms of sustainable communities. There is a potential opportunity to exchange information between Mexico and the United States. A group of programs and organizations developed the *Integrated Sustainable Urban Development* model (*CONAVI,* 2010b). This model was created to promote urban sustainability measures in Mexico (Topelson-De Grinberg, 2010).

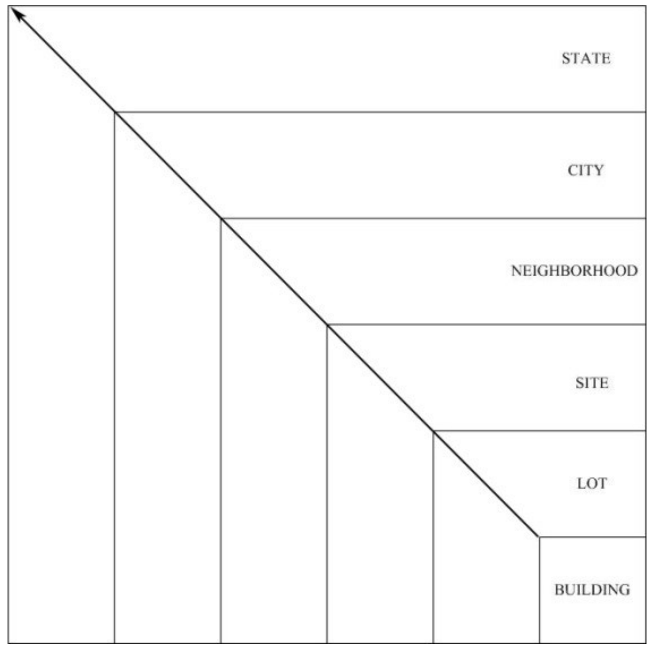

Figure 4. Hierarchical Level from CMPBS (Created with Information from Vittori and Fisk, 2010).

It is vital to discuss early issues and solutions in terms of urban and building scale in Mexico City. One of the main problems of today's Mexico City is urban sprawl. Rhoda and Burton (2010) pointed out the sprawl in Mexico City. According to Rhoda and Burton the following historical events caused the sprawl in Mexico City: fast industrialization in Mexico City and the expansion of the existing railroad system between 1877 and 1910; the appearance of an efficient electric streetcar system in 1910; the development of urban bus services in 1920; and the appearance of private cars around 1950.[6] Rhoda and Burton also mentioned that in Mexico City the high demand for housing around 1940s, due to urban growth and population mobility, also contributed to sprawl. Unfortunately by the late 1940s, the *Distrito Federal*'s government prohibited the construction of new urban neighborhoods

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[6] In comparison to American urban areas, Rybczynski (2010) studied the sprawl and found that the automobile was one of the main reasons cities spread-out horizontally. In addition, the appearance of highways and suburbs made cities become even more horizontal and with less density.

(Larrosa, 1985).[7] The result was the construction of the *Ciudad Satelite* suburb in 1952, in Naucalpan, Mexico.[8] Such suburban developments have negatively impacted the environment causing increased the production of greenhouse gases (GHG). Sprawl has also caused excessive burning of fossil fuels to produce the energy needed because of the increased travel. Thus, if the city is more compact and the services are closer, the people will not travel long distances, and the sprawl and the energy consumed to travel will be reduced in the long term.

Another issue in Mexico City is its' urban regeneration. Castillo-Juarez (2005) and Paquette-Vasalli and Yescas-Sanchez (2009) addressed Mexico City's urban development in the lately 1990s and early 2000s. Castillo-Juarez also said that the central boroughs of the Distrito Federal (Cuauhtemoc, Benito Juarez, Miguel Hidalgo and Venustiano Carranza) lost more than 1.2 million inhabitants between 1970 and 2000. On the other hand, the other 12 boroughs of the Distrito Federal experienced a large stress due to the sprawl over the previously rural areas and natural reserve sites. In addition, the south and southwest boroughs from the periphery in Figure 5 of the Distrito Federal should be protected due to their aquifer recharge capacity (Paquette-Vasalli and Yescas-Sanchez, 2009). Finally, Paquette-Vasalli and Yescas-Sanchez, as well as Castillo-Juarez, pointed out that the Distrito Federal's government decided to focus on the residential construction in its four central boroughs.

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[7] The *Distrito Federal* is Mexico City. Mexico City Metropolitan Area is the *Distrito Federal* plus the *municipios* from the *Estado de Mexico*, or Mexico State.
[8] Naucalpan, Mexico is located inside of the Metropolitan Area of Mexico City.

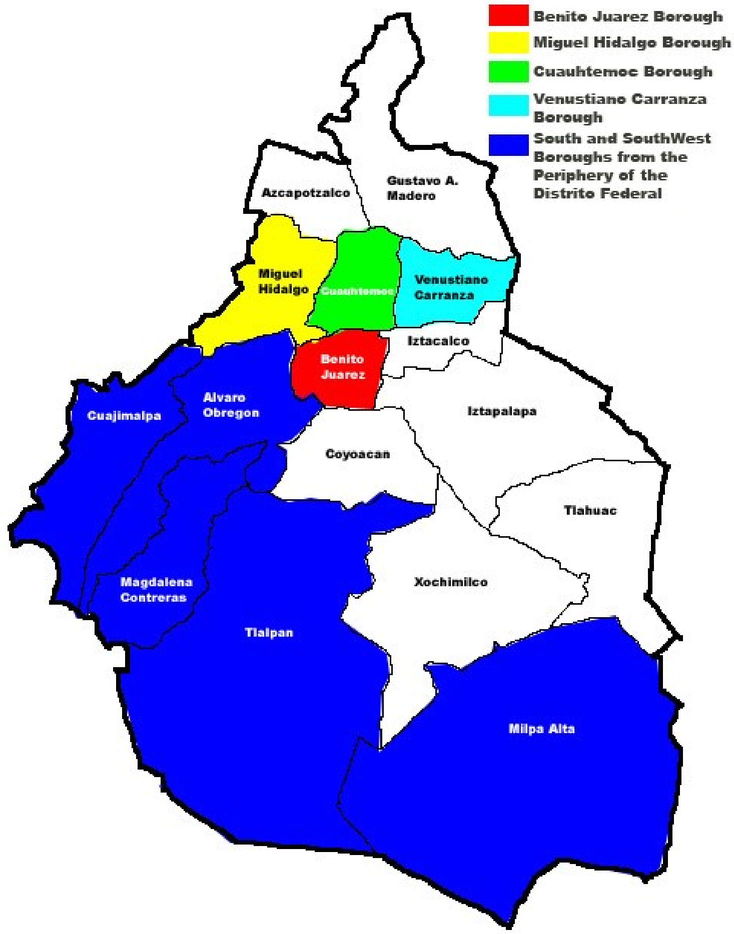

Figure 5. ***Distrito Federal*** **Map with Borough Division (Data from Castillo-Juarez, 2005, Paquette-Vasalli and Yescas-Sanchez, 2009, Map Modified from FotosImagenes, 2013).**
The Contour Lines Were Traced over the Original Image; and the Color Coded Areas and the Titles Were Added. This Map Was Needed to Show the Central Area in Mexico City that Was Repopulated and the Southern Area with the Aquifer Recharge Capacity that Was in Danger Due to the Urban Sprawl. Reprinted from CreativeCommons, Retrieved April 4, 2014, from http://www.fotosimagenes.org/delegaciones-del-distrito-federal-mexico. Copyright 2013 by CreativeCommons. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

Mixed-use, high density and walkable communities reduce sprawl in cities, in contrast to the more horizontal and with less density city vision, create more environmentally-friendly living environments (Glaeser, 2011; Owen, 2009). There was an early effort to create a community-like entity in Mexico from the urban point of view from the *Comision Nacional de Vivienda* (*CONAVI*). *CONAVI* (2007) showed the required urban infrastructure for residential complexes in terms of dwellings and inhabitants (See Table 2) from the Regulatory System of Urban Infrastructure from the *Secretariat of Social Development* (*SEDESOL*, 2012). The first column in Table 2 includes the subsystems that the residential complex can have. The second column is the elements from each subsystem. The third column is the basic unit of service for each element into the residential complex. The fourth to the eighth column shows the elements that are required into the residential complex in terms of the number of dwellings and the total number of people. These provided elements will create a sense of community-belonging and encourage the use of mass alternative transportation, which reduces overall transportation energy-use.

CONAVI's *Redensification Guide for Housing in the Inner City* (2010c) complemented what their 2007 development shows in Table 2. *CONAVI* also suggested the use of existing urban infrastructure in the inner cities to avoid the high investment at the periphery of the cities. This should improve the interaction of the people in the cities and reduce pollution due to a reduced need for transportation, which can also avoid the loss of agricultural lands in the periphery.

Linking to the previous idea, Table 3 shows *CONAVI's 2010 Housing Building Code* (2010a) classification of the different housing types in relation to the family income in Mexico. This code defined the current housing classification in Mexico in terms of constructed area and income. This classification was created due to the price and the housing building areas in Mexico. *CONAVI* named the first column elements analyzed from housing. The second through the seventh columns show the following housing types: economic, popular, traditional, mid-income, residential and residential plus. Areas in the current housing types from Table 3 should be connected with the urban infrastructure for residential complexes from Table 2. The area of a single dwelling multiplied by the number of dwellings required for each complex can give an idea of the area for the residential complex.

Table 2. Urban Infrastructure for Residential Complex (Data from *CONAVI*, 2007). The Original Data from the Columns Was Translated from Spanish to English. This Table Showed the Required Urban Infrastructure for Residential Complexes from *SEDESOL (CONAVI*, 2007), and Set Background for this Study in Terms of Housing in Mexico. Adapted from *Codigo de Edificacion de Vivienda 2007* (p.64), by *Comision Nacional de Vivienda,* 2007, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2007 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Concepts		**Dwellings**	**10,000**	**5,000**	**2,500**	**1,000**	**500**
Subsystems/Elements		**People**	**50,000**	**25,000**	**12,500**	**5,000**	**2,500**
		Basic Unit of Service	**Basic Unit of Service**	**Basic Unit of Service**	**Basic Unit of Service**	**Basic Unit of Service**	**Basic Unit of Service**
Education	Kindergarden	Classroom	o	o	o	o	o
	Elementary school	Classroom	o	o	o	o	o
	Working training center	Workshop	x	x	x		
	General middle school	Classroom	o	o	o	x	
	Technical middle school	Classroom	o	o	o	x	
	General high school	Classroom	x	x	x		
Cultural	Public municipal library	Chair	o	o	o	o	o
	Casa de cultura	m^2	o	o	o	x	x
	Popular social center	m^2	o	o	o	x	x
	Municipal auditorium	Chair	x	x	x		
Health	Health center	Office	o	o	o	o	o
	Family medicine unit	Office	o	o	o	x	
	Aid station	Stretcher	o	o	o	o	
Social welfare	Child development care center	Classroom	o	o	o	x	
	Community development center	Classroom and/or workshop	o	o	o	x	x
Trade and supply	Multipurpose space *(tianguis)*	Space for table	o	o	o	x	x
	Public market	Space for table	o	o	o	x	x
	Convenience store	Store	x	x	x	o	o
Communication	Post office	Window	o	o	o	o	o
	Comprehensive service center	Window	x	x	x		
	Postal administration	Window	o	o	o	x	
	Telegraphic administration	Window	o	o	o		
Transportation	Taxi station	Parking space	x	x	x		
Recreation	Civic square	m^2	o	o	o	x	x
	Playground	m^2	o	o	o	o	o
	Neighborhood garden	m^2	o	o	o	x	x
	Neighborhood park	m^2	o	o	o		
	Cinema	Chair	o	o	o	x	
Sports center	Sports module	m^2	o	o	o	o	o
	Gymnasium	m^2	x	x	x		
	Pool	m^2	x	x	x		
	Sports hall	m^2	o	o	o	x	x
Public administration	Federal government offices	m^2	x	x	x	x	
	Federal public ministry	m^2	o	o	o	x	x
Urban services	Police headquarters	m^2	o	o	o	x	x
	Municipal landfill	m^2	o	o	o	o	o
	Service station (gas)	Dispatcher gun	o	o	o		

Note: The "o" means a required element and the "x" means an optional element.

Table 3. Housing Types Related to Family Income in Mexico (Data from *CONAVI,* 2010a).
The Original Data from the Columns Was Translated from Spanish to English. This Table Complemented the Information Given in the Previous Table 2. The Data Set the Background in this Study for the Different Types of Housing in Mexico. Adapted from *Codigo de Edificacion de Vivienda 2010* (p.55), by *Comision Nacional de Vivienda,* 2010, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2010 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

ELEMENTS ANALYZED FROM HOUSING	ECONOMIC	POPULAR	TRADITIONAL	MID-INCOME	RESIDENTIAL	RESIDENTIAL PLUS
Constructed area	30 m^2	42.5 m^2	62.5 m^2	97.5 m^2	145 m^2	225 m^2
	(323 ft^2)	(457.5 ft^2)	(673 ft^2)	(1,049.5 ft^2)	(1,561 ft^2)	(24,22 ft^2)
Average cost:						
Number of Monthly Minimum Wages in the *Distrito Federal*	118	From 118.1 to 200	From 200.1 to 350	From 350.1 to 750	From 750.1 to 1,500	More than 1,500
Spaces:	Bathroom	Bathroom	Bathroom	Bathroom	Bathrooms (3 to 5)	Bathrooms (3 to 5)
	Kitchen	Kitchen	Kitchen	Toilet	Kitchen	Kitchen
	Mixed-use Area	Living/Dinning Room	Living/Dinning Room	Kitchen	Living room	Living room
				Living Room	Dining room	Dining room
		Bedroom (1 to 2)	Bedrooms (2 to 3)	Dining Room	Bedrooms (3 to 5)	Bedrooms (>3)
				Bedrooms (2 to 3)	Utility Room	Utility Room (1 to 2)
				Utility Room	Family Room	Family Room

Atta (2006) pointed out that the relation between sustainability, urban form and building design can produce significant reductions in energy consumption through intelligent and sustainable planning and architecture.

Malhotra (2009) showed an analysis of off-grid, off-pipe housing in six US climates. She searched for the feasibility of an off-grid, off-pipe approach to achieve energy self-sufficiency in single-family housing. The different climates studied for each city[9] required solutions in terms of energy and water consumption. The following techniques were used for the analysis of single-family housing: solar thermal system for space and water heating requirements; photovoltaic and wind power systems for electricity needs; and rainwater harvesting system for indoor water needs; and septic system for household wastewater and sewage.

[9] Minneaoplis, MN (very cold), Boulder, CO (cold), Atlanta, GA (mixed-humid), Houston, TX (hot-humid), Phoenix, AZ (hot-dry), and Los Angeles, CA (marine).

Precautionary measures applicable to water-use in Mexico City must be considered for this technical potential study. Kemp (2009) pointed out that excessive construction of single-family houses will produce less impervious surfaces and prevent groundwater recharge, which can reduce potable water supplies that depend on surface water sources potable water supply and food production[10] are also elements that are essential for the long-term viability of communities. Therefore, in the future, communities, as well as the cities, will need to rely more on the efficient use and reuse of water including, on-site systems for rainwater harvesting and storage and, eventually its treatment for use in potable water systems (Novotny et al., 2010).

2.2.2. Applications of Low-Energy, Low-Water Use Communities for Case Studies in Mexico and the US.

The following communities that have begun to approach low-energy, low-water use were analyzed: 1) the *Centro Urbano Presidente Aleman,* 2) *the Centro Urbano Presidente Juarez and* 3) *the Centro Urbano Presidente Adolfo Lopez Mateos* in Mexico and 4) The Cityscape (Phoenix, Arizona), 5) Triangle Square (Austin, Texas), 6) Battery Park City (New York City, New York), and 7) East Village (San Diego, California) in the US.

The built environment of the analyzed communities in the current section has to deal with the next climate classifications. *CONAVI* (2006) identified that Mexico City is located in the temperate climate (*Cw)* group.[11] Briggs et al. (2002) described a new climate classification for the US in terms of the performance of the energy-efficiency measures for buildings. Phoenix is located in the hot-dry climate (*BWh*) group; Austin is located in the hot-humid climate (*Caf*) group; New York City is located in the mixed-humid (*Caf/Daf*) group; and San Diego is located in the warm-dry (*BSk/BWh/H*) group.

[10] An analysis of the food production will not be developed for this study.
[11] *CONAVI* (2006) identifies the *Cw* climate from the Köppen system. McKnight (1996) also shows the climate zones and their types in the world.

2.2.2.1. Centro Urbano Presidente Aleman (Multifamiliar Miguel Aleman) in Mexico City, Mexico.

In *Los Multifamiliares de Pensiones,* Pani (1952) mentioned that he was contacted in 1947 by Jose de Jesus Lima, who was the sub-director of the Department of Civil Pension Retirement (*Pensiones Civiles de Retiro or ISSSTE*). Pani was asked to build 200 affordable houses on a site of 40,000 m² (430,556 ft² or 10 acres) at the *Colonia Del Valle* at the *Benito Juarez* borough for the workers of the Department of Civil Pension Retirement. At the time, Pani thought that the potential of the site would be wasted due to the increasing population in Mexico City. Therefore, he proposed other options that he had seen previously in France: the multi-family building and the superblock concepts from Le Corbusier. In the earlier concept, Le Corbusier proposed a population density of 1,000 people for hectare[12] (Larrosa, 1985). In the latter concept, Le Corbusier enhanced the use of the open space and the preservation of the neighborhoods, and still maintained the high density. The complex was inaugurated on September 2, 1949 (See Figure 6) (De Garay-Arellano, 2004).[13]

The final result for the *Centro Urbano Presidente Aleman* was a complex of nine buildings with thirteen floors and six buildings with three floors for a total of 1,080 apartments with approximately 5,000 residents. The buildings have an "L" shape and are placed on the diagonal across the site. Some buildings face west-northwest or east-southeast, while other buildings face north-northeast or south-southwest.[14] This can be seen in Table 4 where the number of buildings and orientations of the mid-rise buildings in the *Centro Urbano Presidente Miguel Aleman* is shown. The buildings have elevators and staircases on

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[12] One *hectare* = 10,000 m² or 2.5 acres.

[13] The Mexican web-based magazine Arquine (2012) opened the international competition "Competition No.15 Re-Populate the 21st Century: Social Housing from the Modern Paradigm." It was also pointed out that Pani viewed the houses as an urban problem that must be integrally solved in terms of social, economical, politics and spatial characteristics. This competition aimed to create new types of housing for the 21st century by reviewing the current housing models involved with theories about redensificaton, sustainability and interaction with the city. The final goal is to provide solutions against the urban sprawl.

[14] *CONAVI* (2010a) recommended apartments facing south or southeast on one side of a centerline. It also recommends avoiding apartments facing northeast on one side of a centerline and apartments facing southwest on the other side of a centerline. The *Multifamiliar Miguel Aleman* has apartments facing south-southwest on one side of the centerline and apartments facing west-northwest on one side of a centerline and apartments facing east-southeast on the other side of the centerline.

the narrow edge side. The floor plan of the smaller apartments have 48 m² (516 ft²) and the larger apartments have 83 m² (893 ft²). Most of the apartments have two stories with an interior staircase. De Anda (2008) mentioned the following structural features of the buildings of the *Multifamiliar Miguel Aleman*: concrete columns and beams, red brick walls and horizontal windows of the buildings. The buildings have concrete slabs, and the windows are clear, single-pane with aluminum frame. The fact that boiler uses liquefied petroleum gas for domestic hot water (DHW) systems was identified after visiting the site.

Table 4. Mid-Rise Buildings in the *Centro Urbano Presidente Miguel Aleman*.

Number of Buildings	Number of Floors	Orientation
6	13	WNW-ESE
3	13	NNE-SSW
6	3	WNW-ESE

These buildings do not have air-conditioning systems and the kitchens and bathrooms are naturally ventilated by the interior courtyards. The buildings' footprints and their open space occupy 20 percent and 80 percent of the site, respectively (De Garay-Arellano, 2002; Larrosa, 1985; Partridge, 1992).

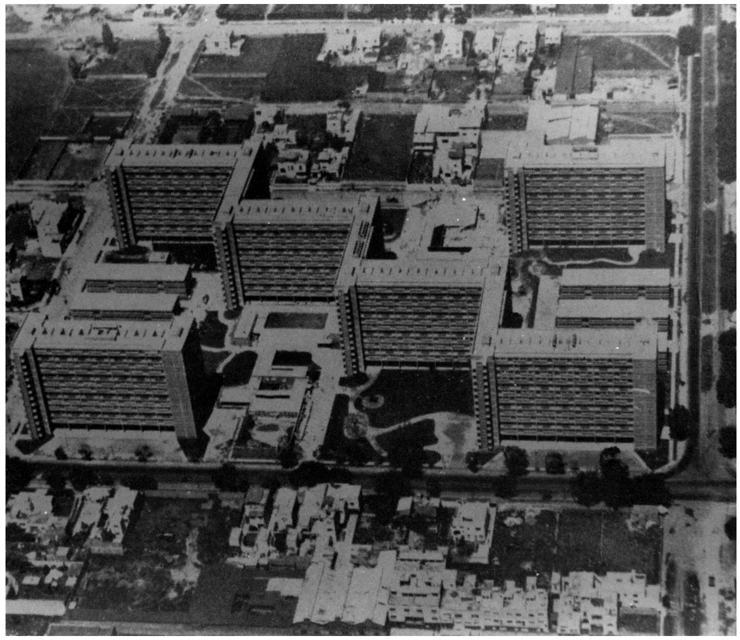

Figure 6. Aerial View of the *Centro Urbano Presidente Aleman* (or *Multifamiliar Miguel Aleman*) in 1949.
Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.17), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission.

The complex implemented different elements on the ground floor such as: retail and grocery stores, administrative offices, a a nursery, laundry room, dispensary, assembly hall and recreation areas (i.e., soccer, basketball, volleyball and a semi-Olympic pool with bathrooms and dressing rooms) (De Garay-Arellano, 2002).[15] The closest alternative transportations to the complex are the *Hospital 20 de Noviembre's* metro station, bus routes, and taxicabs as seen in Figure 7. The complex endured a significant earthquake which occured on September 19, 1985 in Mexico City. This project is widely viewed as the first multi-family complex built in Mexico (and Latin America) that successfully addressed the future population increase in Mexico City (Pani, 1952; Iannini, 1999). Hence, this complex has some characteristics such as high density, mixed-use, close to alternative transportation,

[15] A 600 student school and a casino were proposed in the original idea, but they were not constructed by the end.

and recreation areas among others. This community could be used as a template to rebuild several areas in Mexico City for the future.

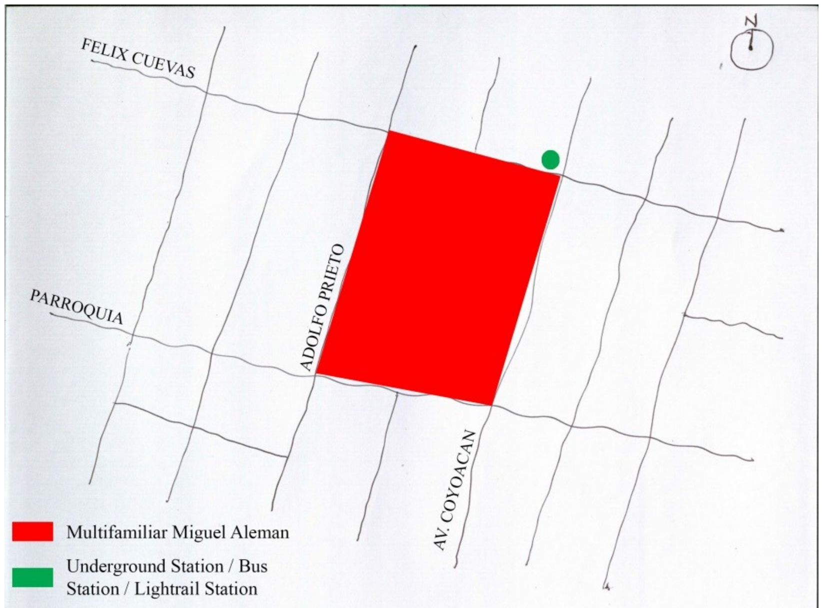

Figure 7. *Multifamiliar Miguel Aleman* (or *Centro Urbano Presidente Miguel Aleman*) Location.

2.2.2.2. Centro Urbano Presidente Juarez (Multifamiliar Benito Juarez) in Mexico City, Mexico.

In 1950, the Department of Civil Pension Retirement (*Pensiones Civiles de Retiro or ISSSTE*) asked Pani (1952) to build a second multi-family complex: *Centro Urbano Presidente Juarez* in a 250,000 m² (2,690,977 ft² or 62 acres) site at the *Colonia Roma* at the *Cuauhtemoc* borough. To design this, Pani used many of the same concepts from the *Centro Urbano Presidente Aleman.* The complex was constructed in two phases. In his design, the *Centro Urbano Presidente Juarez* for Phase One had one building with 13 floors, five buildings with ten floors, four buildings with seven floors, and nine buildings with four floors for a total of 984 apartments and with 3,000 to 5,000 residents. The number of buildings and the number of floors of these buildings can be seen in Table 5. Table 5 shows the mid-rise buildings in the *Centro Urbano Presidente Juarez*. For Phase Two, three more buildings with 13 floors and 63 detached houses of one and two floors would be constructed. The complex was built up from 1950 to 1952 as seen in Figure 8 (Pani, 1952).

Figure 8. Photo from the *Centro Urbano Presidente Juarez* (or *Multifamiliar Benito Juarez*) in 1951-1952.
Reprinted from *Mario Pani: Vida y Obra* (p.41), by G. De Garay-Arellano, 2004, Mexico, D. F., *UNAM*: *Facultad de Arquitectura*, Copyright 2004 by *Patronato Universitario UNAM*. Reprinted with Permission.

Partridge (1992) pointed out that the *Centro Urbano Presidente Juarez* in contrast to the *Centro Urbano Presidente Aleman* did not increase the population density of the earlier project, and that the buildings' footprints only occupied around 7 percent of the site. The buildings were long and narrow and had different orientations.

In contrast to the previous design of the Centro Urbano Presidente Aleman, the elevators and staircases were placed close to the center of each building. Most of the apartments had one floor, but the seven-floor buildings were two-floor apartments. In a similar fashion to the *Centro Urbano Presidente Aleman* project, the buildings do not have air-conditioning systems, and the interior spaces are naturally ventilated by cross ventilation.

The complex had different elements on the ground floor than the *Centro Urbano Presidente Aleman* had, including: retail and grocery stores, a nursery and kindergarten, an administrative office with a dispensary, and recreation areas (Pani, 1952). The closest alternative transportation nowadays to the complex are the *Centro Medico* metro station, bus routes and taxicabs in Figure 9. The *Centro Medico* metro station is located two blocks to the south of the complex.

Table 5. Buildings in the *Centro Urbano Presidente Juarez* (or *Multifamiliar Benito Juarez*) (Pani, 1952).

Phase 1		
Number of Buildings	**Number of Floors**	**Orientation**
1	13	NW-SE
5	10	NW-SW
4	7	N-S
9	4	NE-SW
Phase 2		
Number of Buildings	**Number of Floors**	**Orientation**
3	13	NW-SE
Number of Houses	**Number of Floors**	**Orientation**
63	1 or 2	N-S, NW-SE

Unfortunately, there were several earthquakes that struck the complex after it was built. In September 19, 1985, several buildings of the *Centro Urbano Presidente Juarez* collapsed due to the strongest earthquake recorded (8.1° on the Richter scale) in the coast of Michoacán, Mexico in the Pacific Ocean in several years (Moreno-Murillo, 1995; *UNAM,* n.d.).[16] This event forever changed the lives of all Mexicans and had terrible consequences for Mexico City. Because of the earthquake many people left the inner city and moved to the suburbs in the Mexico City Metropolitan Area or moved to other cities (Camarillo-Carbajal,

[16] There have been several low-intensity earthquakes after the September 19, 1985 in Mexico (and its earthquake aftershock on September 20, 1985).

1987).[17] Since 1985, progress has been made in strengthening buildings against earthquakes (Rahimian and Martinez-Romero, 2003). Therefore, the building codes in Mexico have become more stringent, and the structural design in Mexico has improved enough to allow mid-rise and tall buildings to be constructed.

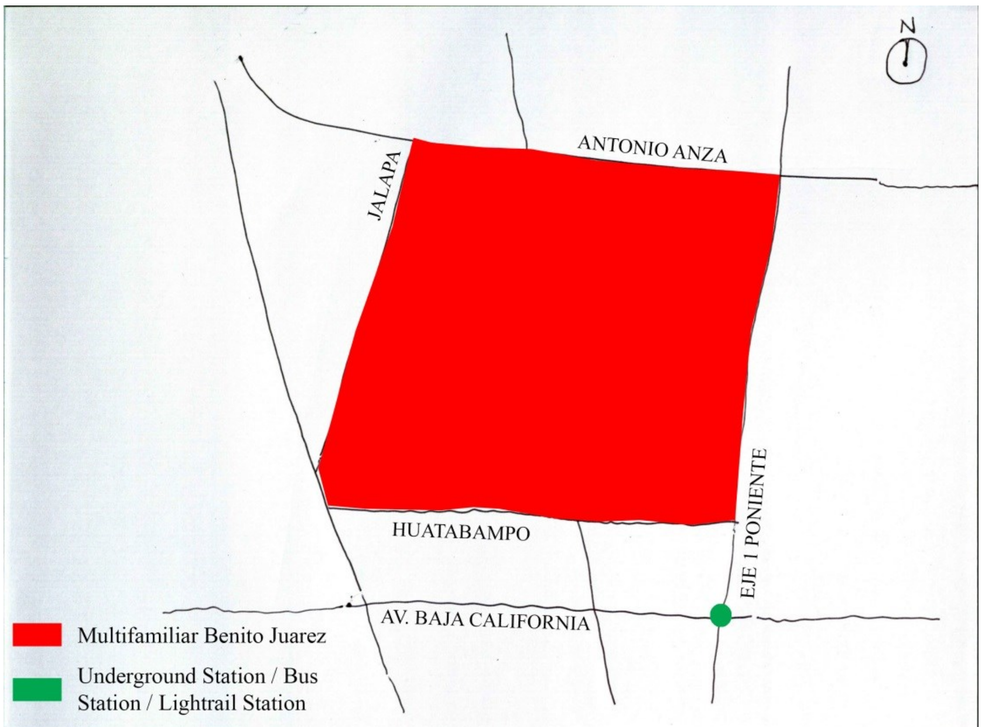

Figure 9. ***Multifamiliar Benito Juarez*** **(or** ***Centro Urbano Presidente Juarez*****) Location.**

2.2.2.3. Centro Urbano Presidente Adolfo Lopez Mateos (Nonoalco-Tlatelolco Housing Unit) in Mexico City, Mexico.

Between 1964 and 1966, Pani built the largest urban complex in Mexico and Latin America: the *Centro Urbano Presidente Adolfo Lopez Mateos,* or the *Nonoalco-Tlatelolco* Housing

[17] The *Servicio Sismologico Nacional* (National Seismological Service) also has a website (http://www.ssn.unam.mx/) and registers the daily earthquakes in Mexico (2011). Since 1985, progress has been made in strengthening buildings against earthquakes.

Unit, on a 1,000,000 m² (10,763,910 ft² or 250 acres), at the *Cuauhtemoc* borough shown in Figure 10 (De Garay-Arellano, 2000).

Figure 10. Photo from the *Centro Urbano Presidente Adolfo Lopez Mateos* (or *Nonoalco-Tlatelolco* Housing Unit) in 1964-1966.
Reprinted from *Mario Pani: Vida y Obra* (p.41), by G. De Garay-Arellano, 2004, Mexico, D. F., *UNAM*: *Facultad de Arquitectura*, Copyright 2004 by *Patronato Universitario UNAM*. Reprinted with Permission.

One intent of this project was to extend the concept of the mixed-use, multi-family housing previously used in the *Centro Urbano Presidente Aleman* and the *Centro Urbano Presidente Juarez.* De Garay-Arellano mentioned that the *Nonoalco-Tlatelolco* Housing Unit was an urban regeneration plan for the decadent surrounding areas of the *Centro Historico* (Old Mexico Inner City or Mexico Inner City Downtown) and followed the same urban model from the *Ville Radieuse* or the *Unite d'Habitation* of Le Corbusier (De Garay-Arellano, 2004). Table 6 contains the historical sites and the public buildings inside of the *Centro Urbano Presidente Adolfo Lopez Mateos* Complex. The *Nonoalco-Tlatelolco* Housing Unit had 102 buildings (Cantu-Chapa, 2011).

The idea of this project was to increase the scale of the mixed-use, multi-family housing that was applied earlier in the *Centro Urbano Presidente Aleman* and the *Centro Urbano Presidente Juarez.* De Garay-Arellano (2004) stated that the complex could hold 80,000 people divided into three superblocks, with apartment buildings that ranged between four and twenty-two floors with a north-south orientation for most of the buildings.

Table 6. Historical Sites and Public Buildings Inside of the *Centro Urbano Presidente Adolfo Lopez Mateos* Complex.

Historical Sites	The Prehispanic Ruins of the City of *Tlatelolco*
	Plaza de las Tres Culturas
	Convento Colonial and *Iglesia de Santiago Tlatelolco*
Public Buildings	*Torre Banobras*
	Torre de la Secretaria de Relaciones Exteriores
	Sindicato de Trabajadores de la Secretaria de Hacienda building
	Admininstracion Inmobiliaria, S. A. building
	1 telephone exchange center
	2 retail zones
	1 covered parking

The tallest apartment buildings (with 14 floors) had retail in the lower floors; the mid-rise buildings (with eight floors) had three bedroom apartments with one and a half bathrooms. The smallest buildings (with four floors) had two bedroom apartments with one bathroom. Table 7 shows the mid-rise buildings in the *Centro Urbano Presidente Adolfo Lopez Mateos*.

The *Centro Urbano Presidente Adolfo Lopez Mateos*, like the *Centro Urbano Presidente Aleman* and the *Centro Urbano Presidente Juarez*, had some additional spaces incorporated into the complex. The additional spaces were the following: an administrative office and several educational institutions (eleven kindergartens, eight elementary schools and three middle schools), and health (six hospitals and clinics) and recreation spaces (Cantu-Chapa, 2001).

Table 7. Buildings in the *Centro Urbano Presidente Adolfo Lopez Mateos* (or *Nonoalco-Tlatelolco* Housing Unit).

Number of Buildings	Number of Floors	Orientation
No Data	14	No Data
No Data	8	No Data
No Data	4	No Data

The buildings' footprints and their open space occupied 20-25 percent and 75-80 percent of the site, respectively (Adria, 2005; De Garay-Arellano, 2004). The closest alternative transportations to the complex are the *Tlatelolco* metro station, bus routes and taxicabs, presented in Figure 11. The *Tlatelolco* underground staton is inside of the *Centro Urbano Presidente Adolfo Lopez Mateos* Complex. Nowadays, the area has become dangerous due to unemployment and poverty. Unfortunately, the earthquake of 1985 collapsed several buildings inside of the complex. Cantu-Chapa said that the first two damaged buildings of the complex were demolished by July 26, 1986 due to their structural damage. The remaining complex is still occupied at the present time.

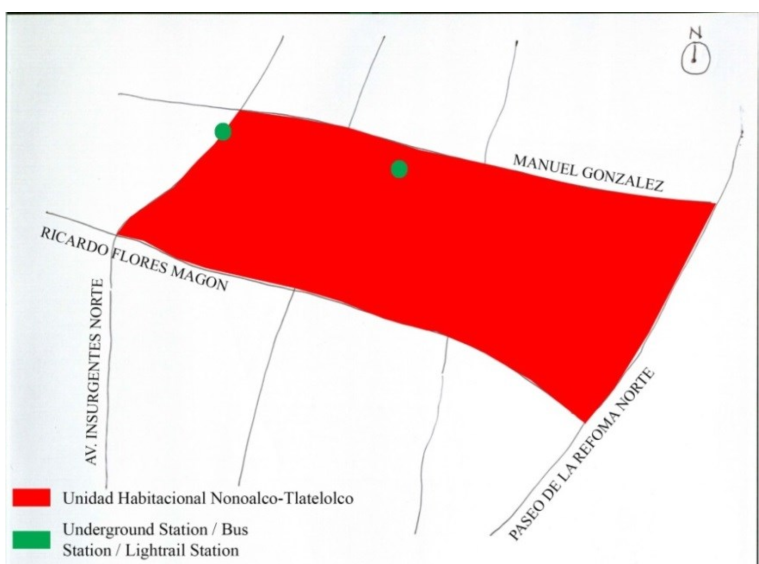

Figure 11. *Nonoalco-Tlatelolco* Housing Unit (or *Centro Urbano Presidente Adolfo Lopez Mateos*) Location.

2.2.2.4. CityScape, Phoenix, Arizona.

The CityScape Project is a new mixed-use center in downtown Phoenix that has an existing 27 floor commercial building, and three other planned buildings: a 36 floor condominium/hotel building, and two 36 floor condominium buildings (Callison, 2011; Emporis, 2012; Weitz, 2012). The number of buildings and the number of floors of these buildings can be seen in Table 8.

Table 8. Buildings in the CityScape Complex in Phoenix (Callison, 2011; Emporis, 2012; Weitz, 2012).

Number of Buildings	Number of Floors	Orientation
1	27	No Data
3	36	No Data

The CityScape Project has a combination of towers with residences, offices, retail and restaurant spaces (see Figure 12) (Callison, 2011; Emporis, 2012; Weitz, 2012). There is parking located in an area of the complex, and the complex will harbor a park to enhance the walkability and the use of open spaces, and to connect with downtown Phoenix.

Figure 12. CityScape Complex in Phoenix (Urban, 2007).
Reprinted from *UrbanLife*, Retrieved July 28, 2013, from http://www.urbanlifeblog.com/2007/10/cityscape-break.html. Copyright 2007 by UrbanLife. Reprinted with Permission.

Table 9 shows the buildings and the campuses close to the CityScape Complex. The closest alternative transportation is the Phoenix's Metro Light Rail line and a bus route (CityScapePhoenix, 2011b). The Metro Light Rail line and the bus route stop in the corner of West Washington Street and South Central Avenue in Figure 13.

Thus, this project is an urban regeneration of an area due to the construction of a mixed-use, multi-family walkable development in downtown Phoenix. The complex is located in an area that takes advantage of mass alternative transportation. Also, the proximity of different venues enhances the walkability of the inhabitants of the complex.

Table 9. Buildings and Campuses Close to the CityScape Complex (CityScapePhoenix, 2011a).

Buildings	The Phoenix Convention Center
	The US Airways Center
	The Chase Field
	The Comerica Theatre (formerly the Dodge Theatre)
	The Arizona Science Center
	The Orpheum Theatre
Campuses	The Arizona State University's Downtown Campus
	The Phoenix Biomedical Campus

Figure 13. CityScape Complex Location.

2.2.2.5. Triangle Square, Austin, Texas.

Peter Calthorpe (2011) designed this 22 acre mixed-use community for the State of Texas General Land Office in Austin, Texas. The community contains 529 apartment homes, over 120,000 ft^2 of retail, commercial and restaurant spaces, and a city park that enhances walkability and the use of open spaces (TriangleAustin, 2012a). Triangle Square has four courtyards surrounded by four-floor residential buildings on the northeast side of the site. The retail occupies the first floor of these buildings. The complex also has lofts and townhouses in a three-floor average building on the southwest side of the site. The retail occupies the first floor of these buildings. A parking lot and a city park were designed inside of the site. The complex was built up on 1999 (TriangleAustin, 2012a).

The complex is located two miles northwest of the University of Texas at Austin campus and downtown Austin (Calthorpe, 2011). The Triangle Square community is not located in downtown Austin but is located inside of the urban fabric of Austin. Table 10 showed the buildings close to Triangle Square. Triangle Square also has alternative transportation through the use of a bus route shown in Figure 14.

Thus, this project is a regeneration of an urban infill due to a mixed-use complex with walkability capacities. The Triangle Square community, as well as the CityScape project, are connected to mass alternative transportation and enhance the walkability of the area.

Table 10. Buildings Close to Triangle Square (TriangleAustin, 2012a).

Buildings	The Seton Medical Center
	The Dell Children's Hospital
	The Austin Museum of Art
	The University of Texas Performance Arts Center
	The Texas Music Museum
	The Texas Memorial Museum
	The Austin Public Library
	The Texas Capitol

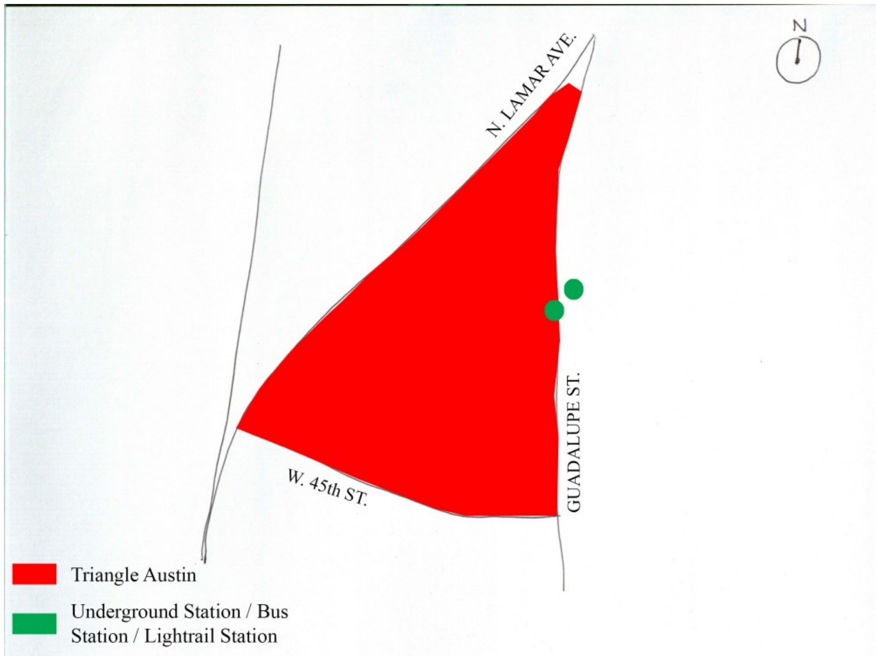

Figure 14. Triangle Square Location.

2.2.2.6. Battery Park City, New York City, New York.

Gordon (1997) showed the synopsis of this waterfront redevelopment between 1968 and 1995. The mixed-use complex was developed on 92 acres next to the World Trade Center and Financial District in downtown New York City. Although they have different type of climates, Mexico City has similar urban characteristics to New York City: they are the most populated cities in Mexico and the US, and the high demand for housing, high density, building proximity, energy and water use efficiency and transportation for both cities is vital to become sustainable. Brand (2009) and Owen (2004, 2009) agreed that New York City is the greenest community in the US due to its high population density, mixed-use buildings and alternative mass transportation among other elements. Also, Glaeser (2011) stated that New York City is one of the greenest cities in the US due to its high population density, the proximity and connection of its inhabitants and the buildings; and its low energy consumption due to its more centralized metropolitan area.

On the other hand, Mexico City is working towards that goal with the *2007 Mexico City Green Plan* (Aguilar-Benignos, 2010; Shandwick, 2013; SMA-GDF, 2010a, b); the

2008-2012 Mexico City Climate Action Program (Shandwick, 2013a; SMA-GDF, 2008); and the *2010 Mexico City Pact* (GDF, 2010a, b; *Fundacion Pensar*, 2013). The *2007 Mexico City Green Plan* (Aguilar-Benignos, 2010; Shandwick, 2013; SMA-GDF, 2010a, b) showed the following goals: enhance land conservation; create housing, and recover and afford public spaces; enhance water infrastructure and sanitation; provide transportation and mobility options to people; reduce air pollution; encourage waste management and recycling; and create and support a climate action program.

The *2008-2012 Mexico City Climate Action Program* (Shandwick, 2013; SMA-GDF, 2008)[18] general goal was to integrate, coordinate and encourage public actions in order to diminish environmental, social, and economic risks from climate change. The *2008-2012 Mexico City Climate Action Program* also promoted the welfare of the population through the reduction and capture of GHG emissions.

The *2010 Mexico City Pact* (*Fundacion Pensar*, 2013) provided the goal of reminding the role that cities play against climate change. It also establishes several voluntary commitments that will promote strategies and actions in order to reduce GHG emissions and adapt the cities to climate change.

Table 11 shows that the *2011 PlaNYC* (CNY, 2013) and the *2007 Mexico City Green Plan* (Shandwick, 2013; SMA-GDF, 2010a, b) have similar sustainable approaches to provide transportation and housing, reduce GHG emissions, encourage cleaner energy systems, and recover ecosystems. Mexico City also has other programs such as the *2008-2012 Mexico City Climate Action Program* and the *2010 Mexico City Pact*. The earlier complements the *2007 Mexico City Green Plan*. The latter is discussed again in section 2.4.2.[19]

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[18] The following strategies were contained in the *2008-2012 Mexico City Climate Action Program:* provide transport corridors for a Bus Rapid Transit (BRT) like the Metrobus and zero emissions transport corridor for trolleybuses; provide ECOBICI individual transport system; enhance minibus and taxicabs replacement programs; build the underground line 12 in Mexico City; apply sustainable housing programs; promote solar energy use regulations; support Mexico City Government Environmental Management System; encourage the Green Roofs Program; and restore ecosystems and compensate for maintaining environmental services (Shandwick, 2013).

[19] New York City's mayor did not sign the *2010 Mexico City Pact* (*Fundacion Pensar*, 2013). The mayors of Boulder, Burnsville, Des Moines, Los Angeles, North Little Rock, Pinecrest, and University City signed the *2010 Mexico City Pact* until 2012.

Table 11. Existing Urban Sustainable Programs.

New York City's Programs	Goals	Mexico City's Programs	Goals
2011 PlaNYC	Clean up brownfields	*2007 Mexico City Green Plan*	Enhance land conservation
	Create sustainable housing and neighborhoods		Create housing, and recover and afford public spaces
	Ensure people are within a 10 min. walking radious from parks and public space		
	Ensure high quality water supply		Enhance water infrastructure and sanitation
	Improve the quality of waterways		
	Expand sustainable transportation		Provide transportation and mobility options to people
	Achieve the cleanest air quality in the USA		Reduce air pollution
	Divert solid waste from landfills		Encourage waste management and recycling
	Reduce energy consumption and provide cleaner energy systems		Create and support a climate action program
	Reduce greenhouse gases		
		2008-2012 Mexico City Climate Action Program	Integrate, coordinate and encourage public actions in order to diminish environmental, social, and economic risks from climate change to promote the welfare of the population through the reduction and capture of GHG
		2010 Mexico City Pact	Remind the role that cities play against climate change and establish several voluntary commitments that will promote strategies and actions in order to reduce greenhouse gas emissions and adapt the cities to climate change

Returning to the discussion of Battery Park City (BPC), the community design had problems due to differences between the city and the state requirements.[20] After the problems were solved, the newly created Battery Park City Authority (BPCA) was put in charge of raising money for the complex. The 1969 Master Development Plan had the following elements: a seven floor retail space that connected seven "pods" (or Le Corbusier's superblocks).

By 1979, six million square feet for commercial spaces and between 12,000 and 16,000 housing units were added to the 1969 Master Development Plan. The only upgrade was to change the southern office area close to the World Trade Center (Gordon, 1997). The complex left some of the Modern architecture elements (i.e., the "pods") and incorporated the following ideas:

- BPC will not be a town inside the city but a section of Lower Manhattan;
- The complex grid will match the grid from Lower Manhattan;
- The complex will enhance different waterfront activities;
- The new complex will also have a more understandable design than the original one;
- It will use the ground level;
- It will reproduce and improve the traditional New York's neighborhoods;
- The commercial center will be the focal point; and
- The land use from the complex will be flexible.

The Battery Park City was shaped by the following neighborhoods in Table 12: the Gateway Plaza, the World Financial Center, the Rector Place, the Battery Place and the "North" Neighborhood with a range of nine to 54 stories, and a combination of residential condominiums, offices, rental apartments and residential buildings, hotels and museums (Emporis, 2011a, 2011b; Gordon, 1997; Luxury Rentals Manhattan, 2011; Wired New York, 2011). Figure 15 shows the location of Battery Park City and the alternative transportation systems in the complex (e.g.metro stations and ferry station).

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[20] There were four major issues involved in the process: the financial return to the city, the proportion of low income housing units, the design of the Project and the arrangements for continuing city participation in project implementation (Gordon, 1997).

The public spaces incorporated were the Esplanade in front of the Gateway Plaza, the Winter Garden in the World Financial Center, the Stuyvesant High School, and the Holocaust Museum. Battery Park City also has alternative transportation through the use of subway and bus routes (Gordon, 1997).

Table 12. Neighborhoods and Buildings in Battery Park City.

Neighborhoods	Buildings	Comments
Gateway Plaza (the previous "Pod III")	Six	Three of them with 34 floors and 1,712 apartments built in June 1982
World Financial Center (from Cesar Pelli)	Four	40 floor office building (for Dow Jones and Oppenheimer) built in 1986, a 51 floor office building built in 1987(for Merrill Lynch), a 54 floor office building (for American Express) built in 1985, and a 29 (approx.) floor office building built in 1986 (for Merrill Lynch)
Rector Place	10	Liberty Court (rental apartments) of 44 floors in 1987, the Liberty Terrace (residential condominium) of 25 floors built in 1986, the Liberty House Condominiums (residential condominium) of 27 floors built in 1986, the 225 Rector Place (residential condominium) of 23 floors built in 1986, the Hudson View East (residential condominium) of 18 floors built in 1986, the One Rector Park (rental apartments) of 15 floors built in 1986, the 350 Hudson Tower (residential condominium) of 15 floors built in 1991, the Hudson View West (residential condominium) of nine floors built in 1985, the Soundings (residential condominium) of nine floors built in 1985, and the Battery Pointe (residential condominium) of nine floors built in 1986
Battery Place	Six	Millennium Point (residential condominium, hotel and museum) of 38 floors built in 2001, the Liberty View Condominiums (residential condominium) of 28 floors built in 1993, the Regatta (residential) of nine floors built in 1988, the River Watch (residential) of nine floors built in 1999, the South Cove Plaza (rental apartments) of nine floors built in 1999, and the Cove Club (residential condominium) of nine floors
"North" Neighborhood	Seven	Liberty Luxe (rental apartments) of 32 floors built in 2010, the Solaire (rental apartments) of 27 floors built in 2003, the Verdesian (residential) of 27 floors built in 2006 (the first residential high-rise building in the USA to get a Platinum LEED certification in 2006), the Tribeca Bridge Tower (rental apartments) of 25 floors built in 1998, the Tribeca Green (rental apartments) of 24 floors built in 2005, the Tribeca Park (rental apartments) of 27 floors built in 1999 and the Tribeca Pointe (rental apartments) of 42 floors built in 1998

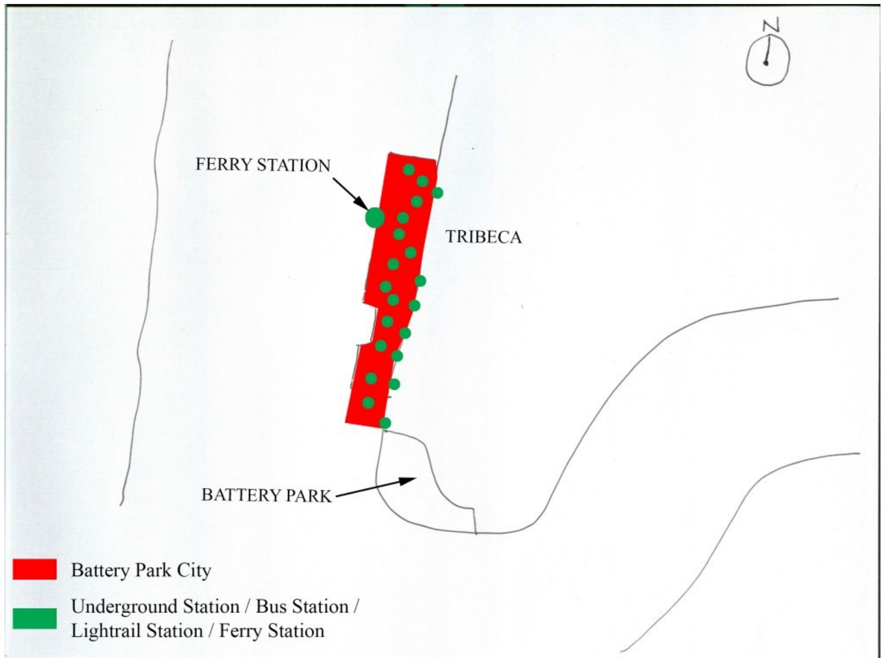

Figure 15. Battery Park City Location.

Some buildings in the Battery Park City have energy-efficient and water-use technologies that can be applied to the analyzed community in Mexico City. The Renewable Energy Design + Engineering for Building Integration Company showed that some of the buildings in the area have Building Integrated Photovoltaic (RELAB, 2011). Relating to energy-efficient and water-use technologies topic, Talend (2007) exhibited that The Solaire Building, that achieved a LEED Gold rating, has become a model in both New York City and the State of New York due to its energy efficiency, enhanced indoor quality, on-site water treatment, storm water reuse for two green roofs and purification, and recycling building materials.

Engle (2006) presented Peter Costa, a plumbing designer who designed the rooftop collection systems for the buildings in the complex. The system contains a 17,500 gallon membrane bioreactor-equipped septic tank with UV rays and ozone for water purification that was placed in The Solitaire Building. The Solitaire is one of several buildings in the BPCA that has separate plumbing systems: gray water systems for bathroom sinks and showers, black water from toilets and grease water from kitchens and sinks.

Thus, the following strategies are identified from this community: on-site solar energy generation due to the exposed area (BIPV on the windows or the façades) of the buildings, and the rainwater harvesting of the roofs and the water treatment systems for gray, black and grease water. Also, the BPCA was an urban waterfront regeneration of an area due to the construction of a mixed-use community in downtown (Lower Manhattan) New York City. Areas in New York City can achieve low-energy, low-water use due to its high population density, the low energy consumption due to the proximity and connection of the population and the buildings, the enhancement of walkability activities and the high rainwater catchment area to reduce municipal water-use.

2.2.2.7. East Village, San Diego, California.

The East Village neighborhood has 325 acres consisting of refurbished warehouses with residential units, as well as galleries, shops, artists' lofts, and studios (CCDC, 2011). The neighborhood has several attractions including: Petco Park, the new Central Library, the San Diego City College, the New School of Architecture + Design, the San Diego Fashion Institute, two high schools, the Thomas Jefferson School of Law, and retail spaces. The area surrounding the Petco Park has received a strong economical investment: 1,056,900 ft^2 of retail space, 2,396 hotel rooms and 2,429 residential units, and the East Village Square with 500,000 ft^2 for retail, entertainment and office spaces to the north of the ballpark (San Diego Source, 2011).

The East Village Neighborhood was shaped by the complexes in Table 13 among others. Some buildings in the complexes have the following energy-efficiency characteristics: Individual heat pumps for heating and cooling, double-pane windows, energy-efficient heating and cooling, double Low-e glass, energy-efficient air-conditioning and forced air heating, Energy Star appliances, and roller shades for windows.

Figure 16 shows the location of the East Village neighborhood and the alternative transportation systems (e.g. trolley stations and buses stations) In terms of public space, a new 57,000 ft^2 park on 14th Street and Island Avenue will be added to the area.

Figure 16. East Village Neighborhood Location.

The alternative transportations are the bus routes and the Park to Bay Link that connects the Balboa Park and the San Diego Bay along the 12th Avenue (CCDC, 2011). Thus, this community is a regeneration of an area due to a mixed-use complex in downtown San Diego. The CityScape and Triangle Square Projects as well as the East Village neighborhood are connected to mass alternative transportation and enhance the walkability of the area.

Table 13. Complexes and Buildings in East Village.

Complexes	Buildings	Characteristics
Alcazar Apartments	One	Four floors, built in 1929
Alta Condos	One	21 floors, built in 2007
Diamond Terrace Condos	One	14 floors, built in 2005
Element Condos	One	Eight floors, built in 2006
Icon Condos	Four	One building of 24 floors, one building with four floors, one building with nine floors and one building of five floors; all of them built in 2007
M2i Condos	Two	Seven floors each one, both of them built in 2005
Metrome Condos	One	Eight floors, built in 2005
Nexus Condos	One	Eight floors, built in 2006
Park Boulevard East Condos	One	Six floors, built in 2005
Park Boulevard West Condos	One	Six floors, built in 2004
Park Terrace Condos	Two	one building of eight floors and one building of 14 floors, both of them built in 2006
Parkloft Condos	One	11 floors, built in 2002
The Legend Condos	One	23 floors, built in 2006
The Mark Condos	One	33 floors, and 11 townhouses, all of them built in 2007
Union Square	Three	Seven floors each one, all of them built in 2004

2.3. Urban Patterns in Mexico City

The urban patterns in Mexico City were studied through its urban space composition and its transportation.

2.3.1. Urban Space Composition in Mexico City.

Mexico is a representative, federal and democratic Republic divided in one *Distrito Federal* and 31 states (SCJN, 2005). The *Distrito Federal*, inside Mexico City Metropolitan Area, is further divided into *delegaciones* (boroughs). The States are further divided into administrative units known as *municipios* (municipalities) (Cantu-Chapa, 2001). One metropolitan zone in Mexico is defined as "a group of two or more *municipios* containing a city of at least 50,000 inhabitants. The city can exceed the *municipio's* limits by incorporating adjacent urban *municipios*, performing an urban influence on adjacent urban *municipios*, and maintaining a good socioeconomic integration on adjacent urban *municipios*. This definition also groups those *municipios* with special characteristics towards future urban planning projects and urban policies. A metropolitan zone also is a *municipio* with a city of one million or more inhabitants, as well as cities of 250,000 or more people with a conurbation process with cities in the US" (*SEDESOL/CONAPO/INEGI,* 2004; 2007).

It is essential to discuss the reasons for the population mobility from the rural to urban areas in Mexico. People in Mexico have migrated from the rural to the urban areas searching for higher-paying jobs, better housing and improved services (Cantu-Chapa, 2001). The urban population in Mexico has increased since 1940 due to the strong private economic investments in the industrial, real-estate and service sectors in these urban areas.

The Greater Mexico City mega-region has more than 45 million people and generates $290 billion in Light-based Regional Product (LRP) (Florida, 2008). This region produced more than half of the LRP in all of Mexico. Tim Gulden[21] obtained the LRP after using spatial and statistical techniques and estimating the amount of economic activity on a world's map. Thus, it can be assumed from Florida, Gulden and Mellander (2008), that Greater Mexico City's mega-region has become an important economic area that can benefit the inhabitants of the city. This will increase the economical development of Mexico City in the long run, and represent an interesting market for foreign investment.

The Mexico City Metropolitan Area is located inside the Mexico City Basin (Garza, 2000).[22] The Mexico City Basin is a hydrological endorheic basin[23] surrounded by mountains. The hydrology of the basin has caused flooding in the capital city since the Aztec

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[21] Tim Gulden is a researcher at the University of Maryland's Center for International and Security Studies. He developed the methodology for the LRP with Richard Florida and Charlotta Mellander. Florida et al. (2008) talked about this methodology.

[22] The Mexico City Basin is located between the 19ºN and the 20ºN and has an area of 9,600 km², or 3,706 sq. mi. (Garza, 2000). The Mexico City Metropolitan Area is located at 19.24ºN and has an area of 7,854 km², or 3,032 sq. mi. (King-Binelli, 1994; *SEDESOL/CONAPO/INEGI,* 2007). The average altitude of the Mexico City Basin is 2,240 m, or 7,349 ft.

[23] Ricketts et al. (1999) defined an endorheic basin as "referring to a closed basin with no natural watercourses leading to the sea."

period. Some years after the conquest of the city of *Mexico-Tenochtitlan* (inside of the old *Distrito Federal*), the Spanish solved the flooding problem by filling of the existing lakes and constructing several drainage works.

Each building use in Figure 17 has a different color code: the red portion is used for retail, the purple section is for industry, the grey part is for infrastructure, the pink space is used for mixed-use, the light green segment is used for recreation, the yellow sector is used for residential, and the dark green zone is used for preservation. The residential area,[24] which is in yellow, is the largest in the city. The technical potential study will analyze the concept of a mixed-use, multi-family low-energy, low-water use community that can be extended to certain areas with only residential use (mainly single-family). These residential areas will become multi-family areas and prevent the excessive use of the car and the sprawl of the city.

Mixed-use, close-together and connected buildings are essential in this technical potential study of low-energy, low-water use communities in Mexico City. Soleri visualized the cities as vertical entities that could cover 1/10 of the site and consume 1/20 of the energy (Register, 2006). An example of this kind of vertical city is New York. The vertical nature of the buildings is a result of the high population density of the city. A vertical city, in contrast to a horizontal one, allows proximity and connectivity of its inhabitants and the buildings that minimizes horizontal transportation. The vertical and compact New York City is one of the greenest cities in the US and has low-energy consumption due to its more centralized metropolitan area (Glaeser, 2011). This is the path that Mexico City must follow in the short term.

The height of the buildings for this technical potential study is worth noting. There is no unique definition for tall buildings (CTBUH, 2012). The buildings can show some characteristics for "tallness" in any of the following three categories:

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[24] The urban residential patterns are generally driven by the housing market, but the urban residential patterns for low-income people are driven mainly by government (Kunz, 2003).

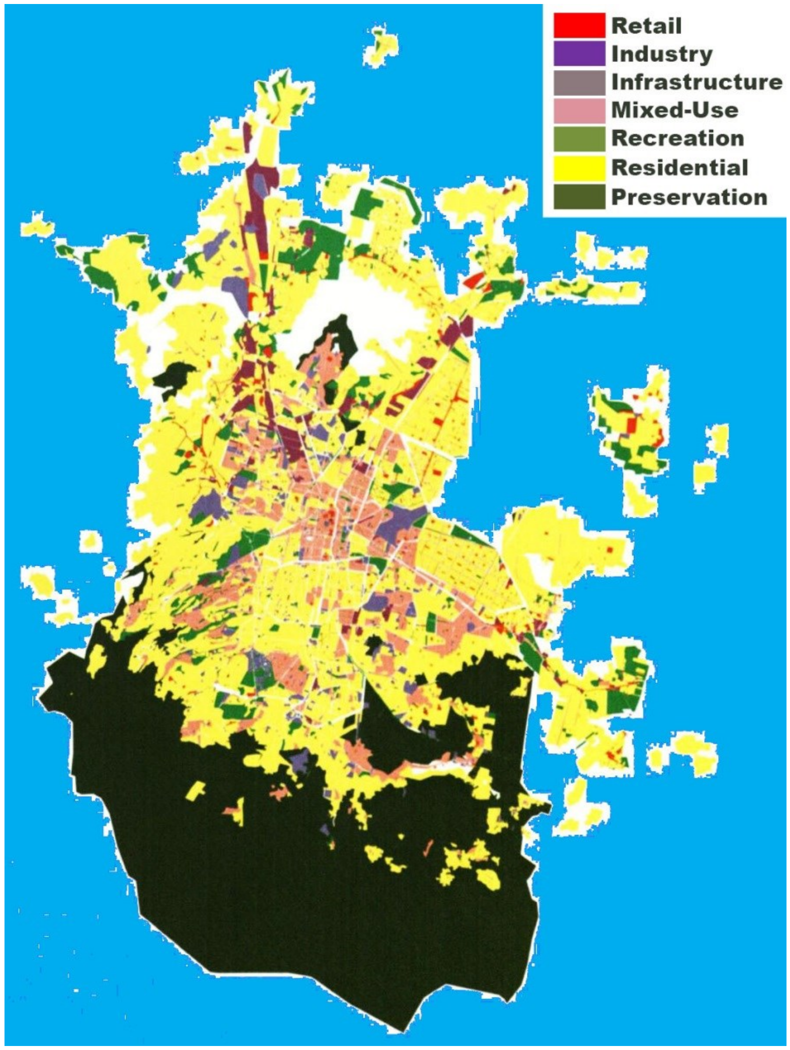

Figure 17. Areas in the Mexico City Metropolitan Area with Different Building Uses. The Background of the Original Image Was Changed from White to Cyan for Printing Purposes, and the Titles for the Areas of the Original Image Were Translated from Spanish to English and Located on the Upper Right Corner.
Reprinted from *La Ciudad de Mexico en el Fin del Segundo Milenio.* (p.517), by G. Garza, 2000, Mexico, D. F., *El Colegio de Mexico*, Copyright 2000 by *Colegio de Mexico*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

1) Height Relative to Context: This feature is related to the context where the building is located, not only the height of the building. The CTBUH showed an example of a fourteen floor building in a European city or suburb. This building has a "tallness" characteristic in comparison to its urban context. On the other hand, the same

fourteen floor building cannot be considered tall in high-rise cities such as Chicago or Hong Kong.

2) Proportion: This is another feature to be considered, as well as the height relative to the context, in addition to the height of the building. The building can be considered tall if it looks slender in comparison to the high mass of the low-rise context.
3) Tall Building Techologies: This feature allows buildings to be considered tall if the building has technology associated to tall buildings such as specific vertical transport technologies and structural wind bracing as a product of height among others.

Therefore, the number of floors is a poor indicator to classify a tall building (CTBUH, 2012). This is because the floor-to-floor height differs between different buildings and functions.

The CTBUH (2010) provided a table that shows the World's 50 Tallest Urban Agglomerations in Table 14. The first column of the table is the ranking of the cities. The second column is the name of the city. The third column is the country where the city is located. The fourth column, which is used to rank the entries, is the total sum of the combined height of the buildings in the city (ft).[25] The fifth column is the number of buildings over 328 ft. (100 m). The sixth column is the urban agglomeration or the urban population from the metropolitan area. The seventh column is the number of people per feet. This is the result of dividing the sixth column by the fourth column. The eighth column is the number of people per building. This is the result of dividing the sixth column by the fifth column.

It appears that Los Angeles, Sao Paulo and Rio de Janeiro can be compared to Mexico City in terms of: the number of buildings, the urban population and the number of people per building. It can also be observed that Rio de Janeiro and Los Angeles are close to Mexico City in terms of the number of buildings: 90 in Rio de Janeiro and 73 in Los Angeles versus 114 in Mexico City. Likewise, Sao Paulo is close to Mexico City in terms of urban population: 18.7 million people in Sao Paulo versus 18.1 million people in Mexico

[25] The height was estimated from the building story count, due to the lack of public building height (CTBUH, 2012). Also, the CTBUH used the following height calculator formula:
Hunknown = 3.55s + 9.75 + 2.65 (s/25), where s = Story Count, H = Building Height (CTBUH, 2010).
According to this formula, the CTBUH considered the buildings from the fourth column as mixed-use (CTBUH, 2010).

City. Finally, Rio de Janeiro and Los Angeles are similar to Mexico City in terms of number of people per building: 121,111 in Rio de Janeiro and 189,438 in Los Angeles compared to 158,772 in Mexico City.

In addition to the population, city area and building characteristics in Table 14, the climate factor is also important for the comparison of the cities to Mexico City.

Therefore, from the CTBUH (2010) data, it is seen that Los Angeles, Sao Paulo and Rio de Janeiro are cities that could be related to Mexico City in terms of number of buildings, urban population and number of people per building. However, none of the three cities compare to Mexico City in regards to its altitude and its direct and indirect impacts on climate.

2.3.2. Transportation in Mexico City.

It is essential to discuss the historical development of transportation in Mexico City between 1877 and 1950. Rhoda and Burton (2010) pointed out some historical facts of the transportation in Mexico City in section 2.2.1. In 1998, the Mexico City Metropolitan Area had around four million vehicles such as private vehicles, trucks, buses, taxicabs, etc. (Garza, 2000). In the same year, above 2.73 million of private vehicles were driven only in the *Distrito Federal* and around 3.5 million of private vehicles were driven in Mexico City. The 3.5 million of cars represented the 88 percent of total vehicles in Mexico City Metropolitan Area. This amount of vehicles pollutes the atmosphere in Mexico City and increases the time spent in traffic. Mexico City's cars contributed 82 percent of the emissions of one of the most detrimental GHG in the City: nitrous oxide (Quadri-De la Torre, 2009). Private vehicles and taxis account for more than 48 percent and 18 percent of all vehicle fuel consumed in Mexico City, respectively (ICLEI, 2011). *INEGI* (2012) showed that Mexico had 21.1 million private vehicles registered in 2010. Some plans must be done to counteract the pollution generated by these vehicles.

Table 14. World's 50 Tallest Urban Agglomerations (Data Taken from CTBUH, 2010). The Original Data Was Changed from Metic Units to the English Units. The Information Contained in this Table Pointed out that Other Cities, as well as Mexico City, are Growing Vertically (i.e., Mid-Rise and Tall-Buildings). Adapted from *Tall Buildings: the 2010 CTBUH Reference Guide of the What, When and Where of Tall and Urban* (p.15), by Council on Tall Buildings and Urban Habitat, 2010, Chicago, Ill: Council on Tall Buildings and Urban Habitat. Copyright 2010 by Council on Tall Buildings and Urban Habitat. Adapted for Scholarly Purposes under Fair Use.

Ranking	City	Country	Combined Heights (ft)	Number of Buildings > 328 ft	Urban Agglomeration	People/ Feet	People/ Building
1	Hong Kong	HK SAR	1,151,270	2,635	6,890,000	6	2,615
2	New York	USA	359,488	791	19,712,000	55	24,920
3	Dubai-Sharjah-Ajman	UAE	260,235	495	2,000,000	8	4,040
4	Tokyo-Yokohama	Japan	244,852	574	34,250,000	140	59,669
5	Shangai	China	202,087	439	14,240,000	70	32,437
6	Bangkok	Thailand	171,682	403	8,000,000	47	19,851
7	Chicago	USA	156,761	335	8,646,000	55	25,809
8	Guangzhou-Foshan	China	132,099	280	11,460,000	87	40,929
9	Seoul-Foshan	South Korea	127,428	283	19,500,000	153	68,905
10	Sao Paulo	Brazil	123,049	329	18,700,000	152	56,839
11	Kuala Lumpur	Malaysia	117,946	265	5,100,000	43	19,245
12	Shenzhen	China	116,345	243	14,000,000	120	57,613
13	Toronto-Hamilton	Canada	108,903	271	5,671,000	52	20,926
14	Singapore	Singapore	105,668	237	4,000,000	38	16,878
15	Chongqing	China	103,612	225	2,910,000	28	12,933
16	Panama City	Panama	99,607	210	750,000	8	3,571
17	Manila	Philippines	89,334	194	19,150,000	214	98,711
18	Miami-Ft. Lauderdale	USA	87,553	204	4,919,000	56	24,113
19	Mumbai	India	85,838	216	17,000,000	198	78,704
20	Jakarta	Indonesia	78,120	180	20,600,000	264	114,444
21	Macau	Macau SAR	77,549	146	525,000	7	3,596
22	Osaka-Kobe-Kyoto	Japan	75,388	176	17,250,000	229	98,011
23	Beijing	China	74,269	178	12,405,000	167	69,691
24	Moscow	Russia	65,078	147	13,250,000	204	90,136
25	Tianjin	China	61,913	141	8,110,000	131	57,518
26	Nanjing	China	57,042	114	3,170,000	56	27,807
27	Recife	Brazil	55,790	146	3,175,000	57	21,747
28	Buenos Aires	Argentina	53,480	134	12,000,000	224	89,552
29	Sydney	Australia	45,943	102	3,641,000	79	35,696
30	Honolulu	USA	44,736	122	718,000	16	5,885
31	Mexico City	Mexico	44,638	114	18,100,000	405	158,772
32	Dalian	China	44,359	99	3,210,000	72	32,424
33	Houston	USA	43,329	91	3,912,000	90	42,989
34	Doha	Qatar	39,724	78	600,000	15	7,692
35	Istanbul	Turkey	39,639	94	11,100,000	280	118,085
36	Curitiba	Brazil	38,960	105	2,750,000	71	26,190
37	San Francisco-Oakland	USA	38,346	89	5,320,000	139	59,775
38	Wuhan	China	37,996	83	5,040,000	133	60,723
39	Atlanta	USA	36,815	80	3,500,000	95	43,750
40	Busan	South Korea	36,513	70	3,600,000	99	51,429
41	Chengdu	China	36,251	87	4,235,000	117	48,678
42	Shenyang	China	34,768	76	4,830,000	139	63,553
43	Rio de Janeiro	Brazil	34,689	90	10,900,000	314	121,111
44	Los Angeles	USA	34,017	73	13,829,000	407	189,438
45	Paris	France	33,367	84	10,400,000	312	123,810
46	Melbourne	Australia	32,692	70	3,372,000	103	48,171
47	Qingdao	China	32,662	73	2,155,000	66	29,521
48	Abu Dhabi	UAE	32,298	61	600,000	19	9,836
49	Salvador	Brazil	31,124	82	2,900,000	93	35,366
50	Xiamen	China	30,927	75	1,560,000	50	20,800

In a more aggressive plan against the transportation problem and the pollution related to it, the *2007 Mexico City's Green Plan* (ICLEI, 2012) was created to address the use of environmentally-friendly transportation options. The improvements will be focused on two key areas: the subway expansion and the bus routes expansion. It will also expand additional bus corridors, replace the old microbuses with new microbuses, and encourage people to travel by foot, bicycle or mass transportation.

Linking to the idea of urban low-impact transportation, the *Gobierno del Distrito Federal* (*PCGDF*, 2012) showed various types of public transportation currently used in Mexico City such as: the *Mexico City Metro*; the *Metrobus* (or Bus Rapid Transport); the trolleys; the lightweight train (southern area of Mexico City); the suburban train (connects some northern suburban areas of Mexico City with downtown); taxicabs; microbuses, buses, and *combis* (shuttles); and the eco-bikes.

There was an idea to introduce electric cars in the short term, and then increase in the long term the number of electric vehicles in Mexico. One hundred Nissan Leafs were sold as an ecological taxicab project from the Mexico City's government (Quadri-De la Torre, 2009). The taxicab electric car project in Mexico is currently in standby (Cantera, 2013). The main problem is that the prices for the electric vehicles are too high, and the infrastructure either for electric public or private vehicles has not yet been developed. The introduction of electrical cars in Mexico in order to save energy and reduce pollution will take several years.

High-efficiency cars are a feasible solution for the transportation sector in Mexico. Table 15 exhibited a list of efficient cars sold in Mexico from *Comision Nacional para el Uso Eficiente de la Energia* (*CONUEE*) (Aleman, 2013).

These cars in Table 15 are the latest high-efficiency cars, whose efficiency ranges from 34.6 to 45.3 mpg. In general, 24.9 mpg is the common fuel efficiency per mile for new cars sold from 1990 to 2008 in Mexico (Medina-Ramirez, 2012).

The number of trips per day is estimated from *IGECEM* (2007) and Islas-Rivera et al. (2004). *IGECEM* (2007) was used to determine the origin and destination trips in 2007. Islas-Rivera et al. (2004) stated that 16.1 percent represents the private transportation in

2000. The *Multifamiliar Miguel Aleman* complex must have 1,620 parking spaces (*GDF*, 2011).

The number of trips per person per day in Mexico City was found in a study of Sanchez-Cataño et al. (2009). For the technical potential study 2.5 trips/person/day was assumed for Mexico City. The average private car lifetime in Mexico City was reviewed from Medina-Ramirez (2012). 41 km, or 25.47 mi. per day in Mexico City was assumed. The fuel efficiency per kilometer or mile for new cars from 1990 to 2008 is also found in the study from Medina-Ramirez, which was 10.6 km/lt, or 24.9 mpg.

Information from Oak Ridge National Laboratory (2013) was used to estimate the amount of gallon of conventional fuel burned by the cars of the complex. 125,000 BTU/gal of conventional fuel was considered.

Table 15. Efficient Cars Sold in Mexico from *CONUEE* (Aleman, 2013).

Model	Fuel Efficiency	
	km/lt	mpg
Dodge i10	19.27	45.3
Chevrolet Spark	17.57	41.3
Toyota Yaris	17.4	40.9
Dodge Attitude	16.47	38.7
Suzuki Swift	16.3	38.3
Seat Ibiza	16.23	38.2
Chevrolet Matiz	15.97	37.6
Ford Ikon	15.9	37.4
Seat Toledo	15.7	36.9
Smart Fortwo	15.62	36.7
VW Beetle	15.54	36.6
VW Polo	15.34	36.1
Nissan March	15	35.3
Nissan Versa	15	35.3
VW Golf	14.7	34.6

2.4. Building Characteristics in Mexico City

The building codes, energy norms and an energy guide in Mexico; the sustainable achievements for the housing sector in Mexico; and the bioclimates in Mexico were studied to comprehend the building characteristics in Mexico City.

2.4.1. Building Codes, Energy Norms, Energy Guide and Building Codes with a Sustainabilty Chapter in Mexico.

Building codes, energy norms and energy guide are required in order to shape the low-energy, low-water use community in Mexico City. Mexico has building codes and is looking to take the lead on environmental issues. There are also existing energy norms that should be observed.

There are more than 100 local building codes in Mexico as shown in Table 16 (*CONAVI,* 2010a). Every city and town in Mexico must have a building code. The *Building Code for the Distrito Federal* is enforced by law and applied by code officials only in the cities that decide to apply this building code.[26] Builders in Mexico City follow this code. The updated *2005 Building Code for the Distrito Federal* (Arnal-Simon and Betancourt-Suarez, 2005) is taught in most of the Departments and Faculties of Architecture and Engineering in Mexico. The *Building Codes for the Distrito Federal* also have *Normas Tecnicas Complementarias*[27] that are usually updated and complement the requirements of the building code. These norms are enforced by law, and one example (i.e., *GDF,* 2011) is shown in Table 16.

The current mandatory energy norms in Mexico are the following: the Mexican Official Norm "NOM-020-ENER-2011 Energy-Efficiency for Building Envelopes for Residential Buildings" (*CONUEE*, 2011) and the Mexican Official Norm "NOM-008-ENER-2001 Energy-Efficiency for Building Envelopes for Non-Residential Buildings" (*CONUEE,*

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[26] If a city or town does not have its own local building code, the city or town applies the *Building Code for the Distrito Federal* (*CONAVI,* 2007).
[27] Supplementary Technical Standards.

2001).[28] Both energy norms exhibited the requirements and characteristics to define building envelopes for residential and non-residential buildings in Mexico.

CONAVI reviewed more than 100 local building codes in Mexico in order to create the *2007 Housing Building Code* (*CONAVI*, 2010a). *CONAVI* (2006) created an energy-efficiency guide for housing that was the first official guide in Mexico to include sections for bioclimatic design and sustainability for each climate region. The International Code Council (2012) was involved in the development of the *2007 Housing Building Code*.[29] *CONAVI's 2007 Housing Building Code* was the first building code with a sustainability chapter, and is the first version for the *2010 Housing Building Code*. *CONAVI's 2010 Housing Building Code* is an applicable technical-administrative and regionally-adapted model that should respect the local authorities' autonomy in Mexico. Therefore, the *2007 Housing Building Code* and the *2010 Housing Building Code* are not enforced by law.

Table 16. Building Codes, Energy Norms and Energy Guides in Mexico.

Type	Name	Reference	Enforced by Law or Voluntary
Building Codes	The 100 building codes stated by *CONAVI*	*CONAVI,* 2010a	Enforced by Law
Building Codes	*1974 Building Code for the Distrito Federal*	*DDF,* 1974	Enforced by Law (only in those cities that decide to apply it)
	1987 Building Code for the Distrito Federal	*DDF,* 1987	
	1992 Building Code for the Distrito Federal	*DDF,* 1992	
	1999 Building Code for the Distrito Federal	Arnal-Simon and Betancourt-Suarez, 1999	
	2005 Building Code for the Distrito Federal	Arnal-Simon and Betancourt-Suarez, 2005	
Supplementary Technical Standards	i.e. *Norma Tecnica Complementaria para el Proyecto Arquitectonico*	*GDF* , 2011	Enforced by Law
Energy Norms	NOM-020-ENER-2011 Energy-Efficiency for Building Envelopes for Residential Buildings	*CONUEE,* 2011	Enforced by Law
	NOM-008-ENER-2001 Energy-Efficiency for Building Envelopes for Non-Residential Buildings	*CONUEE,* 2001	
Energy Guide	*Uso Eficiente de la Energia en la Vivienda*	*CONAVI,* 2006	Voluntary
Building Codes (with Sustainability	*2007 Housing Building Code*	*CONAVI,* 2007	Voluntary
	2010 Housing Building Code	*CONAVI,* 2010a	

[28] The Mexican Official Norms (*NOM*) are mandatory in Mexico, while the Mexican Norms (NMX) are only recommendations (Huerta-Ochoa, 1998).
[29] Bioclimatic design elements from the guide (*CONAVI,* 2006) were considered for the *2007 Housing Building Code.*

2.4.2. Sustainable Achievements in Mexico.

The Mexican government has accomplished significant progress in the sustainable field, focusing on housing, and is concerned about the current climate change in the world and its future consequences. Mexico has made progress towards energy-efficiency and sustainability topics due to the exchange of information, science and technology between Mexico and other countries. The recent building codes with a sustainability chapter, the international conferences, and the reports and documents produced after the conferences bring the possibility for the creation of guides for low-energy, low-water use communities in Mexico City.

The general sustainable achievements in Mexico, which are shown in Table 17, are the following: the consulting from the International Code Council (ICC, 2012) for the development of the *2007 Housing Building Code* (*CONAVI,* 2007), and the hosting of three important international conferences to begin to address these issues:

1) The 2010 United Nations Climate Change Conference at the city of Cancun, Mexico (CC2010, 2011a; UNFCCC, 2011),
2) The World Mayors Summit on Climate 2010 at Mexico City (WMSC, 2010) and
3) The United Nations Human Settlements Programme Global Observance of World Habitat Day 2011 at the city of Aguascalientes, Mexico (UN-Habitat, 2011a, b).

Countries like Colombia and Brazil are adopting the Mexican *2010 Housing Building Code* (Hirata-Nagazako in Ortigoza, 2010). Therefore, other countries are following the development of Mexico in terms of energy-efficiency, energy renewable technology and sustainability, and its application to the housing sector.

Table 17. General Sustainable Achievements in Mexico.

Subject	Achievement
Building Code (with Sustainability Chapter)	The creation of the *2007 Housing Building Code*
Conferences	The presentation of the *2010 United Nations Climate Change Conference* at Cancun, Mexico
	The presentation of the *World Mayors Summit on Climate 2010* at Mexico City
	The presentation of the *United Nations Human Settlements Programme Global Observance of World Habitat Day 2011* at Aguascalientes, Mexico

The conferences discussed the following topics: the climate issues in Mexico and the commitment to reduce the $MMtCO_2$ emissions at the Cancun 2010 conference; the commitment to develop strategies, measures, public policies, laws, plans and campaigns to reduce greenhouse gas emissions at the Mexico City 2010 conference; and the population and urban growth, and the importance of the cities' opposition to the climate change at the Aguascalientes 2011 conference. At the end of each conference they released the following:

1) the report *Executive Summary Special Climate Change Program 2009-2012* (CC2010, 2011b) from the Cancun 2010 Conference,
2) the document *The Mexico City Pact* (*Fundacion Pensar*, 2013; WMSC, 2010) from the Mexico City 2010 Conference, and
3) the report *Cities and Climate Change: Policy Directions* (UN-Habitat, 2011c) from the Aguascalientes 2011 Conference.

As a result of the Cancun 2010 conference, Mexico's government set a goal to reduce 50 percent of its GHG by 2050, which included an estimated production in 2006 of 144.63 $MMtCO_2e$ in the transportation sector, 24.88 $MMtCO_2e$ in the residential plus the commercial sector and 56.83 $MMtCO_2e$ in the industrial sector in Figure 18 (CC2010, 2011b). The estimated reduction goal by 2012 was 5.74 $MMtCO_2e$ in the transportation sector, 5.53 $MMtCO_2e$ in the residential plus the commercial sector and 0.52 $MMtCO_2e$ in the industrial sector. Clearly, the largest $MMtCO_2e$ producer in Mexico is the transportation sector, followed by the industrial sector, and finally the residential and the commercial sectors. Therefore to meet the goal of the Cancun 2010 conference, Mexico needs to impact all three sectors.

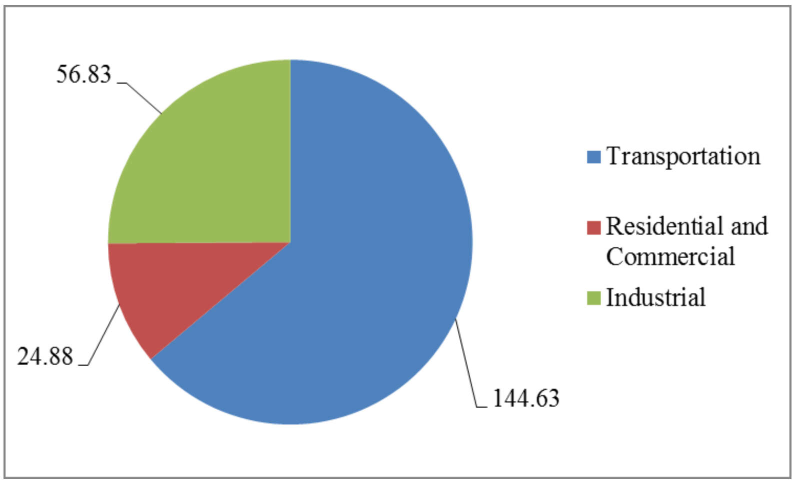

Figure 18. MMtCO2e Production in Mexico in 2006 (Created with Data from CC2010, 2011b).

In the *Mexico City Pact* from the Mexico City 2010 Conference, city mayors from different regions from the world signed this voluntary pact to remind the world's population of the role that cities play against climate change. It also established several voluntary commitments that will promote strategies and actions in order to reduce GHG emissions and adapt the cities to climate change. The general applicability of the study relies on the fact that cities will need strategies, measures, public policies, laws, plans and campaigns to reduce GHG emissions. Therefore, the final result of the dissertation is to develop a guide for low-energy, low-water use communities for Mexico City through community-wide energy-use. Such a guide is reinforced by the characteristics of the *2010 Mexico City Pact* in order to reduce community-wide energy-use and save potable water-use in cities.

The UN-Habitat (2011c) specified that the urban population in the world has quintupled between 1950 and 2011. There is good international awareness in terms of urban sustainability that reinforces the idea of people like Brand (2009), Glaeser (2011), Owen (2004, 2009) and Soleri (in Register, 2006) among others, about sustainable, energy-efficient, water-saving, compact and walkable cities. The report also states that the least developed countries[30] have the fastest rates of urbanization in the world. When combined, the least developed and the developing countries comprise three quarters of the population in the world. The same report also mentioned that the world's population is becoming more urban and that there is an increase in the production of greenhouses gases: including carbon dioxide, methane, nitrous oxide, halocarbons and other fluorinated gases. Nevertheless, it has been reported that the innovations and technologies developed in cities can help to reduce emissions and adapt to current and future climate changes.[31]

The following sustainable achievements for the housing were presented in Cancun 2010 Conference:

- The *This is your House* (*CONAVI,* 2010b; Hirata-Nagasako*,* 2009) and the *Green Mortgage* (*CONAVI,* 2010b) programs provide wages in order to install energy-efficiency measures, energy renewable technologies, and water saving measures among others into the dwellings and reach sustainability level.[32]
- In order to obtain a new house through government wages, it is mandatory to use energy-efficiency measures, energy renewable technologies, and water saving measures among others (*CONAVI,* 2010b)

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[30] The Committee for Development Policy (CDP) (UN-OHRLLS 2011) has to review the category of Least Developed Countries (LDC) every three years. The criteria to identify the LDC include: the gross national income (GNI), human assets (HAI) and economical vulnerability index (EVI).

[31] Brand (2009) and Glaeser (2011) shared this same idea about the cities.

[32] The basic package of eco-technologies to get a wage from *CONAVI's This is your House* program has the following requirements: site without risk and with good location; efficient use of energy; energy saving lamps; thermal insulation; solar water heater; water-efficient features (i.e., water-saving accessories, shower, toilet and meters); management of urban solid waste and maintenance (*CONAVI,* 2011a). The *Green Mortgage* program has encouraged the following energy and water savings into dwellings: energy saving bulbs, fluorescent lamps, LED bulbs, high-efficiency air-conditioning, roof and wall insulation, reflective roof, solar collectors, water saving toilet and shower among others (*CONAVI*, 2010b; *INFONAVIT*, 2011b; 2012a, b).

- The *Integrated Sustainable Urban Development*[33] program was created to promote urban sustainability measures in Mexico (*CONAVI,* 2010b; Topelson-De Grinberg, 2010). The *Integrated Sustainable Urban Developments* must be pointed out, because they are developed outside existing cities in contrast to the idea of developing areas in the inner cities in this technical potential study. These communities could become new cities in the near future. The main problem is that these communities could produce less population density in the existing surrounding cities in the long run.
- The Mexican government wants to apply the Clean Development Mechanism (*CDM*) of the Kyoto Protocol to sustainable housing, and the goal is to reduce five percent of GHG emissions[34] between 2008 and 2012 (*CONAVI,* 2010b). The technical potential study of a low-energy, low-water use community in Mexico City could qualify as a future *CDM* project and obtain carbon credits. The *CDM* allows a country with an emission-reduction commitment under the Kyoto Protocol (Annex B Party)[35] to implement carbon emission-reduction projects in developing countries (UNFCC, 2012c). The projects can earn saleable Certified Emission Reduction (CER)[36] credits towards their Kyoto Protocol targets. The United Nations Framework Convention on Climate Change (UNFCC, 2009) showed simplified baseline and monitoring methodologies for small scale *CDM* projects. The goal is to reduce energy consumption in new, grid-connected single and multi-family residential buildings through efficient building design, energy-efficiency technologies and renewable energy technologies. Some examples include efficient appliances, high efficiency heating and cooling systems, passive solar design, thermal insulation and photovoltaic systems. The *CDM* is included in the *Executive Summary Special Climate Change*

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[33] Translated from the *Desarrollos Urbanos Integrales Sustentables* (*CONAVI,* 2010b; Topelson-De Grinberg, 2010).

[34] Carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulfur hexafluoride.

[35] The UNFCC (2012a, b) defined Annex B Party as an Annex to the Kyoto Protocol that specified the emission limitation and reduction commitment for each Party included in Annex I (UNFCC, 2012b) to the Convention (Annex I Party) as a percentage of that Party's emissions in its base year or period. Mexico is registered in the Amendment to Annex B of the Kyoto Protocol (UNFCC, 2012d, e)

[36] The UNFCC (2012b) defined the Certified Emission Reduction (CER) as a Kyoto unit that represents an allowance to emit one $MMtCO_2$. The CERs are related to emission reductions from *CDM* projects.

Program 2009-2012. It is a strategy to achieve the United Nations 2050 greenhouse gas emissions reduction.

- Due to an expected growth in the low-income and the mid-income markets in the coming decade, there will be an improvement of energy-efficiency of the housing sector (*CONAVI*, 2012). A vital point is that the technical potential study of a low-energy, low-water use community in Mexico City could become a Nationally Appropriate Mitigation Action (NAMA)[37] project in the future, which could obtain funding from Mexican and international agencies.[38]

2.4.3. Bioclimates in Mexico.

Bioclimate analysis is important in order to know the relationship between the people and the environment in Mexico City and how this relationship should impact the building's design.

Morillon et al. (2002) used tools such as the psychrometric charts from Givoni (1976) and Olgyay (1963) and the mathematical methods from Fanger (1973) to verify the results of the created *Atlas Bioclimatico de la Republic Mexicana*.[39] King-Binelli (1994) and Morillon-Galvez (2004; 2005) showed the main characteristics of the different bioclimates in Mexico. *CONAVI* used the information from the studies from Givoni, King-Binelli, Olgyay and Morillon-Galvez, and the mathematical methods from Auliciems and Fanger, in its guide as references for the final bioclimatic study for Mexico.

CONAVI presented the nine categories of bioclimates in Mexico: hot-dry, hot-semi-humid, hot-humid, humid-temperate, temperate, dry-temperate, dry-semi-cold, semi-cold and humid-semi-cold. Mexico City is located in the temperate climate (*Cw)* group and in the

[37] A NAMA, previously applied by the German Development Cooperation (GDC, 2012) and the German Passive House Institute (GPHI, 2012), is expanding the scope from *Green Mortgage (INFONAVIT,* 2011a), the *This is your House* (*CONAVI,* 2010b) and programmatic *CDM* activities in order to increase the number of energy-efficient homes and improve their greenhouse gas emissions performance (*CONAVI*, 2012).
[38] Notimex (2014) informed that a NAMA project for Mexican Sustainable Houses will receive a funding of 14 million euros. This NAMA will be the first in the world to become a design, monitoring and verification tool, in order to ensure environmental low-impact and affordable houses for the people. It also says that the Mexican government wants high-density cities with environmentally-friendly characteristics and reduction of automobile use and gas consumption.
[39] Szokolay was used to define the thermal comfort zone in Mexico.

semi-cold bioclimate. The *Cw* temperate climate in Mexico has dry winter and rainy summer seasons. The Tropic of Cancer divides Mexico in two thermal zones. The thermal comfort zone in the tropics is from 74 º F to 85 º F (or 23.3 º C to 29.4ºC).[40] Mexico City is located in this area. The thermal comfort zone points out the thermostat setpoints for the heating and cooling in the spaces of the housing.

2.5. Potential Energy-Efficiency Measures and Water-Efficiency Measures for Mixed-Use Buildings in Mexico City

The potential energy-efficient measures that should be analyzed in low-energy, low-water use communities in Mexico City include: building envelope, mechanical systems and equipment, daylighting and lighting systems and appliances, natural ventilation and the inclusion of renewable energy technologies (i.e., passive solar systems, solar photovoltaic systems, and domestic hot water systems). Similarly, the potential technologies for water-efficiency measures comprise: rainwater harvesting systems for collecting, storing and delivering water; and greywater treatment and water-use reduction systems.

2.5.1. Building Envelope Measures for Mexico City.

Mexico has two different types of norms: the Mexican Official Norm (*NOM*) and the Mexican Norm (*NMX*). Table 18 showed the norms for building envelope measures in Mexico.

The first mandatory *Mexican Official Norm (NOM)* in Table 18 includes the following test methods: density; thermal conductivity; water vapor permeability; adsorption of moisture and water absorption; and the use of the appropriate terminology of thermal insulation materials used in Mexico.

The second and third mandatory *Mexican Official Norms (NOM)* in Table 18 deals with the test methods to calculate heat gains through the building envelope between a base-case building and a proposed building; the calculation for heat gains through the building

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[40] The thermal comfort zone in the US is from 69ºF to 80ºF (20.5ºC to 26.7ºC).

envelope of the proposed building; the use of building orientation in order to reduce heat gains; and the use of window panes with vertical and horizontal shading devices.

The last one of the norms in Table 18 is a voluntary *Mexican Norm* (*NMX*) that presents the classification of Mexico by thermal zones, and the use of R-Value for the walls and the roof for the housing envelope in the *Distrito Federal.*

In addition to the norms, *CONAVI* (2006, 2007) made suggestions in terms of architecture and urban design, solar shading control, ventilation, fenestration, building materials, air-conditioning systems and vegetation regarding the energy efficiency of building envelopes for the semi-cold bioclimate in Mexico City. Some of these suggestions from *CONAVI* were previously used by Van Lengen (2008).[41] Table 19 showed the ideas of Van Lengen's ideas about strategies applied to the building envelope for housing in temperate climates. These suggestions were made originally for single-family housing. Nevertheless, certain of these suggestions could be used for multi-family housing in Mexico as well.

Table 18. Norms for Building Envelope Measures in Mexico.

Type of the Norm	Name of the Norm	Title of the Norm
Mexican Official Norm (NOM)	*NOM-018-ENER-1997* (*SENER,* 1997)	*Thermal Insulation for Buildings. Characteristics, Limits and Test Methods*
	NOM-008-ENER-2001 (*SENER,* 2001)	*Energy-Efficiency for Building Envelopes for Non-Residential Buildings*
	NOM-020-ENER-2011 (*SENER,* 2011)	*Energy-Efficiency for Building Envelopes for Residential Buildings*
Mexican Norm (NMX)	*NMX-C-460-ONNCCE-2009* (*ONNCCE,* 2009)	*Building Industry-Insulation-"R" Value for the Housing Envelope by Thermal Zone for Mexican Republic-Specification and Verification*

[41] Van Lengen was borned in the Netherlands. He worked for the United Nations and a number of government agencies in Latin America (TIBA, 2012). The Spanish version of *The Barefoot Architect* was published in Mexico in 1981 (Van Lengen, 2008).

Table 19. Ideas of Van Lengen About Some Strategies Applied to the Building Envelope for Housing in Temperate Climates (Van Lengen, 2008).
This Table was Created from a Section of a Larger Table from the Original Source, and Helped to Find Potential Strategies for Daylighting and their Results Applied to the Semi-Bioclimate from Mexico City. Adapted from *The Barefoot Architect A Handbook for Green Building* (p.19), by J. Van Lengen, 2008, Bolinas, CA: Shelter Publications, Inc., Copyright 2008 by Johan Van Lengen. Adapted for Scholarly Purposes under Fair Use.

Strategies	Results of the Application from the Strategies
Use of thick material walls (i.e., adobe, brick or concrete)	Delays heat loss from the interior spaces
Place big windows on the southern façade	Provides solar gains during the winter
Protect big windows on the southern façade with shading devices	Avoids overheating during the summer
Use roofs with medium tilts	Collects rainwater
Use of vegetation	Protects house against winds
Insulate the floor	Protects the floor slab against the cold site

2.5.2. Mechanical Systems and Equipment for Mexico City Residences.

In a similar fashion as the US, *CONAVI* (2007) pointed out the use of Mexican Official Norms for mechanical systems. Table 20 shows the norms for mechanical systems and equipment in Mexico. These norms explained the characteristics of either the central, packaged and split HVAC systems or the unitary systems.

Table 20. Norms for Mechanical Systems and Equipment in Mexico (*CONAVI,* 2010a).

Type of the Norm	Name of the Norm	Title of the Norm
Mexican Official Norm (NOM)	*NOM-011-ENER-2006* (*CONUEE,* 2007)	*Energy Efficiency for Central, Packaged and Split HVAC Systems, as well as their Characteristics, Test Methods and Tags for Nationally HVAC Products*
	NOM-021-ENER/SCFI-2008 (*CONUEE,* 2008b)	*Energy Efficiency and Safety Requirements for Unitary Systems, as well as their Characteristics, Test Methods and Tags for Nationally HVAC Products*

CONAVI also stated that the temperate, dry-temperate, dry-semi-cold, semi-cold and humid-semi-cold bioclimates do not need air-conditioning systems. It is vital for this section to show those cities in Mexico that require air-conditioning systems. The housing sector, spanning both the northern area of Mexico with a hot-dry climate and the coastal area with a hot-humid climate, has a higher demand in air-conditioning systems. Table 21 showed the span of bioclimates in Mexico that require mechanical systems and equipment.

Figure 19 shows the cities that require mechanical systems. This figure supplemented the information from Table 21. The energy consumption for air-conditioning systems in northern and coastal areas has the second highest average consumption in the nation. *CONAVI* recommended using the total equivalent temperature differential method (TETD) from the *ASHRAE* (1993)[42] to evaluate the user's thermal comfort in a dwelling.

Morillon-Galvez et al. (2004) showed an evaluation for the bioclimatic methods that used 24-hour mean monthly temperature and relative humidity data for three cities in Mexico: Mexico City, Guadalajara and Cuernavaca. These results were verified with the results from Fanger's method and were shown as isopleth diagram of air-conditioning requirements. The isopleth diagrams of air-conditioning requirements (e.g., Figure 20 for semi-cold bioclimate where Mexico City is located) were designed for the conditions of thermal sensations in a place for a whole year. Then, the *monthly comfort, hot and cold conditions* were fitted with the scale used in the *ASHRAE* (2001) in Chapter 8. These diagrams showed the following energy-efficiency suggestions for the semi-cold bioclimate in Mexico City in Table 22. It is highly recommended to apply passive solar heating strategies due to the cold nights, especially in the winter.

[42] In the TETD, the response factor technique was used with wall and roof assembiles from which data was derived to calculate TETD values as functions of sol-air temperature and maintained room temperature (ASHRAE, 1993).

Table 21. Span of Bioclimates in Mexico that Require Mechanical Systems and Equipment (*CONAVI,* 2010a).
This Table was Created from a Section of a Larger Table of the Original Source. It Helped to Point out those Cities that Require Air-Conditioning Systems Compared to Mexico City that Does Not Require Due to its Bioclimate. The Original Table Did Not Have the Cities. Adapted from *Codigo de Edificacion de Vivienda 2010* (p.316), by *Comision Nacional de Vivienda,* 2010, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2010 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Bioclimate	Cities Located in Bioclimate	Mechanical Systems and Systems Requirements
Hot-Dry	*Mexicali, Hermosillo, Cd. Juarez, Chihuahua, Cd. Obregon, Culiacan, Gomez Palacios, La Paz, Monterrey and Torreon*	Heating and cooling systems (cooling especially for the summer season)
Hot-Semi-Humid	*Cd. Victoria, Mazatlan, Colima, Merida and Tuxtla Gutierrez*	Mechanical ventilation
Hot-Humid	*Campeche, Manzanillo, Tapachula, Acapulco, Cozumel, Cancun, Chetumal, Villahermosa, Tampico and Veracruz*	Mechanical air and humidity extraction during the summer season
Humid-Temperate	*Cuernavaca and Tepic*	Ceiling mechanical ventilators

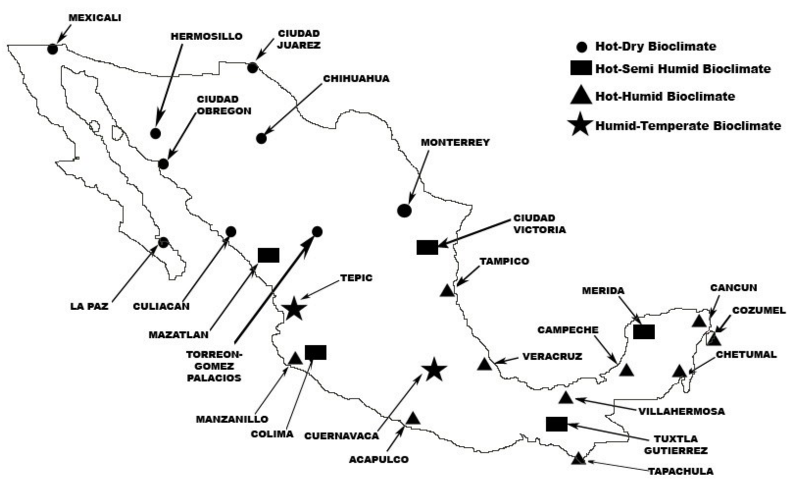

Figure 19. Cities in Mexico with Hot-Dry, Hot-Semi Humid, Hot-Humid and Humid-Temperate Bioclimate (City Information from *CONAVI,* 2007; 2010a; Map Modified from *CONAVI,* 2005).
This Map was Created by Drawing the Contour Line of the Mexican Republic from the Original Image and the Bioclimates from the Original Image Were Eliminated for the Final Map. Titles of the Cities and Bioclimates Were Added. This Map Was Required to Show those Bioclimates that Use Air-Conditioning Systems in Mexico. Adapted from *Hacia un Codigo de Edificacion de Vivienda.* (p.18), by *CONAVI*, 2005, Mexico, D. F.: *CONAVI*. Copyright 2005 by *CONAVI*. Adapted for Scholarly Purposes under Fair Use.

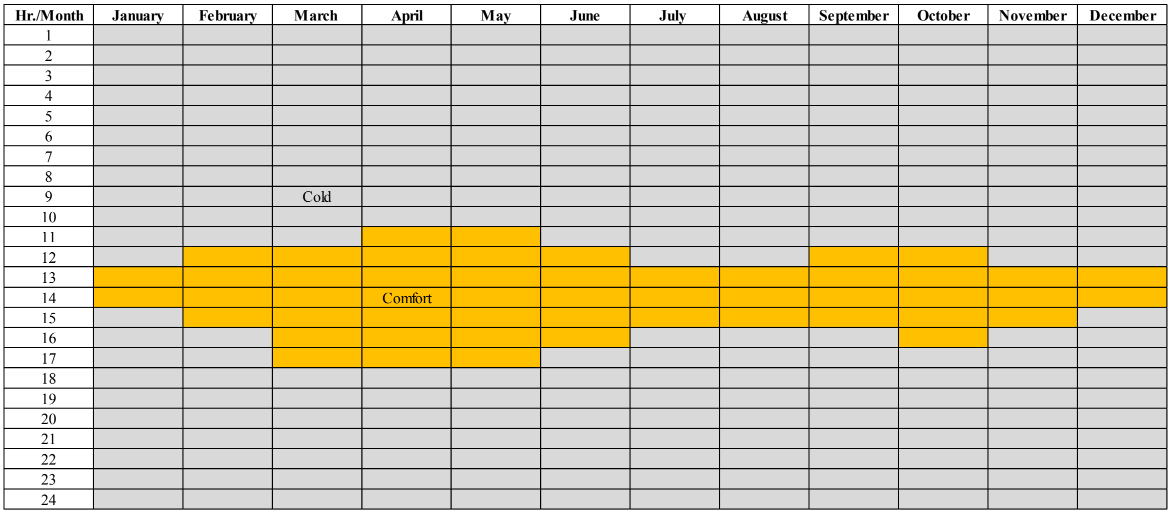

Figure 20. Isopleth Diagram of Air-Conditioning Requirements for the Semi-Cold Bioclimate (Table Modified from *CONAVI*, 2006).
The Original Table had the Isopleth Diagram from the 18:00 of One Day to the 17:00 of Next Day. The Table for this Study Considered a Complete Day from 1:00 to 24:00. This Figure Was Needed to Show those Hours in Thermal Comfort throughout the Year. Adapted from *Uso Eficiente de la Energia en la Vivienda.* (p.45), by *Comision Nacional de Vivienda*, 2006, Mexico, D. F.: *Comision Nacional de Vivienda*. Copyright 2006 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

The electrical energy for the housing sector in Mexico has subsidies, which are not equal between the northern and the southern states in Mexico (Sheinbaum-Pardo and Rodriguez-Padilla, 2000). The northern states with hot-dry climate and higher income, compared to the southern states with hot-humid and lower-income, receive higher subsidies in Mexico. The hot summer season in the north justified the higher subsidies to promote the use of the air-conditioning systems.

Table 22. Energy-Efficiency Suggestions for the Semi-Cold Bioclimate in Mexico City (Created with Information from *CONAVI*, 2006).

Conditions of Thermal Sensations	Months	Suggestions
Monthly Cold Conditions	From July to February	Take advantage of passive solar heating: direct gains on south and east facades during the mornings and indirect gains during the evenings
		Avoid heat losses through windows
		Use transition spaces between interior and exterior
Monthly Comfort Conditions	From March to June, and September and October	Use heat storage in floors, ceilings and walls on the west and south facades
		Change air from interior spaces for hygiene

The use of air-conditioning systems for the hot-humid southern and southeastern states is high due to its high humidity. The hot summer rates for electricity (utility price structure) are designed for the hot-dry climates in the northern states and only consider the national average temperature. Then, the hot summer rates should consider the national average temperature and the humidity levels in the country. This will allow the hot-humid southern states to reach an average lower temperature to get a better rate to pay for air-conditioning systems. Thus, passive design strategies must be studied and applied to the buildings in Mexico City, before considering the use of air-conditioning systems.

2.5.3. Daylighting and Lighting Systems and Appliances.

In order to achieve a low-energy building, it is important to orient windows properly to maximize daylighting harvesting and reduce the use of electric lighting in buildings in Mexico City.

2.5.3.1. Daylighting.

The *Normas Tecnicas Complementarias para el Proyecto Arquitectonico* (*GDF*, 2011) pointed out that window area on a building's façade need to be controlled. These norms recommended that the minimum percentage should be 17.5 percent for each window in livable spaces.[43] In addition, the norm included requirements that all living spaces should have natural daylighting through windows to the exterior or to a courtyard. Table 23 provided strategies for the semi-cold bioclimate of Mexico City (*CONAVI*, 2010a).

2.5.3.2. Lighting Systems and Appliances.

Cooking, hot water, lighting and appliances were the highest energy consumption elements in the Mexican housing sector (there was no difference between single-family and multi-family) (*CONAVI*, 2006).[44] *CONAVI* also stated that cooking was the highest energy consumption of the four end-uses. The appliances (and air-conditioning, if it was affordable) occupied the third average national place. Finally, most residential buildings in Mexico City are internal-load dominated as discussed in the guide *Uso Eficiente de la Energia en la Vivienda*.

Houses in Mexico should use compact fluorescent lamps to help achieve the standards of "NOM-017-ENER/SCFI-2008" (*CONUEE,* 2008a; *CONAVI,* 2010a). In addition, interior spaces in housing must achieve a lower electric power density rating for lighting. For the retail area, the requirements are stated in the norm "NOM-007-ENER-2004" (*CONAE*, 2005a; *SENER*, 2005). *CONAE* (2005a) and *SENER* (2005) pointed out that the lighting power density for the grocery store/convenience store is 1.85 W/ft².

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[43] The following are livable spaces: bedrooms, living rooms, dining rooms, and TV rooms among others (*GDF*, 2011).

[44] The US is different from Mexico in terms of building loads. Huang et al. (1999) mentioned a study (*1993 Residential Energy Consumption Survey* (RECS)) where they found that multi-family buildings in the US were internal-load dominated buildings in terms of cooling loads. For heating loads, they concluded that the conduction of walls and windows, and the infiltration (infiltration is the largest contributor), contributed the most to heating loads and total loads in multi-family buildings.

Table 23. Strategies for Daylighting in Semi-Cold Bioclimate in Mexico (Created with Information from *CONAVI,* 2010a).
This Table was Created from a Section of a Larger Table from the Original Source, and Helped to Find Potential Strategies for Daylighting and their Results Applied to the Semi-Bioclimate from Mexico City. Adapted from *Codigo de Edificacion de Vivienda 2010* (p.309-311), by *Comision Nacional de Vivienda,* 2010, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2010 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Strategies	Results of the Application of the Strategies
Avoid blinds	Improves direct solar access
Place horizontal windows on the upper area of the walls	Provides daylighting
Shade southern facades with horizontal eaves	Reduces overheat during the summer season
Shade windows on southwest facades with vertical mullions	Reduces overheat during the hot spring and summer afternoons
Use porches and lobbies	Creates transition spaces between interior and exterior spaces

Quadri-De la Torre (2008) showed an analysis between different traditional and energy-efficient measures in Mexico such as lighting, refrigerators, TVs, washing machines, and miscellaneous appliances among others. Maqueda-Zamora and Sanchez-Viveros (2011) developed a daily profile of the average energy-use for an unidentified group of houses in Mexico's central area. Figure 21 shows the average hourly energy-use profile for an unidentified group of houses in Mexico's central area.

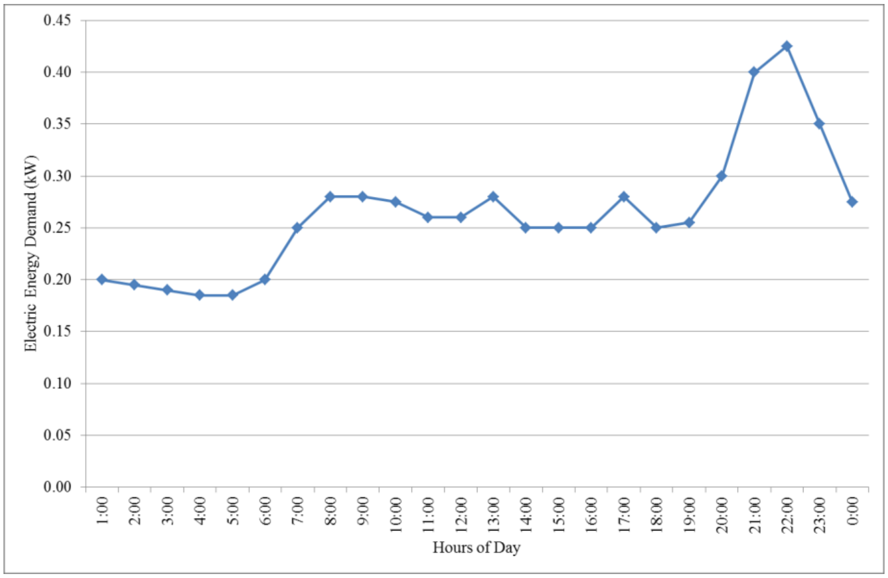

Figure 21. Average Energy-Use Profile for an Unidentified Group of Houses in Mexico's Central Area (Data Taken from Maqueda-Zamora and Sanchez-Viveros, 2011).
The Background Was Changed from Pink to White, and the Titles Were Translated from Spanish to English. This Figure Was Required for this Study to Set the Base-Case Energy Profile for the Simulation. Adapted from "Curvas de Demanda de Energia Electrica en el Sector Domestico de Dos Regiones de Mexico," by M. R. Maqueda-Zamora and L. A. Sanchez-Viveros, 2011, *Boletin Instituto de Investigaciones Electricas,* p.175. Copyright 2011 by *Instituto de Investigaciones Electricas.* Adapted for Scholarly Purposes under Fair Use.

2.5.4. Natural Ventilation.

Natural ventilation should be considered for the base-case of the simulated building from the selected community. It removes the air from the interior spaces without the use of air-conditioning systems in Mexico City. Table 24 presents the suggestions that *CONAVI* made for the use of natural ventilation as an energy-efficiency measure for the semi-cold bioclimate in Mexico City. Natural ventilation could be an important low-energy cooling strategy in Mexico City (i.e., thermal mass with nighttime natural ventilation), when the summer season reaches higher ambient temperatures.

Table 24. Strategies for Natural Ventilation in Semi-Cold Bioclimate in Mexico (Created with Information from *CONAVI,* 2010a).
This Table was Created from a Section of a Larger Table from the Original Source, and Helped to Find Potential Strategies for Natural Ventilation and their Results Applied to the Semi-Bioclimate from Mexico City. Adapted from *Codigo de Edificacion de Vivienda 2010* (p.312-314), by *Comision Nacional de Vivienda,* 2010, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2010 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Strategies	Results of the Application of the Strategies
Provide operable windows	Allows people to control the wind flow depending of the interior space temperature conditions
Provide well-sealed windows	Avoids heat losses during extreme cold conditions
Place windows on the south-southeast side of the building. (The openings must be less than 80 percent of the total wall area)	Provides warm air during the mornings
Reduce the number of windows on north, northeast, northwest and west facades	Avoids the night cold wind during the winter season
Place horizontal windows on the upper area of the walls	Provides cross natural ventilation

Areas with energy savings using natural ventilation instead of air-conditioning are located in a map in Mexico using the Geographic Information System (GIS) Map Maker software (Oropeza-Perez and Morillon-Galvez, 2011). A successful mathematical model used in Brazil was adapted to Mexico, and the results were displayed in the GIS Map Maker software. This tropical climate based-model applied to the residential and commercial sectors in Mexico in 2006 saved 3.71 percent and 6.24 percent of the total energy consumption (Morillon-Galvez and Oropeza-Perez, 2009). Thus, natural ventilation is a meaningful measure that should be considered for the mixed-used complex in this technical potential study.

2.5.5. Rainwater Harvesting Systems; and Greywater Reuse Systems and Water-Use.

Water has a vital role in the survival of cities and communities in the world. Cities have been intrinsically connected to water resources, and the scarcity or absence of water could cause the collapse of urban life (Novotny et al., 2010). Rainwater harvesting systems and greywater reuse systems take advantage of natural water supply that are increasingly essential for humanity, and reduce the need of municipal city water.

2.5.5.1. Rainwater Harvesting Systems.

Rainwater harvesting systems can be divided into rainwater catchment, delivery and storage systems (Gould and Nissen-Petersen, 1999). Roofs are the main component of a rainwater catchment system. The catchment area must also be combined with gutters and the rainwater delivery systems. Rainwater catchment, delivery and storage systems that provide drinking, washing and irrigation water in a low-energy, low-water use community in Mexico City can make a significantly decrease in community's municipal water-use and the energy associated with it. The tabulated monthly water precipitation values to determine the rainwater availability in Mexico City was obtained from *Comision Nacional del Agua* (*CONAGUA*, 2010b) and *INEGI* (2012).

Anaya-Garduño (1998) provided calculation procedures for regional rainwater harvesting and storage for temperate climates in Latin America and the Caribbean.[45] These calculations can easily be applied to the buildings in Mexico City to determine the effectiveness of a particular rainwater harvesting system. Such systems are essential to the survival of the low-energy, low-water use communities in Mexico City.

Mexico, as many other countries, has significant water problems. Sixty-eight percent of the monthly rainfall in Mexico occurs between June and September (33 percent of the year), which requires significant storage use year-round (*CONAGUA*, 2011). In addition, just providing adequate potable water to Mexico City's growing population may prove to be a challenge in the future. *Consejo Nacional de Poblacion* (*CONAPO*) has estimated that Mexico's population will increase by 12.3 million between 2010 and 2030.[46] In addition, Mexico's population will become 81 percent urban by 2030 which will further strain the municipal water resources in the Mexico City Valley, thereby increasing the need for more rainwater collection systems as well as water conservation. Water conservation and harvesting are essential to the development of low-water use communities in Mexico.

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[45] Calculation procedures for semi-arid, arid and sub-humid climates are also developed in Anaya-Garduño.
[46] The amount of 12.3 million people estimated between 2010 and 2030 is referenced from *CONAPO's 2007* report *Proyecciones de la Poblacion de Mexico. 2005-2050* (*CONAGUA,* 2011). *CONAPO* (Ojeda-Lavin, 2013a, b) displayed that the population in Mexico in 2010 was 114.2 million people and the estimated population in 2030 is 137.4 million people. This means that the population in Mexico will have 1.16 million people each year for a period of 20 years.

2.5.5.2. Greywater Reuse and Water-Use Reduction Systems.

The water-use consumption for the apartments was taken from the studies of Morales-Novelo and Rodríguez-Tapia (2007) and Arreguin-Cortes (2000). The calculation for the hydraulic and sanitary systems for single-family and multi-family buildings was provided from Becerril (2007).[47] The water-use for the grocery store was obtained from the *Norma Tecnica Complementaria para el Proyecto Arquitectonico* (GDF, 2011).

Ecological bathroom fixtures for housing in Mexican building codes were reviewed. *CONAVI* (2010a) showed the requirements for hydraulic and sanitary systems, and suggested some norms standards for bathroom fixtures such as ecological showers and low-flush toilets. These requirements for the bathroom fixtures should be applied in order to achieve low-water use in housing in Mexico.

The Student Water Investigators Showing How (SWISH, 2013) was used to calculate the water savings for the bathroom and kitchen fixtures. It has been reported that the toilets and the showers consume 70 percent of the daily domestic water-use (*SACM,* 2012). Therefore, the use of water-saving devices can reduce more than 50 percent of this 70 percent. Water-saving devices such as; such as low-flow sinks and bathroom showers, and low-flush toilets, are recommended to reduce water-use in Mexican houses (*INE*, 2009a). The greywater generated in a house in Mexico is between 50 and 80 percent of the domestic wastewater (*INE*, 2009b).

[47] This textbook is used for basic systems courses in several universities in Mexico, and is known as a simplified method from the *Building Code for the Distrito Federal* to calculate the hydraulic and sanitary systems.

2.5.6. Passive Solar Systems.

In order for passive solar systems to function properly, the system on a building's façade should be carefully controlled[48] as suggested by the *Norma Tecnica Complementaria para el Proyecto Arquitectonico* (*GDF*, 2011).

Energy-efficiency suggestions for the semi-cold bioclimate in Mexico City are given in terms of the conditions of thermal sensations *"monthly cold conditions"* and *"monthly comfort conditions."* (*CONAVI*, 2006)[49] During the *"monthly cold conditions"* (July to February) for the semi-cold bioclimate in Mexico, the housing can benefit from the following suggestions: direct passive solar heating on the south and east façades during the mornings and indirect passive solar heating on the west façade during the evenings (i.e., heat released from daytime storage). Such housing should avoid heat loss through their windows and use porches and lobbies as transition spaces between interior and exterior spaces. During the *"monthly comfort conditions"* (from March to June and from September to October) for the semi-cold bioclimate in Mexico, the housing can benefit from the following suggestions: thermal mass heat storage in floors, ceilings and walls in the west and south façades and proper air change from interior spaces for health purposes.

CONAVI provided the following suggestions in Table 25 for the designer of the building envelope. These design guides help to achieve energy-efficiency through passive solar design for the semi-cold bioclimate in Mexico.

Givoni (1998) and Van Lengen (2008) have extensive discussions about passive solar heating and passive cooling systems applied to buildings. Givoni presented different passive solar heating systems such as direct solar gain, thermal storage walls, wall convective loops, the Barra system[50] and sunspaces. The following passive cooling techniques in buildings should be considered: thermal mass with daytime and nighttime natural ventilation; radiant

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[48] These requirements for passive solar systems are also related to the requirements for daylighting and natural ventilation.

[49] The following cities must follow these suggestions: Mexico City, Tlaxcala, Puebla, Morelia and Toluca.

[50] The system, created in Italy by Horazio Barra, consists of the following layers on a southern facade: a vertical glazing, air chamber, and thermal wall mass, and a horizontal air chamber and concrete ceiling. The solar radiation strikes the thermal mass behind the glazing. The air, provided by openings in the lower area of the wall, increases its temperature inside of the air chamber and rises vertically. The hot air is conducted horizontally through an air chamber. The concrete ceiling has some openings and introduces the hot air into the housing spaces.

cooling through the re-radiation of the thermal mass to the night sky; direct evaporative cooling; and indirect evaporative cooling through roof ponds with movable insulation to re-radiate the thermal mass to the night sky and wetted conductive impermeable walls.

Table 25. Strategies for Passive Solar Systems in Semi-Cold Bioclimate in Mexico (Created with Information Taken from *CONAVI,* 2010a).
This Table was Created from a Section of a Larger Table from the Original Source. It Helped to Find Potential Strategies for Passive Solar Systems and their Results Applied to the Semi-Bioclimate from Mexico City. Adapted from *Codigo de Edificacion de Vivienda 2010* (p.309-311), by *Comision Nacional de Vivienda,* 2010, Mexico, D. F.: *Comision Nacional de Vivienda*, Copyright 2010 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Strategies	Results of the Application of the Strategies
Avoid setbacks or protrusions on the facades	Allows thermal mass in the exterior walls to get direct solar gains
Use courtyards	Creates ventilated greenhouses or sunspaces
Use horizontal eaves on southern facades	Protects from the summer sun angle
Use vertical mullions on southwestern facades	Prevents heating gains from the hot spring and summer afternoons
Use porches and lobbies	Creates transition spaces between interior and exterior spaces

Van Lengen (2008) emphasized the use of large south-facing windows to provide direct solar gain during the winter, thick heavy weight walls with regional materials such as adobe, brick or concrete to delay the heat loss from the interior spaces, and insulation of the floor slab to avoid the heat loss to the ground for the housing sector in the temperate climate. In general, the south-facing windows will need protection against the summer sun through carefully designed shading. These suggestions were made originally for single-family housing; however, these suggestions can be used for multi-family housing in Mexico City as well.

2.5.7. Solar Photovoltaic and Domestic Hot Water Systems.

Solar photovoltaic systems (for electricity) and domestic hot water systems (for heat) and their possible application to the low-energy, low-water use communities in Mexico City have a far-reaching potential.

The Mexican national solar atlas helps to understand the potential for solar design properties in Mexico due to its location and climatic characteristics.[51] Mexico has abundant solar radiation, although the solar radiation values are not completely uniform in the country (Hernandez et al., 1991). The northwest area of Mexico has the highest amount global solar radiation due to the clear sky of the desert environment. On the other hand, the states close to the Gulf of Mexico and the southern states have a high cloudiness that results in a low solar radiation. Finally, areas below 15° N have a high cloudiness due to the close proximity to the humid equatorial zone and nearby oceans. Thus, the potential for solar electric systems and solar domestic hot water systems in Mexico City are feasible due to its location over the high cloudiness sector that goes from 15°N to the equator.

The advantages of the solar technology in Mexico are next: the use of renewable energy; that solar energy is well developed in the world and it is easy to install; the avoidance of carbon dioxide; and the low pollution of the air and water used in the process (Fernandez-Zayas and Chargoy-Del Valle, 2005). The creation of Solar Laws prevents the construction of structures that can block access to solar insolation for the use of photovoltaic and solar collectors (*CONAVI*, 2007).

The *Secretaria de Energia* reported an increase of 20.2 percent of solar collectors and photovoltaic in the housing sector in 2009 (*SENER,* 2010). This is due to two factors: the increase of contracts for low voltage connections to the grid between the *CFE* (2011) and the users that generate electricity through renewable energy, and the creation of new companies related to the photovoltaic electricity production in the country.

2.5.7.1. Solar Photovoltaic Systems.

Solar photovoltaic (PV) systems consist of the following components: photovoltaic panels, an inverter, electric cables and a bidirectional electric meter. The photovoltaic panels are made of numerous photovoltaic cells that convert sunlight into electricity. The inverter converts the direct current generated from the photovoltaic panels into alternating current for use in a building. This alternating current is either used at home or sent back to the electric

[51] Mexico is located inside the tropical and the subtropical zones.

grid depending upon the amount being generated as compared to the amount being used on-site. The *Mexican Electricity Federal Utility* (*Comision Federal de Electricidad* (*CFE*)) provides the bidirectional meter, which measures the energy in two forms: the electricity consumed on-site (or energy received) and the electricity sent back to the electric grid (*CONAVI,* 2010a). In a PV system, the solar energy collected during the day is used directly in the house. If there is any additional electricity, it is considered as surplus. This surplus is sent to the electric grid through the bidirectional meter of the *CFE*. On the other hand, at night when there is no solar radiation, the house consumes electricity through the electric grid provided by the *CFE*.

2.5.7.2. Solar Domestic Hot Water Systems.

The slow development of solar collectors in Mexico is a result of the following problems: the initial high costs of renewable energy systems; the low cost of natural gas in Mexico; a lack of legislation to prevent the construction of structures that block access to solar radiation and the need for conventional backup heaters during the cloudy days; a lack of knowledge about solar energy technology and a lack of projects using solar collectors prevents homeowners from learning about the systems; and its maintenance (De Buen-Rodriguez, 2005; Fernandez-Zayas and Chargoy-Del Valle, 2005). Through the *PROCALSOL* program (*CONAE,* 2007) and the *Hipoteca Verde* (*Green Mortgage*) program (*INFONAVIT,* 2011b) the use of solar thermal collectors has expanded in the country.

Solar collectors are used in the following bioclimates in Mexico: humid-temperate, temperate, dry-temperate, dry-semi-cold, semi-cold and humid-semi-cold (*CONAVI*, 2010a). Solar collectors must comply with the norms or standards for thermal performance and functionality. The hydraulic, thermal, mechanical and the piping design of the solar water heater systems must comply with the requirements from the local Building Code, *Reglamento de Impacto Ambiental y Riesgo* (*Environmental Impact and Risk Regulations*), *Reglamento de la Ley Ambiental* (*Environmental Law Regulation*), *Reglamento de la Ley de Desarrollo Urbano* (*Urban Development Act Regulation*) and *Reglamento de la Ley de Proteccion Civil* (*Civil Protection Act Regulation*) among others.

The following types of solar collectors are most commonly used in housing: integral collector-storage (*ICS*), flat-plate collectors and evacuated-tube collectors (NREL, 2003). The *ICS* has an interconnected tank and collector with an energy-absorbing surface enclosed in an insulated box with a transparent cover to allow solar radiation. *ICS* is recommended for mild-climates (Duffie and Beckman, 2006; NREL, 2003). The flat plate collector is an insulated, weatherproofed box with a dark absorber plate under one or more glass covers. The flat-plate collector is the most commonly used due to the following characteristics: good use of beam and diffuse solar radiation, does not need a sun-tracking device, is mechanically simpler than concentrating collectors, and requires little maintenance. The flat-plate collector is the standard by which all collectors are compared (Ramlow and Nusz, 2006). The evacuated-tube collectors are mainly used in commercial buildings, and are better suited for places that need temperature over 160°F and places with overcast conditions cold climates (Ramlow and Nusz, 2006). The evacuated-tube has a shortened maintenance schedule and decreased overall lifespan in residential applications. The flat-plate collector has better efficiency than the evacuated-tube collector, if the collector inlet temperature above ambient temperature is below 70°F. Therefore, due to the explained characteristics, the flat-plate collector is recommended for the low-energy, low-water use community in Mexico City.

There are two types of solar water systems: active and passive. The type of solar water system depends in the following characteristics: the site, the climate, installation considerations, cost and the way the system will be used (NREL, 2003). In general, solar active water systems are compound of a solar collector, storage tank, heat exchangers, a heat transfer fluid, pumps, piping and piping insulation, thermometers, controls, various valves and pressure gauges (Ramlow and Nusz, 2006). Active solar water systems usually have one or more pumps to circulate the heat transfer fluid. Passive solar water systems have most of the same components with the exception of pumps and controls, which are not usually needed (NREL, 2003). Solar active water systems are more efficient than passive ones. Thus, a solar active water system should be applied to the community in Mexico City.

2.6. Tools to Analyze Energy Consumption

Methodologies and tools for community-wide energy-use analysis were reviewed for this technical potential study. The following methodologies and tools that were developed to provide a community-wide energy-use analysis:

- Comprehensive Community Energy Management Planning or CCEMP (Hittman and Associates, 1978; UCB, 1980) developed a complete methodology to measure existing community-wide energy-use and to allow decision-makers to evaluate different energy conservation programs. There is information required by the CCEMP which could not be gotten or found from Mexico City, such as mail surveys, booth surveys, city tax records, utility records, and reports from economic development councils. Only census bureau estimates and information from regional transportation districts were partially obtained.
- Community Energy Assessment and Design Support or CEADS (JCEM and VAP, 1995) provided procedures to assess community form, renewable energy techniques, energy conservation measures, and transportation modes. A soft energy community tool based on sustainable planning concepts and renewable energy sources was created by JCEM and VAP and was applied to a site close to Fukuyama City (Tabb et al, 2000). Later, the CEADS was based on this soft energy community tool and was introduced in US. It has elements such as defaults, rules and weather files. It is not clear if the defaults (i.e., building construction, energy generation and transportation) and rules (i.e., site-specific data such as solar insolation, temperature, wind and agricultural data) files could be easily overwritten and used in Mexico City. Also, the weather files were only available for US and Japanese cities.
- Comprehensive Community NO_x Emission Reduction Toolkit or CCNERT (Sung, 2004) provided a general framework for community-wide energy-use to help decision-makers understand the impact of various energy conservation options; understand the data collection; apply simplified procedures to estimate each sector's energy-use; and reduce NO_x emissions in a community. The CCNERT was applied to College Station, TX. This toolkit used information from College Station such as the general characteristics of the residential sector from the Community Information

System (CIS) and the utility bills among others. This type of information is imposible to get from Mexico's housing sector.

In the same way, the following tools were reviewed in terms of energy analysis at the neighborhood and city level: the Sustainable Urban Neighborhood Tool (SUNtool) funded by the Swiss Federal Office of Education and Science and coordinated by the Solar Energy and Building Physics Laboratory at the Ecole Polytechnique Federale de Lausanne (LESO-PB, 2013a, b); and the Urban Modelling Interface (UMI) developed by the Sustainable Design Lab at the Massachusetts Institute of Technology (Reinhart, 2013).

The SUNTool was created in order to develop sustainability criteria between urban planners and building designers (LESO-PB, 2013b). The software has four classes of model: microclimate[52], thermal, stochastic[53] and plant (Robinson et al., 2007). Until 2006, the software suffered some delay, and it was only available in a preliminary beta version. The current status of this tool is unknown (Reinhart et al, 2013).[54] The UMI tool can model the environmental performance of neighborhoods and cities regarding operational energy-use, walkability and daylighting potential and was targeted for architects and urban planners (Reinhart, 2013). This tool uses Rhino software to create the buildings, EnergyPlus for the thermal calculation for each building, Daysim for the daylighting replication and custom Python scripts for walkability evaluations (Reinhart et al, 2013). Daylighting and walkability calculations are beyond the limits of the technical potential study. There is also no document yet that validates or show any sort of accuracy for the UMI tool in terms of thermal simulation.

In addition to the CCEMP, the CEADS, the CCNERT, the SUNtool, and the UMI, the energy analysis tools have different capabilities for simulating building and renewable energy systems. The CCEMP, the CEADS, and the CCNERT, do not have enough flexibility or need information that was not found for the community analysis in Mexico City. The SUNtool is not publicly available, and the UMI seemed too complex and is a recent software without peer-reviewed documentation yet.

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[52] The microclimate class covered the radiation modeling and the temperature prediction.
[53] The stochastic class covered the occupant presence; window openings; lights and shading devices; electrical and water appliances; and waste.
[54] Its website (www.suntool.net) is not working properly.

In order to analyze community-wide energy use in Mexico City, an ensemble of energy analysis software for solar collectors and photovoltaics will be required. Therefore, the following software were reviewed: Climate Consultant (for analysis of environmental design strategies); DOE-2.1e, DOE-2.2, Ecotect, EnergyPlus, eQuest and TRNSYS (for building energy analysis); TRNSYS and F-Chart (for solar collectors) and TRNSYS and PV F-Chart (for photovoltaics).

The Climate Consultant software was reviewed due to its capability to show environmental design strategies in an annual hourly-based with a psychrometric chart (Clayton et al., 1988; US DOE, 2012). This software provided ideas about energy-efficient measures to be applied into the methodology. Also, Crawley et al. (2005) provided a comparison of different whole-building simulation tools. The tools reviewed included: DOE-2.1e, DOE-2.2, eQuest, EnergyPlus, TRNSYS and Ecotect.

DOE-2.1e is a widely used software that can simulate a broad range of HVAC systems, effects of thermal mass, different insulation materials, equipment, or lighting, and predicts the annual hourly energy-use and energy cost of a building using a variety of different weather data files (LBL/LASL, 1980a, 1980b). It is also an hourly whole-building energy simulation tool that uses the BDL processor to translate the inputs, and four replication subprograms that are executed in sequence: Loads, Systems, Plant and Economics. It also uses the weighting factor method to calculate the thermal loads (Winkelmann et al, 1993). DrawBDL is used to see the building geometry from the DOE-2 input files. DOE-2 simulations were compared against measured data, other simulation methods and analytical calculations (Haberl and Cho, 2004). This comparison presented the following results:

- A variation from 10 to 26 percent compared to measured data.
- An agreement from 1 to 30 percent versus results by other programs, and from 1 to 15 percent when weighted by building size.
- A variation from 0 to 5 percent compared to analytical calculations.

DOE-2.2 is based on the DOE-2.1e software, and provides more accurate and flexible simulation of window, lighting, and HVAC systems than DOE-2.1e (LBNL/JJH & Associates, 2004). The software has one subprogram, the BDL Processor, which translates the input. It also has three simulation subprograms: Loads, HVAC and Econ. The simulation is performed in sequence, and each subprogram produces printed reports of the calculations. Two steps are required to calculate the load: the heat gain to the space and the room weighting factors (LBNL/JJH & Associates, 2006). The heat gain is the amount of heat that goes into the air or is absorbed by the walls and furnishings in the space. The room weighting factors are applied to the heat gain to determine the load.

eQuest has a DOE-2.2 engine with a more user-friendly interface, which performs a comparative analysis of building designs and technologies. It can model shading, fenestration, interior building mass, envelope building mass, and heating and air-conditioning systems (Hirsch & Associates, 2010). The DOE-2.2 engine inside eQuest performs an hourly simulation of the building for a one year period. It calculates the heating or cooling loads for each hour of the year, based on the following factors: walls, windows, glass, people, plug loads, and ventilation. The results in eQuest are shown graphically. eQuest is quick to produce results in order to take decisions in early design stages. It can also import drafted floorplans from AutoCAD, and create and assign characteristics to the zones.

EnergyPlus is a modular tool that can model heating, cooling, lighting, ventilation, water and other flows in buildings (Crawley et al., 2005; US DOE, 2009b). Its code is based in the combined features from DOE-2.1e and BLAST. EnergyPlus uses the response factor method for the transient heat transfer through multilayered walls. The software allows user-specified time steps of less than an hour, and performs the load calculation and replication of the response of the systems and plant for each time step. This integrated solution shows an accurate space temperature prediction in terms of system and plant sizing, occupant comfort and occupant health calculations. Users can evaluate realistic system controls, moisture adsorption and desorption in building elements, radiant heating and cooling systems, and interzone air flow.

TRNSYS is also a modular software with a library that includes components for multi-zone building models, solar thermal and photovoltaic systems, renewable energy systems, HVAC systems, cogeneration and fuel cells (Klein et al., 2004). This modular tool assembles smaller components in order to simulate complex energy systems. The subroutines in TRNSYS representing physical components are combined and solved with a building envelope thermal balance and an air network model at each time step. New mathematical models can be added to this tool due to its modular nature.

Ecotect can model thermal, lighting, shading and acoustics among others (Crawley et al., 2005). It is also a 3D modeler that allows a visual feedback of the input data in the file. The main advantage is the feedback at the conceptual building design stages. The intention is to allow designers to take a holistic approach to the design process. This software can be used to model the whole complex for this technical potential study.

F-Chart software was reviewed for analysis and design of active and passive solar heating systems (Klein and Beckman, 1983). The "f-chart" method developed by Klein is a correlation of hundreds of simulations of solar heating systems using TRNSYS for many climates, conditions and systems. PV F-Chart was reviewed for design and analysis of photovoltaic systems (Klein and Beckman, 1985). The software uses the concept of utilizability which is the fraction of the incident solar radiation that can be converted into useful energy. F-Chart and PV F-Chart are simplified programs for the design and analysis of solar collectors and PVs.

This technical potential study requires an ensemble of software to model these measures for the mixed-use building. There is no a single software that can simulate the lighting systems and appliances, the solar collectors and photovoltaics. For the apartments, DOE-2.1e, EnergyPlus and eQuest can model the lighting systems and appliances. Air-conditioning systems are not required for the housing in Mexico City. TRNSYS, F-Chart and PV-Chart can replicate the solar collectors and the photovoltaics. The lighting, appliances and air-conditioning systems for the grocery store can be modeled with DOE-2.1e, EnergyPlus and eQuest.

CHAPTER III
SIGNIFICANCE AND LIMITATIONS

This study contributes to the development of a step-by-step procedure to analyze the low-energy, low-water use community technical potential in Mexico City. The study includes the analysis of energy and water-efficiency measures, along with renewable energy-use systems. Such a low-energy, low-water use community intends to reduce energy and potable water consumption; and decrease the use of personal automobiles through its increased use of mixed-use and walkability. Public and private sectors specialized in housing developments are the main target of this study, which can use the procedure to analyze and transform a regular community into a real low-energy, low-water use community.

The proposed procedure to develop such this community in Mexico City can be seen as a response to the need of strategies or plans to reduce the greenhouse gas emissions in big cities, as it is signed in the *2010 Mexico City Pact.*

The gradual proceeding for analyzing energy, water and transportation use reduction could be adopted and adapted to other cities with similar climate (e.g., Tlaxcala, Puebla, Morelia and Toluca) and similar urban population to Mexico City.

This technical potential study will focus in the following elements:

1) How to reduce energy-use in Mexico City's mixed-use buildings through improved building envelope measures, with considering the use of thermal mass and shading devices, the use of daylighting and efficient electrical systems with the application of daylighting controls, high-effienciency lamps and appliances.
2) How to reduce personal car use in Mexico City by incorporating residential, commercial, recreational facilities (i.e., mixed-use) into a community and reducing driving distances to motivate walking.
3) How to improve efficient production of energy and water by exploring the on-site use of photovoltaic systems, solar domestic hot water systems, the rainwater harvesting and greywater reuse systems.

This technical potential study has the following limitations:

1) It focuses on the Mexico City area,[55] because it represents an area that is home to 17 percent[56] of the Mexican population. This could have a significant reduction in the houses' energy-use in local level, but is expected to promote similar communities at national level.
2) It uses a case-study community at Mexico City. The case-study community is the *Multifamiliar Miguel Aleman* on a site of 10 acres at the *Colonia Del Valle* at the *Benito Juarez* borough in Mexico City. This is an historical center that has characteristics suitable for the low-energy, low-water use analysis. The complex contains nine buildings with thirteen floors and six buildings with three floors for a total of 1,080 apartments with approximately 5,000 residents. The case-study community currently has mixed use buildings (i.e., multi-family housing and retail), has a good location with existing and potential alternative transportation (bus and underground) and its open space.
3) The analysis will be done to one of the nine buildings with thirteen floors. This selected building is located in the north side of the site. The model analysis is applied to the small dry goods convenience store in the first floor, and to the apartments' zone from the second to the thirteenth floor.
4) The development of such low-energy, low-water use communities for this technical potential study follows local construction codes.
5) For the building energy simulation the eQuest program was selected. It has a DOE-2.2 engine with a user-friendly interface tool, and produces full annual hourly simulation results in a reasonable time. This is a strong quality considered for the simulation process for the current technical potential study due to the extracted hourly

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[55] The area of Mexico City is 3,032 sq. mile or 7,854 km² (*SEDESOL/CONAPO/INEGI,* 2007).
[56] In 2008, the population of Mexico City was 19.2 million people (*SEDESOL/CONAPO/INEGI,* 2007). In 2010, the population of Mexico was 112.3 million people (*INEGI*, 2013).

reports to create the final tables and graphs for the building energy-use for the apartment section and the grocery store section. Also, the air-conditioning systems that are simulated in this technical potential study are not complex at all. The apartment section does not have an air-conditioning system and the retail area is a small convenience store. This technical potential study requires an ensemble of software to model these measures for the mixed-use building. There is no a single software that can simulate the lighting systems and appliances, the solar collectors and photovoltaics. The software that will be used, besides eQuest, to achieve low-energy levels in the *Multifamiliar Miguel Aleman* are Climate Consultant (to provide design strategies to use in the eQuest); F-Chart (to analyze a solar domestic hot water systems); and PV F-Chart (to provide on-site energy from photovoltaic systems).

Therefore, this technical potential study will contribute to the body of knowledge by applying energy and water-efficiency strategies at urban community level in Mexico City and providing a guide to achieve energy and water savings. These mixed-use communities with low-energy and low-water potential will allow the cities to be compact, well-connected and pollute less in the long term.

CHAPTER IV

METHODOLOGY AND ITS APPLICATION TO THE TECHNICAL POTENTIAL STUDY

This chapter presents the step-by-step procedure in order to build up the framework to calculate the technical potential for the community-wide energy-use and water-use savings for a low-energy, low-water use community in Mexico City. The process will consist of the following eight points:

1) Search for urban communities or neighborhoods with possible high-density, mixed-use and low-energy, low-water use characteristics in Mexico City. This research identifies the characteristics of a case-study community in Mexico City in order to develop the baseline energy, water and transportation use. The following communities were analyzed in this potential technical study: the *Centro Urbano Presidente Aleman, the Centro Urbano Presidente Juarez and the Centro Urbano Presidente Adolfo Lopez Mateos* in Mexico and The Cityscape community in Phoenix (AZ), Triangle Square in Austin (TX), Battery Park City in New York City (NY) and East Village in San Diego (CA) in the US.
2) Calculate the base-case buildings as follows:
    a. Calculate the energy-use by building type (e.g., apartments and grocery store in this technical potential study) according to people's activities and consider the fixtures required by code. Energy simulations are performed in this procedure.
    b. Consider the percentage of hours inside the thermal comfort zone for each section of the building. This analysis is accomplished by applying computer simulations and hand calculations using spreadsheets.
    c. Determine water-use according to the number of the fixtures and the flushes per fixture required by code (e.g., apartments and grocery store in this technical potential study). This research is accomplished with hand calculations using spreadsheets.

d. Analyze the activities of the people living in the complex in order to set a transportation base-case. This inquiry is also performed with hand calculations using spreadsheets.
e. Estimate the cost for the base-case energy and water consumption using spreadsheets.

3) Calculate the reduced-case buildings as follows:
    a. Estimate energy savings in the mixed-use buildings by implementing energy-efficient measures. Energy simulations are performed in this analysis.
    b. Calculate water savings in the mixed-use buildings by applying low-water fixtures, and greywater reuse treatment and rainwater harvesting systems. This analysis is performed with hand calculations using spreadsheets.
    c. Reduce the use of personal automobiles due to the community's mixed-use and walkability. This inquiry is also realized with hand calculations using spreadsheets.
    d. Determine the cost for the reduced-case energy and water consumption using spreadsheets.
4) Obtain the reduction percentages for energy, water and transportation use.
5) Generate a guide for low-energy, low-water use communities in Mexico City.
6) Give final conclusions.
7) Provide recommendations for future research.

This chapter also presents the application of the methodology, by applying the step-by-step procedure for the technical potential study of the *Multifamiliar Miguel Aleman* case-study community as follows: 1) identification of the case-study community; 2) determination of base-case building energy-use and building water-use, and community baseline transportation use; 3) selection of energy-efficiency and water-use measures, high-efficiency transportation, and calculation of the final reduced energy, water and transportation use; calculation of the potential for on-site energy generation through renewable energy-use systems; and sizing of renewable energy and rainwater systems; 4) simulation and comparison of the reduced energy, water and transportion case to the baseline community; 5) estimation of the base-case and energy-efficient cost and base-case and water-efficient cost for the community; and 6) development of a guide for low-energy, low-water use communities for Mexico City.

4.1. Identifying the Case-Study Community

The *Multifamilar Miguel Aleman* (or *Centro Urbano Presidente Aleman*) is proposed as the case-study community in Mexico City. The reasons the research targeted this community as the base-case for energy, water and transportation use for this technical potential study are the following:

1) The technical potential study focuses on Mexico City because it represents an area that is home to 17 percent of the Mexican population.
2) The existing *Multifamilar Miguel Aleman* complex has the potential to become a low-energy, low-water use community due to its mixed-use building type (residential and grocery store), its multi-family housing type, its location, its existing and potential alternative transportation (bus and underground) and its existing open space.
3) The community is located in the *Benito Juarez* borough of the *Distrito Federal*. The improvement of this community in Mexico City can be feasible due to the repopulation of the four central boroughs of the Distrito Federal (*Cuauhtemoc, Benito Juarez, Miguel Hidalgo* and *Venustiano Carranza*).
4) The *Multifamilar Miguel Aleman* was the best documented community found in the literature review in terms of architectural and construction documents. Table 26 and Table 27 show the summary of the literature. Table 26 shows the General Characteristics of the Communities' Case Study.
5) Table 27 exhibits the Energy, Water and Alternative Transportation Characteristics of the Case-Study Communities. Information for the six communities is presented, regarding the energy characteristics, the water characteristics, and the alternative transportation characteristics. Measures such as energy efficient lamps and appliances, and greywater reuse treatment applied to the American communities should be considered to the center to be analyzed for this technical potential study.

Table 26. General Characteristics of the Case-Study Communities.

Community Characteristics	*Multifamiliar Miguel Aleman*	*Multifamiliar Benito Juarez*	*Nonoalco-Tlatelolco* Housing Unit	CityScape	Triangle Square	Battery City Park	East Village
City	Mexico City	Mexico City	Mexico City	Phoenix	Austin	New York City	San Diego
Climate	Temperate	Temperate	Temperate	Hot-Dry (Briggs et al., 2000)	Hot-Humid	Mixed-Humid	Warm-Dry
Community Type	Urban	Urban	Urban	Urban	Urban	Urban	Urban
Community Site Area	40,000 m² (10 acres)	250,000 m² (62 acres)	1,000,000 m² (250 acres)	18 acres	22 acres	92 acres	325 acres
Building Type	Mixed-use (Residential, Retail, Library, Nursery)	Mixed-use (Residential, Retail)	Mixed-use (Residential, Retail, Health Area)	Mixed-use (Residential, Retail, Offices, Restaurant Areas)	Mixed-use (Apartment Homes, Retail, Commercial and Restaurant Areas)	Mixed-use (Residential Condominums, Offices, Rental Apartments, Retail, Hotels, Museums)	Mixed-use (Residential units, Retail, Hotel, Offices)
Outside Public Area	Recreation Area	Recreation Area	Historical Sites, Public Buildings, Recreation Area, and Educational Institutions.	Park	Park	Gateway Plaza, Winter Garden in the World Financial Center, Stuyvesant High School, Holocaust Museum	Petco Park, Central Library, San Diego City College, New School of Architecture+Design, San Diego Fashion Institute Park, two high schools, Thomas Jefferson School of Law, retail zones and a park
No. of Buildings	15	19 (Phase I) + 3 (Phase II)	102	2	*	33	22 +
References	*CONAVI*, 2006; De Garay-Arellano, 2002, 2004; Larrosa, 1985; Pani, 1952	Cetto, 1961; *CONAVI*, 2006; Pani, 1952; Partridge, 1992	Adria, 2005; Cantu-Chapa, 2001; *CONAVI*, 2006; De Garay-Arellano, 2000, 2004; Pan, 1952	Brigss et al., 2002; Callison, 2011; CityScapePhoenix, 2011a; Emporis, 2012; Weitz, 2012	Brigss et al., 2002; Calthorpe, 2011; TriangleAustin, 2012a, b, c	Brigss et al., 2002; Emporis, 2011a, 2011b; Gordon, 1997; Luxury Rentals Manhattan, 2011; Wired New York, 2011	Brigss et al., 2002; CCDC, 2011; Diamond Terrace, 2012; San Diego Downtown, 2012; Viva-City, 2012; WelcometoSanDiego, 2012a, b, c, d, e, f, g, h, i, j, k; 92101UrbanLiving, 2012

Table 27. Energy, Water and Alternative Transportation Characteristics of the Case-Study Communities.

	Multifamiliar Miguel Aleman	*Multifamiliar Benito Juarez*	*Nonoalco-Tlatelolco Housing Unit*	**CityScape**	**Triangle Square**	**Battery City Park**	**East Village**
Energy Characteristics	Single-pane windows, domestic hot water system, liquefied gas use with boiler	No data	No data	No data	No data	Building Integrated PhotoVoltaic (BIPV) in several buildings of the complex.	Individual heat pumps for heating and cooling, double-pane windows, energy-efficient heating and cooling, double Low-e glass, energy-efficient air conditioning and forced air heating, Energy Star appliances, and roller shades for windows.
Water Characteristics	No data	No data	No data	No data	No data	On-site water treatment and storm water reuse for two green roofs in The Solaire building. Rooftop collection systems in several buildings of the complex. A 17,500 gallon membrane bioreactor-equipped septic tank with UV and ozone for purification in The Solitaire building. Gray water systems for bathroom sinks and showers; black water from toilets; and grease water from kitchens and sinks in the Solitaire building.	No Data
Alternative Transportation Characteristics	There is a new metro station under construction on the norteast corner of the complex. Also, the complex is close to the Zapata metro station, bus routes and taxicabs.	The complex is close to the Centro Medico metro station, bus routes and taxicabs.	The complex is close to the Tlatelolco metro station, bus routes and taxicabs.	The complex is close to Phoenix's Metro Light Rail and bus routes.	The complex is close to bus routes.	The complex is close to subway stations and bus routes.	The complex is close to the Park to Bay Link and bus routes.
References				CityScapePhoenix, 2011b		Engle, 2006; Gordon, 1997; RELAB, 2011; Talend, 2007	Almarerealty, 2012; 92101UrbanLiving, 2012; Diamond Terrace, 2012; Google Earth; WelcometoSanDiego, 2012c, f, g, h, j, l, m

In this technical potential study the *Multifamilar Miguel Aleman* is the target community as the base-case for the energy, the water and the transportation use. The concept of a low-energy, low-water use community in Mexico City is best accomplished with mixed-use, high-density buildings with on-site energy production (e.g., solar) and rainwater harvesting, storage and treatment systems. Such an integrated community will reduce both energy and municipal water consumption, and will provide buildings with acceptable thermal comfort. Also, the improved walkability in the community, the use of its open spaces and readily available, safe, mass transportation will encourage the sense of community-belonging, should improve the physical and psychological health of its residents, and should reduce overall transportation energy-use because its citizens will have access to selected stores within their community.

4.2. Determining Base-Case Community Energy-Use, Water-Use and Transportation Use

An energy-use baseline, water-use baseline and community transportation use is determined for the *Multifamiliar Miguel Aleman*.

4.2.1. Base-Case Building Energy-Use.

The base-case building energy-use was assumed for a single building in the complex, in order to simplify the calculation. The multi-family apartments' area (from the second to the thirteenth floor) and the retail area (the first floor) were split in order to calculate the base-case building energy-use.

4.2.1.1. Base-Case Energy-Use for Multi-Family Apartments.

The process used to simulate and analyze the base-case building energy-use for the apartments of the *Multifamiliar Miguel Aleman* is the following:

1) The apartment section of the building was modeled with eQuest in Figure 22. Before going further in eQuest, a floorplan of the building was created with AutoCAD and imported as *.dxf* to eQuest in Figure 23. Each floorplan was divided into two zones and required the following data input: building's type and geometry, and apartment's

type and geometry; construction details; interior space characteristics; and mechanical systems as seen in Figure 24.[57]

2) The real data from electricity bills from six single-family houses in Mexico City were compared to the assumed energy consumption from the apartment section.

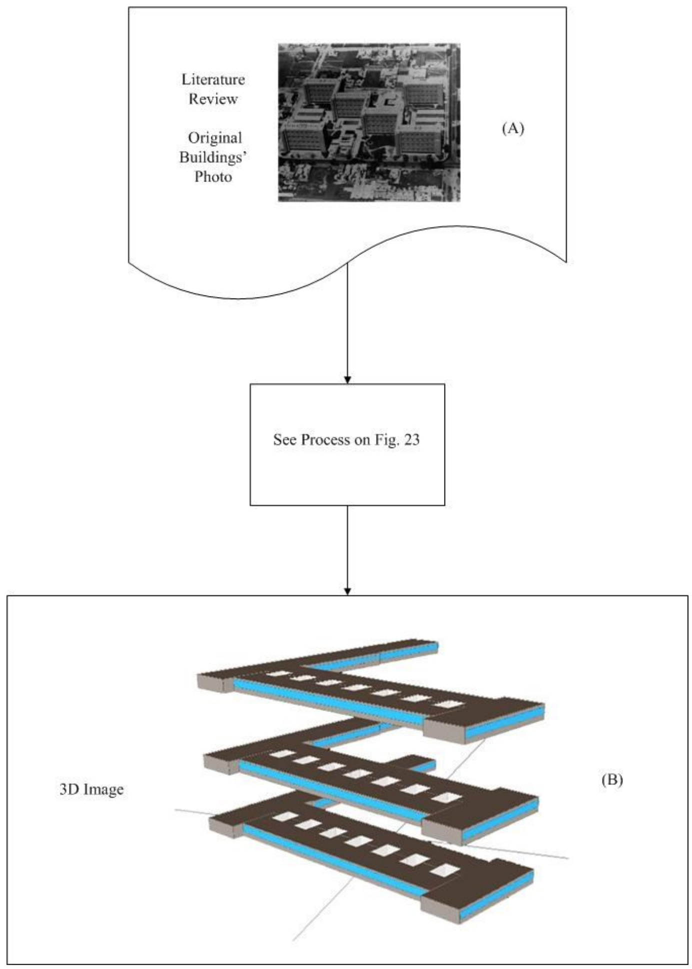

Figure 22. General Simulation Block for Apartments.
(A) Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.17), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission. (B) 3D Image Created with eQuest.

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[57] The mechanical system was simulated in the software, although housing in Mexico City does not require air-conditioning system due to its climate.

3) The simulation results were processed using Excel spreadsheets. The graphs generated showed the comparison between the interior zone temperature and the outside dry-bulb temperature, and the electricity energy consumed per year.

The base-case building energy-use was assumed for a single building in the complex, in order to simplify the calculation. The largest building of the complex has an "L" shape and is placed on the diagonal across the site in Figure 25.

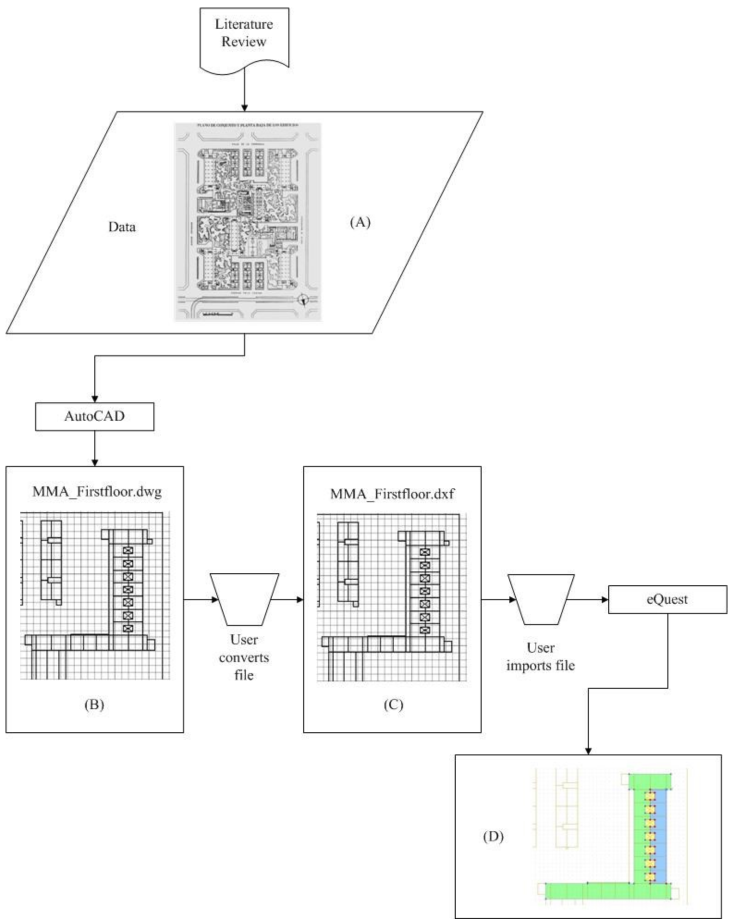


Figure 23. Simulation Process from Literature Review.
(A) Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.243), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with permission. (B) Image of the Floorplan from the MMA_Firstfloor.dwg. (C) Image of the floorplan from the MMA_Firstfloor.dxf. (D) Image of the Floorplan Produced with eQuest.

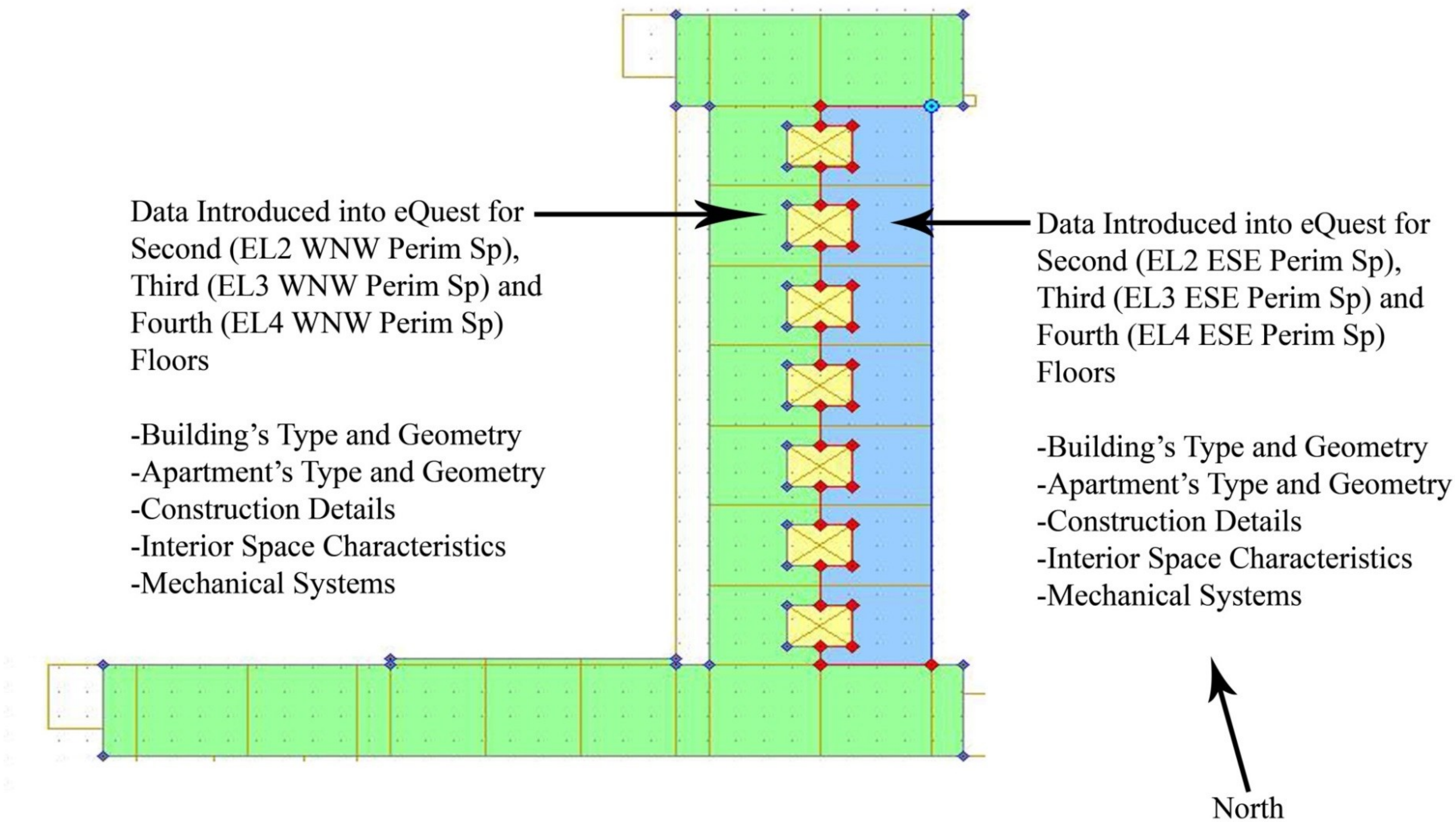
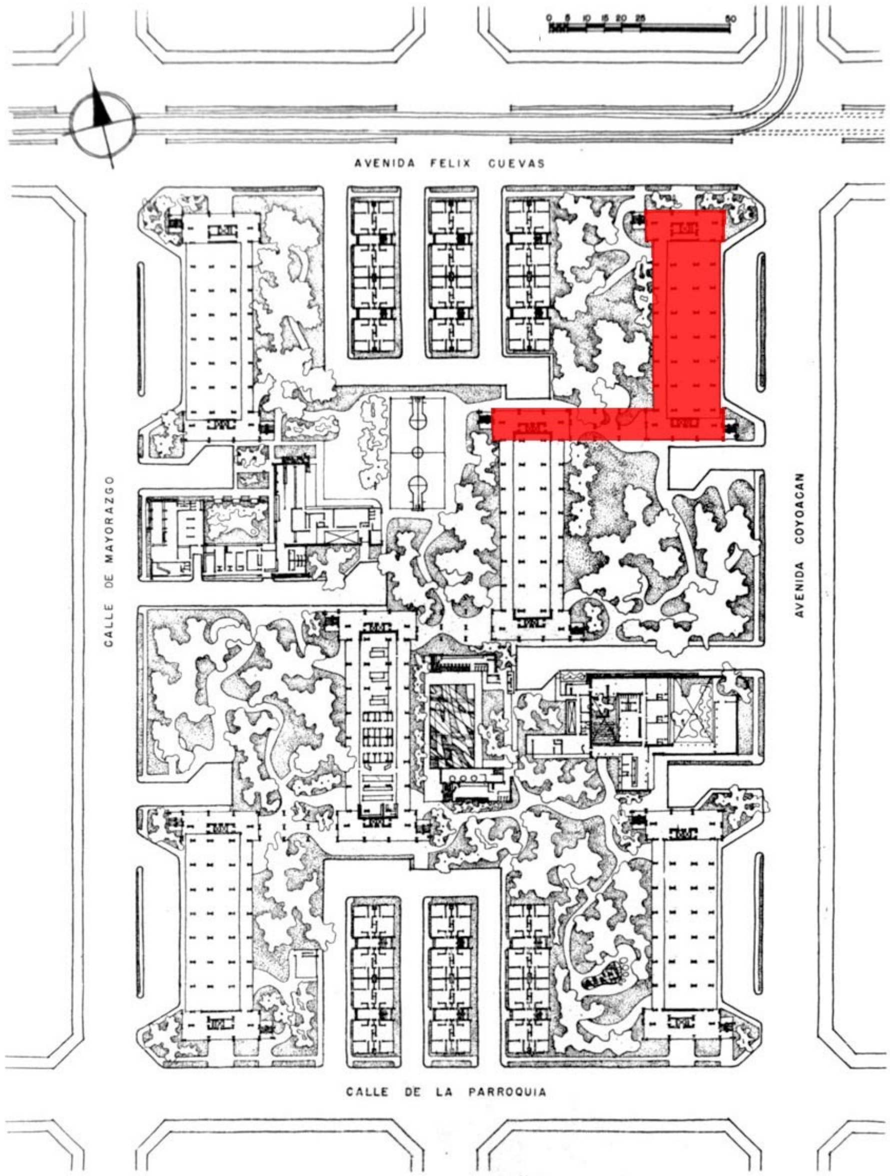


Figure 24. Two Zones per Floor Simulated for the Apartment Section of the Building.



PLANO DE CONJUNTO Y PLANTA BAJA DE LOS EDIFICIOS

Figure 25. Buildings' Ground Floorplan of the Centro Urbano Presidente Aleman (or Multifamiliar Miguel Aleman) in 1949.
The Original Image was Rotated 180° in Order to Have the North Orientation Pointing Upwards for Architectural Standards. Also, the Building Selected for the Simulation was Highlighted in Red Color from the Original Image. Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.243), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

The building selected to be modeled was the first "L" shape building in Figure 26. This selected building (in Figure 27, Figure 28 and Figure 29) is located in the corner of *Felix Cuevas Avenue* and *Coyoacan Avenue*[58]. This building faces East-Southeast and West-Northwest. The multi-family apartment area (the second through thirteenth floors) and the retail's area (the first floor) are split in order to calculate the base-case building energy-use.

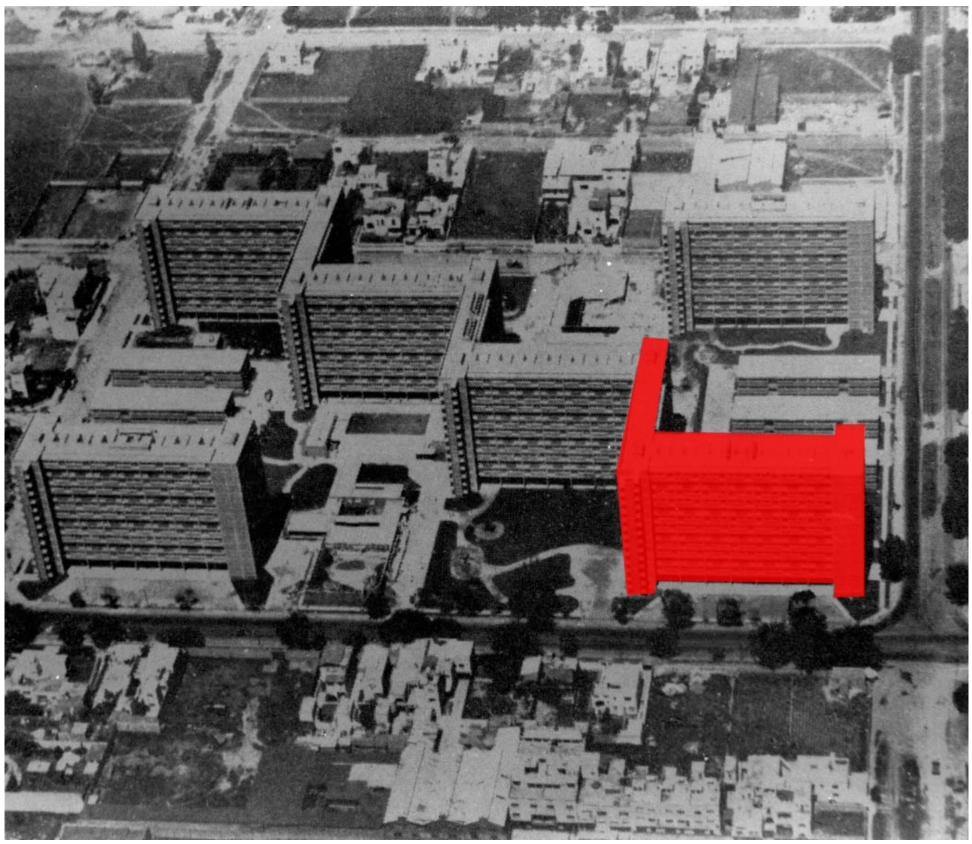


Figure 26. Aerial View of the Centro Urbano Presidente Aleman (or Multifamiliar Miguel Aleman) in 1949.
The Building Selected for the Simulation was Highlighted in Red Color from the Original Image. Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952)*. (p.17), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

[58] Translated from *Avenida Felix Cuevas* and *Avenida Coyoacan*.

Figure 27. Building Selected for the Energy Simulation from the *Multifamiliar Miguel Aleman* at the Corner of *Felix Cuevas Avenue* and *Coyoacan Avenue* (East-SouthEast Façade) (Photo by Jose Luis Bermudez Alcocer).

Figure 28. Building Selected for the Energy Simulation from the *Multifamiliar Miguel Aleman* at the Corner of *Felix Cuevas Avenue* and *Coyoacan Avenue* at Street Level (South-SouthWest Façade) (Photo by Jose Luis Bermudez Alcocer).

Figure 29. Building Selected for the Energy Simulation from the *Multifamiliar Miguel Aleman* at the Corner of *Felix Cuevas Avenue* and *Coyoacan Avenue* (South-SouthWest Façade) (Photo by Jose Luis Bermudez Alcocer).

The apartment section of the selected building has complex characteristics to simulate. The first complex characteristic is the distribution of the apartment types. The building has four different types of apartments. Apartment types A and D have two floors and apartment type B and C have one floor. The third, sixth, ninth and twelfth floors in Figure 30 have the horizontal circulations, the access and the public spaces[59] of apartment types A and D, and the access of apartment types B and C. The second, fourth, fifth, seventh, eighth, tenth, eleventh and thirteenth floors in Figure 31 have the private spaces[60] of apartment types A and D.

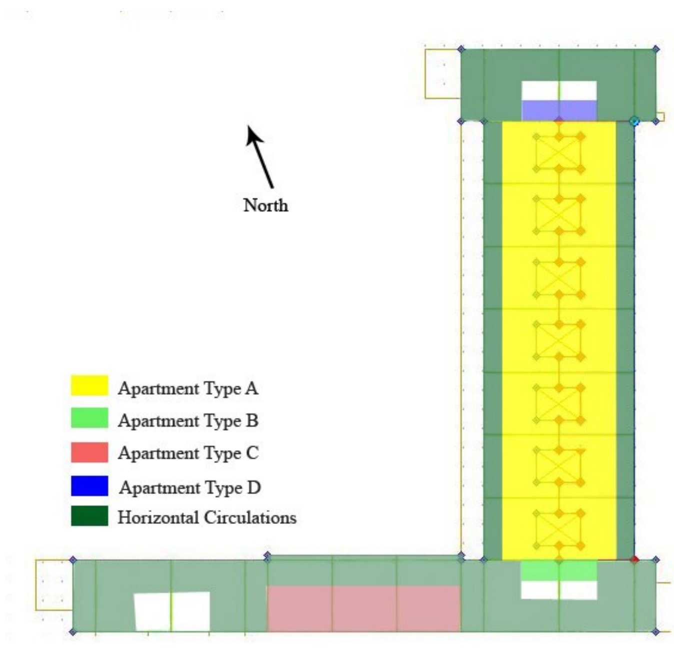


Figure 30. Third, Sixth, Ninth and Twelfth Floors with Access for Each Apartment.

Apartment types B and C have one floor, and are located in the third, sixth, ninth and twelfth floors. Due to the intricacy of the two-floor condition of apartment types A and D, the assumption was to simulate the building with one apartment type with one floor.

[59] The public spaces are the living room and the kitchen.
[60] The private spaces are bedrooms and bathrooms.

Apartment types A has the largest number of apartments in the community as shown in Table 28, and is selected as the base for the simulation. This inference caused the second complex characteristic.

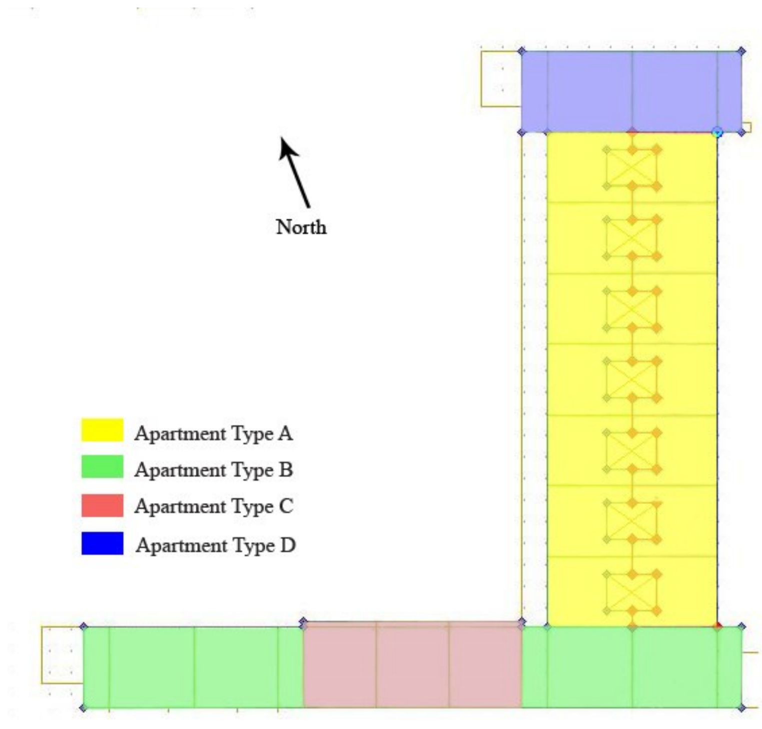


Figure 31. Second, Fourth, Fifth, Seventh, Eighth, Tenth, Eleventh and Thirteenth Floors with Private Spaces for Each Apartment.

Table 28. *Multifamiliar Miguel Aleman*'s Apartment Types.

	Apartment Area (m^2)	Apartment Area (ft^2)	Number of Apartments	Total Area per Apartment Type (m^2)	Total Area per Apartment Type (ft^2)
Type A	70	750	672	47,040	504,000
Type B	64	689	160	10,240	110,240
Type C	65	700	32	2,080	22,400
Type D	83	893	72	5,976	64,296
Type E	48	506	144	6,912	72,864
		Total	1,080	72,248	773,800

The second complex characteristic is the window-to-wall ratio. Table 29 displays the window-to-wall ratio (WWR) for the apartment types of the selected building. Apartment types A, B, C and D have a WWR of 44, 47, 47 and 30 percent, respectively. Due to the "apartments with one-floor" assumption, the WWR per apartment will decrease as shown in Table 30 and the number of apartments for this building will increase. Apartment types A, B, C and D would have had a WWR of 54, 47, 47 and 47 percent, respectively. If all the apartment types are used to the simulation, the number would increase from 208 to 312. Nevertheless, the final premise is to keep it simple and simulate the building as follows:

1) Use apartment type A, because it has the largest number of apartments and this will impact the whole community,
2) Consider one-floor apartments, and
3) Divide the floor area by the apartment type A area and multiply this number by 12 floors to get the total number of apartments in the building:
    a. 15,102 ft^2/750 ft^2 = 20 apartments per floor X 12 floors = 240 apartments

Table 29. Window-to-Wall Ratio for the Apartment Types of the Selected Building (Existing Building).

Apartment Type	Floor	Wall			Window			Window-to-Wall Ratio
		Length	Width	Total	Length	Width	Total	
		ft	ft	ft²	ft	ft	ft²	
A	First	11	9	102	8	3	24	
	Second	23	9	202	23	5	109	
		Total Wall Area		304	Total Window Area		132	44
B	First	71	9	635	75	4	297	47
C	First	71	9	635	75	4	297	47
D	First	11	9	102	4	3	11	
	Second	12	9	106	12	4	50	
		Total Wall Area		208	Total Window Area		61	30

Table 30. Window-to-Wall Ratio for Apartment Types of the Selected Building (for the Simulation).

Apartment Type	Floor	Wall			Window			Window-to-Wall Ratio
		Length	Width	Total	Length	Width	Total	
		ft	ft	ft^2	ft	ft	ft^2	
A	First	23	9	202	23	5	109	54
B	First	71	9	635	75	4	297	47
C	First	71	9	635	75	4	297	47
D	First	12	9	106	12	4	50	47

4.2.1.1.1. Apartment Section Modeling.

First, Table 28 shows that the apartment type A was selected as the basis of the analysis, because it has the largest number of apartments in the complex. This two-story dwelling was considered as one-floor in order to simplify the building's simulation.

It is critical to point out the existence of the weather data file for Mexico City before going into the simulation. MEXICO91, a weather data file from the DOE-2 website (Hirsch, 2006), was used to model the building from the *Multifamilar Miguel Aleman* community.

The massing of the building was assumed as three floors or shells. These three shells were created in order to shorten the building's replication. The floorplans were created through the AutoCAD software. Only one floorplan was created during the process due to the copying capabilities of the software. All the characteristics of the shells are the same, with the exception of the floor and roof materials. The second floor was created and exported to the software as a *.dxf* file. This floor was copied twice, and each one was placed in its proper position.

4.2.1.1.2. General Shell and Building Footprint Data Introduced for the Residential Section.

Table 31 displays the parameters used for the general shell information and the building footprint. This table has the data of the position of the three shells of the building's apartment section. Figure 32 shows the three shells created to simulate the whole-building geometry. The first shell was located at the Cartesian coordinates x equals to 0 ft., y equals to 0 ft., and z equals to 11.8 ft. that is the second floor on top of the retail area into the first floor. The second shell was located at x equals to 0 ft., y equals to 0 ft., and z equals to 56.1 ft. and is the third floor in the middle of the building. This floor has a multiplier equal to 10, which means it simulates 10 floors of the building. The third floor was located at x equals to 0 ft., y equals to 0 ft., and z equals to 109.2 ft. is the top floor. Each shell will have 15,103 ft² but the third one has 151,030 ft². The area of the apartment section was then 181,225 ft².

Table 31. General Shell and Building Footprint Data Introduced for the Residential Section.

Item	Name of Parameter		Base-Case Input	References	Comments
Shell		Specify Exact Site Coordinates (Second Floor)	0 ft, 0 ft, 11.8 ft		Second Floor
		Specify Exact Site Coordinates (Third Floor)	0 ft, 0 ft, 56.1 ft		Third Floor
		Specify Exact Site Coordinates (Fourth Floor)	0 ft, 0 ft, 109.2 ft		Fourth Floor
	Area and Floors	Building Area	15,103 ft²	Approximated from the floorplan (Pani, 1952)	Per Floor
		Number of Floors	12	Assumed from picture taken by Jose Luis Bermudez Alcocer	See Fig.27 and Fig.29
		Below Grade	0		
		Shell Multiplier (Second Floor)	1	Assumption	Second Floor
		Shell Multiplier (Third Floor)	10	Assumption	Third Floor
		Shell Multiplier (Fourth Floor)	1	Assumption	Fourth Floor
Building Footprint	Zone Names		EL2 WNW Perim Sp (G.WNW1)		Second Floor
			EL2 ESE Perim Sp (G.ESE2)		
			EL3 WNW Perim Sp (G.WNW1)		Third Floor
			EL3 ESE Perim Sp (G.ESE2)		
			EL4 WNW Perim Sp (G.WNW1)		Fourth Floor
			EL4 ESE Perim Sp (G.ESE2)		
	Zone characteristics		Conditioned		
	Building Orientation		13°	Approximated from the floorplan (Pani, 1952)	
	Height Floor to Floor		8.85 ft	Aproximated from picture taken by Jose Luis Bermudez Alcocer	See Fig.38
	Height Floor to Ceiling		7.87 ft	Aproximated from picture taken by Jose Luis Bermudez Alcocer	See Fig.37

Table 32 shows the following calculations used during the analysis process: the number of apartments, the number of people per floor, the number of apartments per building, the number of people per building, the number of buildings in the complex, and the number of people in the complex. The first column shows the hand calculations and the second column is the results from these calculations.[61]

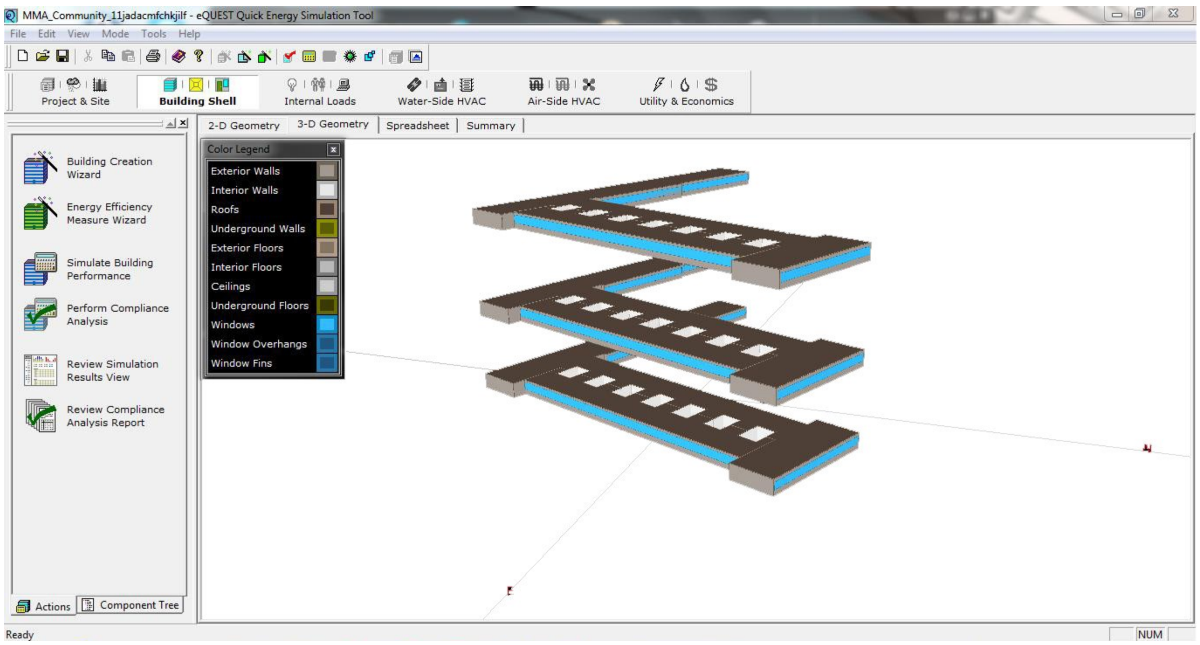


Figure 32. Shells Simulated in eQuest for the Multi-Family Section.

Table 32. Calculations for the *Multifamiliar Miguel Aleman*.

15,102 ft² of the floor area / 750 ft² of the apartment area	20 apartments
20 apartments per floor X 4 people per apartment	80 people
20 apartments per floor X 12 floors	240 apartments
240 apartments X 4 people per apartment	960 people per building
1,080 original apartments / 240 apartments in the complex	4.5 buildings
960 people per building X 4.5 buildings	4,320 people in the complex

[61] 750 ft² was the area of the apartment assumed for the calculation, because it has the largest amount of apartments in the complex. The analysis of this apartment will therefore impact in the whole complex.

The building footprint information is shown in Table 31. The second floor (or shell) was drafted using the AutoCAD software. Figure 33 shows that the building has lightwells. Although the kitchens in Figure 34 and the bathrooms[62] in Figure 35 use these lightwells, the lightwells do not bring light into the spaces; they only provide ventilation.

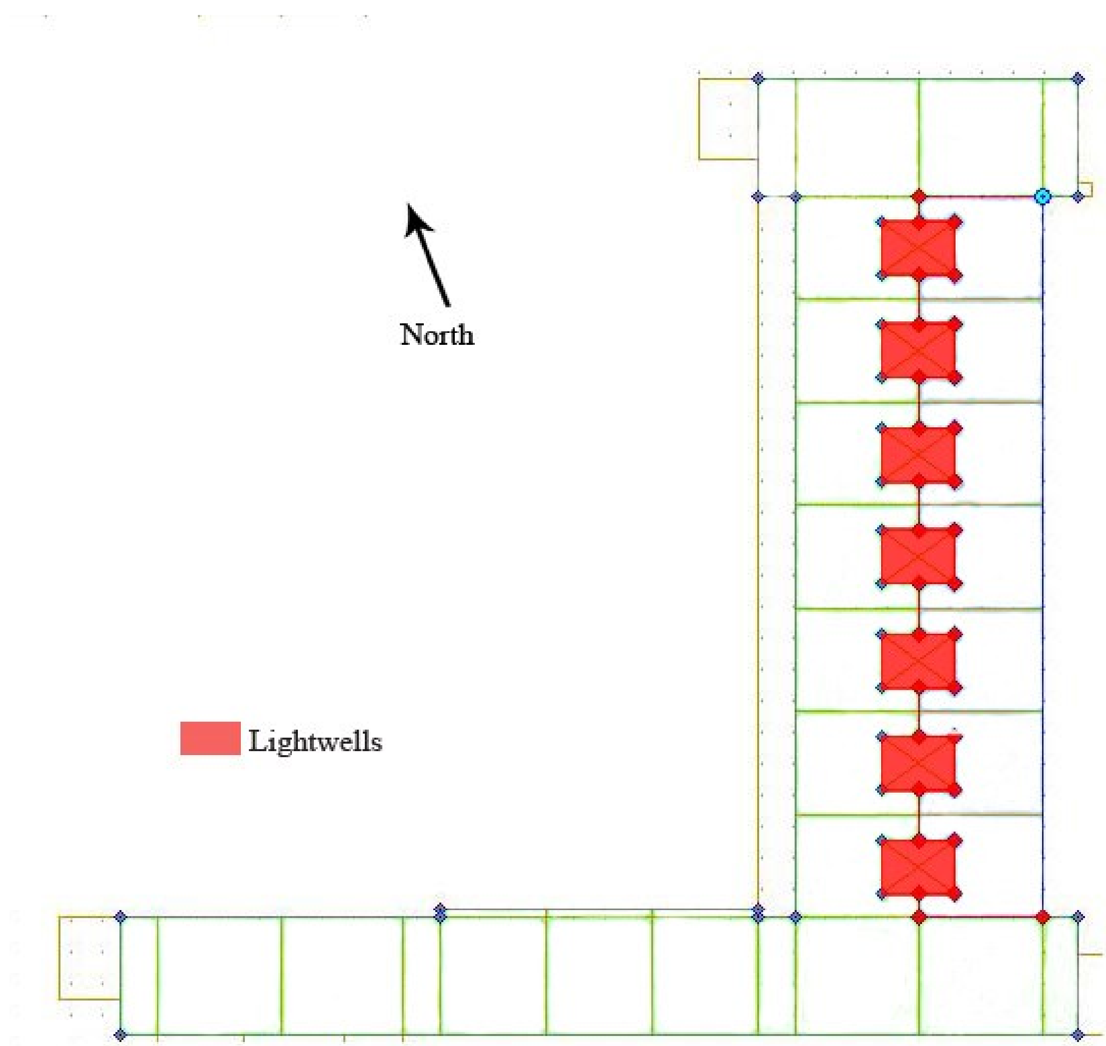


Figure 33. Floorplan Modeling with Lightwells.

[62] The small bedroom also ventilates through the lightwells.

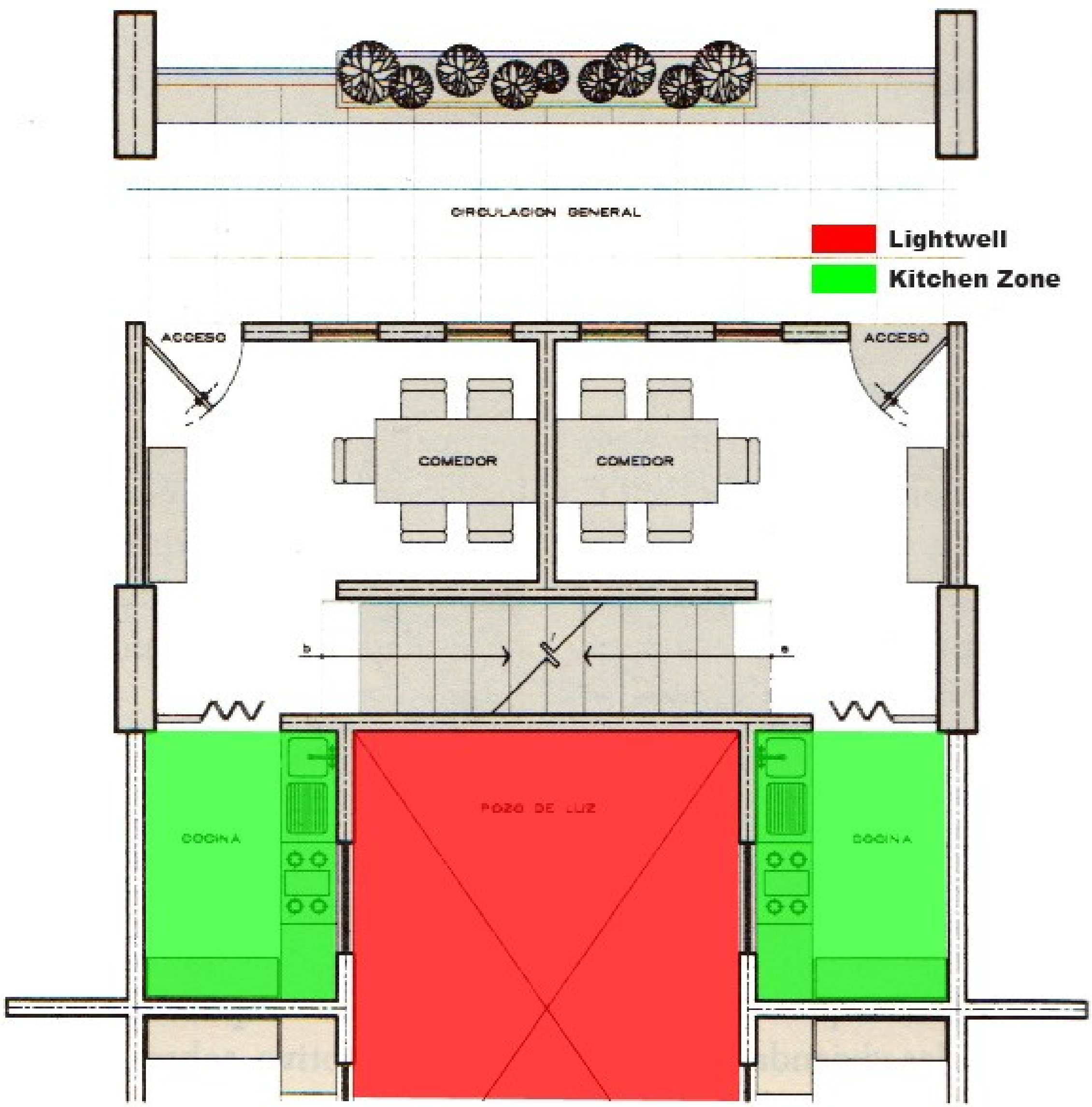


Figure 34. Apartment Type A Access Floorplan with Lightwells (De Anda, 1952). The Natural Ventilation Achieved in the Kitchens and the Bathrooms Was Pointed out by Highlighting Them in Green Color and Red Color over the Original Image. Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.254), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

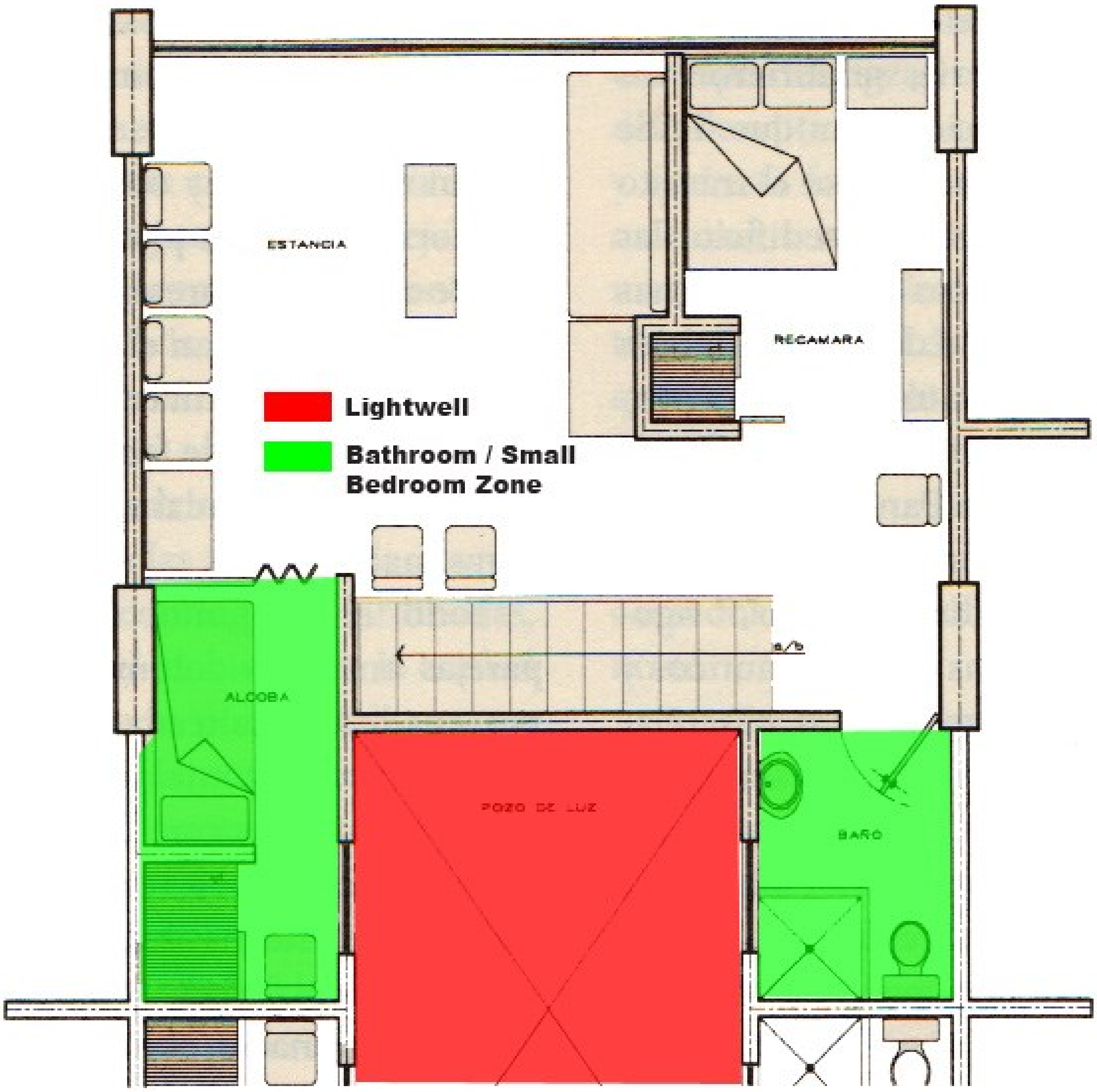


Figure 35. Apartment Type A Lower (or Upper) Floorplan with Lightwells. The Natural Ventilation Achieved in the Kitchens and the Bathrooms Was Pointed out by Highlighting Them in Green Color and Red Color over the Original Image. Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.254), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

The second floor shell is divided into two zones, EL2 WNW Perim Sp (G.WNW1) and EL2 ESE Perim Sp (G.ESE2), as shown in Figure 36 in order to simulate the lightwells of the building.[63] The information from the second shell was copied to create the third and fourth shells. The zones for the third shell were called EL3 WNW Perim Sp (G.WNW1) and EL3 ESE Perim Sp (G.ESE2); the zones of the fourth shell are called EL4 WNW Perim Sp (G.WNW1) and EL4 ESE Perim Sp (G.ESE2). Finally, the following information was input: the zone was considered as a conditioned zone; the building orientation was 13°. Figure 37 shows the height floor-to-floor (8.85 ft.); and Figure 38 shows the height floor-to-ceiling (7.87 ft.).[64]

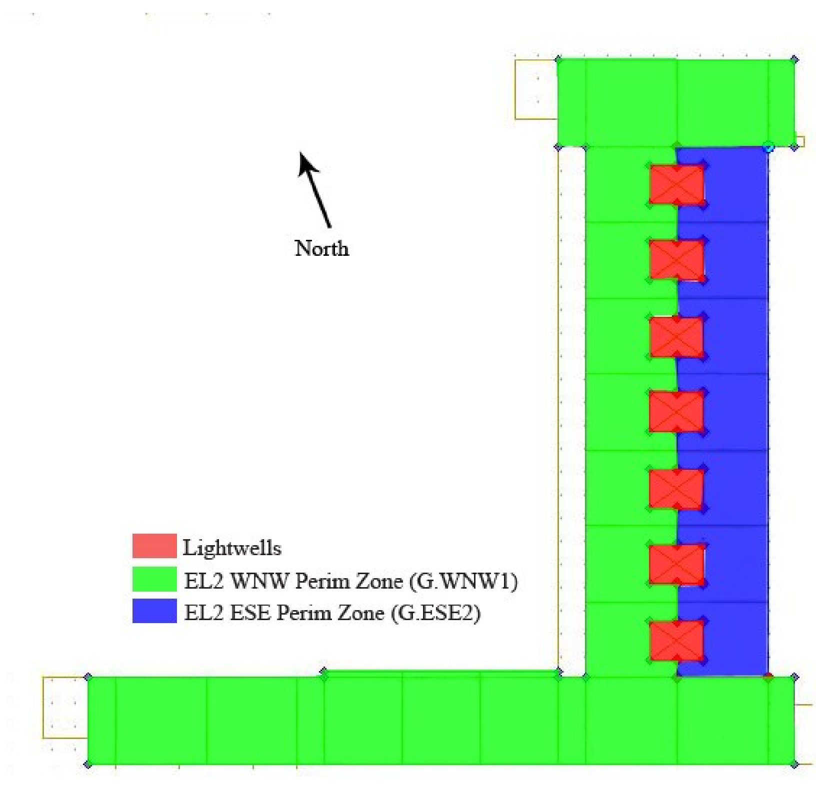


Figure 36. Floorplan with Lightwells and Zones.

[63] No windows were simulated on the walls of the lightwells. This goes further the limits of the study. Daylighting and CFD analysis for multiple floors are suggested for future research.
[64] The interior spaces do not have ceilings.

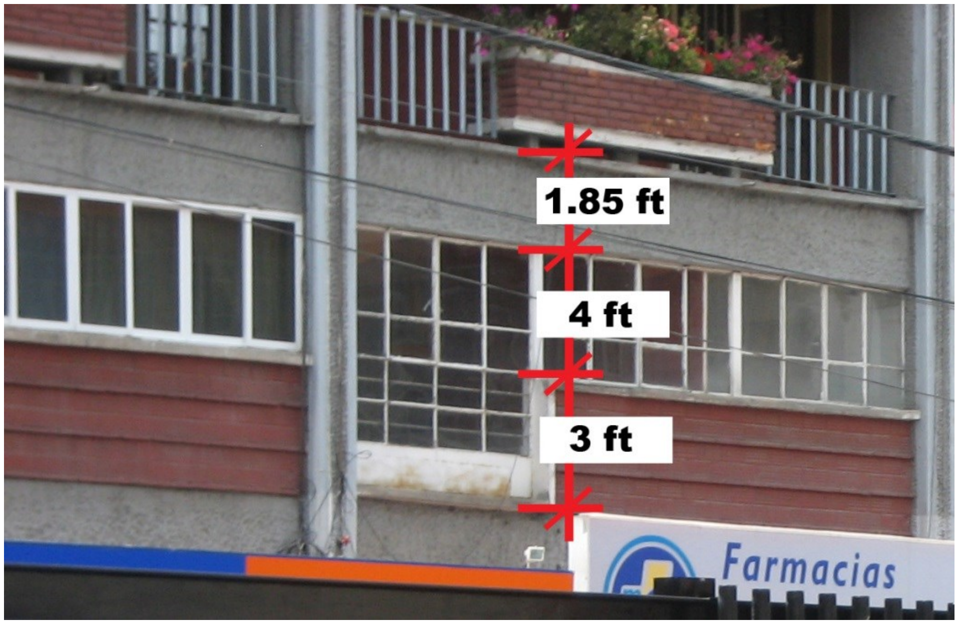


Figure 37. Detail to Calculate Height Floor-to-Floor on the Façade for the Apartments. (Photo by Jose Luis Bermudez Alcocer).

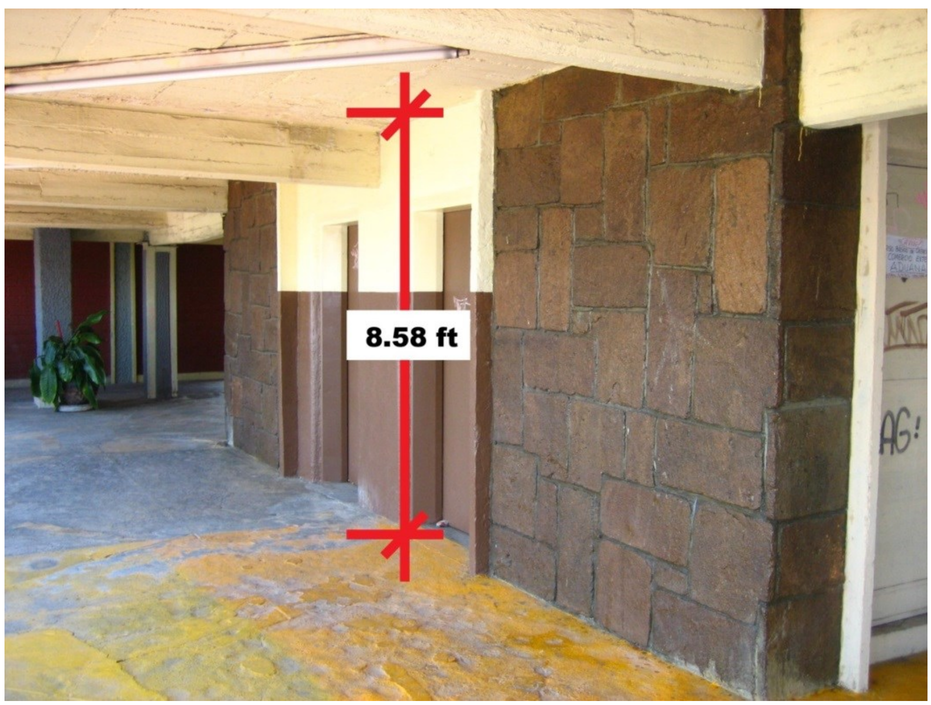


Figure 38. Detail to Calculate Height Floor-to-Ceiling for the Apartments (Photo by Jose Luis Bermudez Alcocer).

Table 33, Table 34 and Table 35 have the data of the building envelope construction for the second floor shell, the third floor shell, and the fourth floor shell, respectively. The roof, walls and floor layers are shown here. The second floor shell is shown in Table 33. Roof_1 has an 8 inches (in.) concrete slab to simulate the roof for this shell.[65] Wall_1 has an 8 in. brick wall to simulate vertical exterior walls.[66] As a reminder, the second floor shell was not placed on the site, but it is placed 11.8 ft. above the site, which was considered to expose the building to more realistic ambient conditions. In the eQuest program, if the floor of the zone was assigned as a floor, the software could have assumed that the zone was placed on the ground. In order to avoid this issue, the floor was created as an exterior wall. Thus, Wall_2 has an 8 in. concrete slab to simulate the floor for this shell,[67] and the overall R-value is given 100 h-ft²-°F/BTU in order to insulate the slab.

The third floor shell is displayed in Table 34. Roof_1 has an 8 in. concrete slab to simulate the roof for this floor.[68] Wall_1 has an 8 in. brick wall to simulate vertical exterior walls.[69] The floor of this shell has an 8 in. concrete slab, which is adiabatic and is placed over a conditioned space. The slab does not have insulation.

The fourth floor shell is exhibited in Table 35. Roof_2 has the following layers from outside to inside: linoleum tile, 4 in. brick, 1 in. board insulation, 1 in. roof gravel, and 8 in. concrete slab to simulate the roof for this floor.[70] Wall_1 has an 8 in. brick wall to simulate vertical exterior walls.[71] The floor has an 8 in. concrete slab, is adiabatic and is placed over conditioned space. The slab does not have insulation.

The weighting factors are related to building construction (Hirsch and Associates, 2009). The software recognizes two types of constructions: delayed and quick.[72] The earlier

[65] The overall R-Value is 3.991 h-ft²-°F/BTU.
[66] The overall R-Value is 3.798 h-ft²-°F/BTU.
[67] Another layer of ¾ of concrete was added to increase the width of the slab.
[68] The overall R-Value is 3.991 h-ft²-°F/BTU.
[69] The overall R-Value is 3.798 h-ft²-°F/BTU.
[70] The overall R-Value is 9.007 h-ft²-°F/BTU.
[71] The overall R-Value is 3.798 h-ft²-°F/BTU.
[72] Constructions are assignable components in eQuest and define the heat transfer properties from surfaces such as walls, roofs and floors (Hirsch & Associates, 2009).

Table 33. Shell Data Introduced for the Second Floor of the Residential Section.

Item	Name of Parameter			Base-Case Input	Reference	Comments
Building Envelope Constructions	Roof Surfaces	Roof_1	Surface Type	Roof		
			Layer	Concrete 80 lbs.	Assumed from existing data (De Anda, 2008)	
			Overall R-Value	3.991 h-ft²-°F/BTU		
	Above Grade Walls	Wall_1	Surface Type	Vertical Exterior Wall		
			Layer	Surface Air Film		
			Layer	Brick	Assumed from existing data (De Anda, 2008)	
			Layer	Surface Air Film		
			Overall R-Value	3.798 h-ft²-°F/BTU		
Building Envelope Constructions	Ground Floor	Wall_2	Exposure	Exposed to Ambient		
			Layer	Surface Air Film	Assumed from existing data (De Anda, 2008)	
			Layer	Brick		
			Layer	Brick	Assumed from existing data (De Anda, 2008)	
			Insulation R-Value	94.964 h-ft²-°F/BTU		
			Overall R-Value	100 h-ft²-°F/BTU		

Table 34. Shell Data Introduced for the Third Floor of the Residential Section.

Item	Name of Parameter			Base-Case Input	References	Comments
Building Envelope Constructions	Roof Surfaces	Roof_1	Surface Type	Roof		
			Layer	Concrete 80 lbs.	Assumed from existing data (De Anda, 2008)	
			Overall R-Value	3.991 h-ft²-°F/BTU		
	Above Grade Walls	Wall_1	Surface Type	Vertical Exterior Wall		
			Layer	Surface Air Film		
			Layer	Brick	Assumed from existing data (De Anda, 2008)	
			Layer	Surface Air Film		
			Overall R-Value	3.798 h-ft²-°F/BTU		
	Ground Floor	Exposure		Over Conditioned Space (Adiabatic)		
		Construction		8 in. Concrete	Assumed from existing data (De Anda, 2008)	

Table 35. Shell Data Introduced for the Fourth Floor of the Residential Section.

Item	Name of Parameter			Base-Case Input	References	Comments
Building Envelope Constructions	Roof Surfaces	Roof_2	Surface Type	Roof		
			Layer	Surface Air Film		
			Layer	Linoleum Tile	eQuest Default from DOE-2 Reference Manual Version 2.1 Part 2 (LBL/LASL, 1980b)	
			Layer	Brick		
			Layer	Board Insulation		
			Layer	Roof Gravel		
			Layer	Concrete 80 lbs.	Assumed from existing data (De Anda, 2008)	
			Layer	Surface Air Film		
			Overall R-Value	9.077 h-ft²-°F/BTU		
	Above Grade Walls	Wall_1	Surface Type	Vertical Exterior Wall		
			Layer	Surface Air Film		
			Layer	Brick	Assumed from existing data (De Anda, 2008)	
			Layer	Surface Air Film		
			Overall R-Value	3.798 h-ft²-°F/BTU		
	Ground Floor	Exposure		Over Conditioned Space (Adiabatic)		
		Construction		8 in. Concrete	Assumed from existing data (De Anda, 2008)	

uses transfer functions to account for the time delay associated with the thermal mass of envelope constructions.[73] The latter is specified by using only U-factors.[74] The model for the apartment section uses the delayed construction mode in exterior walls, roof and floor.[75] In the model, the weighting factor was introduced with a floor weight equal to zero. This means that the software is allowed to calculate the custom weighting factors by itself. Each floor was considered as a zone with no interior walls or ceilings. The zone only has a floor, walls and a roof. There are no exterior doors in these replicated zones.

4.2.1.1.3. Window Data Introduced for the Residential Section.

The information for the building exterior windows is shown in Table 36, Figure 39, Figure 40, Figure 41 and Figure 42. The different windows for each wall were computer-generated as a single equivalent window in order to simplify the model. All the windows in the complex are operable with single pane clear glass and aluminum frame without break. Unfortunately, there was limited on-site information about u-value, shading coefficient, and visible transmittance in Mexico. Therefore, this information was obtained from the Center for Sustainable Building Research, the Alliance to Save Energy, and the Lawrence Berkeley National Laboratory (CSBR/ASE/LBNL, 2012).[76]

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[73] Hirsch & Associates (2009) suggest seeing this topic in the 1993 ASHRAE Fundamentals Handbook, p.26.3.
[74] Hirsch & Associates (2009) say that the quick construction mode should be used only in steady-state heat transfer calculations (i.e., $UA\Delta T$).
[75] There were not interior floors in any shell considered in the model. However, the walls that split each zone in each shell are taken by eQuest as "interior walls", and recognized as quick constructions. These "interior walls" are assumed to not alter the energy consumption calculation.
[76] U-Value = 1.11 BTU/h-ft² °F, shading coefficient = 0.86, and visible transmittance = 0.9.

Table 36. Data Input for Windows for Second, Third and Fourth Floors of the Residential Section.

Item	Name of Parameter			Base-Case Input	References	Comments
Window Type			Number of Panes	Single	Assumed from picture taken by Jose Luis Bermudez Alcocer	See Fig.40, Fig.41 and Fig.42
			Frame Type	Aluminum w/o Break, Operable		
			Frame Wd. (in.)	1.3 in.		
			Glass Tint	Clear Glass		
			U-Value	1.11 Btu/h-ft² °F	CSBR/ASE/LBNL, 2012	
			Shading Coefficient	0.86		
			Visible Transmittance	0.90		
Window Dimensions, Positions and Quantities	1.- Glass	Width (ft)		4.25	Approximated from the floorplan (Pani, 1952); Assumed from picture taken by Jose Luis Bermudez Alcocer	See Fig.40
		Window ht (ft)		70		
		Sill		0		
		% Windows (floor to floor,	East	0		
			West	0		
			South	47.2		
			North	0		
	2.- Glass	Width (ft)		4.75	Approximated from the floorplan (Pani, 1952); Assumed from picture taken by Jose Luis Bermudez Alcocer	See Fig.41
		Window ht (ft)		160		
		Sill		0		
		% Windows (floor to floor,	East	53.0		
			West	53.0		
			South	0		
			North	0		
	3.- Glass	Width (ft)		3.96	Approximated from the floorplan (Pani, 1952); Assumed from picture taken by Jose Luis Bermudez Alcocer	See Fig.42
		Window ht (ft)		150		
		Sill		0		
		% Windows (floor to floor,	East	0		
			West	0		
			South	44.0		
			North	0		

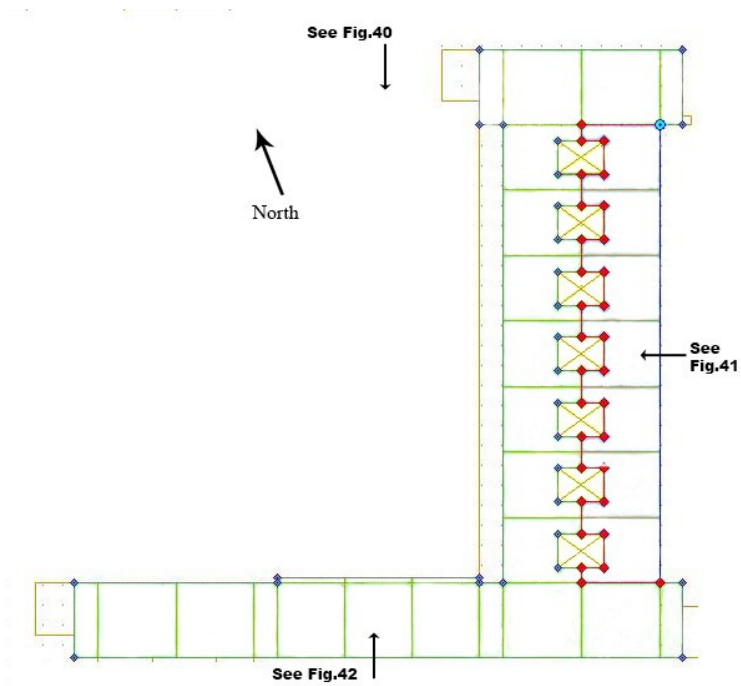


Figure 39. Location of the Photos on the Floorplan.

Figure 40. Single-Glass Window on North-NorthEast Façade. (Photo by Jose Luis Bermudez Alcocer).

Figure 41. Single-Glass Window on East-SouthEast Façade. (Photo by Jose Luis Bermudez Alcocer).

Figure 42. Single-Glass Window on South-SouthWest Façade. (Photo by Jose Luis Bermudez Alcocer).

4.2.1.1.4. Daylighting Controls Data Introduced for the Residential Section.

Table 37 contains the information for daylighting. For this study the daylighting controls were deactivated for the base-case to allow for the calculation of the energy consumption of the base-case model without any savings due to daylighting (Hirsch and Associates, 2009).

Table 37. Data Input for Daylighting Controls for Second, Third and Fourth Floors of the Residential Section.

Wizard Screens	Name of Parameter		Input	Reference	Comments
Daylighting	Daylighting	Daylighting Controls	No		
		Daylit	Side Lighting		
		Daylit Area Method	CA Title-24 2008	eQuest Default	
		Area	1,441 Sq.Ft. (12%) of Top Floor is Daylightable	Calculated by eQuest	
		Design Light Level	50 fc	ASHRAE, 2010a	
		Lighting Control Method	Dimming: 30% Light (30% PWR)	eQuest Default	

The daylighting sensors were placed as follows:

1) The daylighting controls were rotated in order to face the windows. Figure 43 presents the origin point (where X equals to 0, Y equals to 0 and Z equals to 0) and the daylighting controls for the zone WNW Perimeter Space (G.WNW1). Figure 44 shows the origin point (where X equals to 0, Y equals to 0 and Z equals to 0) and the daylighting control for the zone ESE Perimeter Space (G.ESE2).
2) Table 38 shows the daylighting control location in the zones. The sensors 1 and 2 from the WNW Perim Zone were located targeting south-southwest and north-northeast, respectively.

Table 38. Daylighting Control Location per Zone for the Apartments.

Zone	Daylighting Control	Azimuth	X	Y	Z
EL2 WNW Perimeter Space (G.WNW1)	System 1	180	98.6	15.7	2.5
	System 2	270	200	-40.0	2.5
ELE2 ESE Perimeter Space (G.ESE2)	System 1	180	72.4	7.5	2.5
EL3 WNW Perimeter Space (G.WNW1)	System 1	180	98.6	15.7	2.5
	System 2	270	200	-40.0	2.5
ELE3 ESE Perimeter Space (G.ESE2)	System 1	180	72.4	7.5	2.5
EL4 WNW Perimeter Space (G.WNW1)	System 1	180	98.6	15.7	2.5
	System 2	270	200	-40.0	2.5
ELE4 ESE Perimeter Space (G.ESE2)	System 1	180	72.4	7.5	2.5

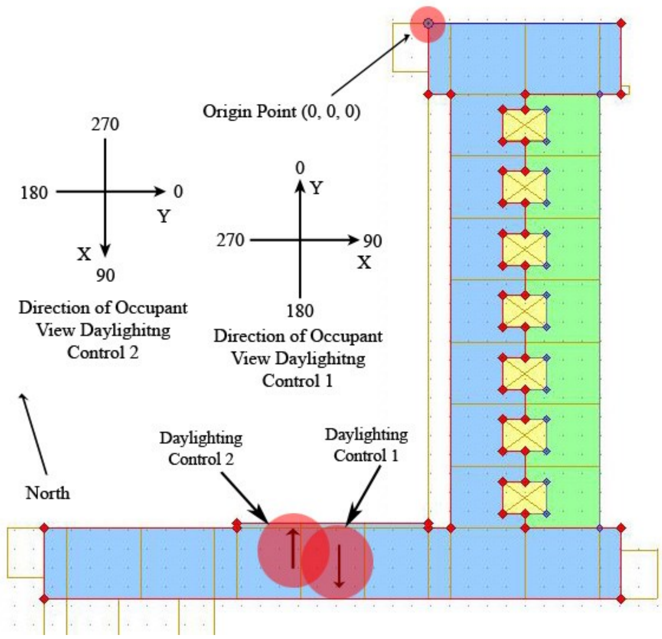


Figure 43. Daylighting Controls into the Zone WNW Perimeter Space of the Apartments (G.WNW1).

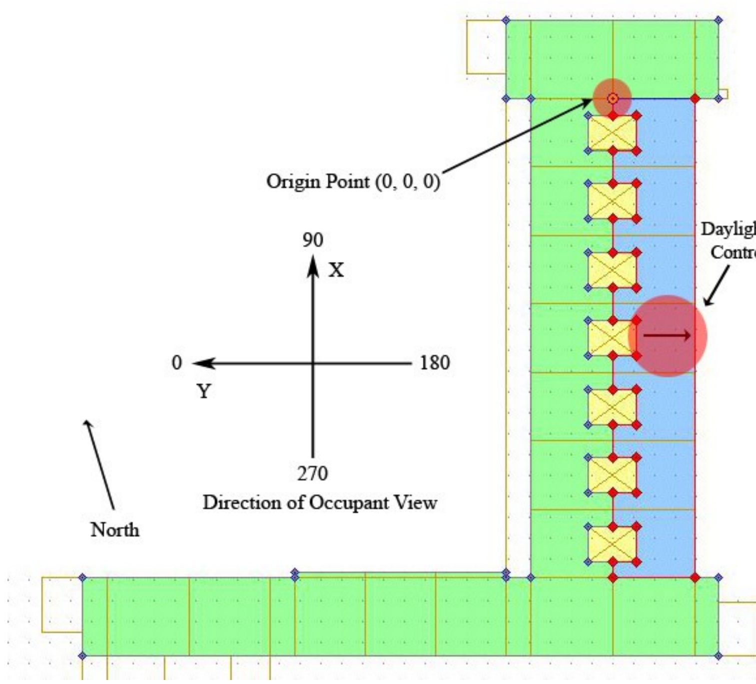


Figure 44. Daylighting Controls into the Zone ESE Perimeter Space of the Apartments (G.ESE2).

4.2.1.1.5. Lighting, Appliances, Occupancy and Infiltration Data Introduced for the Residential Section.

The parameters used for the lighting, appliances, occupancy and infiltration data were selected to obtain the building energy base-case. The previous study by Maqueda-Zamora and Sanchez-Viveros (2011) covered a larger number of unidentified dwellings in Mexico's central area where Mexico City is located. The study by Quadri-De la Torre (2008) was also consulted in order to create the energy-use consumption profile for the multi-family apartments of the *Multifamiliar Miguel Aleman.*

Table 39 shows the simulation input values for the apartment type A of the *Multifamiliar Miguel Aleman*. The following traditional measures were used from Quadri-De la Torre (2008) for the analysis: a 60-Watt incandescent lighting bulb, a 250-Watt refrigerator, a 400-Watt TV, and a 400-Watt washing machine. Miscellaneous appliances were assumed to have a total of 50 Watts for this analysis.

Table 39. Simulation Input Values for the Existing Equipment in the Apartment Type A of the *Multifamiliar Miguel Aleman* (Information Taken from Quadri-De la Torre, 2008).

Apartment Type A (750 ft²)			
Traditional Measures	**Brand**	**Model**	**W**
Lighting Bulb	Phillips	Phillips Softone	60
Refrigerator	Mabe	Traditional	250
TV	Samsung	Traditional	400
Washing Machine	Easy	Traditional	400
Miscellaneous Appliances			50

The next step was to create a daily energy-use profile for the apartment. Figure 45 shows an average energy-use profile that was obtained from Maqueda-Zamora and Sanchez-

Viveros (2011).[77] This was used as the basis for the daily energy-use profile for the apartment of the *Multifamiliar Miguel Aleman.*

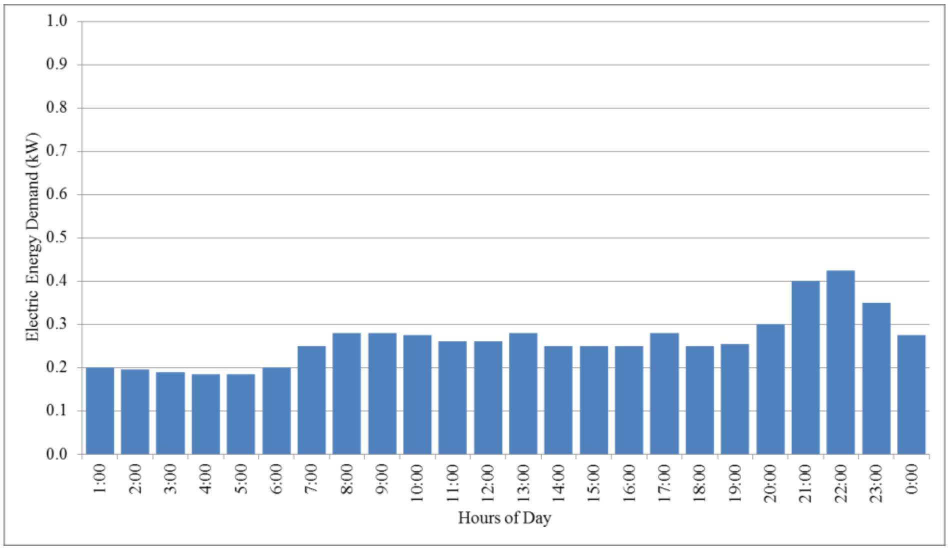


Figure 45. Average Energy-Use Profile for an Unidentified Group of Houses in Mexico's Central Area (with Data from Maqueda-Zamora and Sanchez-Viveros, 2011). The Background Was Changed from Pink to White, the Titles Were Translated from Spanish to English, and the Chart Was Changed from a Line to Columns. This Figure Was Required for this Study to Set the Base-Case Energy Profile for the Simulation. Adapted from "Curvas de Demanda de Energia Electrica en el Sector Domestico de Dos Regiones de Mexico," by M. R. Maqueda-Zamora and L. A. Sanchez-Viveros, 2011, *Boletin Instituto de Investigaciones Electricas,* p.175. Copyright 2011 by *Instituto de Investigaciones Electricas.* Adapted for Scholarly Purposes under Fair Use.

The third step was to mimic the existing electric energy demand from Figure 45 for the apartment of the *Multifamiliar Miguel Aleman.* Table 40 shows the values that were used to calculate the base-case number of incandescent lighting for the apartment. The first column is the name of the space, the second column is the area of the space and the third column is the lighting power for each space. The lighting power for each space was obtained from the *CONAVI*'s *2010 Housing Building Code* (2010a). The fourth column is the total

[77] The states refered in the article to Mexico's central area correspond to the following ones: Morelos, Guerrero, some cities of Mexico State and Puebla, and the Distrito Federal.

Watts for each space after multiplying the second and third columns. The fifth column is the wattage from the selected incandescent bulb and the sixth column is the number of incandescent lamps for each space after dividing the fourth by the fifth columns. (The number of lamps in Table 40 is rounded). Using this procedure, the number of lamps used for the calculations are the following: Main Bedroom with two lamps, Bedroom 2 with two lamps, Living Room A with six lamps, Living Room B with a lamp, bathroom with a lamp, kitchen with one lamp and dining room with three lamps. The total number of lamps was, therefore, 16 for the entire apartment.

Table 40. Base-Case Incandescent Lighting Calculation for Apartment Type A of the *Multifamiliar Miguel Aleman.*

	Area	Lighting Power	Total	Lamp	
	ft²	W/ft²	W	W/lamp	Final Lamps
Main Bedroom	91	1.2	110	60	2
Bedroom 2	73	1.2	88	60	2
Living Room A	285	1.3	371	60	6
Living Room B	49	1.3	63	60	1
1 Bathroom	57	1.3	74	60	1
Kitchen	57	1.3	74	60	1
Dining Room	137	1.3	179	60	3
				Total	16

Table 41 shows the hourly electricity of the 250-Watt refrigerator, a 400-Watt TV, a 400-Watt washing machine, and a total of 50 Watts from miscellaneous appliances. The first column is the hours of the day. The third to the fifth columns are the electric appliances. The energy for each appliance was obtained by multiplying the number of each appliance by the Watts of the appliance divided by 1,000 in order to get kiloWatts (kW).

Figure 46 shows the 24-hour profile for total electricity for all lighting and appliances. The total electricity use for lighting was:

(16 lamps X 60 W for each incandescent lamp) X (1kW/1,000W) = 0.960 kW

The total energy for each appliance per hour is seen in Table 41.

Table 41. Base-Case Hourly Electricity Use for the Appliances.

	Refrigerator	TV	Washing Machine	Miscellaneous Appliances
Time (hr)	0.25 (kW)	0.4 (kW)	0.4 (kW)	0.05 (kW)
1:00	0.25	0.00	0.00	0.00
2:00	0.25	0.00	0.00	0.00
3:00	0.25	0.00	0.00	0.00
4:00	0.25	0.00	0.00	0.00
5:00	0.25	0.00	0.00	0.00
6:00	0.25	0.00	0.00	0.00
7:00	0.25	0.00	0.00	0.05
8:00	0.25	0.00	0.00	0.05
9:00	0.25	0.00	0.00	0.05
10:00	0.25	0.00	0.40	0.05
11:00	0.25	0.00	0.00	0.05
12:00	0.25	0.00	0.00	0.05
13:00	0.25	0.00	0.00	0.05
14:00	0.25	0.40	0.00	0.05
15:00	0.25	0.40	0.00	0.05
16:00	0.25	0.40	0.00	0.05
17:00	0.25	0.00	0.00	0.05
18:00	0.25	0.40	0.00	0.05
19:00	0.25	0.00	0.00	0.05
20:00	0.25	0.40	0.00	0.05
21:00	0.25	0.40	0.00	0.05
22:00	0.25	0.40	0.00	0.05
23:00	0.25	0.00	0.00	0.00
0:00	0.25	0.00	0.00	0.00

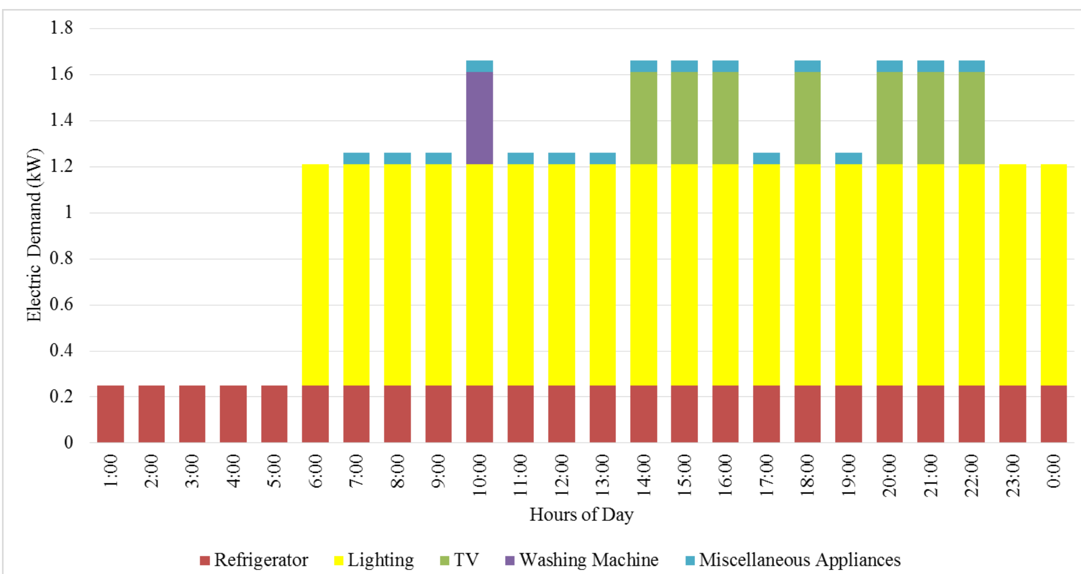


Figure 46. 24-Hour Profile for Total Electricity Consumption for Lighting and Appliances.

The electricity consumption shown in Figure 46 needed to be reduced. To accomplish this, the first step was to reduce the consumption of the lighting for each space. Table 42 shows the assumed electric energy demand of the lighting in kiloWatts used for each space of apartment type A. The electricity use for each space was obtained by:

((Number of lamps in the space) X 60 Watts per lamp)/1,000 = kiloWatts

Therefore, the following results were determined as shown in Table 42 for each space: the Main Bedroom hads 0.120 kW, Bedroom 2 had 0.120 kW, Living Room A had 0.360 kW, Living Room B had 0.060 kW, the bathroom had 0.060 kW, the kitchen had 0.060 kW and the dining room had 0.180 kW.

Table 42. Assumed Base-Case Electric Demand of the Lighting in KiloWatts for Each Space for Apartment Type A.

	Lighting						
Spaces	**Main Bedroom**	**Bedroom 2**	**Living Room A**	**Living Room B**	**Bathroom**	**Kitchen**	**Dining Room**
Number of Lamps	2	2	6	1	1	1	3
Watts per Lamp (W)	60	60	60	60	60	60	60
Total Energy per Space (W)	120	60	360	60	60	60	180
Total Energy per Space (kW)	0.120	0.120	0.360	0.060	0.060	0.060	0.180

Table 43 shows the assumed base-case 24-hour electricity use for the lighting in each space of the apartment type A. The first column is the hour of the day. The second through eighth columns are the different spaces of the apartment. In Table 43 the electricity use is only shown when the lighting is on. The ninth column is the total energy for lighting for each hour. The tenth column is the number of lamps turned-on each hour in all the rooms.

Figure 47 shows the 24-hour profile of the electricity use for the lighting from Table 43 and the electricity use of the appliances from Table 41. Table 43 displays 16 60-Watt lamps, and Table 41 shows the assumed electricity 24-hour use profileof a 250-Watt refrigerator, a 400-Watt TV, a 400-Watt washing machine, and a total of 50 Watts for miscellaneous appliances for each hour. As mentioned before, the idea was to mimic the profile showed in Figure 45.

Table 43. Assumed Base-Case 24-Hour of the Electricity Use for the Lighting in Each Space of the Apartment Type A.

	Main Bedroom	Bedroom 2	Living Room A	Living Room B	Bathroom	Kitchen	Dining Room		
Lamps	**2**	**2**	**6**	**1**	**1**	**1**	**3**		
Time (hr.)	**0.120 (kW)**	**0.120 (kW)**	**0.360 (kW)**	**0.060 (kW)**	**0.060 (kW)**	**0.060 (kW)**	**0.180 (kW)**	**Total Energy per Space (kW)**	**Lamps Turn On Per Hour**
1:00								0.000	0
2:00								0.000	0
3:00								0.000	0
4:00								0.000	0
5:00								0.000	0
6:00	0.120	0.120		0.060				0.300	4
7:00	0.120	0.120		0.060	0.060			0.360	5
8:00	0.120			0.060	0.060	0.060	0.180	0.480	8
9:00	0.120				0.060	0.060		0.240	4
10:00					0.060	0.060		0.120	2
11:00					0.060	0.060		0.120	2
12:00					0.060	0.060		0.120	2
13:00						0.060	0.180	0.240	4
14:00							0.180	0.180	3
15:00							0.180	0.180	3
16:00							0.180	0.180	3
17:00						0.060		0.060	1
18:00					0.060	0.060		0.120	2
19:00			0.360	0.060		0.060		0.480	8
20:00			0.360			0.060		0.420	7
21:00			0.360	0.060	0.060			0.480	8
22:00		0.120	0.360	0.060	0.060	0.060	0.180	0.840	13
23:00			0.360	0.060	0.060	0.060	0.180	0.720	12
0:00	0.120		0.360	0.060	0.060	0.060		0.660	11

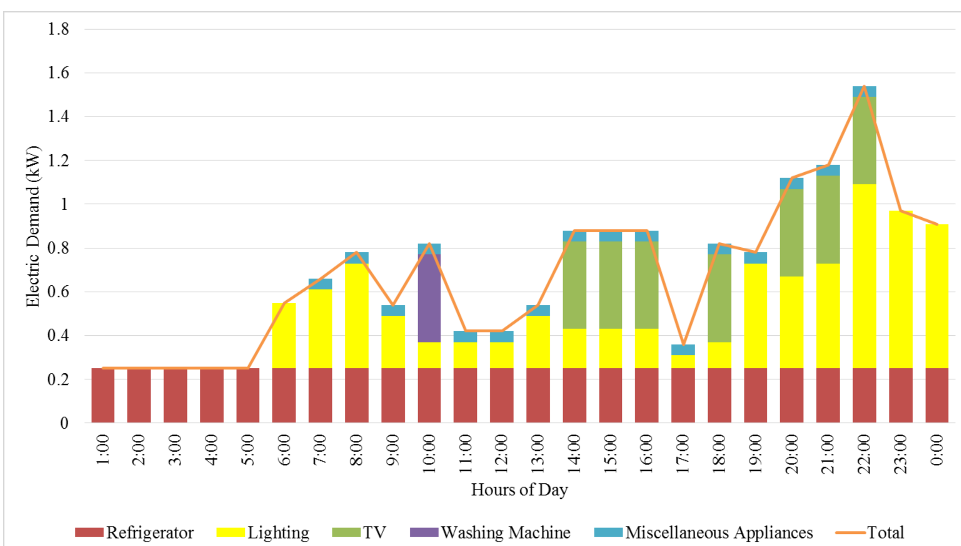


Figure 47. Partial Profile of the Electric Demand for Lamps and Electric Appliances.

The next step was to match the hourly electricity use from Figure 47 using the profile from Figure 45. Table 44 presents a comparison of the total estimated hourly electricity use for apartment type A and the hourly electricity use from the *Instituto de Investigaciones Electricas* (*IIE*).[78] The first column is the hour of the day. The second column is the total estimated hourly electricity use (kW). This column is the sum for each hour of the total electricity use for lighting from Table 43, and the sum of the total electricity use for appliances (i.e., refrigerator, TV, washing machine and miscellaneous appliances) from Table 41. The third column is the hourly electricity use from Maqueda-Zamora and Sanchez-Viveros (2011) from the *IIE* study in kW.

Table 44. Comparison ofthe Total Estimated Hourly Electricity Use for Apartment Type A and the Hourly Electricity Use from *IIE*.

Time	Total Hourly Estimated Electricity Use	IIE Hourly Estimated Electricity Use
hr.	kW	kW
1:00	0.25	0.20
2:00	0.25	0.20
3:00	0.25	0.19
4:00	0.25	0.19
5:00	0.25	0.19
6:00	0.55	0.20
7:00	0.66	0.25
8:00	0.78	0.28
9:00	0.54	0.28
10:00	0.82	0.28
11:00	0.42	0.26
12:00	0.42	0.26
13:00	0.54	0.28
14:00	0.88	0.25
15:00	0.88	0.25
16:00	0.88	0.25
17:00	0.36	0.28
18:00	0.82	0.25
19:00	0.78	0.26
20:00	1.12	0.30
21:00	1.18	0.40
22:00	1.54	0.43
23:00	0.97	0.35
0:00	0.91	0.28
Total	16.30	6.33

[78] The electricity use from the column titled *IIE* was obtained from the researchers Maqueda-Zamora and Sanchez-Viveros (2011) from the *Instituto de Investigaciones Electricas* (Maqueda-Zamora and Sanchez-Viveros, 2011). *IIE* is the Mexican Electrical Research Institute.

Figure 48 also shows the comparison between the total estimated hourly electricity use for apartment type A and the hourly electricity use from the *IIE*. The total estimated hourly electricity use is almost three times the electricity use from the *IIE* between 8:00 and midnight. One possible reason for this is that the total estimated hourly electricity use did not consider the fraction of time that the lighting and the appliances were not on.

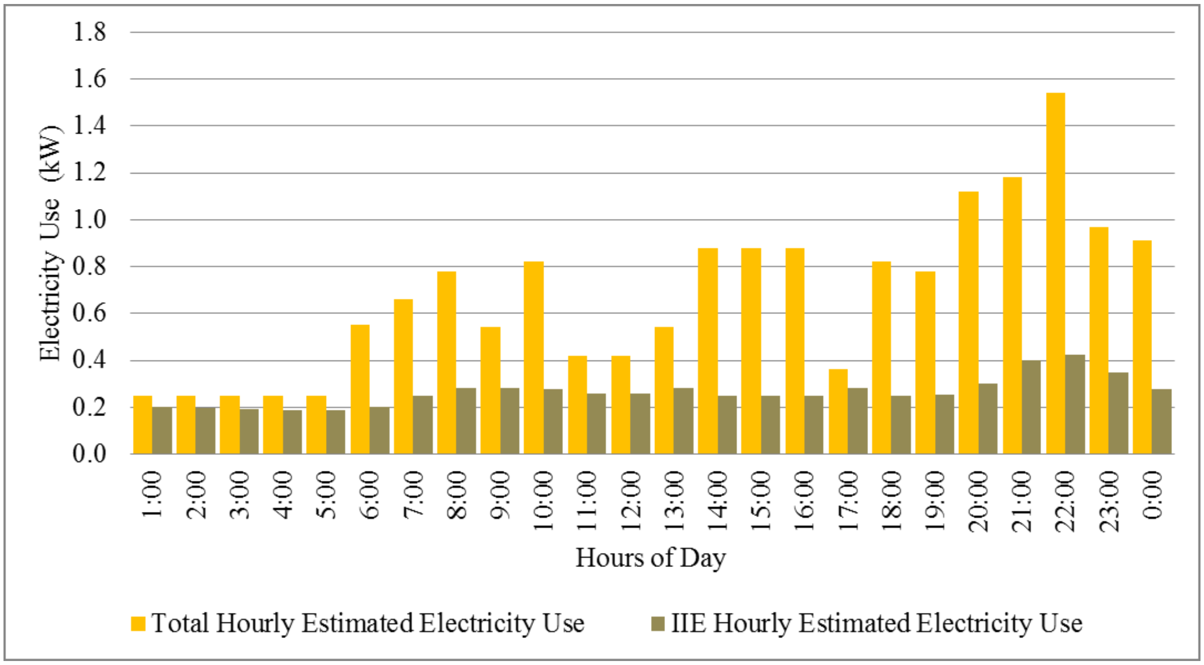


Figure 48. Comparison between the Total Hourly Estimated Electricity Use for Apartment Type A and the Electric Demand from *IIE*.

Table 45 presents the hourly scaling factor for the lighting and appliances. The first column is the hour of the day. The second column is the fraction of time that the lighting was used for each hour. From the third column through fifth columns is the fraction of time that each electric appliance was used during the day. Finally, the total electricity use for the lighting from Table 43 was multiplied by the second column of Table 45. The columns for electric appliances (i.e., refrigerator, TV, washing machine and miscellaneous appliances) from Table 41 were multiplied to the third, fourth, fifth and sixth columns of Table 45, respectively.

Table 45. Hourly Scaling Factor for the Lighting and Appliances.

		Appliances			
Time	**Lighting**	**Refrigerator**	**TV**	**Washing Machine**	**Miscellaneous Appliances**
1:00	0.25	0.25	0.25	0.25	0.25
2:00	0.25	0.25	0.25	0.25	0.25
3:00	0.25	0.25	0.25	0.25	0.25
4:00	0.25	0.25	0.25	0.25	0.25
5:00	0.25	0.25	0.25	0.25	0.25
6:00	0.25	0.25	0.25	0.25	0.25
7:00	0.25	0.25	0.25	0.25	0.25
8:00	0.25	0.25	0.25	0.25	0.25
9:00	0.25	0.25	0.50	0.25	0.25
10:00	0.25	0.25	0.50	1.00	0.25
11:00	0.25	0.25	0.50	0.25	0.25
12:00	0.25	0.25	0.50	0.25	0.25
13:00	0.25	0.25	0.25	0.25	0.25
14:00	0.50	0.25	0.25	0.25	0.25
15:00	0.50	0.25	0.25	0.25	0.25
16:00	0.50	0.25	0.25	0.25	0.25
17:00	1.00	0.25	0.25	0.25	0.25
18:00	1.00	0.25	0.50	0.25	0.25
19:00	1.00	0.25	0.25	0.25	0.25
20:00	1.00	0.25	0.25	0.25	0.25
21:00	1.00	0.25	0.75	0.25	0.25
22:00	0.50	0.25	0.75	0.25	0.25
23:00	0.50	0.25	1.00	0.25	0.25
0:00	0.25	0.25	0.25	0.25	0.25

Table 46 establishes the results from the application of the scaling factors for the lighting and appliances (i.e., refrigerator, TV, washing machine and miscellaneous appliances). Table 47 shows a comparison between the total scaled electricity use for apartment type A and the electricity use from the *IIE*. In Table 47, the first column is the hour of the day. The second column is the total estimated scaled electricity use for each hour. This column is the sum for each hour of the total electricity from the lighting from and the appliances from Table 46. The third column is the hourly electricity use from Maqueda-Zamora and Sanchez-Viveros (2011) from the *IIE* study. In general, the total scaled estimated electricity use approximately matches the total electricity use from the *IIE* study.

Table 46. Results for the Scaled Lighting and Appliances.

	Lighting	Refrigerator	TV	Washing Machine	Miscellaneous Appliances
Time (hr.)	kWh	kWh	kWh	kWh	kWh
1:00	0.0000	0.0625	0.0000	0.0000	0.0000
2:00	0.0000	0.0625	0.0000	0.0000	0.0000
3:00	0.0000	0.0625	0.0000	0.0000	0.0000
4:00	0.0000	0.0625	0.0000	0.0000	0.0000
5:00	0.0000	0.0625	0.0000	0.0000	0.0000
6:00	0.0750	0.0625	0.0000	0.0000	0.0000
7:00	0.0900	0.0625	0.0000	0.0000	0.0125
8:00	0.1200	0.0625	0.0000	0.0000	0.0125
9:00	0.0600	0.0625	0.0000	0.0000	0.0125
10:00	0.0300	0.0625	0.0000	0.4000	0.0125
11:00	0.0300	0.0625	0.0000	0.0000	0.0125
12:00	0.0300	0.0625	0.0000	0.0000	0.0125
13:00	0.0600	0.0625	0.0000	0.0000	0.0125
14:00	0.0900	0.0625	0.1000	0.0000	0.0125
15:00	0.0900	0.0625	0.1000	0.0000	0.0125
16:00	0.0900	0.0625	0.1000	0.0000	0.0125
17:00	0.0600	0.0625	0.0000	0.0000	0.0125
18:00	0.1200	0.0625	0.2000	0.0000	0.0125
19:00	0.4800	0.0625	0.0000	0.0000	0.0125
20:00	0.4200	0.0625	0.1000	0.0000	0.0125
21:00	0.4800	0.0625	0.3000	0.0000	0.0125
22:00	0.4200	0.0625	0.3000	0.0000	0.0125
23:00	0.3600	0.0625	0.0000	0.0000	0.0000
0:00	0.1650	0.0625	0.0000	0.0000	0.0000

Figure 49 shows the electricity use from the *IIE* and the scaled electricity use from lighting and appliances for apartment type A.[79] Nevertheless, there are some differences between the hourly profiles. For example, the scaled electricity use of an apartment type A is well below the use from the *IIE* study until 10:00. Figure 50 provides the detailed end-use for the total scaled electricity use shown in Table 47 and Figure 49. Table 48 shows the hourly profiles for the lighting and appliances before scaling. Figure 50 shows that the only appliance turned on constantly the whole day is the refrigerator. The miscellaneous

[79] The scaled electricity use for the appliances and lighting was made with the most logical sense possible.

appliances were turned on constantly from 7:00 to 10:00. To accomplish this, the following number of lamps was turned on each hour: four at 6:00, five at 7:00, eight at 8:00, four at 9:00 and two at 10:00. The washing machine is the reason why the estimated electricity use exceeds the hourly use of the *IIE* study at 10:00 in Figure 49. From 10:00 to noon there were only two lamps turned on each hour and at 13:00 there are four lamps turned on.

Table 47. Comparison of the Total Scaled Electricity Use for the Apartment Type A and the Electricity Use from the *IIE* Study.

Time	Total Scaled Electricity Use	IIE
hr.	kWh	kWh
1:00	0.0625	0.2000
2:00	0.0625	0.1950
3:00	0.0625	0.1900
4:00	0.0625	0.1850
5:00	0.0625	0.1850
6:00	0.1375	0.2000
7:00	0.1650	0.2500
8:00	0.1950	0.2800
9:00	0.1350	0.2800
10:00	0.5050	0.2750
11:00	0.1050	0.2600
12:00	0.1050	0.2600
13:00	0.1350	0.2800
14:00	0.2650	0.2500
15:00	0.2650	0.2500
16:00	0.2650	0.2500
17:00	0.1350	0.2800
18:00	0.3950	0.2500
19:00	0.5550	0.2550
20:00	0.5950	0.3000
21:00	0.8550	0.4000
22:00	0.7950	0.4250
23:00	0.4225	0.3500
0:00	0.2275	0.2750
Total	6.5700	6.3250

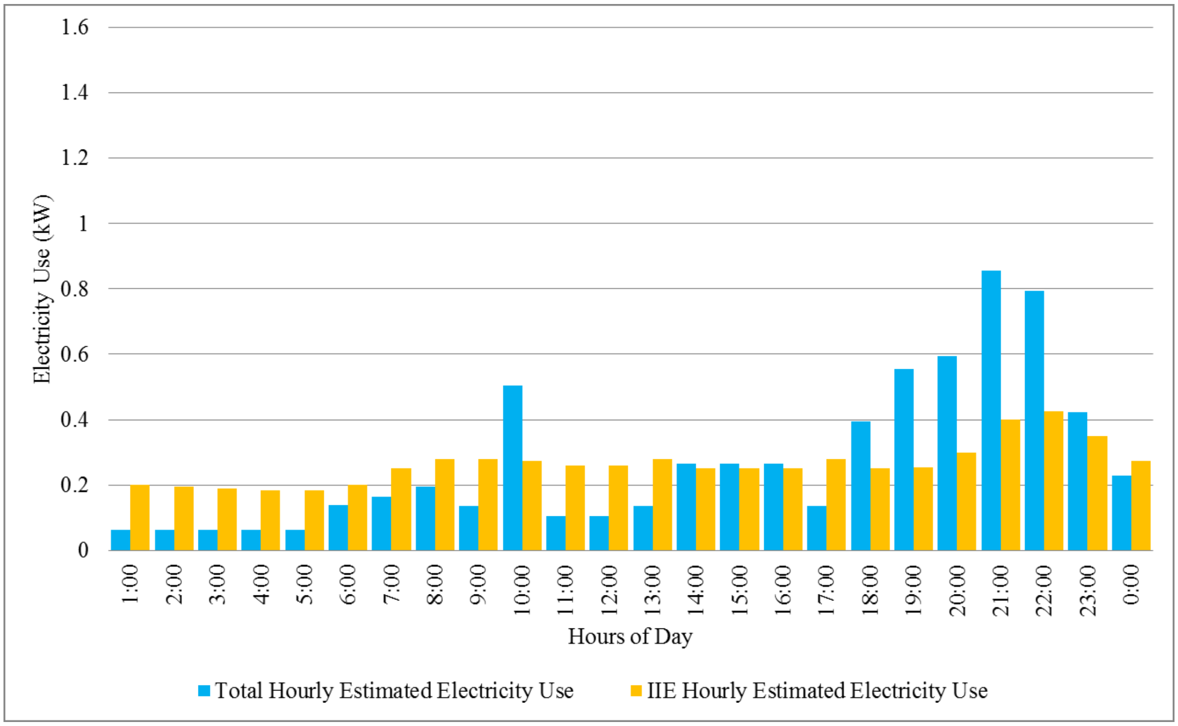


Figure 49. Comparison between the Total Hourly Estimated Electricity Use for the Apartment Type A (after Been Scaled) and the Hourly Electricity Use from the *IIE* Study.

Nevertheless, the estimated electricity use, as shown in Figure 49, was lower than the profile from *IIE*. Both profiles closely match from 14:00 to 16:00. In Figure 50, three lamps are turned on each hour from 14:00 to 16:00, and the TV was used during these hours. The estimated electricity use profile dropped lower than *IIE*'s profile at 17:00 in Figure 49. In Figure 50, one lamp was turned on at 17:00. From 18:00 to 22:00 the estimated electricity use profile remained higher than the *IIE*'s profile in Figure 49.

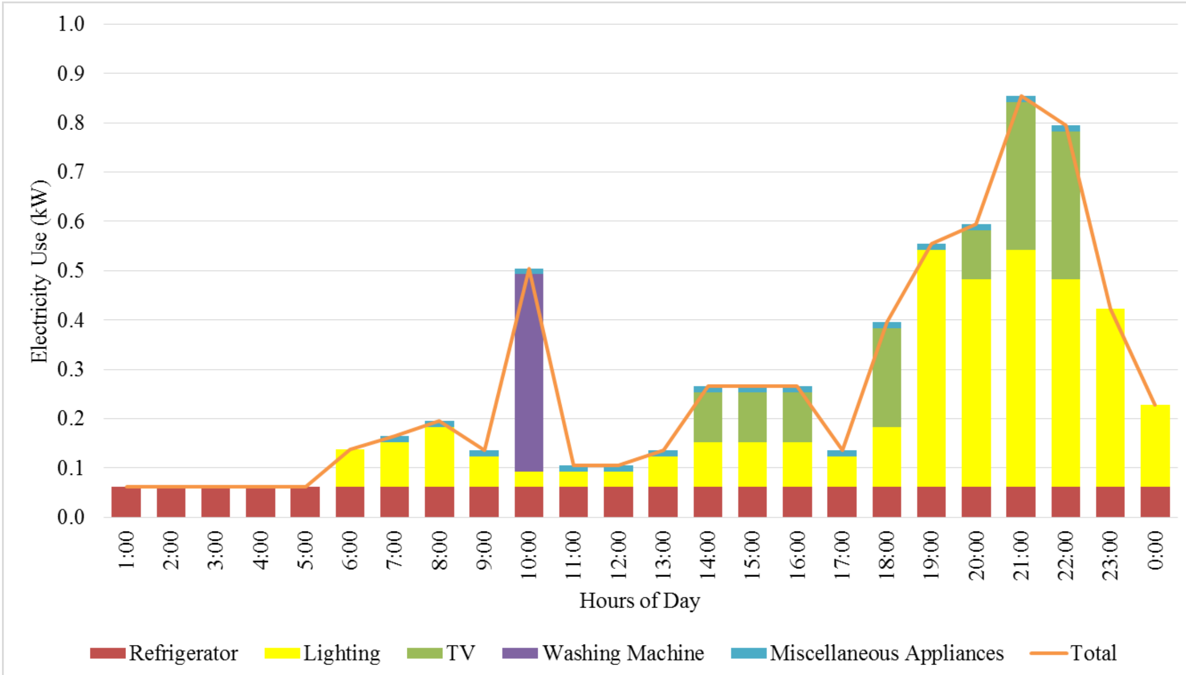


Figure 50. Profile of the Fraction of Daily Peak for each Hour for Lighting and Appliances.

The following numbers of lamps were turned on per hour: two at 18:00, eight at 19:00, seven at 20:00, eight at 21:00 and 13 at 22:00 in Figure 50. The TV was used at 18:00, 20:00, 21:00 and 22:00 in Figure 50. The increased number of lamps turned on and the length of time the TV was watched are the main reasons for the estimated electricity use surpassing the *IIE*'s profile. In Figure 49, the estimated electricity use profile dropped and almost matched the *IIE*'s profile. 12 lamps were turned on at 23:00 in Figure 50. Finally, in Figure 49, the *IIE*'s profile is higher than the estimated electricity use profile. 11 lamps are turned on at midnight in Figure 50.

Unfortunately, the data from the profile in Figure 50 cannot be used directly in the simulation software, because the electricity use input for the simulation must be broken down into lighting and appliance values.[80] The software then multiplies the lighting and appliance hourly profiles (i.e., 0-100 percent) times the maximum lighting and appliance loads. 0.480 kW was the maximum load for an hour for lighting during the day. This amount was divided by each hour to create the second column from Table 49. The final lighting density load used in the software was 0.635555 W/ft². 0.475 kW was the maximum load for an hour for appliances during the day. This amount was divided by each hour to create the third column from Table 49. The final appliance density load used in eQuest was 0.620400 W/ft².

As mentioned before, Table 48 shows the hourly profiles for the lighting and appliances before scaling. On the other hand, Table 49 exhibits the hourly profiles for lighting and appliance schedules after scaling. The values presented in Table 49 do not have units because these are the fraction of the electricty consumed each hour. If 6.8125 and 6.9474 from Table 49 were multiplied by 0.4800 kW and 0.4750 kW and then added, the final result is 6.5700 kW. Finally, the two columns in Table 49 were used to create the hourly profiles for lighting and appliances schedules to introduce to the software. Both schedules were divided into Figure 51 for lighting and Figure 52 for appliances.

[80] 6.5700 kWh/day was the original input.

Table 48. Hourly Profiles for Lighting and Appliance Schedules before Scaling.

	Lighting	Appliances
hr.	kW	kW
1:00	0.0000	0.0625
2:00	0.0000	0.0625
3:00	0.0000	0.0625
4:00	0.0000	0.0625
5:00	0.0000	0.0625
6:00	0.0750	0.0625
7:00	0.0900	0.0750
8:00	0.1200	0.0750
9:00	0.0600	0.0750
10:00	0.0300	0.4750
11:00	0.0300	0.0750
12:00	0.0300	0.0750
13:00	0.0600	0.0750
14:00	0.0900	0.1750
15:00	0.0900	0.1750
16:00	0.0900	0.1750
17:00	0.0600	0.0750
18:00	0.1200	0.2750
19:00	0.4800	0.0750
20:00	0.4200	0.1750
21:00	0.4800	0.3750
22:00	0.4200	0.3750
23:00	0.3600	0.0625
0:00	0.1650	0.0625
Total	3.2700	3.3000

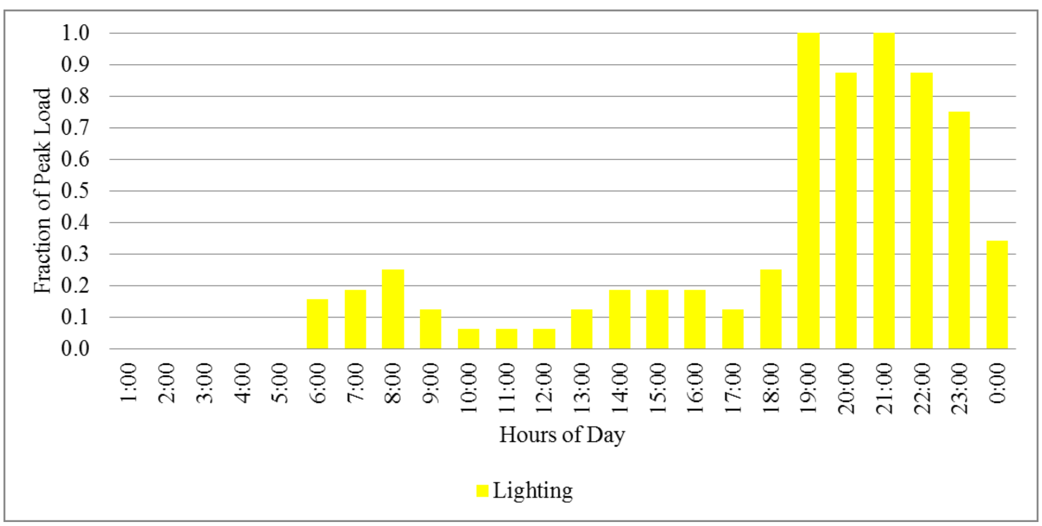


Figure 51. Profile for Lighting Schedule for the Apartments.

Table 49. Hourly Profiles for Lighting and Appliance Schedules after Scaling.

Time	Lighting	Appliances
1:00	0.0000	0.1316
2:00	0.0000	0.1316
3:00	0.0000	0.1316
4:00	0.0000	0.1316
5:00	0.0000	0.1316
6:00	0.1563	0.1316
7:00	0.1875	0.1579
8:00	0.2500	0.1579
9:00	0.1250	0.1579
10:00	0.0625	1.0000
11:00	0.0625	0.1579
12:00	0.0625	0.1579
13:00	0.1250	0.1579
14:00	0.1875	0.3684
15:00	0.1875	0.3684
16:00	0.1875	0.3684
17:00	0.1250	0.1579
18:00	0.2500	0.5789
19:00	1.0000	0.1579
20:00	0.8750	0.3684
21:00	1.0000	0.7895
22:00	0.8750	0.7895
23:00	0.7500	0.1316
0:00	0.3438	0.1316
Total	6.8125	6.9474

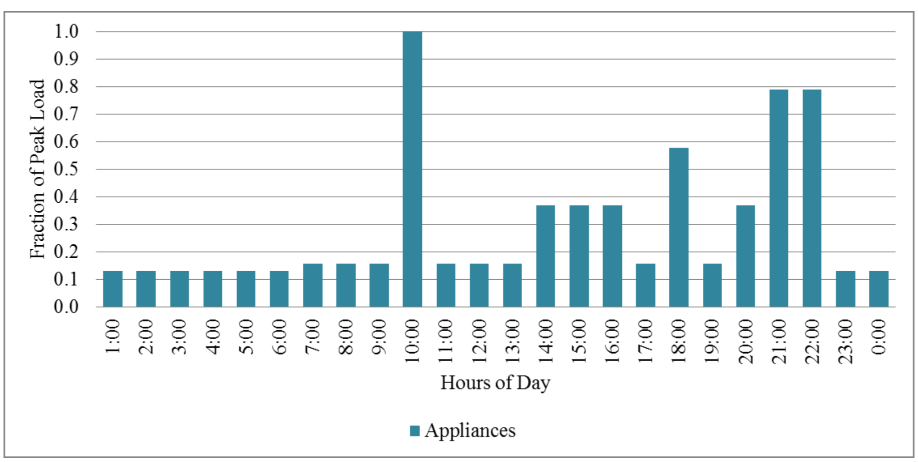


Figure 52. Profile for Appliance Schedule for the Apartments.

The occupancy and infiltration schedules were addressed next. To begin, a hand calculation was used to estimate the number of people per zone. Table 50 shows the zones for each floor shell modeled. The first column is the floor, the second column is the zones divided from each floor and the third column is the area for each zone.

Table 50. Zones for Each Shell Modeled in eQuest.

Floor	Zones	Area
Second	EL2 WNW Perim Spc (G.WNW1)	11,356 ft²
	EL2 ESE Perim Spc (G.ESE2)	3,746 ft²
Third	EL3 WNW Perim Spc (G.WNW1)	11,356 ft²
	EL3 ESE Perim Spc (G.ESE2)	3,746 ft²
Fourth	EL4 WNW Perim Spc (G.WNW1)	11,356 ft²
	EL4 ESE Perim Spc (G.ESE2)	3,746 ft²

The EL2 WNW Perim Spc (G.WNW1) and EL2 ESE Perim Spc (G.ESE2) were used for the hand calculations as follows:

11,356 ft² EL2 WNW Perim Spc (G.WNW1) /750 ft² apartment = 15 apartments
4 people per apartment multiplied by 15 apartments = 60 people/floor
11,356 ft²/60 people = 189.2666 ft² for EL2 WNW Perim Spc (G.WNW1)

3,746.1 ft² EL2 ESE Perim Spc (G.ESE2) /750 ft² apartment = 5 apartments
4 people per apartment multiplied by 5 apartments = 20 people/floor
3,746.1 ft²/20 people = 187.3050 ft² for EL2 ESE Perim Spc (G.ESE2)

Finally, the 189.26 ft² for EL2 WNW Perim Spc (G.WNW1) and the 187.30 ft² for EL2 ESE Perim Spc (G.ESE2) are repeated for the third floor and the fourth floor. Figure 53 displays the occupancy schedule for the apartments. Figure 53 was generated for the occupancy schedule profile for the simulation. In this study, it was assumed that the occupancy would be one from midnight to 6:00. The occupancy was reduced to 0.75 from

7:00 to 8:00, and to 0.5 at 9:00, because the residents left to go to work and study among other activities. Later, it was reduced to 0.2 from 10:00 to noon, and dropped as low as 0.35 at 13:00. It increases to 0.6 from 14:00 to 16:00 because the residents come back home to eat; and rises to 0.75 from 17:00 to 19:00 after school or work is over. Finally, the occupancy increases to one after 20:00.

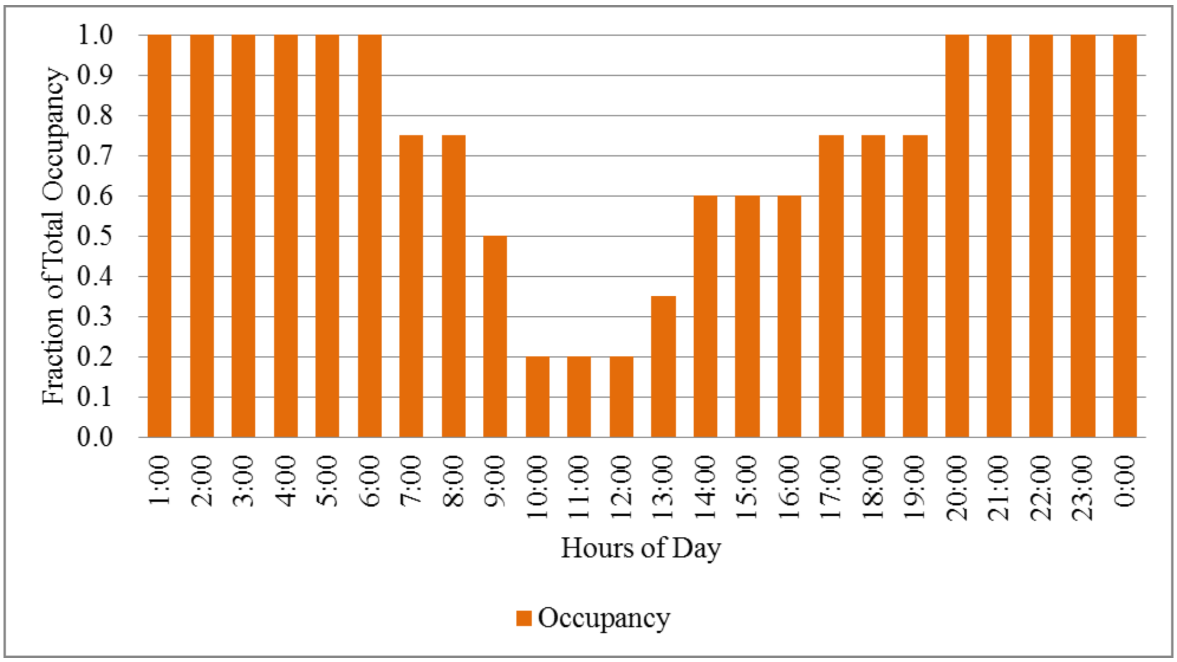


Figure 53. Profile for the Occupancy Schedule for the Apartments.

There were three parameters given for the infiltration: the Sherman-Grimsrud method, the Air Changes per hour (ACH/hr) that equal to 0.35[81] into the zone, and the infiltration schedule as displayed in Figure 54.

[81] Chapman (2012) suggested changing the infiltration in the internal loads to 0.35 Air Changes per hour (ACH/hr.) for naturally ventilated spaces. This is a way to account for natural ventilation in eQuest for LEED calculations. This approach was helpful to define the infiltration for the current study.

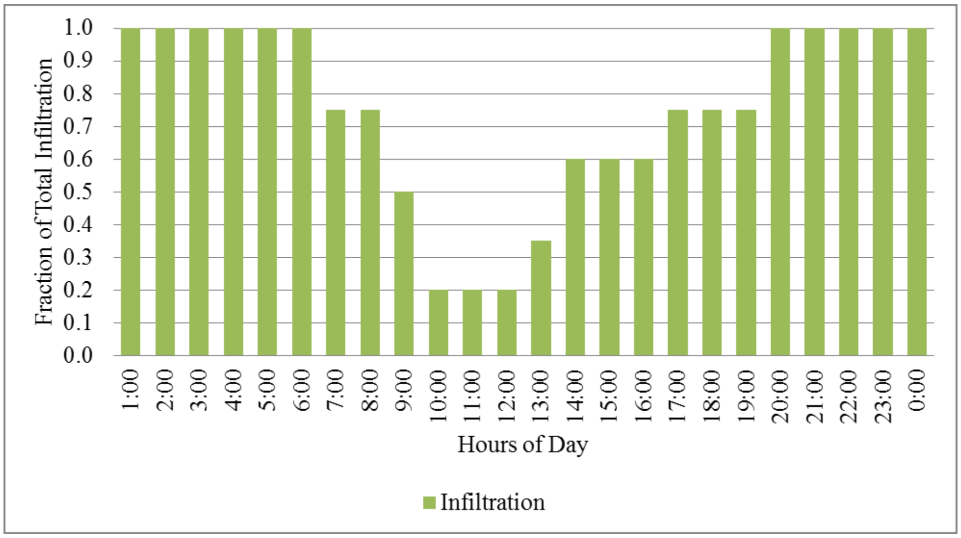


Figure 54. Profile for the Infiltration Schedule for the Apartments.

4.2.1.1.6. Air-Conditioning System Data Used for the Residential Section.

The air-conditioning system input that was used for the second, third and fourth floors is presented in Table 51. Table 51 presents the air-side system data, the seasonal thermostat setpoints and design temperatures parameters. The air-side system type was a Packaged Single-Zone (PSZ)[82] DX System for the cooling source with electric resistance for heating. A system per shell was used for each floor. The system had a ducted return air path.[83]

[82] eQuest Help Topic, Moore (2009) and Chapman (2011) pointed out that the only systems that support natural ventilation are RESYS, RESYS2, PSZ, PVVT and EVAP-COOL.
[83] DOE-2.1e Manual (LBL/LASL, 1980a) informs that the PSZ system may have a duct. The current building does not have a ceiling.

Table 51. Data Input for Air-Conditioning System for Second, Third and Fourth Floors of the Residential Section.

Item	Name of Parameter			Base-Case Input	References	Comments
Air-Conditioning Systems	System Type	Cooling Source		DX Coils		
		Heating Source		Electric Resistance		
		System Type		Packaged Single Zone DX, Electric Heat	*CONUEE,* 2007; eQuest Help Topic; Moore, 2009; Chapman, 2011	
		System per Area		System per Shell		
		Return Air Path		Ducted		
	Seasonal Thermostat Setpoints	Occupied (°F)	Cool	120°F	*CONAVI,* 2006	
			Heat	50°F		
		Unoccupied (°F)	Cool	120°F		
			Heat	50°F		
	Design Temperatures	Indoor	Cooling Design Temperature	118°F	IBPSA, 2012	
			Heating Design Temperature	52°F		
		Supply	Cooling Design Temperature	55°F		
			Heating Design Temperature	78°F		
	System Size	Cooling	Overall Size	Auto-Size	eQuest Default	
			Typical Unit Size	135-240 kBtuh or 11.25-20 tons	eQuest Default	
			Condenser Type	Air-Cooled	eQuest Default	
			Efficiency	EER 8.500	eQuest Default	
		Heating	Size	Auto-Size	eQuest Default	
Fan	Operation	Cycle Fans at Night		No Fan Night Cycling	LBL/LASL, 1980a	
		Fan Mode		Intermittent	LBL/LASL, 1980a	

The seasonal thermostat setpoints had a range of 120°F for cooling and 50°F for heating. The reason to use this range was to avoid the use of the air-conditioning system to function during the year and allow the inspection of the interior temperatures. The cooling design temperature was 70°F and the heating design temperature was set to 72°F. This is consistent with *CONAVI* (2006, 2007) who stated that the semi-cold bioclimates do not need air-conditioning systems. The assigned range allows the interior temperature to float and never activate the system. This then allows the simulation to model the apartment section only with energy consumption of lighting and appliances during the year. For that reason, it was essential to know Mexico City's thermal comfort zone. *CONAVI* (2006) stated that the thermal comfort zone in this tropical climate is from 74ºF to 85ºF, or 23.3ºC to 29.4ºF. The simulation will show the electricity consumption of the base-case. The final goal is to maintain thermal comfort as much as possible with low-energy-use strategies.

The size used for cooling and heating systems was the default size by the software.[84] *CONUEE* (2007) required and authorized the use of Packaged Single Zone systems in Mexico. Therefore, a PSZ system was used. The system fans were auto-sized by the software, with no fan working during the night. In addition, the fan was assigned as intermittent.

4.2.1.1.7. Domestic Hot Water Equipment for the Residential Section.

In Mexico, the Liquefied Petroleum (LP) gas Domestic Hot Water (DHW) equipment is often located outside the building's envelope as shown in Figure 55. The water tanks are located outside of the apartments in Figure 55. Therefore, the DHW was not simulated with eQuest. The thermal energy required for DHW was assumed to be provided by the solar domestic hot water system simulated with F-Chart program.

4.2.1.1.8. Obtain the Hourly Reports.

Table 52 shows the hourly reports available with the eQuest simulation program. These reports are a valuable resource in order to create the final tables and graphs for the building energy base-case for the apartment section (and the grocery store section). Each variable type is selected from a drop-down menau and has several hourly reports. Each hourly report has a variable list number.

[84] Although this size may be large for a residence, since it never turned-on it had no impact on the results.

Figure 55. Liquefied Petroleum (LP) Gas Tanks Located on the Rooftop of One of the Small Three-Story Buildings in the Complex. (Photo by Jose Luis Bermudez Alcocer).

Table 52. Hourly Reports Obtained from eQuest.

Report	Units	eQuest Sub-program	Variable Type	Variable List
Outdoor Dry-Bulb Temperature	°F	Loads	Global	4
Outdoor Wet-Bulb Temperature	°F			3
Sensible Heating Load	Btu/hr.		Building Loads	1
Latent Heating Load				2
Sensible Cooling Load				19
Latent Cooling Load				20
Outdoor Dry-Bulb Temperature	°F	Systems	Global	4
Outdoor Wet-Bulb Temperature	°F			3
Zone Temperature	°F		Thermal Zone	6
Return Air Humidity Ratio	lb H_20/lb dry air		HVAC System	35

4.2.1.1.9. Obtain the Results for Electricity Consumption for the Residential Section.

Finally, the eQuest simulation gave the following results for the replication of the residential section: 286.40 kWh (X 1,000) for lighting and 289.06 kWh (X 1,000) for appliances as shown in Table 53 and Figure 56.

Table 53. Monthly Energy Consumption by End-Use in kWh (X 1,000) for the Apartments.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Area Lights	24.32	21.97	24.32	23.54	24.32	23.54	24.32	24.32	23.54	24.32	23.54	24.32	286.40
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Misc. Equip.	24.55	22.17	24.55	23.76	24.55	23.76	24.55	24.55	23.76	24.55	23.76	24.55	289.06
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0.0
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Pumps & Aux.	0.03	0.02	0	0	0	0	0	0	0	0	0.02	0.02	0.10
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Space Heat	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	48.9	44.16	48.88	47.3	48.88	47.3	48.88	48.88	47.3	48.88	47.32	48.9	575.56

In order to check the results of the simulation, a sanity check was used to make sure that the ouput results were appropriate for the input data. Table 54 and Table 55 were used to cross-check the electricity use for the lighting and appliances introduced before the simulation and the energy obtained after the simulation. The energy-used for lighting was 3.27 kWh/day-apartment. Table 54 shows that 3.27 kWh/day-apartment for each month is obtained after the building was modeled. The energy introduced for appliances was 3.30 kWh/day-apartment. Table 55 displays that 3.30 kWh/day-apartment for each month is obtained after the building was simulated. This cross-check showed that the input values for the lighting and appliances were reasonable.

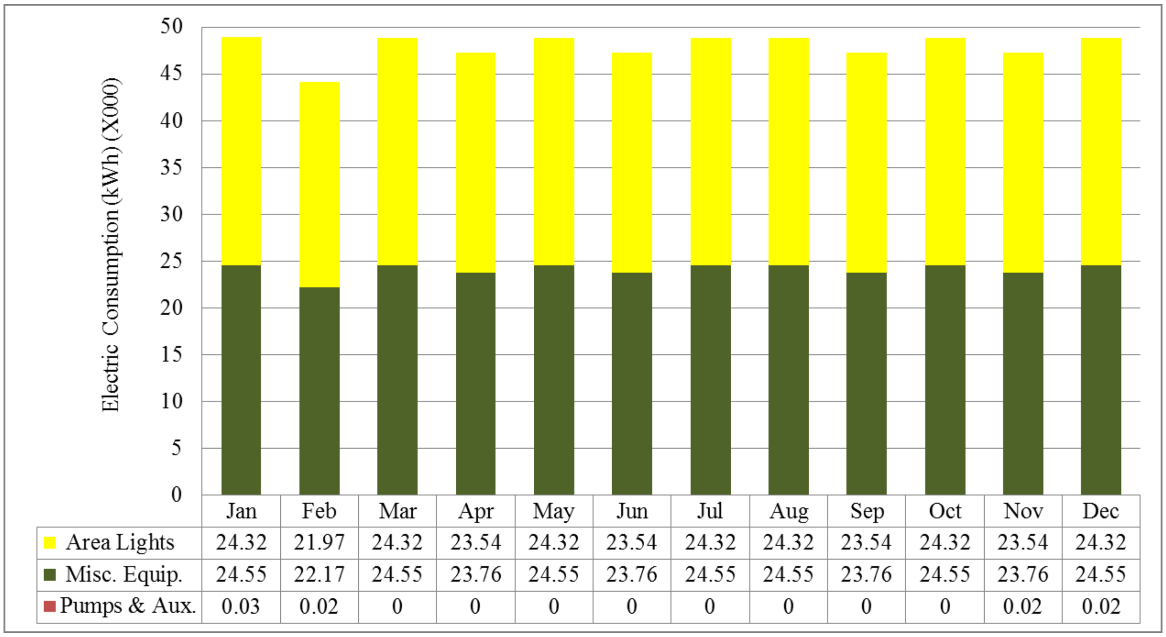


Figure 56. Monthly Energy Consumption by End-Use for the Apartments.

Table 54. Sanity Check for Lighting Consumption Obtained from the Base-Case Building Simulated with eQuest.

	Month	January	February	March	April
	Days of Month	31	28	31	30
	kWh/day-building (X 1,000)	0.7845	0.7846	0.7845	0.7847
kWh/day-apartment	kWh/day-building	784.52	784.64	784.52	784.67
3.27	kWh/day-apartment	3.27	3.27	3.27	3.27

Table 55. Sanity Check for Appliances Consumption Obtained from the Base-Case Building Simulated With eQuest.

	Month	January	February	March	April
	Days of Month	31.00	28.00	31.00	30.00
	kWh/day-building (X 1,000)	0.7919	0.7918	0.7919	0.7920
kWh/day-apartment	kWh/day-building	791.94	791.79	791.94	792.00
3.30	kWh/day-apartment	3.30	3.30	3.30	3.30

4.2.1.1.10. Obtain the Results for Electricity Consumption using Natural Ventilation Modeling for the Residential Section.

Although the eQuest software has the capability to model the effect of natural ventilation, it does not have the accuracy that could be obtained with computer fluid dynamics (CFD) software. For this study the Sherman-Grimsrud ventilation method was applied to the residential section of the building. For all the hours the fan schedule in the S1 Sys1 (PSZ) Fan Schedule were assigned a value of one during the day (i.e., the fan is "ON"). This value means that the windows were opened for all or part of the hour if natural ventilation provided enough cooling to keep the zone temperature within or below the assigned ventilation temperature schedule. A natural ventilation schedule was also created for the ventilation temperature schedule.[85] Finally, 50°F was assigned to Vent-Temp-Sch.[86]

The air-conditioning system did not consume any electricity when using the natural ventilation mode. When using this mode, the simulation gives the same energy consumption as shown in Table 56 and Figure 57: 286.40 kWh (X 1,000) for lighting and 289.06 kWh (X 1,000) for appliances as shown in Table 56 and Figure 57.

Table 56: Monthly Energy Consumption by End-Use in kWh (X 1,000) after Applying the Natural Ventilation Model in eQuest for the Apartments.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
End-use	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)
Area Lights	24.32	21.97	24.32	23.54	24.32	23.54	24.32	24.32	23.54	24.32	23.54	24.32	286.40
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Misc. Equip.	24.55	22.17	24.55	23.76	24.55	23.76	24.55	24.55	23.76	24.55	23.76	24.55	289.06
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0.0
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Pumps & Aux.	0.03	0.02	0	0	0	0	0	0	0	0	0.02	0.02	0.10
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Space Heat	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	48.9	44.16	48.88	47.3	48.88	47.3	48.88	48.88	47.3	48.88	47.32	48.9	575.56

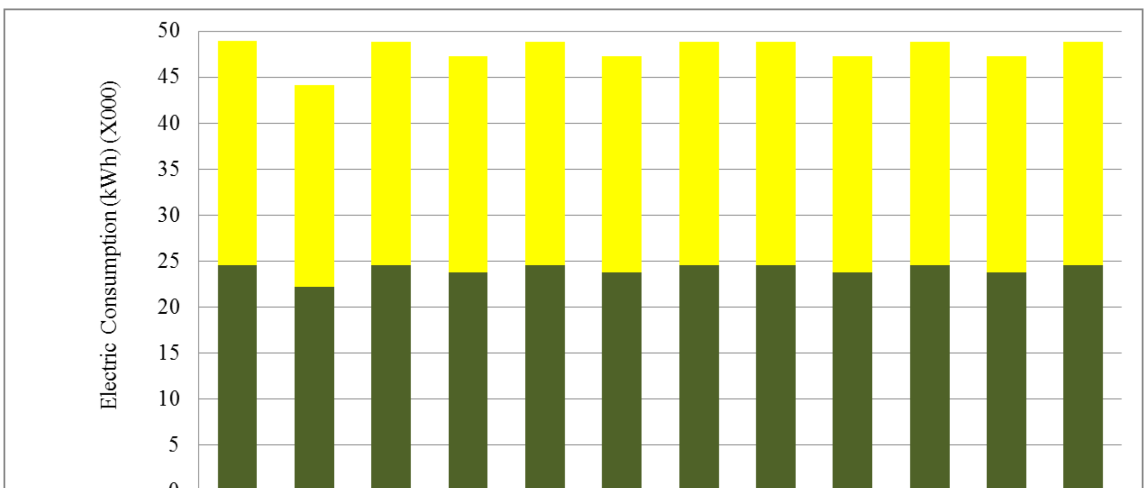
[85] S1 Sys1 (PSZ) natural ventilation schedule (Nat Vent Sch) was created for the Vent-Temp-Sch.
[86] The window is closed once the temperature reaches the boundary temperature of 50°F. This means that the window is open for temperatures over 50°F.

(((((286.40 kWh + 289.06 kWh) X 1,000)/(365 days/ 1 year)))/ (181,226 ft²/building)) X (1,000 W/ 1 kW) = 8.6996 Wh/day-ft².

The energy consumption for the whole complex needed the total number of buildings shown in Table 32. To accomplish this, the equivalent of 4.5 buildings was calculated for the *Multifamiliar Miguel Aleman* community. The simulation showed the multi-family apartments' base-case energy consumption was calculated to be 575,560 kWh/year. The electricity consumption for the whole complex is shown as next:

575,560 kWh/year per building X 4.5 buildings = 2,590,020 kWh/year for the *Multifamiliar Miguel Aleman* community.

Therefore, 2.6 MWh/year is the total energy consumed for the apartment section of the 4.5 buildings in the whole complex.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area Lights	24.32	21.97	24.32	23.54	24.32	23.54	24.32	24.32	23.54	24.32	23.54	24.32
Misc. Equip.	24.55	22.17	24.55	23.76	24.55	23.76	24.55	24.55	23.76	24.55	23.76	24.55
Pumps & Aux.	0.03	0.02	0	0	0	0	0	0	0	0	0.02	0.02

Figure 57. Monthly Energy Consumption by End-Use after Applying the Natural Ventilation Model in eQuest for the Apartments.

4.2.1.2. Base-Case Energy-Use for the Grocery Store.

This section presents the process to simulate and analyze the base-case building energy-use for the grocery store of the *Multifamiliar Miguel Aleman.* The process used is the following:

1) The grocery store in the lower portion of the building was modeled with eQuest as shown in Figure 58. Before going further in eQuest, the floorplan was first drafted with AutoCAD and imported as *.dxf* to eQuest in Figure 59. The floorplan for the grocery store required the following data input: building's type and geometry, construction details; interior space characteristics; and mechanical systems (*CONUEE*, 2007) in Figure 60.
2) This grocery store did not consider a refrigeration system. It was assumed to be a small dry goods grocery store with electricity use for lighting, and refrigerators for cold beverages, sodas, milk, juice, water, and freezers for yogurts, and several small freezers for icecream and frozen goods.
3) There was no data available from Mexico to compare the simulated energy consumption of the grocery stores. Therefore, data from the Commercial Building Energy Consumption Survey (CBECS) (2003) was compared to the simulated energy consumption from the grocery store.
4) The simulations' results were further processed using spreadsheets. The graphs generated with the spreadsheets showed the comparison between the interior zone temperature and the outside dry-bulb temperature as wells as the electricity consumed per year.

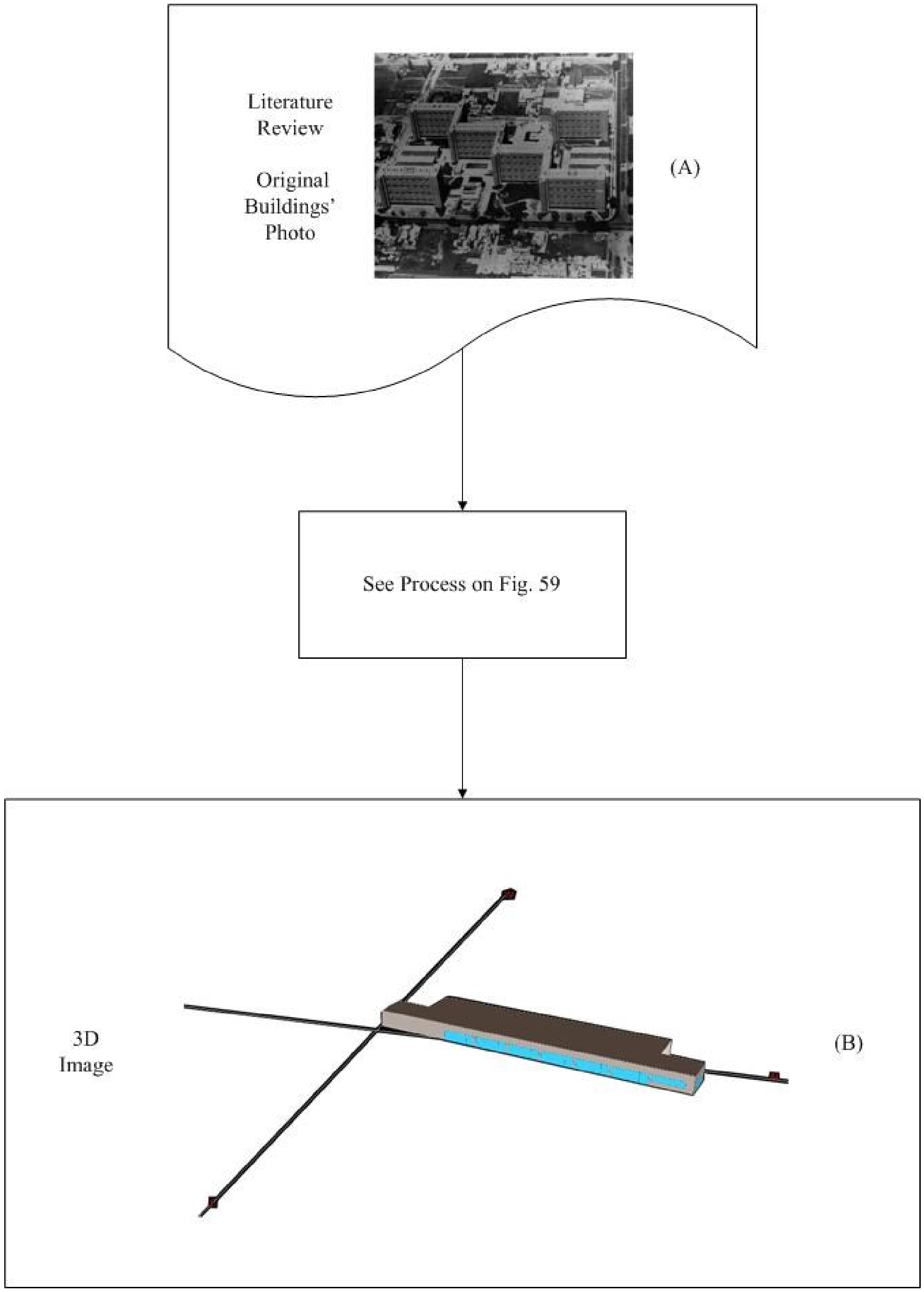


Figure 58. General Simulation Process for the Grocery Store.
(A) Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.17), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with Permission. (B) 3D Image Created with eQuest.

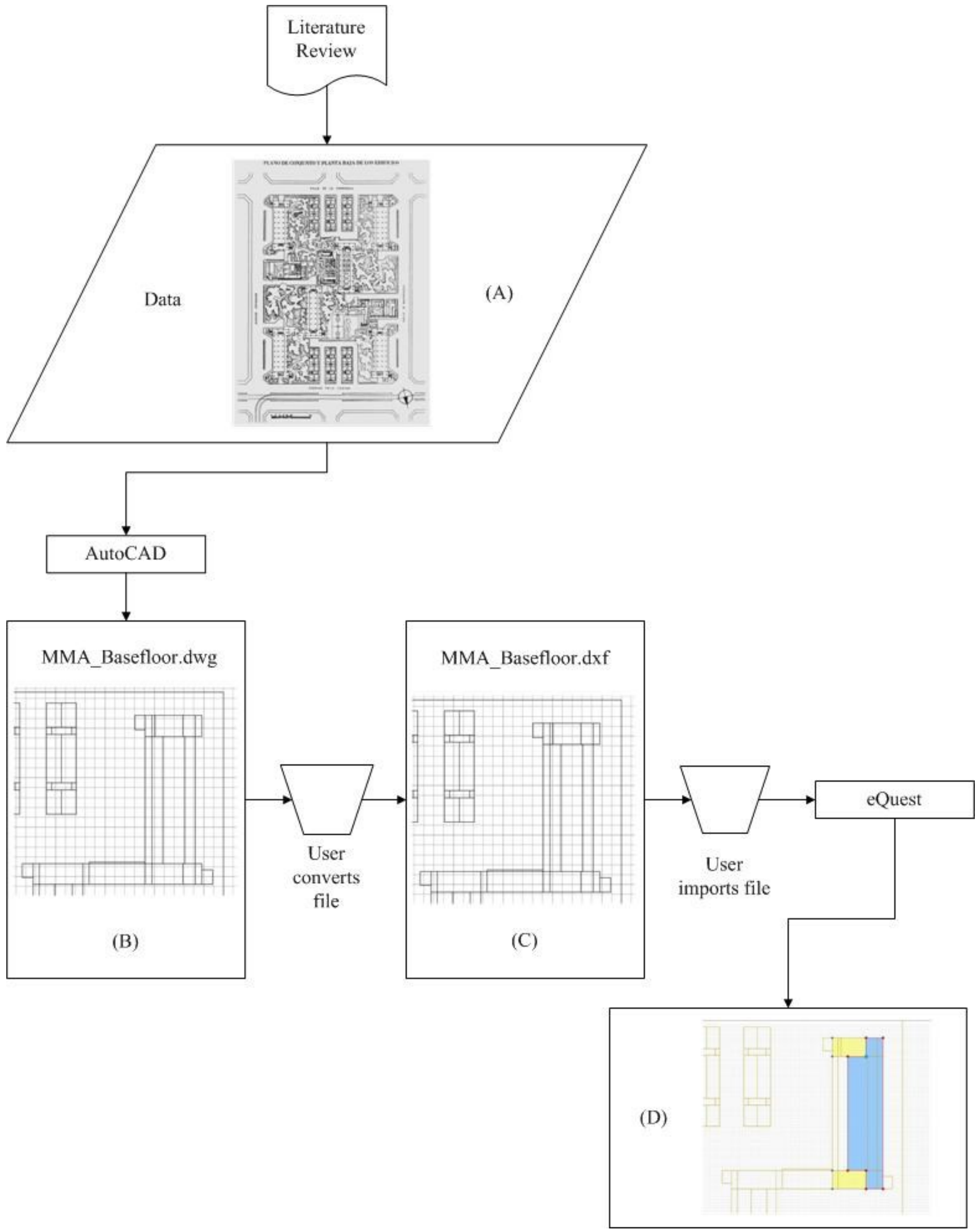


Figure 59. Simulation Process Including Information from the Literature Review. (A) Reprinted from *Vivienda Colectiva de la Modernidad en Mexico: Los Multifamiliares Durante el Periodo Presidencial de Miguel Aleman (1946-1952).* (p.243), by E. X. De Anda, 2008, Mexico, D. F., *UNAM*: *Instituto de Investigaciones Esteticas (IIE)*, Copyright 2008 by *Patronato Universitario UNAM*. Reprinted with permission. (B) Image of the Floorplan from the MMA_Basefloor.dwg. (C) Image of the Floorplan from the MMA_Basefloor.dxf. (D) Image of the floorplan Produced with eQuest.

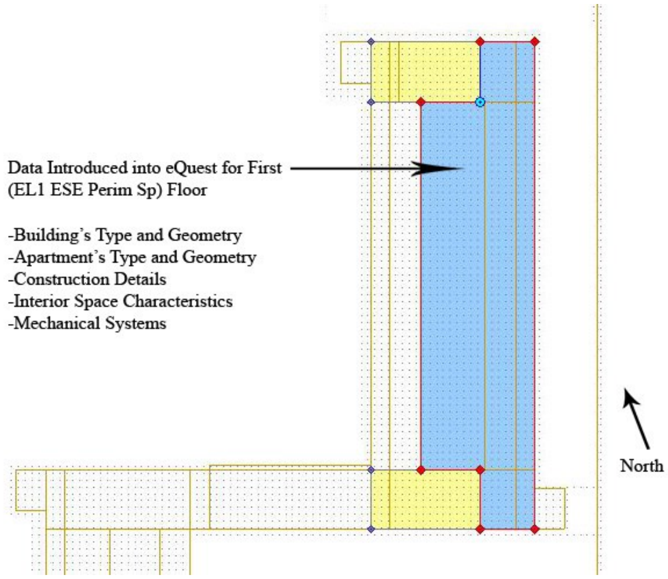


Figure 60. Zone Simulated for the Grocery Store Section of the Building.

The base-case building for the grocery store only has one floor. This floor is the basement of the previously analyzed building for the residential apartment complex. This selected building (in Figure 61, Figure 62 and Figure 63) is located in the corner of Felix Cuevas Avenue and Coyoacan Avenue. As a reminder, the retail area (the first floor) and the multi-family apartments' area (the second through thirteenth floors) were separately simulated in order to calculate the base-case building energy-use.

Figure 61. First Floor of the Building Analyzed: Part 1 (Photo by Jose Luis Bermudez Alcocer).

Figure 62. First Floor of the Building Analyzed: Part 2 (Photo by Jose Luis Bermudez Alcocer).

Figure 63. First Floor of the Building Analyzed: Part 3 (Photo by Jose Luis Bermudez Alcocer).

4.2.1.2.1. Grocery Store Section Modeling.

In the same manner as the apartment simulation, the MEXICO91, a weather data file from the DOE-2 website (Hirsch, 2006), was used to model the grocery store in the building. The grocery store used a single zone created and analyzed with the software.

4.2.1.2.2. General Shell and Building Footprint Data Introduced for the Grocery Store Section.

Table 57 displays the parameters introduced for the general shell information and the building footprint. This table has the data of the position of the only zone of the building's grocery store. Figure 64 shows the single-floor shell created to simulate the whole-building geometry. The first floor shell is located at the Cartesian coordinates x equals to 0 ft., y equals to 0 ft., and z equals to 0 ft. and has 9,217 ft². The building footprint data is also provided in Table 57. The zone name for the shell is called EL1 ESE Perim Sp (G.ESE1). The following information was used for the input: the zone is considered as conditioned zone; the building orientation is 13°. Figure 65 shows the floor-to-floor height floor-to-floor (11.8 ft.); and the floor-to-ceiling height was assumed as 10.8 ft.[87]

Finally, Table 57 has the parameters of the building envelope construction for this zone. Roof_3 has an 8 inch (in.) concrete slab to simulate the roof for this shell.[88] Wall_1 has an 8 in. brick wall to simulate the vertical exterior walls.[89] This shell was placed as show at the site, and has direct contact with the earth.

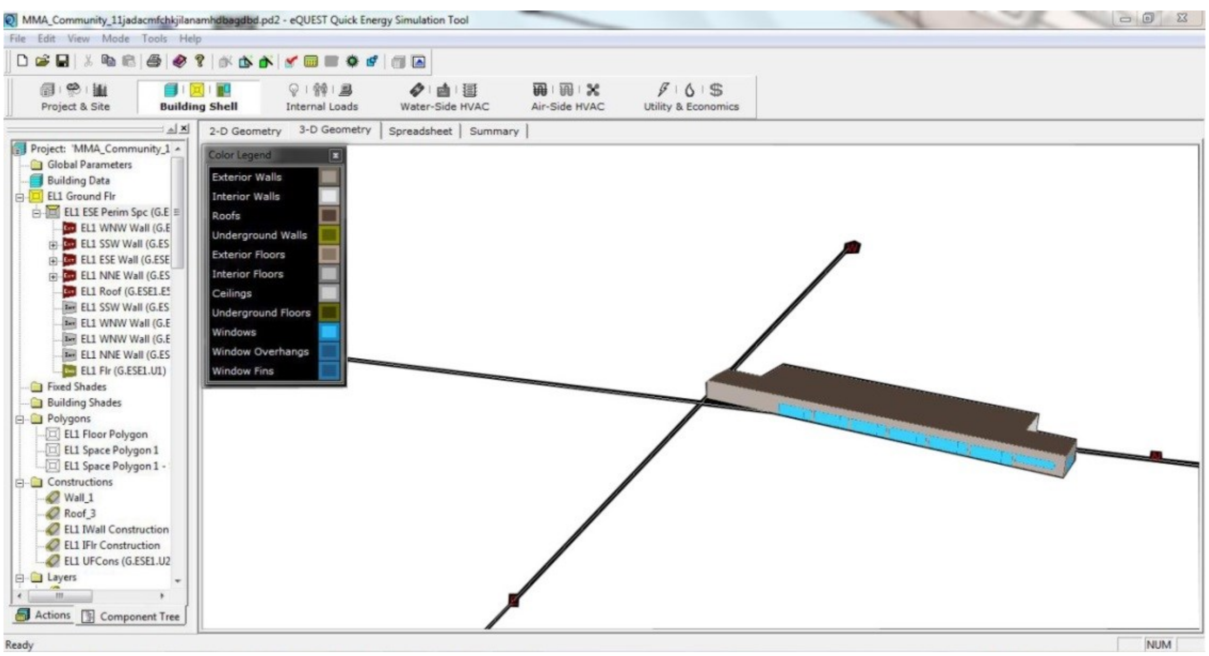


Figure 64. Shell Simulated in eQuest for the Grocery Store Section.

[87] The interior spaces do not have ceilings.
[88] The overall R-Value is 96.009 h-ft²-°F/BTU. This R-Value is modeling a high insulated roof, because the apartment section is not placed above the zone in this file. Therefore, the roof needs to be highly insulated in order to avoid heat gains to the zone.
[89] The overall R-Value is 3.810 h-ft²-°F/BTU. The decimals are slightly different from the R-Value of the Wall_1 in the apartment section.

Table 57. General Shell and Building Footprint Data Introduced for the Grocery Store Sector.

Item	Name of Parameter			Base-Case Input	References	Comments
Shell	Area and Floors	Specify Exact Site Coordinates		0 ft, 0 ft, 0 ft		
		Building Area		9,217 ft²	Approximated from the floorplan (Pani, 1952)	Per Floor
		Number of Floors		1	Approximated from pictures taken by Jose Luis Bermudez Alcocer	See Fig.61, Fig.62 and Fig.63
		Below Grade		0	N/A	
		Shell Multiplier		1	Assumption	
Building Footprint		Zone Names		EL1 ESE Perim Sp (G.ESE1)		
		Zone characteristics		Conditioned		
		Building Orientation		13°	Approximated from the floorplan (Pani, 1952)	
		Height Floor to Floor		11.8 ft	Approximated from picture taken by Jose Luis Bermudez Alcocer	See Fig.65
		Height Floor to Ceiling		10.8 ft		
Building Envelope Constructions	Roof Surfaces	Roof_3	Surface Type	Roof		
			Layer	Concrete 80 lbs.	Assumed from existing data (De Anda, 2008)	
			U-Value	0.024 Btu/h-ft²-°F		
	Above Grade Walls	Wall_1	Surface Type	Vertical Exterior Wall		
			Layer	Surface Air Film (AL01)		
			Layer	Brick	Assumed from existing data (De Anda, 2008)	
			Layer	Surface Air Film (AL01)		
			U-Value	2.70 Btu/h-ft²-°F		
		Exposure		Earth Contact		
		U-Value		0.010 Btu/h-ft²-°F		
	Ground Floor	Interior Finish		Ceramic/Stone Tile	Assumed from pictures taken by Jose Luis Bermudez-Alcocer	
		Construction		8 in. Concrete	Assumed from existing data (De Anda, 2008)	

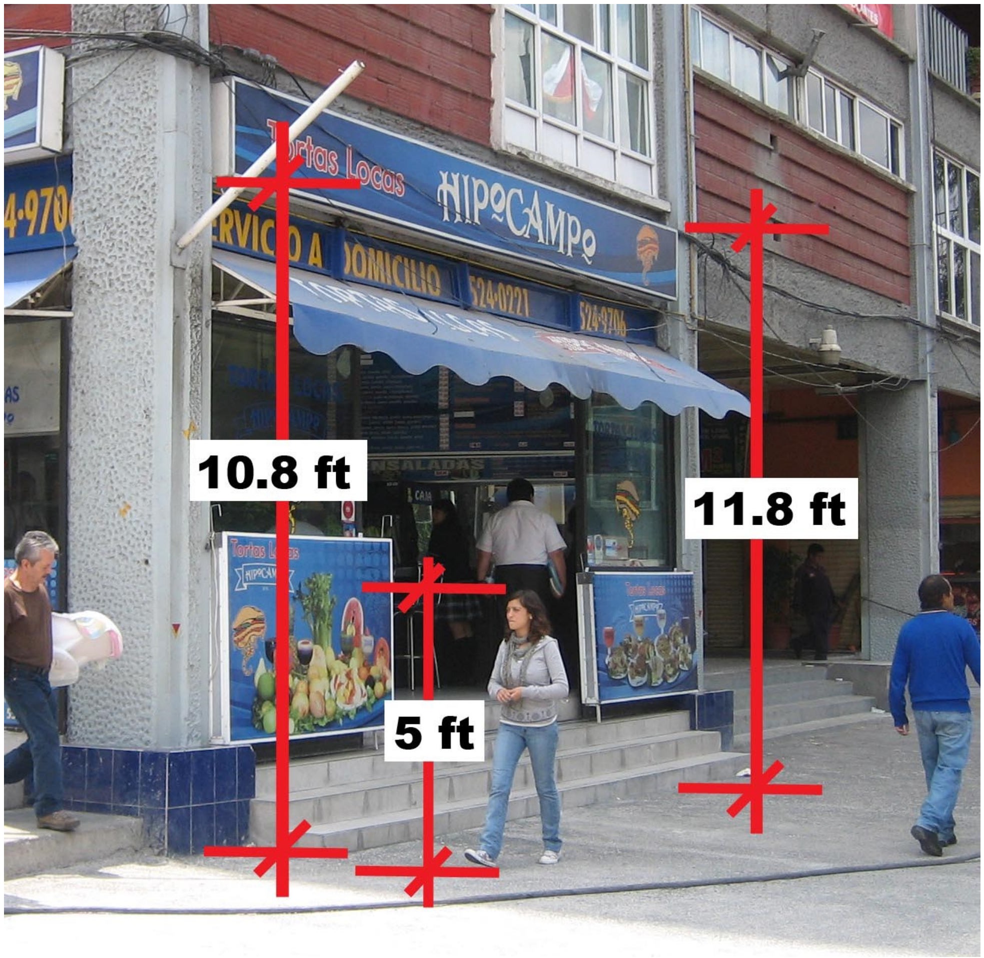


Figure 65. Detail to Calculate Floor-to-Floor Height on the Façade for the Grocery Store. (Photo by Jose Luis Bermudez Alcocer).

In a similar fashion as the simulation of the apartment, custom weighting factors were used here (Hirsch & Associates, 2009). In the model, the custom weighting factors were introduced by setting the floor weight equal to zero. Each floor was considered as one zone with no interior walls or ceilings. The zone only has a floor, walls and a roof.

4.2.1.2.3. Door Construction Data Introduced for the Grocery Store Section.

Table 58 shows the parameters for exterior doors. The existing doors in this shell are single-clear glass doors with aluminum frame as present in Figure 66 and Figure 67.

Table 58. Doors Data Introduced for the Grocery Store Sector.

Item	Name of Parameter			Base-Case Input	References	Comments
Doors	Door Types	1.- Glass	East	5	Approximated from the floorplan (Pani, 1952); Assumed from pictures taken by Jose Luis Bermudez Alcocer	Fig.66
			West	0		
			South	0		
			North	0		
		2.- Glass	East	1		Fig.67
			West	0		
			South	0		
			North	2		
		3.- Glass	East	0		
			West	0		
			South	0		
			North	2		
	Door Dimensions and Construction/Glass Definitions	1.- Glass	Ht. (ft)	7	Approximated from the floorplan (Pani, 1952); Assumed from pictures taken by Jose Luis Bermudez Alcocer	Fig.66
			Wd. (ft)	5.4		
			Construction or Glass Category	Single Clear/Tint		
			Glass Type	Single clear 1/4 in. (1001)		
			Frame Type	Aluminum w/o Break		
			Frame Wd. (in.)	3 in.		
		2.- Glass	Ht. (ft)	7 ft		Fig.67
			Wd. (ft)	5.6 ft		
			Construction or Glass Category	Single Clear/Tint		
			Glass Type	Single clear 1/4 in. (1001)		
			Frame Type	Aluminum w/o Break		
			Frame Wd. (in.)	3 in.		
		3.- Glass	Ht. (ft)	7 ft		
			Wd. (ft)	5.2 ft		
			Construction or Glass Category	Single Clear/Tint		
			Glass Type	Single clear 1/4 in. (1001)		
			Frame Type	Aluminum w/o Break		
			Frame Wd. (in.)	3 in.		

Figure 66. Exterior Doors on East-SouthEast Façade. (Photo by Jose Luis Bermudez Alcocer).

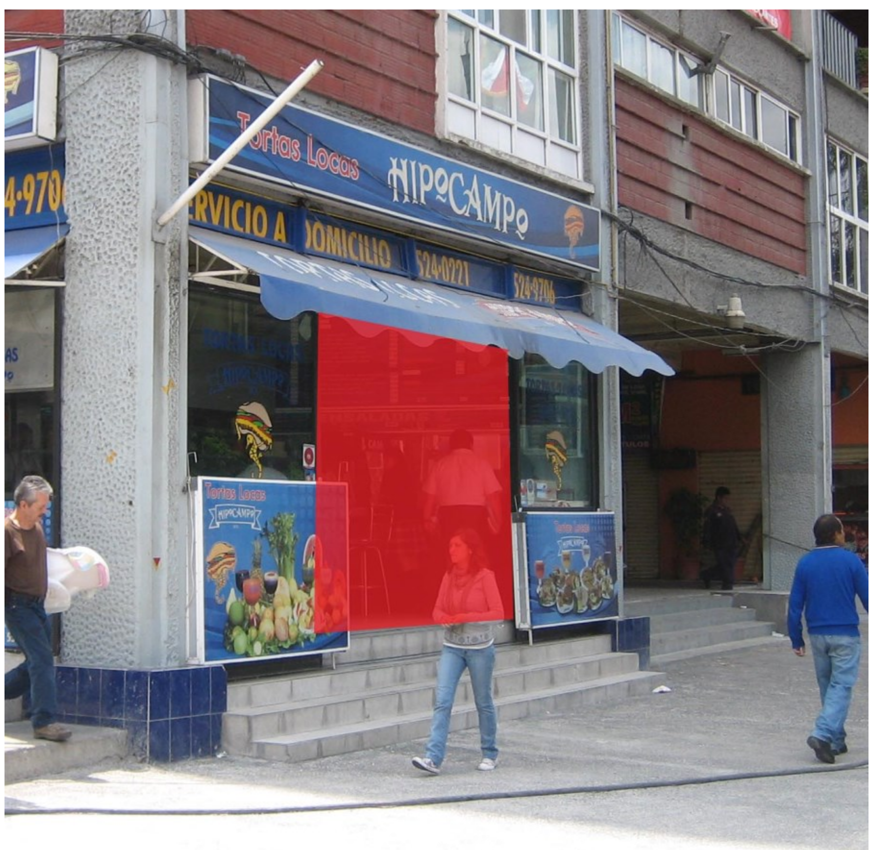


Figure 67. Exterior Doors on North-NorthEast Façade in the Red-Colored Rectangle. (Photo by Jose Luis Bermudez Alcocer).

4.2.1.2.4. Window Data Introduced for the Grocery Store Section.

The information for the building exterior windows is shown in Table 59. The windows in the complex are shown in Figure 61, Figure 62, Figure 63 and Figure 67, which are operable with single pane glazing and aluminum frames without a thermal break. There was not enough information found for u-value, shading coefficient, and visible transmittance in Mexico. Therefore, this information was obtained from the Center for Sustainable Building Research, the Alliance to Save Energy, and the Lawrence Berkeley National Laboratory (CSBR/ASE/LBNL, 2012).[90]

4.2.1.2.5. Daylighting Controls Data Introduced for the Grocery Store Section.

The parameters used for locating the daylighting sensors are shown in Table 60. To perform the simulation, the daylighting controls were deactivated for the base-case simulation. It is critical that this information is not needed in the base-case, but it is activated once the store is simulated using energy-efficient measures. This allowed the calculation of the energy consumption of the base-case model without any savings due to daylighting (Hirsch & Associates, 2009). The procedure to place the sensors is used the following steps:

1) Turn on the daylighting controls.
2) Rotate the daylighting controls in order to face the windows. Figure 68 presents the origin point (where X equals to 0, Y equals to 0 and Z equals to 0) and the daylighting controls for the zone ESE Perimeter Space (G.ESE1).
3) Table 61 shows the daylighting control location into the zones. The sensors 1 and 2 from the ESE Perim Zone were located on the south-southwest orientation. Once the energy-efficiency measures were run together in Case 8 and 9, these two systems face south.

---

[90] U-Value = 1.11 BTU/h-ft² °F, shading coefficient = 0.86, and visible transmittance = 0.9.

Table 59. Windows Data Introduced for the Grocery Store Sector.

Item	Name of Parameter				Base-Case Input	References	Comments
Windows	Window Type	1.- Glass	Number of Panes		Single	Assumed from pictures taken by Jose Luis Bermudez Alcocer	
			Frame Type		Aluminum w/o Break, Operable		
			Frame Wd. (in.)		1.3 in.		
			Glass Tint		Clear Glass		
			U-Value		1.11 Btu/h-ft² °F	CSBR/ASE/LBNL, 2012; AEDG ASHRAE, 2006	
			Shading Coefficient		0.86		
			Visible Transmittance		0.90		
	Window Dimensions, Positions and Quantities	1.- Glass	Width (ft)		16.13	Approximated from the floorplan (Pani, 1952); Assumed from pictures taken by Jose Luis Bermudez Alcocer	
			Window ht (ft)		7		
			Sill		0		
			% Windows (floor to floor, including frame)	East	4.5		
				West	0		
				South	47.2		
				North	0		
		2.- Glass	Width (ft)		16.68	Approximated from the floorplan (Pani, 1952); Assumed from pictures taken by Jose Luis Bermudez Alcocer	
			Window ht (ft)		7		
			Sill		0		
			% Windows (floor to floor, including frame)	East	4.6		
				West	0		
				South	0		
				North	0		
		3.- Glass	Width (ft)		19.82	Approximated from the floorplan (Pani, 1952); Assumed from pictures taken by Jose Luis Bermudez Alcocer	
			Window ht (ft)		4		
			Sill		3		
			% Windows (floor to floor, including frame)	East	3.2		
				West	0		
				South	0		
				North	0		

Table 60. Daylighting Controls Data Input for First Floor of the Grocery Store Sector.

Item	Name of Parameter		Base-Case Input	References	Comments
Daylighting	Daylighting	Daylighting Controls	No		
		Daylit	Side Lighting		
		Daylit Area Method	CA Title-24 2008	eQuest Default	
		Area	1,441 Sq.Ft. (12%) of Top Floor is Daylightable	Calculated by eQuest	
		Design Light Level	50 fc	ASHRAE, 2010a	
		Lighting Control Method	Dimming: 30% Light (30% PWR)	eQuest Default	

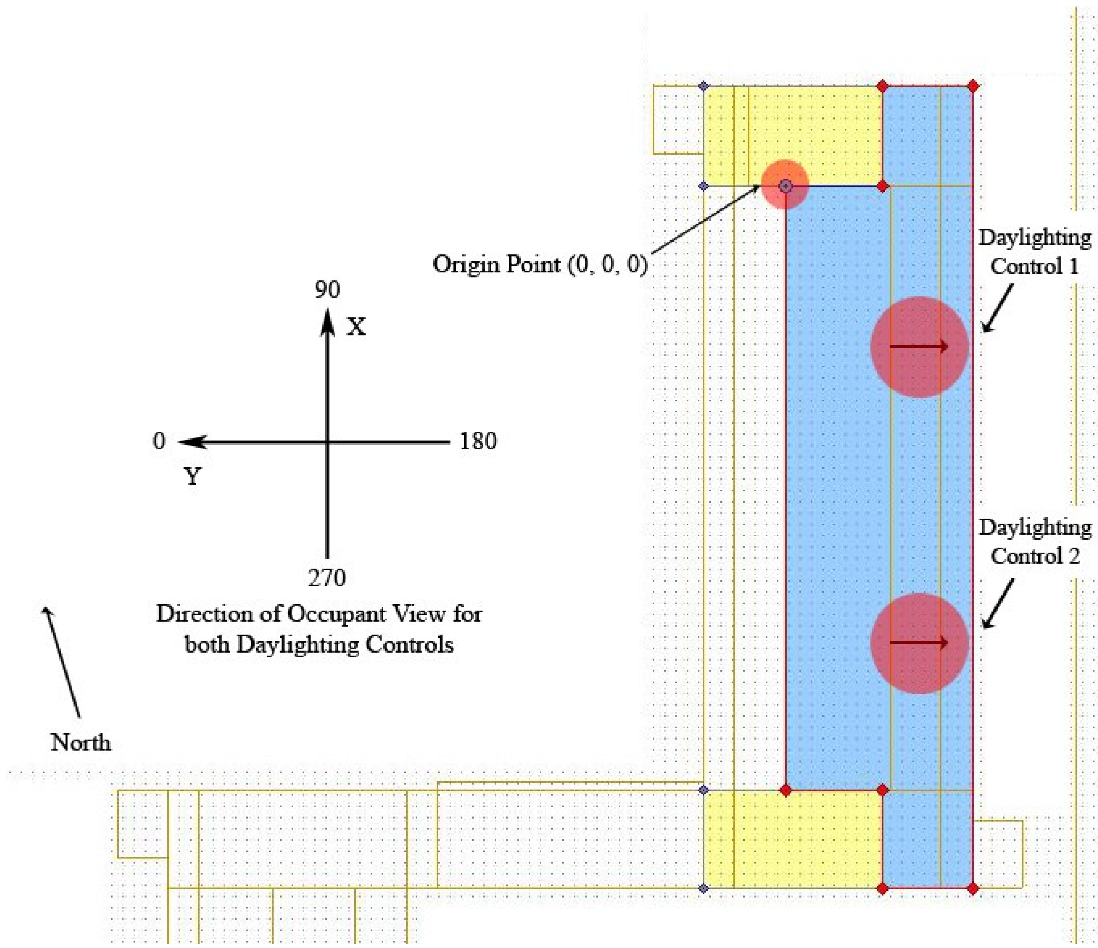


Figure 68. Daylighting Controls into the the Zone ESE Perimeter Space of the Grocery Store (G.ESE1).

Table 61. Daylighting Control Location in the Zone for Grocery Store.

Zone	Daylighting Control	Azimuth	X	Y	Z
ELE1 ESE Perimeter Space (G.ESE1)	System 1	0	25	40.0	3.0
	System 2	0	100	40.0	3.0

4.2.1.2.6. Lighting, Appliances, Occupancy and Infiltration Data Used for the Grocery Store Section.

The lighting and appliance power use, and the representative lighting, appliance, occupancy and infiltration schedules were essential to obtain the building energy base-case. However, before going further, it was required to set a EUI for the grocery store. Therefore, the national average EUI for the food sales building types were obtained from the 2003 CBECS report (US EIA, 2006), which gave a value of 199.7 kBtu/ ft^2-year. By comparison in this study the simulation result showed 123.5 kBTU/ ft^2-year. The national average electricity use from the US EIA for the food sales building type was 49.4 kWhr/ft^2-year (US EIA, 2006), which was reasonably close to the current study's result of 36.21 kWhr/ft^2-year. This value was considered reasonable since it was assumed that both eQuest results (123.56 kBTU/ ft^2-year and 36.21 kWhr/ft^2-year)[91] were below the 2003 CBECS results due to the lack of refrigeration in the grocery store.

The input values for the lighting, equipment, occupancy and infiltration were determined as follows:

- The lighting power density of 1.85 W/ft^2 was assumed, which complies with *CONAE* (2005a) and *SENER* (2005).
- The equipment power density of 1.27 W/ft^2 was assumed. Originally, a value of 0.5 W/ft^2 was considered (Deru et al., 2011; Mukhopadhyay, 2013). However, the number of display cases and their power density were calculated for this technical potential study as follows: the typical store size area is 47,500 ft^2 with 60 refrigerators required (Goetzler et al., 2009). Thus, the estimation number of the refrigerator cases were assumed as follows:
    - (9,217 ft^2 proposed grocery store area X 60 display cases (Goetzler et al., 2009)) / 47,500 ft^2 typical store area = 12 display cases.
    - The Energy Star Commercial Refrigerator Qualified Product List (2013a) is consulted in order to measure the power density. Two different coolers from the brand True are used for the analysis: the 194-GDM-69 and the 196-GDM-

[91] These simulation results are using 2.5 CFM/ft^2.

49F. The 194 modelis a cooler with three doors, and keeps cold beverages, sodas, milk, juice, yogurts, eggs, etc (Pride Marketing & Procurement, Inc., n.d.).[92] Whereas, the 196 model is a freezer with two doors that keeps mainly frozen goods (Pride Marketing & Procurement, Inc., n.d.).

- The power density calculation was calculated as next:
    - o 194-GDM-69 has 8.2 kWh/day X 7 refrigerators = 57.4 kWh/day/24 hr = (2.39 kW X 1,000 W/ 9,217 ft²) = 0.26 W/ft².
    - o 196-GDM-49F has 22.74 kWh/day X 5 refrigerators = 113.7 kWh/day/24 hr = (4.74 kW X 1,000 W/ 9,217 ft²) = 0.51 W/ft².
    - o 0.5 W/ft² (from original power density) + 0.26 W/ft² (from seven-194-GDM-69 refrigerators) + 0.51 W/ft² (from five-196-GDM-49F refrigerators) = 1.27 W/ft²
- The occupancy area/person was calculated to be 124.5 ft²/person (*ASHRAE Standard 62.1-2010*). Hupel (2013) suggested using an occupancy density of 8 people/1,000 ft² for a supermarket from Table 6.1 from *ASHRAE 62.1-2010* (2010).[93] This would yield:
    - o 9,217 ft² X 8 people/1,000 ft² = 73.7 people or approx.74 people.
    - o 9,217 ft²/74 people = 124.55 ft²/person.
- The infiltration was assumed to be 0.161 ACH (Mukhopadhyay, 2013; Hale et al., 2008).
- Next, the schedules for the base-case model were developed using the information from the following sources:
    1) The lighting schedule was based from Mukhopadhyay (2013) in Figure 69.

[92] The 2010-2011 Reference Catalog Foodservice Equipment and Supplies Catalog (Pride Marketing & Procurement, Inc., n.d.) is obtained from Kesco Supply, Inc. Foodservice Equipment and Supplies in Bryan, Texas.
[93] Table 6.2.2.1 Minimum Ventilation Rates in Breathing Zone in *ASHRAE 62.1-2013 Ventilation for Acceptable Indoor Air Quality* (2013).

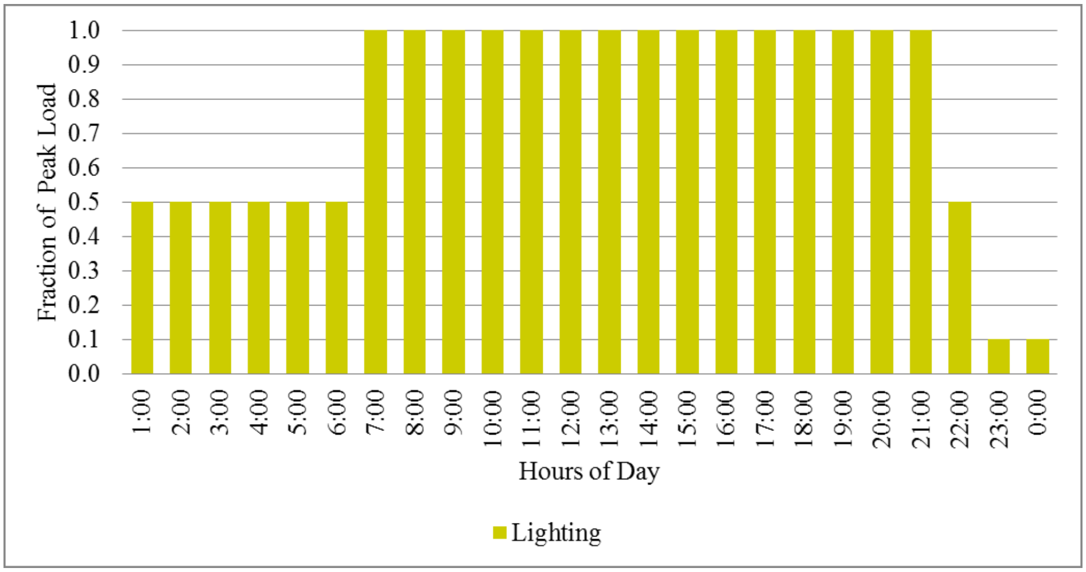


Figure 69. Profile for Lighting Schedule for the Grocery Store.

2) The appliances schedule is based from Deru et al. (2011) and Mukhopadhyay (2013) in Figure 70.

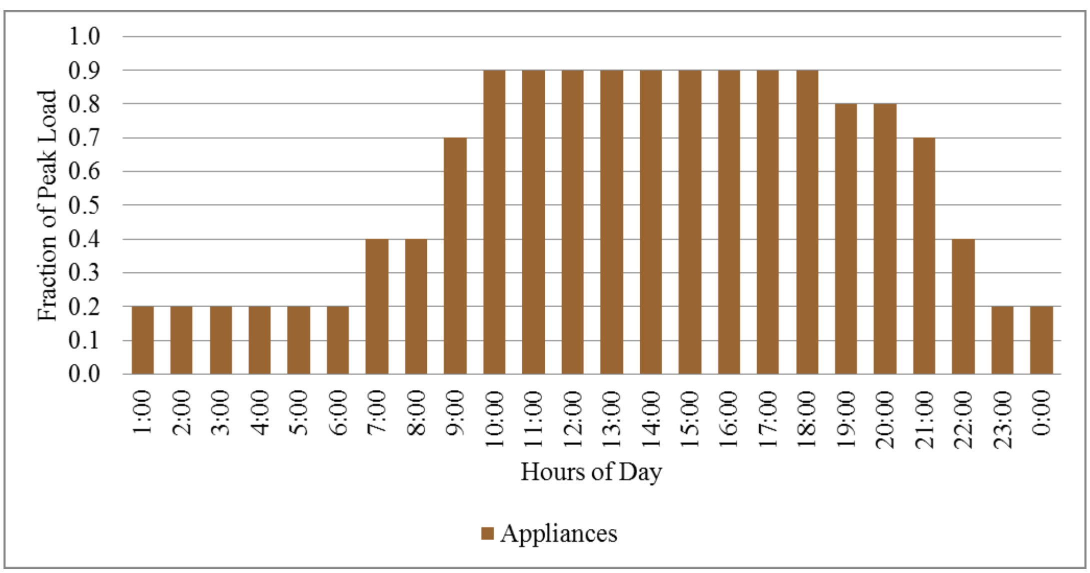


Figure 70. Profile for Appliances Schedule for the Grocery Store.

3) The occupancy schedule is based from Hale et al. (2008) and Mukhopadhyay (2013) in Figure 71.

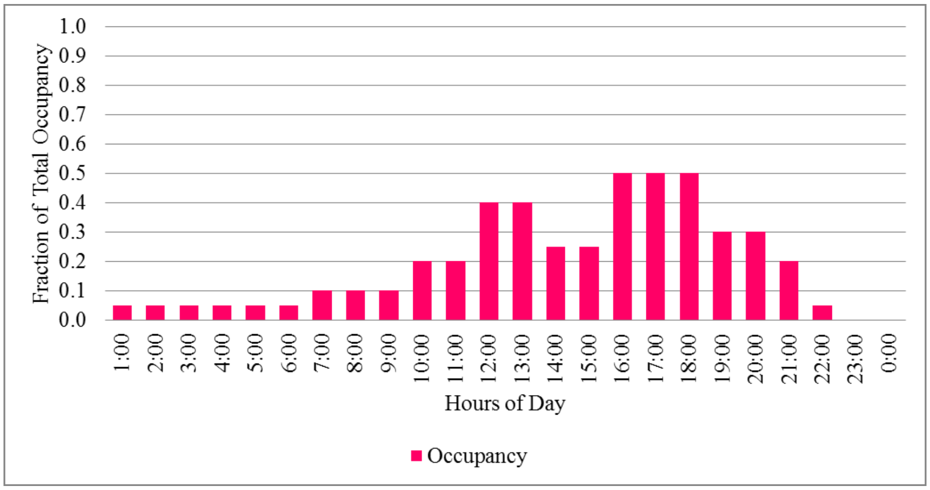


Figure 71. Profile for Occupancy Schedule for the Grocery Store.

4) The infiltration schedule is based from Hale et al. (2008) and Mukhopadhyay (2013) in Figure 72.

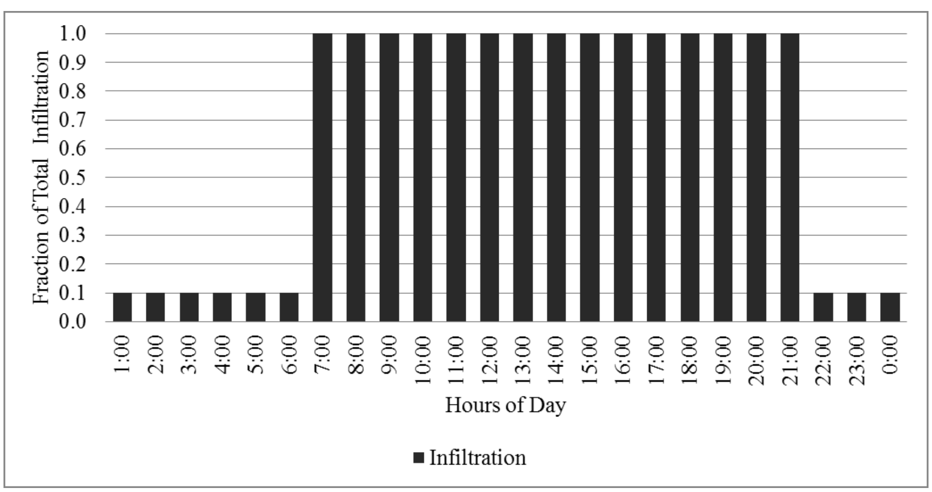


Figure 72. Profile for Infiltration Schedule for the Grocery Store.

4.2.1.2.7. Air-Conditioning System Data Introduced for the Grocery Store Section.

The air-side system type, the seasonal thermostat setpoints and design temperatures data is shown in Table 62. The air-side system chosen was a Packaged Single Zone system with (PSZ) DX Coils for cooling and electric resistance heating. One system per floor shell was assumed for each floor. It also has a ducted return air path.[94] This choice of system is consistent with *CONUEE* (2007) and *DOE-2.1e Reference Manual Part 1* (LBL/LASL, 1980a). The grocery store used the air-conditioning system to maintain the food outside the refrigerators in the best possible condition during the year to sustain good sales.

For the grocery store, the seasonal thermostat setpoints used a range of 72°F for cooling and 70°F for heating. This tight range keeps the grocery store in comfort throughout the year. There are two sets of design temperatures input: the indoor and the supply. The indoor cooling and heating design temperatures are 72°F and 70°F. These indoor temperatures are the indoor temperatures to size the airflow of the PSZ system (eQuest Help Topics).

The supply minimum and maximum design temperatures used were 55°F and 100°F, respectively.[95] These supply temperatures were assumed to be temperature of air to be supplied to the grocery store zone during cooling or heating periods, respectively. They were also used in the DOE-2's HVAC design routine to size the zone airflow, but they were not used during the hourly simulation (eQuest Help Topics). According to the Help Topics Tool in eQuest, the air temperatures supplied to the grocery store on an hourly simulation depend on several other inputs such as: deck temperature control, duct, losses, economizer control, chilled water system control and so on.

To the size the cooling and heating systems the defaults were used in the simulation. The choice of the PSZ system is consistent with *CONUEE* (2007) who authorized these systems in Mexico. The minimum design airflow appointed was 1 CFM/ft². The system fans were auto-sized by the software. In addition, the fan was set to run continuously to introduce

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[94] According to the DOE-2.1e Manual (LBL/LASL, 1980a), the PSZ system may have a duct. In addition, the current building does not have a ceiling.

[95] IBPSA (2012) suggested using +20°F above the heating thermostat setpoint for the maximum supply and -20°F above the cooling thermostat setpoint for the minimum supply. Therefore, it was assumed to use 100°F for maximum supply temperature and 55°F for minimum supply temperature.

fresh air into the zone. The use of the continuous fan helps avoid the build-up of gases or odors produced from people, food, furniture, cardboard, etc. Therefore, the fans system operates continuously the whole day for each day of the year.

Table 62. Air-Conditioning System and Fan Data Introduced for the Grocery Store Sector.

Item	Name of Parameter			Base-Case Input	References	Comments
Air-Conditioning System	System Type	Cooling Source		DX Coils		
		Heating Source		Furnace		
		System Type		Packaged Single Zone DX with Furnace	CONUEE, 2007; eQuest Help Topic; LBL/LASL, 1980a	
		System per Area		System per Shell		
		Return Air Path		Ducted		
	Seasonal Thermostat Setpoints	Occupied (°F)	Cool	72°F		
			Heat	70°F		
		Unoccupied (°F)	Cool	72°F		
			Heat	70°F		
	Design Temperatures	Indoor	Cooling Design Temperature	72°F	IBPSA, 2012	
			Heating Design Temperature	70°F		
		Supply	Minimum Temperature	55°F		
			Maximum Temperature	100°F		
	System Type	Cooling	Overall Size	Auto-Size	eQuest Default	
			Typical Unit Size	135-240 kBtuh or 11.25-20 tons	eQuest Default	
			Condenser Type	Air-Cooled	eQuest Default	
			Efficiency	EER 8.500	eQuest Default	
		Heating	Size	Auto-Size		
	Air Flows	Supply Flow		1 cfm/ft²		
Fan	Operation	Cycle Fans at Night		No Fan Night Cycling	LBL/LASL, 1980a	
		Fan Mode		Continuous	LBL/LASL, 1980a	

4.2.1.2.8. Obtain the Hourly Reports.

Table 63 shows the different hourly reports from the software. These reports were valuable in order to create the final tables and graphs for the building energy base-case for the retail section. These hourly reports were also used and explained in secion 4.2.1.1.8.

Table 63. Hourly Reports Obtained from eQuest.

Report	Units	eQuest Sub-program	Variable Type	Variable List
Outdoor Dry-Bulb Temperature	°F	Loads	Global	4
Outdoor Wet-Bulb Temperature	°F			3
Sensible Heating Load	Btu/hr.		Building Loads	1
Latent Heating Load				2
Sensible Cooling Load				19
Latent Cooling Load				20
Outdoor Dry-Bulb Temperature	°F	Systems	Global	4
Outdoor Wet-Bulb Temperature	°F			3
Zone Temperature	°F		Thermal Zone	6
Return Air Humidity Ratio	lb $H_2$0/lb dry air		HVAC System	35

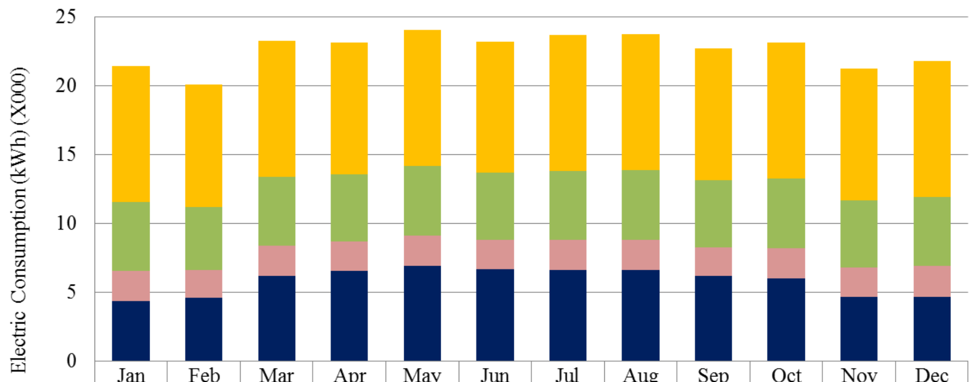
4.2.1.2.9. Obtain the Results for Energy Consumption for the Grocery Store Sector.

Finally, the simulation was run and the results are presented in Table 64. The first column is the energy end-use label. The second through thirteenth column are the energy consumption for each month. The fourteenth column is the total annual energy consumption.

Table 64. Monthly Energy Consumption by End-Use in kWh (X 1,000) for the Grocery Store.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000	kWh X 1,000
Area Lights	9.88	8.93	9.88	9.57	9.88	9.57	9.88	9.88	9.57	9.88	9.57	9.88	116.39
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	5.04	4.56	5.04	4.88	5.04	4.88	5.04	5.04	4.88	5.04	4.88	5.04	59.4
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	2.2	1.98	2.2	2.13	2.2	2.13	2.2	2.2	2.13	2.2	2.13	2.2	25.87
Space Heat	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Cool	4.31	4.61	6.15	6.55	6.92	6.63	6.58	6.6	6.14	6	4.67	4.67	69.84
Total	21.44	20.08	23.27	23.13	24.05	23.21	23.7	23.73	22.71	23.13	21.25	21.8	271.49

Figure 73 displays the data in Table 64. In Figure 73, the lighting, equipment, fans and cooling energy consumption are relatively constant from March to October. The consumption for January, February, November and December slightly droped down compared to the March-October season.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Area Lights	9.88	8.93	9.88	9.57	9.88	9.57	9.88	9.88	9.57	9.88	9.57	9.88
Misc. Equip.	5.04	4.56	5.04	4.88	5.04	4.88	5.04	5.04	4.88	5.04	4.88	5.04
Vent. Fans	2.2	1.98	2.2	2.13	2.2	2.13	2.2	2.2	2.13	2.2	2.13	2.2
Space Cool	4.31	4.61	6.15	6.55	6.92	6.63	6.58	6.6	6.14	6	4.67	4.67

Figure 73. Monthly Energy Consumption by End-Use for the Grocery Store.

Figure 74 and Figure 75 exhibited that the hours during the year are inside the thermal comfort zone. In Figure 74 and Figure 75, the red box is the winter comfort zone, the green box is the summer comfort zone, and the blue points are the annual hourly data from the simulation. 4,688 hours[96] are not inside the 70 to 72°F temperature range originally chosen for the thermostat setpoints. An analysis of the data revealed that the reason why some hours were outside the 70 to 72°F range was because there was not enough air supplied to the zone. A check of the volume of the building is calculated as follows:

9,217 ft² (area of the grocery store) X 11.8 ft (height) = 108,763 ft³

The supply flow using 1 CFM/ft² is determined as next:

9,217.2 ft² (area of the grocery store) X 1 CFM/ft² X 1.15 (sizing ratio) = 10,669 CFM[97]

Therefore, it was suggested to increase the CFM/ft². Table 65 displays different amounts of CFM/ft² in the first column, and the cooling, heating and ventilation energy

[96] 4,688 hours X 100 / 8,760 hours = 53.5 percent of the hours outside the 70 to 72°F.
[97] 10,669 CFM for supply flow is registered in the SV-A Report System Design Parameters for EL1 SYS1 (PSZ).

consumption from the second to the fourth column. The fifth column is the CFM, the sixth column is the minutes that it takes to introduce fresh air into the building, and the seventh column is the ACH.

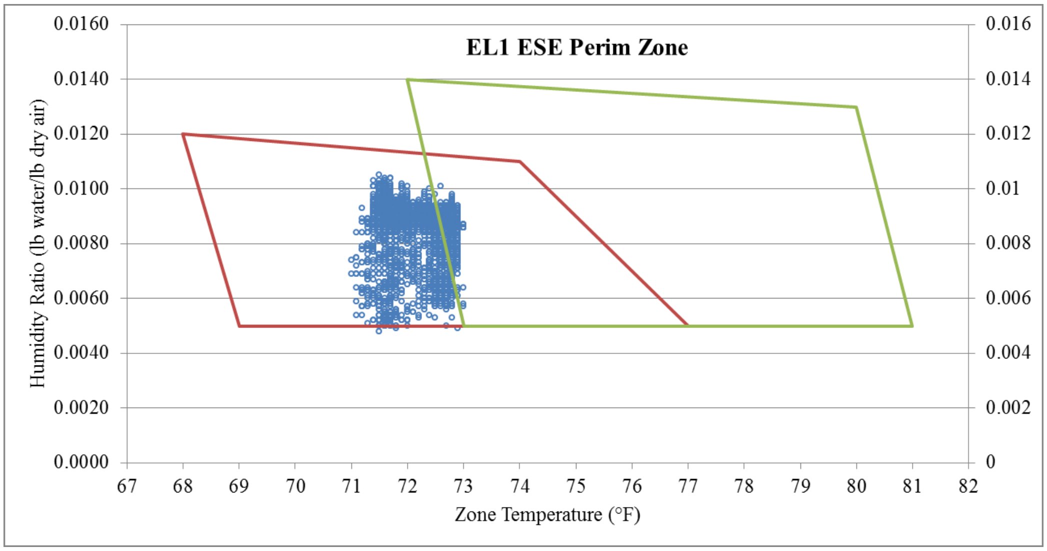


Figure 74. Thermal Comfort Zone Analysis Using 1 CFM/ft² for the Grocery Store.

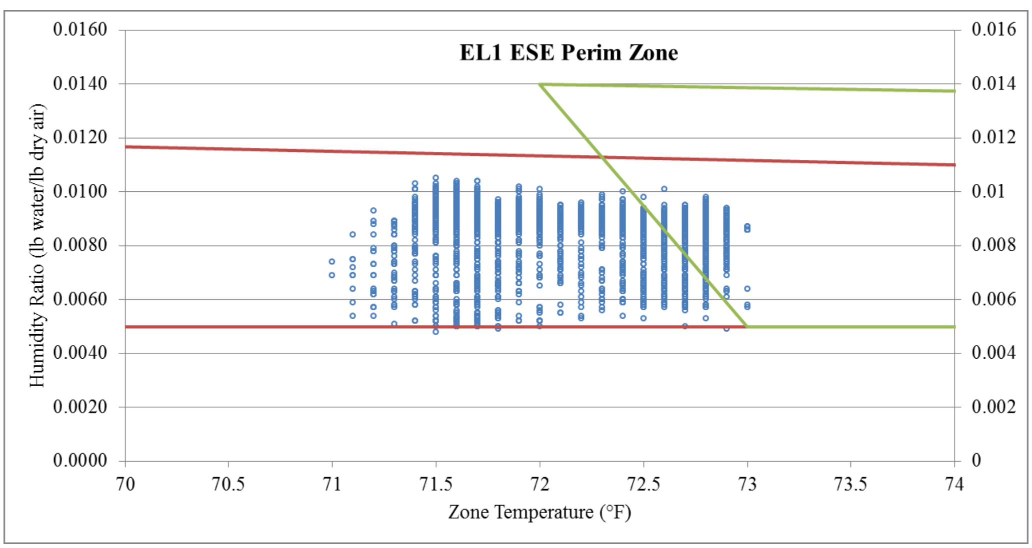


Figure 75. Thermal Comfort Zone Analysis Using 1 CFM/ft² (Enlarged View) for the Grocery Store.

Table 65. Analysis of Different CFM/ft² Applied to the Grocery Store Model.

	Cooling	Heating	Ventilation	Supply Flow		
	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	CFM	Minutes	ACH
1 CFM/ft²	69.84	0	25.87	10,669	10.19	6
2 CFM/ft²	85.05	0	51.41	21,200	5.13	12
2.5 CFM/ft²	93.72	0	64.26	26,500	4.10	15
3 CFM/ft²	102.68	0	77.11	31,799	3.42	18

The 21,200 CFM, the 26,500 CFM, and the 31,799 CFM supply flow in Table 65 were determined as follows:

9,217.2 ft² (area of the grocery store) X 2 CFM/ft² X 1.15 (sizing ratio) = 21,200 CFM

9,217.2 ft² (area of the grocery store) X 2.5 CFM/ft² X 1.15 (sizing ratio) = 26,500 CFM

9,217.2 ft² (area of the grocery store) X 3 CFM/ft² X 1.15 (sizing ratio) = 31,799 CFM

The number of minutes, in Table 65, to introduce fresh air into the building is:

(For 2 CFM/ft²) 108,763 ft³/21,200 ft³/min = 5 min with 12 ACH

(For 2.5 CFM/ft²) 108,763 ft³/26,500 ft³/min = 4 min with 15 ACH

(For 3 CFM/ft²) 108,763 ft³/31,799 ft³/min = 3 min with 18 ACH

To conclude, once the CFM/ft² was raised to 2 in Figure 76, only 351 hours[98] were outside the thermostat range from 70°F to 72°F. If the minimum design flow rate is raised to 2.5 CFM/ft² in Figure 77, all the hours were inside the thermostat range from 70°F to 72°F. Figure 78 shows all the hours inside the thermostat range from 70°F to 72°F using 3 CFM/ft². Therefore, it became clear that more than 1 CFM/ft² should be used to maintain the hours inside the thermal comfort zone during the year. Since, the volume of the building is probably too big for one single PSZ system, for future work, the grocery store should be

[98] 351 hours X 100 / 8,760 hours = 4 percent of the hours outside the 70 to 72°F.

divided into more zones. This would allow for more effective control of the outside air ventilation.

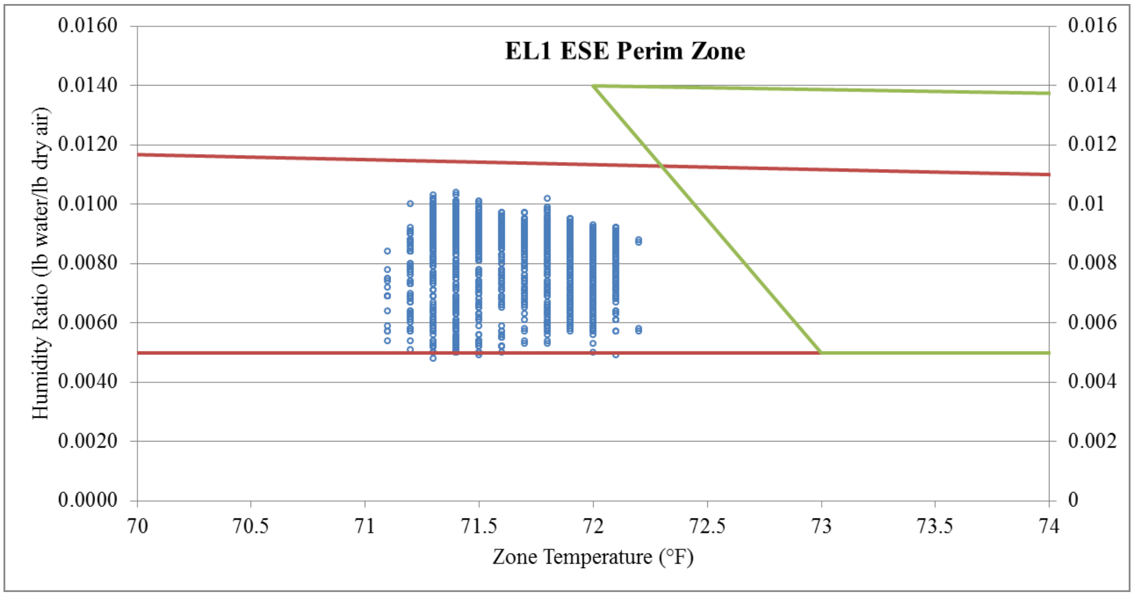


Figure 76. Thermal Comfort Zone Analysis Using 2 CFM/ft² (Enlarged View) for the Grocery Store.

Table 66 shows the EUI comparison between the simulation results and the relevant data from the 2003 CBECS report. In the current study the main reason the total EUI is below the 2003 CBECS results is because of the reduced refrigeration load in the grocery store.

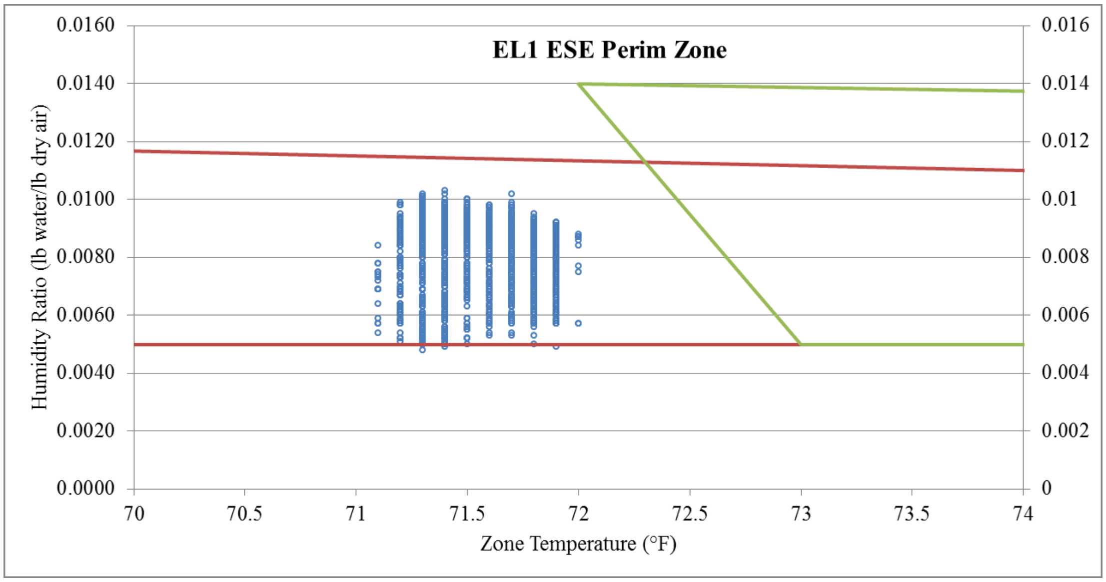


Figure 77. Thermal Comfort Zone Analysis Using 2.5 CFM/ft² (Enlarged View) for the Grocery Store.

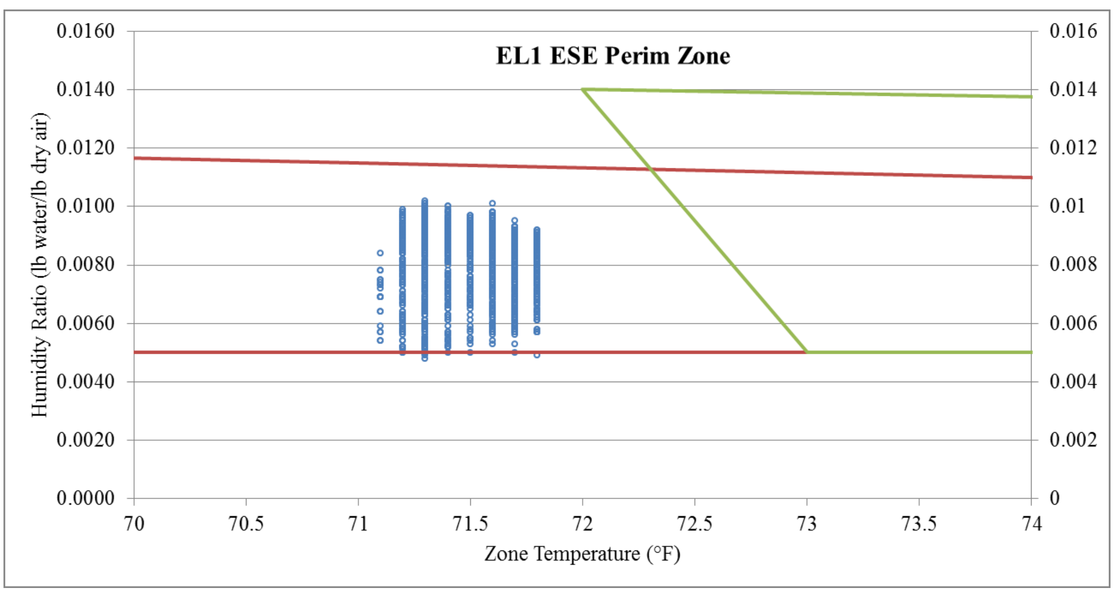


Figure 78. Thermal Comfort Zone Analysis Using 3 CFM/ft² (Enlarged View) for the Grocery Store.

Table 66. **EUI Comparison between the eQuest Results and the 2003 CBECS.**

	1 CFM/ft²	2 CFM/ft²	2.5 CFM/ft²	3 CFM/ft²
kWh/ft²-year (from eQuest results)	29.46	33.88	36.21	38.58
kWh/ft²-year (from the 2003 CBECS)	49.40	49.40	49.40	49.40
kBTU/ft²-year (from eQuest results)	100.51	115.59	123.56	131.63
kBTU/ft²-year (from the 2003 CBECS)	199.70	199.70	199.70	199.70

Figure 79 displays the interior zone temperature and the corresponding outdoor dry-bulb temperature as a time series plot. The interior zone temperature is represented with blue color and the dry-bulb temperature with a light red color. Figure 79 shows the interior zone temperature is tightly controlled in the 70 to 72°F range. This means that the air-conditioning system is working properly and reacting to the loads.

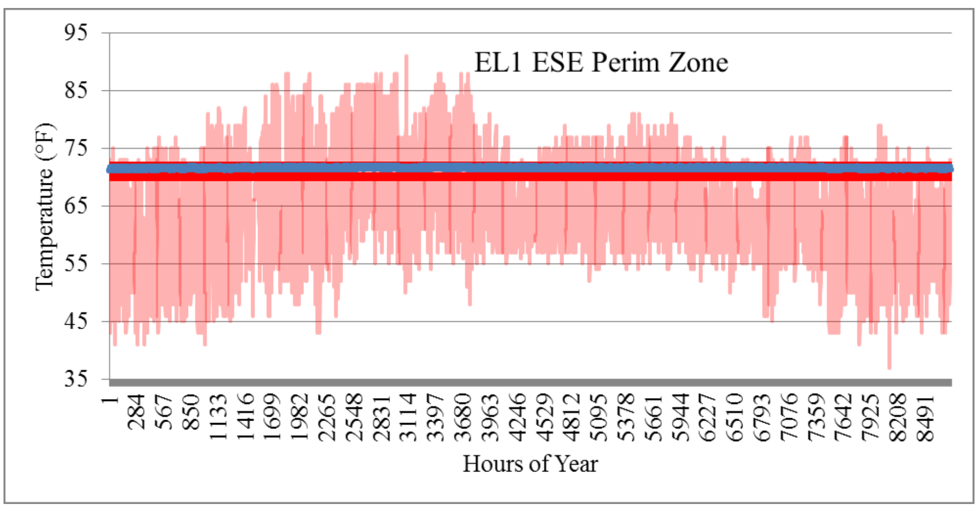


Figure 79. Interior Zone Temperature and Corresponding Dry-Bulb Temperature Time Series Plot for EL1 ESE Perim Zone.

Finally, it was decided that the file with the 2.5 CFM/ft² should be used for the remaining grocery store analysis. Table 67 and Figure 80 display the results from this run. As seen in Table 67, the first column is the end-use. The second through thirteenth column are the energy consumption for each month. The fourteenth column is the total annual energy consumption by end-use.

Table 67. Monthly Electricity Use by End-Use in kWh (X 1,000) for the Grocery Store.

	Jan kWh X 1,000	Feb kWh X 1,000	Mar kWh X 1,000	Apr kWh X 1,000	May kWh X 1,000	Jun kWh X 1,000	Jul kWh X 1,000	Aug kWh X 1,000	Sep kWh X 1,000	Oct kWh X 1,000	Nov kWh X 1,000	Dec kWh X 1,000	Total kWh X 1,000
Area Lights	9.88	8.93	9.88	9.57	9.88	9.57	9.88	9.88	9.57	9.88	9.57	9.88	116.39
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	5.04	4.56	5.04	4.88	5.04	4.88	5.04	5.04	4.88	5.04	4.88	5.04	59.4
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	5.46	4.93	5.46	5.28	5.46	5.28	5.46	5.46	5.28	5.46	5.28	5.46	64.26
Space Heat	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Cool	6.21	6.32	8.2	8.61	9.03	8.66	8.67	8.71	8.15	8.03	6.53	6.59	93.72
Total	26.6	24.74	28.59	28.34	29.41	28.39	29.06	29.1	27.88	28.41	26.26	26.97	333.76

In Figure 80, as well as in Figure 73, the lighting, equipment, fans and cooling energy consumption are very uniform from March to October. The consumption for January, February, November and December slightly drops down compared to the March-October season, which corresponds to a slightly reduced cooling load.

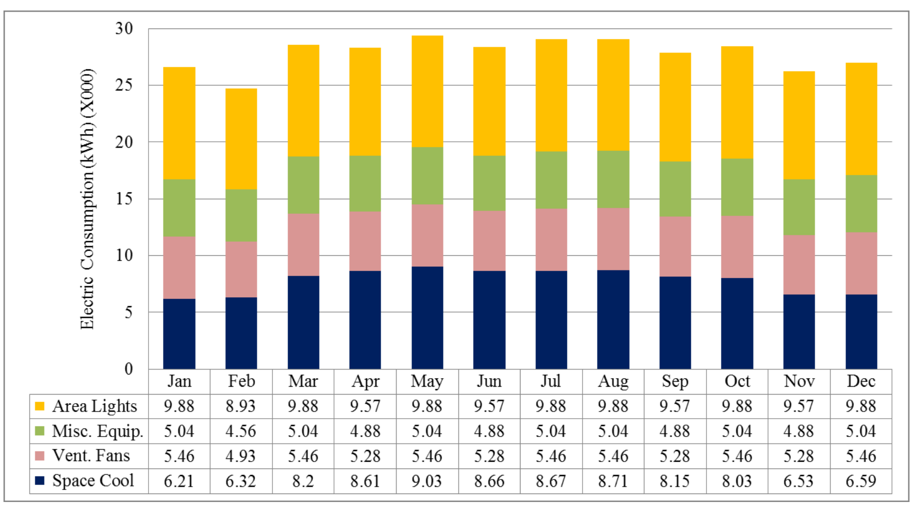


Figure 80. Monthly Energy Consumption by End-Use for the Grocery Store.

4.2.2. Base-Case Building Water-Use.

This section presents the results of the base-case building water-use for the *Multifamiliar Miguel Aleman.* This section is divided in two parts: base-case water-use for multi-family apartments and base-case water-use for the grocery store.

4.2.2.1. Base-Case Water-Use for Multi-Family Apartments.

This section is also divided in two parts: calculation of the potable water-use for fixtures and greywater reuse treatment for multi-family apartments, and the calculation for sizing the potable water storage tank for the multi-family apartments.

4.2.2.1.1 Calculation of the Potable Water-Use for the Fixtures and Greywater Reuse Treatment for Multi-Family Apartments.

First, it is essential to set the minimum potable water supply for the apartment portion of this technical potential study. To accomplish this, the *Gobierno del Distrito Federal* (2011) indicates that the minimum potable water supply for housing is 150 lt./person/day or 40 gal./person/day. Morales-Novelo and Rodríguez-Tapia (2007) also pointed out that the average potable water consumption in 2004 in the Benito Juárez borough is 184.67 lt./person/day or 48.78 gal./person/day. Therefore, the 48.78 gal./person/day was assumed as the baseline potable water supply for the technical potential study due to the official origin of the Morales-Novelo and Rodríguez-Tapia (2007) study applied to the Mexico City Metropolitan Area.

Second, it is fundamental to determine the water expenditure for each fixture in the apartment so changes to a fixture's water-use can be determined to then re-calculate the total reduced potable water-use. To determine this, the study by Arreguin-Cortes (2000) analyzed the water-use for the home's fixtures. Table 68 presents the assumed percentages for the potable water consumption in Mexico from this technical potential study. The first column is the space name in the apartment, the second column is the fixture in the space and the third column is the percentages of the total potable water-use for each fixture. The dwelling spaces' were divided as bathroom, kitchen and utility room.[99]

Table 68. Assumed Percentages for Water Consumption in Mexican Residences (Arreguin-Cortes, 1991).

Space	Fixture	Percentage
		%
Bathroom	Toilet	35
	Shower	30
	Sink	5
Kitchen	Sink	10
Utility Room	Washing Machine	20
	TOTAL	100

Table 69 introduces the base-case water-use per person and per family. The first column is the space name in the apartments. The second column is the fixtures name. Third column through sixth column is the water consumed per day per person per fixture. The percentage from third column in Table 68 was applied in the next example:

Toilet water consumption = 48.78 gal/day/person X 0.35 = 17 gal/day/person

This procedure was also applied for the shower and bathroom sink, the kitchen sink and the washing machine. The results are seen in Table 69.

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[99] There is not a utility room in the analyzed apartments. Therefore, it was assumed this area is located inside the kitchen.

Table 69. Base-Case Water-Use per Person and Per Four Person Family for the Apartments Section.

Space	Regular Fixtures	Lt./day/person	Gal/day/person	Lt./day/family	Gal/day/family
Bathroom	Toilet	64.6	17.1	258.5	68.3
	Shower	55.4	14.6	221.6	58.5
	Sink	9.2	2.4	36.9	9.8
Kitchen	Sink	18.5	4.9	73.9	19.5
Utility Room	Washing Machine	36.9	9.8	147.7	39.0
	TOTAL	184.7	48.8	738.7	195.1

The *Sistema de Aguas de la Ciudad de Mexico* (2012)[100] reported that the toilets and the showers in Mexico consumed 70 percent of the daily domestic water-use. According to Table 69, 65 percent of the water is consumed by the toilet and the shower. Between 50 and 80 percent of the domestic wastewater is greywater and should be reused (*INE,* 2009b).[101]

4.2.2.1.2 Calculation of the Size of the Potable Water Storage Tank for Multi-Family Apartments.

Becerril (2007) provided an approximation of the size of the potable water storage tank for the base-case as follows:

Number of apartments: 1,080.

Number of people/apartment: Four.

1,080 apartments X 4 people/apartment = 4,320 people.

Potable water consumption: 49 gal/person/day, or 185 lt./person/day.

Minimum potable water consumption: 210,750 gal/day, or 797,774 lt/day.

Average water consumption: Q_{ave} = Minimum potable water consumption/(seconds/day) = 210,750 gal/day/(24 hr X 60 min X 60 sec) = 2.44 gal/sec, or 9.23 lt/sec.

Maximum daily water consumption: Daily $Q_{max} = Q_{ave}$ X 1.2 = 2.93 gal/sec, or 11.08 lt/sec.

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[100] Translated from *Water System of Mexico City Mexico* (*SACM*, 2012).
[101] From *National Institute of Ecology* (*INE,* 2009b).

Maximum hourly water consumption: Hourly Q_{max} = Daily Q_{max} X 1.5 = 4.39 gal/sec, or 16.62 lt/sec.

Average maximum consumption per day: Hourly Q_{max} X number of seconds per day = 4.39 gal/sec X (24 hr X 60 min X 60 sec) = 379, 349 gal/day, or 1,435,994 lt/day.

Average maximum consumption per day plus backup: (Hourly Q_{max} X number of seconds per day) + (50 percent of Hourly Q_{max} X number of seconds per day) = 569,024 gal/day, or 2,153,991 lt/day.

Minimum volume required for the fire fighting system:

Total water consumption for a hose: Q_{hose} = 36.98 gal/min, or 140 lt/min.

Total water consumption for two hoses: $2Q_{hose}$ = 36.98 gal/min X 2 = 73.97 gal/min, or 280 lt/min.

Total fire fighting system water consumption: QTSI = $2Q_{hose}$ X 90 min = 6,657 gal, or 25,200 lt.

Useful capacity of the potable water tank: (Average Maximum Consumption per day) + (Average Maximum Consumption per day + Backup) + (Total Fire Fighting System Expenditure) = 379, 349 gal/day + 189,675 gal/day + 6,657 gal/day = 575,681 gal/day, or 2,179,191 lt/day. Finally, some part of this water is pumped up to the apartments. The other part is kept in a tankat ground level as the water required for the fire fighting system. The results of these calculations are located in Table 70.

4.2.2.2. Base-Case Water-Use for the Grocery Store.

First, it is essential to set the minimum potable water supply for the grocery store section of this technical potential study. The water-use for the grocery store was obtained from the GDF (2011), which indicates that two toilets and two sinks were needed up to 25 employees for retail areas. The minimum potable water-use is 300 lt./fixture/day, or 79 gal/fixture/day. The amount of water per day is explained as next:

Table 70. Potable Water Storage Tank Calculation.

Calculation in the Multifamiliar Miguel Aleman		**Units**
Number of Apartments	1,080	Apartment
Number of People/Apartment	4	People
Total Number of People	4,320	People
Water	49	gal/person/day
Minimum Water provided per day	210,750	gal
Average Expenditure	Q_{ave}	
Q_{ave}	(Minimum Required Volume/day)/Seconds/day	
Q_{ave}	2.44	gal/sec
Maximum Daily Expenditure	Daily Q_{max}	
Daily Q_{max}	Q_{ave} X 1.2	
Daily Q_{max}	2.93	gal/sec
Maximum Hourly Expenditure	Hourly Q_{max}	
Hourly Q_{max}	Daily Q_{max} X 1.5	
Hourly Q_{max}	4.39	gal/sec
Average Maximum Consumption/day	Hourly Q_{max} X Number of seconds per day	
Average Maximum Consumption/day	379,349	gal
Average Maximum Consumption/day + Backup	(Hourly Q_{max} X Number of seconds per day) + 50% X (Hourly Qmax X Number of seconds per day)	
Average Maximum Consumption/day + Backup	569,024	gal
Minimum Volume required for the Fire Fighting System		
Total Hose Expenditure	Q_{Hose}	
Q_{Hose}	36.98	gal/min
2 Q_{Hose}	73.97	gal/min
Total Fire Fighting System Expenditure	QTSI	
QTSI	2 Q_{hose} X 90 min	
QTSI	6,657	gal
Useful Capacity of the Tank	UCT	
UCT	Average Maximum Consumption/day + (Average Maximum Consumption/day + Backup) + Total Fire Fighting System Expenditure	
UCT	575,681	gal

79 gal/fixture/day X 4 fixtures[102] = 316 gal/day

316 gal/day /2 = 158 gal/day of greywater from the sinks

Also, the minimum potable water supply for the retail area is 6 lt./m²/day, or 0.15 gal/ft²/day (GDF, 2011). This water could be considered to wash the floor, counters, etc. The amount of water per day as follows:

0.15 gal/ft²/day X 9,217.2 ft² = 1,383 gal/day

Hence, 1,699 gal/day was required for the minimum potable water supply for the grocery store. From this water volume, 158 gal/day for the sinks and 1,383 gal/day for washing are considered as greywater to be reused into the two toilets of the grocery store. The excess water was assumed to be used for landscape irrigation.

4.2.2.3. Summary of Base-Case Water-Use for the Building.

The water-use of the apartment section and the grocery store is:

575,681 gal/day for all the apartments + 1,699 gal/day was required for the minimum potable water supply for the grocery store = 577,380 gal/day for the whole building.

4.2.3. Base-Case Community Transportation Use.

This section exhibits the results of the base-case community transportation use calculation for the *Multifamiliar Miguel Aleman.* These calculations were obtained with a manual calculation with the following information found in the literature review:

1) Number of trips by purpose of trip,
2) Number of miles driven per day,
3) Number of trips per person per day, and
4) Number of miles per gallon.

Table 71 presents the baseline community transportation use. The first column is the activity to be realized by destination, the second column is the number of trips in Mexico City Metropolitan Area, the third column is the percent of trips per activity and the fourth column is the assumed regular trips per day. The fifth column is the distance traveled in

[102] Two toilets and two sinks.

kilometers for all the trips from the fourth column. The sixth column is the gasoline consumption in liters for all the trips from the fourth column. The seventh column is the distance traveled in miles for all the trips from the fourth column. The eighth column is the gas consumption in gallons for all the trips from the fourth column. The ninth column is the amount of gallons of conventional fuel (gasoline) burned from the eighth column.

In Table 71, the destination trips in the first column and the number of trips for the MCMA were obtained from the *IGECEM*'s 2007 report for a survey in MCMA regarding origin and destination trips in 2007.

Table 71. Baseline Community Transportation Use per Day.

Activity	Mexico City Metropolitan Area	Percent	Regular Trips	Distance Traveled	Gas Consumption	Distance Traveled	Gas Consumption	Using Conventional Fuel
Destination Trip	Number of Trips	%	Trips	km	lt	mi	gal	Btu
House	1,599,265	45.2	1,832	75,131	7,088	46,684	1,872	234,049,000
School	523,741	14.8	600	24,604	2,321	15,288	613	76,648,449
Office	359,174	10.2	412	16,873	1,592	10,485	421	52,564,397
Shopping Mall, Retail and Supermarket	322,134	9.1	369	15,133	1,428	9,403	377	47,143,697
Industrial	111,283	3.1	128	5,228	493	3,248	130	16,286,015
Another House	153,163	4.3	175	7,195	679	4,471	179	22,415,036
Hospital	122,514	3.5	140	5,755	543	3,576	143	17,929,701
Restaurant, Bar and Coffee Shop	37,847	1.1	43	1,778	168	1,105	44	5,538,816
Laboratory	40,965	1.2	47	1,924	182	1,196	48	5,995,118
Recreation Center and Gymnasium	25,301	0.7	29	1,189	112	739	30	3,702,747
Park	14,197	0.4	16	667	63	414	17	2,077,722
Another Places	225,035	6.4	258	10,572	997	6,569	263	32,933,401
TOTAL	3,534,619	100	4,050	166,050	15,665	103,179	4,138	517,284,099

Unfortunately, *IGECEM*'s 2007 report did not specify if the trips were accomplished through public or private transportation. Therefore, the number of trips by car was assumed from Islas-Rivera et al.'s report (2004) for the *Secretaria de Comunicaciones y Transporte* and the *Instituto Mexicano del Transporte*. According to this report, 16.1 percent represents the private transportation in 2000 (Islas-Rivera et al., 2004). Therefore, the original number of trips from the *IGECEM*'s report (2007) was multiplied by 0.161 and the results are shown in the second column from Table 71.

The percent of trips from the MCMA were used in order to estimate the number of trips for the private cars at the *Multifamiliar Miguel Aleman*. The percent of trips is displayed in the third column. The number of trips to the house is not 50 percent. Therefore, in this this was interpreted to mean that some people realize more trips than leaving from a place, reaching a destination and coming back to the origin (i.e., home-school-home or home-office-home). In some cases, they may have had an extra trip (i.e., home-school-restaurant-home). These extra trips are difficult to estimate without a survey.

The number of regular trips was calculated with the number of cars multiplied by the trips/person/day. According to the *GDF* (2011) there were 1.5 parking spots per multi-family dwelling with an area above 65 m² and an elevator in the building. Each apartment was assumed to have 69 m², or 750 ft².

1,080 apartments in the complex X 1.5 parking spaces = 1,620 parking spaces.[103]

Sanchez-Cataño et al. (2009) stated 2.5 trips per person per day for Mexico City.[104] Therefore, the total number of regular trips was calculated as follows:

1,620 cars for the complex X 2.5 trips/person driving a car/day = 4,050 trips/day for the complex

The 4,050 trips/day for the complex were multiplied by the percent of trips for each activity on the third column. The third column exhibited the percent of trips to each destination.

Medina-Ramirez (2012) addressed the average private car lifetime of 41 km, or 25.47 mi. per day in Mexico City. Therefore, 41 km/day was multiplied by the number of regular

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[103] The current parking spaces are located in the perimeter of the site. This parking lot is assumed as an underground space. The abscense of cars at street level will enhance pedestrianism and landscape design in the complex.

[104] The number of trips is estimated by comparing Mexico City to other cities, such as Sao Paulo, with similar development levels. The final amount obtained from the research is 2.5 trips/person/day in 2005. Sanchez-Cataño et al. (2009) expect an economical improvement in Mexico to match the current gross domestic product from Germany. Therefore, Mexico City could reach 3.3 trips/person/day by 2030.

trips for each activity on the fourth column, and the results were located in the fifth column. The 25.47 mi. per day was multiplied by the number of regular trips for each activity on the fourth column, and the results are located on the seventh column.

Medina-Ramirez (2012) also informed that the fuel efficiency per kilometer or mile for new cars sold from 1990 to 2008 is 10.6 km/lt, or 24.9 mpg. Therefore, in Table 71 each number of kilometers per activity on the fifth column was divided by 10.6 km/lt, and the results are located on the sixth column. Finally, the number of miles per activity in the seventh column was divided by 24.9 mpg, and the results were located in the eighth column.

Table B-4 from the *Transportation Energy Data Book* from Oak Ridge National Laboratory (ORNL, 2013) was also used to estimate the amount of gallons of conventional fuel burned by the cars in the complex. This yielded a value of 125,000 Btu/gal of conventional fuel, which was then multiplied by the gallons for each activity on the eighth column, and the results are placed in the nineth column.

4.3. Simulating and Comparing the Energy/Water/Transportation Efficient Complex and the Base-Case Community

This section displays the comparison between the base-case community and each one of the energy-efficiency strategies for the complex. It also exhibits the comparison between the base-case water-use and each one of the water-efficiency strategies for the complex. Finally, it shows the transportation energy-use reduction for the colony.

4.3.1. Reduced Energy-Use for the Community.

This section reviews the procedure to determine the energy-efficient case and its comparison to the base-case.

4.3.1.1. Energy-Efficient Use for the Multi-Family Section.

This section presents the process to model and analyze the energy-efficiency measures for the multi-family apartments. According to the literature reviewed, the suggested strategies that can reduce the annual energy-use of the complex are:

For the analysis of building envelope measures and passive solar systems:

1) Rotate the building 90°;
2) Increase the R-Value of the roof;
3) Increase the R-Value of the exterior walls;
4) Place shading devices over external windows;
5) Reduce the window-to-wall ratio;
6) Change the schedules to enhance summer night flush and in the winter close the windows to trap heat;
7) Close the windows once the temperature reaches 60°F, and
8) Increase the infiltration.

For the analysis of daylighting and electrical systems:

1) Use daylighting controls;
2) Use double-clear glazing;
3) Improve the lighting fixture efficiency from incandescent lamps to energy efficient-lamps, and adjust the lighting schedule, and
4) Improve the appliance loads and adjust the appliance schedule.

For the analysis of photovoltaic systems:

- Analyze the use of photovoltaic system using a utility interface system with a photovoltaic monocrystalline module.

For the analysis of domestic hot water systems:

- Analyze the impact of an active solar domestic water system with a flat-plate collector.

In the analysis it was assumed that the strategies for the analysis of the building envelope measures and passive solar systems would bring more hours into the thermal comfort zone. There is not heating or cooling systems. In the analysis it was also assumed that the strategies for the analysis of daylighting and electrical systems would bring more hours into the thermal comfort zone and would reduce the energy consumed in the apartments during the year. Finally, the analysis of photovoltaic systems and domestic hot water systems was assumed to generate on-site electricity and solar thermal energy.

To perform this analysis, parametric runs were used eQuest program with the energy-efficiency for the energy efficiency measures in the multi-family apartments. Hirsch & Associates (2009) stated that the software can run multiple modeling alternatives through a parametric variation of the base-case. The following sections present the procedures for the analysis of the energy-efficient measures.

4.3.1.1.1. Rotate the Azimuth 90°.

By rotating the building, this investigated possible improvements to the thermal comfort of the base-case building during the year. *CONAVI* (2010a) recommended apartments facing south or southeast on one side of a centerline. It also recommended avoiding apartments facing northeast on one side of a centerline and apartments facing southwest on the other side of a centerline. The *Multifamiliar Miguel Aleman* has apartments facing south-southwest on one side of the centerline, and apartments facing west-northwest on one side of a centerline and apartments facing east-southeast on the other side of the centerline. This means that the orientation of the apartments conforms with recommendations by *CONAVI* (2010a). Caton (2010) described the process to create multiple orientations for the building by creating a parametric run that rotates the azimuth 90° clockwise.[105]

4.3.1.1.2. Increase the R-Value of the Roof.

The increase of R-Value for the roof aims to mitigate thermal gains and thermal losses. In order to select this insulation, lines with a new roof are added to the input file. The insulation material chosen was "MinWool Batt R30 (IN05)".[106]

[105] The Help Topic command in eQuest states that the View-Azimuth parameter moves clockwise.
[106] Finally, the roof is called Roof_3.

4.3.1.1.3. Increase the R-Value of Walls.

The increase of the R-Value aims to reduce thermal gains and thermal losses. In order to select this insulation, lines with a new wall are added to the input file. The insulation material chosen was "MinWool Batt R30 (IN05)".[107]

4.3.1.1.4. Change the Incandescent Lamps to LED Lamps and Change the Lighting Power Density.

By changing the lighting fixture types and the lighting power density, this measure seeks to reduce the electricity consumed by the base-case building. LEDs have a very good potential to reduce electricity use. For example, Eartheasy (2012) stated that a 10-Watt LED lamp is equal to a 60-Watt incandescent lamp and a 14-Watt CFL lamp. It also pointed out the extended lifespan: 50,000 hr for LED, 10,000 hr for CFL and 1,200 hr for incandescent. Therefore, LED lamps were selected for the analysis for this case. Unfortunately eQuest does not have an option for LED lamps. Therefore the name "suspended fluorescent lamp" was selected and 10-Watts lamps were assigned.

Mexico has its own voluntary endorsed seal for energy-efficiency lamps and appliances in a similar manner as Energy Star (US DOE, n.d.). This seal is given by the *Fideicomiso para el Ahorro de Energia Electrica* (*FIDE*, 2013a, b, c). Unfortunately, LED lamps for interior zones are not yet certified by *FIDE* (2013d). Therefore, Energy Star lamps were used for this case analysis. Table 72 presents the comparison between traditional and energy-efficient measures for lamps.

Table 72. Comparison between Traditional and Energy-Efficient Measures for Lamps.

Traditional Measures	Brand	Model	Watt	References
Lamp	Phillips	Phillips Softone	60	Quadri, 2008
Energy-Efficient Measures	**Brand**	**Model**	**Watt**	**References**
Lamp	GE Lighting	PLGP301DLEDCN, LED10DP30/FL-L2, LED10DP30S827/35	10	Energy Star, 2013b

[107] Finally, the wall is called Wall_3.

The 60-Watt incandescent lamps were used for the base-case simulation. On the other hand, the 10-Watt lamps were substituted for the incandescent lamps in the energy-saving case. In all cases the lighting profile remained the same. The lighting power density used in this case was 0.105948 W/ft^2. Table 73 exhibits an energy reduction of 41.5 percent. This strategy improved the base-case by cutting down excessive energy consumption.

4.3.1.1.5. Place and Activate Daylighting Controls into the Zones.

By placing and activating daylighting controls into the zones, this measure seeks to reduce the electricity consumed from the base-case apartment section. The idea was to reduce the wattage of the lighting by dimming them during the day. Table 74 exhibits an energy reduction of 4.5 percent. This strategy improved the base-case by cutting down excessive energy consumption.

4.3.1.1.6. Place Shading Devices over Exterior Windows.

Shading devices are a passive strategy that can block unwanted thermal gains into the indoor zone temperature during the summer. The shading analysis was performed using Ecotect and Solrpath. Ecotect aims to visualize the shading conditions of the buildings inside the community. The shading scrutiny from Solrpath was also applied to individual windows.

Just as a reminder, Mexico City is at 20°N. Figure 81 through Figure 83 presents the analysis for June 21st. The solar angle at this time is almost at the zenith at noon. After seeing these figures, it was concluded that the sun was hitting the facades facing southeast at 10:00 and southwest at 14:00. This is because the long façade of the selected building was southwest-northeast. This implied potential overheating in the apartments during the summer. Shading must be provided for this reason.

Table 73. Energy Reduction by Changing Lamps for the Apartments.

	Case 0_Base-Case	Case 4_Change Lamps
	Total	Total
	kWh (X 1,000)	kWh (X 1,000)
Area Lights	286.4	47.74
Task Lights	0	0
Misc. Equip.	289.06	289.06
Heat Reject.	0	0
Refrigeration	0	0
HP Supp.	0	0
Hot Water	0	0
Pumps & Aux.	0.1	0.1
Ext. Usage	0	0
Vent. Fans	0	0
Space Heat	0	0
Space Cool	0	0
Total Energy Consumption	575.56	336.91
Energy Consumption (Percent)		58.5
Energy Reduction (Percent)		41.5

Table 74. Energy Reduction by Activating Daylighting Controls.

	Case 0_Base-Case	Case 5_Place Daylighting Controls
	Total	Total
	kWh (X 1,000)	kWh (X 1,000)
Area Lights	286.4	260.31
Task Lights	0	0
Misc. Equip.	289.06	289.06
Heat Reject.	0	0
Refrigeration	0	0
HP Supp.	0	0
Hot Water	0	0
Pumps & Aux.	0.1	0.1
Ext. Usage	0	0
Vent. Fans	0	0
Space Heat	0	0
Space Cool	0	0
Total Energy Consumption	575.56	549.47
Energy Consumption (Percent)		95.5
Energy Reduction (Percent)		4.5

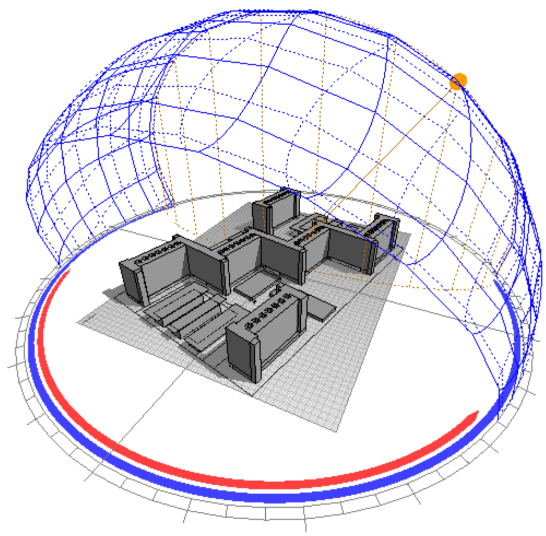


Figure 81. Ecotect Model of the Community Seen from the Southeast on June 21st at 10:00.

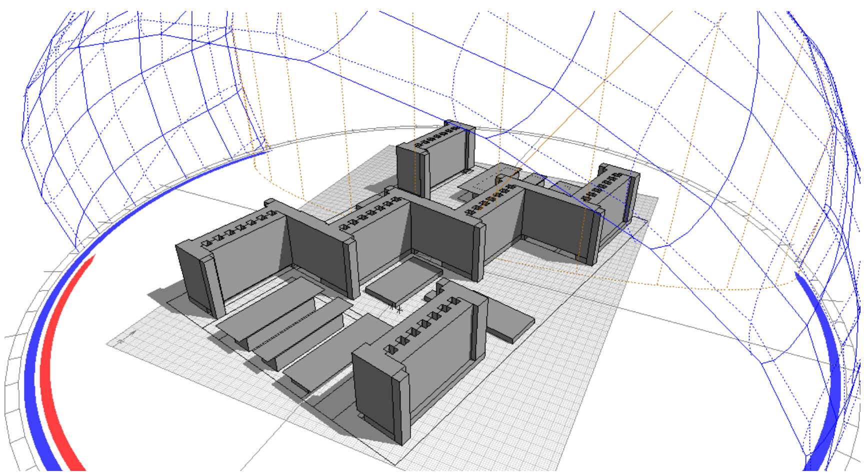


Figure 82. Ecotect Model of the Community Seen from the Southeast on June 21st at 10:00 (Enlarged View).

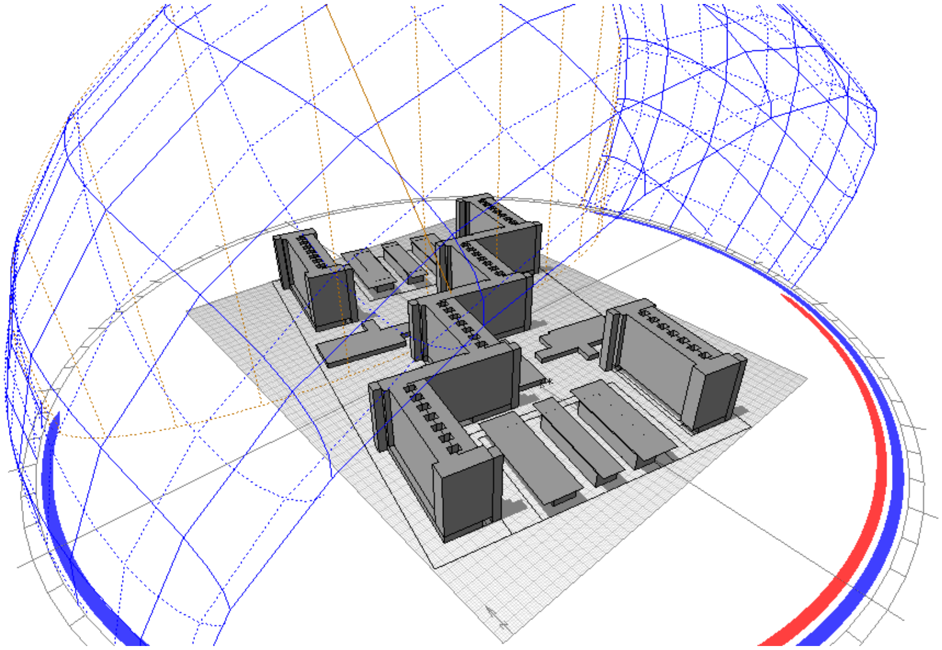


Figure 83. Ecotect Model of the Community Seen from the Southwest on June 21st at 14:00.

Figure 84 and Figure 85 display the building for December 21st. After seeing these figures it was concluded that the sun was hitting the facades facing southeast and southwest at 10:00 and 14:00. Therefore, the south façade was the best one to control unwanted summer gain. The long southwest-northeast façade allowed solar access during the early and later hours of the day for the winter. However, shading must be provided for the summer to avoid the overheating. A movable or retractable device can allow for winter sun angle and can protect against summer sun angle into the spaces. Due to the limitation of replication of complex shading devices into eQuest, an overhang per window was modeled for this technical potential study. Movable shading, lattice structures and use of different schedules among other things are recommended for future work.

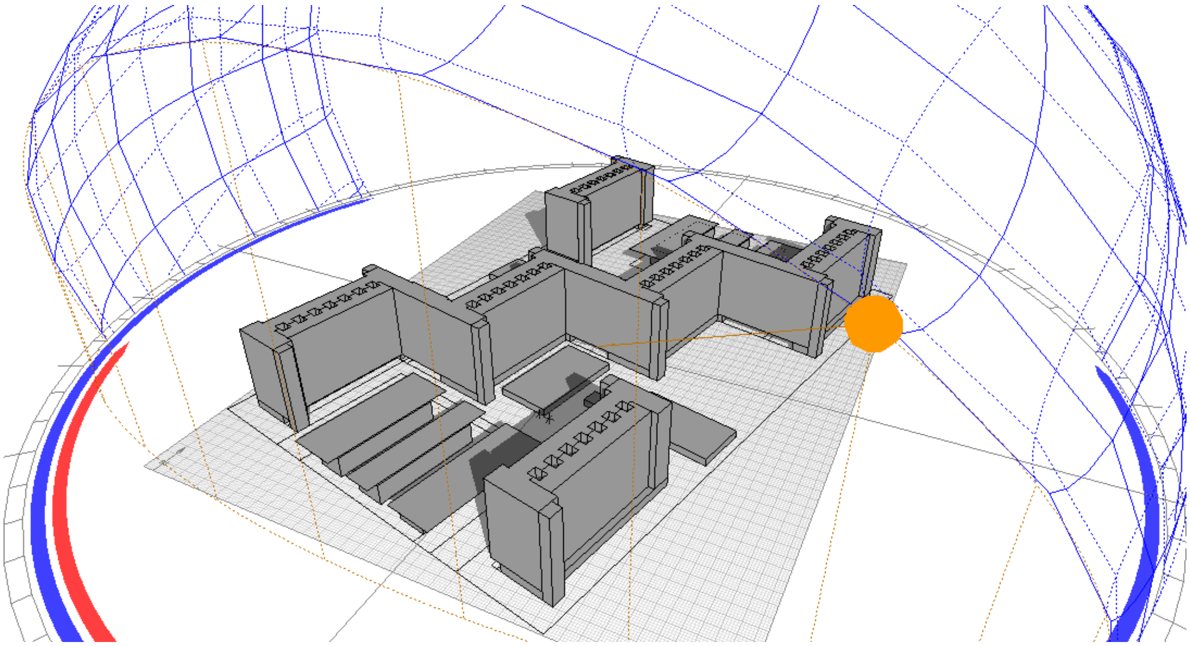


Figure 84. Ecotect Model of the Community Seen from Southeast on December 21st at 10:00.

Figure 86 shows an example of a shading analysis on facades for individual windows with the Solrpath program. The upper left area portion of the screen is a user-interface, where such data as the city, the solar angle, the height and length of the building and the window, the height, width and angle of the shading device, etc. are entered by the user. The upper right portion of the screen shows an image of the shading created with the equidistant sunpath diagram. The lower right and left areas of the screen show multiple building views and the window views, respectively.

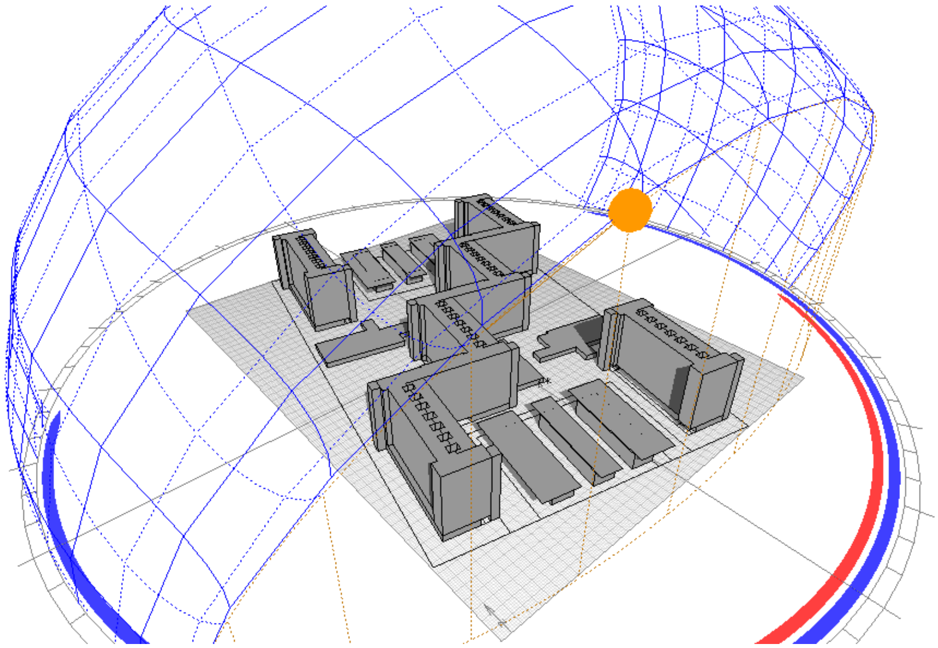


Figure 85. Ecotect Model of the Community Seen from Southwest on December 21st at 14:00.

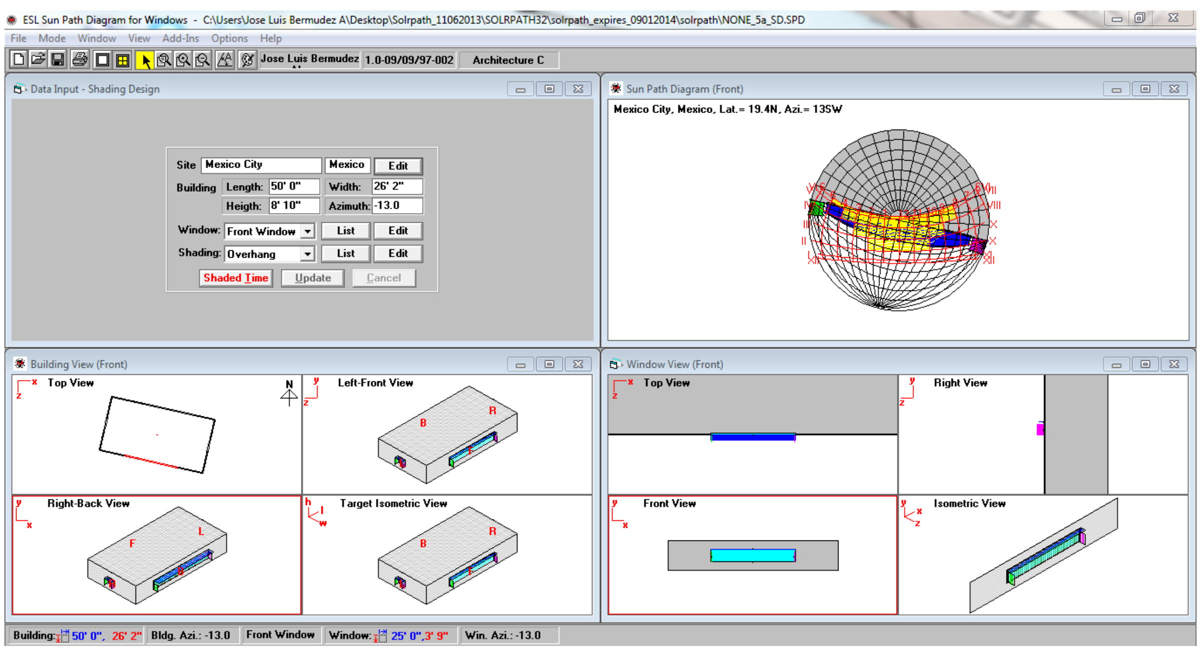


Figure 86. Solrpath for Shading Analysis on Facades for Individual Windows.

Table 75 exhibits the height and the width of the windows, and the depth and the angle of the overhangs for each façade as determined by the Solrpath program. These windows are located on Figure 87.

Before moving to the next section, it is critical to point out that the height and width of the windows, and the depth and angle of the overhangs were modified once the measures were run together. Table 76 indicates the new size of the windows and the updated depth and tilt of the overhangs, which was used in the Case 13_Energy-Efficient Case. The estimation of the windows in Table 76 is explained in section 4.3.1.1.10.

Table 75. Height and Width of the Windows, and Depth and Angle of the Overhangs for the Apartments.

Window	Height	Width	Depth	Angle
ID Number	ft	ft	ft	°
EL2 WNW Win (G.WNW1.E3.W1)	4.5	159.8	5.5	60
EL2 NNE Win (G.WNW1.E6.W1)	4.0	69.8	3.0	90
EL2 NNE Win (G.WNW1.E8.W1)	4.0	69.8	3.0	90
EL2 SSW Win (G.WNW1.E10.W1)	3.7	149.8	1.5	90
EL2 NNE Win (G.WNW1.E15.W1)	4.0	69.8	3.0	90
EL2 ESE Win (G.ESE2.E17.W1)	4.5	159.8	5.0	80
EL3 WNW Win (G.WNW1.E3.W1)	4.5	159.8	5.5	60
EL3 NNE Win (G.WNW1.E6.W1)	4.0	69.8	3.0	90
EL3 NNE Win (G.WNW1.E8.W1)	4.0	69.8	3.0	90
EL3 SSW Win (G.WNW1.E10.W1)	3.7	149.8	1.5	90
EL3 NNE Win (G.WNW1.E15.W1)	4.0	69.8	3.0	90
EL3 ESE Win (G.ESE2.E17.W1)	4.5	159.8	5.0	80
EL4 WNW Win (G.WNW1.E3.W1)	4.5	159.8	5.5	60
EL4 NNE Win (G.WNW1.E6.W1)	4.0	69.8	3.0	90
EL4 NNE Win (G.WNW1.E8.W1)	4.0	69.8	3.0	90
EL4 SSW Win (G.WNW1.E10.W1)	3.7	149.8	1.5	90
EL4 NNE Win (G.WNW1.E15.W1)	4.0	69.8	3.0	90
EL4 ESE Win (G.ESE2.E17.W1)	4.5	159.8	5.0	80

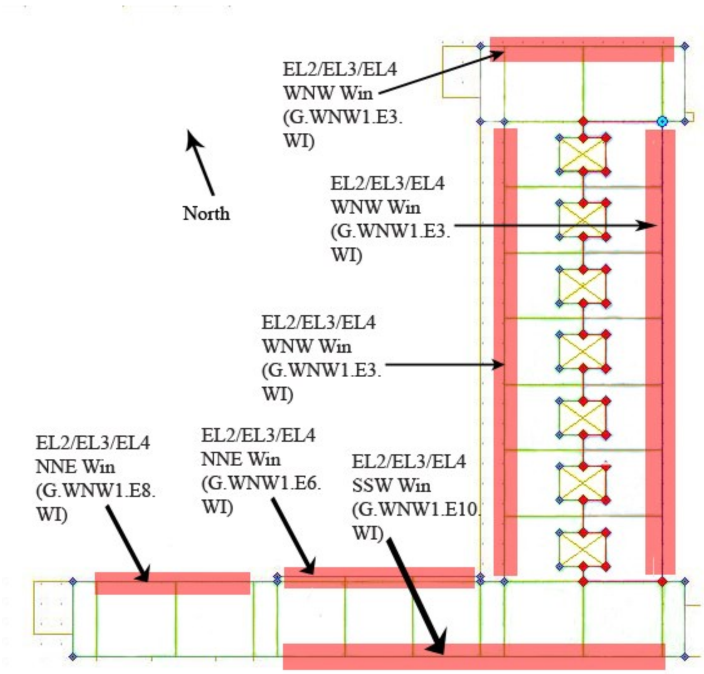


Figure 87. Location of Windows for EL2, EL3 and EL4 Shells.

Table 76. Height and Width of the Windows, and Depth and Angle of the Overhangs for Case 13_Energy-Efficient Case for the Apartments.

Window	Height	Width	Depth	Angle
ID Number	ft	ft	ft	ft
EL2 WNW Win (G.WNW1.E3.W1)	4.0	136.5	3.8	90
EL2 NNE Win (G.WNW1.E6.W1)	4.0	54.1	4.5	70
EL2 NNE Win (G.WNW1.E8.W1)	4.0	54.1	4.5	70
EL2 SSW Win (G.WNW1.E10.W1)	4.0	102.2	5.3	75
EL2 NNE Win (G.WNW1.E15.W1)	4.0	54.1	4.5	70
EL2 ESE Win (G.ESE2.E17.W1)	4.0	136.5	1.3	90
EL3 WNW Win (G.WNW1.E3.W1)	4.0	136.5	3.8	90
EL3 NNE Win (G.WNW1.E6.W1)	4.0	54.1	4.5	70
EL3 NNE Win (G.WNW1.E8.W1)	4.0	54.1	4.5	70
EL3 SSW Win (G.WNW1.E10.W1)	4.0	102.2	5.3	75
EL3 NNE Win (G.WNW1.E15.W1)	4.0	54.1	4.5	70
EL3 ESE Win (G.ESE2.E17.W1)	4.0	136.5	1.3	90
EL4 WNW Win (G.WNW1.E3.W1)	4.0	136.5	3.8	90
EL4 NNE Win (G.WNW1.E6.W1)	4.0	54.1	4.5	70
EL4 NNE Win (G.WNW1.E8.W1)	4.0	54.1	4.5	70
EL4 SSW Win (G.WNW1.E10.W1)	4.0	102.2	5.3	75
EL4 NNE Win (G.WNW1.E15.W1)	4.0	54.1	4.5	70
EL4 ESE Win (G.ESE2.E17.W1)	4.0	136.5	1.3	90

4.3.1.1.7. Change the Appliance Loads and Reduce the Appliance Profile.

As mentioned previously in section 4.3.1.1.4, *FIDE* certifies energy-efficiency appliances, as well as lamps, in Mexico (*FIDE*, 2013a, b, c; US DOE, n.d.). After checking *FIDE*'s website (2013d), it was discovered that the information provided for the appliances was limited. For example, there is no information for washing machines and there is limited information for TVs. Therefore, appliances certified by Energy Star were used in order to keep uniformity with the analysis for Case 5. Table 77 presents the comparison between traditional and energy-efficient[108] measures for appliances.

Table 77. Comparison between Traditional and Energy-Efficient Measures for Appliances.

Traditional Measures	Brand	Model	Watt	References
Refrigerator	Mabe	Traditional	250	Quadri, 2008
TV	Samsung	Traditional	400	
Washing Machine	Easy	Traditional	400	
Miscellaneous Appliances			50	Assumption for the study
Energy-Efficient Measures	**Brand**	**Model**	**Watt**	**References**
Refrigerator	Samsung	RF263BEAESR/AA	54	Samsung, 2013a
TV	Panasonic	TC-L47E50	115	Panasonic, 2013
Washing Machine	Samsung	WF393BTPAWR	254	Samsung, 2013b
Miscellaneous Appliances			25	Assumption for the study

For each apartment, a 250-Watt refrigerator, 400-Watt TV, 400-Watt washing machine and 50-Watt miscellaneous appliances were used for the simulation of the base-case. In contrast, a 54-Watt refrigerator,[109] 115-Watt TV,[110] 254-Watt washing machine[111] and 25-Watt miscellaneous appliances were used for each apartment in the energy-saving case. The appliance profile remained the same for boh simulations. The equipment power

[108] The refrigerator is a 25.6 ft^3, 3-door French door appliance (Samsung, 2013a). The TV has a LED LCD panel (Panasonic, 2013). The washing machine is a 4.6 ft^3 large capacity front-load appliance (Samsung, 2013b).
[109] This amount is for a 475 kWh/year refrigerator that turns on hourly for a fraction of each hour.
[110] This amount is for a 126 kWh/year TV that is turned on for 3 hr/day.
[111] This amount is for a 93 kWh/year washing machine that is turned on for 1 hr/day.

density use in this case is 0.3625 W/ft². Table 78 shows an energy reduction of 34.7 percent for the energy-efficient case versus the base-case.

Table 78. Energy-Savings by Replacing Appliances for the Apartments with Energy-Efficient Appliances.

	Case 0_Base-Case	Case 7_Change Appliances
	Total	**Total**
	kWh (X 1,000)	**kWh (X 1,000)**
Area Lights	286.4	286.4
Task Lights	0	0
Misc. Equip.	289.06	89.6
Heat Reject.	0	0
Refrigeration	0	0
HP Supp.	0	0
Hot Water	0	0
Pumps & Aux.	0.1	0.1
Ext. Usage	0	0
Vent. Fans	0	0
Space Heat	0	0
Space Cool	0	0
Total Energy Consumption	575.56	376.1
Energy Consumption (Percent)		65.3
Energy Reduction (Percent)		34.7

4.3.1.1.8. Place Double-Clear Glazing.

By replacing single-pane glazing with double-pane, clear glazing, this measure looked for a thermal improvement of several hours to the thermal comfort zone from the base-case building during the year. Unfortunately, the next source is the only one found for different window configurations for a high-rise building in Mexico City. Gijon-Rivera et al. (2011) used the ESPr and TRNSYS energy analysis software to simulate the following: a single-clear glass, a single glass with a coating, a double glass with a coating and a double-clear glass for an office building in Mexico City. They found that the best window configuration for Mexico City is the double-pane, clear glazing.

Hirsch and Associates (2009) showed how to simulate a high performance glazing. The example in the eQuest's manual is for a double-pane low-e glass. Therefore, an operable double-pane clear glazing with a thermal break was simulated for this study. Following the example from Hirsch and Associates (2009), 0.88 Btu/hr.-ft²-°F was taken from Table 1 in page 30.6 from the ASHRAE (2001) for an operable double-pane clear glazing with a thermal break. It is also suggested in Hirsch and Associates (2009) that DOE-2 added a film resistance to the frame conductance. It is therefore assumed that 1.15 BTU/hr.-ft²-°F had to be introduced into the numeric value for the window frame conductance.

The new glass type properties were taken from CSBR-UM (2013). As mentioned before, Los Angeles has similar climate to Mexico City. Therefore, it was assumed to use the glazing with properties from Los Angeles to apply to the windows in Mexico City.

4.3.1.1.9. Close the Open Windows when the Temperature Reaches 60°F.

Operable windows were also analyzed in this study. This characteristic was modeled in order to keep the interior zone temperature from going below 60°F. It was assumed that the window closure was a passive strategy that people used to keep the spaces in the comfort zone. Therefore, 50°F was used as the window closure temperature for the base-case.

4.3.1.1.10. Reduce the Window-to-Wall Ratio.

The reduction of the window-to-wall ratio is looked for decreasing the energy-use and harvesting daylighting. The total window area of the apartment section is 36,077 ft² and the total wall area is 59,038 ft². In order to estimate the window-to-wall ratio, the following equation is put into use:

(36,077 ft² for window area/59,038 ft² for wall area) X 100 = 61 WWR

Table 79 features the window-to-wall ratio for the apartment section building. The first column is the façade, the second column is the window area for the façade and the third column is the wall area for the façade. The fourth column is the existing window-to-wall ratio for each façade. The fifth column is the new window-to-wall ratio for each façade. Fleming (2011) suggests multiplying the percent of the existing WWR for each façade by 40 WWR and dividing it by the total WWR. An example is shown as next:

77 WWR for the north façade X (40 WWR/61 WWR) = 51 WWR

Table 80 presents the height and width of the existing and new windows for the apartment section. The areas shown in the last two columns are the result of the new WWR calculated for each façade.

Table 79. Window-to-Wall Ratio for the Apartment Section Building.

Façade	Window Area	Wall Area	Existing Window-to-Wall Ratio	New Window-to-Wall Ratio
	ft²	ft²	%	%
North	10,710	13,859	77	51
East	9,120	13,869	66	43
South	7,128	17,441	41	27
West	9,120	13,869	66	43
TOTAL	36,078	59,038	61	41

4.3.1.1.11. Change the Schedules to Enhance Summer Night Flush and Winter Closed Windows for Heat Trap.

The application of new schedules to enhance summer night flush must be performed for this study. Also, the zone can be comfortable during the winter by closing the windows by changing its schedule. This section is explained in section 4.3.1.1.13.

4.3.1.1.12. Increase Infiltration.

The increase in infiltration tried to model the actual infiltration of typical housing in Mexico City. This was because the dwellings are not sealed in this region. It was assumed that the infiltration of the base-case was changed from 0.35 ACH to 1.0 ACH for this case.

Table 80. Height and Width of Existing and New Windows for the Apartments.

	Existing Windows		New Windows	
Window	**Height**	**Width**	**Height**	**Width**
ID Number	**ft**	**ft**	**ft**	**ft**
EL2 WNW Win (G.WNW1.E3.W1)	4.5	159.8	4.0	136.5
EL2 NNE Win (G.WNW1.E6.W1)	4.0	69.8	4.0	54.1
EL2 NNE Win (G.WNW1.E8.W1)	4.0	69.8	4.0	54.1
EL2 SSW Win (G.WNW1.E10.W1)	3.7	149.8	4.0	102.2
EL2 NNE Win (G.WNW1.E15.W1)	4.0	69.8	4.0	54.1
EL2 ESE Win (G.ESE2.E17.W1)	4.5	159.8	4.0	136.5
EL3 WNW Win (G.WNW1.E3.W1)	4.5	159.8	4.0	136.5
EL3 NNE Win (G.WNW1.E6.W1)	4.0	69.8	4.0	54.1
EL3 NNE Win (G.WNW1.E8.W1)	4.0	69.8	4.0	54.1
EL3 SSW Win (G.WNW1.E10.W1)	3.7	149.8	4.0	102.2
EL3 NNE Win (G.WNW1.E15.W1)	4.0	69.8	4.0	54.1
EL3 ESE Win (G.ESE2.E17.W1)	4.5	159.8	4.0	136.5
EL4 WNW Win (G.WNW1.E3.W1)	4.5	159.8	4.0	136.5
EL4 NNE Win (G.WNW1.E6.W1)	4.0	69.8	4.0	54.1
EL4 NNE Win (G.WNW1.E8.W1)	4.0	69.8	4.0	54.1
EL4 SSW Win (G.WNW1.E10.W1)	3.7	149.8	4.0	102.2
EL4 NNE Win (G.WNW1.E15.W1)	4.0	69.8	4.0	54.1
EL4 ESE Win (G.ESE2.E17.W1)	4.5	159.8	4.0	136.5

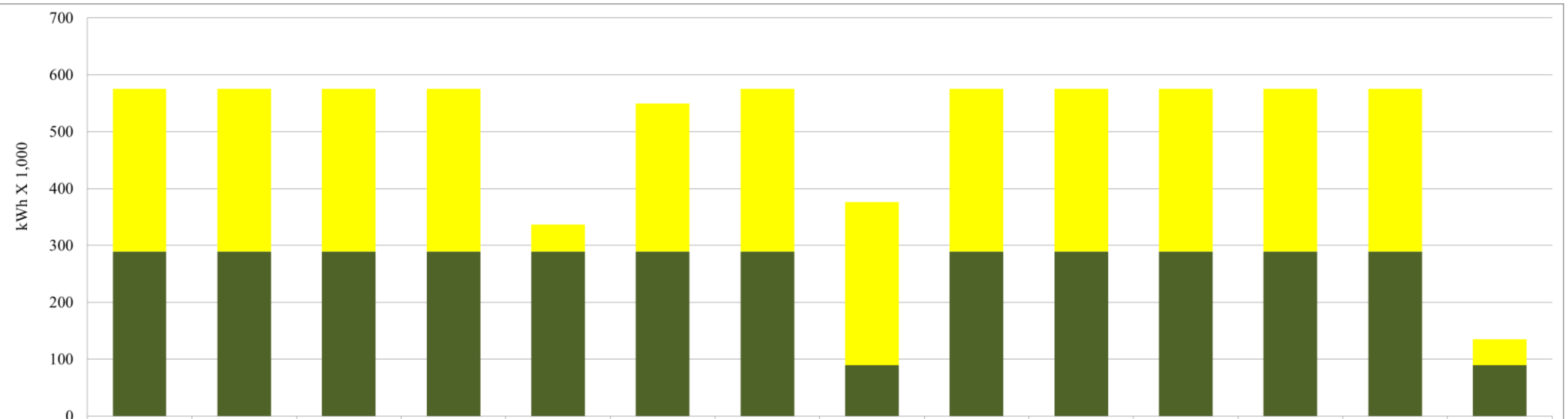
4.3.1.1.13. Final Analysis of the Results of the Energy-Efficiency Measures for the Multi-Family Building.

Energy savings and thermal comfort are the two essential elements for this technical potential study. The multi-family base-case building has an energy consumption of 575,560 kWh/year. Interior conditions are calculated to be in the ASHRAE thermal comfort zone by 20 percent for the year. In this analysis each measure was compared against the base-case file, and the stategy is modeled as a parametric run. Table 81 and Figure 88 present the energy consumption for each case, and Table 81 shows the percentage of energy reduction for each case. The three only cases that reduced energy consumption from the baseline are the following:

1) Case 4 Change Lamps. This modeling changed the interior incandescent lamps to LED lamps and the reduced lighting power density. 41.5 percent of energy is reduced from the base-case,

Table 81. Total Energy Consumption for Each Measure, and Percentage of Energy Reduction for Each Case (Apartments).

	Case 0_Base-Case	Case 1_Rotate Azimuth 90 Degrees	Case 2_Add Roof Insulation R-30	Case 3_Add Wall Insulation R-11	Case 4_Change Lamps	Case 5_Place Daylighting Controls	Case 6-Place Overhangs	Case 7_Change Appliances	Case 8_Place Double Clear Glass	Case 9_Nat Vent Sched_60°F	Case 10_WWR Ratio	Case 11_Wind Schedule	Case 12_Infilt	Case 13_Energy-Efficient Case
	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total	Total
	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)	kWh (X 1,000)
Area Lights	286.4	286.4	286.4	286.4	47.74	260.31	286.4	286.4	286.4	286.4	286.4	286.4	286.4	45.11
Task Lights	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	289.06	289.06	289.06	289.06	289.06	289.06	289.06	89.6	289.06	289.06	289.06	289.06	289.06	89.6
Heat Reject.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0	0	0	0	0
HP Supp.	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ext. Usage	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vent. Fans	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Heat	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Space Cool	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Energy Consumption	575.56	575.56	575.56	575.56	336.91	549.47	575.56	376.1	575.56	575.56	575.56	575.56	575.56	134.81
Energy Consumption (Percent)		100.0	100.0	100.0	58.5	95.5	100.0	65.3	100.0	100.0	100.0	100.0	100.0	23.4
Energy Reduction (Percent)		0.0	0.0	0.0	41.5	4.5	0.0	34.7	0.0	0.0	0.0	0.0	0.0	76.6



	Case 0_Base-Case	Case 1_Rotate Azimuth 90 Degrees	Case 2_Add Roof Insulation R-30	Case 3_Add Wall Insulation R-11	Case 4_Change Lamps	Case 5_Place Daylighting Controls	Case 6-Place Overhangs	Case 7_Change Appliances	Case 8_Place Double Clear Glass	Case 9_Nat Vent Sched_60°F	Case 10_WWR Ratio	Case 11_Wind Schedule	Case 12_Infilt	Case 13_Energy-Efficient Case
Area Lights	286.4	286.4	286.4	286.4	47.74	260.31	286.4	286.4	286.4	286.4	286.4	286.4	286.4	45.11
Pumps & Aux.	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Misc. Equip.	289.06	289.06	289.06	289.06	289.06	289.06	289.06	89.6	289.06	289.06	289.06	289.06	289.06	89.6

Figure 88. Total Energy Consumption for Each Measure (Apartments).

2) Case 5 Place Daylighting Controls. This simulation turned the daylighting controls on and pointed them towards the windows. 4.5 percent of energy is reduced from the baseline, and
3) Case 7 Change Appliances. The replication changes high-energy consuming appliances to high-efficiency appliances and lowered the equipment power density. 34.7 percent of energy is reduced from the orginal case.

The analysis determined that the envelope measures applied to the base-case only had effects on the thermal comfort of the building. This is due to the lack of air-conditioning system in the apartments in Mexico City.

Table 82 exhibits the percentage of hours inside of the thermal comfort zone for each case using the Adaptive Comfort Model in ASHRAE 55-2004 (2004b). This model is set for naturally ventilated buildings with no air-conditioning system. The first column in Table 82 is the name of the measure simulated and the second column is the percentage of hours inside of the comfort zone for the building.

Table 82. Percentage of Hours inside of the Thermal Comfort Zone for Each Case.

Case Name	Percent
Case 0_Base-Case	20
Case 1_Rotate Azimuth 90 Degrees	20
Case 2_Add Roof Insulation R-30	19
Case 3_Add Wall Insulation R-30	19
Case 4_Change Lamps	19
Case 5_Place Daylighting Controls	20
Case 6_Place Shading Devices (Overhangs)	15
Case 7_Change Appliances	15
Case 8_Place Double Clear Glass	18
Case 9_Natural Ventilation Schedule_with 60°F	20
Case 10_Window-to-Wall Ratio	20
Case 11_Window Schedule_Summer 8 hr	49
Case 12_Infiltration	20
Case 13_Energy-Efficient Case	50

Looking to the percentage results for the second column in Table 82, it is clear that the only measure, besides Case 13, that is bringing more hours inside the thermal comfort is Case 11 with the window schedule. This window schedule was created as next:

1) It is required to observe the existing thermal comfort zone graphs from the base-case multi-family building.
2) Table 83 shows hours below 68°F. Table 83 is created with the hours below 68°F for all the zones in the apartment section. The first column is for months and second column is for total hours per month. The third through fourteenth column presents the number of hours below 68°F and the percent of these hours per month.
3) Next, the idea is to establish the seasons for the closed window operation for heat trap and the night flush. According to Table 83, January, February, part of March and September, October, November and December had more than 50 percent of hours below 68°F. Therefore, these months were considered for the closed window operation for the heat trap. The windows were determined to be closed for the whole day.
4) April, May, June, July, August, and part of March and September were acknowledge for the night flushing strategy in this technical potential study. To accomplish this, the windows needed to be closed for several hours and opened the rest of the day, in order to cool down the thermal mass. This assumption is explained further in point 8.
5) March and September were particular months for this technical potential study. According to Figure 89, the interior zone temperature ranged from 47°F and 75°F during the first eight days of March. The indoor temperature surpassed 80°F once it reached March 9th. Therefore, this day was considered as a pivot point for the winter-summer season for this research.

6) Figure 90 exhibits that both the outdoor dry bulb temperature and the interior zone temperature were not constant during May. Nevertheless, several days reached 80°F during the month.
7) In Figure 91, the interior zone temperature range from 55°F and 81°F during the first 10 days of March. The indoor temperature drops down around 71°F once it reached September 11th. Therfore, this day was considered as a pivot point for the summer-winter season for this research.
8) Figure 92 displays the outdoor dry bulb temperature and the interior zone temperature for December. The higher dry bulb and indoor temperature for most of days is around 70°F.
9) The season periods were assumed as follows and simulated with a parametric run:
    a) Winter Closed Windows for Heat Trap: The schedule for winter starts on January 1st and finishes on March 8th. The windows were closed for the whole day.
    b) Summer Night Flush: The schedule for summer starts on March 9th and finishes on September 10th. The number of hours to close the windows was determined in point 9.
    c) Winter Closed Windows for Heat Trap: The schedule for winter starts on September 11th and finishes on December 31st. The windows were closed for the whole day.

Table 83. Hours below 68°F for all Zones in the Apartment Section of the Building.

Month	Total Hours per	EL2 WNW	Percent %	EL2 ESE	Percent %	EL3 WNW	Percent %	EL3 ESE	Percent %	EL4 WNW	Percent %	EL4 ESE	Percent %
January	744	678	91.1	687	92.3	703	94.5	710	95.4	695	93.4	699	94.0
February	672	514	76.5	512	76.2	538	80.1	539	80.2	511	76.0	500	74.4
March	744	383	51.5	355	47.7	375	50.4	355	47.7	347	46.6	334	44.9
April	720	255	35.4	242	33.6	245	34.0	236	32.8	213	29.6	211	29.3
May	744	286	38.4	275	37.0	273	36.7	268	36.0	228	30.6	235	31.6
June	720	386	53.6	372	51.7	379	52.6	372	51.7	351	48.8	346	48.1
July	744	478	64.2	460	61.8	483	64.9	467	62.8	442	59.4	449	60.3
August	744	422	56.7	396	53.2	422	56.7	398	53.5	382	51.3	373	50.1
September	720	510	70.8	476	66.1	514	71.4	489	67.9	485	67.4	472	65.6
October	744	575	77.3	549	73.8	587	78.9	569	76.5	557	74.9	540	72.6
November	720	641	89.0	648	90.0	657	91.3	663	92.1	643	89.3	635	88.2
December	744	681	91.5	689	92.6	700	94.1	708	95.2	686	92.2	690	92.7

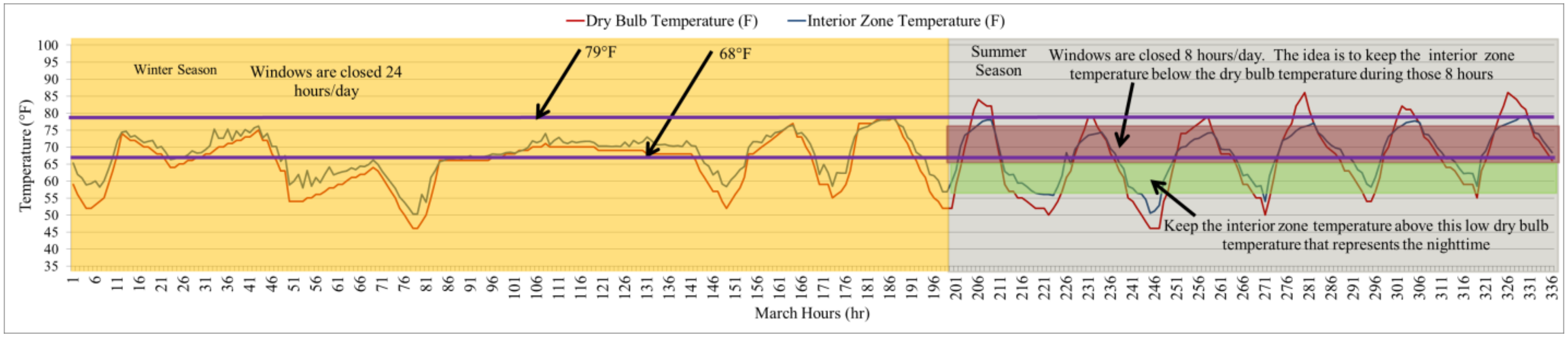


Figure 89. Dry Bulb and Interior Zone Temperatures for March (Case 0_Base-Case).

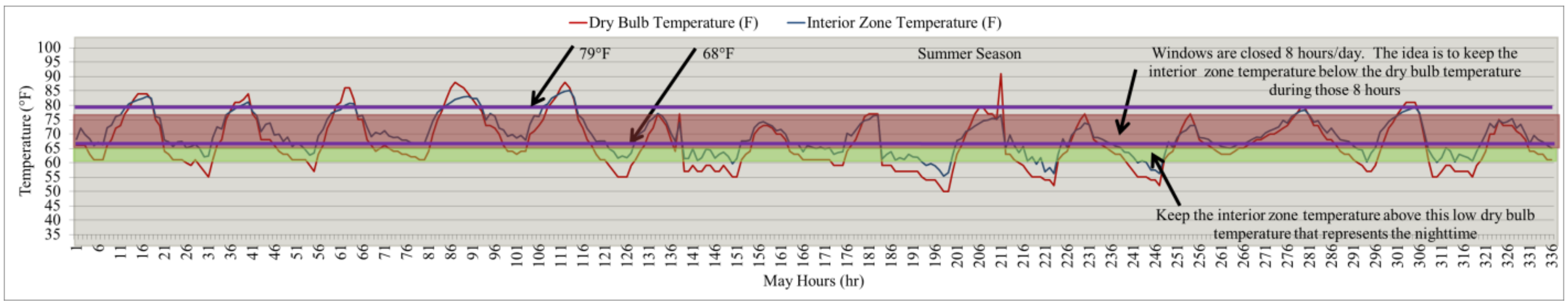


Figure 90. Dry Bulb and Interior Zone Temperatures for May (Case 0_Base-Case).

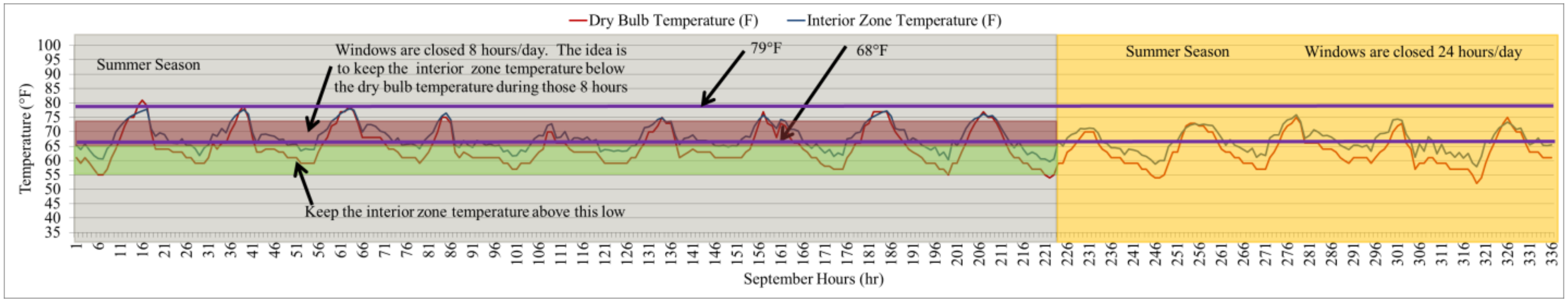


Figure 91. Dry Bulb and Interior Zone Temperatures for September (Case 0_Base-Case).

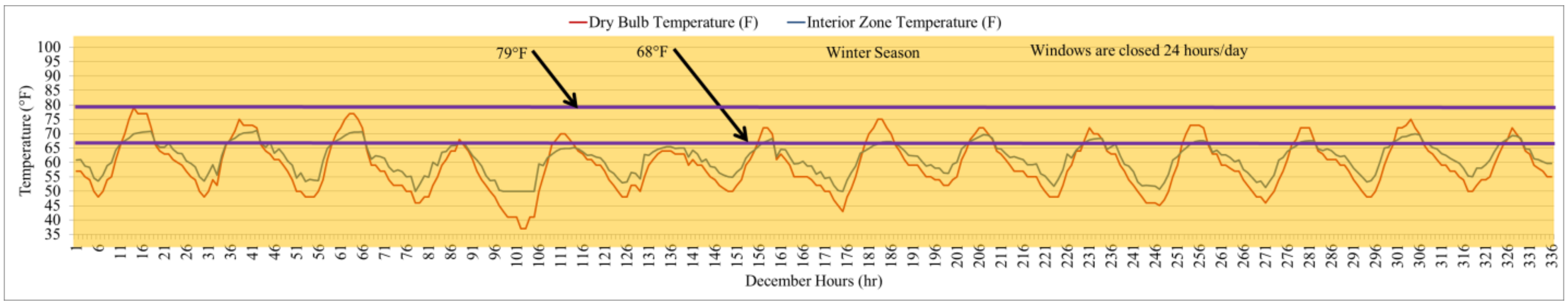


Figure 92. Dry Bulb and Interior Zone Temperatures for December (Case 0_Base-Case).

10) Figure 93 presents the outdoor dry bulb and the interior zone temperature for the 15th day of each month assigned for the summer season.[112] In Figure 93, it is clear that the highest temperatures for these days occurred from 12:00 to 20:00. The analysis showed the outdoor dry bulb and the interior zone temperatures from all the months but June range from 70°F to 84°F. Therefore, a series of simulations were performed beginning at 12:00. It was assumed that the windows should be closed for eight hours. The windows were then opened at 20:00 in order to cool down the interior zone and the thermal mass until the next day. Table 84 exhibits the results of the hours inside thermal comfort zone using the night flush/closed windows for heat trap schedules. Closing the window for an hour in the Case 11_Window Schedule_Summer 1 hr adds 16 to 25 percent of hours in the thermal comfort zone to the base-case results. Closing the window for eight hours in Case 11_Window Schedule_Summer 8 hr adds 19 to 28 percent of hours in thermal comfort zone to the base-case results. The zones in Case 11_Window Schedule_Summer 8 hr reach 33 to 39.5 percent of thermal comfort during the year.

Table 84. Hours inside Thermal Comfort Zone Using Night Flush/Closed Windows for Heat Trap Schedule.

Case Name	Percent (%)
Case 0_Base-Case	19.7
Case 11_Window Schedule_Summer 1 hr	47.3
Case 11_Window Schedule_Summer 2 hr	47.3
Case 11_Window Schedule_Summer 3 hr	47.6
Case 11_Window Schedule_Summer 4 hr	47.6
Case 11_Window Schedule_Summer 5 hr	47.9
Case 11_Window Schedule_Summer 6 hr	48.1
Case 11_Window Schedule_Summer 7 hr	48.8
Case 11_Window Schedule_Summer 8 hr	49.5

[112] These temperatures are obtained from the EL4 ESE Perim Zone.

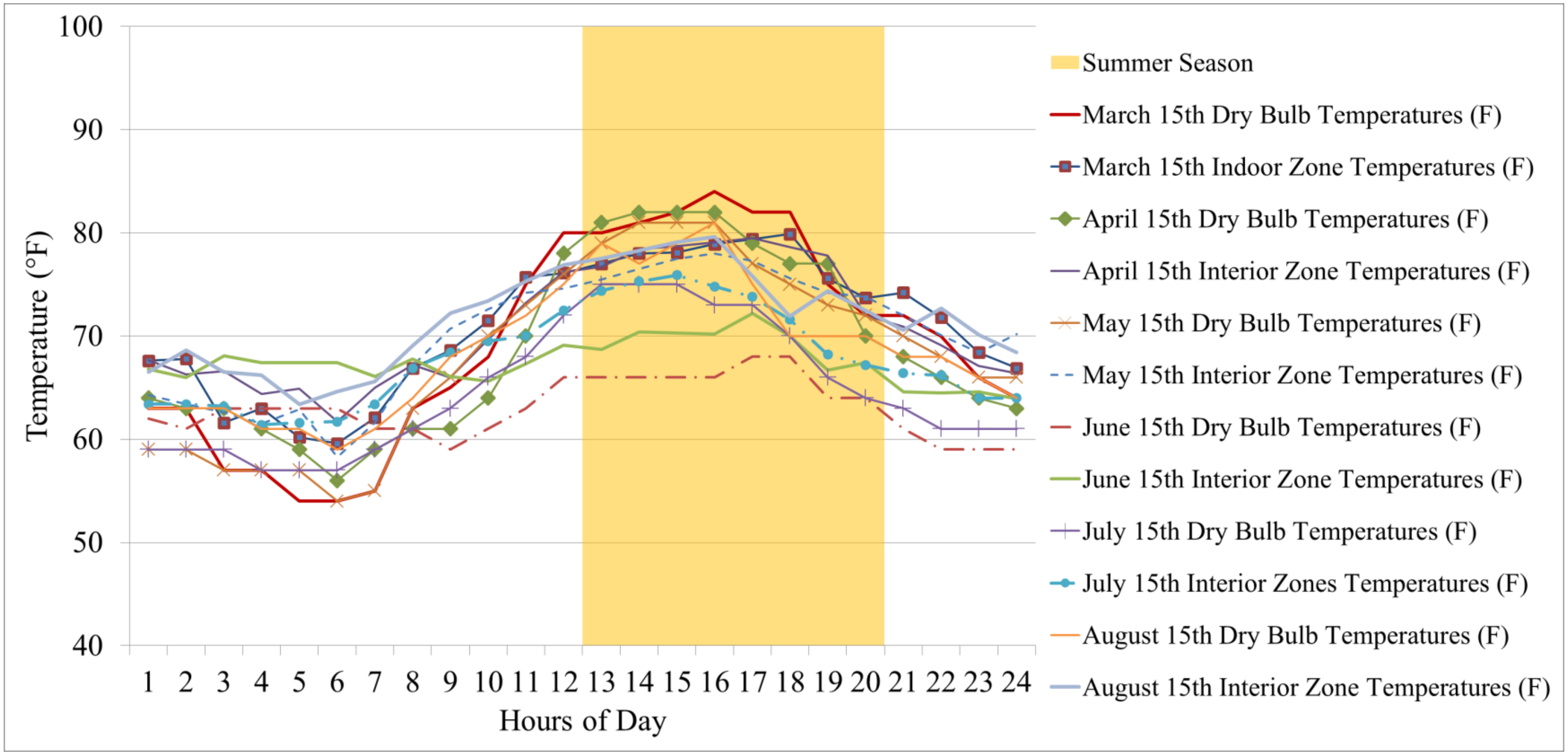


Figure 93. Dry Bulb Temperature and Interior Zone Temperature for the 15th Day of Each Month Assigned to Summer Season.

11) The seasonal periods were assumed as follows:

   a) Winter Closed Windows for Heat Trap: The schedule for winter starts on January 1st and finishes on March 8th. The windows were closed for the whole day.

   b) Summer Night Flush: The schedule for summer starts on March 9th and finishes on September 10th. Windows were closed 12:00 through 20:00 and opened the rest of the day.

   c) Winter Closed Windows for Heat Trap: The schedule for winter starts on September 11th and finishes on December 31st. The windows were closed for the whole day.

12) Case 11_Window Schedule_Summer 8 hr doubles the percent of hours inside the comfort zone. Thus, Case 11_Window Schedule_Summer 8 hr is the best schedule to add hours inside the comfort zone. Case 13_Energy-Efficient Case is the best to save energy, but is not the best one to increase hours inside of the comfort zone.

13) Figure 89 through Figure 92 and Figure 94 through Figure 97 demonstrated the results for both Case 0_Base-Case and Case 11_Window Schedule_Summer 8 hr, respectively. The graphs show that the schedules for winter[113] and summer are working as planned. The complexity of the data from these graphs also revealed:

   a. The temperature for each day of each month is not uniform;

   b. The identification of each hour per month (24 hr/day X 30.5 days/month);

   c. How each hour per month (24 hr/day X 30.5 days/month) behaved once the Case 11_Window Schedule_Summer 8 hr was applied;

   d. The number of hours with the windows closed in summer could start before 12:00;

   e. The number of hours with the windows closed in summer could be more than eight;

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[113] The heat trapped during the winter using the window schedule is maintaining the indoor zone temperature over the outside temperature.

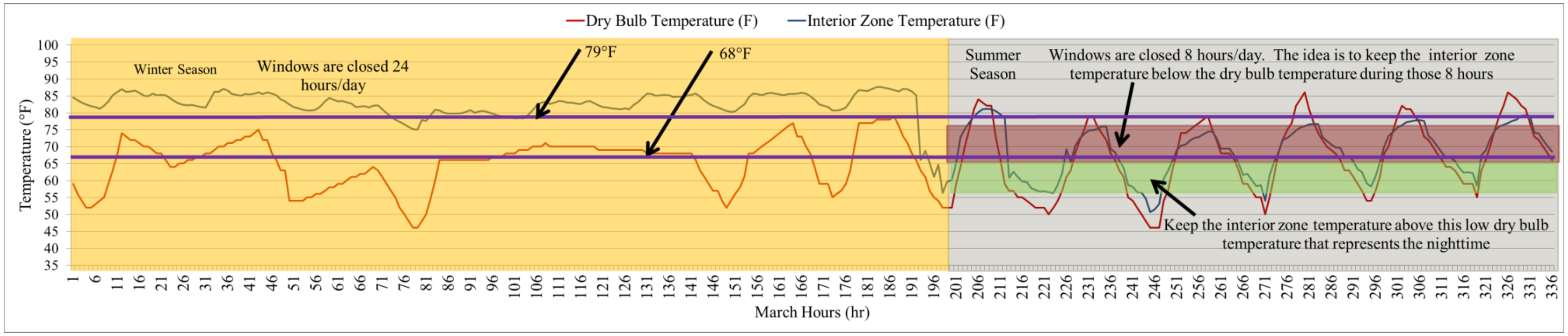

Figure 94. Dry Bulb and Interior Zone Temperatures for March in Case_11_Window Schedule_8 hr.

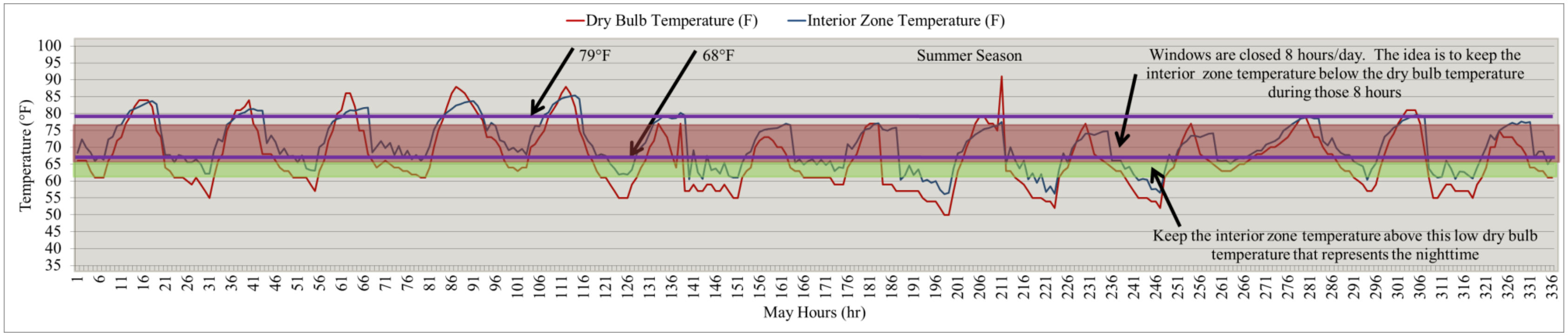

Figure 95. Dry Bulb and Interior Zone Temperatures for May in Case_11_Window Schedule_8 hr.

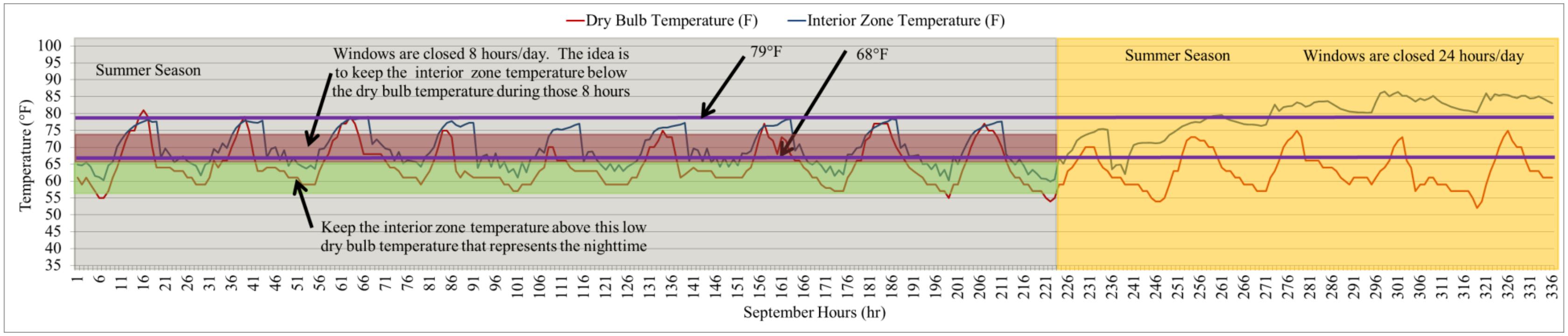

Figure 96. Dry Bulb and Interior Zone Temperatures for September in Case_11_Window Schedule_8 hr.

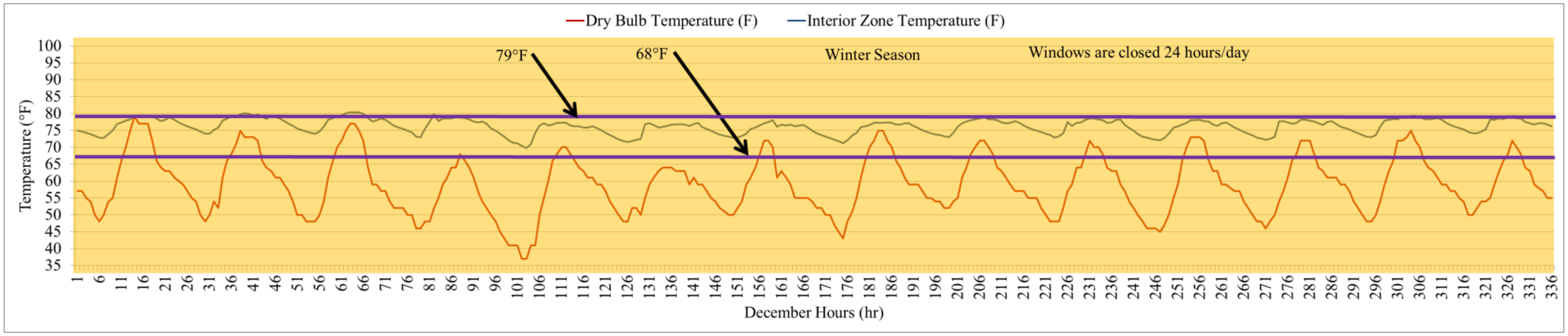

Figure 97. Dry Bulb and Interior Zone Temperatures for December in Case_11_Window Schedule_8 hr.

f. People might open the windows during winter although this analysis emphasized to close the windows for the whole day;
g. In relation to point “f”, another combination of hours during winter could be analyzed if the windows were opened for one, two, three hours, and so on; and
h. The creation of more seasons and addition of more schedules per season.

To conclude, points “a” through “h” proved that the nigh flush/winter sink research could go further beyond the limits of this technical potential study. This new inquiry is set for future work.

Finally, it was required to set the final energy-efficient case from another point of view. Two options were assumed as it follows:

1) Case 14_Window Schedule Plus Natural Ventilation Schedule and
2) Case 15_Final Combined Five Measures.

Case 14 applied a modified natural ventilation schedule over the previous window schedule from Case 11_Window Schedule_Summer 8 hr. This modification changed the interior zone temperature setpoint for the base-case in order to close the windows. This change is moved from 50°F to 60°F. This change affects the condition of the open windows during the summer. The windows will be closed once the indoor temperature reaches 60°F. The latter applies to a combination of the energy-saving measures (i.e., change lamps, change appliances and turn on daylighting controls) and increase thermal comfort measures (i.e., night flush/closed windows for heat trap seasons and new natural ventilation schedule). Figure 98 through Figure 101 displayed the time series plot for March, May, September and December for Case 15_Final Combined Five Measures. These figures have from the first hour from the first day of the month until the 338 hour of the month in order to show the performance of the dry bulb temperature and the interior temperature. If the entire 732 hours of the month (i.e., taking approximately 30.5 days per month) were presented, the image would not be clear enough for the study.

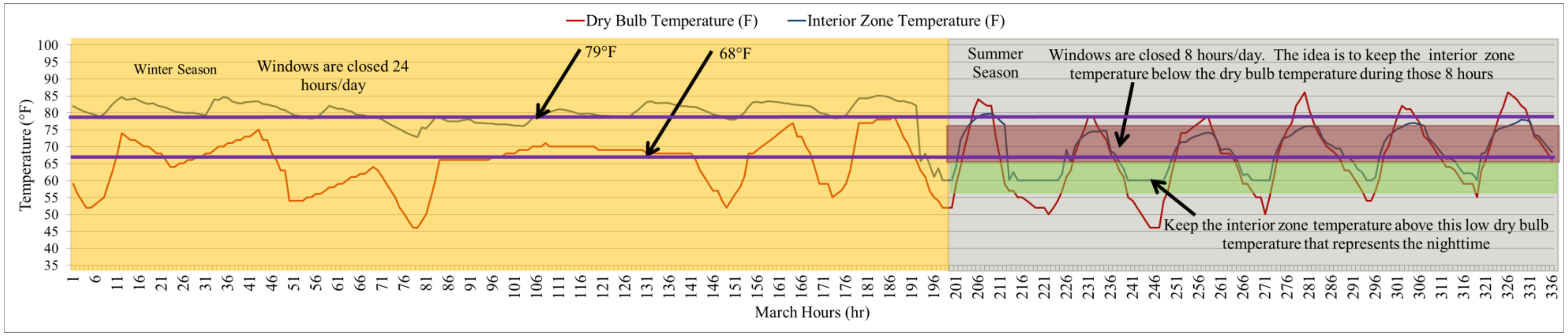

Figure 98. Dry Bulb and Interior Zone Temperatures for March in Case_15.

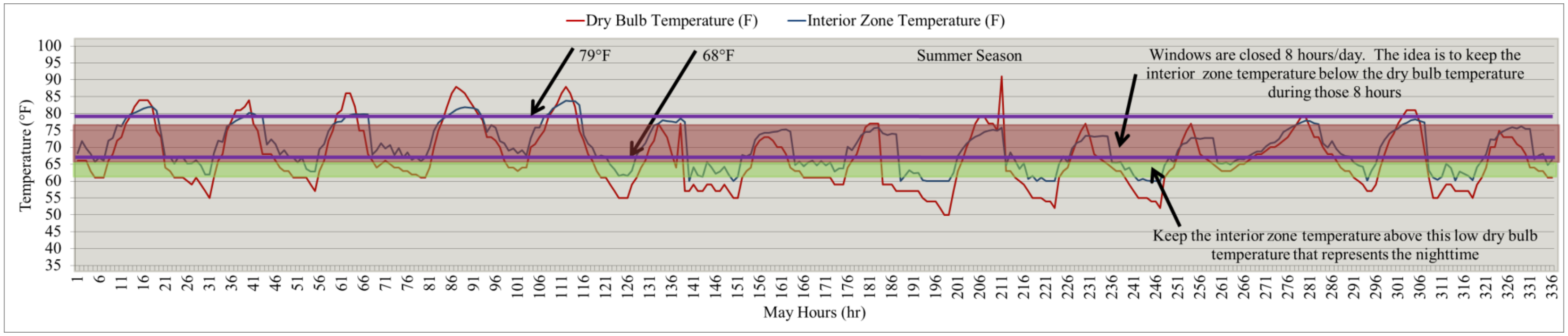

Figure 99. Dry Bulb and Interior Zone Temperatures for May in Case_15.

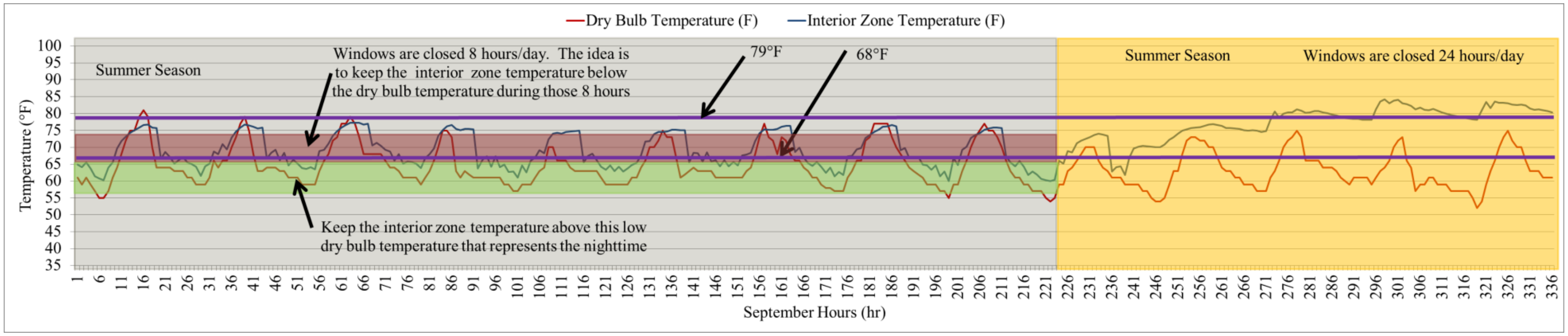

Figure 100. Dry Bulb and Interior Zone Temperatures for September in Case_15.

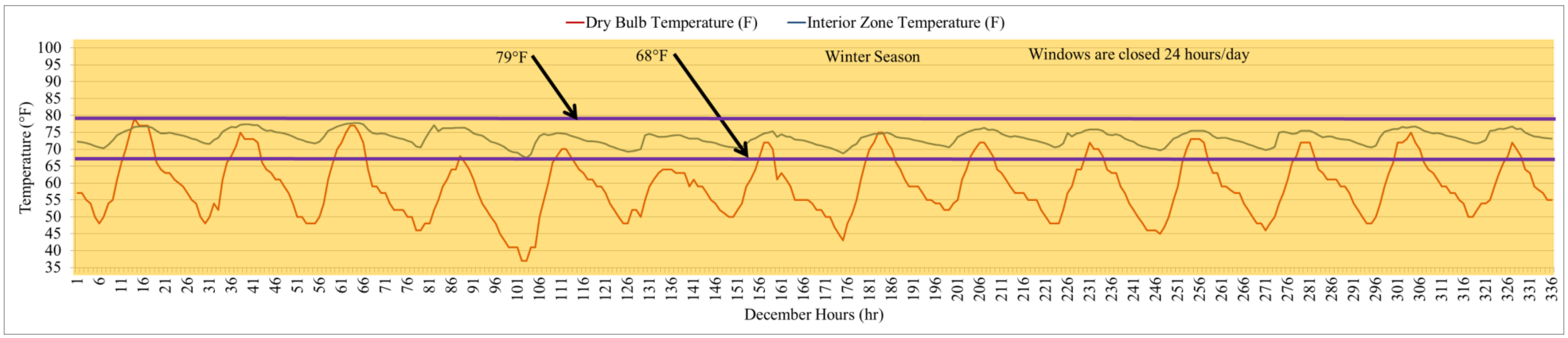

Figure 101. Dry Bulb and Interior Zone Temperatures for December in Case_15.

Table 85 and Figure 102 present the energy consumption, and Table 86 and Figure 103 show the hours inside thermal comfort zone for the following cases:

1) Case 0_Base-Case,
2) Case 11_Window Schedule_Summer 8 hr,
3) Case 13_Energy-Efficient Case,
4) Case 14_Window Schedule plus Natural Ventilation Schedule, and
5) Case 15_Final Combined Five Measures (change lamps, change appliances, turn on daylighting controls, night flush/closed windows for heat trap seasons and new natural ventilation schedule).

Table 85. Energy Consumption for Five Cases.

	Case 0_Base-Case	Case 11_Window Schedule_8 hr	Case 13_Energy-Efficient Case	Case 14_Window Sched + Nat Vent Sched	Case 15_Final Combined Five Measures
	Total	**Total**	**Total**	**Total**	**Total**
	kWh (X 1,000)	**kWh (X 1,000)**	**kWh (X 1,000)**	**kWh (X 1,000)**	**kWh (X 1,000)**
Area Lights	286.4	286.4	45.11	286.4	43.39
Task Lights	0	0	0	0	0
Misc. Equip.	289.06	289.06	89.6	289.06	89.6
Heat Reject.	0	0	0	0	0
Refrigeration	0	0	0	0	0
HP Supp.	0	0	0	0	0
Hot Water	0	0	0	0	0
Pumps & Aux.	0.1	0.1	0.1	0.1	0.1
Ext. Usage	0	0	0	0	0
Vent. Fans	0	0	0	0	0
Space Heat	0	0	0	0	0
Space Cool	0	0	0	0	0
Total Energy Consumption	575.56	575.56	134.81	575.56	133.09
Energy Consumption (Percent)		100	23	100	23
Energy Reduction (Percent)		0	77	0	77

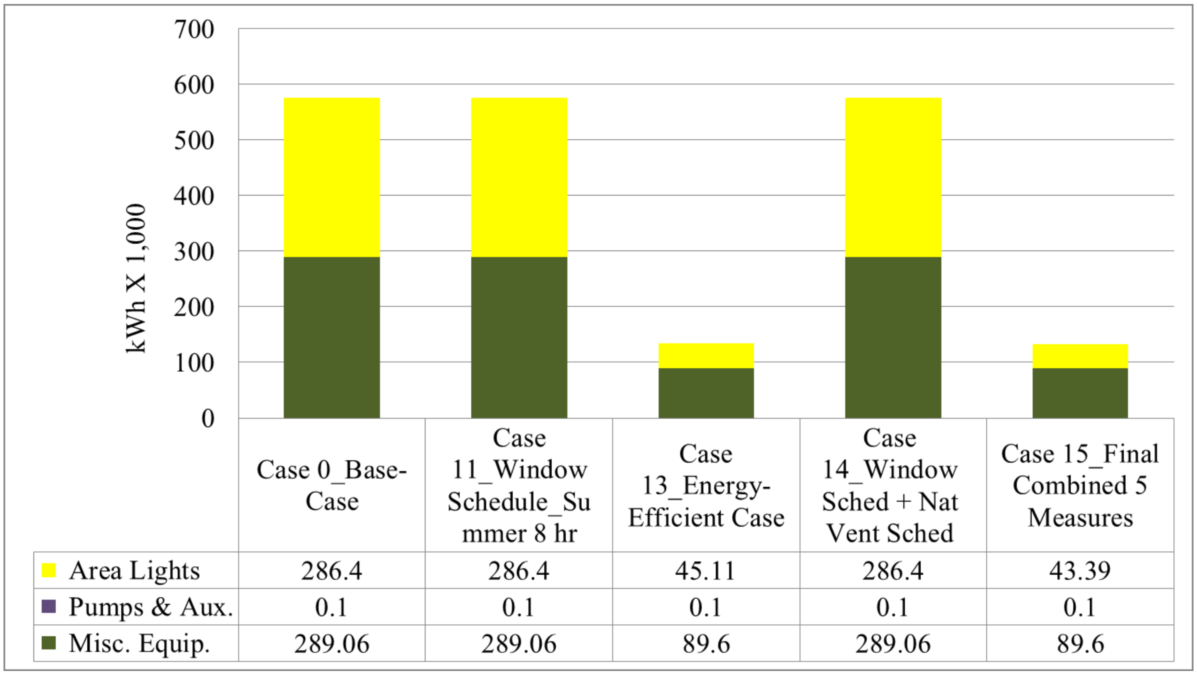

Figure 102. Total Energy Consumption for Five Cases.

Table 86. Percent of Hours inside Thermal Comfort Zone for Five Cases.

Case ID Name	80 Percent
Case 0_Base-Case	20
Case 11_Window Schedule_Summer 8 hr	49
Case 13_Energy-Efficient Case	50
Case 14_Window Sched + Nat Vent Sched	50
Case 15_Final combined 5 cases	50

Figure 103 shows five cases using the adaptive comfort model in ASHRAE 55-2004 (2004b). In Figure 103, the interior zone temperature is located on the y-axis and the outside temperature is located on the x-axis. A diagonal line is added to the graph for each case to show the 1:1 relationship. These are the findings for each graph:

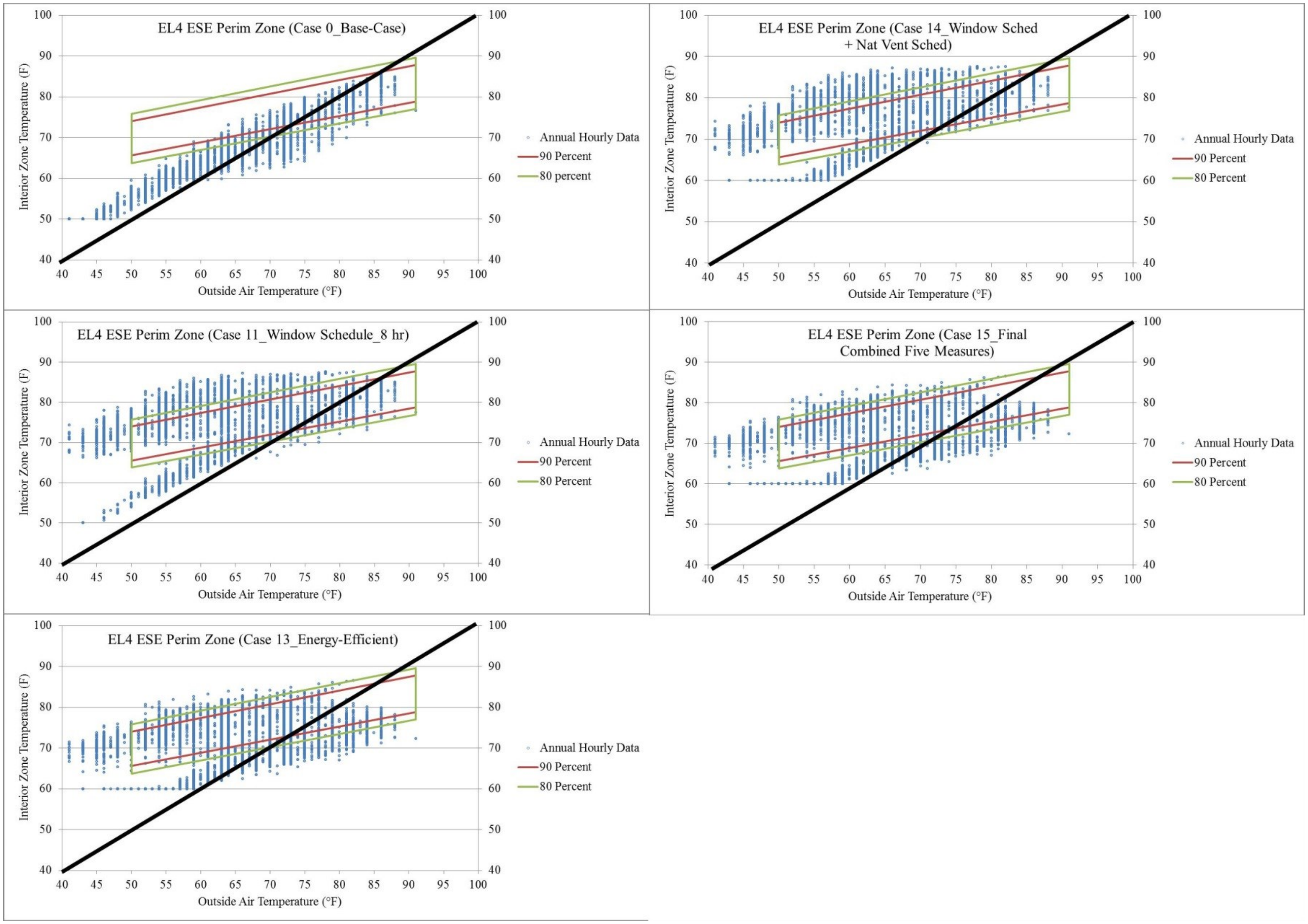

Figure 103. Five Identified Cases Using the Adaptive Comfort Model in ASHRAE 55-2004 (2004b).

1) Case 0_Base-Case, in the upper left corner, displays hours to the left side of the diagonal line. This shows the interior zone temperature is low because there is no air-conditioning system. The only heating source in the zone is the internal heat gains (people, lamps and appliances). In Figure 103, the hours below 65°F interior temperature and 65°F outside temperature represent the nighttime or hours before 7:00 when the activities in the zone have diminished and the outside temperature is cold. The hours above 65°F interior temperature and 65°F outside temperature represent the daytime activities.
2) Case 11_Window Schedule_8 hr, in the left middle plot, shows that the interior temperature rose after applying the summer night flush/winter heat trap to the base-case. The plots show the interior temperatures rising above 80°F corresponding to the hours using the winter heat trap.
3) Case 13_Energy-Efficient, in the lower left corner, exhibits that the interior temperature raised after applying the summer night flush/winter heat trap to the base-case. The hours in Case 13 were not as scattered as Case 11, because the internal heat gains were reduced by changing to energy-efficient lamps and appliances. The hours on the lower left corner stay on 60°F, because of the modeled, operable windows. This characteristic limited the interior zone temperature going below 60°F. The window closure was assumed to be a passive strategy that people had in order to keep the apartments into comfort.
4) Case 14_Window Schedule plus Natural Ventilation Schedule, in the upper right corner, displays that the results in the graph for the Case 14 are similar to the graph for the Case 13. The hours in Case 14 were more scattered compared to Case 13, because the internal heat gains were not reduced.
5) Case 15_Final Combined Five Measures, in the right middle plot, shows the similar results of Case 13_Energy-Efficient. The only strategies used in Case 15 were to change the lamps, change appliances, turn on daylighting controls, night flush/closed windows for heat trap seasons and new natural ventilation schedule. Case 13 uses all the measures from Table 81.

The results of the analysis are shown in Table 85, Table 86 and Figure 102 can be summarized as follows:

1) Case 11_Window Schedule_Summer 8 hr compared to Case 0_Base-Case increased hours inside comfort from 20 percent to 49.5 percent and does not save any energy.
2) Case 13_Energy-Efficient Case contrasted to Case 0_Base-Case saved 77 percent of energy and boosts hours inside comfort from 20 percent to 39 percent. Case 11_Window Schedule_Summer 8 hr by itself added more hours to the thermal comfort (49.5 percent) than Case 13_Energy-Efficient Case (39.4 percent).
3) The combination of the energy-efficiency measures in Case 13 are not the best cases from Case 11, Case 13, Case 14 and Case 15.
4) The Case 14_Window Schedule plus Natural Ventilation Schedule adds some hours from Case 11_Window Schedule_Summer 8 hr. The use of the natural ventilation schedule strategy is essential for the last case.
5) Case 15_Final Combined Five Measures cuts down energy consumption by 76 percent. However, it also adds more comfort hours to Case 0_Base-Case from 20 percent to 50 percent.

4.3.1.2. Analysis of Photovoltaic System for Multi-Family Apartments.

The goal for the use of a photovoltaic system in this technical potential study is to generate on-site electricity and reduce electricity consumed from the grid. The analysis of the photovoltaic system for this technical potential study was completed with the PV F-Chart software. The simulation of the PV system is accomplished for 240 apartments in the building.

In her dissertation, Malhotra (2009) mentioned that the calculations in PV F-Chart are accomplished for each hour for an average day of each month, and these days are then multiplied by the number of days in order to calculate each month. The PV F-Chart software requires a weather data file. There is not a TMY2 or TMY3 weather data file for Mexico City. Then, a TMY2 file was created for Mexico City in order to run the analysis for the photovoltaic system.

The solar radiation, dry-bulb temperature and humidity ratio data from the file Mex_Mexico.City.766790_IWEC were used to determine the climate characteristics for the TMY2 file for Mexico City. The ground reflectance did not appear in the IWEC file and was considered to be 0.7 per month. Finally, Baltazar-Cervantes and Liu (2008) were consulted for a set of psychrometric functions for Excel, in order to process the data from the IWEC file from Mexico City and introduce this data to PV F-Chart. Table 87 displays Mexico City's TMY2 data introduced to PV F-Chart.

Table 87. Mexico City's TMY2 Data Introduced to PV F-Chart.

	Solar Radiation	Dry Bulb Temperature	Humidity Ratio	Ground Reflectance
	BTU/ft²	°F	lbw/lbda	
January	1,308	76.82	0.0080	0.7
February	1,502	80.42	0.0076	0.7
March	1,721	84.02	0.0044	0.7
April	1,808	86.00	0.0049	0.7
May	1,786	86.54	0.0053	0.7
June	1,784	85.82	0.0119	0.7
July	1,750	79.16	0.0193	0.7
August	1,789	79.88	0.0191	0.7
September	1,615	80.60	0.0153	0.7
October	1,476	78.98	0.0172	0.7
November	1,271	79.16	0.0085	0.7
December	1,116	77.36	0.0105	0.7

4.3.1.2.1. Photovoltaic Analysis for Multi-Family Apartments.

As a reminder from part 2.5.7.1 Solar Electric Systems, the *CONAVI*'s code (2010a) stated that in Mexico, the solar energy collected during the day is used directly in the house. If there is any additional electricity, it is considered surplus. This surplus is sent to the electric grid through a bidirectional meter of the *CFE*. On the other hand, at night when there is no solar radiation, the house consumes electricity from the electric grid provided by the *CFE*. The PV F-Chart has a system called utility interface that sells the excess of power generated to the utility. There was no information that showed that on-site energy generated by PV in Mexico could be sold to the *CFE*. Moises Sevilla (Lopez, 2013) explained that the kWh of solar energy sent through the grid was reckoned by the *CFE* and was stored in an "energy bank". These stored solar energy kWh were returned to the dwelling, once the homeowner needs them. Thus, the utility interface system in PV F-Chart was selected to simulate the on-site solar electric power for this technical potential study.

Table 88 presents some photovoltaic module systems sold in Mexico. The first column is the brand name, the second column is the model number and the third column is the type of the PV. The fourth column is the size of the PV, the fifth column is the cell temperature and the sixth column is the general comments of the PV. The seventh column is the maximum wattage of the PV. In order to be successfuel, the chosen PV must have the following characteristics: 1) PV must be sold in Mexico and 2) PV efficiency must be at least 15 percent.

Table 88. Photovoltaic Module Systems Sold in Mexico.

Brand	Model	Type	Size	NOCT	Efficiency	Comments	Maximum	References
			meters or feet	°F	%		Watts	
SolarWorld	SW-265	Monocrystalline	(1.675 m X 1.001 m, or 5.49 ft. X 3.28 ft.)	114.8	15.81	60 cells per module	265	SolarWorld, n.d.
Zythec	ZT 250S/260S/270S	Monocrystalline	(1.59 m X 1.064 m, or 5.21 ft. X 3.49 ft.)	116	15.00	96 cells per module	250-270	Zytech, 2007b
Zythec	ZT 210S/215S	Monocrystalline	(1.58 m X 0.808 m, or 5.18 ft. X 2.65 ft.)	117	16.5-17.00	72 cells per module	210-215	Zytech, 2007c
Solaris	ERDM 250TP/6	Polycrystalline	(1.64 m X 0.990 m, or 5.21 ft. X 3.49 ft.)		15.39	60 cells per module	250	Energia Renovable Solaris, n.d.
Kyocera	KD210GX-LP	Polycrystalline	(1.50 m X 0.990 m, or 4.91 ft. X 3.49 ft.)	120	16.00	54 cells per module	210	Kyocera, n.d.

The datasheet for photovoltaic monocrystalline module was obtained from Zytech (2007a, c). Zytech, a company whose headquarters are located in Zaragoza, Spain, has a branch in Mexico City as well as Cabo San Lucas, Baja California Sur, Mexico. Their data sheet shows the cell temperature (NOCT conditions); the efficiency of the module (17 percent); and the dimension of the module (1.58 m X 0.808 m, or 5.18 ft. X 2.65 ft.) (Zytech, 2007c). The data from the location of the building at Mexico City is the array slope. It was assumed that 50 percent of the rooftop area of the building would have PV and the PV would be oriented towards the south. Table 89 displayed the data introduced to the Utility Interface System in PV F-Chart.

Before running the simulation, a sanity check was performed to calculate the electricity load required for the apartments' section and simulated into PV F-Chart.[114] Table 90 displays the electricity load required for each hour of a day for a single apartment and for the whole apartment section. The first column corresponds to the time. The watts hour per day per apartment are the lighting loads plus the appliance loads shown in the second column. The watts hour per day for the whole apartment section of the building[115] are the lighting loads plus the appliance loads shown in the third column.

Table 89. Data Introduced to the Utility Interface System in PV F-Chart.

Element	Amount	Units
City	Mexico City	City
Cell Temperature (NOCT conditions)	117	°F
Array reference efficiency	0.17	Percent
Array reference temperature	82.4	°F
Array temperature coefficient*1000	2.389	1/°F
Power tracking efficiency	0.9	Percent
Power conditioning efficiency	0.88	Percent
% Standard deviation of load	0	Percent
Array area (no. of panels X panel area)	37,265	ft²
Array slope	20	Degrees
Array azimuth (South=0)	0	Degrees

[114] The electricity load input to PV F-Chart is the sum of the electricity from the bulbs and the appliances multiplied by the time used by the bulb and the appliances.
[115] The load for each hour of the day was multiplied by 240 apartments.

Table 90. Watts per Hour per Day for a Single Apartment and Watts for Each Hour for a Day for the Whole Apartment Section of the Building.

Hour	Wh/day-apartment	Wh/day-apartment section
1:00	62.5	15,000.0
2:00	62.5	15,000.0
3:00	62.5	15,000.0
4:00	62.5	15,000.0
5:00	62.5	15,000.0
6:00	137.5	33,000.0
7:00	165.0	39,600.0
8:00	195.0	46,800.0
9:00	135.0	32,400.0
10:00	505.0	121,200.0
11:00	105.0	25,200.0
12:00	105.0	25,200.0
13:00	135.0	32,400.0
14:00	265.0	63,600.0
15:00	265.0	63,600.0
16:00	265.0	63,600.0
17:00	135.0	32,400.0
18:00	395.0	94,800.0
19:00	555.0	133,200.0
20:00	595.0	142,800.0
21:00	855.0	205,200.0
22:00	795.0	190,800.0
23:00	422.5	101,400.0
0:00	227.5	54,600.0
Total	6,570.0	1,576,800.0

Then, the sanity check was presented as next:

6,570 Wh/day-apartment X 1 day/24 hr. = 273.75 W/apartment

273.75 W/apartment/750 ft^2/apartment = 0.365 W/ft^2

240 apartments/building X 750 ft^2/apartment = 180,000 ft^2/building

180,000 ft^2/building X 0.365 W/ft^2 = 65,700 W/building

65,700 W/building X 24 h/day = 1,576,800 Wh/building-day

1,576,800 Wh/building-day X 30.5 days/month = 48,092,400 Wh/building-month

48,092,400 Wh/building-month X 1 kW/1,000 W = 48,092.4 kWh/building-month

48,092.4 kWh/building-month X 12 month/year = 577,108.8 kWh/building-year

577,108.8 kWh/building-year X 1year/365 days = 1,581.12 kWh/building-day

1,581.12 kWh/building-day X 1 building/240 apartments = 6.588 kWh/day-apartment

This agrees with the 6,570 Wh/day-apartment and 1,576,800 Wh/day-apartment section shown in Table 90.

Therefore, the load per hour from the third column in Table 90 is introduced in the electricity loads per hour in the load screen from PV F-Chart. The 1,533,497.1 Wh/day-apartment section needed to appear in the electricity loads in the final results from PV F-Chart. Table 91 exhibited the PV F-Chart's output from the utility interface system. The first column is for the months. The second column is for *solar*. The *solar* is the total solar radiation incidence on the surface of the flat-plate array. The third column is for *efficiency*. The *efficiency* is the percent of the solar radiaton incident on the flat-plate that is converted to electricity. The fourth column is for *loads*. The *loads* are the total electrical demand from the whole building analyzed. The fifth column is for *f*. The *f* is the percent of the load supplied directly by the flat-plate array. According to the results, 20 percent is covered by the system simulated with PV F-Chart. The sixth column is for *sell*. The *sell* is the total electricity generated by the panels that is not used by the building and is sold back to the utility according to PV F-Chart. By law, on-site energy generated in Mexico cannot be sold to *CFE*. The seventh column is for *buy*. The *buy* is the total electricity that should be purchased from the utility to complement the load. The two final columns mean that the user can sell the electricity excess, from the *sell* column, which represents several hours per month, and the electricity that is required, as displayed on the *buy* column, during selected hours because the on-site PV electricity generation is not enough to cover the load. The PV F-Chart calculated the notion of how much PV electricity can be sent to the grid. It also quantified how much electricity will be needed from the grid to cover the electric load from the apartments.

Table 91. PV F-Chart's Output from the Utility Interface System.

	Solar [kW-hrs]	Efficiency [%]	Load [kW-hrs]	f [%]	Sell [kW-hrs]	Buy [kW-hrs]
Jan	105,267.4	13.43	48,880.8	18.6	3,353.5	39,791.6
Feb	104,725.3	13.18	44,150.4	19.8	3,410.4	35,413.5
Mar	124,534.7	13.02	48,880.8	20.8	4,075.9	38,690.2
Apr	119,108.8	12.94	47,304.0	20.9	3,659.4	37,396.4
May	115,466.2	12.94	48,880.8	20.4	3,165.5	38,897.4
Jun	109,505.0	12.97	47,304.0	20.4	2,858.5	38,667.6
Jul	112,119.8	13.20	48,880.8	20.3	3,086.5	38,942.5
Aug	119,308.3	13.16	48,880.8	20.8	3,631.8	38,692.4
Sep	110,216.5	13.17	47,304.0	19.8	3,407.2	37,942.0
Oct	111,222.4	13.24	48,880.8	19.3	3,531.4	39,451.7
Nov	97,857.9	13.28	47,304.0	18.0	2,940.3	38,807.7
Dec	89,739.8	13.47	48,880.8	16.5	2,544.9	40,792.0
Year	1,319,072.2	13.17	575,532.0	19.6	39,665.3	462,485.2

A sanity check for the calculation is as follows. Table 92 displays the electricity consumed by the building simulated with eQuest and the electricity consumed from the profile introduced to PV F-Chart. The first column is the months of the year. The second to fourth columns are the electricity consumed for each floor[116] simulated. The fifth column is the sum of the electricity consumed in the building. The sixth column is the load obtained from PV F-Chart. The results from the fifth and the sixth columns are the loads obtained after the profile is inserted to eQuest and PV F-Chart. In conclusion, these results almost match, which means the profile used in PV F-Chart is relatively the same that is used in eQuest.

[116] The EL3 floor shell used the multiplier to model 10 floors.

Table 92. Final Electricity Consumed after Subtracting the On-Site Energy Produced from the PV System.

	Electrical Energy			eQuest SS-A	PV F-Chart
	EL2	EL3	EL4	Total Electricity	Total Electricity
	kWh	kWh	kWh	kWh	kWh
JAN	4,082	40,738	4,082	48,902	48,881
FEB	3,684	36,794	3,684	44,162	44,150
MAR	4,074	40,731	4,074	48,879	48,881
APR	3,942	39,416	3,942	47,300	47,304
MAY	4,073	40,730	4,073	48,876	48,881
JUN	3,942	39,416	3,942	47,300	47,304
JUL	4,073	40,729	4,073	48,875	48,881
AUG	4,073	40,729	4,073	48,875	48,881
SEP	3,942	39,416	3,942	47,300	47,304
OCT	4,074	40,731	4,074	48,879	48,881
NOV	3,949	39,423	3,949	47,321	47,304
DEC	4,080	40,736	4,080	48,896	48,881
	Total			575,565	575,532

Another sanity check was used to double-check the results from eQuest for the *load* column and the *f* column from Table 91 as follows:

7,551 ft² X 0.092903 m²/ft² = 701.5 m²

701.5 m² X 150 W/m² = 105,225 W

105,225 W X 6 h/day = 631,350 Wh/day

631,350 Wh/day X 30.5 day/month = 19,256,175 Wh/month

19,256,175 Wh/month X 12 months/year = 231,074,100 Wh/year

231,074,100 Wh/year X 1 kW/1,000 W = 231,074.1 kWhr/year

The load can be checked as next:

575,532 kWh/year X 0.2 = 115,106.4 kWh/year

The 115,106.4 kWh/year is 50 percent of the 231,074.1 kWhr/year that is provided by the 7,551 ft² of PV assuming six hours per day. If the PV only supplies three hours of on-site energy generation, the amount is as follows:

$7{,}551 \text{ ft}^2 \text{ X } 0.092903 \text{ m}^2/\text{ft}^2 = 701.5 \text{ m}^2$

$701.5 \text{ m}^2 \text{ X } 150 \text{ W/m}^2 = 105{,}225 \text{ W}$

105,225 W X 3 h/day = 315,675 Wh/day

315,675 Wh/day X 30.5 day/month = 9,628,087.5 Wh/month

9,628,087.5 Wh/month X 12 months/year = 115,537,050 Wh/year

115,537,050 Wh/year X 1 kW/1,000 W = 115,537.05 kWhr/year

Thus, the 115,537.05 kWh/year on-site energy obtained from the hand calculation is approximately the same as the 115,106.4 kWh/year on-site energy calculated from the PV F-Chart. This means that the PV rooftop area provides 115,106.4 kWh/year of sustainable solar electric energy for three hours during the day.

Finally, in terms of the solar electricity produced for the whole community, the results are shown as follows:

115,106.4 kWh/year-building X 4.5 buildings/community = 517,978.8 kWh/year-community.

4.3.1.3. Analysis of Domestic Hot Water System for Multi-Family Apartments.

The analysis of the domestic hot water system for this technical potential study was completed with the F-Chart software. In her dissertation, Malhotra (2009) mentioned that the calculations in F-Chart are accomplished for each hour for an average day of each month, and these days are multiplied by the days per month to calculate each month. The F-Chart software requires a weather data file. There is not a TMY2 or TMY3 weather data file for Mexico City. Then, a TMY2 file was created for Mexico City in order to run the analysis for the domestic hot water system.

The solar radiation, dry-bulb temperature and humidity ratio data from the file Mex_Mexico.City.766790_IWEC were used to determine the climate characteristics for the TMY2 file for Mexico City in Table 93. The column for the mains is taken from the Los

Angeles' TMY2 weather data file.[117] The reflectance is not included in the IWEC file and was therefore considered to be 0.7 per month. Finally, Baltazar-Cervantes and Liu (2008) were consulted for a set of psychrometric functions for Excel, in order to process the data from the IWEC file from Mexico City and introduce this data to F-Chart. Table 93 displays Mexico City's TMY2 data introduced to F-Chart.

Table 93. Mexico City's TMY2 Data Introduced to F-Chart.

	Solar Radiation	Temperature	Humidity	Water Mains	Reflectance
	BTU/ft²	°F	lbw/lbda	°F	
January	1,308	76.82	0.0080	61.7	0.7
February	1,502	80.42	0.0076	61.8	0.7
March	1,721	84.02	0.0044	61.8	0.7
April	1,808	86.00	0.0049	61.9	0.7
May	1,786	86.54	0.0053	62.0	0.7
June	1,784	85.82	0.0119	62.2	0.7
July	1,750	79.16	0.0193	62.3	0.7
August	1,789	79.88	0.0191	62.4	0.7
September	1,615	80.60	0.0153	62.4	0.7
October	1,476	78.98	0.0172	62.2	0.7
November	1,271	79.16	0.0085	62.0	0.7
December	1,116	77.36	0.0105	61.8	0.7

4.3.1.3.1. Application of Domestic Hot Water System for Multi-Family Apartments.

This technical potential study evaluated the domestic hot water system for the apartments. The goal of the analysis of the domestic hot system in this study was to generate on-site thermal energy using solar energy in order to reduce gas consumption. For this study, the only hydraulic furniture to be considered was the shower. Space heating system was not considered. Therefore, F-Chart program was used to analyze an active domestic hot water system without a space heating system. The simulation of the DHW was accomplished for the 240 apartments of the building with four people per apartment.

[117] As said in section 2.1, Los Angeles, San Diego and Burbank have similar climate to Mexico City. Therefore, data for the water mains can be taken from the weather data file of these cities.

Table 94 presented some DHW systems sold in Mexico. The first column is the brand name, the second column is the model and the third column is the type of the solar collector. The fourth column is the size of the solar collector, the fifth column is the tank size and the sixth column is the other features about the DHW system.

Table 94. DHW Systems Sell in Mexico.

Brand	Model	Type	Collector Size	Tank Size	Comments	References
ROTOPLAS	CI-GBA-66-ET	Flat-Plate	0.945 m X 0.965 m, or 3.10 ft. X 3.16 ft.	Diameter 0.550 m and Length 0.905 m, or Diameter 1.80 ft. X Length 2.96 ft.)	Tank Capacity of 112 lts. made of aluminum and copper; maximum pressure of 3 kg/cm²; 1 solar collector; certified by ONNCCE and CONUEE	ONNCCE, 2010
ROTOPLAS	CI-GBA-25-ET/CI-GBA-80-ET	Flat-Plate	1.837 m X 0.980 m, or 6 ft. X 3.21 ft.	Diameter 0.550 m and Length 1.275 m, or Diameter 1.80 ft. X Length 4.18 ft.)	Tank Capacity of 147.5 lts made of aluminum and copper; maximum pressure of 3 kg/cm²; 1 solar collector; certified by ONNCCE and CONUEE	ONNCCE, 2011a Quadri-De la Torre, 2008
AXOL	AXL Class 240 L	Flat-Plate	2.04 m X 0.92 m, or 6.69 ft. X 3.01 ft.	Diameter 0.4 m and Length 2.04 m, or Diameter 1.31 ft. X Length 6.69 ft.)	Tank Capacity of 240 lts.; 2 solar collectors; enameled tank; maximum pressure of 6 kg/cm²; certified by ONNCCE	CIME Power Systems, 2010
AXOL	AXOL AP 150 L	Flat-Plate	1.94 m X 0.85 m, or 6.36 ft. X 2.78 ft.	Diameter 0.515 m and Length 1.040 m, or Diameter 1.68 ft. X Length 3.41 ft.)	Tank Capacity of 150 lts.; 1 solar collector; steel tank; maximum pressure of 8 kg/cm²; certified by ONNCCE	Modulo Solar, n.d. Modulo Solar, 2013 ONNCCE, 2011b

In order to be successful, the chosen solar collector must have the following characteristics: 1) the DHW system must be sold in Mexico and 2) the thermal solar collector must provide hot water for four people per apartment for this technical potential study. The *Modulo Sola*r's AXOL AP 150 L covered these requirements (*ONNCCE*, 2011c; *Modulo Solar*, n.d., 2013).

Table 95 displays the system parameters of the active domestic hot water system in F-Chart. The first column is the element or system parameter. The second column is the amount to be introduced in the system parameter. The third column is the units.

Additional information about the solar thermal systems came from the product datasheet, the IWEC file, the location of the building at Mexico City and the F-Chart Manual (Klein and Beckman, 1985). As mentioned in section 2.5.7.2, the datasheet for a flat-plate collector system was obtained from *Modulo Solar* (*ONNCCE*, 2011c; *Modulo Solar*, n.d., 2013). *Modulo Solar* is a company whose headquarters are located in Cuernavaca, Morelos, Mexico. The parameter introduced from Modulo Solar's datasheet is the solar collector area of 17.38 ft² (*ONNCCE*, 2011c). Other parameters include the water volume (22,848 gal.)[118] divided by the solar collector area (4,171.2 ft²)[119] to obtain the water volume/area collector (5.47 gal.). The environmental temperature parameter was assumed from the Mexico City's IWEC file. The other parameters are either defaulted by the F-Chart software or cited into the F-Chart Manual (Klein and Beckman, 1985).

Table 96 displays the data introduced to the active solar domestic hot water system in F-Chart. The first column is the element or system parameter. The second column is the amount to be introduced in the system parameter. The third column is the units.

The parameters that were introduced from *Modulo Solar*'s datasheet were the following: one collector panel with an area of 17.38 ft², and one glazing cover (*ONNCCE*, 2011c). The collector slope was assumed from the location of Mexico City, which was finally rounded to 20°. (Garza, 2000; King-Binelli, 1994; *SEDESOL/CONAPO/INEGI*, 2007). The other parameters were either defaulted by the F-Chart software or cited into the F-Chart Manual (Klein and Beckman, 1985).

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[118] Ramos-Niembro and Patiño-Flores (2006) concluded that a person in Mexico City consumes 90 lt (9 lt per minute of shower multiplied by 10 min of shower), or 23.8 gal. of water to shower daily.

23.8 gal. X 4 people/apartment = 95.2 gal. /apartment.

Then, the calculation is needed for daily hot water Use for the simulation:

95.2 gal. /apartment X 240 apartments/building = 22,848 gal. /building

[119] 240 solar collectors X 17.38 ft² = 4,171 ft².

Table 95. System Parameters Introduced to the Active Domestic Hot Water System in F-Chart.

Element	Amount	Units
Location	Mexico City	
Water Volume / collector area	5.47	gal/ft²
Efficiency of fuel usage	70	%
Daily hot water usage	22,848	gal
Water set temperature	122	°F
Environmental temperature	80.2	°F
UA of auxiliary storage tank	7.6	Btu/hr-°F
Pipe heat loss	No	
Collector-store heat exchanger	No	

Table 96. Collector Parameters Introduced to the Active Domestic Hot Water System in F-Chart.

Element	Amount	Units
Number of collector panels	240	Solar collector
Collector panel area	17.38	ft²
FR*UL (Test slope)	0.740	Btu/hr-ft²-°F
FR*Tau*ALPHA(Test intercept)	0.700	
Collector slope	20	Degrees
Collector azimuth (South=0)	0	Degrees
Incidence angle modifier calculation	Glazings	
Number of glass covers	1	
Collector flowrate/area	11	lb/hr-ft²
Collector fluid specific heat	1.00	Btu/lb-°F
Modify test values	No	

Table 97 exhibits the F-Chart's output from the active domestic hot water system. The first column is for the months. The second column is for *solar*. The *solar* is the total solar radiation incidence on the flat-plate collector surface. The third column is for *DHW*. The *DHW* is the total water heating demand. The fourth column is for *auxiliary*. The *auxiliary* is the total auxiliary energy that is required to supply the DHW demand of the system. The fifth column is for *f*. The *f* is the fraction of the DHW demands that is supplied by the flat-plate collector.

A sanity check was applied to double check the results from the F-Chart's simulation as next:

1 solar collectors/apartment X 240 apartments-building = 240 solar collectors-building

240 solar collectors-building X 17.38 ft²/collector = 4,171.2 ft²

The 4,171.2 ft² was the approximated solar collector area. The DHW system must be located over the building's rooftop. The total building's rooftop area is 15,102 ft². Therefore, the area for the DHW system will be 27.62 percent of the 15,102 ft² as follows:

15,102 ft² X 0.2762 = 4,171.17 ft²

Table 97. F-Chart's Output from the Active Domestic Hot Water System.

	Solar	DHW	Aux	f
Months	BTU	BTU	BTU	
January	200,800,000	356,000,000	250,500,000	0.296
February	197,500,000	321,000,000	216,100,000	0.327
March	234,800,000	355,400,000	229,800,000	0.353
April	224,600,000	343,400,000	223,400,000	0.390
May	217,800,000	354,200,000	238,800,000	0.326
June	206,300,000	341,700,000	233,100,000	0.318
July	211,500,000	352,500,000	242,800,000	0.311
August	225,000,000	351,900,000	233,900,000	0.335
September	207,800,000	340,500,000	231,200,000	0.321
October	209,700,000	353,100,000	242,600,000	0.313
November	184,700,000	342,800,000	245,800,000	0.283
December	170,800,000	355,400,000	267,000,000	0.249
Total	2,491,300,000	4,167,900,000	2,855,000,000	0.315

To conclude, Table 97 shows in the fifth column that the system can provide 31.5 percent of the energy to reduce the use of liquefied gas and warm up the water with solar energy. 4,167.9 MMBtu were calculated for 240 apartments/building. The next calculation was realized to obtain the thermal energy needed for the complex:

4,167.9 MMBtu/building X 4.5 building/complex = 18,755.5 MBtu/complex

4.3.1.4. Energy-Efficient Use for the Grocery Store Section.

This section presented the process to model and analyzed the energy-efficiency measures for the grocery store. It was essential to point out, the use of the Climate Consultant software (Clayton et al., 1988; US DOE, 2012) in order to have an idea of the energy-efficient design strategies that can be applied to the technical potential study. Figure 104 shows the psychrometric chart from Climate Consultant with Mexico City's IWEC file.[120] The strategies with the biggest percent were the following: provide internal heat gains, use shading devices and apply heating systems.

According to the results from Climate Consultant (Clayton et al., 1988; US DOE, 2012) and the literature reviewed, the strategies that can have more impact in the grocery store section of the building are the next:

For the analysis of building envelope measures and passive solar systems:

1) Rotate the azimuth to 90°;
2) Increase the R-Value of the exterior walls of the grocery store;
3) Place shading devices over external windows; and
4) Place double-clear glazing.

For the analysis of daylighting and electrical systems:

1) Place and activate daylighting controls;
2) Change the lighting loads; and
3) Change the appliance loads.

It was assumed that these strategies will bring more hours into the thermal comfort zone and reduce the energy consumed in the grocery store during the year. Parametric runs

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[120] This model is known as the Givony-Milne's Bioclimatic Chart (Visitsak, 2007).

were the simulation process used in the software for the energy efficiency measures in the grocery store. The following sections will explain the replication of the energy-efficient measures.

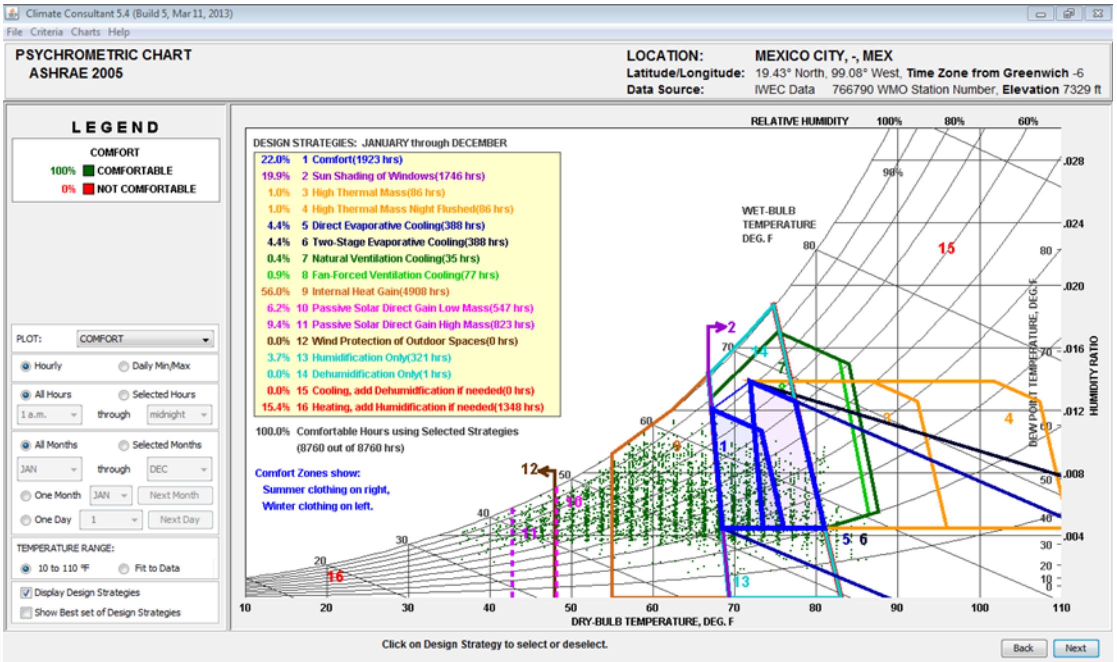

Figure 104. Psychrometric Chart for the Adaptive Comfort Model in ASHRAE 55-2004 for Mexico City from the Climate Consultant software (US DOE, 2012). Reprinted from *Climate Consultant 5.4*, by UCLA Energy Design Tools Group, Copyright 1976, 1986, 2000, 2006, 2008, 2010, 2011 and 2012 by Regents of the University of California. Reprinted with Permission.

4.3.1.4.1. Rotate the Azimuth 90°.

By rotating the building, this measure pursued the thermal improvement of several hours outside of the thermal comfort zone from the base-case building during the year. The grocery story followed the rotation of the apartment building. This strategy was performed, as in the multi-family apartments, though the suggestions of Caton (2010). The azimuth was rotated 90° clockwise with a parametric run.[121]

4.3.1.4.2. Increase the R-Value of Walls.

The increase of R-Value aimed to reduce thermal gains and thermal losses from this exterior vertical element. In order to select this insulation, lines with a new wall are added to the input file. The ASHRAE's Advanced Energy Design Guide (AEDG) for Small Retail Buildings (2006) was consulted in order to apply measures and save energy for the grocery store. An R-11.4 was recommended by the ASHRAE's AEDG (2006) for Zone 3. The southern area of California is located in Zone 3. Mexico City has a similar climate to cities such as Los Angeles and San Diego. The insulation material that was written is "MinWool Batt R11 (IN02)". Finally, the wall was called Wall_4.

4.3.1.4.3. Change the Incandescent Lamps to LED Lamps and the Lighting Power Density.

By changing the lighting power density, this measure seeked to reduce the electricity consumed from the base-case grocery store. 1.3 W/ft² for lighting power was recommended by the ASHRAE's AEDG (2006) for Zone 3.

4.3.1.4.4. Place and Activate Daylighting Controls into the Zones.

By placing and activating daylighting controls into the zones, this measure seeked to reduce the electricity consumed from the base-case grocery store. The same procedure in section 4.3.1.1.5 was followed to create the parametric run and assign the daylighting controls on.

4.3.1.4.5. Change the Appliance Loads.

This measure seeked to reduce the electricity consumed from the base-case grocery store by changing its appliance loads. It was assumed to reduce the appliances power density

[121] The Help Topic command in eQuest states that the View-Azimuth parameter moves clockwise.

level by 25 percent according to the use of EnergyStar appliances from the AEDG (ASHRAE, 2006) and the findings from Mukhopadyay (2013). The estimation was presented as follows:

(1.27 W/ft² from the base-case X 25)/100 = 0.3175 W/ft²

1.27 W/ft² from the base-case – 0.3175 W/ft² = 0.9525 W/ft²

4.3.1.4.6. Place Double-Clear Glazing.

By placing double-clear glazing, this measure looked for thermal improvement of several hours outside of the thermal comfort zone from the base-case grocery store during the year. A double-clear glazing was modeled according to the explanation in section 4.3.1.1.8. It was assumed 1.15 BTU/hr.-ft²-°F to be introduced in the numeric option for window frame conductance in the parametric run. The properties of the new glass type were taken from the AEDG (ASHRAE, 2006) and can be applied to any climate.

4.3.1.4.7. Place Shading Devices over Exterior Windows.

Shading devices is a passive strategy that can block solar access and reduce thermal gains into the indoor zone temperature during summer. This section used Ecotect and Solrpath, as well as section 4.3.1.1.6, in order to determine the depth and width of the overhangs. Figure 81 through Figure 85 showed the shading analysis with Ecotect for the whole community. Figure 86 displayed an example of Solrpath for a window.

Table 98 exhibited the height and the width of the windows, and the depth and the angle of the overhangs. The depth of the overhangs can be used as porch and become a transitional space between the indoor zone and the exterior. This was suggested from *CONAVI* (2006, 2007, 2010a).

Before finishing the section, it was critical to point out that the depth and angle of the overhangs were modified once the measures are finally run together. Table 99 indicated the new size of the windows and the updated magnitude and tilt of the overhangs for case 8 and 9. The windows were located on Figure 105.

Table 98. Height and Width of the Windows, and Depth and Angle of the Overhangs.

Window	Height	Width	Depth	Angle
ID Number	ft	ft	ft	ft
EL1 SSW Win (G.ESE1.E2.W1)	4.0	19.8	1.5	90
EL1 ESE Win (G.ESE1.E3.W1)	6.8	15.9	8.25	80
EL1 ESE Door (G.ESE1.E3.D1)	6.5	4.9	8.25	80
EL1 ESE Win (G.ESE1.E3.W2)	6.8	15.9	8.25	80
EL1 ESE Door (G.ESE1.E3.D2)	7.0	5.4	8.25	80
EL1 ESE Win (G.ESE1.E3.W3)	6.8	15.9	8.25	80
EL1 ESE Door (G.ESE1.E3.D3)	7.0	5.4	8.25	80
EL1 ESE Win (G.ESE1.E3.W4)	6.8	15.9	8.25	80
EL1 ESE Door (G.ESE1.E3.D4)	7.0	5.4	8.25	80
EL1 ESE Win (G.ESE1.E3.W5)	6.8	15.9	8.25	80
EL1 ESE Door (G.ESE1.E3.D5)	7.0	5.4	8.25	80
EL1 ESE Win (G.ESE1.E3.W6)	6.8	16.5	8.25	80
EL1 ESE Door (G.ESE1.E3.D6)	7.0	5.6	8.25	80
EL1 ESE Win (G.ESE1.E3.W7)	4.0	19.8	5.0	80
EL1 NNE Door (G.ESE1.E4.D1)	6.5	5.1	4.75	90
EL1 NNE Door (G.ESE1.E4.D2)	6.5	5.1	4.75	90

Table 99. Height and Width of the Windows, and Depth and Angle of the Overhangs for Case 8_Energy-Efficient Case and Case 9_Final Energy-Efficient Case.

Window	Height	Width	Depth	Angle
ID Number	ft	ft	ft	ft
EL1 SSW Win (G.ESE1.E2.W1)	4.0	19.8	7.25	80
EL1 ESE Win (G.ESE1.E3.W1)	6.8	15.9	2.5	80
EL1 ESE Door (G.ESE1.E3.D1)	6.5	4.9	2.5	80
EL1 ESE Win (G.ESE1.E3.W2)	6.8	15.9	2.5	80
EL1 ESE Door (G.ESE1.E3.D2)	7.0	5.4	2.5	80
EL1 ESE Win (G.ESE1.E3.W3)	6.8	15.9	2.5	80
EL1 ESE Door (G.ESE1.E3.D3)	7.0	5.4	2.5	80
EL1 ESE Win (G.ESE1.E3.W4)	6.8	15.9	2.5	80
EL1 ESE Door (G.ESE1.E3.D4)	7.0	5.4	2.5	80
EL1 ESE Win (G.ESE1.E3.W5)	6.8	15.9	2.5	80
EL1 ESE Door (G.ESE1.E3.D5)	7.0	5.4	2.5	80
EL1 ESE Win (G.ESE1.E3.W6)	6.8	16.5	2.5	80
EL1 ESE Door (G.ESE1.E3.D6)	7.0	5.6	2.5	80
EL1 ESE Win (G.ESE1.E3.W7)	4.0	19.8	1.25	80
EL1 NNE Door (G.ESE1.E4.D1)	6.5	5.1	8.25	80
EL1 NNE Door (G.ESE1.E4.D2)	6.5	5.1	8.25	80

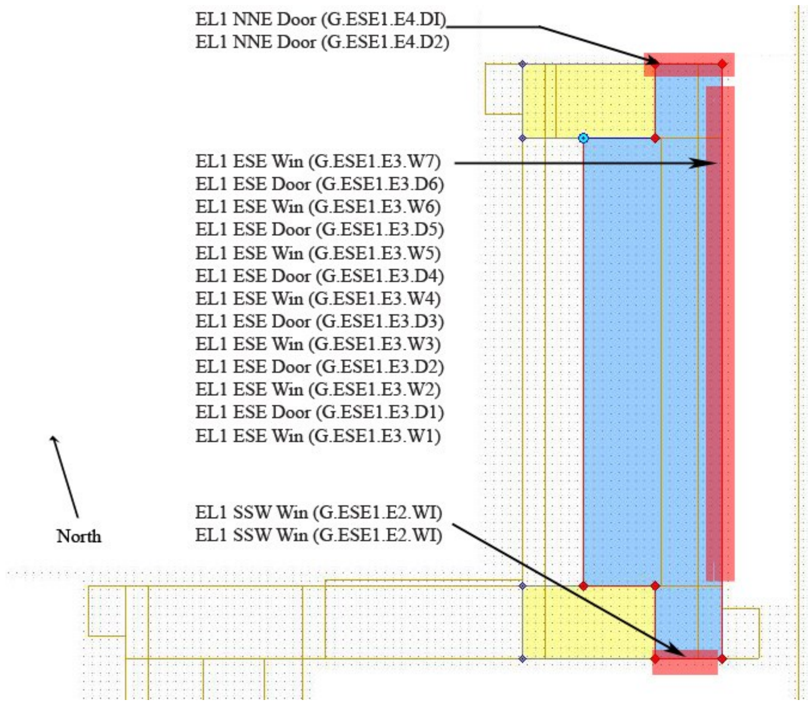

Figure 105. Location of Windows for EL1 Shell.

4.3.1.4.8. Final Analysis of the Results of the Energy-Efficiency Measures for the Grocery Store Section.

Energy savings and thermal comfort were two essential elements for this technical potential study. The grocery store base-case had an energy consumption of 333,757 kWh/year, and the comfort zone for its zones was 99.2 percent for the year.[122]

Each measure took the data from the base-case file, and the stategy was modeled as a parametric run. Table 100 and Figure 106 presented the energy consumption for each case, and the percentage of energy reduction for each one. The strategies that decrease energy consumption from the baseline were the following:

1) Case 1 Rotate Azimuth 90°. The modeling reduced the energy consumption by rotating 90°. 0.2 percent is saved from Case 0.
2) Case 2 Wall Insulation R-30. This result from this measure was similar to the base-case result.

[122] 72 hours have low humidity and are below 0.005 lb water/lb dry air.

3) Case 3 Change Lamps. The simulation changed the lighting power density. 12.7 percent of energy was reduced from the base-case.
4) Case 4 Place Daylighting Controls. The replication turned the daylighting controls on and pointed them towards the windows. 2.7 percent of energy was reduced from the baseline.
5) Case 5 Change Appliances. The imitation changed the equipment power density. 5.5 percent of energy was reduced from the orginal case.
6) Case 6 Place Double-Clear Glass. The modeling changed the single-clear windows to double-clear windows. 0.4 percent of energy was reduced from the baseline.
7) Case 7 Place Shading Devices (Overhangs). The replication placed overhangs on the windows of the facades. 1.5 percent of energy was reduced from the base-case.
8) Case 8 Energy-Efficent Case. This final combined case saved 22.1 percent of energy from Case 0.
9) Case 9 Final Energy-Efficent Case. This final combined case without the 90° azimuth rotation saved 22.5 percent of energy from Case 0. The grocery store was kept in the same position because the apartment section was not moved.

Table 101 exhibits the percentage of hours inside of the thermal comfort zone for each case using the 2005 ASHRAE Handbook of Fundamentals Comfort Model (2005). The first column is the name of the measure simulated and the second column is the percentage of hours inside of the comfort zone for the grocery store.[123]

[123] 28 hours have low humidity and are below 0.005 lb water/lb dry air. This is why the zone is not 100 percent inside thermal comfort.

Table 100. Total Energy Consumption for Each Measure, and Percentage of Energy Reduction for Each Case (Grocery Store).

	Case 0_Base-Case	Case 1_Rotate Azimuth 90 Degrees	Case 2_Add Wall Insulation R-30	Case 3_Change Lamps and Lighting Loads	Case 4_Place Daylighting Controls	Case 5_Change Appliances Loads	Case 6_Place Double Clear Glass	Case 7_Place Shading Devices (Overhangs)	Case 8_Energy-Efficient Case	Case 9_Final Energy-Efficient Case
	Total kWh (X 1,000)	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**	**Total kWh (X 1,000)**
Area Lights	116.39	116.39	116.39	81.79	108.98	116.39	116.39	116.39	77.09	77.24
Task Lights	0	0	0	0	0	0	0	0	0	0
Misc. Equip.	59.39	59.39	59.39	59.39	59.39	44.54	59.39	59.39	44.54	44.54
Heat Reject.	0	0	0	0	0	0	0	0	0	0
Refrigeration	0	0	0	0	0	0	0	0	0	0
HP Supp.	0	0	0	0	0	0	0	0	0	0
Hot Water	0	0	0	0	0	0	0	0	0	0
Pumps & Aux.	0	0	0	0	0	0	0	0	0	0
Ext. Usage	0	0	0	0	0	0	0	0	0	0
Vent. Fans	64.26	64.26	64.26	64.26	64.26	64.26	64.26	64.26	64.26	64.26
Space Heat	0	0	0	0	0	0	0	0	0	0
Space Cool	93.72	93.01	93.7	85.9	92.15	90.3	92.4	88.76	74.02	72.79
Total Energy Consumption	333.76	333.04	333.74	291.33	324.79	315.49	332.44	328.8	259.91	258.83
Energy Consumption (Percent)		99.8	100.0	87.3	97.3	94.5	99.6	98.5	77.9	77.5
Energy Reduction (Percent)		0.2	0.0	12.7	2.7	5.5	0.4	1.5	22.1	22.5

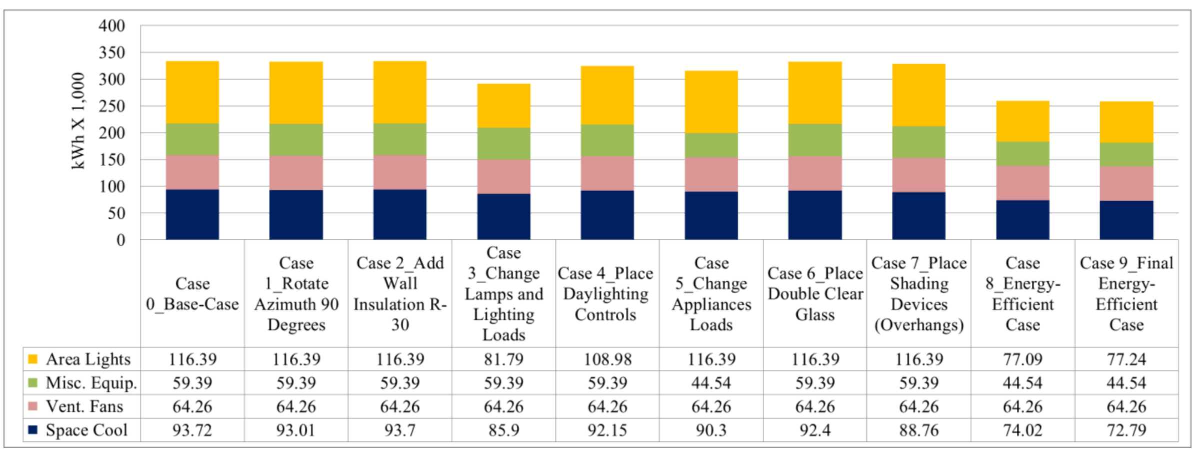

Figure 106. Total Energy Consumption for Each Measure (Grocery Store).

Table 101. Percentage of Hours inside of the Thermal Comfort Zone for Each Case (Grocery Store).

Case Name	Percent
Case 0_Base-Case	99.2
Case 1_Rotate Azimuth 90 Degrees	99.2
Case 2_Add Wall Insulation R-11	99.2
Case 3_Change Lamps and Lighting Loads	99.2
Case 4_Place Daylighting Controls	99.2
Case 5_Change Appliances Loads	99.2
Case 6_Place Double Clear Glass	99.2
Case 7_Place Shading Devices (Overhangs)	99.2
Case 8_Energy-Efficient Case	99.2
Case 9_Final Energy-Efficient Case	99.2

4.3.2. Reduced Water-Use for the Community.

This section analyzed how to reduce water-use for multi-family apartments and reduce water-use for grocery store.

4.3.2.1. Reducing Water-Use for Multi-Family Apartments.

This section calculated the water-use for fixtures and greywater reuse treatment for multi-family apartments, determined the potable water storage tank for multi-family apartments, and calculated the rainwater harvesting system for multi-family apartments.

4.3.2.1.1 Calculation for Water-Use for Fixtures and Greywater Reuse Treatment for Multi-Family Apartments

First, it was essential to calculate the water savings for each fixture used from the base-case water-use model. The Student Water Investigators Showing How (SWISH, 2013) mentioned the water-use for regular fixtures and water saving fixtures in Table 102.

Table 102. Water-Use for Regular Fixtures and Water Saving Fixtures.

Fixture	Regular	Water-Saving
Toilet	6 gal/flush	1.6 gal/flush
Shower	7 gal/min	2.5 gal/min
Sink	3 gal/min	2 to 2.5 gal/min
Washing Machine	40 - 50 gal/load	18-25 gal/load

Using the numbers from Table 102, the following computations were done:

Toilet: ((1.6 gal/flush X 100)/6 gal/flush) = 27 percent

Shower: ((2.5 gal/min X 100)/7 gal/min) = 36 percent

Sink: ((2 gal/min X 100)/3 gal/min) = 67 percent

Washing Machine: ((55 gal/load X 100)/25 gal/min) = 45 percent

These percents were multiplied to each fixture from the fourth column in Table 69:

Toilet: 17.1 gal/day/person X 0.27 percent = 4.6 gal/day/person

Shower: 14.6 gal/day/person X 0.36 percent = 5.2 gal/day/person

Bathroom sink: 2.4 gal/day/person X 0.67 percent = 1.6 gal/day/person

Kitchen sink: 4.9 gal/day/person X 0.67 percent = 3.3 gal/day/person

Washing Machine: 9.8 gal/day/person X 0.45 percent = 4.4 gal/day/person

Table 103 displays the water-use per person and family for the apartments section using water-saving fixtures. The first column is the spaces, the second column is the water-saving fixtures, and the third to sixth columns are the water-use.

Table 103. Water-Use per Person and Family for the Apartments Section Using Water-Saving Fixtures.

Space	Water-Saving Fixtures	Lt./day/person	Gal/day/person	Lt./day/family	Gal/day/family
Bathroom	Toilet	17.2	4.6	68.9	18.2
	Shower	19.8	5.2	79.1	20.9
	Sink	6.2	1.6	24.6	6.5
Kitchen	Sink	12.3	3.3	49.2	13.0
Utility Room	Washing Machine	16.8	4.4	67.2	17.7
	Total	72.3	19.1	289.1	76.4

According to the results from Table 103, 51 percent of the water consumed was in toilets and showers. If 31.7 gal/person/day was considered for toilet and shower from the base-case, the following computation was obtained:

(9.8 gal/person/day for base-case's toilet and shower X 100 percent) X 31.7 gal/person/day = 30.9 percent.

(100 percent of water-use from the base-case) – (30.9 percent of water-use with water-saving toilets and showers) = 69.1 percent of water reduction.

This means that more than the expected 50 percent from the water used in toilets and showers can be reduced with water-saving fixtures (*SACM,* 2012).

According to the results from Table 103, 76 percent of the water consumed generates greywater. If 17 gal/person/day was considered for greywater from the base-case, the following computation is obtained:

(14.5 gal/person/day X 100 percent) / 17 gal/person/day = 85.2 percent

(100 percent of water-use from the base-case) – (85.2 percent of water-use with water-saving sinks, showers and washing machines) = 14.8 percent of water reduction.

This means that 14.8 percent of the greywater from the base-case was saved with water-saving fixtures. Thus, the 85.2 percent of greywater from the reduced case can be recycled and reused into toilets (*INE*, 2009b).[124] Following this train of thought, if the water from the toilet is replaced with treated greywater,[125] the update is seen in Table 104.

Table 104. Water-Use per Person and Family for the Apartments Section Using Water-Saving Fixtures.

Spaces	Water-Saving Fixtures	Lt./day/person	Gal/day/person	Lt./day/family	Gal/day/family
Bathroom	Toilet	0	0	0	0
	Shower	19.8	5.2	79.1	20.9
	Sink	6.2	1.6	24.6	6.5
Kitchen	Sink	12.3	3.3	49.2	13.0
Utility Room	Washing Machine	16.8	4.4	67.2	17.7
	Total	55.0	14.5	220.2	58.2

This action exhibited two water reductions as next:

1) Only 36 percent of the water consumed was from the showers compared to the base-case's 65 percent,[126] and
2) 70 percent of water was reduced from the base-case through water-saving fixtures and greywater treatment.

The greywater for the whole community was calculated as follows:

58.2 gal/day/family (from Table 104) X 1,080 apartments = 62,856 gal/day/community.

This 62,856 gal/day/community of greywater were sent to three underground tanks from the brand Xerxes (2012) in order to be recycled. This was obtained with the following data:

[124] Armando Deffis-Caso (1989) suggested the use of a "tank" with different layers such as gravel and river rocks to filter the greywater, and a "tank" with a grease trap to separate the soap from the water. This second tank is connected to the non-potable water underground tank.
[125] Toilet water is first sent to a septic tank to subtract solids from the water. Finally, the water from the septic tank is connected to the drainage.
[126] This 65 percent represents the water consumption from the toilet and the shower.

One 20,000-gallon tank of 12 ft. of diameter X 29.30 ft of length = 351.60 ft^3.

62,856 gal/day/community of greywater/20,000-gallon tank = 3.1 tanks

As mentioned before, recycled greywater was used for the toilets.[127] The following was calculated:

62,856 gal/day/community of greywater – 19,656 gal/day/community of required recycled greywater for toilets= 43,144 gal/day/community to landscape irrigation.

The current buildings in the site are used to calculate the area for landscape irrigation. The approximated area for watering plants is shown as follows:

430,556 ft^2 of total site area

81,524 ft^2 of the building in the middle of the site plus the two detached buildings on the other corners

430,556 ft^2 - 81,524 ft^2 = 349,032 ft^2

349,032 ft^2 X 15 percent of walkways = 52,355 ft^2

349,032 ft^2 - 52,355 ft^2 = 296,677 ft^2

Quadri-De la Torre (2008) mentioned that Urban Forests' gardeners stated that 79 gal, or 300 lt are needed to irrigate 1,076 ft^2, or 100 m^2. This irrigation is done twice per week during the drought season.

296,677 ft^2/1,076 ft^2 = 276 squares of 1,076 ft^2

276 squares of 1,076 ft^2 X 79 gal = 21,844 gal of water to water plants

The 21,844 gal of water to water plants was easily covered with the 43,144 gal/day/community of treated greywater.

4.3.2.1.2 Calculation for Potable Water Storage Tank for Multi-Family Apartments

According to the equations display in section 4.2.2.1.2, the required potable water supply for the reduced case for the *Multifamiliar Miguel Aleman* was 176,256 gal/day. This

[127] This greywater is pumped up to several tanks on the roof.

amount represented a reduction of 69 percent from the base-case as shown in the next equation:

(176,256 gal X 100)/575,681 gal from the base-case = 31 percent of water per day.

100 percent of base-case water supply – 31 percent of reduced case water supply = 69 percent reduction.

4.3.2.1.3 Calculation for Rainwater Harvesting System for Multi-Family Apartments

Anaya-Garduño (1998) and *INEGI* (2012) were used for rainwater harvesting systems. A modified estimation from Anaya-Garduño (1998) was used for this technical potential study. Firstly, the efficient catchment area for the buildings' roof area of the whole community is 73,391 ft^2.[128] Table 105 is created for the rainwater harvesting calculation. The first column is the name of the state,[129] and the second column is the months of the year. Third through sixth column display the assessment of the rainwater catchment by the roof area.

Table 105. Rain Harvesting Calculation.

State	Month	Rain Precipitation (in.)	Rain Precipitation (ft)	Rain Catchment Volume (ft^3)	Rain Catchment Volume (gal)
Distrito Federal	January	0.004	0.0003	23.85	178.43
	February	0.027	0.0023	166.96	1,248.98
	March	0.316	0.0263	1,932.02	14,452.53
	April	1.552	0.1294	9,493.15	71,013.66
	May	1.092	0.0910	6,678.59	49,959.36
	June	5.062	0.4219	30,960.06	231,597.31
	July	8.990	0.7491	54,979.15	411,272.57
	August	6.197	0.5164	37,901.03	283,519.36
	September	3.974	0.3312	24,305.31	181,816.38
	October	2.418	0.2015	14,788.32	110,624.29
	November	0.854	0.0712	5,223.62	39,075.36
	December	0.035	0.0029	214.67	1,605.84
	TOTAL	30.521	2.5435	186,666.72	1,396,364.06

The computation for January was shown as follows:

Third column: 0.004 in. of rain precipitation is taken from *INEGI* (2012)

[128] This roof area corresponds to the sum of the building in the middle of the site plus the two detached tall buildings on the corners minus the area of the lightwells.
[129] The Distrito Federal is not a state.

Fourth column: 0.004 in. X 1 ft/12 in. = 0.0003 ft.

Fifth column: 73,391 ft^2 X 0.0003 ft. = 23.85 ft^3 of rain catchment volume for January

Sixth column: 23.85 ft^3 X 1 gal/0.1336 ft^3 = 178.43 gal of rain catchment volume for January.

The total amount of rainwater catchment could be used for landscape irrigation or injected into the aquifer through injection wells (US EPA, 2012).

4.3.2.2. Reducing Water-Use for Grocery Store.

First, as mentioned in section 4.2.2.2, the following was the water-use in the grocery store:

158 gal/day of greywater for two toilets,

158 gal/day of greywater for two sinks, and

1,383 gal/day for washing

If the water-use reduction fixtures were applied to the toilets and the sinks from the base-case, the results were exhibit as next:

Toilets: 158 gal/day X 0.27 percent = 42.66 gal/day

The remaining water-use for the toilets was replaced with recycled greywater from the sinks and the water-use for washing.[130] The remaining greywater was used for landscape irrigation.

Bathroom sinks: 158 gal/day X 0.67 percent = 105.86 gal/day

Bathroom sinks: 158 gal/day - 105.86 gal/day = 52.14 gal/day

Water-use for sinks was reduced to 33 percent per day. The final water-use for the grocery store is shown with the following estimation:

1,699 gal/day - 1,435 gal/day = 264 gal/day

[130] The toilet water is sent to septic tank to subtract solids from the water, and finally the tank is connected to the drainage.

The water-use of the grocery store was reduced by 15 percent. Finally, there was not enough information to calculate the size of potable water supply, toilet water and greywater tanks.

4.3.3. Reduced Community Transportation Use.

This section exhibits the results of the reduced community transportation use for the *Multifamiliar Miguel Aleman.* This section is solved as a technical potential through manual calculations and a table. First, it is essential to estimate the number of reduced trips for this case, the number of trips/person/day, and the number of miles/day. The reduced cases will be added one after another.

4.3.3.1. First Reduced Case (Basecase Minus Shopping mall, Retail and Supermarket Trips)

Zero trips to shopping mall, retail and supermarket were assumed for the first reduced case. This is because the complex for this technical potential study has a supermarket in-situ. The manual calculation for the trips for the first reduced case was the next:

Shopping mall, retail and supermarket trips = 369.1 trips/day X 2[131] = 738.2 trips/day

4,050 trips/day - 738.2 trips/day = 3,312 trips/day

(3,312 trips/day X 100)/4,050 trips/day = 81.8 percent of possible trips

(81.8 percent of possible trips X 2.5 trips/person/day from baseline)/100 percent = 2.04 trips/person/day

(41 km/day X 2.04 trips/person/day)/2.5 trips/person/day = 33.5 km/day

33.5 km/day X 1 mi/1.609344 km = 20.8 mi/day

Table 106 displays the results for the first reduced case. If this first case is compared to the base-case, the next cut downs are obtained:

1) 18 percent of daily trips are reduced from the base-case.
2) 18.4 percent of trips/person/day is reduced from the baseline.

[131] The trips are multiplied by two because people will go to the shopping mall, retail and supermarket, and then come back home.

3) 18.4 percent of miles/day, or km/day is reduced from the base-case.
4) 33 percent of miles, or km is reduced from the baseline.
5) 33 percent of gal. or lt is reduced from the base-case.
6) 33 percent of BTU is reduced from the baseline.

Table 106. First Reduced Case Community Transportation Use per Day.

Activity	Percent	Trips	Distance Traveled	Gas Consumption	Distance Traveled	Gas Consumption	Burning Conventional Fuel
Destination Trip	**%**	**Trips**	**km**	**lt**	**mi**	**gal**	**BTU**
House	45.2	1,463	49,061	4,628	30,485	1,223	152,837,773
School	14.8	600	20,120	1,898	12,502	501	62,677,613
Office	10.2	412	13,798	1,302	8,574	344	42,983,400
Shopping Mall, Retail and Supermarket	9.1	0	0	0	0	0	0
Industrial	3.1	128	4,275	403	2,656	107	13,317,537
Another House	4.3	175	5,884	555	3,656	147	18,329,412
Hospital	3.5	140	4,706	444	2,924	117	14,661,626
Restaurant, Bar and Coffee Shop	1.1	43	1,454	137	903	36	4,529,247
Laboratory	1.2	47	1,574	148	978	39	4,902,378
Recreation Center and Gymnasium	0.7	29	972	92	604	24	3,027,841
Park	0.4	16	545	51	339	14	1,699,012
Another Places	6.4	258	8,645	816	5,372	215	26,930,577
TOTAL	100	3,312	111,034	10,475	68,993	2,767	345,896,416

4.3.3.2. Second Reduced Case (Basecase Minus (Shopping Mall, Retail and Supermarket Trips Plus Recreation Center and Gymnasium Trips))

Zero trips to recreation center and gymnasium were assumed for the second reduced case. This is because the complex for this technical potential study has a recreation center in-situ. The manual calculation for the trips for the second reduced case was the next:

Recreation center and gymnasium trips = 29 trips/day X 2[132] = 58 trips/day + 738.2 trips/day for shopping mall, retail and supermarket trips = 796.2 trips/day

4,050 trips/day - 796.2 trips/day = 3,254 trips/day

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[132] The trips are multiplied by two because people will go to the recreation center and gymnasium, and then come back home.

(3,254 trips/day X 100)/4,050 trips/day = 80.3 percent of possible trips

(80.3 percent of possible trips X 2.5 trips/person/day from baseline)/100 percent = 2.01 trips/person/day

(41 km/day X 2.01 trips/person/day)/2.5 trips/person/day = 32.9 km/day

32.9 km/day X 1 mi/1.609344 km = 20.5 mi/day

Table 107 shows the results for the second reduced case. If this second case is compared to the base-case, the next cut downs are obtained:

1) 19.6 percent of daily trips are reduced from the base-case.
2) 19.6 percent of trips/person/day is reduced from the baseline.
3) 18.2 percent of miles/day, or km/day is reduced from the base-case.
4) 35.4 percent of miles, or km is reduced from the baseline.
5) 33.2 percent of gal, or lt is reduced from the base-case.
6) 35.4 percent of BTU is reduced from the baseline.

Table 107. Second Reduced Case Community Transportation Use per Day.

Activity	Percent	Trips	Distance Traveled	Gas Consumption	Distance Traveled	Gas Consumption	Burning Conventional Fuel
Destination Trip	**%**	**Trips**	**km**	**lt**	**mi**	**gal**	**BTU**
House	45.2	1,434	47,247	4,457	29,358	1,177	147,186,291
School	14.8	600	19,767	1,865	12,283	493	61,579,931
Office	10.2	412	13,556	1,279	8,423	338	42,230,626
Shopping Mall, Retail and Supermarket	9.1	0	0	0	0	0	0
Industrial	3.1	128	4,200	396	2,610	105	13,084,305
Another House	4.3	175	5,781	545	3,592	144	18,008,406
Hospital	3.5	140	4,624	436	2,873	115	14,404,855
Restaurant, Bar and Coffee Shop	1.1	43	1,428	135	888	36	4,449,926
Laboratory	1.2	47	1,546	146	961	39	4,816,522
Recreation Center and Gymnasium	0.7	0	0	0	0	0	0
Park	0.4	16	536	51	333	13	1,669,257
Another Places	6.4	258	8,493	801	5,278	212	26,458,938
TOTAL	100	3,254	107,180	10,111	66,598	2,671	333,889,058

4.3.3.3. Third Reduced Case (Basecase Minus (Shopping Mall, Retail and Supermarket Trips Plus Recreation Center and Gymnasium Trips Plus Parks Trips))

Zero trips to parks were assumed for the third reduced case. This is because the complex for this technical potential study has parks in-situ. The manual calculation for the trips for the third reduced case is the next:

Parks trips = 16.3 trips/day X 2[133] = 32.6 trips/day + 58 trips/day for recreation center and gymnasium trips + 738.2 trips/day for shopping mall, retail and supermarket trips = 828.8 trips/day

4,050 trips/day - 828.8 trips/day = 3,221 trips/day

(3,221 trips/day X 100)/4,050 trips/day = 79.5 percent of possible trips

(79.5 percent of possible trips X 2.5 trips/person/day from baseline)/100 percent = 1.99 trips/person/day

(41 km/day X 2.01 trips/person/day)/2.5 trips/person/day = 32.6 km/day

32.6 km/day X 1 mi/1.609344 km = 20.3 mi/day

Table 108 showed the results for the third reduced case. If this third case was compared to the base-case, the next cut downs were obtained:

1) 20.4 percent of daily trips are reduced from the base-case.
2) 20.4 percent of trips/person/day is reduced from the baseline.
3) 20.3 percent of miles/day, or km/day is reduced from the base-case.
4) 36.7 percent of miles, or km is reduced from the baseline.
5) 36.7 percent of gal, or lt is reduced from the base-case.
6) 36.7 percent of BTU is reduced from the baseline.

[133] The trips are multiplied by two because people will go to the recreation center and gymnasium, and then come back home.

Table 108. Third Reduced Case Community Transportation Use per Day.

Activity	Mexico City Metropolitan Area	Percent	Regular Trips	Distance Traveled	Gas Consumption	Distance Traveled	Gas Consumption	Burning Conventional Fuel
Destination Trip	**Number of Trips**	**%**	**Trips**	**km**	**lt**	**mi**	**gal**	**BTU**
House	1,599,265	45.2	1,418	46,243	4,363	28,734	1,152	144,059,090
School	523,741	14.8	600	19,569	1,846	12,160	488	60,962,959
Office	359,174	10.2	412	13,420	1,266	8,339	334	41,807,515
Shopping Mall, Retail and Supermarket	322,134	9.1	0	0	0	0	0	0
Industrial	111,283	3.1	128	4,158	392	2,584	104	12,953,213
Another House	153,163	4.3	175	5,723	540	3,556	143	17,827,979
Hospital	122,514	3.5	140	4,578	432	2,844	114	14,260,532
Restaurant, Bar and Coffee Shop	37,847	1.1	43	1,414	133	879	35	4,405,342
Laboratory	40,965	1.2	47	1,531	144	951	38	4,768,265
Recreation Center and Gymnasium	25,301	0.7	0	0	0	0	0	0
Park	14,197	0.4	0	0	0	0	0	0
Another Places	225,035	6.4	258	8,408	793	5,225	210	26,193,845
TOTAL	3,534,619	100	3,221	105,045	9,910	65,272	2,618	327,238,740

4.3.3.4. Fourth Reduced Case (Third Reduced Case with High-Efficiency Cars Fuel Efficiency)

An increase in the cars' fuel efficiency mpg or km/lt was assumed for the fourth reduced case.[134] 45.3 mpg or 19.27 km/lt from a Dodge i10 was selected from a list of high-efficiency cars published by the *CONUEE* (Aleman, 2013). The manual calculation for the trips for the fourth reduced case was the next:

Trips from the third reduced case = 828.8 trips/day

4,050 trips/day - 828.8 trips/day = 3,221 trips/day

(3,221 trips/day X 100)/4,050 trips/day = 79.5 percent of possible trips

(79.5 percent of possible trips X 2.5 trips/person/day from baseline)/100 percent = 1.99 trips/person/day

(41 km/day X 2.01 trips/person/day)/2.5 trips/person/day = 32.6 km/day

32.6 km/day X 1 mi/1.609344 km = 20.3 mi/day

Table 109 showed the results for the fourth reduced case. If this fourth case was compared to the base-case, the next cut downs were obtained:

[134] Garcia (2012) mentioned that the proposed norm *NOM-163* demands new cars with at least 35 mpg or 14.9 km/lt. This measure will save 440 million of petrol barrels up to 2030. This norm is still in standby.

1) 20.4 percent of daily trips are reduced from the base-case.
2) 20.4 percent of trips/person/day is reduced from the baseline.
3) 20.3 percent of miles/day, or km/day is reduced from the base-case.
4) 36.7 percent of miles, or km is reduced from the baseline.
5) 65 percent of gal, or lt is reduced from the base-case.
6) 65 percent of BTU is reduced from the baseline.

Table 109. Fourth Reduced Case Community Transportation Use per Day.[135]

Activity	Mexico City Metropolitan Area	Percent	Regular Trips	Distance Traveled	Gas Consumption	Distance Traveled	Gas Consumption	Burning Conventional Fuel
Destination Trip	**Number of Trips**	**%**	**Trips**	**km**	**lt**	**mi**	**gal**	**BTU**
House	1,599,265	45.2	1,418	46,243	2,400	28,734	634	79,243,713
School	523,741	14.8	600	19,569	1,016	12,160	268	33,534,373
Office	359,174	10.2	412	13,420	696	8,339	184	22,997,388
Shopping Mall, Retail and Supermarket	322,134	9.1	0	0	0	0	0	0
Industrial	111,283	3.1	128	4,158	216	2,584	57	7,125,275
Another House	153,163	4.3	175	5,723	297	3,556	78	9,806,776
Hospital	122,514	3.5	140	4,578	238	2,844	63	7,844,402
Restaurant, Bar and Coffee Shop	37,847	1.1	43	1,414	73	879	19	2,423,281
Laboratory	40,965	1.2	47	1,531	79	951	21	2,622,917
Recreation Center and Gymnasium	25,301	0.7	0	0	0	0	0	0
Park	14,197	0.4	0	0	0	0	0	0
Another Places	225,035	6.4	258	8,408	436	5,225	115	14,408,654
TOTAL	3,534,619	100	3,221	105,045	5,451	65,272	1,440	180,006,779

4.4. Identifying Costs for Energy, Water and Transportation Base-Case and Reduced Cases

This section consisted of the cost analysis for the energy, water and transportation use of the *Multifamiliar Miguel Aleman*. It was essential for the technical potential study to establish the annual energy consumption and water consumption, and transportation for the base-case building. The cost for the base-case's annual energy and water consumption, and

[135] Except the last column that are $MMtCO_2$ per gallons of gasoline consumed per year.

transportation were greatly impacted by the application of energy-efficiency and water measures and transportation use decrease.

4.4.1. Calculation of Annual Energy Consumption Cost for the Multifamiliar Miguel Aleman in Mexico City.

This section presented the calculation of the base-case annual energy consumption cost for the *Multifamiliar Miguel Aleman* in Mexico City.

4.4.1.1. Annual Energy Consumption Cost in Base-Case Multi-Family Apartments.

This section was for the analysis of the multi-family apartments. The base-case energy consumption for the analyzed building into the complex is 575,565 kWh/year-building. In order to obtain approximated energy consumption per apartment per year, the next was done:

575,565 kWh/year-building/240 apartments/building = 2,398 kWh/year-apartment

2,398 kWh/year-apartment/12 months/year = 200 kWh/month-apartment

The electricity rates from the CFE (n.d. (a), (b)) for 2013 were used to calculate the annual cost for the *Multifamiliar Miguel Aleman* complex. In order to select an electric rate, Table 110 displays the monthly dry-bulb temperature from Mexico City's IWEC file. The electricity rates for dwelling were dependent in their summer minimum average temperature in Mexico. These electricity rates were shown in Table 111. The chosen electric rate, the 1B, had a summer minimum average temperature close to 28.3°C, or 83°F (*CFE*, n.d. (a)).[136]

[136] The summer season is considered in this study between April and August.

Table 110. Monthly Average Dry-Bulb Temperature from Mexico City's IWEC File.

Month	Dry-Bulb Temperature
	°F
January	76.82
February	80.42
March	84.02
April	86
May	86.54
June	85.82
July	79.16
August	79.88
September	80.6
October	78.98
November	79.16
December	77.36

Table 111. Monthly Electricity Rates Adjustment Factors in Mexico for 2013 (*CFE*, n.d. (a)).

Electricity Rate	Summer Minimum Average Temperature
1	Domestic use
1A	Domestic use for areas with summer minimum average temperature equal to 25°C, or 77°F
1B	Domestic use for areas with summer minimum average temperature equal to 28°C, or 82.4°F
1C	Domestic use for areas with summer minimum average temperature equal to 30°C, or 86°F
1D	Domestic use for areas with summer minimum average temperature equal to 31°C, or 87.8°F
1E	Domestic use for areas with summer minimum average temperature equal to 32°C, or 89.6°F
1F	Domestic use for areas with summer minimum average temperature equal to 33°C, or 91.4°F

The 1B electricity rate was divided into two: Table 112 for the summer season and Table 113 for the no-summer season (*CFE*, n.d. (b)). The kWh ranges and the amount per month was calculated by the *CFE* (n.d. (b)).[137] The six hottest months, as state by the *CFE*, during the year must use Table 112. The six hottest months from Table 110 were February, March, April, May, June and September. The other months, as specified by the *CFE*, during

[137] For the economic analysis of this technical potential study, one Mexican Peso equals to 0.079 US Dollars (http://www.xe.com/currencyconverter/convert/?Amount=1&From=MXN&To=USD)

the year must use Table 113. These other months were January, July, August, October, November and December.

The summer season in Table 112 had three measures: basic, medium and surplus. The basic measure was from one to 125 kWh, the medium measure was from 126 to 225 kWh and the surplus measure was more than 226 kWh. The no-summer season in Table 113 also had three measures: basic, medium and surplus. The basic measure was from one to 75 kWh, the medium measure was from 76 to 175 kWh and the surplus measure was more than 176 kWh. These measures were vital to calculate the annual cost of the base-case electricity use of an apartment.

Table 112. 1B Electricity Rates for Summer Season for 2013 (*CFE*, n.d. (b)).

	Mexican Pesos			US Dollars		
	Basic	Medium	Surplus	Basic	Medium	Surplus
	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh
Months	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh
January	0.68	0.79	2.71	0.05	0.06	0.21
February	0.68	0.79	2.72	0.05	0.06	0.21
March	0.68	0.79	2.73	0.05	0.06	0.22
April	0.69	0.80	2.74	0.05	0.06	0.22
May	0.69	0.80	2.75	0.05	0.06	0.22
June	0.69	0.80	2.75	0.05	0.06	0.22
July	0.69	0.81	2.76	0.05	0.06	0.22
August	0.69	0.81	2.77	0.05	0.06	0.22
September	0.70	0.81	2.78	0.05	0.06	0.22
October	0.70	0.81	2.79	0.06	0.06	0.22
November	0.70	0.82	2.80	0.06	0.06	0.22
December	0.70	0.82	2.81	0.06	0.06	0.22

Table 113. 1B Electricity Rates for No-Summer Season for 2013 (*CFE*, n.d. (b)).

	Mexican Pesos			US Dollars		
	Basic	Medium	Surplus	Basic	Medium	Surplus
	From 1 to 75 kWh	From 76 to 175 kWh	More than 176 kWh	From 1 to 75 kWh	From 76 to 175 kWh	More than 176 kWh
Months	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh
January	0.76	0.93	2.71	0.06	0.07	0.21
February	0.76	0.93	2.72	0.06	0.07	0.21
March	0.76	0.93	2.73	0.06	0.07	0.22
April	0.77	0.94	2.74	0.06	0.07	0.22
May	0.77	0.94	2.75	0.06	0.07	0.22
June	0.77	0.94	2.75	0.06	0.07	0.22
July	0.77	0.95	2.76	0.06	0.07	0.22
August	0.78	0.95	2.77	0.06	0.07	0.22
September	0.78	0.95	2.78	0.06	0.08	0.22
October	0.78	0.95	2.80	0.06	0.08	0.22
November	0.79	0.96	2.81	0.06	0.08	0.22
December	0.79	0.96	2.81	0.06	0.08	0.22

Before going into detail of the calculation, it is essential to remind that the Mexican electricity utility bills are paid bi-monthly. The bi-monthly periods were considered as following: January-February, March-April, May-June, July-August, September-October and November-December. This was shown in the sixth and the eleventh columns in Table 114 and Table 115.

As a reminder, it was determined that an apartment consumed 200 kWh/month. The 200 kWh/month-apartment was consumed in the summer season as next: 125 kWh for the basic measure and 75 kWh for the medium. Table 114 displays the electricity consumption for the summer season. The first column is the month of the year. The second column is the basic measure. The 125 kWh was multiplied by each month of the second column in Mexican Pesos from Table 112. The third column is the medium measure. The 75 kWh was multiplied by each month of the third column in Mexican Pesos from Table 112. The fourth column is the surplus measure. The fifth column is the total electricity consumption of 200 kWh/month-apartment. The sixth column is the bi-monthly payment. The data from seventh to eleventh column is converted to US Dollars. From fifth to seventh column in Table 112 are multiplied to 125, 75 and 0 kWh and placed from seventh to nineth column in Table 114.

Table 114. Monthly Amount per Base-Case Apartment for Summer Season in 2013 (*CFE*, n.d. (b)).

	Mexican Pesos					US Dollars				
	125 kWh	22 kWh	0 kWh			125 kWh	22 kWh	0 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	147 kWh/month	kWh/bi-month	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	147 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	0.00	0.00	0.00	0.00	102.51	0.00	0.00	0.00	0.00	8.10
February	85.13	17.38	0.00	102.51		6.72	1.37	0.00	8.10	
March	85.38	17.45	0.00	102.82	205.96	6.74	1.38	0.00	8.12	16.27
April	85.63	17.51	0.00	103.14		6.76	1.38	0.00	8.15	
May	85.88	17.58	0.00	103.45	207.22	6.78	1.39	0.00	8.17	16.37
June	86.13	17.64	0.00	103.77		6.80	1.39	0.00	8.20	
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
September	86.88	17.84	0.00	104.72	104.72	6.86	1.41	0.00	8.27	8.27
October	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
Annual payment	515.00	105.40	0.00	620.40	620.40	40.69	8.33	0.00	49.01	49.01

The 200 kWh/month-apartment was consumed in the no-summer season as next: 75 kWh for the basic measure, 100 kWh for the medium and 25 kWh for the surplus. Table 115 displayed the electricity consumption for the no-summer season. The first column is the month of the year. The second column is the basic measure. The 75 kWh was multiplied by each month of the second column in Mexican Pesos from Table 113. The third column is the medium measure. The 100 kWh was multiplied by each month of the third column in Mexican Pesos from Table 113. The fourth column is the surplus measure. The 25 kWh was multiplied by each month of the third column in Mexican Pesos from Table 113. The fifth column is the total electricity consumption of 200 kWh/month-apartment. The sixth column is the bi-monthly payment. The data from seventh to eleventh column was converted to US Dollars. From fifth to seventh column in Table 113 were multiplied to 75, 100 and 25 kWh and placed from seventh to nineth column in Table 115.

The total amount per apartment in 2013 is presented in Table 116. The first column is the month of the year. The second column is the bi-monthly kWh cost for the summer season in Mexican Pesos. The third column is the bi-monthly kWh cost for the no-summer season in Mexican Pesos. The fouth column is the total bi-monthly kWh cost for the year in Mexican Pesos. The fifth column is the bi-monthly kWh cost for the summer season in US Dollars. The sixth column is the bi-monthly kWh cost for the no-summer season in US Dollars. The seventh column is the total bi-monthly kWh cost for the year in US Dollars.

Table 115. Monthly Amount per Base-Case Apartment for No-Summer Season in 2013 (*CFE*, n.d. (b)).

	Mexican Pesos					US Dollars				
	125 kWh	75 kWh	0 kWh			125 kWh	75 kWh	0 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	200 kWh/month	kWh/bi-month	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	200 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	0.00	0.00	0.00	0.00	144.38	0.00	0.00	0.00	0.00	11.41
February	85.13	59.25	0.00	144.38		6.72	4.68	0.00	11.41	
March	85.38	59.48	0.00	144.85	290.18	6.74	4.70	0.00	11.44	22.92
April	85.63	59.70	0.00	145.33		6.76	4.72	0.00	11.48	
May	85.88	59.93	0.00	145.80	292.08	6.78	4.73	0.00	11.52	23.07
June	86.13	60.15	0.00	146.28		6.80	4.75	0.00	11.56	
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
September	86.88	60.83	0.00	147.70	147.70	6.86	4.81	0.00	11.67	11.67
October	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
Annual payment	515.00	359.33	0.00	874.33	874.33	40.69	28.39	0.00	69.07	69.07

Table 116. Total Amount per Base-Case Apartment in 2013 (CFE, n.d. (b)).

	Mexican Pesos			US Dollars		
	Summer	No-Summer	Total	Summer	No-Summer	Total
Months	$	$	$	$	$	$
January February	144.38	149.63	294.00	11.41	17.17	28.58
March April	290.18	0.00	290.18	22.92	0.00	22.92
May June	292.08	0.00	292.08	23.07	0.00	23.07
July August	0.00	305.63	305.63	0.00	35.08	35.08
September October	147.70	154.13	301.83	11.67	17.70	29.37
November December	0.00	309.83	309.83	0.00	35.57	35.57
Annual payment	874.33	919.20	1,793.53	69.07	105.52	174.59

Finally, the cost for the electricity consumption for the analyzed base-case apartment section is shown as next:

MX$ 1,793.53 per year/apartment X 240 apartments/building = MX$ 430,447.2 per year/building

US$ 174.59 per year/apartment X 240 apartments/building = US$ 41,901.6 per year/building

The cost for the electricity consumption for the whole complex is shown as next:

MX$ 430,447.2 per year/building X 4.5 buildings/complex = MX$ 1,937,012.4 per year/complex

US$ 41,901.6 per year/building X 4.5 buildings/complex = US$ 188,557.2 per year/complex.

4.4.1.2. Annual Energy Consumption Cost in Energy-Efficient Multi-Family Apartments.

Case 15 from section 4.3.1.1.13 was chosen to be analyzed for annual energy consumption costs. The estimation was presented as follows:

133,089 kWh/year-building/240 apartments/building = 555 kWh/year-apartment.

555 kWh/year-apartment/12 months/year = 46 kWh/month-apartment.

Table 117 and Table 118 feature the monthly amount per energy-efficient apartment for summer season and no-summer season in 2013, respectively. Table 119 shows the total cost for the whole year.

The cost for the electricity consumption for the analyzed energy-efficient apartment section was exhibited as next:

US$ 31.94 per year/apartment X 240 apartments/building = US$ 7,665.6 per year/building.

The cost for the electricity consumption for the whole complex was displayed as next:

US$ 7,665.6 per year/building X 4.5 buildings/complex = US$ 34,495.2 per year/complex.

Table 117. Monthly Amount per Energy-Efficient Apartment for Summer Season in 2013 (*CFE*, n.d. (b)).

	Mexican Pesos					US Dollars				
	46 kWh	0 kWh	0 kWh			46 kWh	0 kWh	0 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	200 kWh/month	kWh/bi-month	From 1 to 125 kWh	From 126 to 225 kWh	More than 226 kWh	200 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	0.00	0.00	0.00	0.00	31.33	0.00	0.00	0.00	0.00	2.47
February	31.33	0.00	0.00	31.33		2.47	0.00	0.00	2.47	
March	31.42	0.00	0.00	31.42	62.93	2.48	0.00	0.00	2.48	4.97
April	31.51	0.00	0.00	31.51		2.49	0.00	0.00	2.49	
May	31.60	0.00	0.00	31.60	63.30	2.50	0.00	0.00	2.50	5.00
June	31.69	0.00	0.00	31.69		2.50	0.00	0.00	2.50	
July	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
August	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
September	31.97	0.00	0.00	31.97	31.97	2.53	0.00	0.00	2.53	2.53
October	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
November	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
December	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
Annual payment	189.52	0.00	0.00	189.52	189.52	14.97	0.00	0.00	14.97	14.97

Table 118. Monthly Amount per Base-Case Apartment for No-Summer Season in 2013 (*CFE*, n.d. (b)).

	Mexican Pesos					US Dollars				
	46 kWh	0 kWh	0 kWh			46 kWh	0 kWh	0 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 75 kWh	From 76 to 175 kWh	More than 176 kWh	200 kWh/month	kWh/bi-month	From 1 to 75 kWh	From 76 to 175 kWh	More than 176 kWh	200 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	34.91	0.00	0.00	34.91	34.91	2.76	0.00	0.00	2.76	2.76
February	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
March	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
April	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
May	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
June	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
July	35.60	0.00	0.00	35.60	71.35	2.81	0.00	0.00	2.81	5.64
August	35.74	0.00	0.00	35.74		2.82	0.00	0.00	2.82	
September	0.00	0.00	0.00	0.00	36.02	0.00	0.00	0.00	0.00	2.85
October	36.02	0.00	0.00	36.02		2.85	0.00	0.00	2.85	
November	36.16	0.00	0.00	36.16	72.45	2.86	0.00	0.00	2.86	5.72
December	36.29	0.00	0.00	36.29		2.87	0.00	0.00	2.87	
Annual payment	214.73	0.00	0.00	214.73	214.73	16.96	0.00	0.00	16.96	16.96

Table 119. Total Amount per Energy-Efficient Apartment in 2013 (CFE, n.d. (b)).

	Mexican Pesos			US Dollars		
	Summer	No-Summer	Total	Summer	No-Summer	Total
Months	$	$	$	$	$	$
January February	31.33	34.91	66.24	2.47	2.76	5.23
March April	62.93	0.00	62.93	4.97	0.00	4.97
May June	63.30	0.00	63.30	5.00	0.00	5.00
July August	0.00	71.35	71.35	0.00	5.64	5.64
September October	31.97	36.02	67.99	2.53	2.85	5.37
November December	0.00	72.45	72.45	0.00	5.72	5.72
Annual payment	189.52	214.73	404.25	14.97	16.96	31.94

4.4.1.3. Annual Energy Consumption Cost in Base-Case Grocery Store.

This section was for the analysis of the grocery store. The energy consumption of the grocery store was 333,757 kWh/year. According to *CFE* (n.d., (c)), the electricity rate number 2 was applied to the commercial spaces. In order to determine the monthly consumption, the next calculation was done:

333,757 kWh/year/12 months/year = 27,813 kWh/month

The 27,813 kWh/month was input to the spreadsheet. Table 120 shows the electricity rate number applied to commercial spaces in 2013. This rate had three measures: basic, medium and surplus. The basic measure was from one to 50 kWh, the medium measure was from 51 to 100 kWh and the surplus measure was more than 101 kWh.

Table 120. Electricity Rate Numer 2 Applied to Commercial Spaces for 2013 (*CFE*, n.d., (c)).

	Mexican Pesos			US Dollars		
	Basic	Medium	Surplus	Basic	Medium	Surplus
	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh
Months	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh	$/kWh
January	2.22	2.68	2.95	0.18	0.21	0.23
February	2.18	2.63	2.90	0.17	0.21	0.23
March	2.16	2.61	2.88	0.17	0.21	0.23
April	2.18	2.64	2.90	0.17	0.21	0.23
May	2.24	2.71	2.98	0.18	0.21	0.24
June	2.22	2.68	2.95	0.18	0.21	0.23
July	2.19	2.65	2.92	0.17	0.21	0.23
August	2.21	2.67	2.94	0.17	0.21	0.23
September	2.19	2.64	2.91	0.17	0.21	0.23
October	2.24	2.70	2.97	0.18	0.21	0.23
November	2.26	2.73	3.01	0.18	0.22	0.24
December	2.27	2.74	3.02	0.18	0.22	0.24

Table 121 displays the monthly amount per base-case grocery store in 2013. The annual cost for the electricity consumed for the grocery store was MXN $ 981,644 or USD $ 77,549.[138]

[138] The lamps, appliances, fans and space cooling consume 116,390 kWh/year, 59,400 kWh/year, 64,260 kWh/year and 93.72 kWh/year, respectively.

Table 121. Monthly Amount for Base-Case Grocery Store in 2013 (*CFE*, n.d., (c)).

	Mexican Pesos					US Dollars				
	50 kWh	51 kWh	27,713 kWh			50 kWh	51 kWh	27,713 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh	333,757 kWh/month	kWh/bi-month	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh	333,757 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	111.00	134.10	81,836.49	82,081.59	162,551.07	8.77	10.59	6,465.08	6,484.45	12,841.53
February	108.85	131.50	80,229.14	80,469.49		8.60	10.39	6,338.10	6,357.09	
March	108.15	130.65	79,702.59	79,941.39	160,633.23	8.54	10.32	6,296.50	6,315.37	12,690.02
April	109.15	131.85	80,450.84	80,691.84		8.62	10.42	6,355.62	6,374.66	
May	112.15	135.50	82,667.88	82,915.53	164,941.59	8.86	10.70	6,530.76	6,550.33	13,030.39
June	110.95	134.05	81,781.06	82,026.06		8.77	10.59	6,460.70	6,480.06	
July	109.65	132.45	80,811.11	81,053.21	162,662.33	8.66	10.46	6,384.08	6,403.20	12,850.32
August	110.40	133.35	81,365.37	81,609.12		8.72	10.53	6,427.86	6,447.12	
September	109.25	131.95	80,506.27	80,747.47	163,385.01	8.63	10.42	6,359.99	6,379.05	12,907.42
October	111.80	135.00	82,390.75	82,637.55		8.83	10.67	6,508.87	6,528.37	
November	113.00	136.45	83,277.57	83,527.02	167,471.03	8.93	10.78	6,578.93	6,598.63	13,230.21
December	113.60	137.15	83,693.26	83,944.01		8.97	10.83	6,611.77	6,631.58	
Annual payment	1,327.95	1,604.00	978,712.31	981,644.26	981,644.26	104.91	126.72	77,318.27	77,549.90	77,549.90

The cost for the electricity consumption for the analyzed base-case grocery store was MX$ 981,644 per year for the grocery store, or US$ 77,549 per year for the grocery store.

4.4.1.4. Annual Energy Consumption Cost in Energy-Efficient Grocery Store.

This section was for the analysis of the grocery store. The energy consumption of the energy-efficient grocery store was 258,830 kWh/year. In order to determine the monthly consumption, the next calculation was done:

258,830 kWh/year/12 months/year = 21,569 kWh/month

The 21,569 kWh/month was input to the spreadsheet. Table 122 shows the electricity rate applied in 2013 to the energy-efficient grocery store.

Table 122. Monthly Amount for Energy-Efficient Grocery Store in 2013 (*CFE*, n.d., (c)).

	Mexican Pesos					US Dollars				
	50 kWh	51 kWh	21,469 kWh			50 kWh	51 kWh	21,469 kWh		
	Basic	Medium	Surplus	Total	Bi-monthly payment	Basic	Medium	Surplus	Total	Bi-monthly payment
	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh	258,830 kWh/month	kWh/bi-month	From 1 to 50 kWh	From 51 to 100 kWh	More than 101 kWh	258,830 kWh/month	kWh/bi-month
Months	$	$	$	$	$	$	$	$	$	$
January	111.00	134.10	63,397.96	63,643.06	126,036.16	8.77	10.59	5,008.44	5,027.80	9,956.86
February	108.85	131.50	62,152.76	62,393.11		8.60	10.39	4,910.07	4,929.06	
March	108.15	130.65	61,744.84	61,983.64	124,549.15	8.54	10.32	4,877.84	4,896.71	9,839.38
April	109.15	131.85	62,324.51	62,565.51		8.62	10.42	4,923.64	4,942.68	
May	112.15	135.50	64,042.03	64,289.68	127,889.70	8.86	10.70	5,059.32	5,078.88	10,103.29
June	110.95	134.05	63,355.02	63,600.02		8.77	10.59	5,005.05	5,024.40	
July	109.65	132.45	62,603.60	62,845.70	126,122.44	8.66	10.46	4,945.68	4,964.81	9,963.67
August	110.40	133.35	63,032.98	63,276.73		8.72	10.53	4,979.61	4,998.86	
September	109.25	131.95	62,367.45	62,608.65	126,682.78	8.63	10.42	4,927.03	4,946.08	10,007.94
October	111.80	135.00	63,827.34	64,074.14		8.83	10.67	5,042.36	5,061.86	
November	113.00	136.45	64,514.35	64,763.80	129,850.93	8.93	10.78	5,096.63	5,116.34	10,258.22
December	113.60	137.15	64,836.38	65,087.13		8.97	10.83	5,122.07	5,141.88	
Annual payment	1,327.95	1,604.00	758,199.20	761,131.15	761,131.15	104.91	126.72	59,897.74	60,129.36	60,129.36

The cost for the electricity consumption for the analyzed energy-efficient retail was displayed as follows:

MX$ 761,131 per year for the grocery store, or US$ 60,129 per year for the grocery store.

4.4.2. Calculation of Annual Water Consumption Cost for the Multifamiliar Miguel Aleman in Mexico City.

This section presented the calculation of the base-case and water-efficient annual water consumption cost for the *Multifamiliar Miguel Aleman* in Mexico City.

4.4.2.1. Annual Water Consumption Cost in Base-Case Multi-Family Apartments.

This section was for the analysis of the base-case multi-family apartments. The water consumption for a person was 184.67 lt./person/day or 48.78 gal./person/day in section 4.2.2.1.1. The estimation of the base-case water consumption was presented as next:

184.67 lt/person/day X 4 person/apartment = 738.68 lt/apartment/day

The water consumption cost was obtained from water bills for a house in Mexico City. The water payment is bi-monthly in Mexico. Table 123 is the bi-monthly water cost per base-case apartment. The first column is for the bi-month, the second column is the liters consumed per apartment, the third column is the water cost in Mexican Pesos/lt and the fourth column is the total cost per bi-month. The fifth column is the gallons consumed per apartment, the sixth column is the water cost in US Dollars and the seventh column is the total cost per bi-month.

Table 123. Bi-Monthly Water Cost per Base-Case Apartment.

Bi-month	lt	MXN/lt	MXN	gal	USD/gal	USD
January/February	43,582	0.014	615.9	164,976.27	0.001	180.9
March/April	45,059	0.014	646.6	170,568.69	0.001	190.0
May/June	45,059	0.016	706.8	170,568.69	0.001	207.6
July/August	45,798	0.014	640.3	173,364.90	0.001	188.1
September/October	45,059	0.014	642.3	170,568.69	0.001	188.7
November/December	45,059	0.014	647.4	170,568.69	0.001	190.2
Total	269,618	0.014	3,899.2	1,020,615.92	0.001	1,145.5

The total cost for the water of the base-case community was presented as follows:

USD $1,145.5 for water consumption/apartment X 1,080 apartments/community = USD $1,237,117.6 for water consumption /community.

4.4.2.2. Annual Water Consumption Cost in Water-Efficiency Multi-Family Apartments.

This part was for the analysis of the water-efficiency multi-family apartments. The water consumption for a person was calculated as 55 lt./person/day or 14.52 gal./person/day in section 4.3.2.1.1. The estimation of the base-case water consumption was exhibited as next:

55 lt/person/day X 4 person/apartment = 220 lt/apartment/day

Table 124 was the bi-monthly water cost per water-efficiency apartment.[139] The first column is for the bi-month, the second column is the liters consumed per apartment, the third column is the water cost in Mexican Pesos/lt and the fourth column is the total cost per bi-month. The fifth column is the gallons consumed per apartment, the sixth column is the water cost in US Dollars and the seventh column is the total cost per bi-month.

Table 124. Bi-Monthly Water Cost per Water-Efficiency Apartment.

Bi-month	lt	MXN/lt	MXN	gal	USD/gal	USD
January/February	12,980	0.014	183.4	49,134.65	0.001	53.9
March/April	13,420	0.014	192.6	50,800.23	0.001	56.6
May/June	13,420	0.016	210.5	50,800.23	0.001	61.8
July/August	13,640	0.014	190.7	51,633.02	0.001	56.0
September/October	13,420	0.014	191.3	50,800.23	0.001	56.2
November/December	13,420	0.014	192.8	50,800.23	0.001	56.6
Total	80,300	0.014	1,161.3	303,968.57	0.001	341.2

The total cost for the water of the base-case community is presented as follows:

USD $341.2 for water consumption/apartment X 1,080 apartments/community = USD $368,448.96 for water consumption /community.

4.4.2.3. Annual Water Consumption Cost in Base-Case Grocery Store.

This section was for the analysis of the base-case grocery store. The water consumption was 1,699 gal/day, and the cost was assumed from the water bills from the apartment section. Table 125 is the bi-monthly water cost. The total cost of the water for the store was USD $20,688.

[139] For the economic analysis of this technical potential study, one Mexican Peso equals to 0.079 US Dollars (http://www.xe.com/currencyconverter/convert/?Amount=1&From=MXN&To=USD)

Table 125. Bi-Monthly Water Cost for Base-Case Grocery Store.

Bi-month	lt	MXN/lt	MXN	gal	USD/gal	USD
January/February	379,453	0.030	11,307.7	1,436,384.35	0.002	3,321.9
March/April	392,315	0.030	11,825.5	1,485,075.34	0.002	3,474.0
May/June	392,315	0.030	11,691.0	1,485,075.34	0.002	3,434.5
July/August	398,747	0.030	12,019.4	1,509,420.84	0.002	3,530.9
September/October	392,315	0.030	11,691.0	1,485,075.34	0.002	3,434.5
November/December	392,315	0.030	11,825.5	1,485,075.34	0.002	3,474.0
Total	2,347,461	0.030	70,356.8	8,886,106.57	0.002	20,668.8

4.4.2.4. Annual Water Consumption Cost in Water-Efficiency Grocery Store.

The water consumption was 1,435 gal/day, and the cost was assumed from the water bills from the apartment section. In the same manner as Table 125, Table 126 was the bi-monthly water cost. The total cost of the water for the water-saving store was USD $17,458.

Table 126. Bi-Monthly Water Cost for Water-Efficiency Grocery Store.

Bi-month	lt	MXN/lt	MXN	gal	USD/gal	USD
January/February	320,518	0.030	9,551.4	1,213,290.73	0.002	2,805.9
March/April	331,383	0.030	9,988.8	1,254,419.23	0.002	2,934.4
May/June	331,383	0.030	9,875.2	1,254,419.23	0.002	2,901.1
July/August	336,815	0.030	10,152.6	1,274,983.48	0.002	2,982.5
September/October	331,383	0.030	9,875.2	1,254,419.23	0.002	2,901.1
November/December	331,383	0.030	9,988.8	1,254,419.23	0.002	2,934.4
Total	1,982,863	0.030	59,429.2	7,505,951.11	0.002	17,458.6

CHAPTER V
RESULTS

The results for this technical potential analysis are presented in terms of population and energy consumption in Mexico City; the reduction of energy and water use for the multi-family apartments and the grocery store; the reduction of transportation use at community level; the reduction of energy and water costs for the multi-family apartments and the grocery store; and the guide for low-energy, low-water use communities for Mexico City.

5.1. Results for Population and Energy Consumption in Mexico City

The analysis shows some findings in Mexico in terms of population and energy consumption.

The population in Mexico[140] is concentrated in the South-central states with some "isolated" cities. The South-central area in Mexico has approximately the 50 percent of the population of the country. Mexican cities are spread out, horizontal cities with two or three-floor buildings. The need for housing close to different activites (e.g., school, office, etc.) with energy and water-savings solutions is high in this area, and the area to build in the cities in this area is low. Thus, the idea of high-density, mixed-use, multi-family buildings should be considered for this area.

The energy consumption in the housing sectors for Mexico is 6.8 MMBtu/person in 2005. The appliances' purchase in 2011 in Mexico reached US$1,985 million. The trends show that the purchase of electric appliances for Mexican residences will increase an 8.9 percent from 2012 to 2020. This will raise the energy consumption per household. Air-conditioning use in Mexico City is limited due to its climate and economical situation. Therefore, more efficient appliances are needed in houses in Mexico City.

To conclude, the new and also the existing mixed-use buildings in their multi-family apartment section for the temperate climate in Mexico City should have energy-efficient solutions that emphasize solar water heating, natural ventilation, daylighting, rainwater harvesting, and very efficient electric appliances to reduce energy-use. Building envelope

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[140] Optimal space solutions for the new houses for an average family of four members are needed in Mexico.

measures (i.e., increase wall r-value, place shading devices and double-clear glazing) and daylighting and electrical systems should be applied to the retail portion of the mixed-use building.

5.2. Results for the Multi-Family Apartments

Table 127 to Table 130 show the input for the base-case and energy-efficient case for the apartments. The input for the shell and the building footprint is located in Table 127. There is no change in this information between the base-case and the energy-efficient case.

Table 127. Shell and Building Footprint Inputs for Apartments.

Item	Name of Parameter		Base-Case Input	Energy-Efficient Case Input
Shell	Area and Floors	Building Area	15,103 ft²	
		Number of Floors	12	
		Below Grade	0	
Building Footprint	Zone Names		EL2 WNW Perim Sp (G.WNW1)	
			EL2 ESE Perim Sp (G.ESE2)	
			EL3 WNW Perim Sp (G.WNW1)	
			EL3 ESE Perim Sp (G.ESE2)	
			EL4 WNW Perim Sp (G.WNW1)	
			EL4 ESE Perim Sp (G.ESE2)	
	Zone characteristics		Unconditioned	
	Building Orientation		13°	
	Height Floor to Floor		8.85 ft	
	Height Floor to Ceiling		7.87 ft	

Table 128 has the information for the building envelope. The analysis from the building performance shows that the increase of U-Value for the walls and roof does not improve the thermal comfort of the base-case. Thus, no changes are done to the energy-efficient case.

Table 128. Building Envelope Constructions Inputs for Apartments.

Item	Name of Parameter			Base-Case Input	Energy-Efficient Case Input
Building Envelope Constructions	Slab	Roof_1	Surface Type	Roof	
			Layer	Concrete 80 lbs.	
			U-Value	0.237 Btu/h-ft²-°F	
	Exterior Walls	Wall_1	Surface Type	Vertical Exterior Wall	
			Layer	Surface Air Film	
			Layer	Brick	
			Layer	Surface Air Film	
			U-Value	0.248 Btu/h-ft²-°F	
	Floor from Second Floor	Wall_2	Exposure	Exposed to Ambient Conditions	
			Layer	Surface Air Film	
			Layer	Brick	
			Layer	Brick	
			U-Value	0.010 Btu/h-ft²-°F	
	Roof from Fourth Floor	Roof_2	Surface Type	Roof	
			Layer	Surface Air Film	
			Layer	Linoleum Tile	
			Layer	Brick	
			Layer	Board Insulation	
			Layer	Roof Gravel	
			Layer	Concrete 80 lbs.	
			Layer	Surface Air Film	
			U-Value	0.107 Btu/h-ft²-°F	

The window inputs for the base-case and the energy-efficiency case is shown in Table 129. The window type, window-to-wall ratio and the dimensions of the windows are not changed at all according to the results of the thermal comfort analysis. Night flushing for summer and heat closed windows for winter are performed in order to improve the hours inside the comfort zone. Windows are closed once the interior temperature reaches 60°F.

Table 129. Window Inputs for Apartments.

Item	Name of Parameter			Base-Case Input	Energy-Efficient Case Input
Window Type	Number of Panes			Single	
	Frame Type			Aluminum w/o Break, Operable	
	Frame Wd. (in.)			1.3 in.	
	Glass Tint			Clear Glass	
	U-Value			1.11 Btu/h-ft² °F	
	Shading Coefficient			0.86	
	Visible Transmittance			0.90	
Window Strategies	Summer Night Flushing			No	Yes
	Heat Closed Windows for Heat Trap			No	Yes
Window-to-Wall Ratio				60 percent	60 percent
Window Dimensions, Positions and Quantities	1.- Glass	Width (ft)		4.25	
		Window ht (ft)		70	
		Sill		0	
		% Windows (floor to floor,	East	0	
			West	0	
			South	47.2	
			North	0	
	2.- Glass	Width (ft)		4.75	
		Window ht (ft)		160	
		Sill		0	
		% Windows (floor to floor,	East	53.0	
			West	53.0	
			South	0	
			North	0	
	3.- Glass	Width (ft)		3.96	
		Window ht (ft)		150	
		Sill		0	
		% Windows (floor to floor,	East	0	
			West	0	
			South	44.0	
			North	0	

Table 130 has the inputs for the loads, occupancy, infiltration, daylighting, air-conditioning systems and fans. The lighting and appliances are changed to 0.10 and 0.36 W/ft², respectively. The daylighting controls are activated in order to adjust the artificial lighting according to the natural daylighting. The fan is modified to intermittent in order to avoid energy consumption.

The energy consumption in Case 15 in Figure 107 and Table 131 shows a reduction of 77 percent from the base-case. This case proves to be the optimal one in order to reduce energy consumption and keep quality comfort for 50 percent of the year. The apartment section of the building can also reach a near net zero energy by applying the on-site energy produced of 115,106.4 kWh/year from the PV.

	Case 0_Base-Case	Case 15_Final Combined 5 Measures
Area Lights	286.4	43.39
Pumps & Aux.	0.1	0.1
Misc. Equip.	289.06	89.6

Figure 107. Annual Energy Consumption for the Apartments Base-Case and Final Energy-Efficient Case.

Table 130. Loads, Occupancy, Infiltration, Daylighitng, Air-Conditioning Systems and Fans Inputs for Apartments.

Item		Name of Parameter		Base-Case Input	Energy-Efficient Case Input
Loads		Lighting		0.63 W/ft²	0.10 W/ft²
		Appliances		0.62 W/ft²	0.36 W/ft²
Occupancy		EL2 WNW Perim Sp (G.WNW1)		60	
		EL2 ESE Perim Sp (G.ESE2)		20	
		EL3 WNW Perim Sp (G.WNW1)		60	
		EL3 ESE Perim Sp (G.ESE2)		20	
		EL4 WNW Perim Sp (G.WNW1)		60	
		EL4 ESE Perim Sp (G.ESE2)		20	
Infiltration		Method		Sherman-Grimsrud	
				0.35 ACH	
Daylighting		Daylighting Controls		No	Yes
		Daylit			Side Lighting
		Daylit Area Method			CA Title-24 2008
		Area			5,999 Sq.Ft. (36%) of Top Floor is Daylightable
		Design Light Level			50 fc
		Lighting Control Method			Dimming: 30% Light (30% PWR)
Air-Conditioning Systems		Cooling Source		DX Coils	
		Heating Source		Electric Resistance	
		System Type		Packaged Single Zone DX, Electric Heat	
		System per Area		System per Shell	
		Return Air Path		Ducted	
	Seasonal Thermostat Setpoints	Occupied (°F)	Cool	120°F	
			Heat	50°F	
		Unoccupied (°F)	Cool	120°F	
			Heat	50°F	
	Design Temperatures	Indoor	Cooling Design Temperature	118°F	
			Heating Design Temperature	52°F	
		Supply	Cooling Design Temperature	55°F	
			Heating Design Temperature	78°F	
	System Size	Cooling	Overall Size	Auto-Size	
			Typical Unit Size	135-240 kBtuh or 11.25-20 tons	
			Condenser Type	Air-Cooled	
			Efficiency	EER 8.500	
		Heating	Size	Auto-Size	
Fan	Operation	Cycle Fans at Night		No Fan Night Cycling	
		Fan Mode		Intermittent	

Table 131. Energy Consumption for Base-Case and Final Energy-Efficient Case.

	Case 0_Base-Case	Case 15_Final Combined 5 Measures
	Total	Total
	kWh (X 1,000)	kWh (X 1,000)
Area Lights	286.4	43.39
Task Lights	0	0
Misc. Equip.	289.06	89.6
Heat Reject.	0	0
Refrigeration	0	0
HP Supp.	0	0
Hot Water	0	0
Pumps & Aux.	0.1	0.1
Ext. Usage	0	0
Vent. Fans	0	0
Space Heat	0	0
Space Cool	0	0
Total Energy Consumption	575.56	133.09
Energy Consumption (Percent)		23.1
Energy Reduction (Percent)		76.9

5.3. Results for the Grocery Store

Table 132 to Table 135 show the input table for the base-case and energy-efficient case for the grocery store. In Table 132, the only change is the increase of the U-value for the wall from 2.70 Btu/h-ft^2-°F in the base-case input to 0.065 Btu/h-ft^2-°F in the energy-efficient case.

Table 132. Shell, Building Footprint, Building Envelope Constructions and Doors Input for the Grocery Store.

Item	Name of Parameter			Base-Case Input	Energy-Efficient Case Input
Shell	Area and Floors		Building Area	9,217 ft^2	
			Number of Floors	1	
			Below Grade	0	
Building Footprint			Zone Names	EL1 ESE Perim Sp (G.ESE1)	
			Zone characteristics	Conditioned	
			Building Orientation	13°	
			Height Floor to Floor	11.8 ft	
			Height Floor to Ceiling	10.8 ft	
Building Envelope Constructions	Roof Surfaces	Roof_3	Surface Type	Roof	
			Layer	Concrete 80 lbs.	
			U-Value	0.024 Btu/h-ft^2-°F	
	Above Grade Walls	Wall_1	Surface Type	Vertical Exterior Wall	
			Layer	Surface Air Film (AL01)	
			Layer	Brick	
			Layer	Surface Air Film (AL01)	
			U-Value	2.70 Btu/h-ft^2-°F	0.065 Btu/h-ft^2-°F
			Exposure	Earth Contact	
			U-Value	0.010 Btu/h-ft^2-°F	
	Ground Floor		Interior Finish	Ceramic/Stone Tile	
			Construction	8 in. Concrete	
			Ext/Cav Insul.	No Perimeter Insulation	

Table 133 shows the door inputs for the grocery store. There is a change in the small window part of the door from a single clear glazing without thermal break in the base-case to a double clear glazing with thermal break in the energy-efficient case.

Table 133. Doors Input for the Grocery Store.

Item	Name of Parameter			Base-Case Input	Base-Case Input
Doors	Door Types	1.- Glass	East	5	
			West	0	
			South	0	
			North	0	
		2.- Glass	East	1	
			West	0	
			South	0	
			North	2	
		3.- Glass	East	0	
			West	0	
			South	0	
			North	2	
	Door Dimensions and Construction/Glass Definitions	1.- Glass	Ht. (ft)	7	
			Wd. (ft)	5.4	
			Construction or Glass Category	Single Clear/Tint	Double Clear
			Frame Type	Aluminum w/o Break	Aluminum w/ Break
			Frame Wd. (in.)	3 in.	
		2.- Glass	Ht. (ft)	7 ft	
			Wd. (ft)	5.6 ft	
			Construction or Glass Category	Single Clear/Tint	Double Clear
			Frame Type	Aluminum w/o Break	Aluminum w/ Break
			Frame Wd. (in.)	3 in.	
		3.- Glass	Ht. (ft)	7 ft	
			Wd. (ft)	5.2 ft	
			Construction or Glass Category	Single Clear/Tint	Double Clear
			Frame Type	Aluminum w/o Break	Aluminum w/ Break
			Frame Wd. (in.)	3 in.	

There are some changes made from the base-case in Table 134. The lighting and the appliances power are changed to 1.3 and 0.95 W/ft² (AEDG, 2006; Mukhopadyay, 2013); the infiltration is modified to 0,161 ACH (Mukhopadyay, 2013; Hale et al., 2008) and the sensors are activated. These changes are done in order to cutdown energy consumption.

Table 134. Windows, Loads, Occupancy, Infiltration and Daylighting Input for the Grocery Store.

Item	Name of Parameter				Base-Case Input	Base-Case Input
Windows	Window Type	1.- Glass	Number of Panes		Single	Double
			Frame Type		Aluminum w/o Break, Operable	Aluminum w/ Break, Operable
			Frame Wd. (in.)		1.3 in.	
			Glass Tint		Clear Glass	
			U-Value		1.11 Btu/h-ft² °F	0.69 Btu/h-ft² °F
			Shading Coefficient		0.86	0.44
			Visible Transmittance		0.90	0.45
	Window Dimensions, Positions and Quantities	1.- Glass	Width (ft)		16.13	
			Window ht (ft)		7	
			Sill		0	
			% Windows (floor to floor, including frame)	East	4.5	
				West	0	
				South	47.2	
				North	0	
		2.- Glass	Width (ft)		16.68	
			Window ht (ft)		7	
			Sill		0	
			% Windows (floor to floor, including frame)	East	4.6	
				West	0	
				South	0	
				North	0	
		3.- Glass	Width (ft)		19.82	
			Window ht (ft)		4	
			Sill		3	
			% Windows (floor to floor, including frame)	East	3.2	
				West	0	
				South	0	
				North	0	
Loads	Lighting				1.85 W/ft²	1.3 W/ft²
	Appliances				1.27 W/ft²	0.95 W/ft²
Occupancy	EL1 ESE Perim Sp (G.ESE1)				74	
Infiltration	Method				5 ACH	0.161 ACH
Daylighting	Daylighting	Daylighting Controls			No	Yes
		Daylit				Side Lighting
		Daylit Area Method				CA Title-24 2008
		Area				1,441 Sq.Ft. (12%) of Top Floor is Daylightable
		Design Light Level				50 fc
		Lighting Control Method				Dimming: 30% Light (30% PWR)

Table 135 is the air-conditioning system and the fan inputs. The system working in the grocery store is compared to the system in the apartments. The supply flow is changed to 2.5 CFM in order to maintain the hours inside the 70 to 72°F range.

Table 135. Air-Conditioning System and Fan Input for the Grocery Store.

Item	Name of Parameter			Base-Case Input	Base-Case Input
Air-Conditioning System	System Type	Cooling Source		DX Coils	
		Heating Source		Furnace	
		System Type		Packaged Single Zone DX with Furnace	
		System per Area		System per Shell	
		Return Air Path		Ducted	
	Seasonal Thermostat Setpoints	Occupied (°F)	Cool	72°F	
			Heat	70°F	
		Unoccupied (°F)	Cool	72°F	
			Heat	70°F	
	Design Temperatures	Indoor	Cooling Design Temperature	72°F	
			Heating Design Temperature	70°F	
		Supply	Minimum Temperature	55°F	
			Maximum Temperature	100°F	
	System Type	Cooling	Overall Size	Auto-Size	
			Typical Unit Size	135-240 kBtuh or 11.25-20 tons	
			Condenser Type	Air-Cooled	
			Efficiency	EER 8.500	
		Heating	Size	Auto-Size	
	Air Flows	Supply Flow		1 cfm/ft²	2.5 cfm/ft²
Fan	Operation	Cycle Fans at Night		No Fan Night Cycling	
		Fan Mode		Continuous	

Table 136 and Figure 108 exhibit the total energy consumption for the base-case and the final energy-efficient case. The energy-efficient case shows an energy reduction of 22.5 percent. The final conclusion for the grocery store is that it is 100 percent inside comfort and almost one fourth of the energy can be saved with the measures applied to it.

Table 136. Total Energy Consumption for Each Measure, and Percentage of Energy Reduction for Each Case (Grocery Store).

	Case 0_Base-Case	Case 9_Final Energy-Efficient Case
	Total	Total
	kWh (X 1,000)	kWh (X 1,000)
Area Lights	116.39	77.24
Task Lights	0	0
Misc. Equip.	59.39	44.54
Heat Reject.	0	0
Refrigeration	0	0
HP Supp.	0	0
Hot Water	0	0
Pumps & Aux.	0	0
Ext. Usage	0	0
Vent. Fans	64.26	64.26
Space Heat	0	0
Space Cool	93.72	72.79
Total Energy Consumption	333.76	258.83
Energy Consumption (Percent)		77.5
Energy Reduction (Percent)		22.5

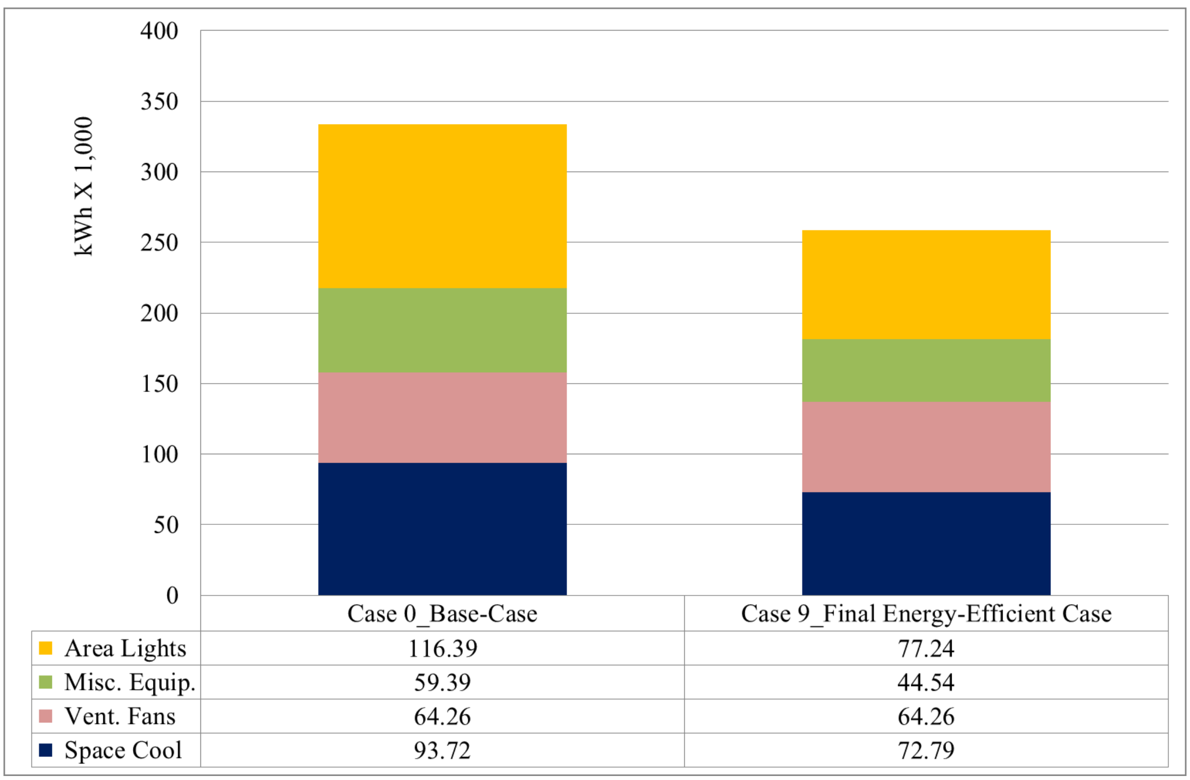

Figure 108. Total Energy Consumption for Each Measure (Grocery Store).

5.4. Results for the Final Energy Reductions for the Community

Table 137 and Figure 109 display the annual energy consumption for the 1,080 apartments inside of the community. These are the numbers from the simulated buildings. The highest reductions are in the apartments.

Table 137. Annual Energy Consumption Percentages for Apartments and Grocery Store.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		kWh/year (X 1,000)	kWh/year (X 1,000)	kWh/year (X 1,000)	%
Energy Use for Apartments	Area Lights	1,288.8	195.3	1,093.5	85
	Misc. Equip.	1,300.8	403.2	897.6	69
Energy Use for Grocery Store	Area Lights	523.8	347.6	176.2	34
	Misc. Equip.	267.3	200.4	66.8	25
	Vent. Fans	289.2	289.2	0.0	0
	Space Cool	421.7	327.6	94.2	22

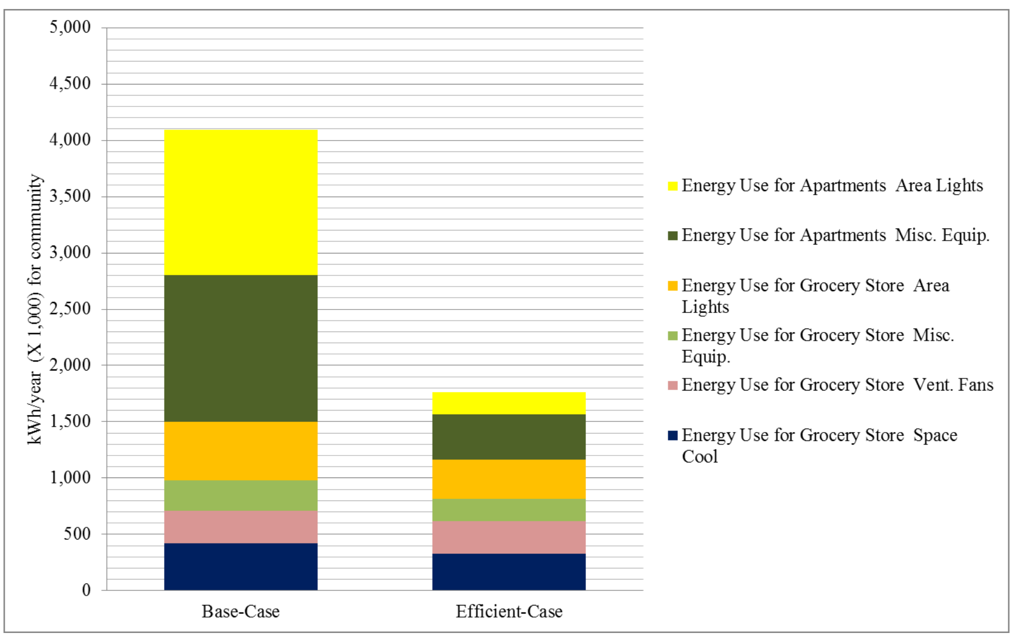

Figure 109. Annual Energy Consumption Chart for Apartments and Grocery Store.

The energy for the lighting and the miscellaneous equipment from the apartments in Table 138 and Figure 110 are added in order to determine the total savings for the apartments.

Table 138. Annual Energy Consumption Percentages for Apartments (Lamps Plus Appliances) and Grocery Store.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		kWh/year (X 1,000)	kWh/year (X 1,000)	kWh/year (X 1,000)	%
Energy Use for Apartments	Area Lights + Misc. Equip	2,589.6	598.5	1,991.1	77
Energy Use for Grocery Store	Area Lights	523.8	347.6	176.2	34
	Misc. Equip.	267.3	200.4	66.8	25
	Vent. Fans	289.2	289.2	0.0	0
	Space Cool	421.7	327.6	94.2	22

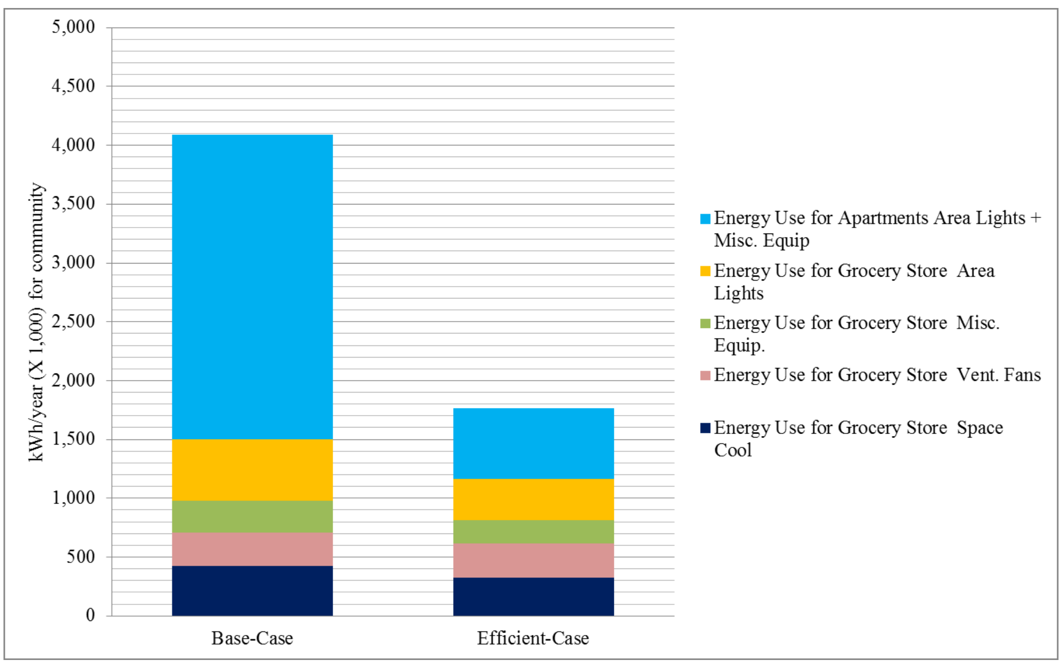

Figure 110. Annual Energy Consumption Chart for Apartments (Lamps Plus Appliances) and Grocery Store.

Table 139 and Figure 111 display the energy savings due to the application of the PV. 97 percent can be saved for the apartment section of the building. Also, the DHW result from section 4.3.1.3.1 shows a 31.5 percent reduction of the energy to reduce the use of LP gas and warm up the water with solar energy. The DHW results are not included in Table 139 and Figure 111.

Table 139. Annual Energy Consumption Percentages for Apartments (Lamps Plus Appliances) Minus the PV Energy, and Grocery Store.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		kWh/year (X 1,000)	kWh/year (X 1,000)	kWh/year (X 1,000)	%
Energy Use for Apartments	(Area Lights + Misc. Equip) - PV	2,589.6	80.5	2,509.1	97
Energy Use for Grocery Store	Area Lights	523.8	347.6	176.2	34
	Misc. Equip.	267.3	200.4	66.8	25
	Vent. Fans	289.2	289.2	0.0	0
	Space Cool	421.7	327.6	94.2	22

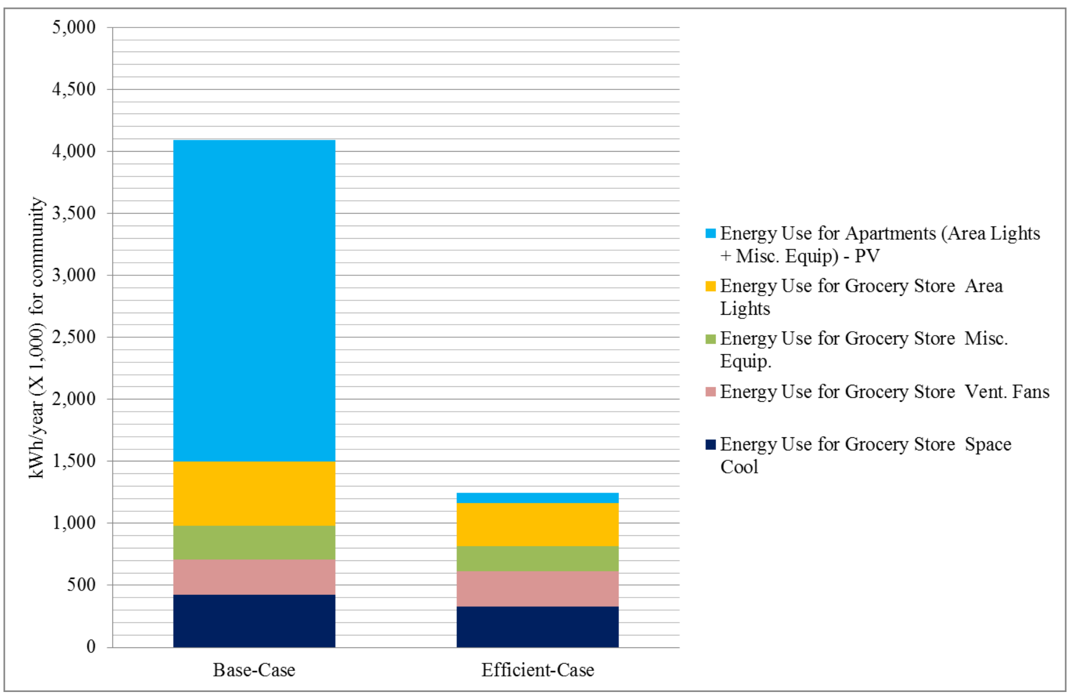

Figure 111. Annual Energy Consumption Chart for Apartments (Lamps Plus Appliances) Minus the PV Energy, and Grocery Store.

Table 140 and Figure 112 show the conversion of the energy consumed in the whole building from kWh/year to MMBtu. The apartment section has a 97 percent savings. The energy for cars is also added here. There are 1,620 gasoline cars used for the base-case and 1,620 high-efficiency cars are used for efficient case in Table 140 and Figure 112. The tons of CO_2 produced from the apartments and the grocery store are displayed in Table 141 and Figure 113. The factors used for the CO_2 emissions are the following ones: 3.29 X 10^{-3} tons CO_2/kWh and 1.9 X 10^{-4} tons CO_2/km, or 3.06 X 10^{-4} tons CO_2/mi (*Grupo Bimbo*, 2007). Finally, 64 percent of tons of CO_2 emissions are reduced from the apartment, grocery store and automobile use for this technical potential analysis.

Table 140. Annual Energy Consumption Percentages for Apartments and Grocery Store in MMBtu.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		MMBtu	MMBtu	MMBtu	%
Energy Use for Cars	Car	517	180	337	65
Energy Use for Apartments	(Area Lights + Misc. Equip - PV)	8,836	275	8,561	97
Energy Use for Grocery Store	Area Lights	1,787	1,186	601	34
	Misc. Equip.	912	684	228	25
	Vent. Fans	987	987	0	0
	Space Cool	1,439	1,118	321	22

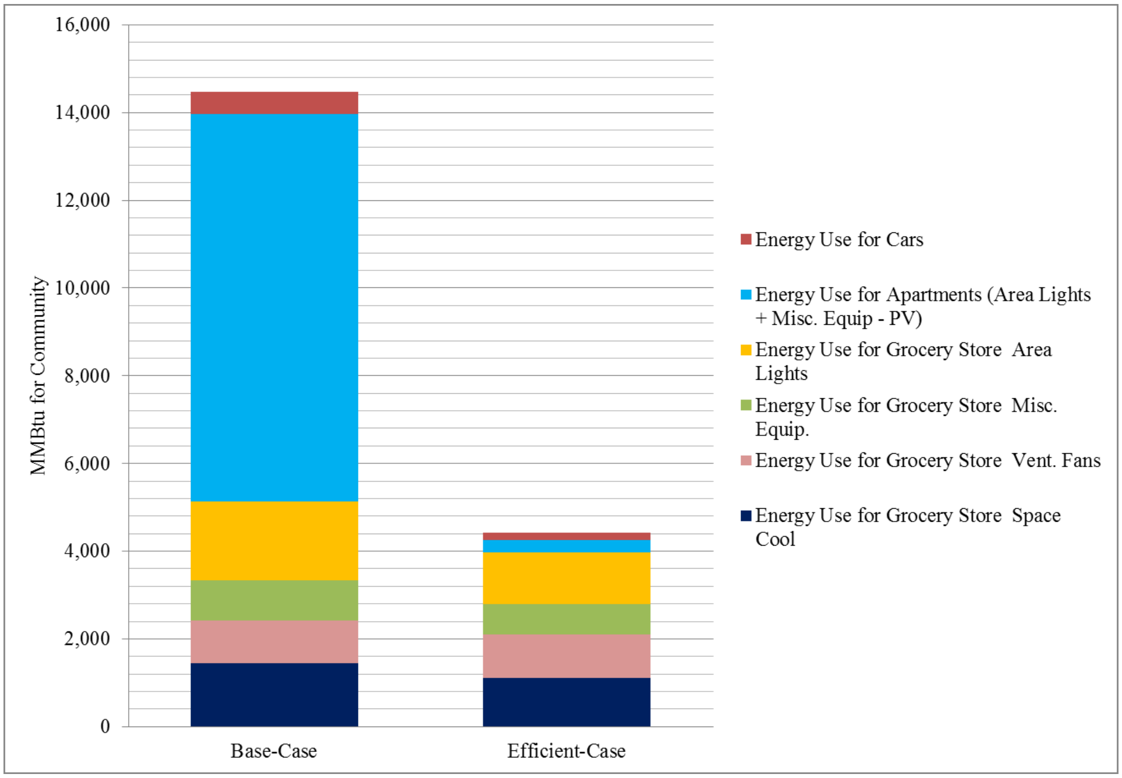

Figure 112. Annual Energy Consumption Chart for Apartments and Grocery Store in MMBtu.

Table 141. Annual Energy Consumption Percentages for Apartments and Grocery Store (Tons of CO_2).

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction	Base-Case	Efficient-Case
		$MMtCO_2$	$MMtCO_2$	$MMtCO_2$	%		
Carbon Footprint for Cars	Car	11,533.0	4,016.0	7,517.0	65	Section 4.2.3	Section 4.3.3.4
Carbon Footprint for Apartments	(Area Lights + Misc. Equip - PV)	8,525.4	1,059.8	7,465.6	97	Section 4.2.1.1.10	Sections 4.3.1.1.13 and 4.3.1.2
Carbon Footprint for Grocery Store	Area Lights	1,724.3	1,144.3	580.0	34	Section 4.2.1.2.9	Section 4.3.1.4.8
	Misc. Equip.	879.9	659.9	220.0	25		
	Vent. Fans	952.0	952.0	0.0	0		
	Space Cool	1,388.5	1,078.4	310.1	22		

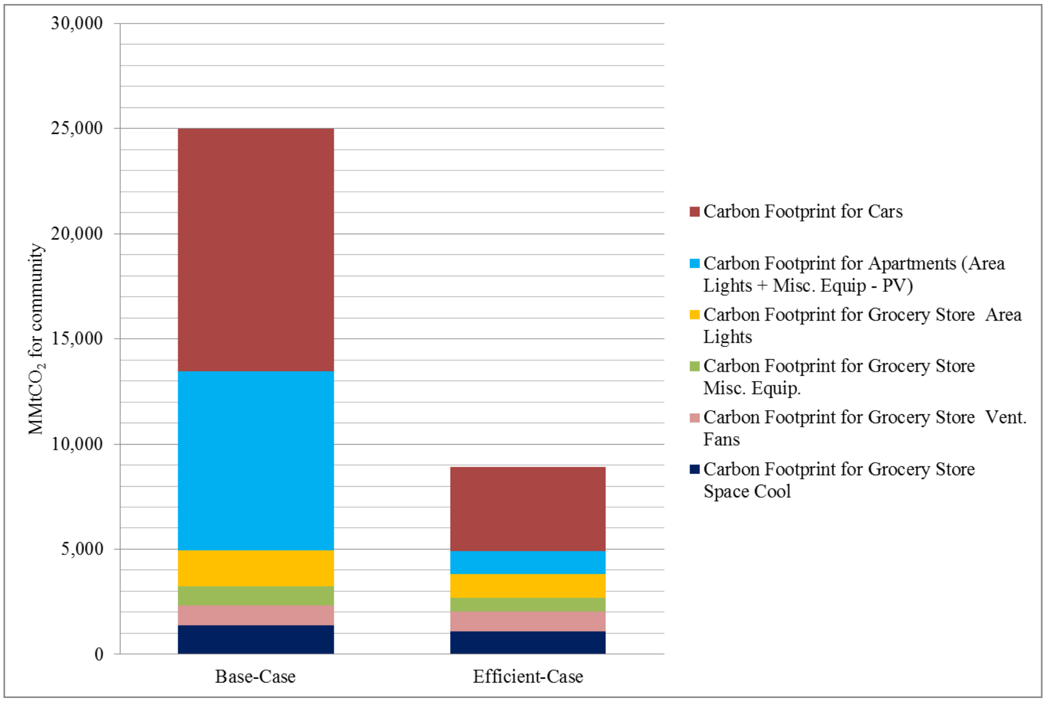

Figure 113. Annual Energy Consumption Chart for Apartments and Grocery Store (Tons of CO_2).

5.5. Results for the Final Water Reductions for the Community

Table 142 and Figure 114 display the reductions after applying low-water fixtures and greywater reuse treatment for a single apartment. The bathroom toilet will use recycled water. The other fixtures are using low-flow and low-flush fixtures. Table 143 and Figure 115 show the same situation as Table 142 and Figure 114 for the 1,080 apartments.

Table 142. Annual Water Consumption Percentages for Apartments.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
Space		Gal/day/family	Gal/day/family	Gal/day/family	%
Bathroom	Toilet	68.3	0.0	68.3	100
	Shower	58.5	20.9	37.6	64
	Sink	9.8	6.5	3.3	33
Kitchen	Sink	19.5	13.0	6.5	33
Utility Room	Washing Machine	39.0	17.7	21.3	55

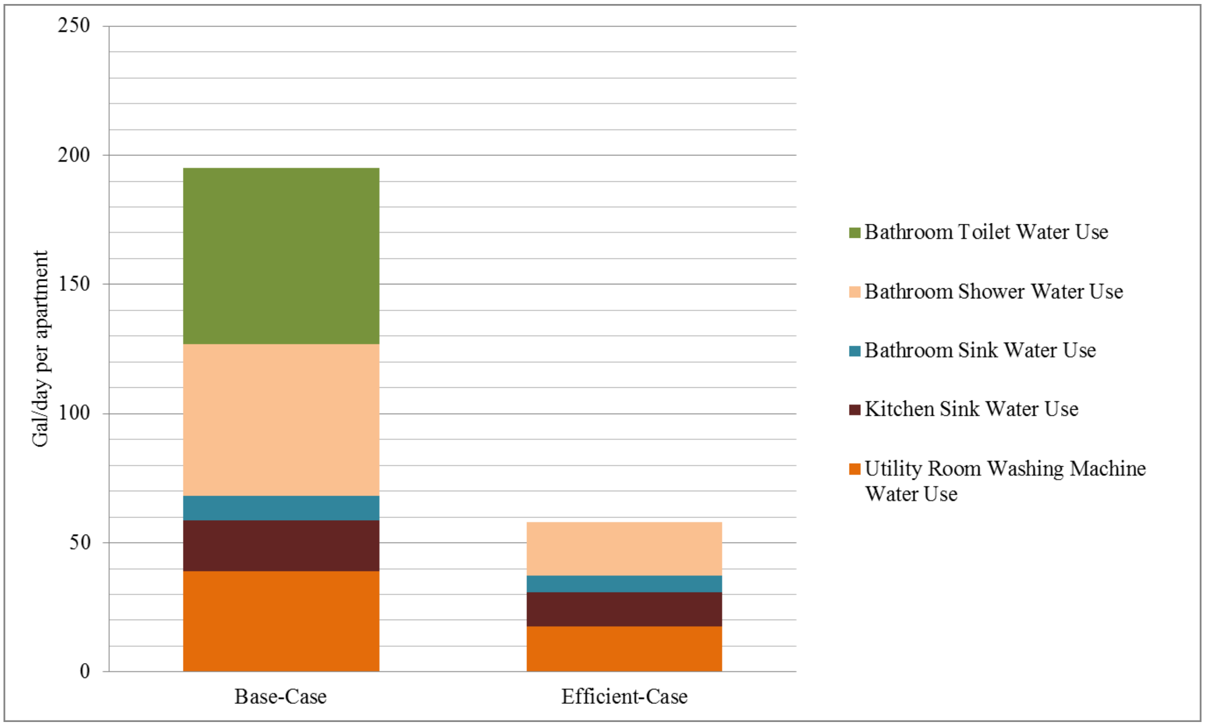

Figure 114. Annual Water Consumption Chart for Apartments.

Table 143. Annual Water Consumption Percentages for Apartments in the Community.

Concept	**Element Analyzed**	**Base-Case**	**Efficient-Case**	**Difference Reduction**	**Reduction**
Space		Gal/day/family	Gal/day/family	Gal/day/family	%
Bathroom	Toilet	26,923,274	0.0	26,923,274.1	100
	Shower	23,077,092	8,241,818.6	14,835,273.5	64
	Sink	3,846,182	2,564,121.3	1,282,060.7	33
Kitchen	Sink	7,692,364	5,128,242.7	2,564,121.3	33
Utility Room	Washing Machine	15,384,728	6,993,058.2	8,391,669.9	55

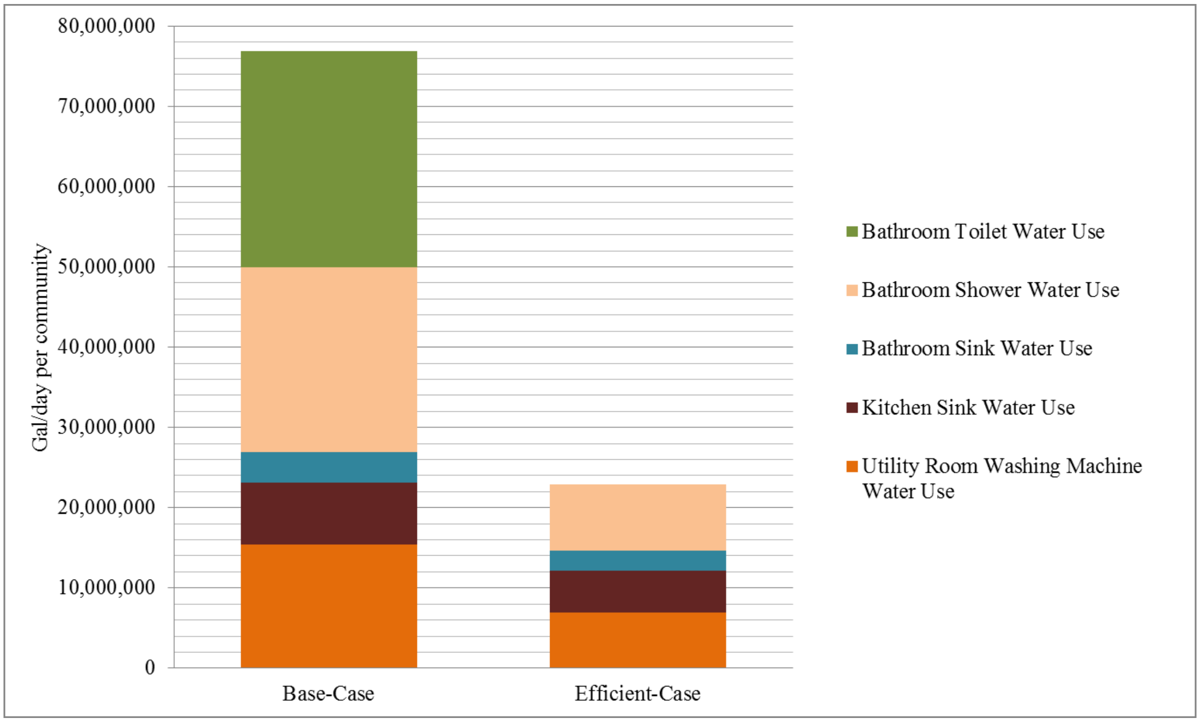

Figure 115. Annual Water Consumption Chart for Apartments in the Community.

Table 144 and Figure 116 display the reduction for the potable water tank of the whole community. The discussion for this point is explained in section 4.2.2.1.2.

Table 144. Annual Water Consumption Percentages for Apartments in the Community (Water Tank).

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
Space		Gal/day/comm	Gal/day/comm	Gal/day/comm	%
Water Tank	Ave. Max. Consumption per day	379,349	113,066	266,283.0	70
	Backup from Ave. Max. Consumption per day	189,675	56,533	133,142.0	70
	Total Fire Fighting System Expenditure	6,657	6,657	0.0	0

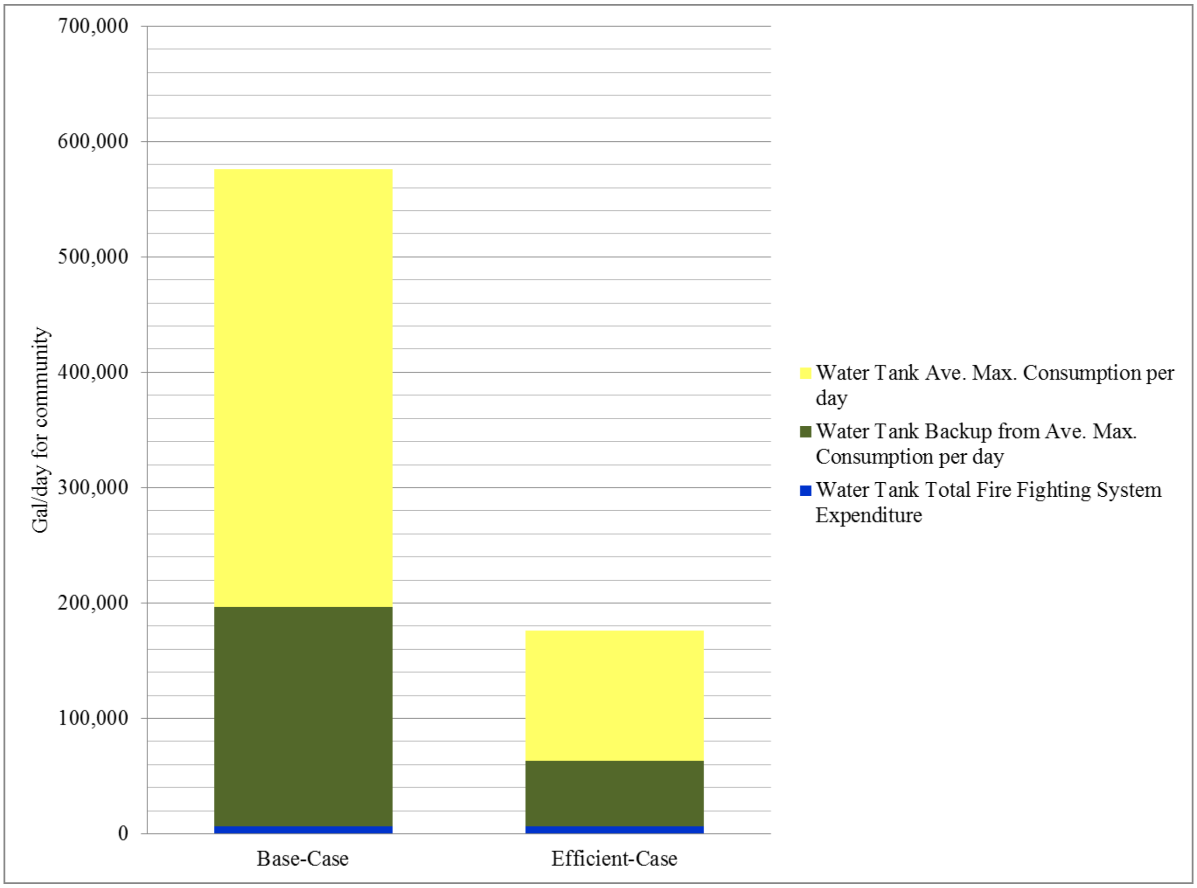

Figure 116. Annual Water Consumption Chart Apartments in the Community (Water Tank).

Table 145 and Figure 117 exhibit reductions after applying low-water fixtures and greywater reuse treatment for the grocery store. The bathroom toilet will use recycled water. The other fixtures are using low-flow and low-flush fixtures. The potable water supply could not be reduced due to requirements of the code.

Table 145. Annual Water Consumption Percentages for Grocery Store in the Community.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
Space		Gal/day	Gal/day/family	Gal/day/family	%
Bathroom	Toilet	158.0	0.0	158	100
	Sink	158.0	52.1	106	67
Potable Water Supply		1,383.0	1,383.0	0	0

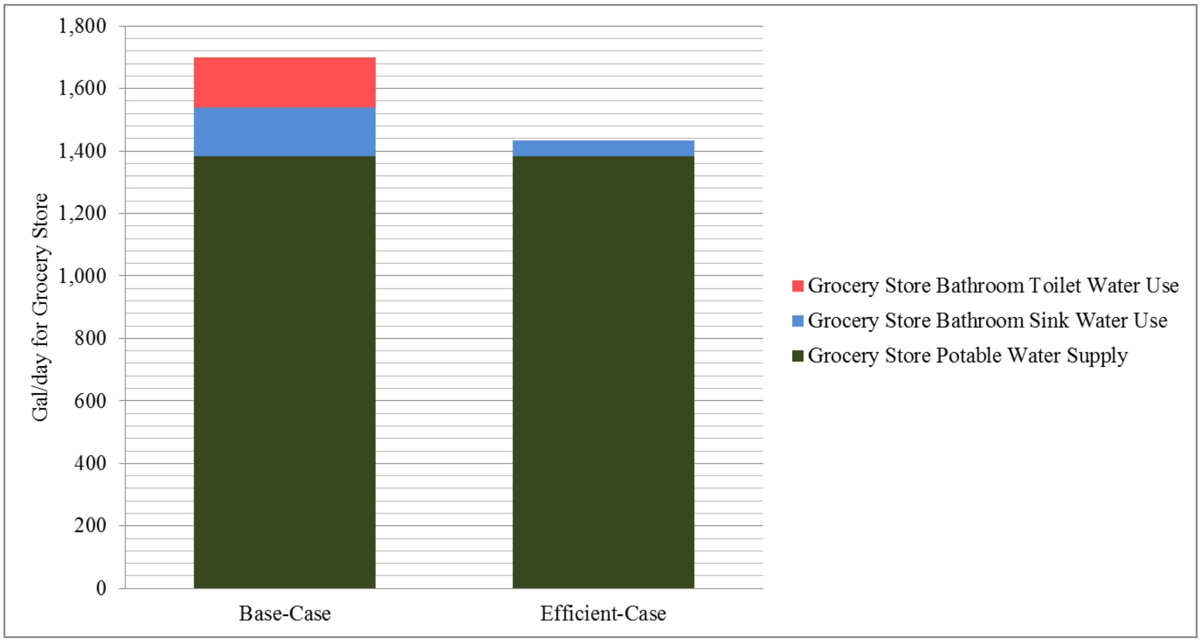

Figure 117. Annual Water Consumption Chart for Grocery Store in the Community.

5.6. Results for the Final Costs Reductions for the Community

Table 146 and Figure 118 show the energy cost reductions after the analysis is performed. The electricity cost in the apartments and the grocery store is cutdown by 82 and 22 percent.

Table 146. Annual Energy Cost Percentages for Apartments and Grocery Store in the Community.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		US Dollar	US Dollar	US Dollar	%
Cost	Apartments Energy Cost	188,557	34,495	154,062	82
	Grocery Store Energy Cost	77,549	60,129	17,420	22

Table 147 and Figure 119 show the water cost reductions through the hand calculation analysis with spreadsheets. The water cost in the apartments and the grocery store is saved by 70 and 16 percent.

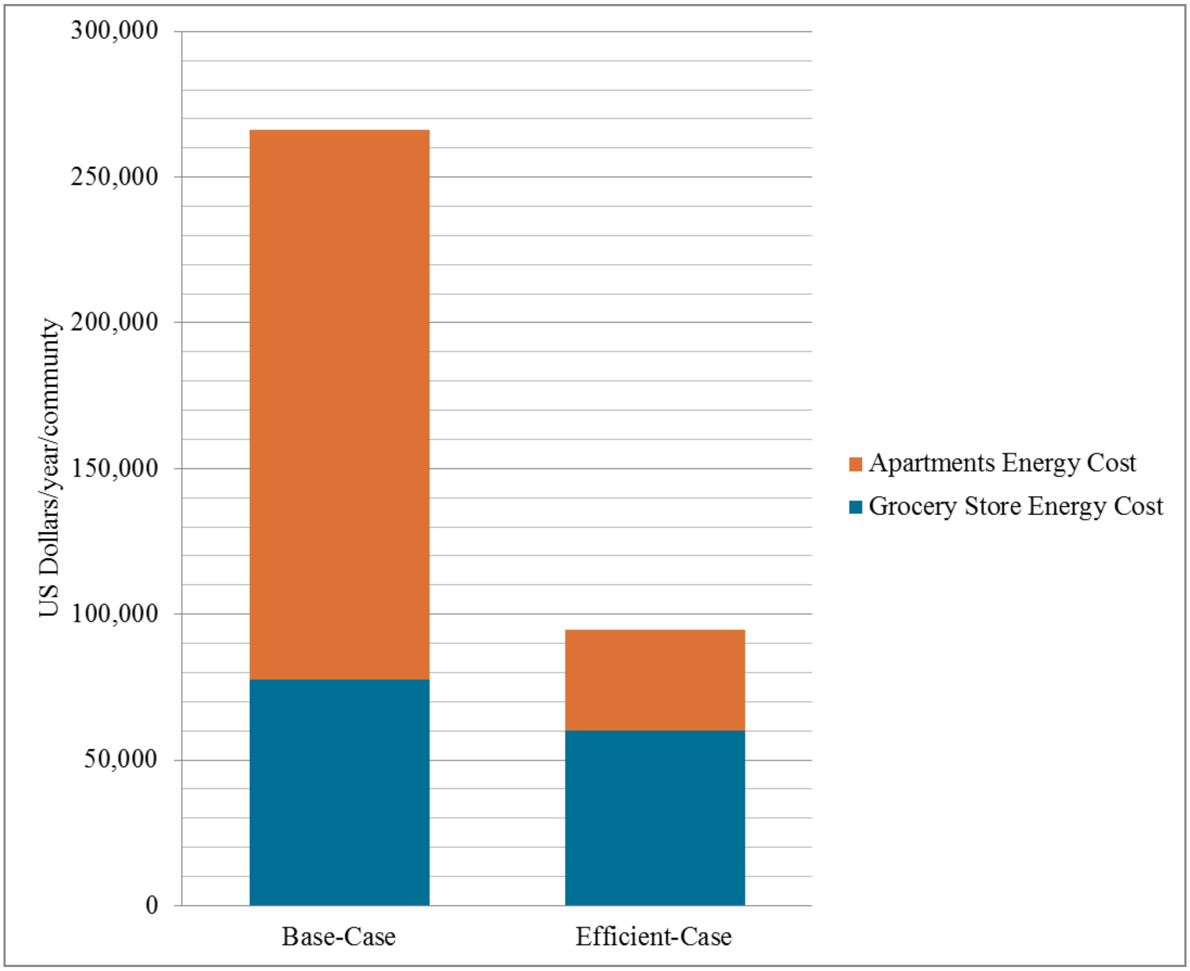

Figure 118. Annual Energy Cost Chart for Apartments and Grocery Store in the Community.

Table 147. Annual Water Cost Percentages for Apartments and Grocery Store in the Community.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Reduction
		US Dollar	US Dollar	US Dollar	%
Cost	Apartments Water Cost	1,237,118	368,449	868,669	70
	Grocery Store Water Cost	20,688	17,458	3,230	16

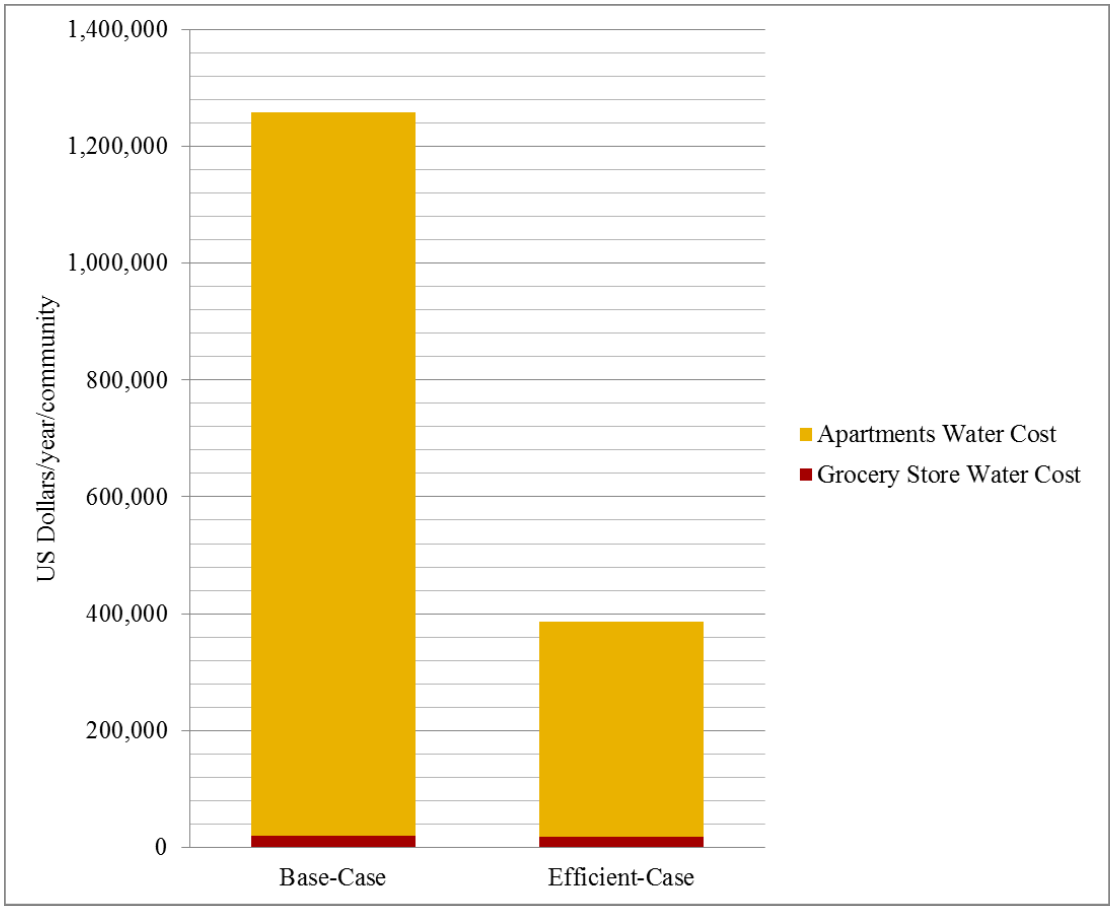

Figure 119. Annual Water Cost Percentages for Apartments and Grocery Store in the Community.

5.7. Guide for Low-Energy, Low-Water Use Communities for Mexico City

Figure 120 shows some characteristics to be used for the guide for low-energy, low-water use communities for Mexico City. Table 148 is created in order to get a 77 percent reduction for the apartment's low-energy section of the community for Mexico City.[141] The energy section of the apartments in Mexico City needs to comply with mandatory energy norms (*CONUEE*, 2011; *SENER,* 1997) and building code/design norm (Arnal-Simon and Betancourt-Suarez, 2005; *GDF*, 2011). There are also requirements from building codes (*CONAVI*, 2010a) that must be followed.

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[141] The PV is not considered in this table. 97 percent reduction can be achieved by applying PVs.

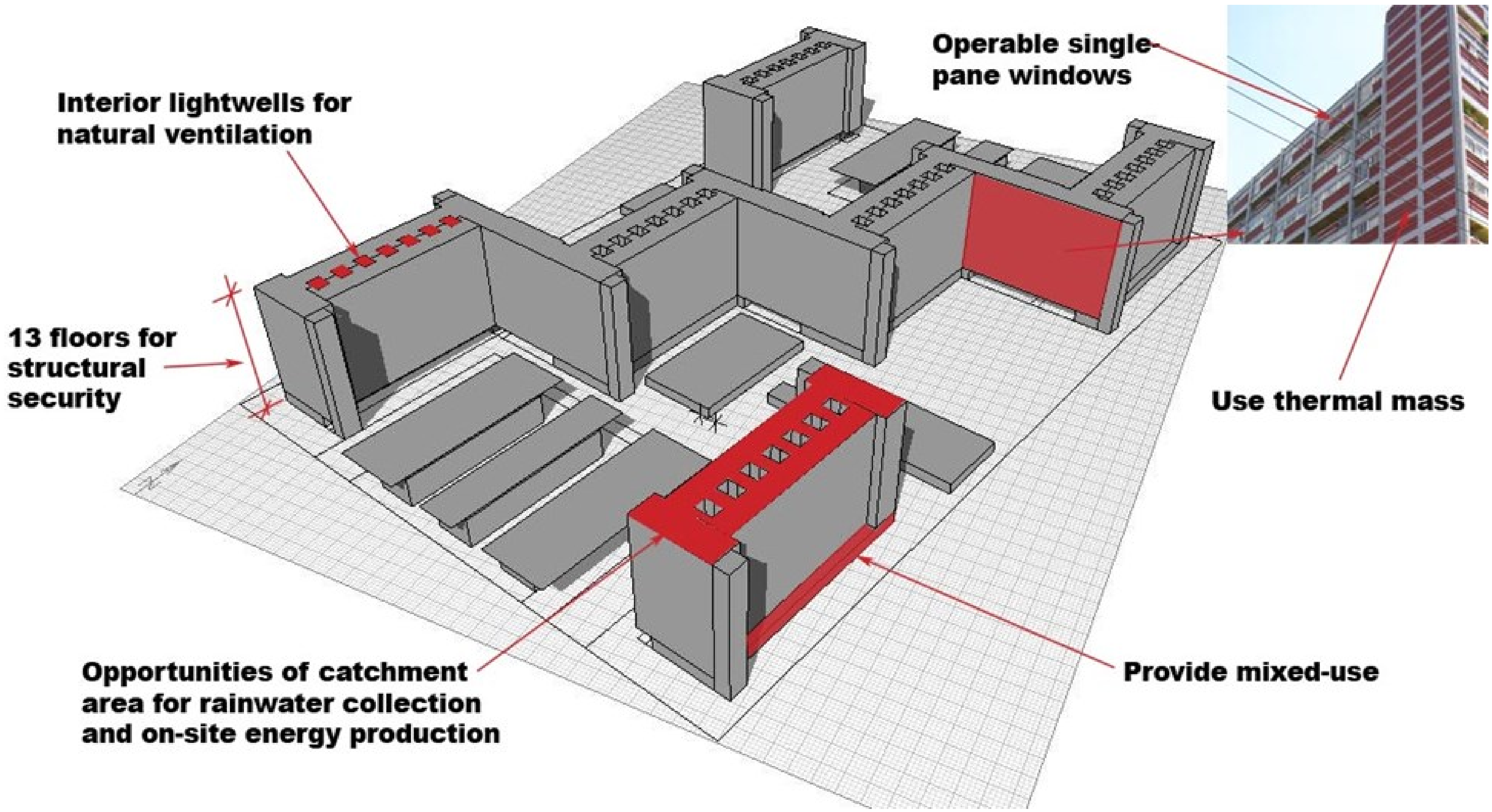

Figure 120. Characteristics to Be Used for the Guide for Low-Energy, Low-Water Use Communities for Mexico City. (The Photo Placed on the Upper Right Corner Was Taken by Jose Luis Bermudez Alcocer).

Table 148. Recommendation Table for the Apartments' Low-Energy Section in Mexico City.

Item	Component		Recommendation
Envelope	Roofs	U-Value	0.237 Btu/h-ft2-F
	Walls	U-Value	0.248 Btu/h-ft2-F
	Floors	U-Value	0.010 Btu/h-ft2-F
	Vertical Glazing	Window-to-Wall	60 percent
		Glass	Single-Clear
		Type	Operable
		U-Value	1.11 Btu/h-ft2-F
		Shading Coefficient	0.86
		Visible Transmittance	0.9
		Frame	Aluminum w/o thermal break
		Exterior Sun Control	No
		Window Close	If interior temperature less than 60°F
	Schedule	Night-Flushing	Yes (Summer Season)
		Heat Sink	Yes (Winter Season)
	Building Orientation	Azimuth	13°
Daylighitng/Lighting	Lighting Power Density	Lighting	0.11 W/ft²
	Daylighting Control	Dimming	Yes
Plug Loads	Miscellaneous Appliances	Appliances	0.36 W/ft²
Infiltration	Infiltration	Infiltration	0.35 ACH

Table 149 represents the features that provide a 70 percent reduction for the apartments' low-water section of the community for Mexico City. Greywater treatment reuse is considered in these numbers. The water section of the apartments in Mexico City needs to comply with mandatory codes (Arnal-Simon and Betancourt-Suarez, 2005; *GDF*, 2011) or with mandatory norms inside a code (*CONAVI*, 2010a).

Table 149. Recommendation Table for Apartments' Low-Water Section in Mexico City.

Item	Component		Recommendation
Water Use	Bathroom	Toilet	0 gal/day/family
		Shower	21 gal/day/family
		Sink	6.5 gal/day/family
	Kitchen	Sink	13 gal/day/family
	Utility Room	Washing Machine	18 gal/day/family

Table 150 is created in order to get 22 percent reduction for the grocery store's low-energy section of the community for Mexico City. The energy section of the grocery store in Mexico City needs to comply with mandatory energy norms (*CONAE*, 2005a; *CONUEE*, 2001). There are no codes focusing in energy reduction in grocery stores in Mexico. It is suggested to follow the requirements from standards (ASHRAE, 2004a, 2010; Deru et al., 2011; Energy Star, 2013a; Goetzler et al., 2009).

Table 151 is created in order to get 16 percent reduction for the grocery store's low-water section of the community for Mexico City. Greywater treatment reuse is considered in these numbers. The water section of the grocery store in Mexico City needs to comply with mandatory codes (Arnal-Simon and Betancourt-Suarez, 2005; *GDF*, 2011).

The recommendations to reduce 65 percent of Btu consumption for transportation use are to enhance mixed-use and change to high-efficiency cars.

Table 150. Recommendation Table for the Grocery Store's Low-Energy Section in Mexico City.

Item	Component		Recommendation
Envelope	Roofs	U-Value	0.024 Btu/h-ft2-F
	Walls	U-Value	0.065 Btu/h-ft2-F
	Floors	U-Value	0.010 Btu/h-ft2-F
	Vertical Glazing	Window-to-Wall	40 percent
		Glass	Double-Clear
		Type	Operable
		U-Value	0.69 Btu/h-ft2-F
		Shading Coefficient	0.44
		Visible Transmittance	0.45
		Frame	Aluminum w/thermal break
		Exterior Sun Control	Yes (Overhangs)
	Building Orientation	Azimuth	13°
Daylighitng/Lighting	Lighting Power Density	Lighting	1.30 W/ft²
	Daylighting Control	Dimming	Yes
Plug Loads	Miscellaneous Appliances	Appliances	0.95 W/ft²
Infiltration	Infiltration	Infiltration	0.161 ACH
System	Interior Design Temperatures	Cooling	72°F
		Heating	70°F
	Supply Design Temperatures	Minimum Supply Temperature	55°F
		Maximum Supply Temperature	100°F

Table 151. Recommendation Table for the Grocery Store's Low-Water Section in Mexico City.

Item	Component		Recommendation
Water Use	Bathroom	Toilet	0 gal/day
		Sink	6.5 gal/day

Therefore, the design suggestions from the guide for low-energy, low-water use communities for Mexico City are displayed as follows:

1) After the analysis, these are some basic space concepts to create the buildings inside of the low-energy, low-water use communities for Mexico City as follows:
    - The current *Multifamiliar Miguel Aleman* building has survived earthquakes due to the structural solution provided for its 13 floors. Therefore, new buildings must follow the structural requirements in the current building code. This is beyond the limits of this study.
    - Include interior lightwells to enchance natural ventilation for the interior spaces.
    - Use thermal mass for walls and roofs. Avoid any obstacles on the facades of the building. This is essential to allow thermal mass to get direct heat gains in Mexico City's climate (*CONAVI*, 2006, 2007, 2010a). Combine thermal mass and night cooling in order to cool down the interior zones and the thermal mass during the summer nights.
    - Follow *CONAVI*'s (2010a) recommendation for building orientation: avoid apartments facing northeast on one side of a centerline and apartments facing southwest on the other side of a centerline.
    - Use operable single-pane windows with aluminum frame. The operable windows will allow the implementation of strategies such as night flush/closed windows for heat trap seasons and new natural ventilation schedule.
    - Provide at least one dry good grocery store, recreation center and park into the community (i.e., locate the grocery store at street level as part of the building).
2) The basic space concepts to provide infrastructure for the low-energy, low-water use communities for Mexico City after the analysis are:
    - The reduction of private cars use must be achieved through the application of low-energy, low-water use communities. Trips/person/day reduction is achieved by the mixed-use community in the technical potential study that has a grocery store, recreation center and park.

- The community should be placed close to offices, schools or industry in order to reduce more trips/person/day, encourage people to use less their cars, walk more and use public transportation.
- The proliferation of mixed-use complexes will reduce the demand of excessive parking spaces and boost people to use more public transportation.

This guide aims to be an answer to the idea proposed by the *2010 Mexico City Pact*: establish a voluntary commitment to promote strategies and actions in order to reduce GHG emissions and adapt the cities to climate change. The funding for the low-energy, low-water use communities could be obtained through a NAMA project.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine and investigate a potential scenario to reduce energy, water and transportation use in Mexico City by implementing low-energy, low-water use communities. This analysis included the application of energy-efficient measures; the use of on-site energy generation (i.e., passive solar, solar domestic hot water, and solar photovoltaic systems among others) applied to the buildings in a case-study community; the implementation of low-water use strategies; and the reduction of private transportation use due to the incorporation of on-site retail. It was achieved by investigating the previous literature concerning the population and energy consumption for Mexico; studying the existing communities in Mexico; the building characteristics and urban patterns in Mexico City; and establishing a base-case energy, water and transportation use for an existing community in Mexico City. It also considered tools to analyze community-wide energy and water use, including a combined analysis that uses energy simulation software for whole-building energy analysis; renewable energy systems; generation and use of on-site renewable energy; and water-saving and transportation reduction calculations. The final outcome of the technical potential study includes a guide to help design low-energy, low-water use communities in Mexico City.

6.1. Summary of Methodology

The methodology used in this technical potential study involved the determination of the best characteristics for a complex; energy analysis using different software; and hand calculations with spreadsheets for water, transportation and costs estimation. The case study analysis was performed on the existing *Multifamiliar Miguel Aleman* community. It was essential to point out that the *Centro Urbano Presidente Aleman* or *Multifamiliar Miguel Aleman* is an existing multi-family, mixed-use well-connected complex that has endured for more than 60 years. In addition energy-efficient measures (e.g. energy-efficient lamps and appliances) and water-efficient measures (e.g. low-flush toilets and greywater reuse) from examples in other communities were applied to reduce the energy and water analysis.

The energy software used in this study include eQuest for the calculationtion of whole-building energy performance; F-Chart for DHW and PV F-Chart for PV system calculations; Ecotect and Solrpath for shading analysis; and Climate Consultant for possible energy-efficient strategies. The energy-use in the apartments was determined only with lighting and appliances. Air-conditioning systems were not required for housing in Mexico City. The water, transportation and economic determination were performed with hand calculations using spreadsheets.

The energy-efficient building for the apartment and the grocery store sections required the design application of low-energy lighting and appliances, and daylighting controls. Additionally, harvestable on-site energy with PV and DHW were analyzed for the apartments. High-insulated walls, double-clear glazing and shading devices were applied to the dry-good grocery store. The water-saving measures included low-flush and low-water fixtures in combination with greywater reuse treatment to reduce its water usage. The transportation needs were expected to be reduced because of the local accessibility to a grocery store, a recreation center and a park. In this manner, the procedure was developed and applied to the *Multifamiliar Miguel Aleman* community. The reduced percentages for the community in terms of energy, water, transportation and costs were presented in a series of tables and graphs. Finally, a guide was developed that includes a series of recommendation tables and general suggestions for the design of a community.

6.2. Summary of Analysis and Results

6.2.1. Summary for Energy-Efficient Use Community.

The results from the analysis for the apartments showed that five strategies (high-efficiency lamps and appliances, daylighting controls, night flush/closed windows for heat trap seasons, and natural ventilation schedule) can provide lower energy-use and better thermal comfort. Applying the strategies to the apartment complex saves 77 percent of the energy, and can provide 50 percent of the hours by using the ASHRAE adaptive comfort model during the year without auxiliary cooling or heating. The results from the analysis for the grocery store showed that the new energy-efficient case provided significant energy-use reduction and full-time thermal comfort. To accomplish this, building envelope measures (i.e., increased wall r-value, shading devices and double-clear glazing), daylighting, and high-efficiency lighting and appliances measures were applied to the base-case. This energy-efficient grocery store saved 22.5 percent of energy consumption, and had 100 percent of the hours in the ASHRAE comfort zone during the year.

In terms of photovoltaics, the potential for renewable electricity generated on-site for the apartments was 115,106 kWh/year. This could reduce the total electricity use for the apartment section by 3 percent. A solar domestic hot water system could provide 32 percent of the energy required for the hot water needs of the apartments.

6.2.2. Summary for Reduced Water-Use Community.

The apartments and the convenience store could reduce water-use by applying low-flush and greywater reuse treatments. This requires the use of potable water supply, toilet water, greywater and rainwater harvesting pipes and tanks. If implemented, 70 percent of the water-use could be cut down from the apartments. In addition, the size of the potable water tank, which had a average maximum water consumption per day plus the backup plus the fire-fighting system, could be reduced by 69 percent from the base-case due to the cutback of water-use consumption in the community.[142] The grocery store had a water-use reduction of 15 percent by applying low-flush toilets and greywater reuse treatment.

6.2.3. Summary for Reduced Community Transportation Use.

The reduction of the use of private automobiles could be achieved through the design and application of a mixed-use, low-energy, low-water use community. If implemented, 37 percent energy-use (Btu) could be accomplished, and a 65 percent energy-use (Btu) was achieved through mixed-use plus high-efficiency cars. Such well-situated mixed-use communities in the urban area could encourage people to use their cars less and walk more. These centers could also reduce the demand of excessive parking spaces and motivate people to use more public transportation.

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[142] Some part of this water is pumped up to the apartments. The other part is kept in the tank as the water required for the fire fighting system.

6.2.4. Summary of Annual Energy and Water Consumption Cost in Multifamiliar Miguel Aleman Complex.

The application of strategies such as high-efficiency lighting and appliances and daylighting controls reduced the annual energy consumption and the apartments' operation costs. Eighty-one percent of energy cost was reduced for the apartment section of the building. In the same manner, energy-efficient measures were applied to the grocery store and a final energy cost reduction of 22 percent was achieved. The money saved from the reduction of energy-use for one year in the apartment section could then be applied toward the purchase of the solar PVs and the solar DHW for the building.

For the water-use reduction measures, low-flow sinks and bathroom showers, low-flush toilets and greywater reuse treatment were analyzed for the apartments. Seventy percent of water cost was saved by applying the previous measures. In the same manner, low-flow sinks, low-flush toilets and greywater reuse treatment were used in the grocery store. As a result a reduction of 15 percent was achieved in the water cost for the convenience store.

6.2.5. Summary of the Guide for Low-Energy, Low-Water Use Communities for Mexico City.

There were two major points in this guide: 1) the parameters that provided energy, water and carbon footprint reductions for the apartments and the grocery store and 2) general suggestions in terms of community design.

Table 152 and Figure 121 displayed the final reductions from the application of the guide. In Figure 121, the left columns represented the annual energy-use for the community, the middle columns indicated the annual water-use for the community and the right columns showed the potable water supply for the tank for the apartment section of the community. The achievements of this guide for this technical potential low-energy, low-water use community study were:

Table 152. Final Reductions of the Application of the Guide for Low-Energy, Low-Water Use Community in Mexico City.

Concept	Element Analyzed	Base-Case	Efficient-Case	Difference Reduction	Percent Reductior
		MMBtu/year	MMBtu/year	MMBtu/year	%
Energy Use for Cars	Car	517	180	337	65
Energy Use for Apartments	(Area Lights + Misc. Equip - PV)	8,836	275	8,561	97
Energy Use for Grocery Store	Area Lights	1,787	1,186	601	34
	Misc. Equip.	912	684	228	25
	Vent. Fans	987	987	0	0
	Space Cool	1,439	1,118	321	22
		Million Gal/year	Million Gal/year	Million Gal/year	%
Apartments Bathrooms Water Use	Toilet	27	0	27	100
	Shower	23	8	15	64
	Sink	4	3	1	33
Apartments Kitchen Water Use	Sink	8	5	3	33
Apartments Utility Room Water Use	Washing Machine	15	7	8	55
Grocery Store Bathroom Water Use	Toilet	0.06	0.00	0	100
	Sink	0.06	0.00	0	100
Grocery Store Potable Water Supply		0.5	0.5	0	0
Apartments Potable Water Tank	Ave. Max. Consumption	138	41	97	70
	Backup from Ave. Max. Consumption per day	69	21	49	70
	Total Fire Fighting System Expenditure	2	2	0	0

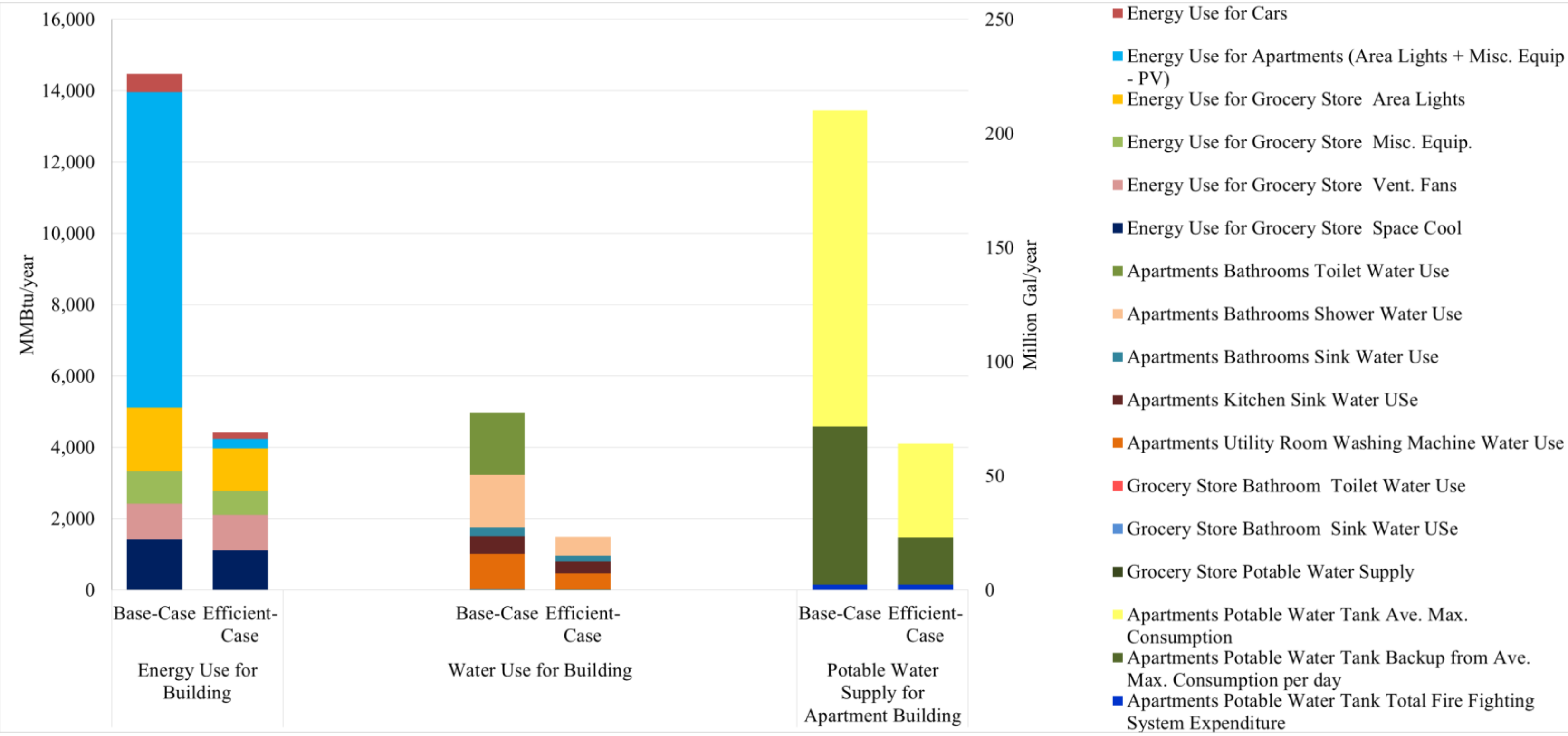

Figure 121. Final Reductions of the Application of the Guide for Low-Energy, Low-Water Use Community in Mexico City.

- A carbon footprint reduction of 65 percent by reducing energy-use consumption and transportation use. The apartment energy consumption was reduced to 97 percent of its original load with the use of PV. In addition, energy-efficient lamps and appliances and daylighting saved 77 percent for the apartments. The PV cuts down an additional 86 percent of the 23 percent of energy consumed in the apartments, which begin to approach net-zero energy-use.
- Twenty-two percent of the base-case grocery store energy-use was reduced by using the following strategies: increased R-Value in the exterior walls; shading devices over external windows; use of double-clear glazing; the use of daylighting controls; and a change to the lighting and appliance loads.
- The whole community (apartments plus grocery store) has a reduction of 69 percent in water-use.
- The apartments' water consumption had water savings of 70 percent. This was accomplished by using low-flow sinks and bathroom showers; low-flush toilets; and greywater reuse treatment.
- The grocery store water consumption had a reduction of 16 percent due to low-flow sinks; low-flush toilets; and greywater reuse treatment.
- Seventy percent of the community potable water tank was reduced for the apartment section. The average maximum consumption numbers came from the water-use from the apartments' bathroom toilets, showers and sinks, the kitchen sinks and the washing machines. The estimation of the average maximum consumption plus the backup had a 70 percent reduction. The total water-use of fire fighting system remained the same.

6.3. Conclusions

The reduction of energy, water and transportaton energy-use provides a local impact in terms of the community of Mexico City. The application of the procedure for the low-energy, low-water use center to other areas in Mexico City will also have a higher impact in terms of an improved urban area. The enhancement of these communities is proved by the following benefits:

- The opportunity of mixing building types in a site by constructing vertical mid-rise buildings instead of occupying several blocks with two-storey buildings with a single use.
- The reduction of energy and water consumption in the energy.
- The reduction of transportation use and annual pollution due to the location of infrastructure inside of the center (i.e. grocery store, recreation center and park).
- The ability to control the city's sprawl by placing similar communities inside of the city close to existing infrastructure and public transportation (e.g., underground, buslines, etc).
- The opportunities of additional catchment areas for rainwater collection and on-site energy production with solar PVs and solar DHW systems on a mid-rise building compared to only rooftop area of two single-family houses. Few obstacles that could block the solar access on the rooftop of a mid-rise building are an advantage over a two or three-storey single-family house.

The guide, that is the result of the step-by-step procedure of the technical potential study, aimed to help public and private sectors specialized in housing developments to understand the process to analyze and build-up centers with low-energy, low-water use. It will also allow the transformation of potential communities into low-energy, low-water use centers.

To conclude, this guide is an answer to the idea proposed by the *2010 Mexico City Pact*: to promote strategies and actions in order to adapt the cities to climate change. The guide includes energy, water and transportation strategies in order to reduce their use at community level. The community's savings will have a huge impact at Mexico City's urban ecological scale in the future. This guide could also be applied in other areas of the city for a similar result at the short term. It also could be adopted for other countries at the long term, in the same manner when Brazil and Colombia adopted the Mexican *CONAVI's 2010 Housing Building Code*.

The funding for the low-energy, low-water use communities can be obtained through a NAMA project. The recommendation is to follow the guide in order to build new, or even rebuild old, centers or neighborhoods in Mexico City with mixed-use, vertical and compact areas that will allow proximity between buildings, multi-family apartments with energy and water-savings solutions, and reduce pollution emissions linked to transportation and avoid the city's sprawl.

6.4. Recommendations for Future Research

1) The combination of night flush/closed windows for heat trap seasons and new natural ventilation schedule strategies in the apartments should be analyzed with advanced simulation (i.e., CFD) to improve the thermal comfort and reduce energy-use.
2) Further study of passive and active strategies in grocery stores is needed. As an example, natural ventilation must be studied and applied in order to reduce the energy consumption to the store without jeopardizing product conditions.
3) Further study in vernacular architecture or low-tech strategies is required. As an example, how to control the exterior environment (i.e., polluted air) from impacting the interior environment once the windows are opened.
4) Distributed electricity (DE) with combined heat and power (CHP) is viewed for future research. DE should be investigated because it could lower the cost of electricity, reduce the pollution and the resultant production of GHG, as well as decrease the vulnerability of the electric system to extreme weather (WADE, 2003). Therefore, a group of high density buildings inside the community using DE electricity generation with CHP has the potential to consume less source energy, pollute less and reduce the building's carbon footprint.
5) Incorporate other building types to the community such as offices, hotels, libraries, schools, hospitals, etc. in order to reduce the number of trips with private transportation.
6) The energy analysis for elevators and exterior lighting were not included in this technical potential study and will be pursued for future work.
7) Finally, it is recommended for future work to use specialized software as Daysim and Radiance for further analyze daylighting analysis and Computer Fluid Dynamics (CFD) in order to complement the ventilation analysis from eQuest. An example is the daylighting and ventilation analysis of the lightwells of the building.

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APPENDIX A

COMPARISON OF POPULATION AND ENERGY CONSUMPTION FROM MEXICO AND THE US[143]

The analysis in this section consisted of an updated version of the symposium paper by Bermudez-Alcocer and Haberl (2010) that compared population density by state, total population by state, population by cities and energy consumption between Mexico and the US. This was a paper presented at the 2010 17th Symposium on Improving Building Systems in Hot and Humid Climates in Austin, Texas.

A.1. Population Density by State

Figure 122 shows the population density by state in Mexico in 2005 (*INEGI*, 2008b). The Federal District (Distrito Federal)[144] had the highest population with 15,210 people/sq. miles, which is also ten times the population of the second most populated state. Mexico (or Estado de Mexico)[145] (1,623), Morelos (854), Tlaxcala (693), Aguascalientes (491), Guanajuato (414) and Puebla (407) ranged between 400 and 1,200 people/sq. miles. Figure 123 and Figure 124 show the location of these states in relation to the climate regions in Mexico. The states with the most population density in Mexico are in the South-central

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[143] This chapter is an updated version of a symposium article presented at the 2010 17th Symposium on Improving Building Systems in Hot and Humid Climates in Austin, Texas with permission from the Energy Systems Laboratory (ESL) at Texas A&M University.

[144] *Distrito Federal* is the capital from Mexico. It could be considered the 32nd state in the country under the name of Estado del Valle de Mexico (State of the Valley of Mexico), if the Federal supreme powers of the Nation move to other place (Silva-Badillo, 1988)

[145] Mexico (or Estado de Mexico) is a name given to the second most populated state in Mexico. The population of the Metropolitan Zone of Mexico City is formed by the Distrito Federal and 40 municipios (municipalities) within Mexico (or Mexico State), which include: Acolman, Atenco, Atizapan de Zaragoza, Chalco, Chiautla, Chicoloapan, Chiconcuac, Chimalhuacan, Coacalco de Berriozabal, Cocotitlan, Coyotepec, Cuautitlan, Cuautitlan Izcalli, Ecatepec de Morelos, Huehuetoca, Huixquilucan, Ixtapaluca, Jaltenco, La Paz, Melchor Ocampo, Naucalpan de Juarez, Nextlalpan, Nezahualcoyotl, Nicolas Romero, Papalotla, San Martin de las Piramides, Tecamac, Temamatla, Teoloyucan, Teotihuacan, Tepetlaoxtoc, Tepotzotlan, Texcoco, Tezoyuca, Tlalmanalco, Tlalnepantla de Baz, Tultepec, Tultitlan, Valle de Chalco Solidaridad and Zumpango and one municipio (municipality) from Hidalgo: Tizayuca.

zone. These states fall in the temperate,[146] hot-dry jungle,[147] hot-humid jungle[148] and semi-arid[149] climate zones.

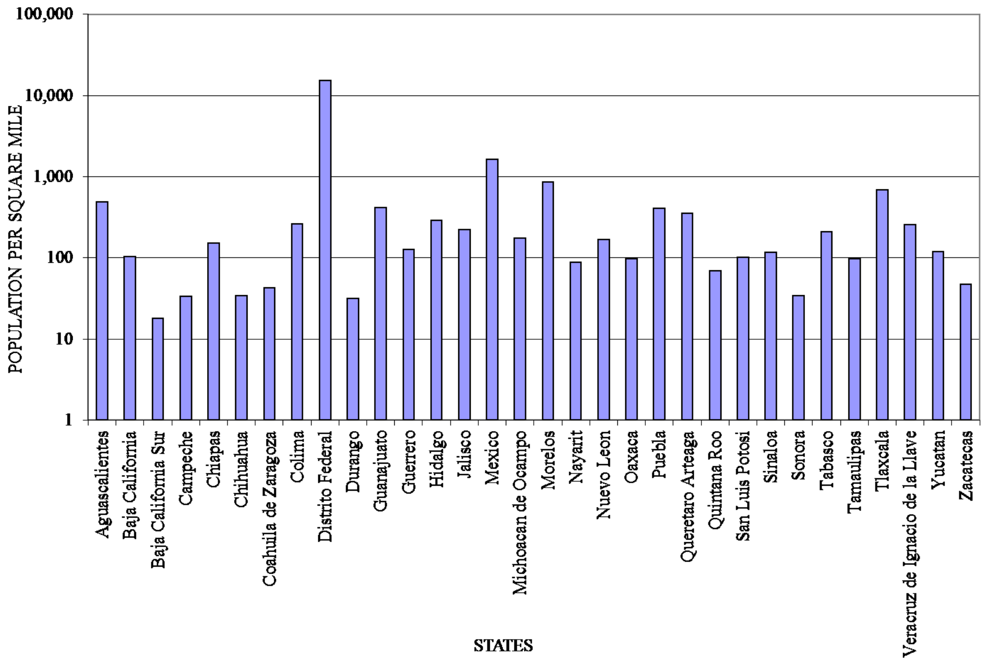

Figure 122. Population Density by State in Mexico (2005) with Data from *INEGI* (2008b).

[146] *Distrito Federal*, Tlaxcala and some areas of Aguascalientes, Guanajuato, Mexico, Morelos and Puebla
[147] Some areas of Mexico, Morelos and Puebla.
[148] Some areas of Puebla.
[149] Some areas of Aguascalientes and Guanajuato.

Figure 123. Location of the States with higher Population Density in Mexico (created with Data of the Population of the States from *INEGI*, 2008b and Map Data from *INEGI*, 2010).
This Map Was Created by Drawing the Contour Lines of the Mexican States; Changing the Color of the Oceans from Blue to White and the North Orientation of the Original Image; and Identifying the States with Higher Population Density with Black Color. Reprinted from *Instituto Nacional de Estadistica y Geografia*, Retrieved June 2, 2010, from *Instituto Nacional de Estadistica y Geografia* http://www.inegi.org.mx/ Copyright 2014 by *Instituto Nacional de Estadistica y Geografia*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

Figure 124. Climate Region Map of Mexico (Map Data from *CONAVI,* 2005). This Map Was Created by Drawing the Contour Lines of the Bioclimates in Mexico from the Original Image; Changing the Background from White to Grey, Changing the Colors of the Bioclimates (i.e., Marine, Hot-Humid and Hot-Dry) to Match the Colors of the Bioclimates from the US in Figure 127; and Translating the Titles of the Bioclimates and Re-Locating them in the Final Image. Adapted from *Hacia un Codigo de Edificacion de Vivienda.* (p.18), by *Comision Nacional de Vivienda*, 2005, Mexico, D.F.: *Comision Nacional de Vivienda*. Copyright 2005 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Figure 125 shows the population density by state in the US in 2008 (US Census Bureau, 2010b). In 2008, the District of Columbia had 9,638 people/square mile, which is ten times the density of the next highest states (e.g. New Jersey and Rhode Island). The states of New Jersey (1,170), Rhode Island (1,005), Massachusetts (828), Connecticut (722), Maryland (576), Delaware (446) and New York (412) range between 400 and 1,200 people/square mile. Figure 126 and Figure 127 show the location of these states against the climate regions of the US. The states with most population density (people/square mile) in the US are in the Northeastern zone. These states fall in the cold[150] and the mixed-humid[151] climates.

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[150] New York, Massachusetts, Rhode Island and Connecticut.
[151] New Jersey, Delaware, Maryland and D.C.

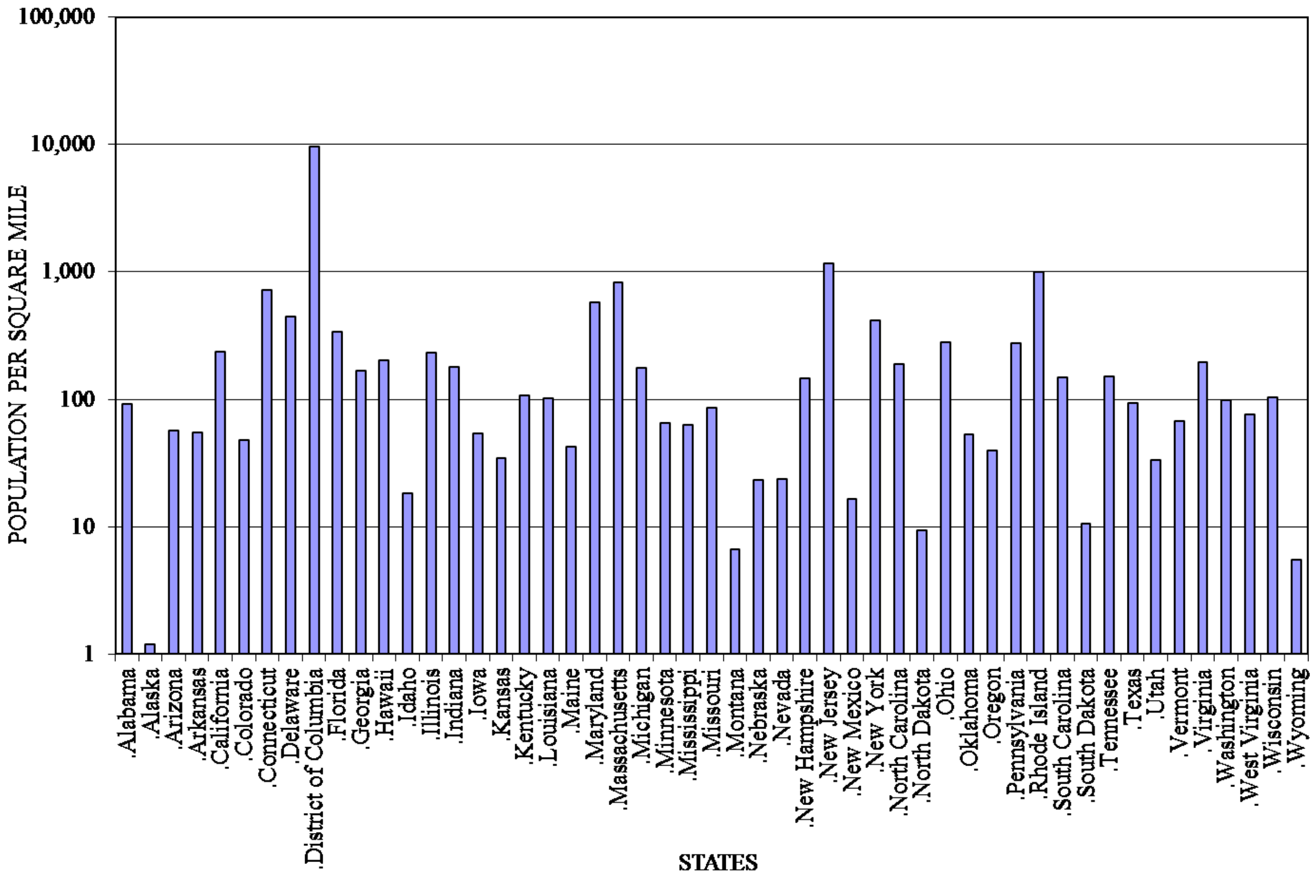

Figure 125. Population Density by State in the US (2008) from US Census Bureau (2010b).

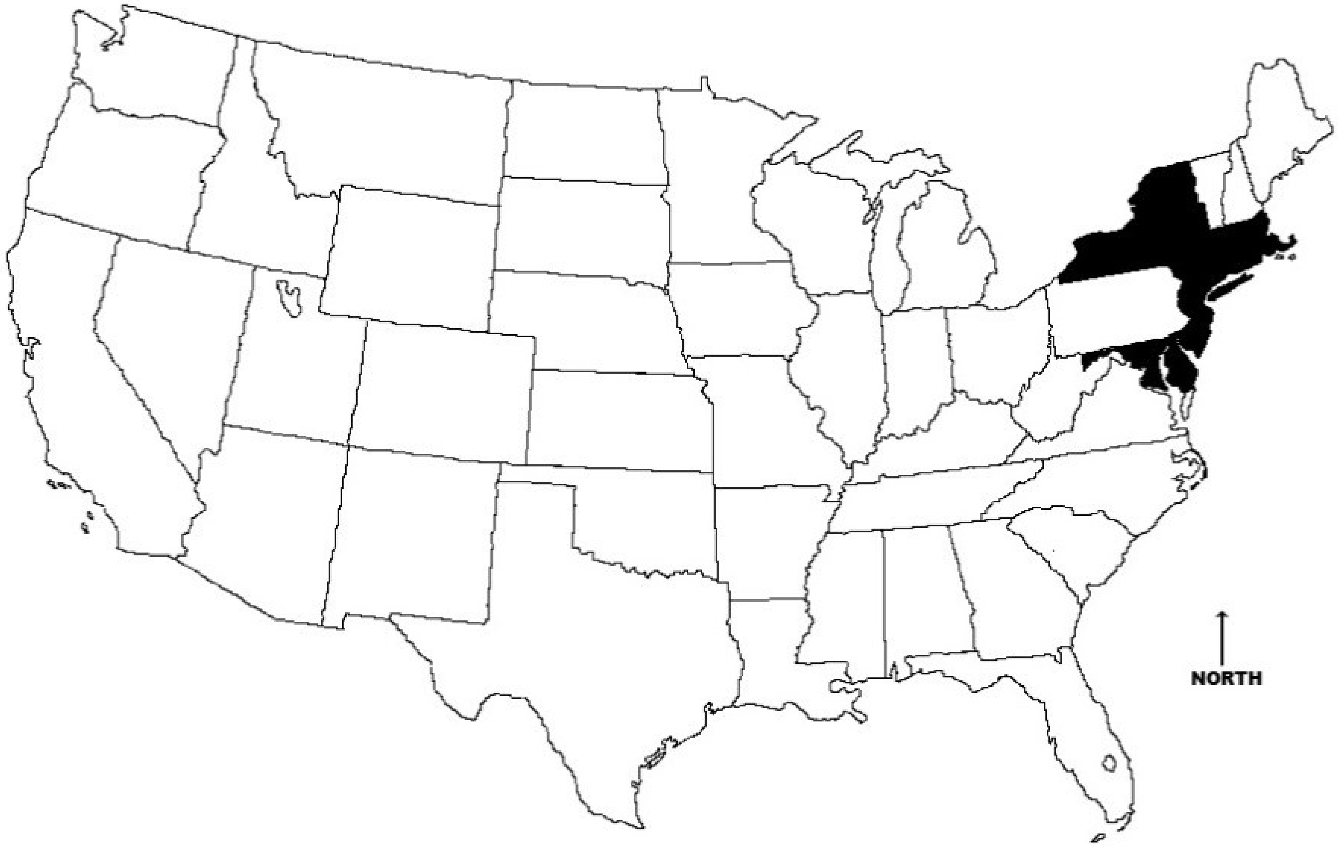

Figure 126. Location of the States with higher Population Density in the US (Population Data from US Census Bureau, 2010b and Map Data from United States Map, 2010).
This Map Was Created by Drawing the Contour Lines of the American States; Placing a North Orientation to the Original Image; Identifying the States with Higher Population Density with Black Color; Deleting the Names of the States and Using a White Background. Adapted from United States Map, Retrieved July 3, 2010, from United States Map http://www.united-states-map.com/US7241z.htm Copyright 2014 by United States Map. Adapted for Scholarly Purposes under Fair Use.

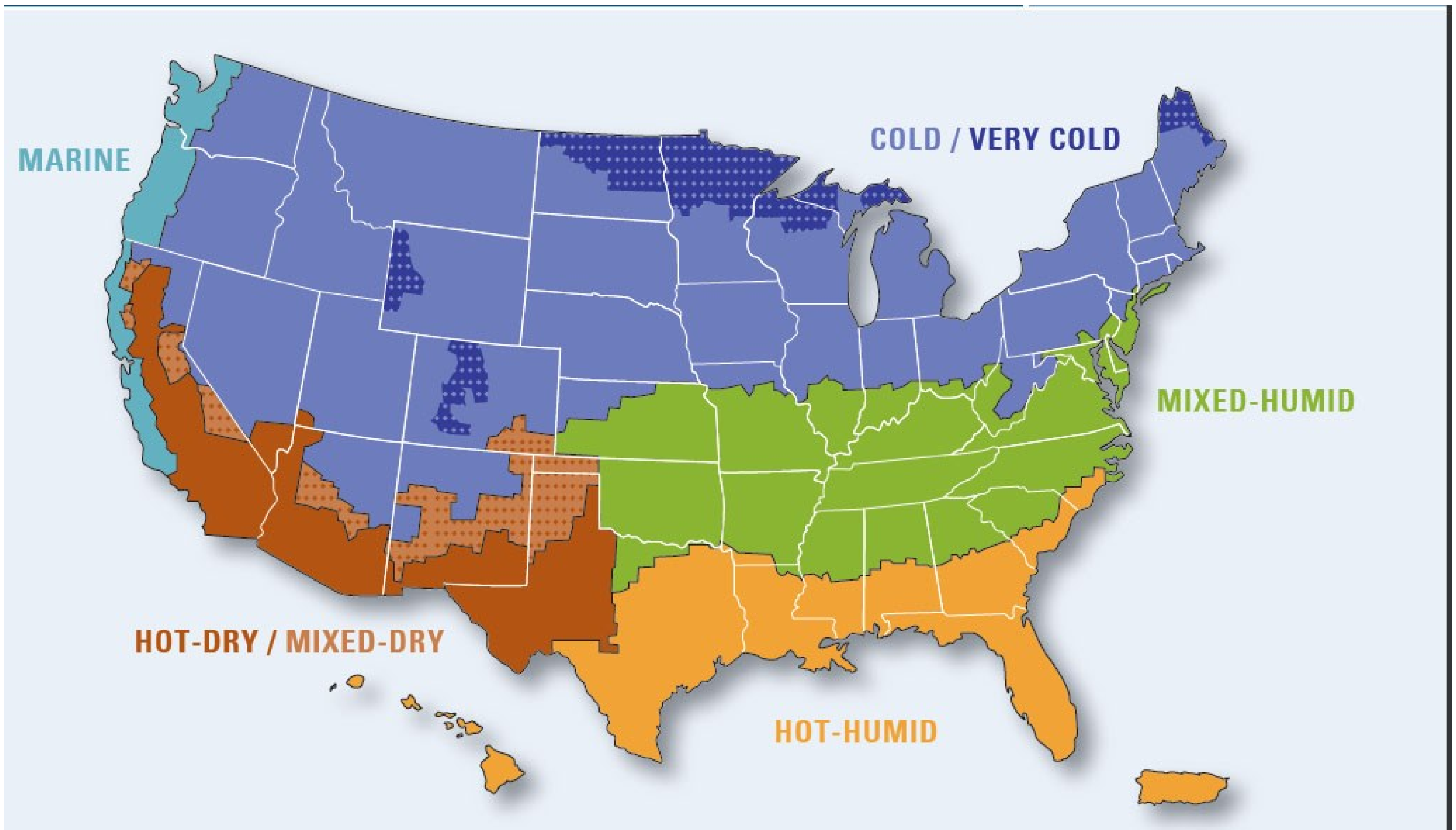

Figure 127. Climate Region Map of the US (US DOE, 2007).
Reprinted from "High-Performance Home Technologies: Guide to Determining Climate Regions by County" by Pacific Northwest National Laboratory operating contractor of the Pacific Northwest National Laboratory for the U.S. Department of Energy, 2007, *Building America Best Practices Series, December*, p.1. Pacific Northwest National Laboratory. Reprinted with permission.

The states with higher population density in Mexico and the US fall in very different types of climates: temperate, hot-dry jungle, hot-humid jungle and semi-arid in Mexico (in Figure 122, Figure 123 and Figure 124), and cold and mixed-humid in the US (in Figure 125, Figure 126 and Figure 127). Based on this analysis, the housing sector for the most populated regions of the US is in very different climate zones than the most populated areas of Mexico. Therefore, if low-energy housing could be developed for the Mexico City area it would have a large impact on the whole country.

A.2. Total Population by State

The second type of analysis considered is the total population by state. Figure 128 and Figure 129 show the total population by state in Mexico in 2005. Mexico (or Estado de Mexico) (14.01 million) is the only state that surpasses the 10 million people in Mexico. Distrito Federal (8.72), Veracruz de Ignacio de la Llave (7.11), Jalisco (6.75) and Puebla (5.38) ranged between five and nine million people.

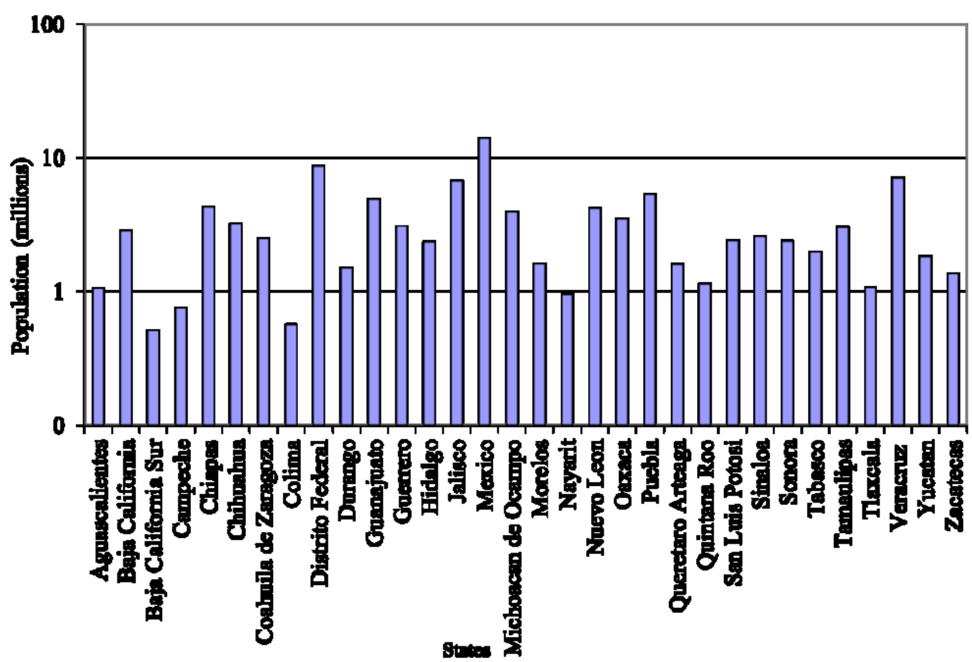

Figure 128. Total Population in Mexico by State (2005) with Data from *INEGI* (2008b).

Figure 129. Location of the Most Populated States in Mexico (created with Population Data from *INEGI*, 2008b and Map data from *INEGI*, 2010).
This Map Was Created by Drawing the Contour Lines of the Mexican States; Changing the Color of the Oceans from Blue to White and the North Orientation of the Original Image; and Identifying the Most Populated States with Black Color. Reprinted from *Instituto Nacional de Estadistica y Geografia*, Retrieved June 2, 2010, from *Instituto Nacional de Estadistica y Geografia* http://www.inegi.org.mx/ Copyright 2014 by *Instituto Nacional de Estadistica y Geografia*. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

In a similar fashion as Mexico, Figure 130 and Figure 131 show the population by state in the US in 2008, which indicates that California surpassed 35 million people; Florida, New York and Texas ranged between 15 and 25 million people; and Michigan, Ohio and Pennsylvania range between 10 and 14 million people. Georgia and North Carolina were close to 10 million people. States such as Arizona, Indiana, Maryland, Massachusetts, Minnesota, Missouri, New Jersey, Tennessee, Virginia, Washington and Wisconsin ranged between five and nine million people. In contrast to looking at the population density the total population by state showed the US population is fairly well distributed across different climate zones. However, in contrast to the US, the population in Mexico is more concentrated in the South-central area in the valley that surrounds Mexico City.

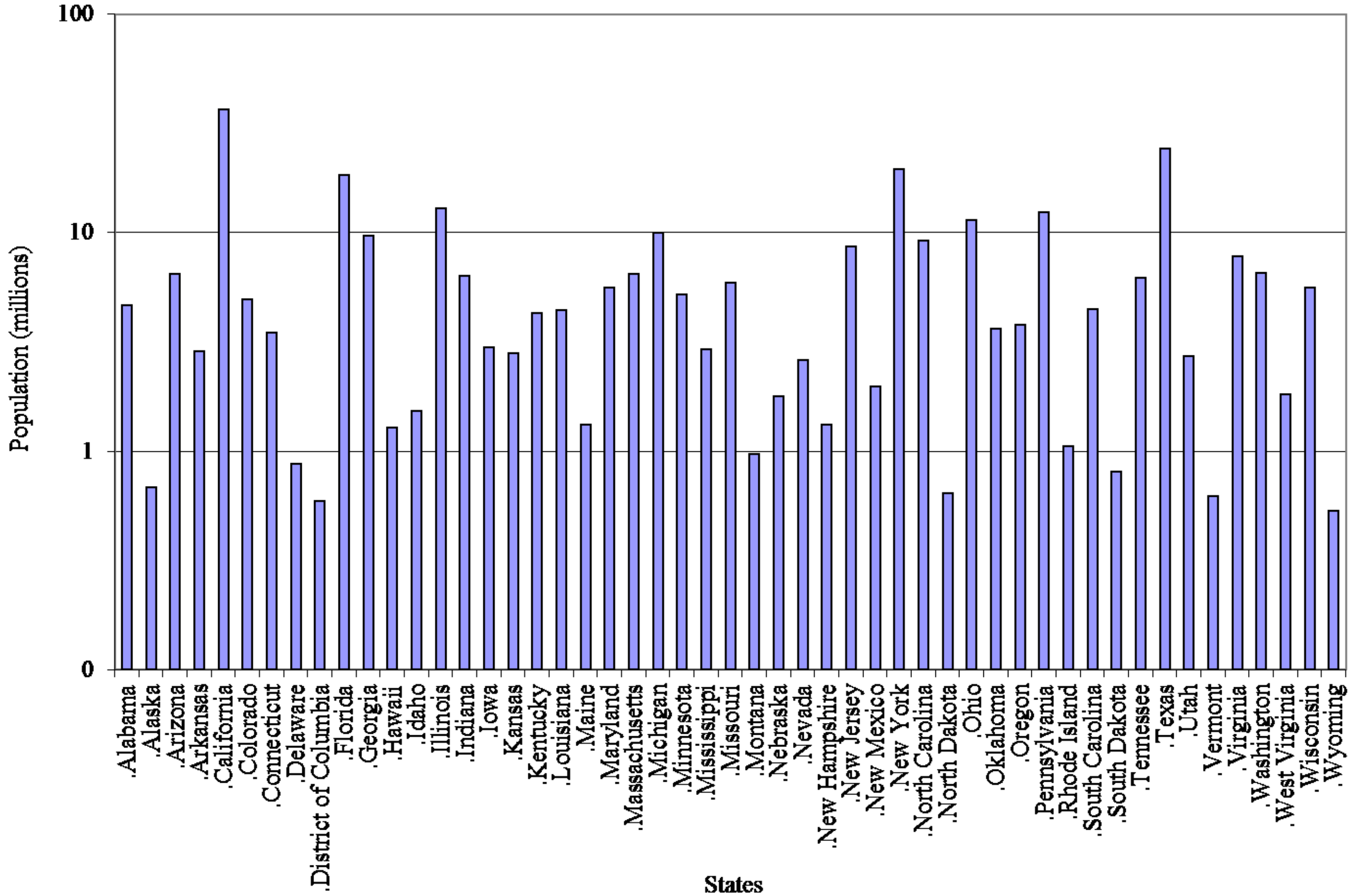

Figure 130. Total Population in the US by State (2008) from US Census Bureau (2010b).

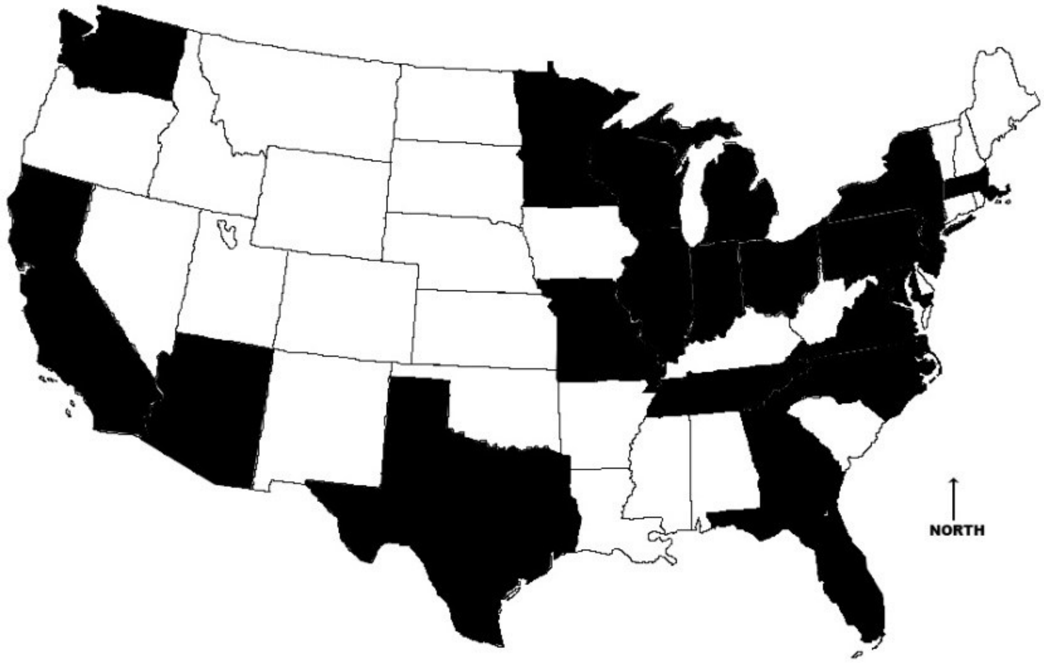

Figure 131. Location of the most Populated States in the US (created with Data from US Census Bureau, 2010b and Map data from United States Map, 2010).
This Map Was Created by Drawing the Contour Lines of the American States; Placing a North Orientation to the Original Image; Identifying the Most Populated States with Black Color; Deleting the Names of the States and Using a White Background. Adapted from United States Map, Retrieved July 3, 2010, from United States Map http://www.united-states-map.com/US7241z.htm Copyright 2014 by United States Map. Adapted for Scholarly Purposes under Fair Use.

A slightly different set of conclusions can be obtained from the analysis from Figure 128 to Figure 131. These tables and figures show the total state population distribution in the US is clearly more spread-out than in Mexico. In 2005, Mexico had one state (Mexico) with more than 10 million people; 27 states with a population between one and 10 million people and four states with less than one million people. In contrast to the US, the population in Mexico is more concentrated in the South-central area in the valley that surrounds Mexico City. Three states in Mexico shared the highest population density (people/sq. mile) and are the most populated states (population in millions) of the country.[152] Following these three most populated states, the other states in Mexico with high population, such as Jalisco and

[152] Distrito Federal, Mexico and Puebla are in the South-central area of the country.

Veracruz de Ignacio de la Llave, are in different states with different climate zones. Jalisco has temperate, semi-arid and hot-dry jungle climates, and Veracruz de Ignacio de la Llave has temperate, hot-dry and hot-humid jungle climates. On the other hand, the US in 2008 had seven states with more than 10 million people; 36 states with a population between one and 10 million people and eight states with less than one million. New York was the only state in the US that shared high population density (people/sq. mile) and was one of the most populated states (population in millions) in the country. Therefore, if one were to try to include housing beyond the valley surrounding Mexico City, one would need to consider some very different climate zones.

A.3. Population by Cities

In the third analysis the population of the US and Mexico is viewed by cities. Figure 132 and Figure 133 show the cities with at least 500,000 people or more in Mexico in 2005: Acapulco, Aguascalientes, Cancun, Chihuahua, Ciudad Juarez, Cuernavaca, Guadalajara (701 HDD65°F and 0 CDD50°F), La Laguna, Leon, Merida (10 HDD65°F and 11,112 CDD50°F), Mexico City (1,203 HDD65°F and 4,762 CDD50°F), Monterrey (844 HDD65°F and 8,326 CDD50°F), Morelia, Oaxaca, Queretaro, Puebla-Tlaxcala, Reynosa-Rio Bravo, Saltillo, San Luis Potosi, Toluca, Tijuana, Tampico, Tuxtla Gutierrez, Veracruz, Villahermosa and Xalapa (*CONAVI,* 2006; *INEGI,* 2008c; Stein et. al., 2010). In contrast to the US, the cities in Mexico with the most population in different climates are the following: Tijuana (marine), Cancun (hot-humid jungle), Mexico City (temperate), Ciudad Juarez (hot-dry), Acapulco, Veracruz and Tuxtla Gutierrez (hot-dry jungle), Guadalajara (semi-arid) and Monterrey and Reynosa-Rio Bravo (hot-humid).

One additional feature can be seen by comparing housing counts with populations. For example, in Mexico the houses usually have extended families. In 2005, the average number of people in a house in Mexico is four (*INEGI,* 2008a). In comparison, in 2000 the US had an average of 2.5 people living in a house (US Census Bureau, 2010b). This would imply that energy efficient residences in Mexico would need to focus more on occupant-related activities, such as cooking, clothes washing and lighting.

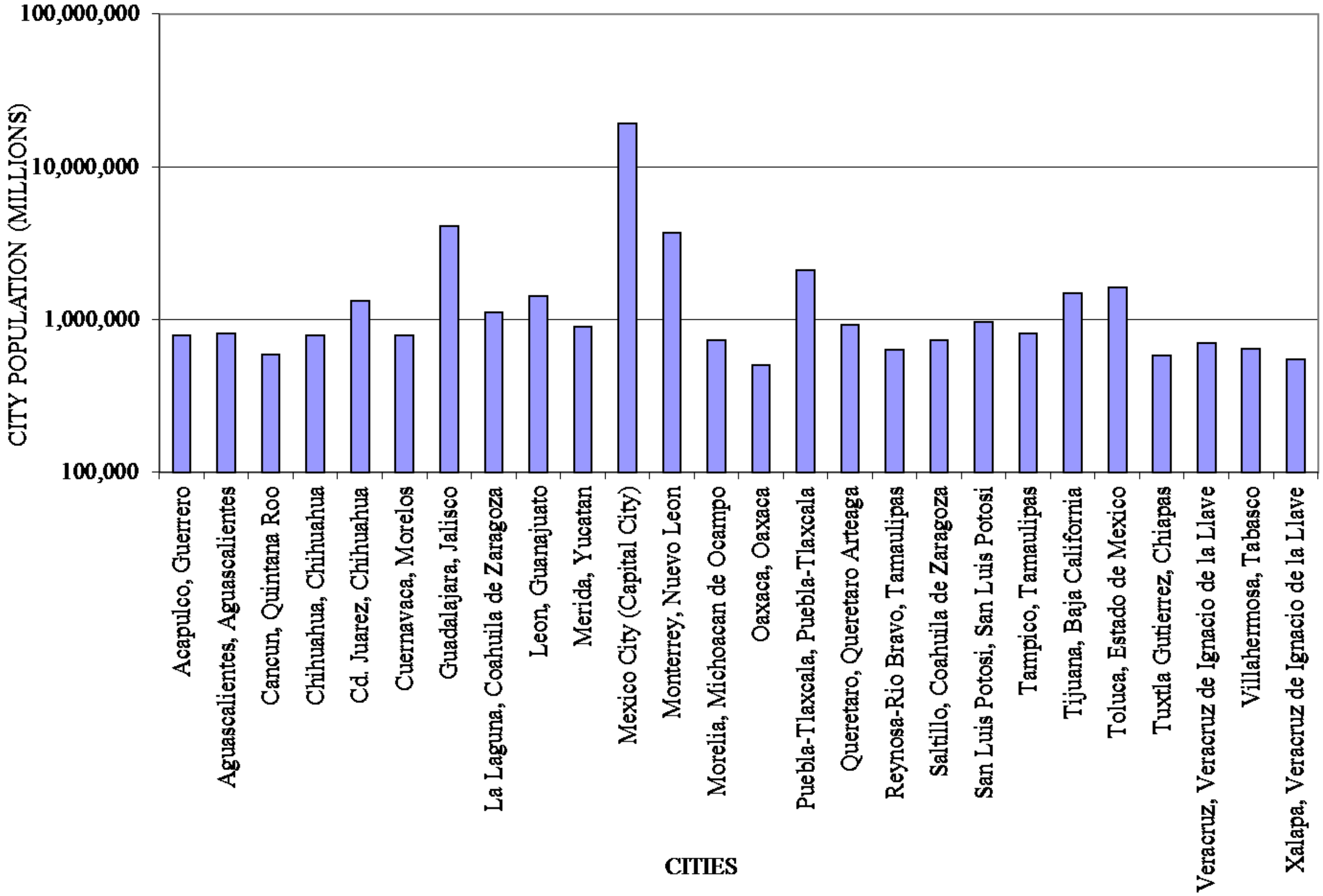

Figure 132. Cities with at least 500,000 People or more in Mexico (2005) with Data from *INEGI* (2008c).

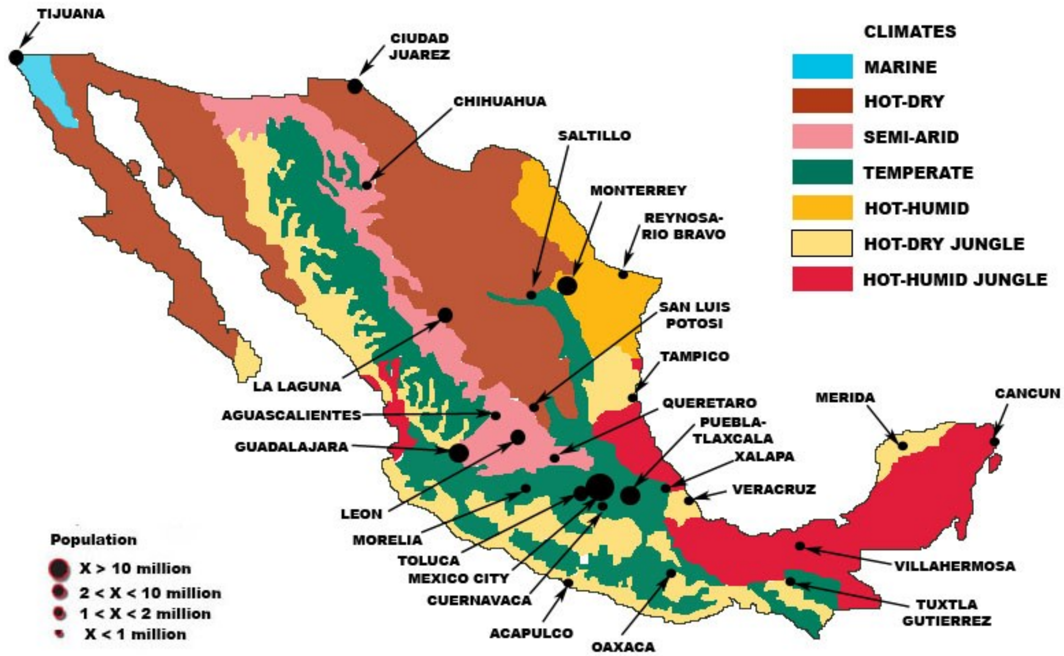

Figure 133. Cities with at least 500,000 People or more in Mexico (2005) (Map Data from *CONAVI*, 2006 and Population Data from *INEGI,* 2008c).
This Map Was Created by Drawing the Contour Lines of the Bioclimates in Mexico from the Original Image; Changing the Background from White to Grey, Changing the Colors of the Bioclimates (i.e., Marine, Hot-Humid and Hot-Dry) to Match the Colors of the Bioclimates from the US in Figure 127; Translating the Titles of the Bioclimates and Adding the Population Numbers in the Lower Left Corner. This Figure Was Needed to Show What Bioclimate is Held in Mexican Cities. Adapted from *Hacia un Codigo de Edificacion de Vivienda.* (p.18), by *Comision Nacional de Vivienda*, 2005, Mexico, D. F.: *Comision Nacional de Vivienda*. Copyright 2005 by *Comision Nacional de Vivienda*. Adapted for Scholarly Purposes under Fair Use.

Figure 134 and Figure 135 show the cities with at least 500,000 people or more in the US in 2008 (US Census Bureau, 2010c). The only two metropolitan cities to surpass 10 million people are New York-North New Jersey-Long Island (NY-NJ) (New York City is 5,027 HDD65°F and 3,342 CDD50°F) and Los Angeles-Long Beach-Santa Ana (CA) (Los Angeles is 1,458 HDD65°F and 4,777 CDD50°F and Long Beach is 1,430 HDD65°F and 5,281 CDD50°F) with 19.0 and 12.8 million people, respectively (Stein et. al., 2010). In the US, there are 26 metropolitan cities between two and 10 million people such as Chicago-Naperville-Joliet (Chicago is 6,536 HDD65°F and 2,941 CDD50°F), Dallas-Fort-Worth-

Arlington (Dallas is 2,259 HDD65°F and 6,587 CDD50°F, and Fort-Worth is 2,304 HDD65°F and 6,557 CDD50°F) and Philadelphia-Camden-Wilmington (Philadelphia is 4,954 HDD65°F and 3,623 CDD50°F). There are 22 metropolitan cities between one and two million people such as Las Vegas-Paradise (Las Vegas is 2,407 HDD65°F and 6,745 CDD50°F), San Jose-Sunnyvale-Santa Clara, and Columbus (Columbus is 5,708 HDD65°F and 3,119 CDD50°F). There are 46 metropolitan cities between one and 500,000 people such as Honolulu (0 HDD65°F and 9,949 CDD50°F), Bridgeport-Stamford-Norwalk (Bridgeport is 5,537 HDD65°F and 2,997 CDD50°F), and Albany-Schenectady-Troy (Albany is 6,894 HDD65°F and 2,525 CDD50°F).

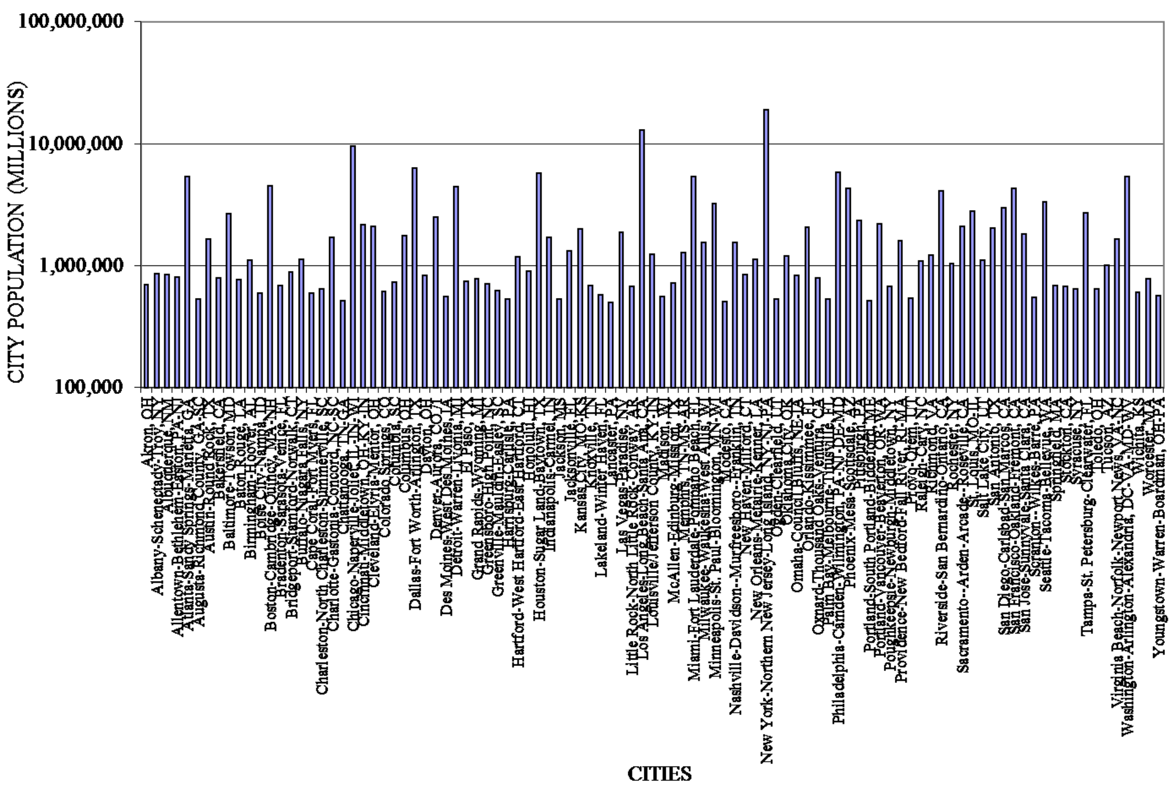

Figure 134. Cities with at least 500,000 People or more in the US (2008) from US Census Bureau (2010b).

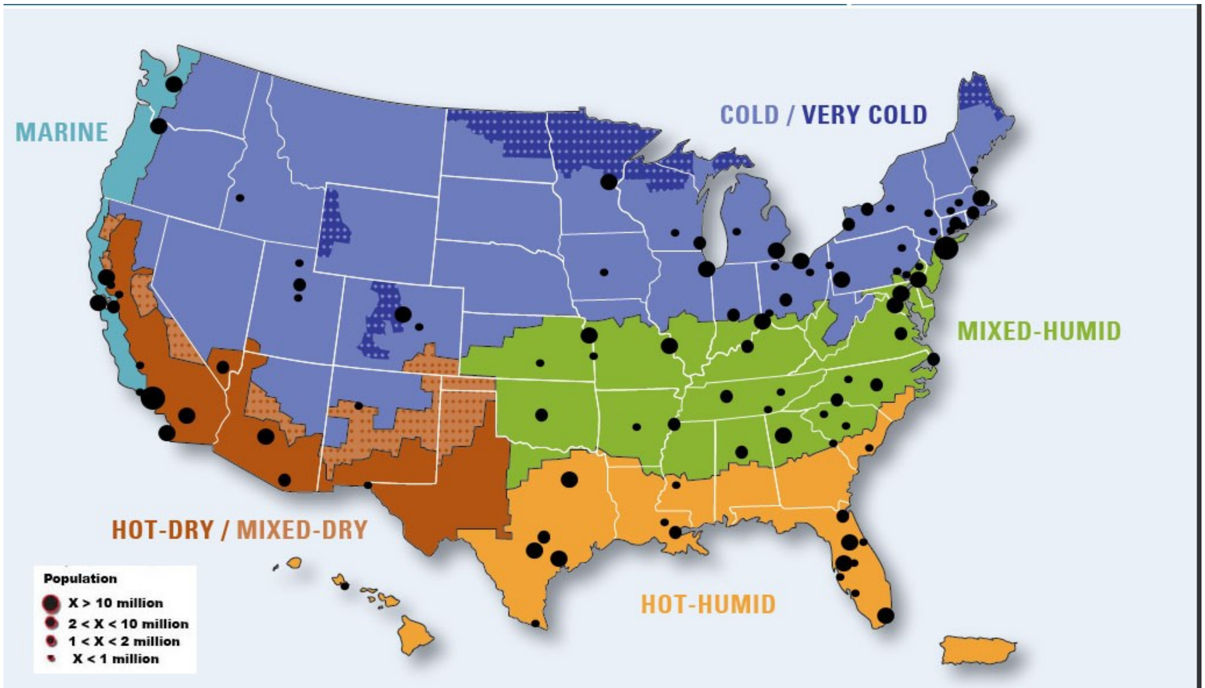

Figure 135. Cities with at least 500,000 People or more in the US (2008) (Population Data from US DOE, 2007). Climate Region Map of the US (US DOE, 2007). Some American Cities Were Added to the Image. The Idea Was to Show the Climate that is Held in the Cities Located in the Final Map. Reprinted from "High-Performance Home Technologies: Guide to Determining Climate Regions by County" by Pacific Northwest National Laboratory Operating Contractor of the Pacific Northwest National Laboratory for the U.S. Department of Energy, 2007, *Building America Best Practices Series, December*, p.1. Pacific Northwest National Laboratory. Reprinted with Permission; Adapted for Scholarly Purposes under Fair Use.

The next facet of the analysis can be seen by comparing information for both countries from Figure 132 and Figure 135. In Figure 132 and Figure 133, it is clear that the population in cities over 500,000 in Mexico is mainly located in the South-central area[153] with some "isolated" cities such as Tijuana, Ciudad Juarez, Monterrey (844 HDD65°F and 8,326 CDD50°F), Acapulco, Tuxtla Gutierrez, Oaxaca, Villahermosa, Merida (10 HDD65°F and 11,112 CDD50°F) and Cancun. In Figure 134 and Figure 135, the population of the US cities above 500,000 can be seen in three main areas: Northeast, Southeast and Southwest,

[153] Mexico City (1,203 HDD65°F and 4,762 CDD50°F), Puebla-Tlaxcala, Toluca, Cuernavaca, Guadalajara (701 HDD65°F and 0 CDD50°F), Morelia, Queretaro, Leon, Xalapa and Veracruz

with "isolated" cities like Seattle (4,908 HDD65°F and 2,021 CDD50°F) and Portland (4,522 HDD65°F and 2,517 CDD50°F) in the Northwest, Denver (6,020 HDD65°F and 2,732 CDD50°F) and Salt Lake City (5,765 HDD65°F and 3,276 CDD50°F) in the Mountain West, and Minneapolis (7,981 HDD65°F and 2,680 CDD50°F) in the West North Central. These areas cover the cold, mixed-humid, hot-humid, hot-dry and marine climate zones. The US shares three climatic zones with Mexico: hot-humid, hot-dry and marine. The main cities located in the Southeast area with hot-humid climate are: Austin (1,688 HDD65°F and 7,171 CDD50°F), Houston (1,371 HDD65°F and 7,357 CDD50°F), San Antonio (1,644 HDD65°F and 7,142 CDD50°F), McAllen, Dallas (2,259 HDD65°F and 6,587 CDD50°F), New Orleans (1,513 HDD65°F and 6,910 CDD50°F), Baton Rouge (1,669 HDD65°F and 6,845 CDD50°F), Jacksonville (1,434 HDD65°F and 6,847 CDD50°F) and Tampa Bay (725 HDD65°F and 8,239 CDD50°F). Cities in the Southwest area with a hot-dry climate are: Phoenix (1,110 HDD65°F and 8,425 CDD50°F), Tucson (1,678 HDD65°F and 6,921 CDD50°F), El Paso (2,708 HDD65°F and 5,488 CDD50°F) and Las Vegas (2,407 HDD65°F and 6,745 CDD50°F). Cities in the Southwest area with a marine climate are: Los Angeles (1,458 HDD65°F and 4,777 CDD50°F), Sacramento (2,749 HDD65°F and 4,474 CDD50°F) and San Francisco (3,016 HDD65°F and 2,883 CDD50°F). These cities represent one third of the population of the 90 cities shown in the Figure 134. From a climatic perspective, the low income houses in these areas in the US would be best to compare and analyze with those in Mexico.

A.4. Energy Consumption in Mexico and the US

Figure 136 and Figure 137 present total energy consumption percentages in Mexico and the US. Figure 138 and Figure 139 points out total energy consumption in QBtu in Mexico and the US. Figure 136 and Figure 138 show that the total energy consumption in Mexico in 2007 was 4.31 Quad Btu (QBtu), and the energy consumption for the residential, commercial, industrial and transportation sectors were 0.70 QBtu, 0.12 QBtu, 1.29 QBtu and 2.05 QBtu, respectively (SENER, 2007). On the other hand, Figure 137 and Figure 139

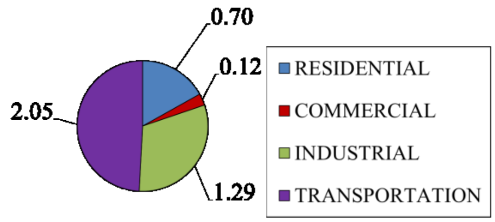

Figure 136. Total Energy Consumption Percentages in Mexico by Sectors in 2007 (with Data from *SENER*, 2007).

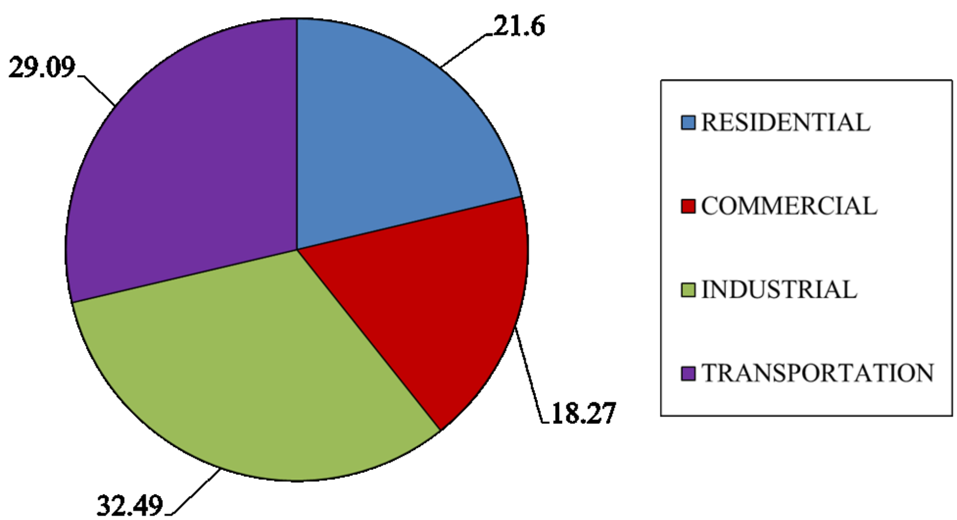

Figure 137. Total Energy Consumption Percentages in the US by Sectors in 2007 (with Data from US DOE, 2007).

show that the total energy consumption in the US in 2007 was 101.46 QBtu, of which the energy consumption for housing was 21.60 QBtu, 18.27 QBtu, 32.49 QBtu and 29.09 QBtu, respectively (US DOE, 2009a). In 2005, Mexico had 103.20 million people (INEGI, 2008a), whereas the US had 304.0 million people in 2008 (US Census Bureau, 2010a), which equals

6.8 MMBtu/person (residential), 1.8 MMBtu/person (commercial), 12.5 MMBtu/person (industrial) and 19.8 MMBtu/person (transportation) in Mexico; and 71.1 MMBtu/person

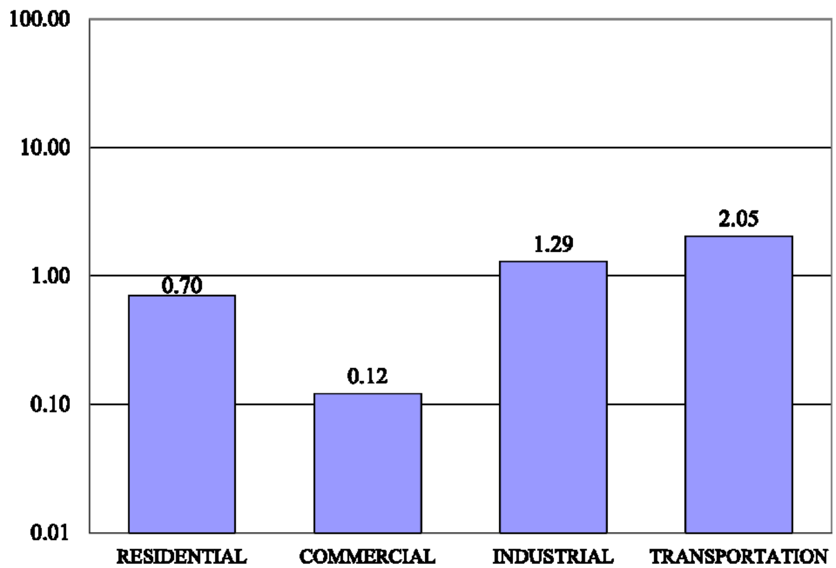

Figure 138. Total Energy Consumption (QBtu) in Mexico in 2007 (Data from *SENER*, 2007).

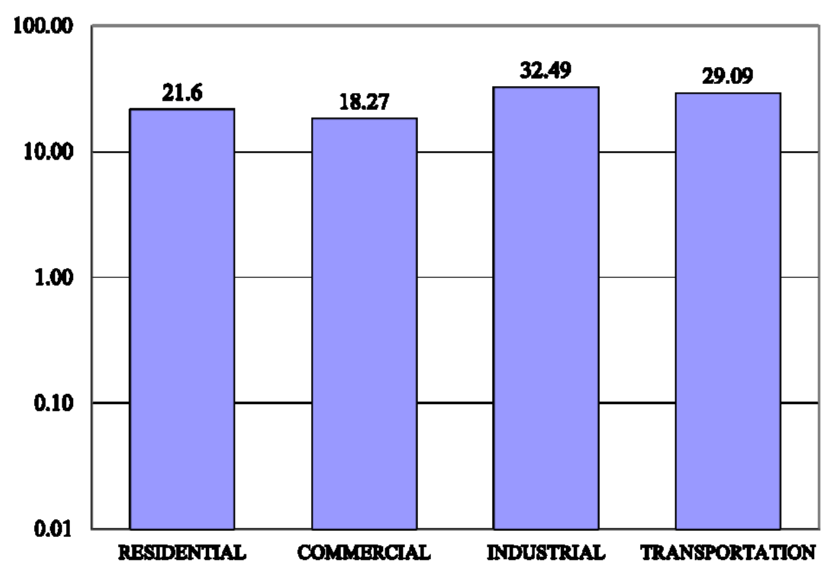

Figure 139. Total Energy Consumption (QBtu) in the US in 2007 (Data from US DOE, 2007).

(residential), 60.1 MMBtu/person (commercial), 106.9 MMBtu/person (industrial) and 95.7 MMBtu/person (transportation) in the US, based on the energy consumption in the respective sectors.

Clearly, the US consumes more energy than Mexico and it would seem that Mexico would have little to learn from the US. Unfortunately, the less affluent population in Mexico tends to buy electrical appliances for their houses when their income increases. Therefore, new houses in Mexico must be designed to be more energy efficient and use renewable energy or they face becoming as energy-consumptive as those in the US. Some organizations, such as the US Department of Energy (US DOE), the International Code Council (ICC) and the National Renewable Energy Laboratory (NREL) teams, are already working with Mexican officials to reduce residential energy-use.

In contrast to the US, the highest energy consumption elements in a house (by order of importance) in Mexico are: cooking, hot water, lighting and appliances (*CONAVI,* 2006). Fortunately, there are energy-efficient solutions that can be applied to Mexican houses such as: solar water heating, natural ventilation, daylighting, rainwater harvesting and very effective electric appliances to reduce energy-use. Unfortunately, many of these solutions were not recognized by early building codes. Later, the *CONAVI* (2007, 2010a) showed the required standards for the energy-efficient solutions in its *2007 and 2010 Housing Building Codes.*[154] The 2012 IECC is the latest updated version, establishes the minimum regulations for energy efficient buildings. *CONAVI* 's *2010 Housing Building Code* is based in the guide *Uso Eficiente de la Energia en la Vivienda* (*CONAVI,* 2006) in Mexico. *CONAVI* (2006) showed elements related to energy-efficiency. Most of the elements in *CONAVI* are climate-based design requirements. It was also the first official guide in Mexico to include sections for bioclimatic design and sustainability for each climate region. It represents an early stage design guide with some bioclimatic design and sustainability strategies.

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[154] The Section 2.5 showed solutions in terms of building envelope measures, mechanical systems, daylighting and lighting systems and appliances, natural ventilation strategies, rainwater harvesting systems, passive solar systems, and solar electric systems and domestic hot water systems.

A.5. Summary of Comparison of Population and Energy from Mexico and the US

In conclusion, the US and Mexico differ in population and energy consumption. The population in Mexico, as shown in the previous figures, is concentrated in the South-central states with some "isolated" cities in comparison with the more spread-out population through the US. The energy consumption in the housing sectors for the US and Mexico was 71.1 MMBtu/person (in 2008) and 6.8 MMBtu/person (in 2005), respectively. It would seem that Mexico would have little to learn from the US. Nevertheless, the less affluent population in Mexico tends to buy electrical appliances for their houses when their income increases. Also, the need of more dwellings in the country is high. Thus, there are some lessons learned from the analysis, which include:

1) The US and Mexico share three climate zones (hot-humid, hot-dry and marine). The solutions given in the existing houses located in these climate zones should be considered and studied for the new houses in these areas.
2) The South-central area in Mexico has approximately the 50 percent of the population of the country. The need for new houses is high and the area to build in the cities of the area is low (e.g. Mexico City). Therefore, the idea of multi family low income house should be considered for this area.
3) The new houses in Mexico must be designed to be environmentally adapted, more energy-efficient, affordable and use renewable energy or they face becoming as energy-consumptive as those in the US.
4) Optimal space solutions for the new houses for an average family of four members in Mexico, which is twice the US average.
5) Mexico does not share the cold and the very cold climate zones of the US. (The cold and the very cold climate zones are located in 50 percent of the territory of the US). The houses for these climates in the US relay on mechanical space heating, ventilating and cooling.

Therefore, we can conclude that new, multi-family apartments for the temperate climate in Mexico City should have energy-efficient solutions that emphasize solar water heating, natural ventilation, daylighting, rainwater harvesting and very effective electric appliances to reduce energy-use.

APPENDIX B

FUEL MIX FOR ELECTRICITY GENERATION DIFFERENCES BETWEEN MEXICO AND THE US

This appendix points out the current fuel mix for electric generation between Mexico and the US. *SENER* (2010) reported in Figure 140 the following electricity energy generated in central electricity plants in Mexico in 2009: nuclear energy-based generated with 0.04 QBtu; wind energy-based generated with 0.01 QBtu; geothermal energy-based generated with 0.02 QBtu; hydro energy-based generated with 0.09 QBtu; coal-based generated with 0.10 QBtu; fuel oil-based generated with 0.02 QBtu; dry gas-based generated with 0.42 QBtu; and diesel-based generated with 0.04 QBtu. The total electricity energy generated in central electric plants in Mexico in 2009 was 0.74 QBtu.

On the other hand, the Lawrence Livermore National Laboratory (LLNL) and the US Department of Energy (US DOE) (2011) reported in Figure 141 the following electricity energy generated in central electricity plants in the US in 2010: nuclear energy-based generated with 8.44 QBtu; wind energy-based generated with 0.92 QBtu; geothermal energy-based generated with 0.15 QBtu; hydro energy-based generated with 2.49 QBtu; coal-based generated with 19.13 QBtu; solar energy with 0.01 QBtu; natural gas-based generated with 7.52 QBtu; biomass-based generated with 0.44 QBtu; and petroleum-based generated with 0.38 QBtu. The total electricity energy generated in central electricity plants in the US in 2010 was 39.49 QBtu.

To conclude appendix B, Mexico consumed 1.87 percent of the total electricity energy generated in 2009, compared to the total electricity energy generated in the US in 2010.[155] This difference proves that Mexico needs to increase the renewable-based energy production in existing areas such as nuclear, wind, geothermal and hydro energy, and develop other areas such as solar and biomass energy.

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[155] The electricity generated in Mexico in 2010 was 0.74 QBtu divided by the electricity generated in the US in 2010 was 39.49 QBtu and multiplied by 100 equals to 1.87 percent difference.

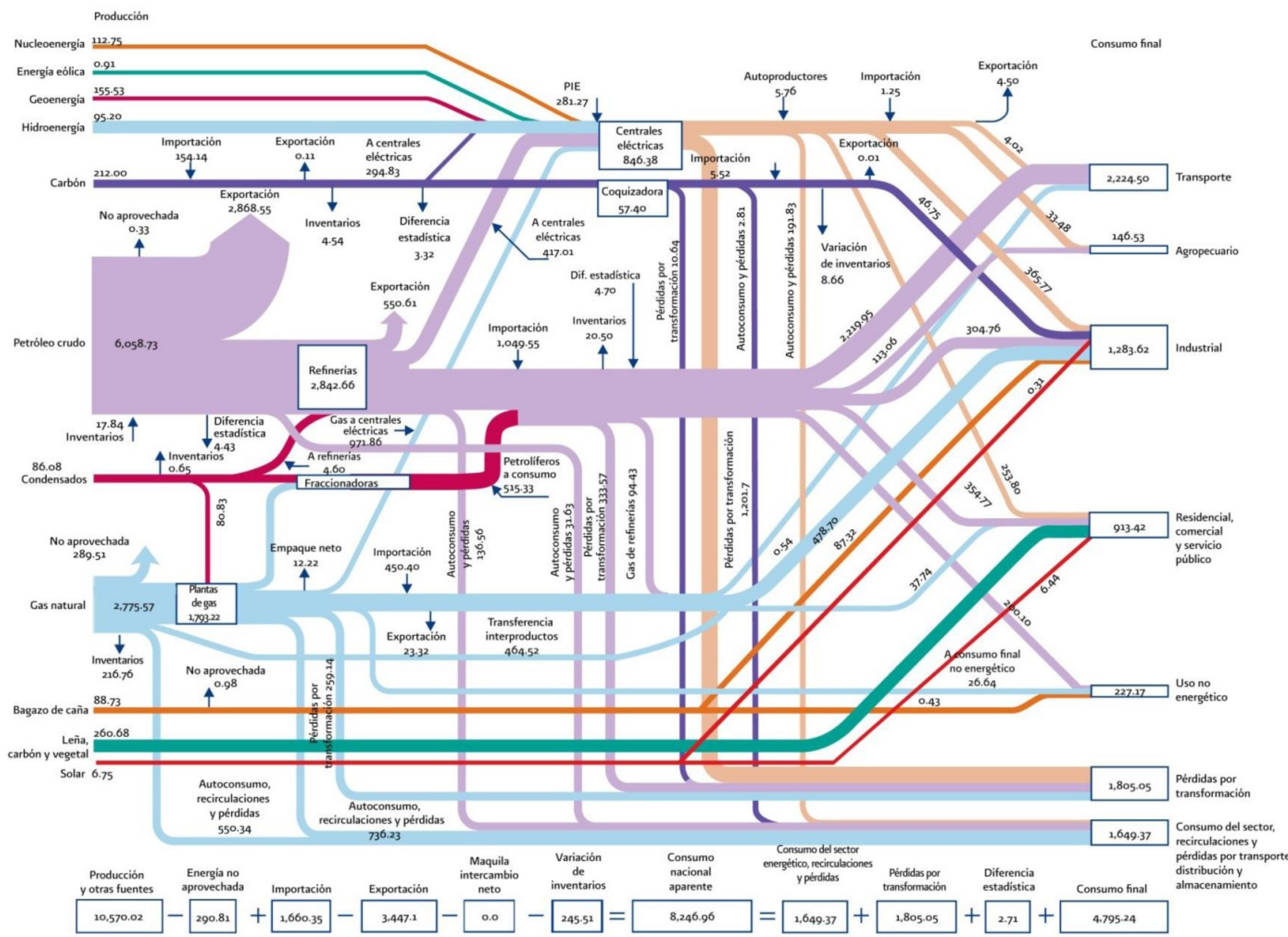

Figure 140. Mexico's National Energy Balance Diagram in 2009.
Reprinted from Balance Nacional de Energia 2009 (p.64), by Secretaria de Energia, 2010, Mexico, D. F., Secretaria de Energia, Copyright 2010 by Direccion de Estadistica y Balances Energeticos de la Secretaria de Energia. Reprinted with Permission.

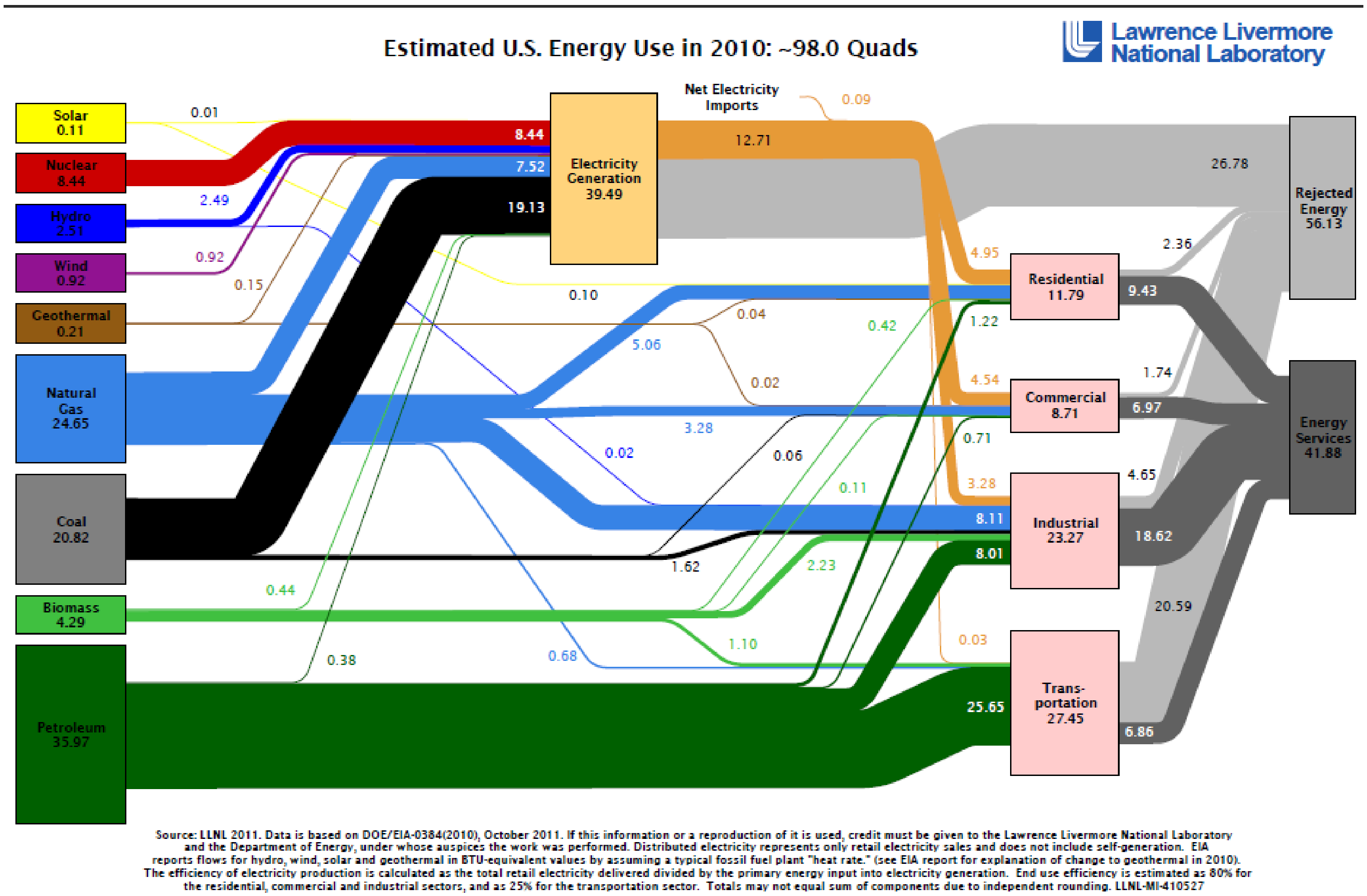

Figure 141. US's National Energy Balance Diagram in 2010 (from LLNL/US DOE, 2011). Reprinted from "Estimated Energy-Use in 2010: 98 Quads" from the website https://flowcharts.llnl.gov/, by Lawrence Livermore National Laboratory, 2009, Copyright 2009 by Lawrence Livermore National Laboratory. Reprinted with permission.

APPENDIX C

PSYCHROMETRIC CHART APPLIED TO THE TECHNICAL POTENTIAL STUDY

eQuest is used to determine possible thermal comfort from the apartments for the whole year. In order to obtain this part of the analysis, Climate Consultant (Clayton et al., 1988; US DOE, 2012b) is used due to its capability to show environmental design strategies in an annual hourly-based with a psychrometric chart. The 2005 ASHRAE Handbook of Fundamentals Comfort Model in Figure 104 is selected for the psychrometric chart scrutiny. It is assumed that this model fits well to the temperature and the relative humidity characteristics from Mexico City.[156] Finally, the 8,760 hours for interior zone temperature and relative humidity from the eQuest model are graphed over the chart.

This research process requires the following steps: 1) assume the points for the winter comfort zone and the summer comfort zone in the psychrometric chart,[157] 2) speculate how to verify if each hour is located or not into any comfort zone, 3) perform some computation in Excel to get functions to verify if each hour is located or not into any comfort zone and 4) apply these functions to the six zones of the building analyzed in eQuest.

Firstly, Table 153 displays the coordinates of the edges for the polygon of the thermal comfort zones. The first column is the edges, the second column and fourth columns are the X-axis for interior zone temperature, and the third and fifth columns are the Y-axis for humidity ratio.[158]

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[156] According to information inside the Climate Consultant software, the ASHRAE Handbook of Fundamentals Comfort Model is divided in winter and summer. The effective temperature is 68°F or 20°C through 74°F or 23.3°C with people wearing winter clothes. It is states that the temperature slightly decreases as the humidity rises during the season. On the other hand, the temperature shifts to 5°F or 2.8°C warmer with clothes during the summer season.

[157] The winter comfort thermal zone is considered from January 1st to March 20th and from November 15th to December 31st. The addition for these two ranges for winter has 3,024 hours. The summer comfort thermal zone is considered from March 21st to November 14th. This range for summer has 5,736 hours.

[158] Baltazar-Cervantes and Liu (2008) are consulted for a psychrometric function for Excel, in order to process the data from interior zone temperature and dew point and get humidity ratio.

Table 153. Coordinates of the Edges for the Polygon for the Thermal Comfort Zones.

	Winter		Summer	
	X	**Y**	**X**	**Y**
A	68	0.012	72	0.014
B	74	0.011	80	0.013
C	77	0.005	81	0.005
D	69	0.005	73	0.005

Secondly, it is speculated that any hour can be verify, if it is located or not into any comfort zone, through the calculation of areas. In the website forum Mathematics Stack Exchange (2013), Freewind requests a suggestion in order to check if a point is inside a rectangle. Lab Bhattacharjee (Mathematics Stack Exchange, 2013) proposes to calculate the area of the rectangle and the areas of the four triangles created by the point inside of the rectangle. He states that if the sum of the areas of the triangles is equal to the area of the rectangle, the point is inside the rectangle. This idea can be modified for the technical potential study, because the thermal comfort zones are polygons. The edge that creates the four triangles inside (or outside) the polygon will be each one of the 8,760 hours of the year, and it is assigned as edge *E*. Thus, the final goal is to look for two equations, or functions in Excel: one to determine the area of the irregular polygon and one to calculate the area of the triangle.

One equation to calculate the area of the irregular polygon and two methods to determine the area of the triangle are found during the process. For the earlier, the user pgc01 (MrExcel.com, 2013) states an equation that can be applied for the polygon. If this equation is applied for the winter and the summer thermal comfort zones in the technical potential study, it looks as next:

X=Area of the Irregular Polygon=1/2*ABS(SUMPRODUCT(A2:A5,B3:B6)-SUMPRODUCT(B2:B5,A3:A6))

Figure 142 and Figure 143 presents the cells that the previous equation uses to obtain the area of the irregular polygon. Just for clarification, the numbers in cells A6 and B6 are the same numbers in cells A2 and B2. These cells are required for the equation.

	A	B
1	**X**	**Y**
2	68	0.012
3	74	0.011
4	77	0.005
5	69	0.005
6	68	0.012

Figure 142. Thermal Comfort Zone for Winter.

	A	B
1	**X**	**Y**
2	72	0.014
3	80	0.013
4	81	0.005
5	73	0.005
6	72	0.014

Figure 143. Thermal Comfort Zone for Summer.

As mentioned before, there are two methods in Excel to obtain the area of the triangle. These methods are Heron's Formula (Mathematics Stack Exchange, 2013) and the Coordinate Geometry (Math Open Reference, 2009). Both methods use the coordinates of the edges to estimate the distance between the points. Before using Heron's Formula, the triangle *ABE* for the winter zone in Table 153 is used as example with some equations required such as:

1) The length of line *AB* for winter zone that is computed like this:

   Line *AB*=*a1*=SQRT((*Ax*-*Bx*))^2+(*Ay*-*By*))^2)

This is also done for the lines *BC, CD* and *DA*. These lines define the side of the polygon.

2) The same equation is applied in order to obtain the line segments AE, BE, CE and DE of the triangles:

   Line *AE*=*b1*=SQRT((*Ax*-*Ex*))^2+(*Ay*-*Ey*))^2)

Line $BE=b2$=SQRT((Bx-Ex))^2+(By-Ey))^2)

The eight lines AB, BC, CD, DA, AE, BE, CE and DE are used for Heron's formula.

1) Heron's formula needs the next formula:

   $u1=(a1+b1+b2)/2$

2) This is Heron's formula to calculate triangle ABE:

   Triangle ABE=SQRT(($u1$*($u1$-$a1$)*($u1$-$b1$)*($u1$-$b2$))

3) This should be done for triangles BCE, CDE and DAE:

   Y=Sum of Triangles= $ABE+BCE+CDE+DAE$

4) After calculating the area of the polygon and the four triangles, the next two equations are applied:

   Polygon=INT((X)*1,000)/1,000

   Triangles=INT((Y)*1,000)/1,000

5) Finally, an IF function is input in Excel. If the areas are the same, the function returns a value of zero. If the areas are different, the function returns a value if one:

   Hour Inside or not Inside of the Thermal Comfort Zone=IF(X=Y,0,1)

The second method found is called the Coordinate Geometry (Math Open Reference, 2009). The same triangle ABE for the winter zone is used as example with some equations required such as:

1) The area of triangle ABE for winter zone that is computed like this:

   X=Triangle ABE=ABS(((Ax*(By-Ey))+(Bx*(Ey-Ay))+(Ex*(Ay-By)))/2)

This is also done for the triangles BCE, CDE and DAE and the areas are added.

2) The area of polygon is also calculated with the equation from the user pgc01 (MrExcel.com, 2013):

   Y=Area of the Irregular Polygon=1/2*ABS(SUMPRODUCT(A2:A5,B3:B6)-SUMPRODUCT(B2:B5,A3:A6))

3) After calculating the area of the polygon and the four triangles, the next two equations are applied:

   Triangles=INT((X)*1,000)/1,000

   Polygon=INT((Y)*1,000)/1,000

4) Finally, an IF function is input in Excel. If the areas are the same, the function returns a value of zero. If the areas are different, the function returns a value if one:

Hour Inside or not Inside of the Thermal Comfort Zone=IF(X=Y,0,1)

Figure 74, Figure 76 and Figure 103 show the final models created with Excel.