PROJECT REPORT

Assessing energy savings from "Cool Roofs" on residential and non-residential buildings in Mexico

Prepared for:

Comisión Nacional de Uso Eficiente de Energía (CONUEE)

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Abstract

Dynamic simulation modeling was used to assess the impacts of cool roofs on energy consumption for non-residential and residential buildings in Mexico. Seven cities, selected from Mexico's six climatic zones, were identified to simulate the energy loads of residential and non-residential buildings. The climates and cities were: humid hot (Villahermosa), sub-humid hot (Mérida), very dry (Hermosillo), dry (Monterrey), humid temperate (Tulancingo), sub-humid temperate (Guadalajara and Mexico City). Weather files for the cities were accessed from Meteonorm. The base case buildings were defined to comply with the national building standards NOM-008-ENER-2001 (non-residential) and NOM-020-ENER-2011 (residential), including the recommended roof insulation levels for overall heat transfer coefficients. The cooling loads were calculated for both buildings in 7 cities. In the simulations, the roof reflectance was changed in order to determine the effect of cool roofs on cooling loads. The results indicate that cooling energy savings were higher in warm and dry climates. Temperate climates do not show significant savings; however, for Mexico City, the savings turn out to be significant for non-residential buildings because of the large building stock. The reduction of carbon emissions resulting from these energy savingswas calculated. The energy savings were also used to calculate the payback period for the installation of a cool roof. Payback periods, in all cases, are considerably shorter than the useful life of the coating (5 years). For dry and warm climates, the cost savings are significant thus the payback periods are shorter than in temperate climates.

In order to assess the potential of cool roof product penetration, five cities were selected to measure current roof color. Images were processed in Manifold GIS 8.0 to calculate the roof area by color. The color of the roof is an indication of the roof's reflectance. Energy consumption, savings and carbon emissions mitigation were calculated from the existing roof reflectance data. For cities of Mérida and Monterrey, located in warm and dry climates, 1.6 TWh savings were calculated and 1,154,000 tons of CO_2 mitigated.

1. Background

Mexico is a member of the Cool Roofs and Pavements Working Group of the Global Superior Energy Performance Initiative (GSEP) of the Clean Energy Ministry (CEM). National Commission of Energy Efficiency Use (CONUEE) was designated as the lead agency to coordinate the efforts of the working group in Mexico. In February 2012, CONUEE organized a conference with interested groups to define a plan of action for cool roofs in Mexico. At this meeting CONUEE requested a study of the technical and economic feasibility of implementing coolroofs in Mexico. The study would be used to justify the development of official regulations. The study was designed to analyze the energy saving potential of cool roofs in Mexico.

Two methods were employed to calculate the potential energy savings. First, dynamic simulations with EnergyPlus were conducted using the reference building from the Mexican Standards NOM-008- ENER-2001 and NOM-020-ENER-2011. The simulations allowed variations to a building's roof solar reflectance value to quantify energy consumption. The second method used satellite images and a geographic information system program (Manifold 8.0), to estimate 5 cities current roof reflectance values and calculate potential energy savingsfor these cities. CONUEE approved the methodology for this study at a meeting on January 30, 2013.

2. Methodology

The authors first set out to characterize the six Mexican climatic zones as defined by National Institute of Geography and Statistics (INEGI) (INEGI, 2009). The Meteonorm database was accessed to obtain the meteorological variables for Mexico's cities. Next, reference model buildings that comply with the Mexican norms NOM-008-ENER-2001 (non-residential building) and the NOM-020-ENER-2011 (residential building) were obtained from WinBuild and Lawrence Berkeley National Labs' Suncode program to use for the dynamic simulations.

For the dynamic simulations, the programs DesignBuilder and EnergyPlus were utilized. These programs calculate the cooling loads from the climatic, architectural and thermal data inputs.For the simulations, 7 cities located in 6 climates were selected. To determine the effect of cool roofs on the buildings' cooling loads, the solar reflectance was modified within a range of 0.1-0.9. The energy consumption for each reflectance level is computed. The potential building energy savings are multiplied by the number of existing buildings for each selected city to estimate of the total saving per city. Additionally, CO_2 emissions are calculated based on modeled energy consumption changes.

The payback period was calculated on the initial investment of a new white roof coating. Maximum payback period was less than a year for non-residential building and 3 years for residential buldings.

Finally, cool roof product penetration was assessed using rooftop images from Google Earth and Manifold GIS 8.0. The results informed an analysis of potential energy savings from cool roofs in these cities considering existing roof reflectance..

3. Mexico's Climate

Climate is the average of the atmospheric conditions over an extended period of time over a large region. Small scale patterns of climate, resulting from influence of topography, soil structure, ground and urban forms are microclimates. Climate in Mexico is varied, more than 50% of the regions are hot and warmed, people would use more electricity for air conditioning and it impacts the energy consumption. The climates of Mexico are diverse. According to INEGI, they can be classified by temperature (hot and temperate) and humidity (humid, subhumid, dry and very dry) (INEGI, 2011).

Central and northern Mexico cover roughly 28% of total Mexican territory and are characterized as a dry climate. These zones are have low rainfall, around 300-600 mm per year, and an average temperature range of 22 to 26 °C or 18 to 22°C in the different regions.

The very dry zones make up 21% of the territory. These zones have mean temperatures within 18-22°C, with extreme cases of 26°C, and annual average rainfall of 100 to 300 mm.

The hot climates are divided into humid hot and subhumid hot sub-categories. The humid hot makes up 5% of Mexico. This climate is characterized by having an annual average temperature between 22 and 26 °C. The average annual rainfall is around 2,000 - 4,000 mm. Meanwhile, the subhumid climate makes up 23% of Mexico and is characterized by annual average temperatures between 22 and 26°C and annual average rainfall between 1,000 – 2,000 mm.

The temperate climate is divided in humid temperate and subhumid temperate sub-categories. The humid temperate makes up 3% of the territory. This climate has annual temperatures between 18 and 22°C and annual rainfall between 2,000 and 4,000 mm. The subhumid temperate makes up about 21% of the territory.

This climate is characterized for average temperatures between 10 and 18°C, and 18-22°C, but in some regions is lower than 10°C. This climate has an annual rainfall between 600 and 1000 mm during the year (INEGI 2011).

Along the coasts of the country, the climates are hot and humid but most of Mexico is hot and dry. The hot climates are either dry or very dry and make up 77% of the territory and 23% the temperate climates.

3.1. Maps of climatic conditions

To visualize the climate of the country in detail, seven hundred cities were selected to carry out annual average maps of radiation, air temperature, wind velocity and cloudiness index. The database Meteonorm was employed to obtain the climatic conditions. The data is from 2005.

The Figure 3.1 shows the 700 cities evaluated. Each state of the Republic and the number of cities per state are shown in Table 3.1. The latitude and longitude of the 700 cities are presented in ANNEX 1 .

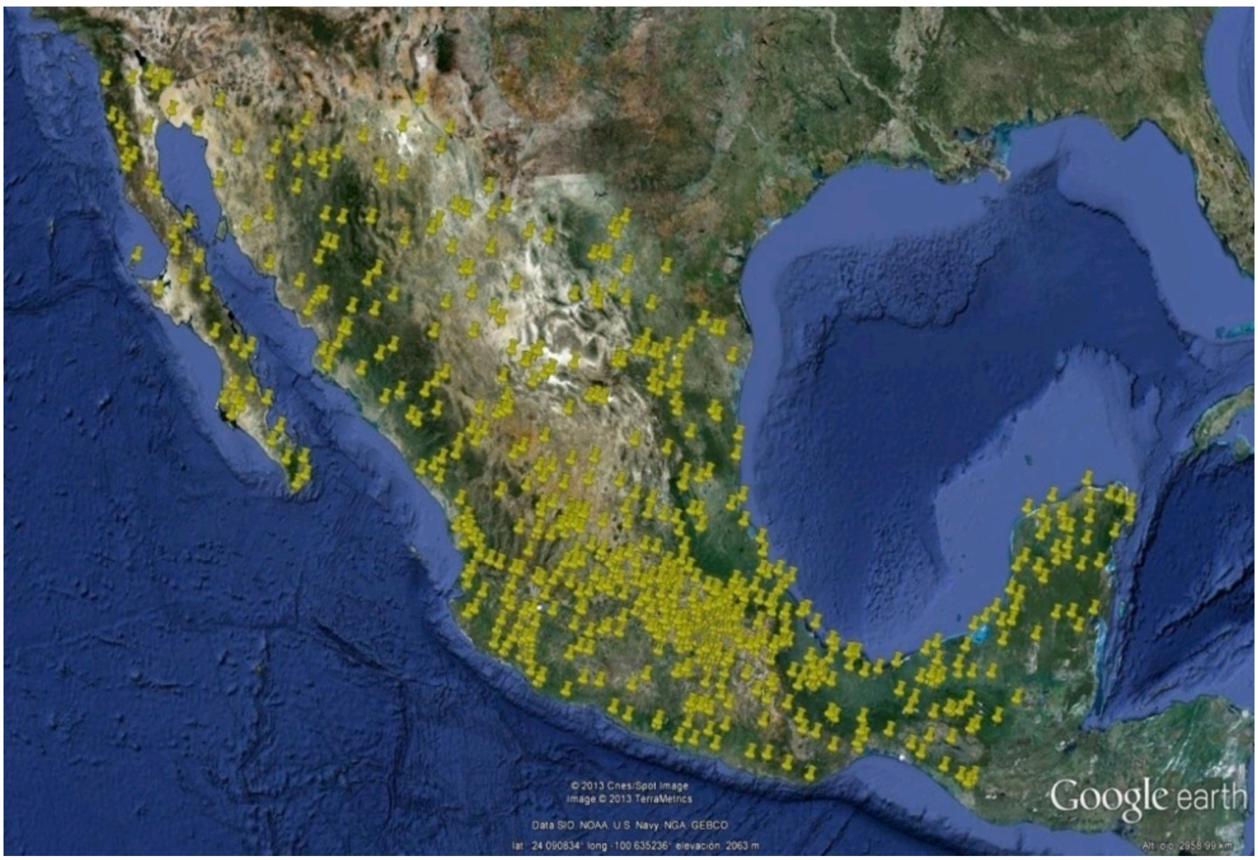


Figure 3.1.Location of the 700 cities in Mexico.

Table 3.1. Number of cities in each state.

No.	State		Number of Cities
1	Aguascalientes	AGS	13
2	Baja California Norte	BCN	20
3	Baja California Sur	BCS	20
4	Campeche	CAMP	17
5	Coahuila	COAH	28
6	Colima	COL	14
7	Chihuahua	CHIH	31
8	Chiapas	CHIS	26

9	Distrito Federal	DF	31
10	Durango	DGO	20
11	Guerrero	GRO	25
12	Guanajuato	GTO	21
13	Hidalgo	HGO	19
14	Jalisco	JAL	35
15	Edo. de Mexico	MEX	44
16	Michoacán	MICH	28
17	Morelos	MOR	19
18	Nayarit	NAY	15
19	Nuevo Leon	NL	16
20	Oaxaca	OAX	33
21	Puebla	PUE	21
22	Queretaro	QRO	14
23	Quintana Roo	QROO	11
24	Sinaloa	SIN	18
25	San Luis Potosi	SLP	18
26	Sonora	SON	29
27	Tabasco	TAB	10
28	Tamaulipas	TAMS	17
29	Tlaxcala	TLAX	15
30	Veracruz	VER	36
31	Yucatan	Yuc	16
32	Zacatecas	ZAC	20

Next, the Figures 3.1.1, 3.1.2 and 3.1.3 present the annual maps of solar radiation, ambient temperature and relative humidity.

3.1.1 Annual solar radiation

The Figure 3.1.1 presents the annual average incident solar radiation (kW/m^2). The scale of solar radiation in the country is between 4.8 kW/m^2 (blue) a 5.8 kW/m^2 (red). The northeast states of Sonora, Sinaloa, and Baja California and the southern state of Guerrero are characterized by medium-high solar radiation 5.5-5.6 kW/m^2 and > 5.7 kW/m^2.The states with medium solar radiation are located in western and Eastern coasts, with values around 5.0 kW/m^2 to 5.4 kW/m^2. The lowest solar radiation <5.0 kW/m^2, is found in the states located close to the Eastern coast (east of Tamaulipas and Veracruz), due to the high humidity.

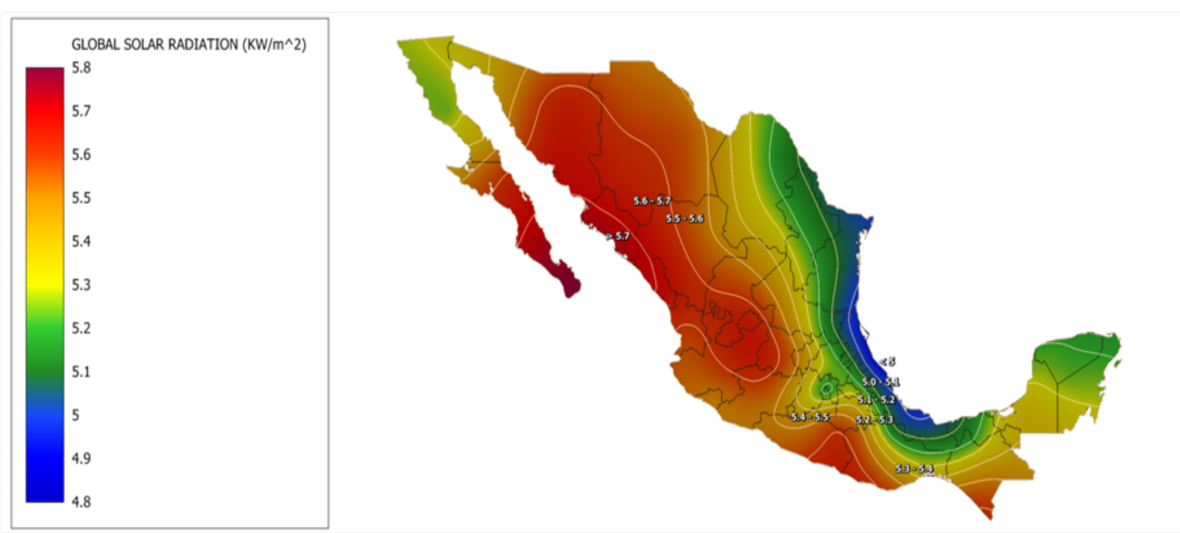


Figure 3.1.1.Annual average incident solar radiation in Mexico.

3.1.2. Annual average ambienttemperature

The Figure 3.1.2 presents the annual average ambient temperature. The range of temperatures in the country is between 5°C (blue) a 35°C (red). The states with high annual temperatures from 23 to 26 °C, or higher than 26°C are located in the north eastern, eastern, south eastern and north eastern coasts. The states with annual average temperatures between 14 to 20°C are located in the center of the country and the states with temperatures lower than 14°C are located also in the center of the country (Mexico City, State of Mexico, Puebla, Hidalgo).

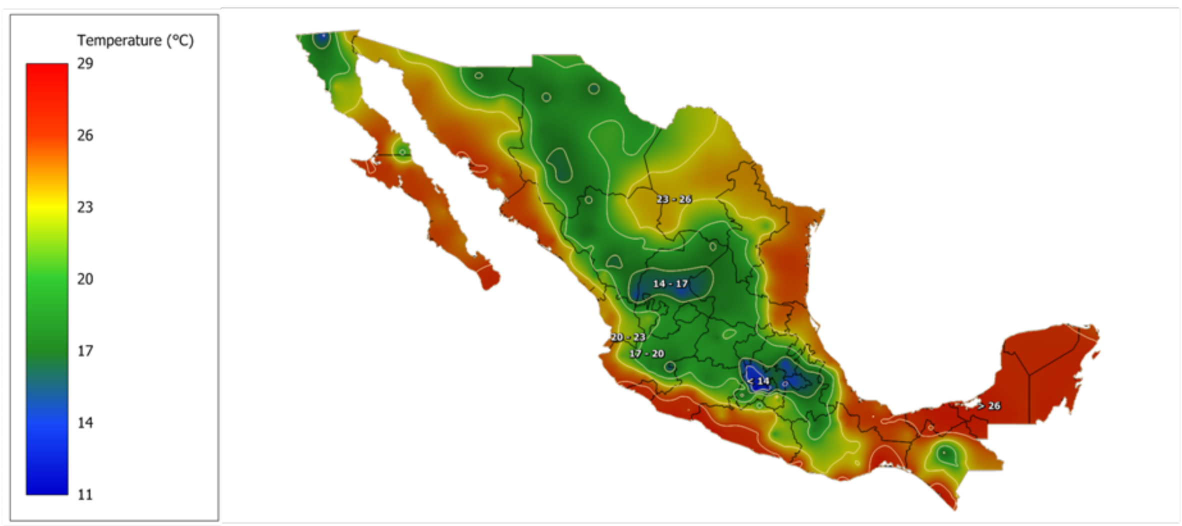


Figure 3.1.2. Annual average ambient temperature in Mexico.

3.1.3 Annual average relative humidity

The Figure 3.1.3 presents the annual average relative humidity for 2005. Relative humidity ranges between 0% (red) and 100% (blue). The states with less relative humidity, <30%, and 30% and 40% are located in the North eastern sections of Mexico (Sonora, Chihuahua, and part of Coahuila). The higher average relative humidity 70%-80% and aboveare found in the eastern, south eastern and south coasts.

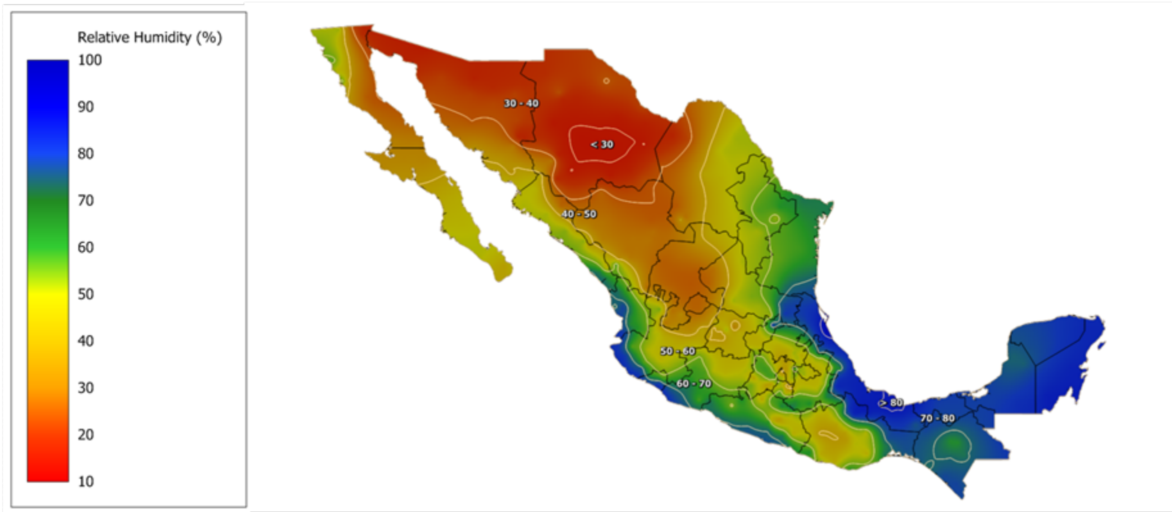


Figure 3.1.3. Annual average relative humidity in Mexico.

4. Selected cities according to the classification of INEGI

Seven cities were selected for the dynamic simulations. The cities are located in all 6 of Mexico's climatic zones. The selection considered the size of the city and the representation of each climate. The cities and their type of climate according to INEGI are presented in Table 4.1

Table 4.1- Subgroups of climates and selected cities.

Site	Type of climate	City
a	Humid hot	Villahermosa
b	Subhumid hot	Mérida
c	Dry	Monterrey
d	Very dry	Hermosillo
e	Humid temperate	Tulancingo
f	Subhumid temperate (b)	Cd. de México
g	Subhumid temperate (a)	Guadalajara

Mexico City (f) and Guadalajara (g) are classified in the same type of climate: subhumid temperate. The differences are that Mexico City has warmer summers than Guadalajara.

The Figure 4.1 shows the groups and subgroups of climates in Mexico according INEGI, 2011. The map indicates the location of the selected cities. The following nomenclature was utilized to identify the cities: (a) Villahermosa (humid and hot climate), (b) Mérida (subhumid hot climate), (c) Monterrey (hot and dry), (d) Hermosillo (very dry), (e) Tulancingo (humid temperate), (f) Mexico City and (g) Guadalajara (subhumid temperate).

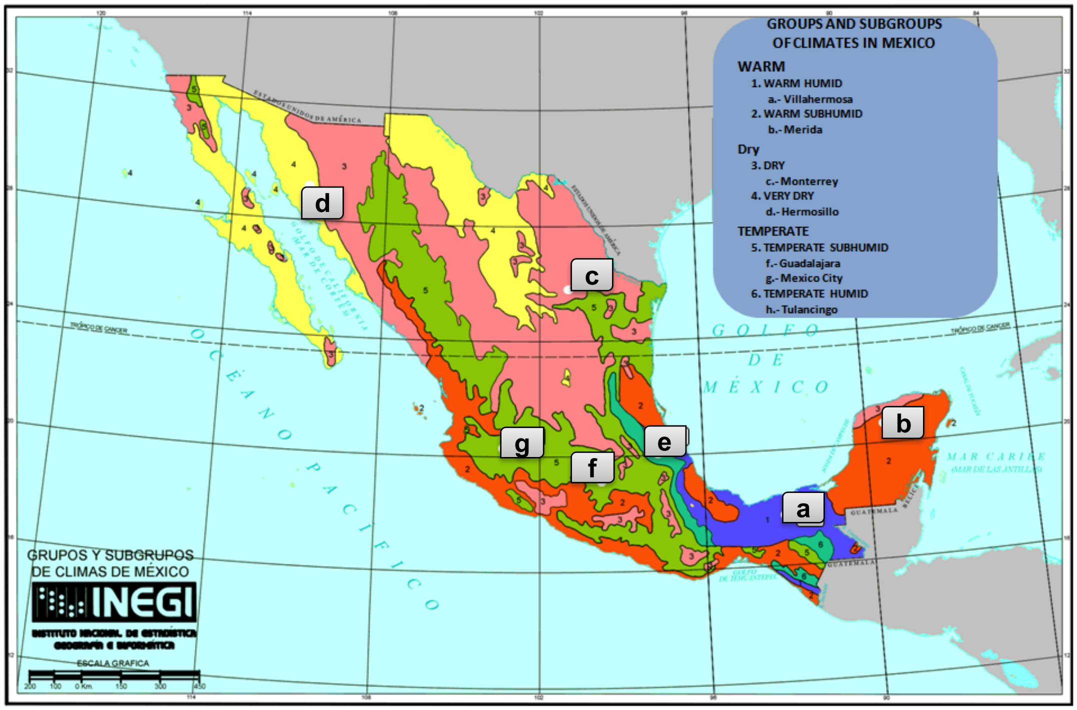


Figure4.1 Groups and subgroups of climates in Mexico

General information about the selected cities

(1) Villahermosa

The metropolitan area of Villahermosa is heavily urbanizedas a result of the combining of two municipalities sharing a constant conurbation often called Villahermosa. The city is located at Tabasco State. Villahermosa is the 22th most populated in Mexico and the second largest in southeastern Mexico, after Mérida. This city has a population of 756,065 and is located at 17° 59'N 92° 55' W and has an average elevation of 9 meters over the sea level. Villahermosa has a tropical monsoon climate; the temperatures during spring and summer do not reach 40 °C, with higher levels than 90% of the relative humidity. During its short "winter", the climate of Villahermosa is really humid and the diurnal temperatures range up to 28 °C.

(2) Mérida

Mérida is the capital and the major city of the Yucatán State, located at 20° 58'N 89° 37' W. The city has an elevation of 8 meters above sea level and is 1,307 km from the Mexico City. This city has a population of 803,920 inhabitants. It borders the states of Quintana Roo and Campeche east to west. Mérida has a tropical wet and dry climate. The average high temperature is 33°C, ranging from 28°C in January to 36°C in May, but temperatures often rise above 38°C in the afternoon. Low temperatures range from 18°C in January to 23°C in May and June. Oftentimes, Merida is warmer than the coastal areas, due to its inland location and low elevation. The rainy season is from June to October. Annual average relative humidity range is from 66% to 89%.

(3) Monterrey

Monterrey isthe capital and thelargest city in the state of Nuevo León. The city is a dense and sprawling urban area. The Monterrey metropolitan area has 1,135,512 inhabitants, with a close regional groupingof9 municipalities raising the population to 4,150,000 inhabitants within an area of 6,680 km². Monterrey is the third most populous city in Mexico. It is located at 25.7 ° N 100.3 ° Wand an elevation of 550 m. Monterrey has a semi-arid climate. Its climate in spring and autumn is temperate and hot in the summer. The highest average during August is 35 °C and the average minimum is 23 °C. Winters are mild, the highest average temperature in January is 20 °C and the average minimum is 8 °C. Temperatures below freezing are rare. The average relative humidity is 62%. Rainfall is scarce, but more prominent during the summer.

(4) Hermosillo

Hermosillo is the capital of the state of Sonora, located at latitude 29° 05'N and 110° 57'W longitude, at an elevation of 282 m above sea level. It is located in central Sonora, approximately 270 km from the U.S border. It has a population of 715.061 inhabitants. The Hermosillo has a warm and very dry desert climate. It has an average annual temperature of 25 °C. During most of the year the weather is warm. Temperatures can range from as low as freezing in January and February to 48 °C in July and August. The average relative humidity is 53%. Rain falls mostly between June and September, with annual precipitation between 75 and 300 millimeters. The winter (December to February) is pleasant with cool nights and warm days, without frost or snow.

(5) Tulancingo

Tulancingo is 90 km from Mexico City and is the second largest city in the state of Hidalgo. It is located at 20° 04' N 98° 22' W;this city has an elevation 2180 m abovesea level. It has a population of about 193,638 inhabitants. Tulancingo's metropolitan area is the result of the urban agglomeration of six cities in the state of Hidalgo, so is the state's second largest and one of the 50 most populous conurbation of Mexico. The climate in Tulancingo is cold-temperatewith an average annual temperature of 14 °C and rainfall between 500 and 553 mm per year. The average relative humidity is 65%. Tulancingo's climate is temperate with rains in summer and dry winter, with occasional frost.

(6) México City

Mexico City is the capital and largest city in Mexico. It is located in the Valley of Mexico, in a large basin in the highlands of central Mexico, at 19 º 24'N, 99 ° 09W, at an altitude of 2,240 m and covers an area of 1,485 km2. It has a population (in the metropolitan area of Mexico) of 20,137,152 inhabitants.Mexico City has a subtropical highland climate, with two distinct seasons. The average annual temperature varies from 12 to 16 °C, depending on the altitude. The lower temperatures usually registered during January and February, they may reach -2 or -5 °C. The maximum temperatures of late spring and summer may reach up to 32 °C. The extremes range from -4.4 ° C to 33.9 °C. The annual average relative humidity is 57%. Rainfall is generally concentrated in the summer months, including hail. The central valley of Mexico rarely gets snow during winter.

(7) Guadalajara

The metropolitan area of Guadalajara is an urban region resulting from the merger of the city of Guadalajara and other locations in the state of Jalisco. Together, these towns and villages are known as the city of Guadalajara. This metropolitan area is the second most populated city in Mexico with a population of 4,364,069 inhabitants. It is located at 20 ° 36'N 103 ° 21 ' W, at an average altitude of 1,570 m. Guadalajara has a humid subtropical climate, the highest temperatures are usually in May with an average of 33 °C, but can reach 39 °C just before the start of the rainy season. The annual average relative humidity is 59%. March is usually the driest month and July the wettest, with an average of 273 mm of rain, over a quarter of the annual average of about 1,002 mm. Winters are relatively warm despite the city's altitude, with January daytime temperatures reaching around 25 °C and night temperatures around 10 °C.

4.1 Climate in the selected cities

According to records of Meteonorm, Figure 4.1.1 shows the minimum, average and maximum annual average temperatures of each of the 7 selected cities. The average annual temperature in the cities is between 16.8 °C and 27.5 °C. The highest average annual temperature was 27.5 °C in Villahermosa followed by Merida (26.7 °C), Hermosillo (24.2 °C), Monterrey (23.2 °C), Mexico City (18.8 °C), Tulancingo and Guadalajara (16.8 °C). The highest annual average maximum temperature was 44.1 °C in Hermosillo, followed by Merida (41.2 °C), Monterrey (40.1 °C), Villahermosa (38.7 °C), Mexico City (34.6 °C), Guadalajara (32.2 °C) and Tulancingo (30.8 °C). The highest annual average minimum temperature was 16.1 °C in Villahermosa followed by Merida (11.3 °C, Hermosillo (3.9 °C), Guadalajara (2.3 °C), Monterrey (1.8 °C), Tulancingo (0.7 °C) and Mexico city (0.5 °C). The greater range in the average seasonal temperatures was 40.2 °C for Hermosillo followed by Monterrey (38.3 °C), Mexico City (34.1 °C), Tulancingo (30.1 °C) , Mérida (29.9 °C) and Villahermosa (22.6 °C) .

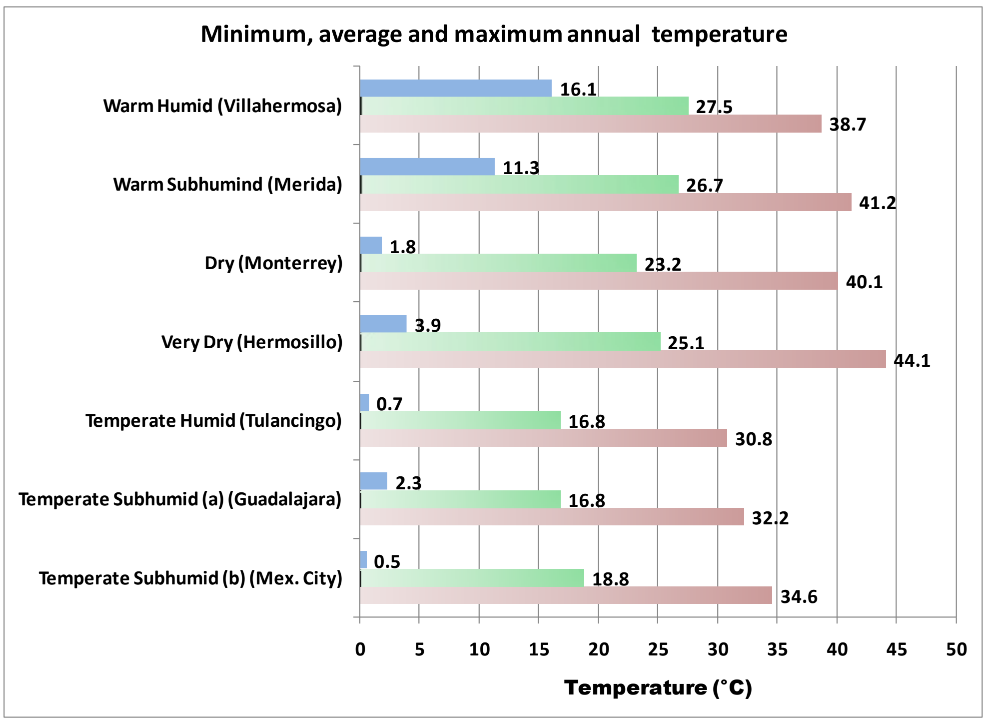


Figure 4.1.1.-Annual maximum, average and minimum temperature.

The Figure 4.1.2 shows the annual incident solar radiation on the seven cities. As can be seen Hermosillo receives more solar energy (2,104 kWh/m^2), followed by Tulancingo (2,048 kWh/m^2), Guadalajara (2,046 kWh/m^2), Mérida (1,920 kWh/m^2), Monterrey (1,863 kWh/m^2), Mexico City (1,798 kWh/m^2) and Villahermosa (1,791 kWh/m^2).

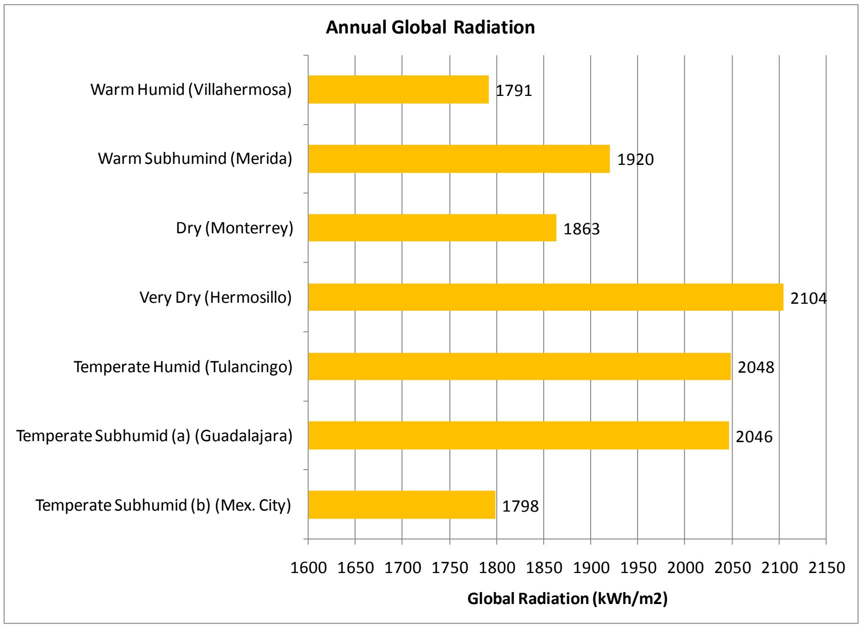


Figure 4.1.2. Annual incident solar radiation.

The Figure 4.1.3 presents the annual average relative humidity of the selected cities. The greatest average relative humidity was Villahermosa (74%) followed by Mérida (73%), Monterrey (60%), Guadalajara (53%), Mexico (52%), and Hermosillo (39%).

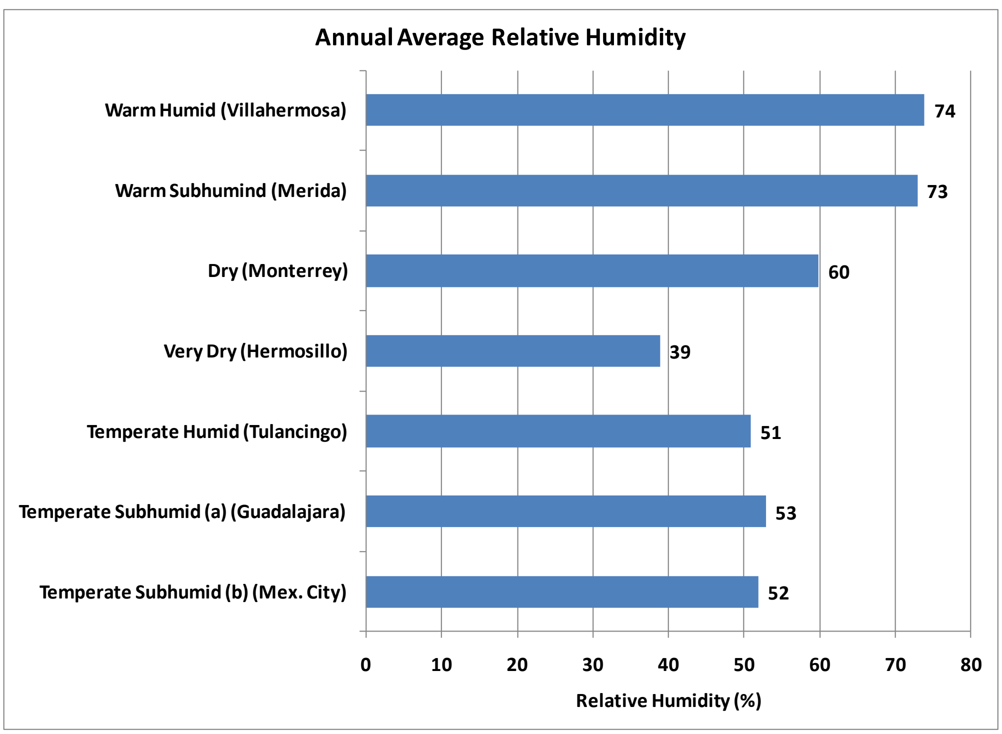


Figure 4.1.3.Annual average relative humidity

The Figure 4.1.4 presents the average annual wind speed of the selected cities. The highest average wind speed was for Mérida (3.4 m/s), followed by Mexico City and Tulancingo (2.9 m/s), Monterrey (2.3 m/s), Hermosillo (1.9 m/s) and Guadalajara (1.8 m/s).

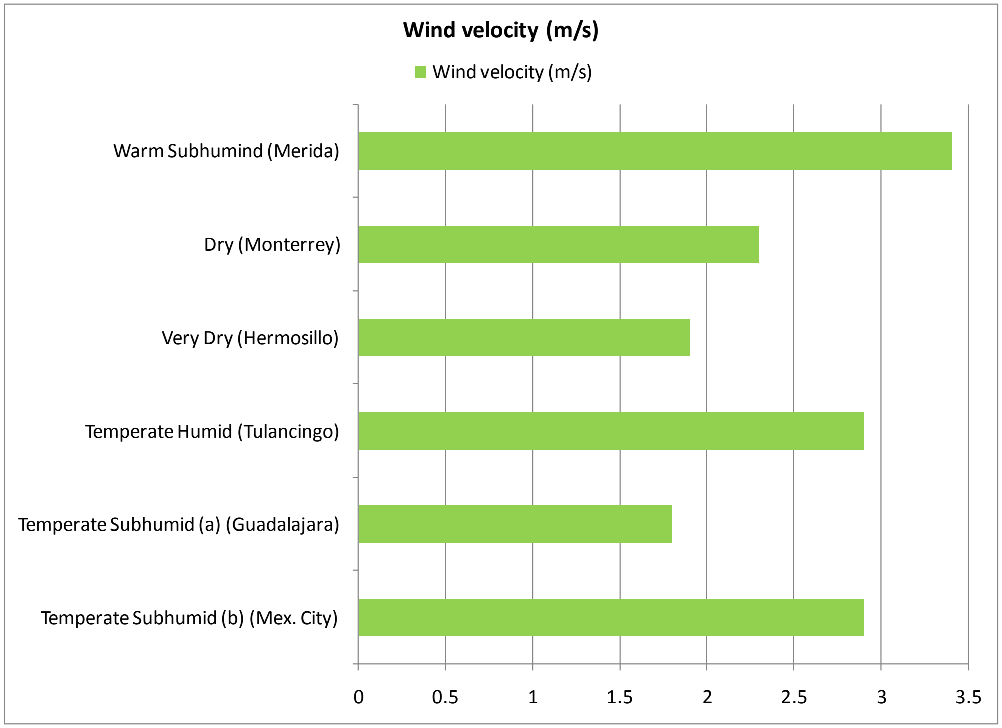


Figure 4.1.4. Annual average wind speed.

The Figure 4.1.5 shows the annual average cloudiness index of the selected cities. The lowest index of cloudiness was for very dry climate (Hermosillo) and highest cloudiness index was for the warm humid climate (Villahermosa), and temperate cities as expected.

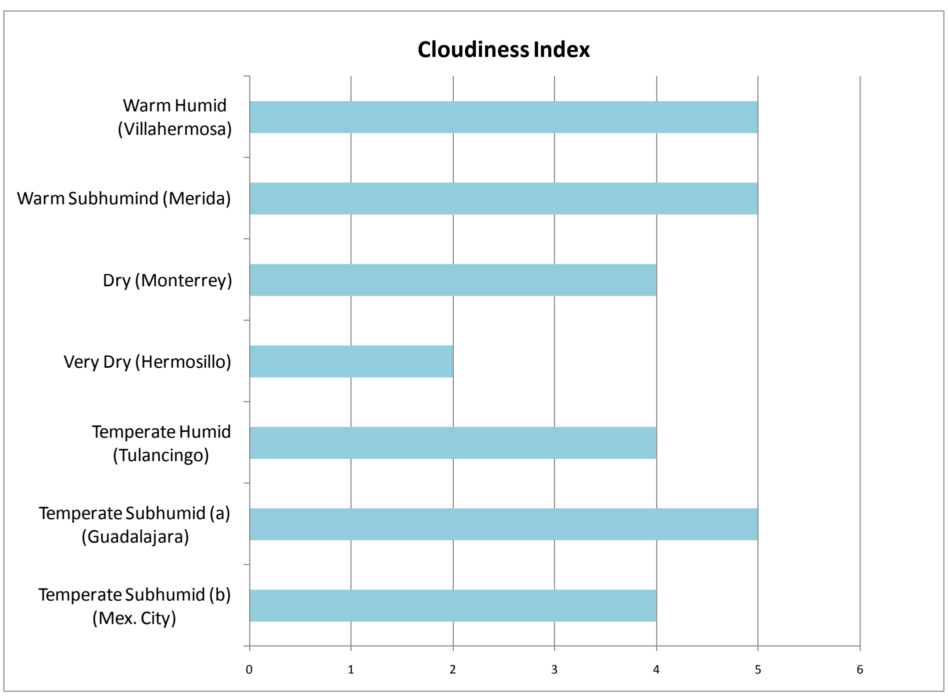


Figure 4.1.5. Annual average cloudiness index.

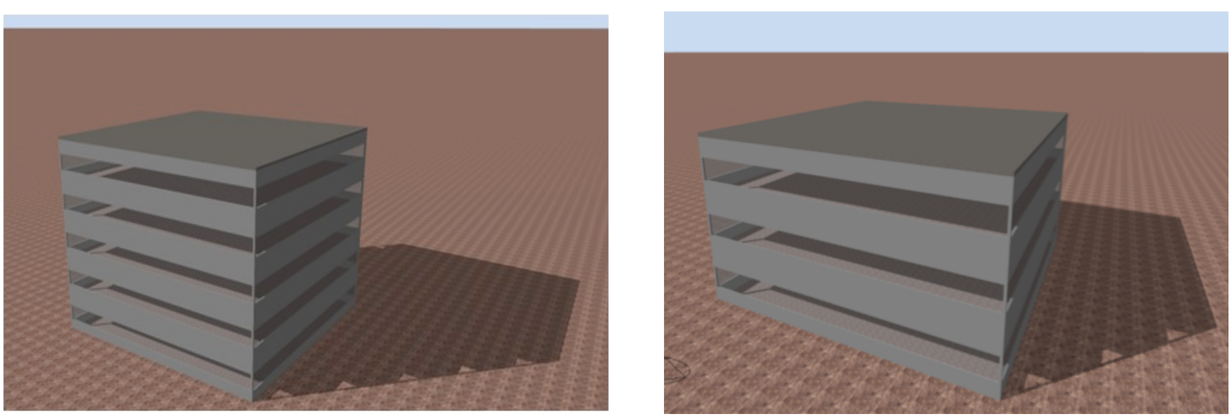
5. Description of the base buildings

The Mexican building energy standards, NOM-008-ENER-2001 (non-residential) and NOM-020-ENER-2011 (residential), utilized reference building prototypes to model the expected building energy savings. These same prototypes, described in the following three references, were used for this study. The prototypes informed the configuration of the buildings, construction materials, thermal and optical properties and zones for the building energy simulations.

1. Energy effective and cost effective building energy conservation measures from Mexico. M.A. Halverson, D.J. Stucky, M. Fredrich, P. Godoy-Kain, J.M. Keller, S. Somasundaran. Pacific NW Laboratory, Richland, Washington. June 1994.
2. A commercial building energy standard for Mexico. J. Huang, J.L. Warner, S. Wiel. Berkeley California. A. Rivas, RAMPA, O. de Buen. CONAE, México.
3. Notes on the typical house description as used with SUNCODE. C. Heard, 1993.

5.1 Base case Non-Residential Building

From the information of references 1 and 2, the configuration and other parameters of the non-residential building were obtained. The Figures 5.1.1 (a) - (b) show the schematic of the non-residential building considered in the development of NOM-008-ENER-2001. Figure 5.1.1 (a) shows a five-story square building for Mexico City and Figure 5.1.1(b) A three-story building for the other cities. The aspect ratio of non-residential building was 1:01, with 25 m of each side. Each floor has an area of 625 m^2 and a window-wall ratio (WWR) of 40%. The HVAC system is supposed to work during occupied hours from 08:00 to 22:00 h from Monday to Friday. The reference temperature (set point) is 25 °C. The albedo of the exterior walls and the roof was 0.25.



(a) (b)

Figure 5.1.1 (a) Non-residential building of five-story for the City of Mexico and (b) Non-residential building of three-story for other cities.

The Table 5.1.1 shows the characteristics of non-residential building. The input parameters that are introduced for the simulation in EnergyPlus are the same as those reported in the references.

Table 5.1.1 Description of the base case Non-residential building

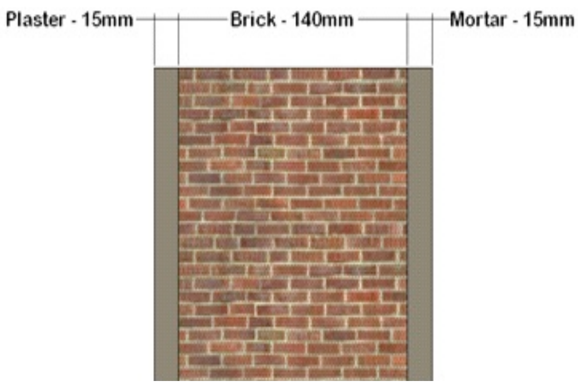
Non-residential building	
Description	**Value**
Number of floors	Mexico City - 5
	Other cities - 3
Building Area	Mexico City: 3125 m^2
Floor height	4 m
Area per floor	669 m^2
Aspect ratio	01:01
Illumination levels	16 W/m^2
Contacts	8 W/m^2
Density of people	9 m^2 per person
Ventilation rate	0.46 m^3/min-m^2
Infiltration rate	1 ACH
Wall reflectance	0.25
Roof reflectance	0.25
Working hours	8:00-22:00 (Mon-Fri)
Set point	25 °C
Window Wall ratio (WWR)	40%

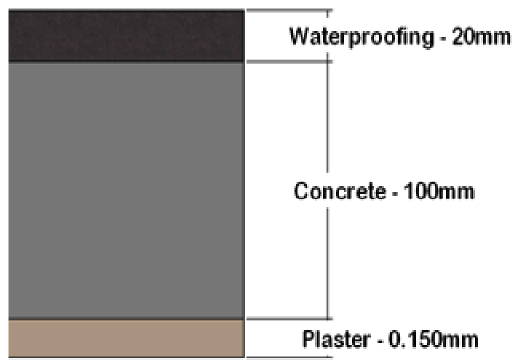
Table 5.1.2 presents building materials, dimensions and thermophysical properties of the building envelope. Construction materials are the same for both, the non-residential and the residential buildings. The main material used for the walls is red brick (brick). The roof is made of waterproof concrete with colored coating on the outside. The floors are concrete slab and covered with tiles. The windows are aluminum frame and clear glass that is 4 mm thick.

Table 5.1.2 Building Materials, dimensions and thermophysical properties

Element	Material Name	ℓ [mm]	*Cp* [J/kg*K]	λ [W/m*K]	*ρ* [kg/m3]
First floor	Tile	10	795	1.136	2600
	Concrete	100	840	1.740	2300
Superior floors	Tile	10	795	1.136	2600
	Concrete	100	840	1.740	2300
	Plaster	15	1000	0.372	800
Wall	Plaster	15	1000	0.372	800
	Brick	140	800	0.81	1600
	Mortar	15	837	0.72	1890
Roof	Plaster	15	1000	0.372	800
	Concrete	100	840	1.740	2300
	waterproofing	20	800	0.17	1127
Window	Clear glass	4	-	-	-

Figure 5.1.2 (a) - (b) shows the detail of the configuration of the wall and roof of the two reference buildings, non-residential and residential. The walls are made of bricks that are14 cm thick, coated on the outside by 15 mm mortar and a 15 mm plaster layer in the inside. Roofs are made of 10 cm of concrete with a plaster layer inside and 20mm of waterproofing coating in the outside. The reflectance of the roof is 0.25 for non-residential building and 0.1 forresidential building





(a) (b)

Figure 5.1.2 (a) Configuration of the wall and (b) configuration of the roof.

The Table 5.1.3 shows the thermal conductance of the envelope of non-residential building with 3 floors. The total thermal conductance is 6,432 W / K.

Table 5.1.3. Thermal conductance of the envelope of the Non Residential building with 3 floors.

Component	Area(m2) A	Overall heat transf. coefficient, K (W/m^2*K)	Total thermal conductance, 1/R (W/K)
Roof	625	2.481	1550.625
Walls	720	2.813	2025.36
Window	480	5.95	2856
Door	0	2.04	0
		Σ=	**6,431.99**

The total thermal conductance for ventilation of non-residential building with 3 floors is presented in Table 5.1.4. The calculation considers the volumetric capacity and density of the air, the air changes per hour and the volume of non-residential building [Athnienitis and Santamouris, 2002].

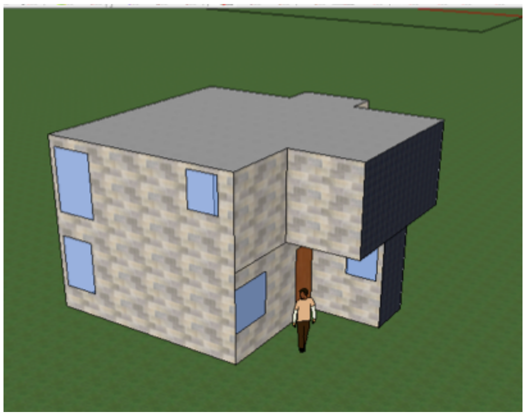
Table 5.1.4. Conductance for ventilation Non-residential building with 3 floors.

Volumetric capacity of moist air ($J/m^3°C$)	Air changes per hour N	Volume V (m^3)	Total thermal conductance, for ventilation, 1/R (W/K)
1200	2	7500	**5,000.00**

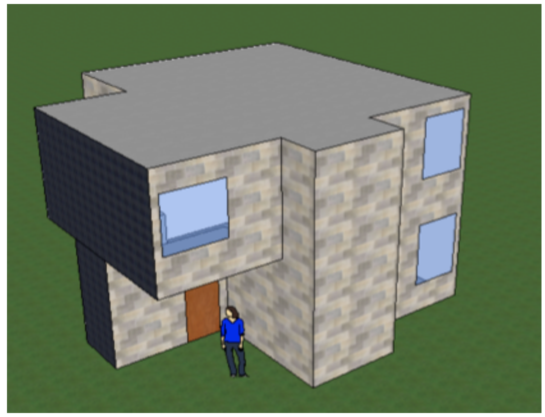
The total conductance of the non-residential building is 6431.99 W/K + 5,000.00 W/K = 11431.98 W / K.

5.2 Base Case Residential Building

The reference residential building used to develop the NOM-020-ENER-2011 is reported in reference (3) C. Heard (1993). This building is a typical two-story house belonging to a horizontal set. Figure 5.2.1 shows the front and back view of this building. The main facade is oriented north. Buildings of the same type are connected by the east and west walls, as shown in Figure 5.2.2.

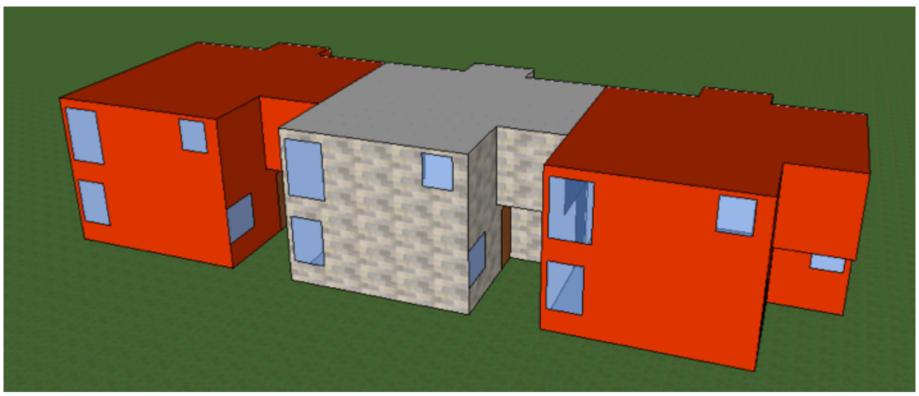


Front view.

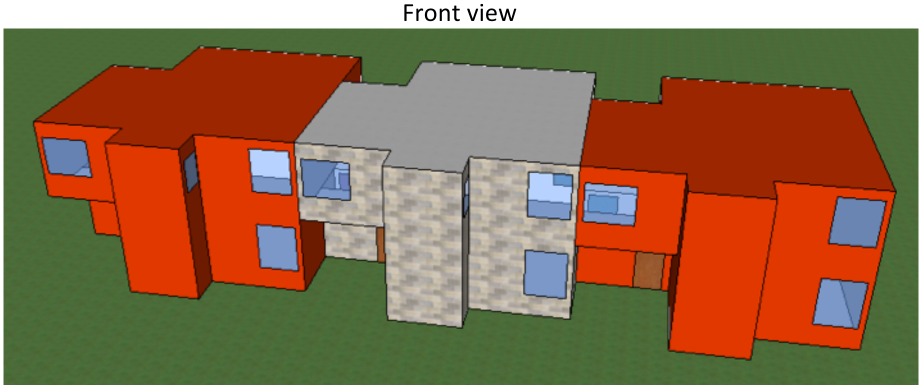


Back view

Figure 5.2.1. Residential building of reference, front and back views.



Front view



Back view

Figure 5.2.2. Set of residential buildings, front and back views.

The total area of the residential building was 88 m^2. The albedo considered for the exterior walls and the roof is 0.1. The reference temperature is 25 °C for the HVAC set point. The occupation of the house is 4 people. Internal gains for kitchen appliances are considered. The central air conditioning system and operates all year Monday through Friday, 1:00 to 9:00h and 15:00 to 24:00 h, and on Saturday and Sunday, 1:00 to 24:00 h. In the SUNCODE program, as reported by C. Heard, heat loads for appliances and people are given in terms of sensible heat loads. EnergyPlus calculates these loads by using a polynomial function defined by the activity of the occupants. In this building, the walls may have more than one window, and the dimensions can be different. Table 5.2.1 presents an overview of residential building, its parameters and values.

Table 5.2.1. Description of the residential building, parameters and values.

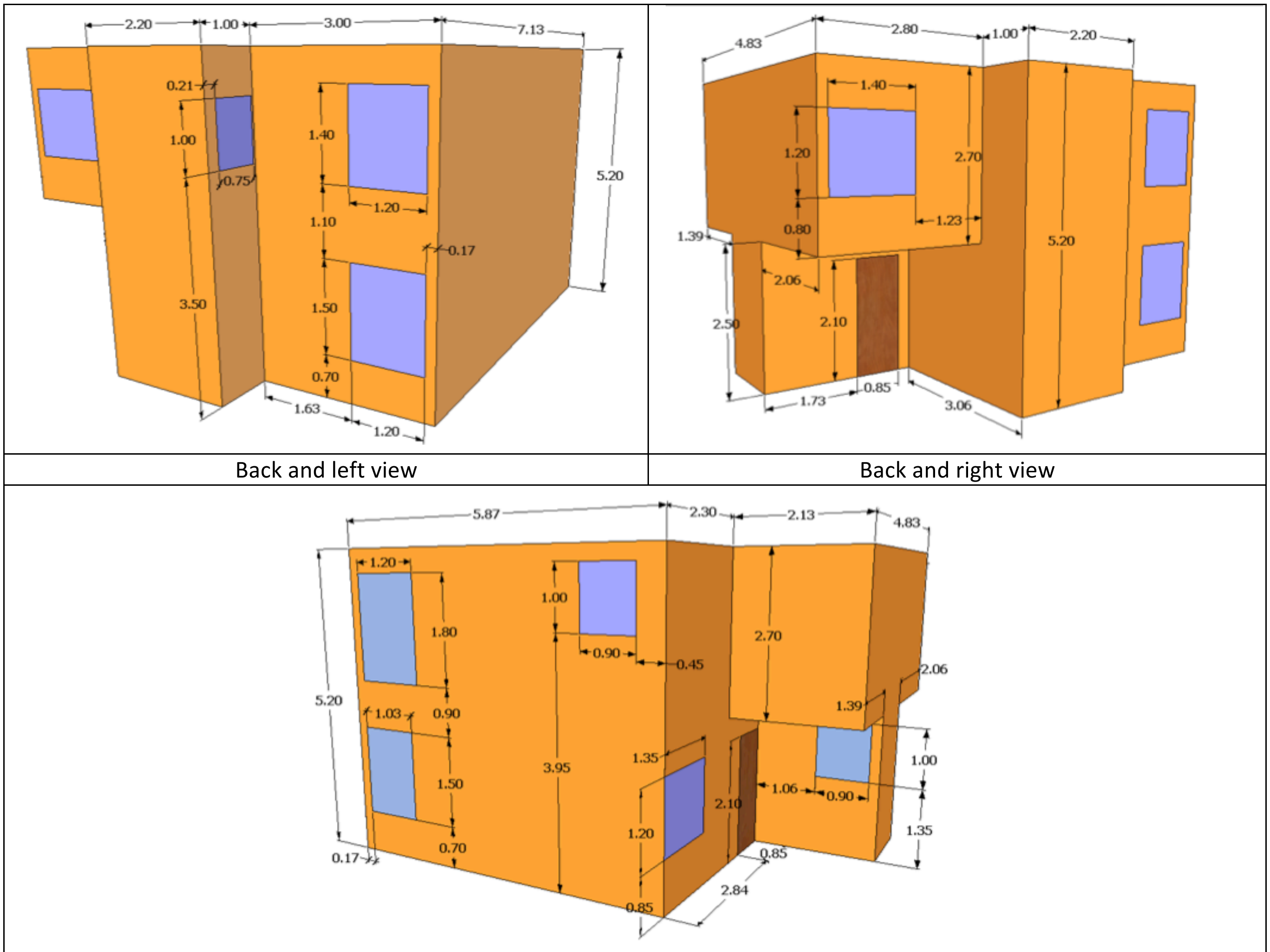
Description	Value
Number of floors	2
City	Mexico City
Total area	88 m^2
Height between floors	2.5 m
Window wall ratio (WWR)	Different for each wall
Aspect ratio	--
Ventilation index	No ventilation
Infiltration index	2 ACH
Walls reflectance	0.1
Roof reflectance	0.1 – 0.9 (parameter of study)
Operative hours	Defined
Set point	25 °C
Contacts	Consumption of appliances
Occupationaldensity	Sensible and latent loads
Cargas de aire acondicionado (HVAC)	Mo-Fri (1-9)hrs and (15-24)hrs Sat-Sun (1-24)hrs

The residential building does not have a window wall ratio defined. Each orientation has a different window design. Table 5.2.2 describes the distribution of openings and their dimensions. The front facade has four windows. The back facade has three windows and a wooden door. The left and right sides have a window. The main and the back doors are made of wood with U=2.04 W/m^2K.

Table 5.2.2. Description for the openings for the building.

Facade	Description	Material	Area (m^2)	K (W/m^2K)
Front	Main door	Wood	1.78	2.04
	Window 1	Glass	1.54	5.95
	Window 2	Glass	2.16	5.95
	Window 3	Glass	0.9	5.95
	Window 4	Glass	0.9	5.95
Back	Back door	Wood	1.78	2.04
	Back door	Glass	1.8	5.95
	Window 4	Glass	1.68	5.95
	Window 5	Glass	1.68	5.95
Right side	Window 6	Glass	1.62	5.95

Figure 5.2.3 shows the dimensions in detail of the residential buildings. The thickness of the wall is 0.17 m, the thickness of the roof is 0.135 m and the height of each floor is 2.5 m.



Back and left view | Back and right view

Front and right view

Figure 5.2.3.3 Dimensions of the base case residential building(dimensions in meters).

Table 5.2.3 presents the building component, the area, the overall heat transfer coefficients and the thermal conductance of the residential building envelope according to NOM-020-ENER-2011. The total thermal conductance is 691.45 W / K

Table 5.1.3. Total thermal conductance of the residential building envelope.

Component	Area (m^2) A	Overall heat transfer coef., K (W/m^2*K)	Total thermal conductance, 1/R W/K
Roof	54.341	2.481	134.8200
Walls	167.735	2.813	471.8385
Windows	13.03	5.95	77.5285
Doors	3.56	2.04	7.2624
		Σ=	**691.45**

The total thermal conductance of residential building ventilation is presented in Table 5.1.4 [Athnienitis and Santamouris, 2002].

Table 5.1.4. Conductance for ventilation of residential building.

Volumetric capacity of moist air (J/m^3°C)	N	V (m^3)	Total thermal conductance for ventilation 1/R (W/K)
1,200	2	252.26	**168.17**

The total conductance of residential bulding is 691.45 W / K +168.17 W / K = 859.62 W / K.

6. Dynamic simulation of the base case buildings.

The calculation of annual cooling loads as function of roof reflectance for the base case buildings was carried out for two cases: Case A no-roof insulation and Case B: roof insulation. The reflectance was modified within the range of 0.1-0.9. The results of the annual cooling loads and energy savings by the use of reflective roofs for the 7 cities in different climates are presented.

6.1 Non-residential building. Case A: no roof insulation.

Figure 6.1.1 shows the annual cooling load of the non-residential building as a function of the roof reflectance (0.1-0.9) for Case A, for all climates: humid hot (Villahermosa), subhumid hot (Mérida), dry (Monterey), very dry (Hermosillo), humid temperate (Tulancingo) and subhumid temperate (Mexico City and Guadalajara). In all climates, as the roof reflectance increases the cooling energy consumption decreases. The higher cooling loads are for Villahermosa and Merida, followed by Hermosillo, Monterrey. The cities of Guadalajara and Mexico City have very similar cooling loads, and Tulancingo has the lowest cooling loads, which has a temperate humid climate. The Table 6.1.1 shows the values of the cooling loads.

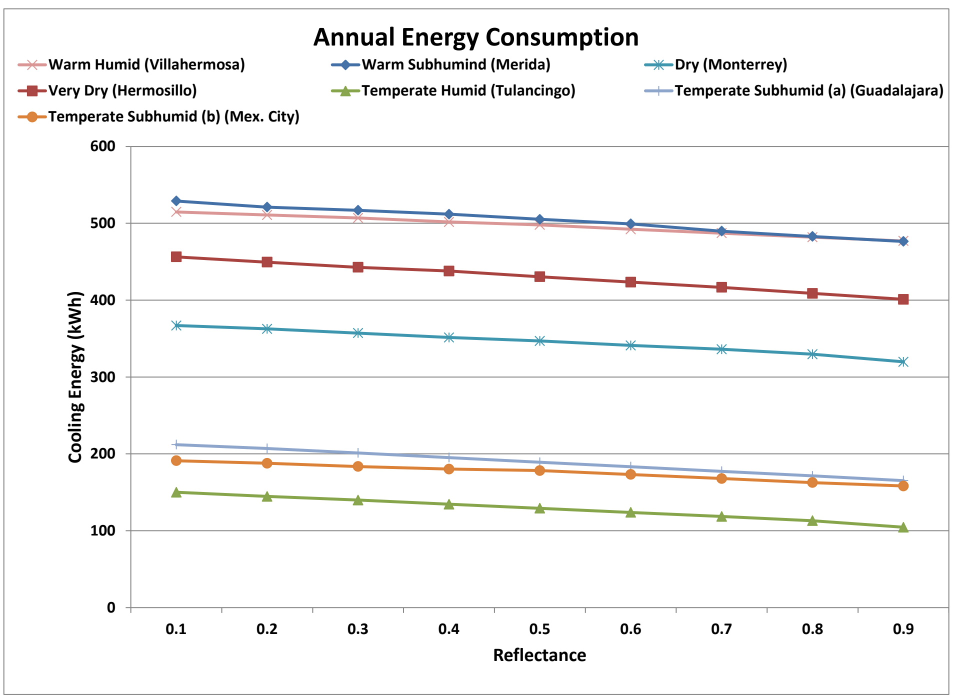


Figure 6.1.1 Annual cooling loads for the non-residential building as a function of roof reflectance in 7 cities in 6 climatic zones.

Table 6.1.1 Values of the annual cooling loads(MWh) for the non-residential building as a function of the roof reflectance for 7 cities in 6 climatic zones

Annual cooling energy (MWh) – Non-Residential building							
Roof reflectance	**Warm Humid (Villahermosa)**	**Warm Subhumid (Mérida)**	**Dry (Monterrey)**	**VeryDry (Hermosillo)**	**Temperate Humid (Tulancingo)**	**Temperate Sub humid(a) (Guadalajara)**	**Temperate Subhumid(b) (Mexico City)**
0.1	514.8	529.0	367.0	456.3	150.0	212.1	191.1
0.2	510.8	521.1	362.7	449.5	144.6	207.1	187.7
0.3	507.0	517.0	357.1	442.8	139.9	201.3	183.6
0.4	501.7	511.9	351.5	437.9	134.5	195.2	180.2
0.5	498.0	505.3	346.9	430.5	129.2	189.1	178.3
0.6	492.2	499.2	341.1	423.5	123.9	183.3	173.2
0.7	487.2	489.8	336.1	416.6	118.6	177.3	168.0
0.8	481.9	482.9	329.7	408.8	113.0	171.4	162.6
0.9	477.1	476.4	319.7	401.1	104.5	165.2	158.2

As can be seen, the cooling loads are very close for the cities of Villahermosa and Merida, as well as Mexico City and Guadalajara.That is why in the following analysis we considered only 5 of the 7 selected cities.

6.1.1 Non-residential building - Case B: roof insulation.

Simulations were carried out considering roof insulation, following the limits of heat gain that are included in NOM-008-ENER-2001. This NOM limits the heat gain through the envelope of non-residential building in order to achieve comfort conditions and to avoid or rationalize energy use in air conditioning systems.To comply the NOM, the calculation of heat gain in the projected building must be less or equal to that of a base building with the same dimensions. It should be noted that the contribution of heat gains depends on the type of envelope and can be controlled through shade, optical properties of glass, low emissivity materials, materials with high heat resistance, or thermal insulation. Table A from the normative appendix for NOM-008-ENER-2001 establishes the values of the overall heat transfer coefficient (K) for walls and roofs of a non-residential building in a variety of cities in Mexico.The models of the reference building were designed considering the overall heat transfer coefficient (K) equal to or less than those established in NOM-008-ENER-2001, so that the energy savings of the buildings that previously met with the official Mexican standards are calculated.

The roof of the reference building is a common roof that consists of a concrete slab, plaster on the inside and waterproof on the outside. For this component the overall heat transfer coefficient (K) is calculated.

Table 6.1.1.1shows the method of calculation of the overall heat transfer coefficient (K) of the ceiling of the non-residential building (no insulation). From the thermophysical properties of the roof, Table 5.1.2, the thermal resistance of the roof of the building is calculated by $R = \frac{1}{ho} + \frac{l}{\lambda} + \frac{1}{hi}$, hence, $U = \frac{1}{R}$.

Table 6.1.1.1 Calculation of thermal resistance and thermal conductance of the roof of the Non Residential building.

Material	Thickness	
Air	-	ho= 13 W/m^2K
Asphalt waterproofing membrane	0.02 m	λ= 0.17 [W/m*K]
Concrete	0.10 m	λ= 1.740
Plaster	0.01 m	λ=0.372
Air	-	hi= 6.6 W/m^2K
	R=	**0.335 m^2K /W**
	K=	**2.98W/m^2K**

The thermal conductance of the roof assembly of the non-residential building for Case A is 2.98 W/m^2K, this value is higher than the one specified in the NOM code. To comply with the code, the insulation values are calculated. If we consider using extruded polystyrene (EPS) insulation, its properties are λ = 0.028 W/mK, Cp = 1470 J/kgK y ρ= 30 kg/m^3. Thus, the thicknesses of EPS roof insulation was calculated for all of the cities listed in NOM-008-ENER-2001. The results of the thickness of the EPS insulation for each of the cities are presented in Table 6.1.1.2.

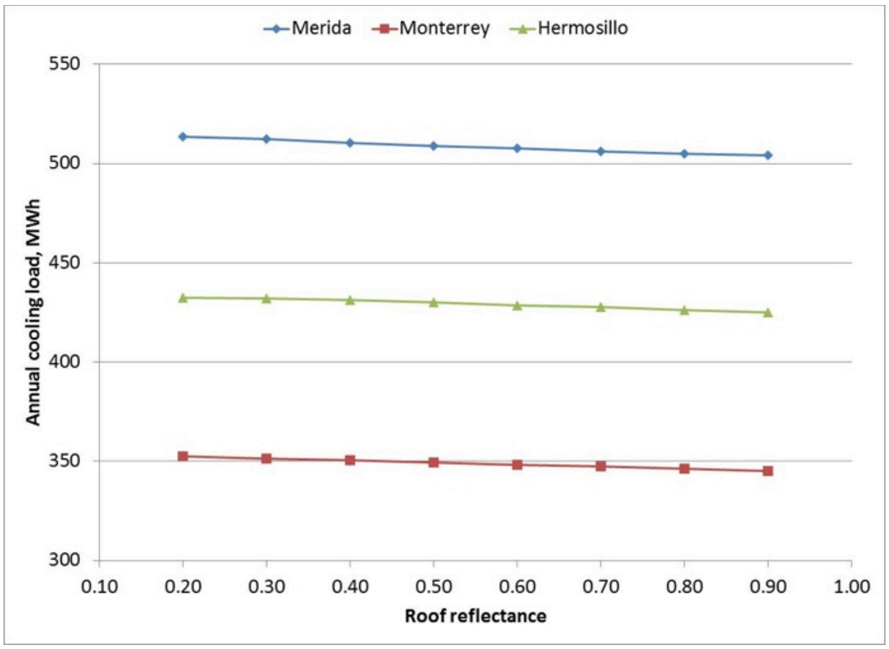
Table 6.1.1.2. Overall heat transfer coefficient (K) and the thickness of the insulation corresponding to the non-residential building.

State	City	$K_{Roof}(W/m^2K)$	Thickness (m)	Thickness (in)
AGUASCALIENTES	Aguascalientes	0.391	0.060	**2.380**
BAJA CAL. SUR	La Paz	0.358	0.067	**2.640**
	Cabo S. Lucas	0.360	0.067	**2.623**
BAJA CALIFORNIA	Ensenada	0.391	0.060	**2.380**
	Mexicali	0.354	0.068	**2.674**
	Tijuana	0.391	0.060	**2.380**
CAMPECHE	Campeche	0.357	0.067	**2.648**
	Cd. Cármen	0.356	0.067	**2.657**
COAHUILA	Monclova	0.357	0.067	**2.648**
	PiedrasNegras	0.356	0.067	**2.657**
	Saltillo	0.391	0.060	**2.380**
	Torreón	0.360	0.067	**2.623**
COLIMA	Colima	0.362	0.066	**2.606**
	Manzanillo	0.358	0.067	**2.640**
CHIAPAS	Arriaga	0.357	0.067	**2.648**
	Comitán	0.391	0.060	**2.380**
	San Cristóbal	0.391	0.060	**2.380**
	Tapachula	0.361	0.066	**2.614**
	Tuxtla Gutiérrez	0.362	0.066	**2.606**
CHIHUAHUA	N. Casas Grandes	0.391	0.060	**2.380**
	Chihuahua	0.365	0.066	**2.581**
	Cd. Juárez	0.363	0.066	**2.597**
	Hidalgo del Parral	0.391	0.060	**2.380**
D.F.	México	0.391	0.060	**2.380**
DURANGO	Durango	0.391	0.060	**2.380**
	Lerdo	0.360	0.067	**2.623**
GUANAJUATO	Guanajuato	0.391	0.060	**2.380**
	León (b)	0.391	0.060	**2.380**
GUERRERO	Acapulco	0.356	0.067	**2.657**
	Chilpancingo	0.391	0.060	**2.380**
	Zihuatanejo	0.362	0.066	**2.606**
HIDALGO	Pachuca	0.391	0.060	**2.380**
	Tulancingo	0.391	0.060	**2.380**
JALISCO	Guadalajara (c)	0.391	0.060	**2.380**
	Huejucar	0.391	0.060	**2.380**
	Lagos de Morelos	0.391	0.060	**2.380**
	Ocotlán	0.391	0.060	**2.380**
	Puerto Vallarta	0.357	0.067	**2.648**
MÉXICO	Chapingo	0.391	0.060	**2.380**
	Toluca	0.391	0.060	**2.380**
MICHOACÁN	Morelia	0.391	0.060	**2.380**
	Lázaro Cardenas	0.358	0.067	**2.640**
	Uruapan	0.391	0.060	**2.380**

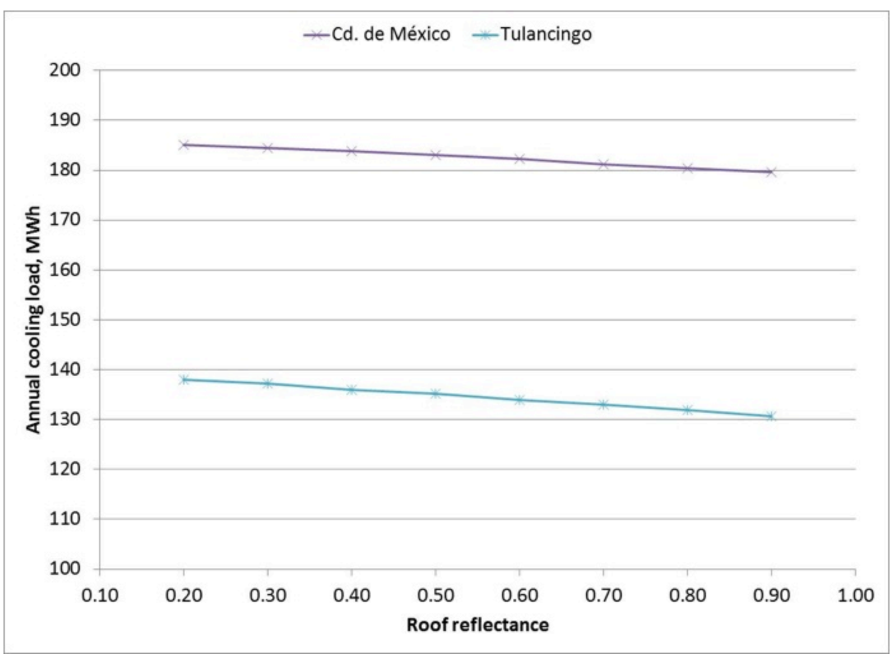
MORELOS	Cuernavaca	0.391	0.060	**2.380**
	Cuautla	0.391	0.060	**2.380**
NAYARIT	Tepic	0.391	0.060	**2.380**
NUEVO LEÓN	Monterrey	0.359	0.067	**2.631**
OAXACA	Oaxaca	0.391	0.060	**2.380**
	Salina Cruz	0.355	0.068	**2.666**
PUEBLA	Puebla	0.391	0.060	**2.380**
	Atlixco	0.391	0.060	**2.380**
	Tehuacán	0.391	0.060	**2.380**
QUERÉTARO	Querétaro	0.391	0.060	**2.380**
	San Juan del Rio.	0.391	0.060	**2.380**
QUINTANA ROO	Cozumel	0.359	0.067	**2.631**
	Chetumal	0.358	0.067	**2.640**
	Cancun	0.355	0.068	**2.666**
	Playa del Carmen	0.356	0.067	**2.657**
SAN LUIS POTOSÍ	Río Verde	0.391	0.060	**2.380**
	San Luis Potosí	0.391	0.060	**2.380**
	Cd. Valles	0.356	0.067	**2.657**
	Matehuala	0.391	0.060	**2.380**
SINALOA	Culiacán	0.355	0.068	**2.666**
	Mazatlán	0.358	0.067	**2.640**
	Guasave	0.355	0.068	**2.666**
	Los Mochis	0.357	0.067	**2.648**
SONORA	Guaymas	0.354	0.068	**2.674**
	Hermosillo	0.352	0.068	**2.692**
	Cd. Obregón	0.357	0.067	**2.648**
	Navojoa	0.348	0.069	**2.728**
	Nogales	0.391	0.060	**2.380**
TABASCO	Villahermosa	0.354	0.068	**2.674**
	Comalcalco	0.356	0.067	**2.657**
TAMAULIPAS	Cd. Victoria	0.357	0.067	**2.648**
	Tampico	0.358	0.067	**2.640**
	Matamoros	0.364	0.066	**2.589**
	Reynosa	0.355	0.068	**2.666**
	Nuevo Laredo	0.354	0.068	**2.674**
TLAXCALA	Tlaxcala	0.391	0.060	**2.380**
VERACRUZ	Coatzacoalcos	0.358	0.067	**2.640**
	Córdoba	0.391	0.060	**2.380**
	Jalapa	0.391	0.060	**2.380**
	Orizaba	0.391	0.060	**2.380**
	Tuxpan	0.360	0.067	**2.623**
	Poza Rica	0.357	0.067	**2.648**
	Veracruz	0.358	0.067	**2.640**
YUCATÁN	Mérida	0.358	0.067	**2.640**
	Progreso	0.359	0.067	**2.631**
	Valladolid	0.360	0.067	**2.623**
ZACATECAS	Fresnillo	0.391	0.060	**2.380**
	Zacatecas	0.391	0.060	**2.380**

The K-values listed in Table 6.1.1.2. range between 0.348-0.391, which corresponds to 2.38-2.73 in inches of extruded polystyrene insulation. Insulation is usually sold in 1", 1.5", 2.0", 2.5", or 3" thickness. Therefore, for the EnergyPlus simulation 2.5 inch thickness is considered, which corresponds to an overall heat transfer coefficient (K) of 0384 W/m^{2}K. Building energy simulations are performed, assuming this new heat transfer coefficient, forMerida, Monterrey, Hermosillo, Mexico City and Tulancingo, corresponding to 5 climatic zones.

Figure 6.1.1.2 (a) - (b) shows the annual cooling load for the reference non-residential building with an insulated roof of 2.5" as a function of the reflectance of the roof. For each city, reduced annual energy load by increasing the roof reflectance is observed. The values are presented in Table 6.1.1.3. The highest annual cooling energy savings by changing reflectance from 0.2 to 0.9 was in Mérida (9.36 MWh) and the lowest was for Mexico City (5.44 MWh).



(a)



(b)

Figura 6.1.1.2 Annual cooling energy consumption of the non-residential building with a 2.5” of insulation in the roof and with solar reflectance ranging from 0.2 to 0.9. (a) Mérida, Monterrey and Hermosillo, (b) Mexico city and Tulancingo.

Table 6.1.1.3 Annual cooling energy consumption of thenon-residential building with 2.5” of insulation in the roof and with reflectance ranging from 0.20 to 0.90 for each city.

Cooling energy (MWh) – Non-residential building					
Roof reflectance	**Subhumid hot (Merida)**	**Dry (Monterrey)**	**Very Dry (Hermosillo)**	**Sub humidTemperate (Cd. de Mex.)**	**Humid Temperate (Tulancingo)**
0.20	513.63	352.40	432.34	185.01	137.98
0.30	512.37	351.31	431.83	184.41	137.19
0.40	510.21	350.42	431.16	183.77	135.97
0.50	508.65	349.21	429.96	182.98	135.12
0.60	507.47	348.14	428.54	182.21	133.86
0.70	506.05	347.49	427.74	181.15	133.01
0.80	504.90	346.10	426.12	180.38	131.96
0.90	504.27	345.11	424.84	179.57	130.66

For the calculation of the annual cooling energy savings, a red roof that has a reflectance of 0.3 was considered as reference. Modifying the reference roof to a white roof with a solar reflectance of 0.6, 0.7 and 0.8 generated annual energy savings in the non-residential building for each city as shown in Figure 6.1.1.3. The results indicate that the largest annual energy savings are obtained for roofing reflectance of 0.8 for all cases. In terms of city and type of climate, the biggest savings are for the city of Mérida (semi-humid warm climate), followed by the City of Hermosillo (very dry), Monterrey (dry), Tulancingo (humid temperate) and Mexico City (temperate semi-humid).

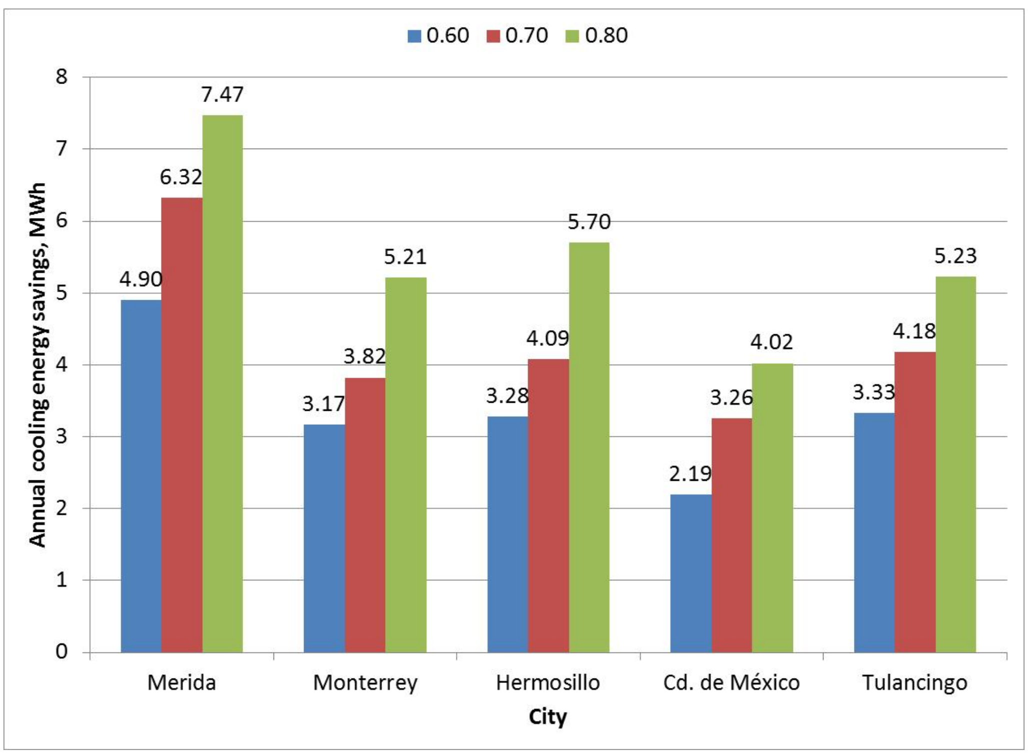


Figure 6.1.1.3.Annual cooling energy savings of the non-residential building having a roof with 2.5” of insulation and solar reflectance of 0.6, 0.7 and 0.8 for each city.

6.1.2 City-wide cool roof annual energy savings from non-residential buildings.

The Census of 2009 from the National Institute of Statistics and Geography (INEGI 2009) reported the number of small, medium and large commercial buildings for each state in Mexico. In this report, the commercial buildings considered are: markets, malls, transport stations, industrial complexes and other commercial buildings. Nationally, in 2009 there were 10,969 commercial buildings. Annual potential cooling energy savings were calculated assuming that all of the commercial buildings reported for each state are located in the city evaluated in that state, and the buildings are similar to the 3 story non-residential building. The Table 6.1.2 shows the number of non-residential buildings per city.

Table 6.1.2.1.Number of Non-residential buildings per city.

City	Number ofNon-residential buildings
Mérida	309
Monterrey	493
Hermosillo	258
Cd. de México	2566
Tulancingo	195

The Figure 6.1.2.1 presents the annual cooling energy savings in GWh considering the number of non-residential buildings per city when changing the solar reflectance from 0.3 (red) to 0.6, 0.7 and 0.8. For the temperate climates, as in Mexico City and Tulancingo, it was considered that 50% of thenon-residential buildings use air conditioners and the other 50% of the buildings do not use it. It was observed that when modifying from conventional red color to a white roof, for Mexico City, even considering that 50% of the non-residential buildings use air conditioning, the energy savings are bigger than any of the other cities.

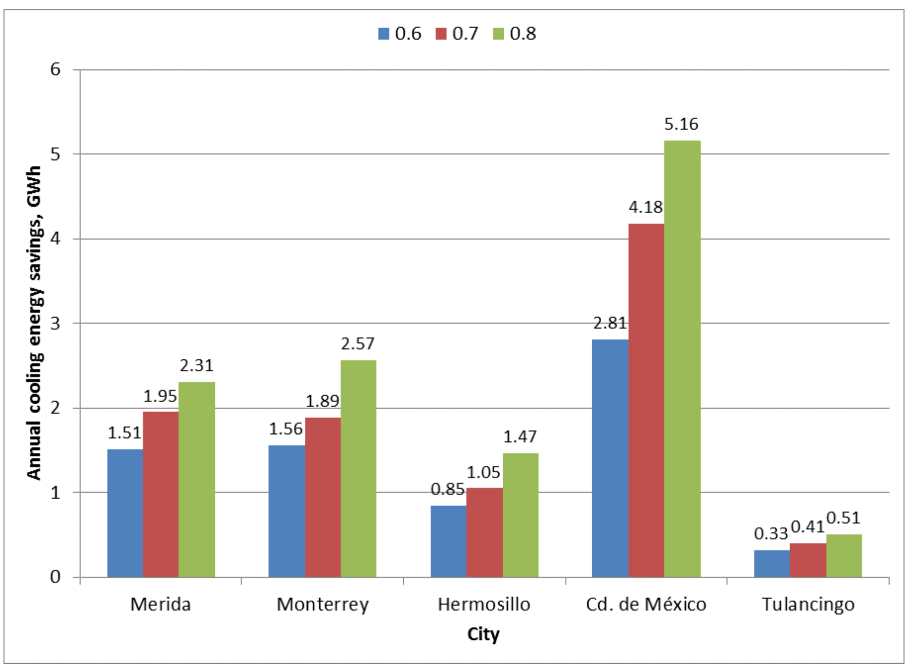


Figure 6.1.2.1. Annual cooling energy savings for the number of non-residential buildings in each city, the buildings have a roof with 2.5" of insulation and a reflectance of 0.6, 0.7 and 0.8.

Figure 6.1.2.2 presents the percentage savings of annual energy loads by changing the solar reflectance of the roof from 0.3 (red) to 0.8 (white) of non-residential building by city. 43% of total savings can be attribuited to cool roof implementation in Mexico City, while savings by cool roof implementation in Tulancingo is minimal.

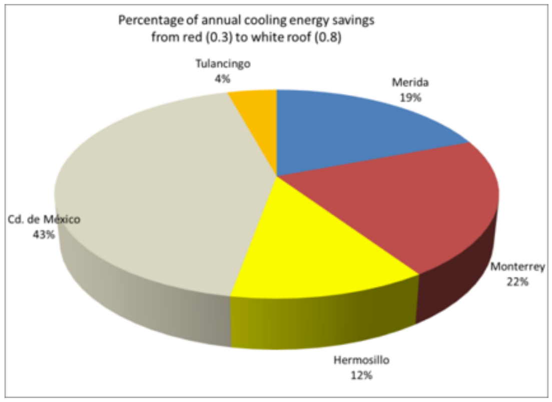


Figure 6.1.2.2. Percentage savings of annual cooling energy loads by changing roof reflectance from 0.3 to 0.8 for 5 cities, for case B: non-residential building with 2.5" of insulation.

6.1.3 Potential greenhouse emissionsreductions from non-residential building energy savings in the selected cities

The calculation of potential greenhouse gas emissions reductions resulting from cooling energy savings were generated following the Environmental Protection Agency of United States (EPA, 2012). The EPA indicates that 1 MWh of electricity is equivalent to 0.706 tons ofCO_2.

The calculation for the CO_2 that would be mitigated when using roofs with a reflectance of 0.6, 0.7 and 0.8 was developed using the results of the cooling energy savings for the non-residential building.

The Figure 6.1.3.1 presents the CO_2mitigation when changing from a red roof (0.3) to a white roof with reflectance of 0.6, 0.7 and 0.8 in the non-residential building. It is observed that when increasing the reflectance of the roofs, the reduction of CO_2emissions increases for all cases. It is worth noting that Merida avoids emitting 5.27 Tons of CO_2.

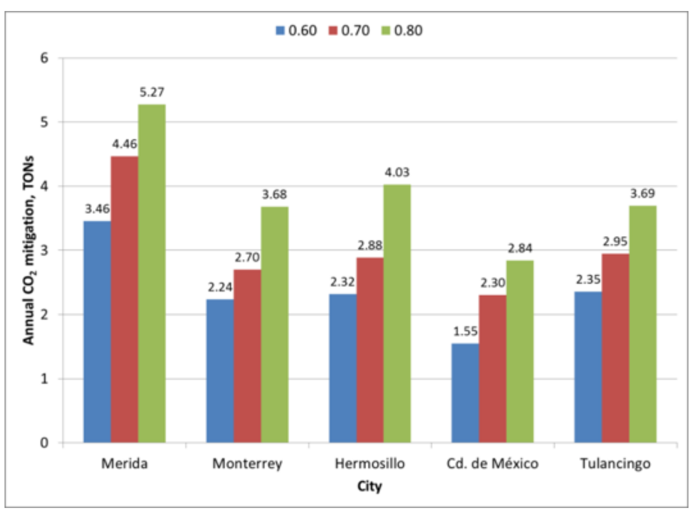


Figure 6.1.3.1 Annual mitigation of CO_2 for the non-residential building having a roof with 2.5" of insulation and solar reflectance of 0.6, 0.7 and 0.8 for each city.

The Figure 6.1.3.2 shows the mitigation of CO_2 emissions when changing from the red roof (0.3) to a white roof with reflectance of 0.6, 0.7 and 0.8 depending on the quantity of non-residential buildings for each city. In the same way, for temperate climates as Mexico City and Tulancingo, it was considered that 50% of the non-residential buildings use air conditioning. The results show that even when assuming that 50% of the non-residential buildings in Mexico City do not use air conditioning, the implementation of cool roofs would help to mitigate from 2.0 to 3.6 kTons of CO_2. The white roofs in cities located in hot climates would annually avoid around 1 to 1.8 kTons of CO_2emissions.

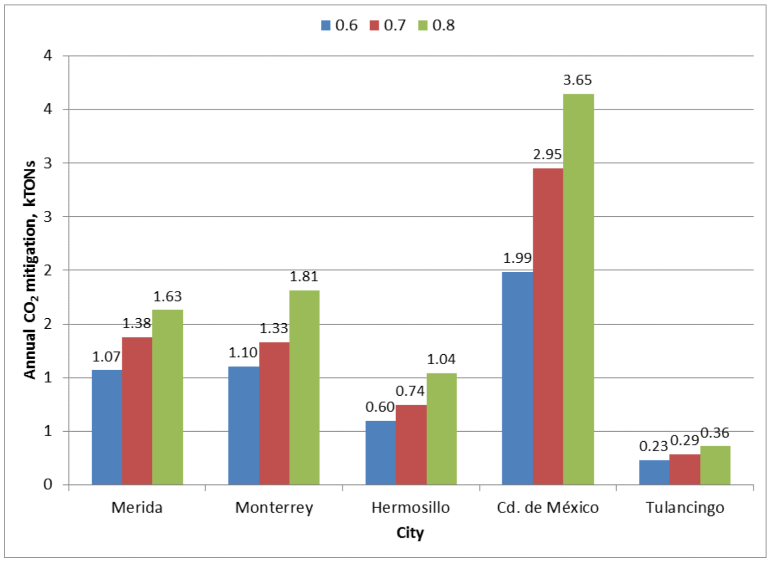


Figure 6.1.3.2Annual mitigation of CO_2 for all the non-residential building in the cities selected,thebuildingshave a roof with 2.5” of insulation and solar reflectance of 0.6, 0.7 and 0.8 for each city.

6.1.4 Monetary savings resulting from the energy savings and emission reductions in non-residential buildings

The savings on energy consumption provided by cool roofs reduce energy production needs and cut greenhouse gases emissions. Assuming that 50% of the non-residential buildings have air conditioning in Mexico City; that means 1286 buldings, the savings on the energy production and the reduction of CO_2 emissions/year due to the increase in solar reflectance from 0.3 to 0.6, 0.7 and 0.8 are estimated. The monetary savings on the energy production is calculated considering that the average cost of the production is **1.08 pesos/kWh**, as reported in by CFE in 2011. The mitigation of CO_2 emissions in terms of vehicles removed from the road was calculated assuming that one vehicle emits 5 tons of CO_2/year (EPA, 2012).

The table 6.1.4.1 presents the results of the analyzed impact regarding monetary savings of energy production and the reduction of CO_2/year when the roofs’ solar reflectance is changed from 0.3 to 0.6, 0.7 and 0.8 in the non-residential buildings located at Mexico City.

Table 6.1.4.1.Energy savings and CO_2 emissions reduction per year for Mexico City when increasing the roof solar reflectance from 0.3 to 0.8 in non-residential buildings.

Roof reflectance	0.6	0.7	0.8	
	Quantity	**Quantity**	**Quantity**	**Units**
Savings on energy consumption	2.81	4.18	5.16	GWh
Monetary savings due to energy production	3,034,800	4,515,400	5,572,800	Pesos
Reduction of CO_2 emissions	1,990	2,950	3,650	Tons
Equivalence in automotive vehicles	398	590	730	Vehicles

Monetary savings per building

The energy savings during the 5-year life cycle of the cool coating for the reference non-residential building are calculated. The typical cost per square meter for coatings with reflectance of 0.3, 0.6, 0.7 and 0.8 are presented in Table 6.1.4.2 together with the roof area of the non-residential building and the total cost. It is observed that the difference of the cost of the products when increasing the reflectance from 0.3 to 0.6 is $2,000.25, the cost when increasing the initial solar reflectance from 0.3 to 0.7 is $10,087.78 and from 0.3 to 0.8 is $18,427.57 MX.

Tabla 6.1.4.2 Current costs for non-residential roof coatings per square $m^2$with a reflectance of 0.3, 0.6, 0.7, and 0.8.

Reflectance	Cost ($/$m^2$)	Roof area (m^2)	Totalcost ($ MX)
0.3 (Red)	$ 26.17	669	$ 17,506.93
0.6	$ 29.16	669	$ 19,507.18
0.7	$ 41.25	669	$ 27,594.72
0.8	$ 53.71	669	$ 35,934.51

The cost per kilowatt hour was calculated from the ordinary electricity rate for medium voltage (OM) from the Federal Commission of Electricity (CFE). It applies to services that allocate less than 100 kW demand, which is $162.66 MX per kilowatt of maximum demand and $1.394 MX per kWh of energy consumed. For example: Assuming 80 kWh as the average peak demand, the cost is $ 13,012 MX ($162.66 x 80kWh) and for an average consumption of 54 MWh for two months (bimonthly) the cost of consumption is $ 75,276 MX (1.394 x 54,000 kWh). Adding the cost of the average peak demand and the cost of the average energy consumed, the two-months cost is $ 88,288 MX. Dividing by 54,000 kWh,we can get $ 1.63 MX which is the total cost per kWh for noni residential buildings.

Considering the cost of $ 1.63/kWh times the annual cooling energy savings for each city from Figure 6.1.2.1, we obtain the cost of cooling energy saved in the 5-year period and subtracting the costs of changing coating reflectance from 0.3 to 0.6, 0.7 or 0.8, the total annual savings for non-residential building are obtained. These results are presented in Figure 6.1.4.1,it can be observed that Merida has the highest savings for non-residential buildings. Due to the differences between the costs of the high reflectance and low reflectance coatings, the savings change varies bycity. For instance, Merida and Mexico City exhibited slightly larger savings with a coating with a reflectance of 0.7 than the coating with a reflectance of 0.8, different results are obtained for Hermosillo where the coating with a solar reflectance of 0.8 is preferred.

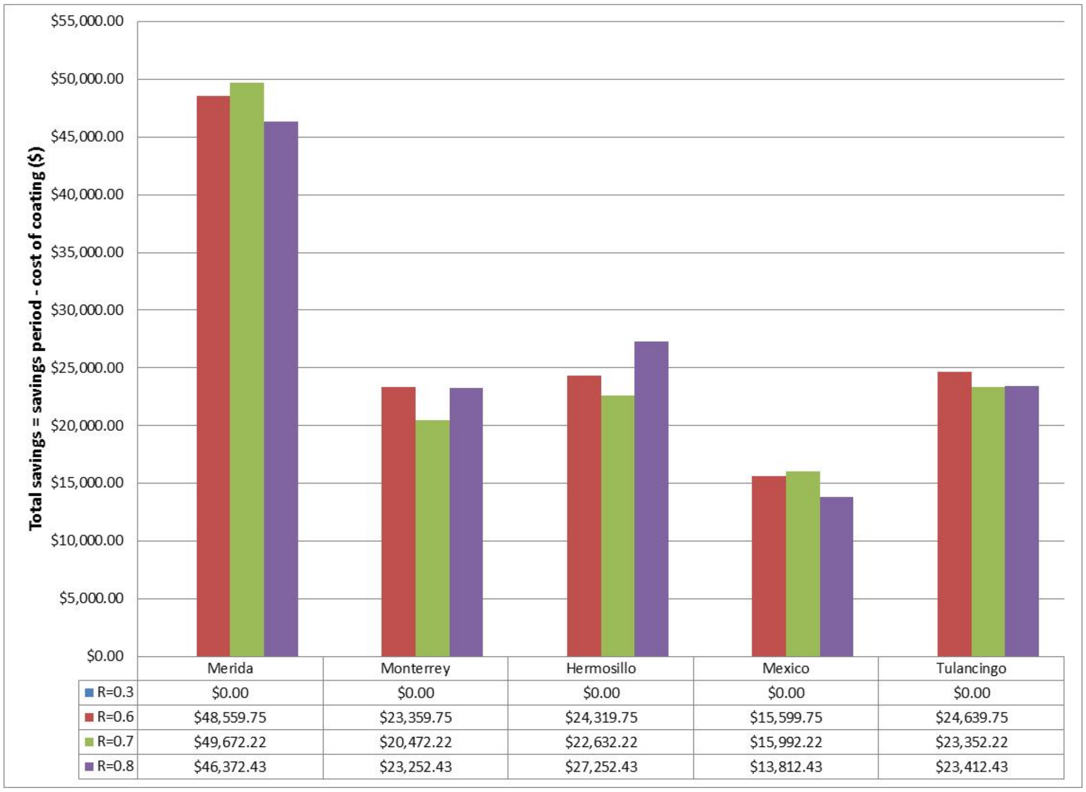


Figure 6.1.4.1.Total savings during the lifecycle of the cool coating when increasing the reflectance of the roof from 0.3 to 0.6, 0.7 and 0.8 in non-residential buildings.

Table 6.1.4.3 shows the bimonthly and annual payback periods of the investment and the savings obtained during the 5-yearlifetime of the coatings on non-residential buildings. Investments in reflective coatings with an initial reflectance of 0.6 indicated the payback periods between 4 to 8 months (2 to 4 bimonthly period). For reflectance of 0.7, investment payback varies between 1-2 years. At a reflectance of 0.8, the payback periods are 1.5 to 3 years. Mérida has the shortest payback, followed by Hermosillo, Monterrey, Tulancingo and Mexico City. It is noteworthy that in all cases the payback period is less than 5 years—the lifetime of the reflective coating.

Table 6.1.4.3. Payback period of the investment from increasing the roof reflectance from 0.3 to 0.6, 0.7 and 0.8 in non-residential buildings.

Reflectance	Investment payback /bimonthly	Investment payback /annual	Total savings (MX) Life time 5 years
Mérida (Warm sub-humid)			
0.6	2	0.3	$48,559.75
0.7	6	1.0	$49,672.22
0.8	9	1.5	$46,372.43
Monterrey (Dry)			
0.6	3	0.5	$23,39.75
0.7	10	1.7	$20,472.22
0.8	14	2.3	$23,252.43
Hermosillo (Very dry)			
0.6	3	0.5	$24,319.75
0.7	10	1.7	$22,632.22
0.8	13	2.2	$27,252.43
Mexico City (Temperate sub-humid)			
0.6	4	0.7	$15,599.75
0.7	12	2.0	$15,992.22
0.8	18	3.0	$13,812.43
Tulancingo (Temperate humid)			
0.6	3	0.5	$24,639.75
0.7	10	1.7	$23,352.22
0.8	14	2.3	$23,412.43

*Investment: R=0.6 ($2,000.25 MX); R=0.7 ($10,087.78 MX); R=0.8 ($18,427.57 MX)

6.2 Residential building. Case A: no roof insulation

The Figure 6.2.1 presents the annual energy loads of the base residential building as function of the solar reflectance of the roof (0.1-0.9) for the climates: humid hot (Villahermosa), subhumid hot (Mérida), dry (Monterrey), very dry (Hermosillo), humid temperate (Tulancingo) and subhumid temperate (Mexico City and Guadalajara). In all cases, as the roof reflectance increases, the cooling energy consumption declines. Villahermosa and Mérida have the highest cooling loads, following Hermosillo and Monterrey. Guadalajara, Tulancingo and Mexico City show the lowest cooling loads. In the Table 6.2.1 the values of the cooling loads for the residential buildings are presented.

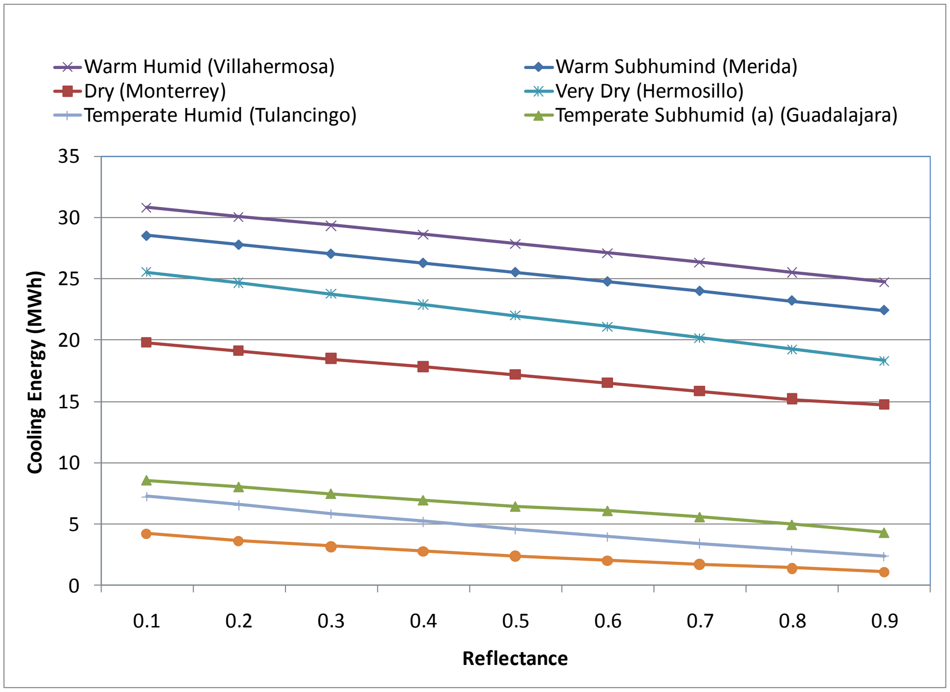


Figure 6.2.1. Annualcooling loads for the residential building as function of roof solar reflectance for 7 cities in the 6 climatic zones.

Table 6.2.1. Annual cooling loads for the residential building as function of reflectance for 7 cities in the 6 climatic zones.

Cooling energy (MWh) – Residential building							
Roof reflectance	**Humid Hot Villahermosa)**	**SubhumidHot(Mérida)**	**Dry (Monterrey)**	**Very Dry (Hermosillo)**	**Humid Temperate (Tulancingo)**	**Sub humid Temperate (a) (Guadalajara)**	**Subhumid Temperate (b) (Mexico City)**
0.1	30.8	28.6	19.8	25.6	7.3	8.6	4.2
0.2	30.1	27.8	19.2	24.7	6.6	8.0	3.6
0.3	29.4	27.1	18.5	23.8	5.9	7.5	3.2
0.4	28.6	26.3	17.8	22.9	5.2	6.9	2.8
0.5	27.9	25.6	17.2	22.0	4.6	6.4	2.4
0.6	27.1	24.8	16.5	21.1	4.0	6.1	2.1
0.7	26.3	24.0	15.8	20.2	3.4	5.6	1.7
0.8	25.5	23.2	15.2	19.3	2.9	4.9	1.4
0.9	24.7	22.4	14.8	18.3	2.4	4.3	1.1

6.2.1 Residential building - Case B: roof insulation.

Simulations were carried out considering roof insulation in the residential building, following the limits of heat gain that are include in NOM-020-ENER-2011. As in the case of non-residential building code, this NOM limits the heat gain gain through the envelop in order to achieve comfort conditions and to avoid or minimize energy demand from air conditioning systems. To comply with this limit, a similar calculate was made as with the non-residential Case B example. Table 6.2.1.1.lists the the overall heat transfer coefficient (K) for the cities listed in NOM-020-ENER-2011. It also includes the thickness of EPS insultation to comply with the NOM's heat transfer coefficient values.

Table 6.2.1.1.Overall heat transfer coefficient (K) and the thickness of the insulation corresponding to the residential building.

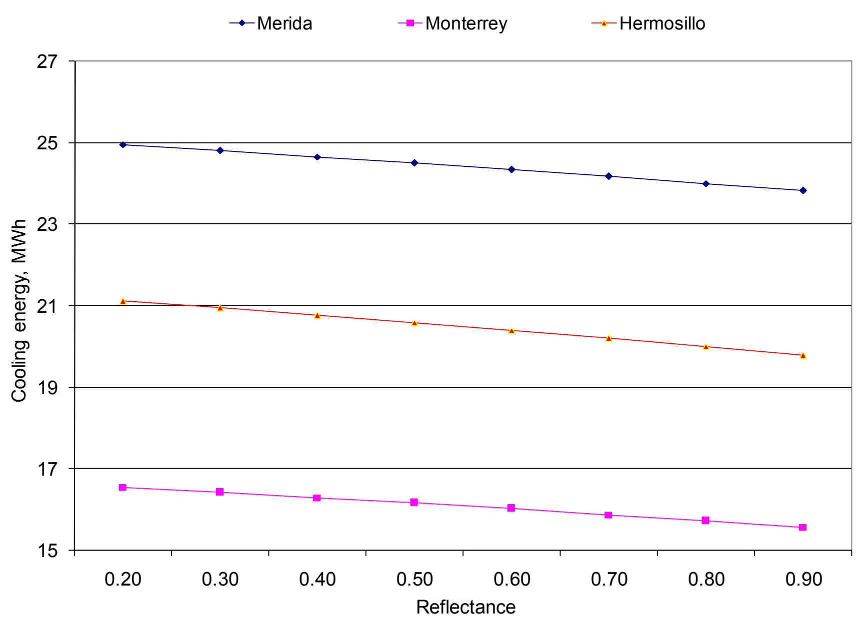
State	City	Roof (W/m^2K)	Thickness (in)
AGUASCALIENTES	Aguascalientes	0.833	**0.884**
BAJA CAL. SUR	La Paz	0.526	**1.656**
	Cabo S. Lucas	0.526	**1.656**
BAJA CALIFORNIA	Ensenada	0.909	**0.773**
	Mexicali	0.476	**1.876**
	Tijuana	0.714	**1.104**
CAMPECHE	Campeche	0.526	**1.656**
	Cd. Cármen	0.526	**1.656**
COAHUILA	Monclova	0.526	**1.656**
	PiedrasNegras	0.526	**1.656**
	Saltillo	0.633	**1.302**
	Torreón	0.526	**1.656**
COLIMA	Colima	0.556	**1.543**
	Manzanillo	0.526	**1.656**
CHIAPAS	Arriaga	0.526	**1.656**
	Comitán	0.833	**0.884**
	San Cristóbal	0.909	**0.773**
	Tapachula	0.526	**1.656**
	Tuxtla Gutiérrez	0.556	**1.543**
CHIHUAHUA	N. Casas Grandes	0.714	**1.104**
	Chihuahua	0.625	**1.324**
	Cd. Juárez	0.625	**1.324**
	Hidalgo del Parral	0.833	**0.884**
D.F.	México	0.909	**0.773**
DURANGO	Durango	0.633	**1.302**
	Lerdo	0.556	**1.543**
GUANAJUATO	Guanajuato	0.714	**1.104**
	León (b)	0.714	**1.104**
GUERRERO	Acapulco	0.526	**1.656**
	Chilpancingo	0.714	**1.104**
	Zihuatanejo	0.556	**1.543**
HIDALGO	Pachuca	0.909	**0.773**
	Tulancingo	0.909	**0.773**
JALISCO	Guadalajara (c)	0.714	**1.104**
	Huejucar	0.714	**1.104**
	Lagos de Morelos	0.833	**0.884**
	Ocotlán	0.714	**1.104**
	Puerto Vallarta	0.526	**1.656**
MÉXICO	Chapingo	0.633	**1.302**

	Toluca	0.909	**0.773**
MICHOACÁN	Morelia	0.633	**1.302**
	Lázaro Cardenas	0.526	**1.656**
	Uruapan	0.633	**1.302**
MORELOS	Cuernavaca	0.714	**1.104**
	Cuautla	0.556	**1.543**
NAYARIT	Tepic	0.714	**1.104**
NUEVO LEÓN	Monterrey	0.556	**1.543**
OAXACA	Oaxaca	0.714	**1.104**
	Salina Cruz	0.526	**1.656**
PUEBLA	Puebla	0.833	**0.884**
	Atlixco	0.714	**1.104**
	Tehuacán	0.714	**1.104**
QUERÉTARO	Querétaro	0.833	**0.884**
	San Juan del Rio.	0.833	**0.884**
QUINTANA ROO	Cozumel	0.526	**1.656**
	Chetumal	0.526	**1.656**
	Cancun	0.526	**1.656**
	Playa del Carmen	0.526	**1.656**
SAN LUIS POTOSÍ	Río Verde	0.556	**1.543**
	San Luis Potosí	0.633	**1.302**
	Cd. Valles	0.526	**1.656**
	Matehuala	0.833	**0.884**
SINALOA	Culiacán	0.526	**1.656**
	Mazatlán	0.526	**1.656**
	Guasave	0.526	**1.656**
	Los Mochis	0.526	**1.656**
SONORA	Guaymas	0.476	**1.876**
	Hermosillo	0.476	**1.876**
	Cd. Obregón	0.476	**1.876**
	Navojoa	0.626	**1.321**
	Nogales	0.626	**1.321**
TABASCO	Villahermosa	0.714	**1.104**
	Comalcalco	0.526	**1.656**
TAMAULIPAS	Cd. Victoria	0.526	**1.656**
	Tampico	0.526	**1.656**
	Matamoros	0.556	**1.543**
	Reynosa	0.556	**1.543**
	Nuevo Laredo	0.526	**1.656**
TLAXCALA	Tlaxcala	0.909	**0.773**
VERACRUZ	Coatzacoalcos	0.526	**1.656**
	Córdoba	0.714	**1.104**

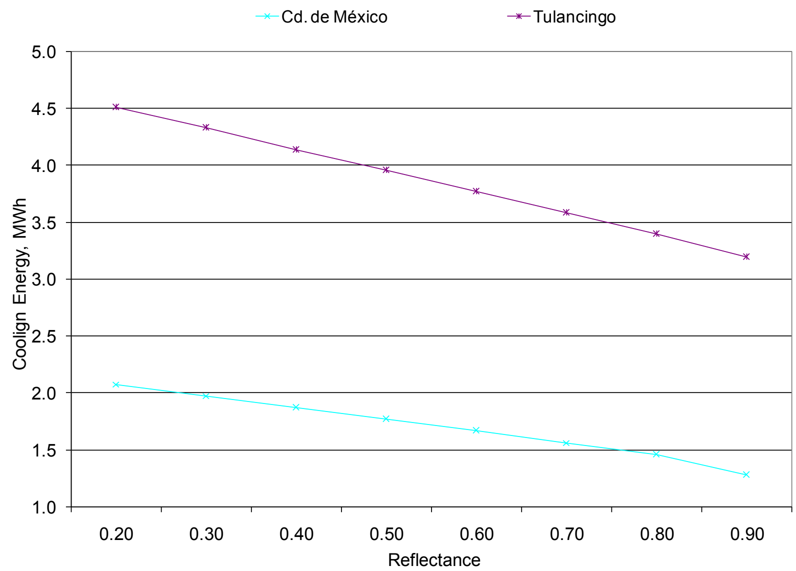
	Jalapa	0.714	**1.104**
	Orizaba	0.714	**1.104**
	Tuxpan	0.526	**1.656**
	Poza Rica	0.526	**1.656**
	Veracruz	0.526	**1.656**
YUCATÁN	Mérida	0.526	**1.656**
	Progreso	0.526	**1.656**
	Valladolid	0.526	**1.656**
ZACATECAS	Fresnillo	0.833	**0.884**
	Zacatecas	0.909	**0.773**

For residential buildings, the overall heat transfer coefficients (K) range from 0.476-0.909 W/m^2K corresponding to insulation thicknesses of 0.77-1.87 inches. For the EnergyPlus simulations in residential buildings, we consider two thicknesses of insulation: 1) 1 inch (K = 0.805 W/m^2K) for Mexico City and Tulancingo, and 2) 2 inches (K = 0.465 W/m^2K) for the cities of Merida, Monterrey and Hermosillo.

Figure 6.2.1.1 (a-b) shows the cooling load as function of the roof reflectance for the residential building with an insulation of 1" (Mexico City and Tulancingo) and 2"(Mérida, Monterrey and Hermosillo). For each city there is a reduction of cooling energy loads. The values are presented in Table 6.2.1.2. It is observed that the highest annual energy savings by changing the reflectance from 0.2 to 0.9 was Mérida (1.14 MWh) while the smallest savings are observed in Mexico City (0.8 MWh).



(a)



(b)

Figure 6.2.1.1 Annual cooling energy consumption for the residential building having a roof with (a) 2” (Mérida, Monterrey y Hermosillo)(b) 1” (Mexico City and Tulancingo) for a reflectance ranging from 0.2 to 0.9.

Table 6.2.1.2Values for the annual cooling energy consumption of the residential building havinga roof with 2” of insulation (Mérida, Monterrey y Hermosillo)and 1” (Mexico City and Tulancingo) and for reflectanceranging from 0.2 and 0.9.

Annual cooling energy (MWh) – Residential building 1” of insulation (U=0.805 W/m^{2}K) and 2” (U=0.465 W/m^{2}K)					
Roof Reflectance	**Sub humid Hot (Merida)**	**Dry (Monterrey)**	**Very Dry (Hermosillo)**	**SubhumidTemperate (Mexico City)**	**HumidTemperate (Tulancingo)**
0.20	24.96	16.55	21.65	2.08	4.51
0.30	24.81	16.42	21.36	1.97	4.33
0.40	24.66	16.29	21.07	1.87	4.14
0.50	24.50	16.15	20.77	1.77	3.96
0.60	24.34	16.01	20.46	1.67	3.77
0.70	24.17	15.87	20.14	1.56	3.59
0.80	24.00	15.72	19.80	1.46	3.40
0.90	23.82	15.56	19.45	1.28	3.20

Taking as reference a roof with a solar reflectance of 0.3 that corresponds to a conventional red roof and increasing the reflectance up to 0.6, 0.7 and 0.8 (white), the cooling energy savings are calculated for the residential building located in each city, the results are presented in the Figure 6.2.1.3. The biggest savings are obtained for the roof with a solar reflectance of 0.8 in all cities. With regard to cities having the buildings with an insulation of 2”, the greatest savings were for the city of Hermosillo (very dry climate), following Merida (sub humid hot) and Monterrey (dry). For buildings having a roof with 1” of insulation, the biggest savings were for Tulancingo (humid temperate), following Mexico City (sub humid temperate). It is worth noting that the savings are similar for Hermosillo and Tulancingo, this happens because they have a different thickness of insulation.

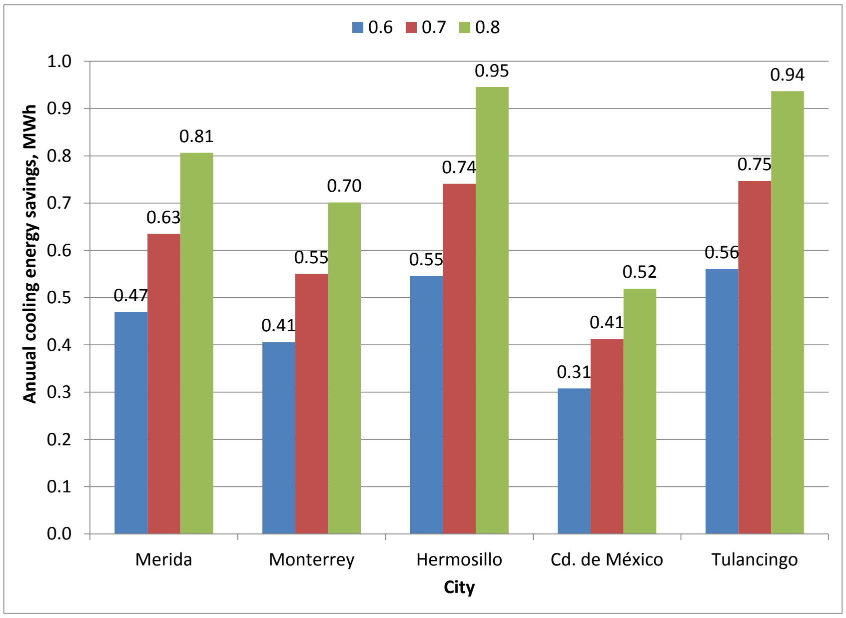


Figure 6.2.1.3 Annual cooling energy savings of the residential building having a roof with 2" of insulation (Mérida, Monterrey and Hermosillo) and 1" of insulation (Mexico City and Tulancingo) with reflectance of 0.6, 0.7 and 0.8.

6.2.2 City-wide cool roof energy savings from residential buildings.

The National Institute of Statistics and Geography reports that there are 28,138,556 residential dwellings in Mexico (INEGI, 2012). The Table 6.2.2.1 presents the number of residential buildings in the states where the selected cities are located.

Table 6.2.2.1 Number of residential cities in each state

State (City)	Number of residential buildings
Yucatán (Mérida)	502,948
Nuevo León (Monterrey)	1,190,804
Sonora (Hermosillo)	703,956
Cd. de México	6,073,798
Hidalgo (Tulancingo)	662,341

With this information, the cooling energy savings are calculated for all residential buildings by state with an insulated roof assuming the roof color changes from red (0.3) to white with reflectance of 0.6, 0.7 and 0.8. For the temperate climates such as Mexico City and Tulancingo, it is considered that only 10% of the residential buildings have AC, while the other 90% of residences do not have air conditioning; for the other cities studied, it is assumed that 100% of residential buildings have AC. The energy savings provided by the roof reflectance changes in the selected cities are shown in Figure 6.2.2.1. The biggest savings are obtained for cities with dry and hot climates, particularly because of the number of existing buildings in Monterrey, this city had the biggest energy savings (840 GWh).

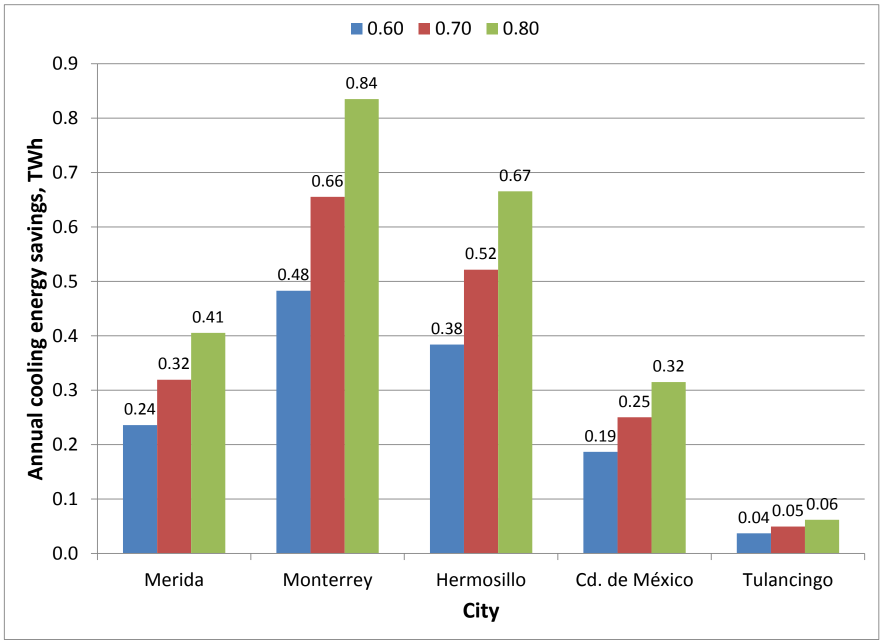
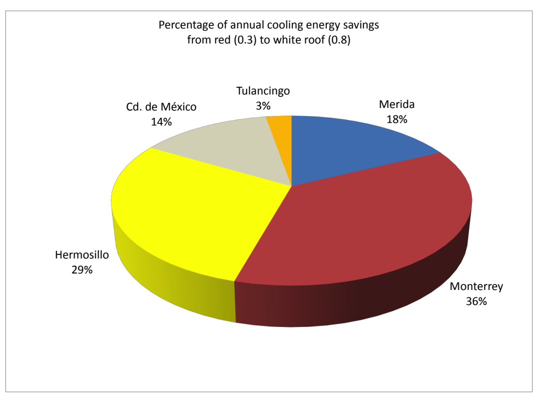


Figure 6.2.2.1. Annual cooling energy savings for each city due to change in the roof reflectance in residential buildings (0.6, 0.7 and 0.8) having an insulation of 1” in the roof (for Mexico City andTulancingo) and 2” (for Mérida, Monterrey and Hermosillo)

Figure 6.2.2.2 presents the percentage savings of annual energy loads by changing the solar reflectance of the roof from 0.3 (red) to 0.8 (white) of residential buildings by city; 36% of total savings can be attributed to cool roof implementation in Monterry while cool roof implementation in Tulancingo is minimal.



6.2.2.2. Percentage savings of annual cooling energy loads by changing roof reflectance from 0.3 to 0.8 for 5 cities, for case B: residential building having roof insulations of 1” (Mexico City and Tulancingo) and 2”(Mérida, Monterrey and Hermosillo)

6.2.3 Greenhouse gas emissions reductions due to cool roofs on residential buildings for each city

The calculations for the mitigation of greenhouse gases were developed similarly to those for the non-residential buildings, the equivalence was provided by Environmental Protection Agency (EPA, 2012). The EPA indicates that 1 MWh of electricity is equivalent to 0.706 Tons of CO_2.

Considering the results for cooling energy savings obtained for the residential building that has a roof with an insulation of 1” and 2”, the calculations of the annual CO_2 that would be mitigated when applying reflective coatings with a reflectance of 0.6, 0.7 and 0.8 were performed. The Figure 6.2.3.1 presents the annual CO_2 reductions for the reference residential building when changing from a red (0.3) to a white roof (0.6, 0.7 and 0.8) and for insulation levels in the roof of 2” (Mérida, Monterrey and Hermosillo) and 1”(México City and Tulancingo).

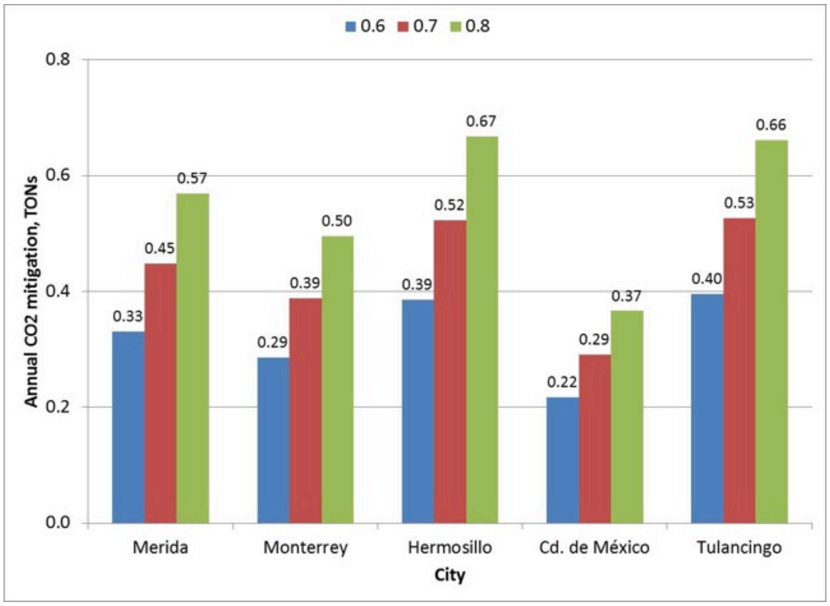


Figure 6.2.3.1 Annual CO_2 mitigation for the residential building having an insulation of 2”(Mérida, Monterrey and Hermosillo) and 1” (Mexico City) and for a roof reflectance of 0.6, 0.7 and 0.8.

The Figure 6.2.3.2 presents the annual CO_2 mitigation when changing from a red (0.3) to a white roof (0.6, 0.7 and 0.8) in the residential buildings of the whole city, considering insulations of 2” (Mérida, Monterrey and Hermosillo) and 1” (Mexico City and Tulancigo). For this type of building, when locatedin temperate climates such as Mexico City and Tulancingo, it is assumed that only 10% of the residential buildings have an air conditioning. In Monterrey,it is observed that the large number of residential buildings lead to an annual CO_2 mitigation of 590 kTons. On the other hand, it can be observed that the temperate cities represent small energy savings.

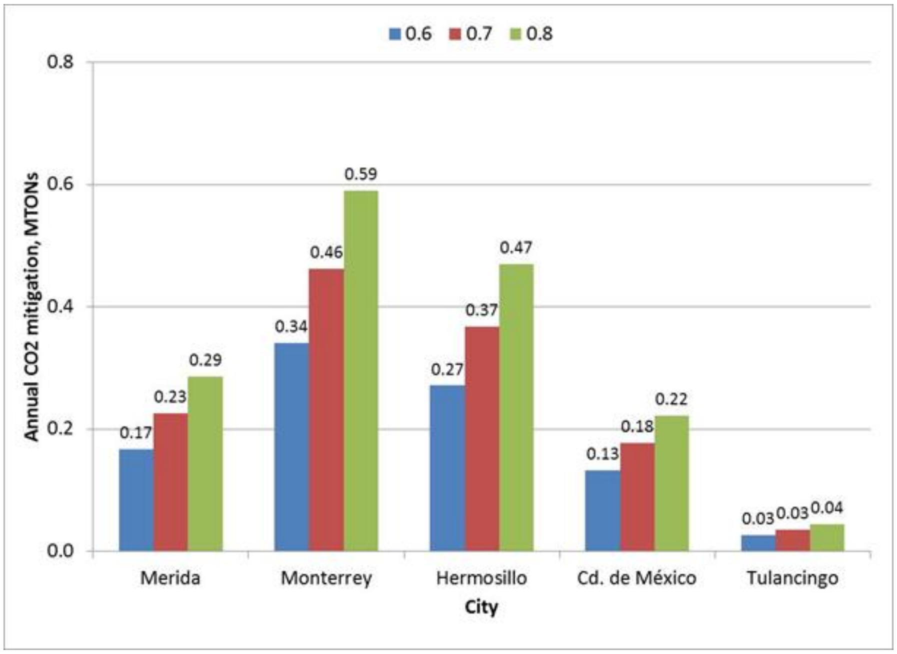


Figure 6.2.3.2 Annual CO_2mitigation for all residential buildings in the selected cities, the buildings have a roof with 1" of insulation (Mexico City and Tulancingo)and 2" of insulation (Mérida, Monterrey and Hermosillo) and solar reflectance of 0.6, 0.7 and 0.8.

6.2.4 Equivalences of the energy savings in residential buildings to monetary savings on energy production and mitigation of CO_2

The energy savings provided by cool roofs represent savings on energy productionan the emission of greenhouse gases. According to the CFE report 2006-2011, during 2011, the average cost of the electricity production was 1.08 pesos/kWh and according to the EPA, one automotive vehicle emits an average of 5 tons CO_2/year. The annual impact on monetary savings for the production of electricity and the impact on CO_2emissions calculated in the current study when changing the solar reflectance in the residential buildings from 0.3 (red) to 0.8 (white) for Monterrey are presented in the Table 6.2.4.1.

Table 6.2.4.1. Annual energy savings and CO_2 mitigation per year for Monterrey when increasing the roof's solar reflectance from 0.3 to 0.8 in all residential buildings.

Roof reflectance	0.6	0.7	0.8	
Concept	**Quantity**	**Quantity**	**Quantity**	**Units**
Savings on energy consumption	0.48	0.66	0.84	TWh
Monetary savings due to energy production	51,840,000	71,280,000	90,720,000	Pesos
Reduction of CO_2 emissions	340,000	460,000	590,000	Tons
Equivalence in automotive vehicles	68,000	92,000	118,000	Vehicles

The potential impact on CO_2 mitigation when using "cool roofs" on residential buildings would be equivalent to removing from service about 6.55% of all motor vehicles (1,800,000 in total) that circulate on the metropolitan area of Monterrey.

Monetary savings per building

This section calculates the energy saving during the 5-year lifecycle of the cool coating for each residential building. The typical cost per square meter for coatings with reflectance of 0.3, 0.6, 0.7 and 0.8 are presented in Table 6.2.4.2 together with the roof area of the residential building and the total cost. It is observed that the difference of the cost of the products when increasing the reflectance from 0.3 to 0.6 is $162.95, the cost when increasing the reflectance from 0.3 to 0.7 is $821.80 and from 0.3 to 0.8 is $1,501.20.

Table 6.2.4.2 Current costs on the market of the coatings per square $m^2$with a reflectance of 0.3, 0.6, 0.7, and 0.8. Roof area of the residential building and total costs.

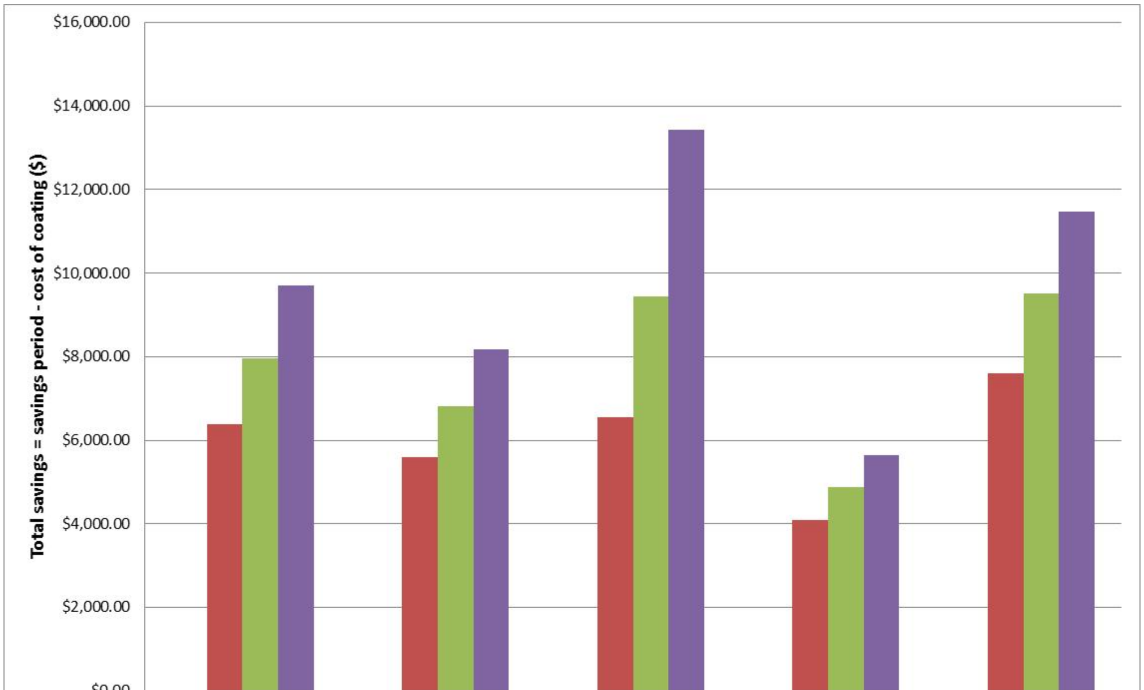
Reflectance	Cost ($/$m^2$)	Area (m^2)	Totalcost ($)
0.3	$ 26.17	54.5	$ 1,426.20
0.6	$ 29.16	54.5	$ 1,589.15
0.7	$ 41.25	54.5	$ 2,248.00
0.8	$ 53.71	54.5	$ 2,927.40

To calculate annual cooling energy costs, the CFE fees for residential buildings vary depending on the time of the year and region. Table 6.2.4.3 shows the fees for residential buildings in 5 cities. It is observed that for Mexico City and Tulancingo, temperate climate, the fees are the same for the whole year. However, for hot and warm regions the fees vary. For example, in Hermosillo the cost of electricity is higher in winter than in summer due to government subsidy. Costs increase depending on energy consumption. If the bimonthly consumption is lower or equal to 75 kW then the cost will be $0.77 MX, but if the electricity bill indicates 125kWh then the cost per kWh increases to $2.77 MX.

Table 6.2.4.3.Fees of CFE for residential buildings for each zone and time of the year.

Mérida and Monterrey Fee 1B		Hermosillo Fee 1F		Cd de México y Tulancingo Fee 1	
Winter					
Limit	**800kWh**	**Limit**	**5000kWh**	**Limit**	**500kWh**
75 kWh	$ 0.77	75 kWh	$ 0.77	75 kWh	$ 0.777
100kWh	$ 0.948	125kWh	$ 0.948	65kWh	$ 0.948
Beyond 100kWh	$ 2.77	Beyond 125kWh	$ 2.77	Beyond 65 kWh	$ 2.77
Summer					
Limit	**800kWh**	**Limit**	**5000kWh**	**Limit**	**500kWh**
125 kWh	$ 0.693	300 kWh	$ 0.575	75 kWh	$ 0.777
100kWh	$ 0.808	900kWh	$ 0.724	65kWh	$ 0.948
Beyond 100kWh	$ 2.77	1300kWh	$ 1.74	Beyond 65 kWh	$ 2.77
		Beyond 1300kWh	$ 2.77		

Considering the monthly energy savings for residential building for each city and multiplying by the current CFE fee, the annual saving in electricity for the residential building are calculated. The total annual savings are calculated considering the savings in cooling energy costs within a period of 5 years minus the cost of the reflective coating that would result from the change from red (0.3) to white (0.6, 0.7 o 0.8). These results are presented in Figure 6.2.4.1, the biggest saving in cooling energy cost isin Hermosillo, while the smallest savings are in Mexico City. For the residential building, the differences between the costs of the coatings with high solar reflectance and the coating with low reflectance (0.3) are not significant for the roof area of the residential building; hence for the five cities the coatings with an initialreflectance of 0.8 showed the biggest savings for the dry and humid hot climates.



	Merida	Monterrey	Hermosillo	Mexico	Tulancingo
R=0.3	$0.00	$0.00	$0.00	$0.00	$0.00
R=0.6	$6,383.81	$5,600.45	$6,560.81	$4,080.83	$7,597.07
R=0.7	$7,971.29	$6,801.10	$9,445.62	$4,886.20	$9,517.22
R=0.8	$9,699.02	$8,167.90	$13,435.57	$5,651.08	$11,471.68

Figure 6.2.4.1.Total annual savings within a period of 5 years.

Table 6.2.4.4 shows the bimonthly and annual payback periods of the investment and the savings obtained during the 5 year lifetime of the cool coatings on residential buildings. Investments in reflective coatings with a reflectance of 0.6 indicate the payback period is 4 months (2 bimonthly periods) for cities of Mérida, Monterrey, Hermosillo and Mexico City, and, 2 months (1 bimontly period) for Tulancingo. For reflectance of 0.7, the investment payback vary between 6 and 8 months (3 to 4 bimonthly periods) and reflectance of 0.8, the payback periods are 8-14 months (4 to 7 bimonthly periods). Mérida indicates the highest payback time of 14 months. In all cases the recovery times are less than the 5 years, the lifetime of the reflective coating.

Table 6.2.4.4. . Payback period of the investment from increasing the roof reflectance from 0.3 to 0.6, 0.7 and 0.8 in residential buildings.

Investment	**\$2,000.25 (R=0.6)**	**\$10,087.78 (R=0.7)**	**\$18,427.57 (R=0.8)**
Reflectance R	Investment payback /bimonthly	Investment payback /annual	Total savings Life time 5 years
	Mérida (Warm sub-humid)		
0.6	2	0.3	\$6,383.81
0.7	3	0.5	\$7,971.29
0.8	4	0.7	\$9,699.02
	Monterrey (Dry)		
0.6	2	0.3	\$5,600.4
0.7	4	0.7	\$6,801.10
0.8	5	0.8	\$8,167.90
	Hermosillo (Very dry)		
0.6	2	0.3	\$6,560.81
0.7	3	0.5	\$9,445.62
0.8	4	0.7	\$13,435.57
	Cd. de México (Temperate sub-humid)		
0.6	2	0.3	\$4,080.83
0.7	4	0.7	\$4,886.20
0.8	7	1.2	\$5,651.08
	Tulancingo (Temperate humid)		
0.6	1	0.2	\$7,597.07
0.7	3	0.5	\$9,517.22
0.8	4	0.7	\$11,471.68

7. Energy consumption, savings and mitigation of greenhouse gases for roof areas according to their color.

To investigate current rooftops in Mexico and to calculate the potential of cool roof penetration, satellite images and a geographical information system program (Manifold 8.0) was used to develop estimates of current roof color (white, red and gray) in five cities—Acapulco, Mexico City, Guadalajara, Mérida and Monterrey.

7.1 Methodology

To delimit the area of study, a reference geographical frame is generated to allow for comparisons between the cities. The extension of the studied area was of approximately 2,500 hectares within a polygon of 7.5 x 5 kilometers. The polygons were located in downtown of each city for considering the most consolidated urban area that best characterizes the city. Because Acapulco's urban area stretches along the bay, it was necessary to adapt the polygontothe most densely populated areas. (Figure 7.1)

Figure 7.1. Studied areas (1) Acapulco, (2) Mexico City, (3) Guadalajara, (4) Merida and (5) Monterrey

The 3,500 hectares of the studied area for each city were distributed in a polygon with proportions of 1:1.5 (7.5 x 5 kilometers approximately) corresponding to a mosaic of 16 images taken at a height of 1.7 km (Figure 7.2). The pictures were exported from the Plus version of Google Earth to conserve the geographical reference, then the images were imported with the original resolution and projection, Lambert conical, and transformed to the coordinate system used to assemble the GIS:WGS84, UTM14North.

In order to identify and select the selected color pixels, the limits for each color are defined in the model of color RGB, in this model a value of intensity for the pixels fluctuates between 0 (black) and 255 (white) for each of the colors that make up the intensity: red (R), green (G) and blue (B). The most brilliant red has the next values R:255, G:0, B:0. If the values for the three colors are identical, the color gray is obtained. When the three colors have a value of 255, the result is pure white and when the value is 0, it is pure black.

Figure7.1.Example of a photo mosaic.

Once defined the RGB model, the programManifold System 8.0 is utilized with the next selection window (Figure 7.3)

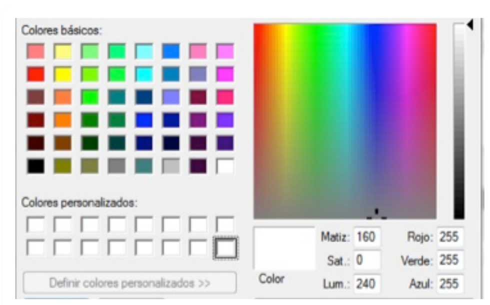


Figure 7.3.Representation RGB model in Manifold System8.0.

For the color white, the minimum value for the intensity is defined as R:240,G:240, B:240 and for the gray the limits are defined as R:240 G: 240 B: 240 and maximum R: 70 G: 70 B: 70. To identify red roofs, the pixels with values are within the vertices a) R: 70 G: 70 B: 70; b) R: 255, G: 070, B: 000; c) R: 170, G: 085 B: 085, this zone is shown in Figure 7.4.

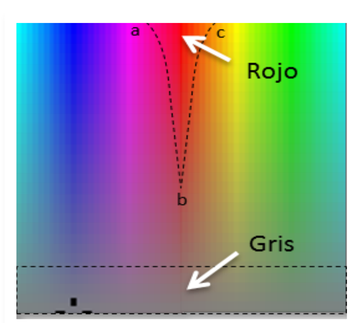


Figura7.4. RGB zones for red (rojo) and gray (gris) used in this model

To identify the surface of the selected pixels, we separated the image in layers of colors. In each layer, the pixels corresponding to streets were eliminated and were divided in 48 quadrants to facilitate processing (Figure 7.5).

The pixels released in each layer are subjected to a process known as vectorization, by which the program generates points, lines and areas transforming the information to vectors that can be categorized and measured, this is known as a raster.

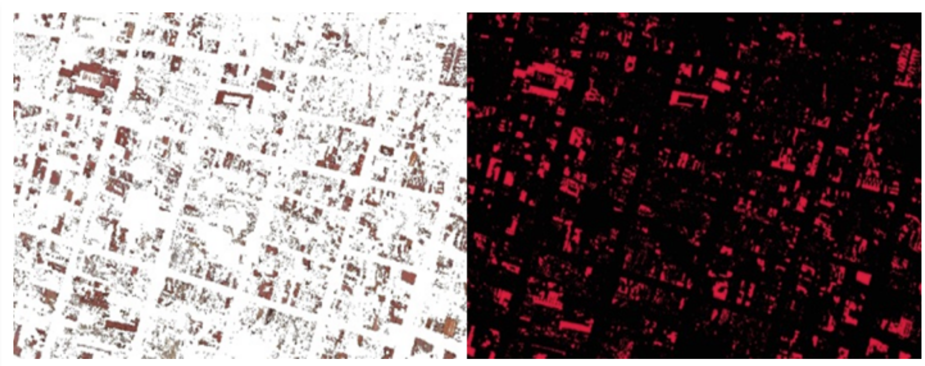


Figure7.5. Areas obtained from pixels

7.2 Areas of the debugged images in the areas of cities

The Figure 7.6 presents the GIS images for the debugged areas for white, gray and red colors for the cities of Acapulco, Mexico City, Guadalajara, Mérida and Monterrey. The biggest distribution is the color gray in all cities. The Table 7.1 shows these results.

The study area includes streets and diverse infrastructure that do not represent roof surface area. The blocks represent the areas that contain buildings that were taken into account, disaggregatedinto red, gray and white roofs. The category for “other colors” is made up of different coatings and vegetation.

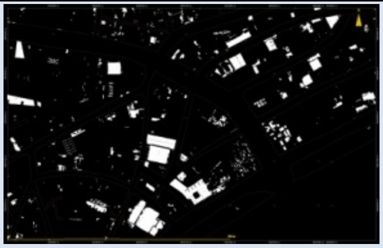
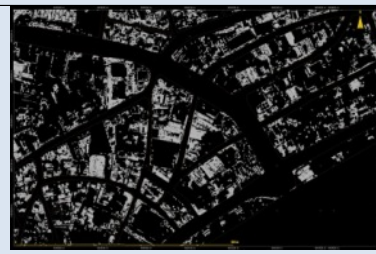
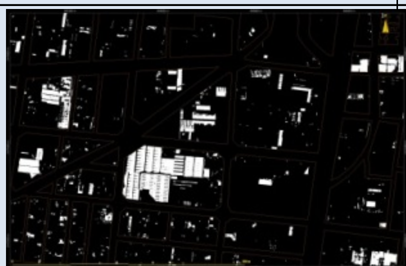
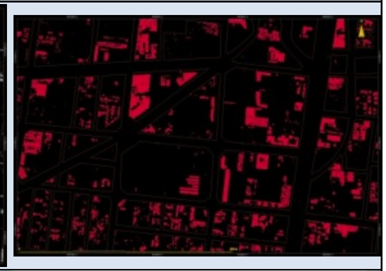
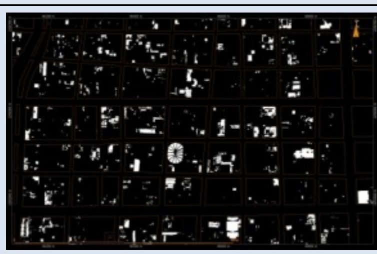
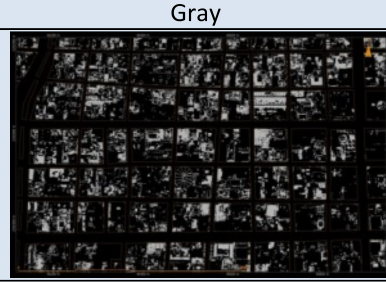
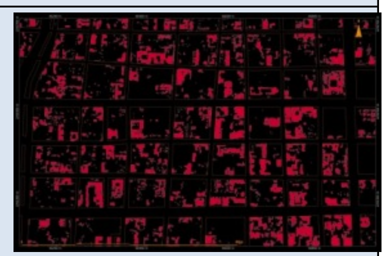
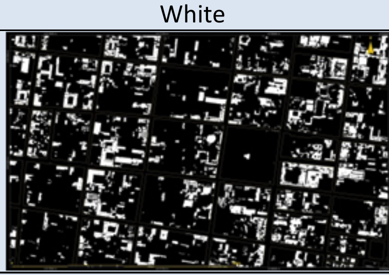
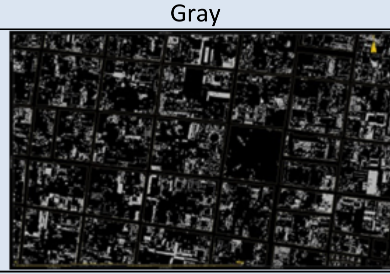
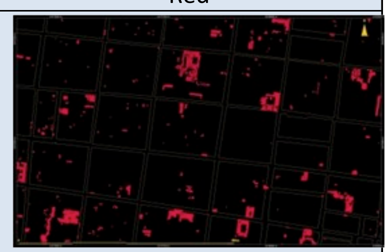
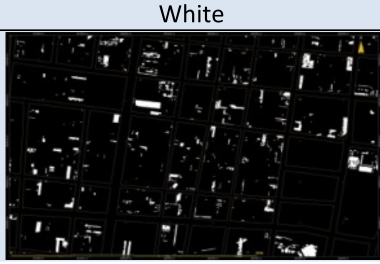
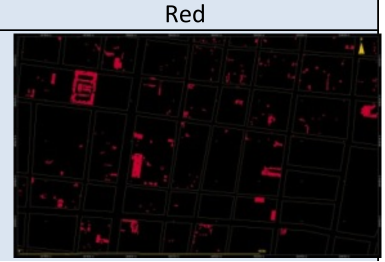
Acapulco White	Gray	Red
		
Mexico City white	Gray	Red
		
Guadalajara White	Gray	Red
		
Merida White	Gray	Red
		
Monterrey White	Gray	Red
		

Figure7.6 Debugging GIS images by color.

Table7.1 Areas and percentage of streets, blocks and roof for each city

Concept	Acapulco, Guerrero		Guadalajara, Jalisco		Mexico City		Mérida, Yucatán		Monterrey, Nuevo León	
Studied area for each city (m^2)	**36,724,610.56**	**100%**	**39,862,806.66**	**100%**	**39,882,162.81**	**100%**	**39,788,003.75**	**100%**	**38,811,950.69**	**100%**
Streets, channels, infrastructure	5,594,854.15	**15%**	10,415,380.90	**26%**	11,512,747.65	**29%**	6,444,685.11	**16%**	8,864,807.68	**23%**
Blocks	31,129,756.41	**85%** *100%*	29,447,425.76	**74%** *100%*	28,369,415.16	**71%** *100%*	33,343,318.64	**84%** 100%	29,947,143.01	**77%** 100%
○ White roofs	1,582,439.38	5%	2,331,319.11	8%	1,873,186.90	7%	3,730,136.76	11%	1,793,193.38	6%
○ Gray roofs	3,518,058.14	11%	7,030,545.86	24%	4,107,150.46	14%	5,528,183.60	17%	6,356,934.81	21%
○ Red roofs	1,311,907.16	4%	3,967,189.28	13%	4,120,271.16	15%	610,880.99	2%	845,153.76	3%
○ Other colors	24,717,351.73	79%	16,118,371.51	55%	18,268,806.64	64%	23,474,117.29	70%	20,951,861.06	70%

We took into account the energy consumption simulated with EnergyPlus for both residential and non-residential building in Merida, Monterrey and Mexico City, with the finding that 10% of urban area is occupied by non-residential buildings and 90% of the area is occupied by Residential buildings. With the area of the base residential building (53.71 m^2) and non-residential (669 m^2), the number of residential buildings per area are calculated and the energy consumption for the white roof (ρ =0.7), gray roof (ρ=0.50) and red roof (ρ=0.3). These results are presented in Table 7.2 where changing the gray roofs (0.5) and red ones (0.3) to white roof (0.7) yields the biggest savings in Mérida and Monterrey, 63.7 and 65.2 GWh, respectively. For Mexico City it was found that 46.1 GWh could be saved for the selected area (39.9 km^2=3,990 hectares) even though the climate is sub humid temperate.

Table 7.2 also estimates the mitigation of greenhouse gases based on EPA equivalences.We assumed that 1 MWh of electricity is equivalent to 0.706 Tons of CO_2.The mitigation of CO_2 is 45, 46 and 32.6 kTons of CO_2 for Mérida, Monterrey and Mexico City, respectively. In the three selected cities, for an area of approximately of 39.8 km^2, cooling energy savings were 175 GWh, leading to greenhouse gas mitigation of 123 kTons of CO_2 if the roofs in residential buildings are substituted by roof with a reflectance of 0.7.

Table 7.3 presents an extrapolation to estimate the energy savings for each city when changing from a gray and red roof, across the entire urban zone of Merida, Monterrey and Mexico City (INEGI, 2009). Here it is supposed that each city has 90% of residential buildings and 10% of non-residential buildings that were changed from gray and red to a white roof with a solar reflectance of 0.7. The energy savings and CO_2 mitigation are also estimated.

The city of Mérida has a total area of 421 km^2, the number of areas of GIS images (39.8 km^2) is 10.6 squares, each square generates savings of 63.7 MWh, in such a way that the total savings of Merida city would be 673.8 GWh with a mitigation of greenhouse gases of 475.7 kTons of CO_2. Similarly for other cities, it is worth to mention that Monterrey has less white roofs than Mérida but the consumption is bigger and the savings are bigger, even though both urban sprawls are similar.

With respect to Mexico City, it has a larger urban area, and thus more roof surface so the savings are greater than Mérida and Monterrey. In the same way, the CO_2 mitigation will also be more significant. The total cooling energy savings for the three cities is estimated to be 3,325.5 GWh (3.3 TWh) with a mitigation potential of 2,347 kTons of CO_2.