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Reference Vertical Multifamily Building in Mexican Climates Using the Synthetical Average Building Approach

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Abstract **-** Mexico has made continuous efforts to develop sustainable buildings through diverse energy efficiency policies and programs. However, in contrast with other countries, Mexico still needs to implement a nationwide plan to create zero-energy buildings. This study proposes a reference residential multifamily building, based on the European Energy Performance of Buildings Directive (EPBD), as a first step toward developing a nearly zero-energy building concept in the country. The proposed reference building was defined by implementing the synthetical average building approach using statistical data from national surveys. The main objective of this investigation was to characterize the average performance of this type of building so it can serve as a basis for future energy performance studies. Six different cities corresponding to six climates were studied: Chilpancingo (warm semi-warm subhumid); Durango (dry temperate and semi-cold semi-dry); La Paz (warm dry - very dry); Mexico City (subhumid temperate); Tepic (temperate semi-warm subhumid) and Tlaxcala (subhumid temperate). Energy consumption for lighting, appliances, hot domestic water, and cooking was estimated, so the base energy requirements for the reference building were established. The annual final energy consumption for the building was estimated between 72,974 kWh/year and 84,213 kWh/year, and the energy intensity for the houses based on the built surface varied between 56.4 kWh/m^2·year and 65.1 kWh/m^2·year. High energy consumption values were present in homes built in temperate climates, mainly driven by domestic hot water needs. Establishing the base energy consumption of buildings supports the development of sustainable construction, helping with the mitigation of energy-related emissions and thereby reducing the environmental impact of buildings.

Keywords**:** reference building; EPBD; net-zero; nZEB; sustainable building

1. Introduction

The European Union (EU) has made notable efforts in developing nearly zero-energy buildings (nZEB), especially since 2010, when the Energy Performance of Buildings Directive (EPBD) introduced the obligation to make all new buildings built nZEB no later than 31 December of 2020 [1]. Although not all countries in the EU have the same level of development in terms of sustainable buildings, there is an important gap between the European countries and countries in the rest of the world, with only a few exceptions [2].

According to a bibliometric analysis made in Scopus on the topic of Net Zero-Energy Buildings (NZEB), the non-European countries with the most publications on this topic are China (407 documents), USA (305 documents), Canada (172 documents), and South Korea (146 documents). While the rest of the top 10 are occupied by European countries (led by Italy with 604 documents). A scarce number of publications have been performed, particularly in Latin America; the countries with the largest number of studies published are Brazil (37 documents), Chile (13 documents), Ecuador (10 documents), Mexico (7 documents), and Panama (7 documents).

Mexico is a country that historically has shown interest in developing sustainable buildings. Several policies and programs have been established to improve energy efficiency in different types of buildings. For example, in the residential sector, it is possible to find funding programs for the acquisition of efficient devices for both electricity and water consumption, such as the Green Mortgage (*Hipoteca Verde*) program from the Institute of the National Housing Fund (INFONAVIT) and the Social Housing Sustainable Improvement program (*Programa de Vivienda Social en la Modalidad de Mejoramiento Integral Sustentable*) from the Trust for Electrical Energy Savings (FIDE) [3][4]. In the non-residential buildings sector, at the national level, the Building Energy Efficiency Program for Federal Public Administration has been implemented since 1999; this program makes it obligatory for all federal administration institutions to implement energy efficiency strategies in their buildings to reduce energy consumption in a continuous improvement process [5].

Some policies, such as those that seek to improve the energy efficiency in building envelopes and home appliances, positively impact the overall energy efficiency of current buildings [6]. These policies and programs aim to achieve efficient buildings in the country; however, not a single one has incorporated a concept for nZEB or NZEB goals as a requirement. The development of nZEB or NZEB policies in Mexico and Latin America could have a positive impact on several issues, such as energy poverty, which is estimated to be present in 36 % of Mexican homes [7]. Another issue is that efficient buildings can contribute to mitigating atmospheric pollution derived from fossil fuel combustion, which at a global level is estimated to contribute to the death of 3.3 million people [8]. Furthermore, during the COVID-19 pandemic, environmental degradation was related to an increment in the mortality rate in several cities in Mexico. [9]

One of the first actions European countries took to accomplish the Energy Performance of Buildings Directive (EPBD) indicators was establishing reference buildings (RB) for different types of buildings. Such buildings are considered representative in terms of functionality and traditions of each geographic region [10]. Therefore, the Synthetical Average Building approach defines a reference building as a fictional building that incorporates characteristics of a particular type of building defined after analyzing statistical data from a large sample of the same kind of building [11].

Despite the advantages of vertical housing within cities, this type of housing is still uncommon in some parts of Mexico. According to data from the Main Housing Registry (RUV: *Registro Unico de Vivienda*), from the total 2,875,039 homes registered between 2013 and 2024, only 27.61 % correspond to vertical housing [12]. There have been sparse efforts in Mexico to characterize energy use in the residential sector. In European countries, energy performance certificates were implemented to evaluate the energy efficiency level of buildings. These certificates are obligatory for the sale or rent of homes, and they allow the government to obtain statistical data on their residential stock. A similar process was established in Mexico under the Green Housing Evaluation System (SISEVIVE), which estimated energy and water consumption from new houses, giving them a grade from A to G. The scope of this program was limited, being explicitly implemented for homes seeking for government subsidies. In total, 500,181 houses were evaluated up to the year 2020; after that year, the program ended [13].

This document shows the process for creating a residential reference building (RB) representative of typical conditions from six different cities in Mexico. The cities studied were selected because they have different climates. Information from the National Survey on Energy Consumption in Private Homes (ENCEVI), the National Survey on Time Use (ENUT), and the National Housing Survey (ENVI) was used to define characteristics of the RB representative of houses nationwide. The RB definition was performed using the synthetical average building approach, to use it in a future nZEB concept definition for Mexico. The development of sustainable buildings, especially nZEBs, has the potential to mitigate energy-related air contaminants, therefore improving the health of people within urban zones and reducing the environmental impact of buildings.

2. Methods

In this study, the RB was created for a vertical residential building, also known as a multifamily building. This building type was chosen because it offers advantages to sustainable city development by helping densify urban centers and better use soil and natural resources [14].

In the absence of a specific program to characterize energy use in houses in Mexico, it is necessary to use other tools to obtain national estimates. One of these tools is the ENCEVI by the National Institute of Statistics and Geography (INEGI) from 2018. This survey aimed to obtain statistical information on people living in Mexican homes, specifically energy patterns, and consumption habits [15]. Other important tools were the ENUT from 2019 and the ENVI from 2020.

2.1. Cities

For the selection of cities, the percentage of homes required in relation to inhabited homes from the 2020 ENVI was taken as a basis, assuming that the states with the greatest need for housing are those that will have to build a greater amount of housing in the near future [16]. Subsequently, sustainable housing development in these states is critical.

The states were ordered based on their need for housing, and then the climatic region was identified based on the state capital climate, according to the INEGI climate classification [17]. Subsequently, the five cities with the greatest need for housing were selected, eliminating the cities where a climate classification was repeated. It was decided to include Mexico City as it is the country's capital. The selected cities and their climatic classifications are shown in Table 1.

Table 1: Studied cities and climates.

State	Required/ Inhabited housing (%)	City	Geographic region	Climate according to INEGI	Köppen climate classification
Guerrero	35.3	Chilpancingo	South	Warm semi-warm subhumid	Aw
Tlaxcala	32	Tlaxcala	Central	Dry temperate and semi-cold semi-dry	Cwb
Baja California Sur	29.5	La Paz	North	Warm dry, very dry	BWh
Mexico City	29.5	-	Central	Subhumid temperate	Cwb
Nayarit	23.9	Tepic	Central	Temperate semi-warm subhumid	Csa
Durango	21.0	Durango	North	Subhumid temperate	BSk

3. Results

Considering existing layouts from multifamily buildings, a new design was created for the RB geometry and internal distribution (Figure 1). The main criteria for selecting the final design were to reduce the outside surfaces of each house without limiting access to natural light. The designed RB has a ground floor for commercial activities; the following four floors contain residential space. On each building level, four homes are placed; all four houses have the same surface (80.82 m^2); however, on each level, two houses have three bedrooms, while the other two have two. The size of each house places them in the "Traditional" housing category (close to 70 m^2) according to local criteria [18]. This category represents 28.95 % of all houses built and registered between 2013 and 2024 [12].

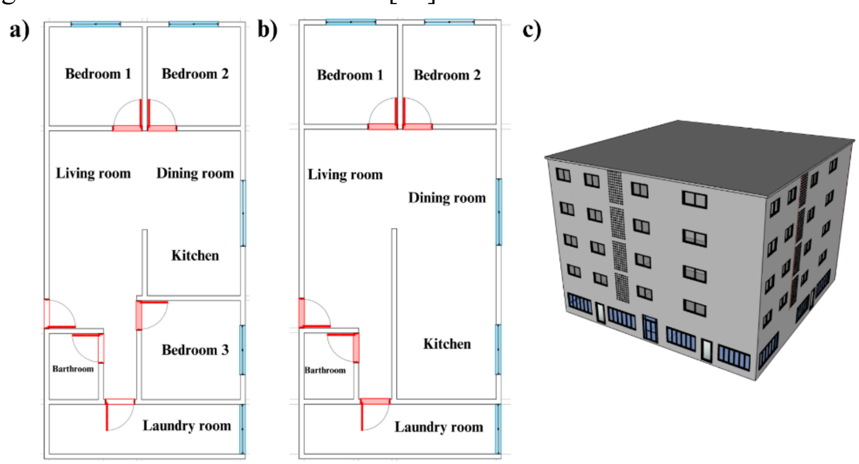

Fig. 1: Reference Building. a) Three-bedroom house b) Two-bedroom house c) 3D visualization

3.1. Constructive materials

The ENVI from 2020 was used as a reference to define the constructive materials of the RB. This survey aims to obtain statistical information about houses in the country. The results from this survey show that 92.4 % of the sample use materials like brick, concrete block, stone, and mortar for the walls in their homes [16]. As the survey does not specify which material is utilized, it was decided to use concrete blocks for the RB, as it is known for being one of the most frequent materials in the construction for this type of building in Mexico [19][20].

For the roof of the building, the National Housing Survey shows that most of the sample (78.4 %) indicated a concrete slab or a joist and vault system [16]. Once again, the survey groups both systems mentioned making it impossible to define the most used material. In this case, the joist and vault system were chosen because of the availability of energy data from manufacturers [21].

Finally, no insulating material was considered because, according to data from the ENCEVI, 98.99 % and 95.28 % of the interviewed families indicated not using insulation in walls and roofs, respectively. The same consideration applies to windows, as 99.46 % of the surveyed indicated not using any insulation[1] in this constructive element [15].

3.2. Occupants

Another critical aspect of the energy performance estimation of the building is the number of occupants since they define the use time of all energy systems within each house. It was decided to consider 14 occupants per level, distributed between the four houses. This distribution provides the building with an average of 3.5 occupants per house, practically the same value as the national average [22]

Data from the ENUT were used to estimate the average time Mexicans spend inside and outside their homes based on their activities. At first, a differentiation between males and females was made; however, despite the type of activities varying between genders, the time spent outdoors did not significantly differ. According to the information collected, Mexicans, on average, sleep 7.57 hours a day and perform 11 hours of non-domestic activities per week (aside from job-related activities) [23]. Based on this information, the occupancy profile was created, which was necessary to determine the time of use of household appliances and air conditioning systems.

3.3. Lighting system

According to data from ENCEVI, the most common lighting technology is compact fluorescent lamps (CFL). The data show that of the 226.4 million lamps used in the residential sector, 72 % corresponds to CFL, while 16 % still corresponds to incandescent lamps and only 12 % to LED [15]. Based on this information, it was decided to consider CFL technology for the lighting system of the RB. In order to find the necessary number and power of the lamps, a lighting analysis was carried out with the DIALUX software, using as reference the illumination recommendations for the different spaces in a house [24][25]. Later, the LENICALC ® software developed by the Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA) was used to estimate the energy consumption for lighting according to the guidelines from the EN 15193-1:2017 standard [26]. The data necessary for using this software was assessed using the data available in ENCEVI, and the annual average time for sunrise and sunset was estimated for the six cities.

3.4. Air conditioning system

According to data from ENCEVI, air conditioning devices are absent from most homes in Mexico. Only 41.8 % of homes in the northern states use air conditioning for cooling, the highest value in comparison to central states (1.3 %) and southern states (12.4 %). A similar trend can be observed for heating, with 20.5 % of homes in northern states having some sort of device for heating, and only 2.5 and 1.6 % in central and southern states, respectively [15].

3.5. Domestic hot water

[1] A strategy to avoid excessive heat or cold, according to the survey “insulation”: roof insulation, wall insulation and advanced windows

According to the ENCEVI survey, most homes in Mexico use liquefied petroleum gas as fuel for water heating, with the water heater with a deposit tank being the most common (45 % of the sample). In order to estimate the gas consumption for domestic hot water (DHW), a system of this type was selected (76 % efficiency), and a simplified methodology was used to estimate gas consumption based on the water network's average temperature and the amount of water needed [27].

$$Q_{req} = \frac{m_{water} CP_{water} (T_{water,\,user} - T_{water,network})}{\eta_{heater}} \tag{1}$$

3.6. Cooking

Data from the ENCEVI survey was used to estimate the energy consumption used for cooking in Mexican houses. According to the data, 85 % of homes in the country use a stove for cooking. Of these devices, 95.4 % correspond to gas stoves with manual or electronic start-up. On average, each family uses the stove for 1.88 hours daily, and the majority of interviewed people (68 %) claimed to be using two burners simultaneously while cooking [15]. Using this data and the characteristics of a stove selected through the Federal Consumer Protection Agency (PROFECO) quality report, the energy consumption was estimated at 0.40 kg of liquidated gas daily per home [28].

3.7. Air infiltration

A typical value for air infiltration in Mexican houses has not been published; however, the “Energy Conservation Code for Buildings in Mexico” recommends not exceeding five air changes per hour (ACH) in the warmer climatic zones and not more than three ACH in the rest of the country [24]. Because of the lack of a specific recommended value, it was considered to use a value of 1.5 ACH, the corresponding value of a house classified as “loose” [29].

3.8. Appliances

Using data from the ENCEVI survey, a list of electric appliances commonly used in Mexican homes was defined by their average use time and the most common use frequency [15], presented in Table 3. Quality reports from the PROFECO were used to estimate the power level of each device. The aim was to select devices whose power made them representative of the mean found within the market [30].

Table 2: Common appliances in Mexican households and their average use time.

Appliance	**Average use time (minutes)**	**Times per month**
Refrigerator	Continuous	Continuous
Washing machine	127	4
T.V.	224	6
Iron	65	4
Microwave	15	16
Blender	10	18
Mixer	16	3
Coffee maker	29	19
Toaster	12	9
Hair dryer	17	13
Laptop	153	16
Modem	1348	30

3.9. Base energy

Once the statistical data were analyzed and the main characteristics of the RB were selected, it was possible to estimate an energy basis for the building and the selected cities. This baseline considers 1) electrical energy consumption for appliances, 2) gas consumption for cooking, and 3) gas consumption for DHW.

As mentioned before, the ENCEVI survey showed that many homes in Mexico do not use heating and cooling devices. Such requirements will be determined through energy simulations. This activity is planned for subsequent steps; therefore, it is not considered for this study stage.

According to the indications of the EPBD, energy performance must be indicated in terms of primary energy, which is representative of the energy products extracted directly from some natural resource. According to the EPBD, each member state must determine a conversion factor to estimate primary energy from final energy. In the case of Mexico, this conversion factor has yet to be officially published, so it was decided to use data from the National Energy Balance to estimate a conversion factor for this study. This report uses the Physical Energy Content approach, where the standard physical energy value of the primary energy form is used as a production value [31].

Based on the final consumption of electrical energy and liquefied gas, a comparative analysis was conducted against the primary energy reported for the generation plants. A primary energy/final energy conversion factor of 1.93 for electrical energy and 1.11 for liquefied gas was estimated. With these values, the building's energy performance was estimated in terms of primary energy, as seen in Table 3.

Table 3. Energy requirements of the reference building for the selected cities.

City	**Final gas consumption (kWh/year)**		**Final electrical energy consumption (kWh/year)**		**Building base energy consumption (kWh/year)**		**Base energy use intensity per house (kWh/ m^2 · year)**	
	DHW	Cooking	Appliances	Lighting	Final energy	Primary energy	Final energy	Primary energy
Chilpancingo	26,225	28,673	15,309	6,014	76,221	101,541	58.9	78.5
Durango	30,346				80,342	106,075	62.1	82.0
La Paz	22,978				72,974	97,970	56.4	75.8
Mexico City	34,217				84,213	110.333	65.1	85.3
Tepic	25,600				75,596	100,854	58.5	78.0
Tlaxcala	34,217				84,213	110,333	65.1	85.3

A comparative analysis was performed for electricity using the reported data in ENCEVI. This survey does not collect data on the amount of energy consumed by houses in kWh; therefore, the only option is to use the last payment reported in the survey. The average bimonthly payment was calculated by considering the State where the house was built, the built surface, and the domestic tariff when the survey occurred (winter 2018). This average payment value was compared with an estimated cost calculated from the electrical energy consumption of the RB and the cost of the corresponding tariff.

From this comparison, it was estimated that the houses in the RB would pay approximately $228.78 MXN for their energy consumption. According to the survey, people in these states spent an average of $295 MXN when they were surveyed (Chilpancingo: $304, Mexico City: $239, Durango: $239, La Paz: $520, Tepic: $272, and Tlaxcala: $198).

A second comparison was made for gas consumption. The most common way households buy gas is through cylinder tanks. According to ENCEVI, the most common purchases are 30 and 20 kg tanks. According to data from their states, 30 kg tanks are more common for the selected cities in La Paz, Durango, and Tepic. However, in Mexico City, Chilpancingo, and Tlaxcala, 20 kg tanks are more common.

For the comparison, it was estimated how much gas would be consumed in each RB house. Then, it was estimated how much the most common cylinder would last in each case. Finally, that estimated duration was compared to the estimated duration for each city according to ENCEVI. A problem with this approach is that the survey indicates ranges for the gas duration, so the percentage of houses with similar duration indicates in which range the estimated duration would fall and how many dwellings indicated to have that same range.

Table 4. Gas consumption comparison between the RB houses and the ENCEVI data.

Cities	Monthly estimated gas consumption (kg)	Estimated duration with the most common tank (months)	Surveyed houses with a similar duration (%)
Chilpancingo	21.3	0.94	21
Mexico City	24.4	0.82	41
Durango	22.9	1.31	33
La Paz	20.0	1.5	20
Tepic	21.0	1.43	18
Tlaxcala	24.4	0.82	46

4. Conclusion

A reference multifamily building for six cities in Mexico was defined using the synthetical average building approach. Statistical data from national surveys was used to define the typical characteristics of this type of building, specifically for the characteristics that have a significant role in energy consumption in buildings. The energy consumptions from appliances, lighting, DHW, and cooking were considered. Although no air conditioning energy was considered for this study, the estimated total energy consumption serves as a base for future energy performance analysis, especially considering the future development of nZEB and ZEB buildings in Mexico.

According to the results, the base final energy consumption for the RB varies between 72,974 kWh/year and 84,213 kWh/year, depending on the city. Meanwhile, the primary energy consumption of the RB varies between 97,970 kWh/year and 110,333 kWh/year. Considering the final energy intensity for the houses in the RB (taking as reference their built area), values between 56.4 kWh/m^2·year and 65.1 kWh/m^2·year are present, and between 75.8 kWh/ m^2·year and 85.3 kWh/m^2·year for primary energy.

Tlaxcala, Durango, and Mexico City had the highest energy consumption. These cities have temperate climates, with winters colder than the rest of the studied cities, which results in a high domestic hot water requirement. In future analyses, air conditioning requirements will differ depending on the energy necessary for thermal comfort (cooling and heating).

From the comparison between the RB final energy and the data from the ENCEVI, it was found that the electrical energy spent on the RB houses was similar to that reported for the houses in the same state and with the same built area. The only exception is La Paz where reported costs were higher, although this may change once air conditioning is considered as La Paz is located in a region where temperatures are high and cooling is more common. Although air conditioning consumption was not considered, the comparison is adequate as most surveyed homes declared not having air conditioning devices. The comparison for gas consumption also showed that the estimated value is within ENCEVI's survey. Although making a perfect reference building is impossible, it is a good first step to understanding actual energy consumption.

Considering that no reference building can represent the whole residential stock of any country, in the absence of a mechanism that allows the characterization of this type of building in Mexico, the elaboration of an RB through the synthetical average building approach can be helpful for future energy efficiency programs in buildings, specifically in the residential sector. It is also a good first step towards developing nZEB and ZEB in Mexico as a tool to face the country's current environmental and energy supply issues.

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