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Energy Efficiency Calculation a Case Study: "Residential Project in Tampico, Tamaulipas, Mexico

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A B S T R A C T

This study presents an analysis of the energy efficiency of a single-family home located in the conurban area of Tampico, Tamaulipas, evaluated according to the methodology of the Mexican Official Standard NOM-020-ENER-2011. The evaluation was carried out by calculating thermal gains due to conduction and radiation through the architectural envelope, considering variables such as material type, orientation of enclosures, and local climatic conditions. It was determined that the dwelling generates a total thermal load of 34,507.49 W, exceeding the normative limit (11,194.88 W) by over 200%. This excess is primarily due to the absence of thermal insulation in walls and roofs, as well as the use of single-pane glass without solar protection. These results indicate a poor thermal performance of the building, compromising both indoor environmental comfort and energy efficiency. It is concluded that applying passive bioclimatic design strategies and incorporating appropriate construction technologies are necessary to reduce heat gain and ensure compliance with energy efficiency standards in warm regions. In this paper it is also included some strategies to

Keywords: energy efficiency, housing, bioclimatic architecture, NOM-020-ENER-2011, thermal load, thermal envelope, environmental comfort, passive design

1. Introduction

In a context of growing concern over climate change and rising energy costs (Medina-Pérez et al., 2023), calculating the energy efficiency of homes is particularly relevant in the conurban area of Tampico, Madero, and Altamira. This region, characterized by its warm-humid climate and high ambient humidity for much of the year (Ruiz et al., 2023), faces significant challenges related to thermal comfort and excessive energy consumption, particularly due to the intensive use of air conditioning systems.

Evaluating energy efficiency in this area not only optimizes electricity use, reducing household bills, but also lessens the burden on the local electrical system, which operates near its maximum capacity during the summer months. An efficient home, well-designed and built with materials suitable for the tropical climate, can maintain pleasant indoor temperatures with less energy use, significantly improving the quality of life for its inhabitants (Biere Arenas et al., 2023).

Furthermore, in Tampico, Madero, and Altamira, where urban development has accelerated rapidly (Leal, 2025), promoting energy efficiency in new and existing homes is a key strategy for fostering more resilient and sustainable cities. Implementing energy evaluations from the architectural design phase, complying with standards such as NOM-020-ENER-2011, and encouraging the use of passive technologies and renewable energies can make a difference in building a more sustainable urban environment.

Additionally, calculating energy efficiency contributes to increasing property values in an increasingly competitive and sustainability-aware real estate market, also aligning with national and international environmental commitments undertaken by Mexico (Alvear et al., 2023).

Therefore, in the conurban area of Tampico, Madero, and Altamira, calculating and improving the energy efficiency of homes is not just a desirable option, but an urgent necessity to reduce environmental impact, improve family economics, and build a more comfortable and sustainable future for the region.

This report presents a case study of a residential project (Figure 1a) in an area of Tampico, Tamaulipas, located at 22∘15’53.19’’N latitude and 97∘51’50.83’’W longitude, which is situated at the adjoining corner of Loma de Chapultepec and Ignacio Morones Prieto streets on a vacant lot with an area of approximately 740 m2 (Figure 1b).

Figure 1. a) 3D residential project. b) Project location.

2. Method

2.1 General Concept

The architectural proposal corresponds to a two-story single-family residence, designed with a contemporary, functional approach adapted to the warm-humid climate characteristic of the southern region of Tamaulipas. The project prioritizes natural ventilation, cross-ventilation, and the integration of outdoor spaces as a passive strategy for thermal comfort.

2.1.1. Layout

Ground Floor (Figure 2)

- Access Vestibule: Reception area connecting the exterior with the living-dining room.
- Living Room: Main social area with an approximate dimension of 7.00 m×5.00 m, creating an open and flexible space.
- Dining Room: Adjacent to the living room, with dimensions of approximately 4.00 m×5.00 m.
- Bar: Complementary space of 2.00 m×4.00 m, integrated into the social area.
- Kitchen: With an estimated size of 4.00 m×4.00 m, directly connects to:
  - Pantry: 2.00 m×2.00 m (independent storage).
- Terrace: Covered outdoor area of 7.00 m×5.00 m, ideal for outdoor activities.
- Laundry Room: Approximately 3.00 m×3.00 m, contiguous to the service room.
- Service Room: Space of 3.00 m×3.00 m with a full bathroom (B.C.).
- Guest Bathroom (B.C.): 2.00 m×2.00 m, located near the vestibule.
- Storage Room: 2.00 m×2.00 m, located at the rear.
- Access Porch: Covered, approximately 4.00 m×2.00 m.

Upper Floor (Figure 2)

- Master Bedroom: Private area of approximately 7.00 m×5.00 m, includes:
  - Dressing Room: 4.00 m×2.00 m
  - Full Bathroom (B.C.): 4.00 m×2.00 m
- Girl's Bedroom: 5.00 m×4.00 m, with closet and shared bathroom.
- Boy's Bedroom: Similar, 5.00 m×4.00 m.
- Baby's Bedroom: More compact, 4.00 m×4.00 m.
- Study: Multifunctional space of approximately 5.00 m×4.00 m.
- Secondary Bathrooms: 2.00 m×2.00 m each, well-distributed to serve the bedrooms.

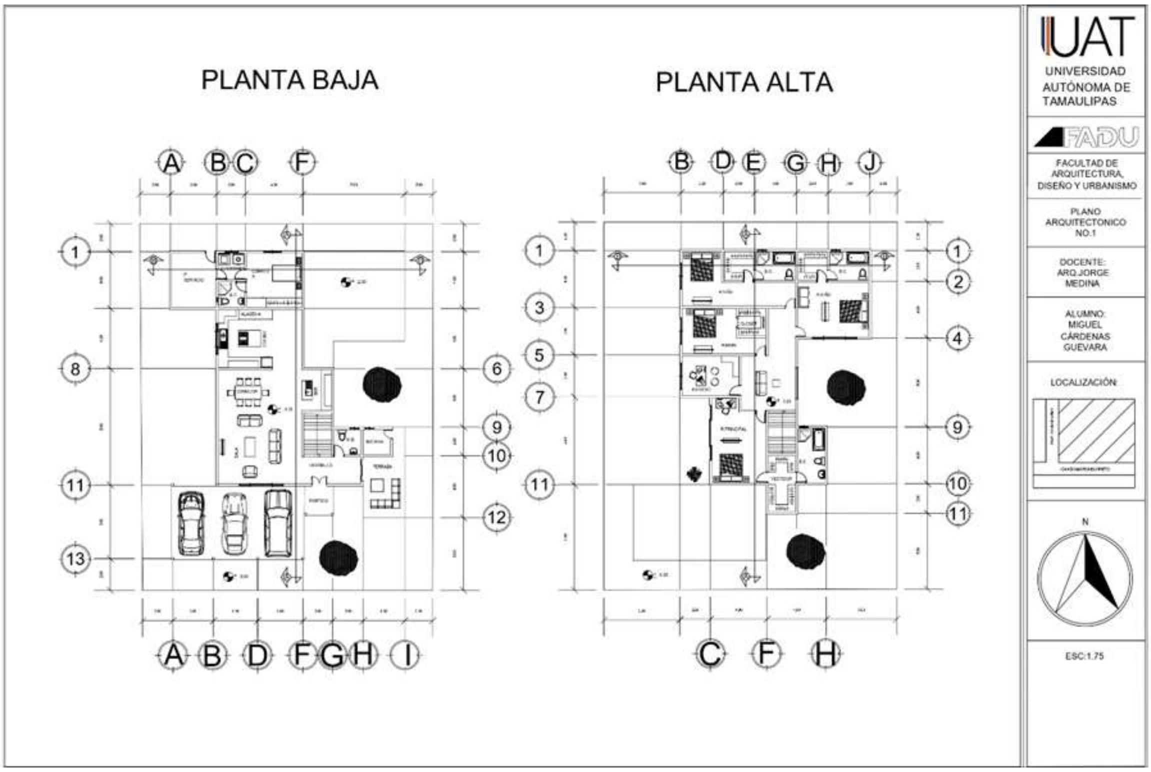

Figure 2. Design plans of the upper and ground floors of the proposed dwelling design.

2.2. Facade Design

The facade language (Figure 3 a-d) is contemporary:

- Front Facade: Average height of 3.15 m to 4.48 m per level, with volumetric design based on well-defined horizontal and vertical lines. Large openings protected by eaves control direct solar radiation.
- Rear Facade: Wide openings to allow visual access to the terrace and green areas.
- Side Facades: Fewer windows, controlling lateral sun exposure.

2.3. Environmental Characteristics

- Cross-ventilation: Arrangement of aligned windows (8 windows) on opposite axes.
- Solar Protection: Through covered terraces, eaves, and projected shadows.
- Indoor-Outdoor Relationship: Fluid, allowing enjoyment of the immediate surroundings.
- Optimal Dimensions: Spacious areas allow good air circulation and thermal comfort.

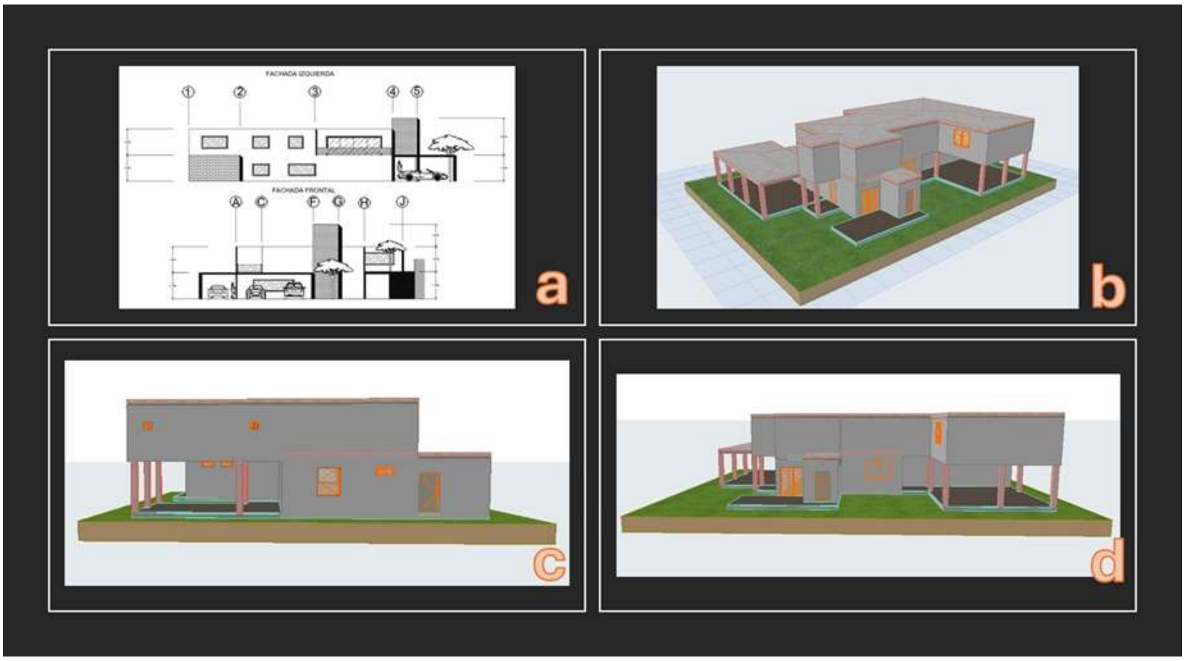

Figure 3. a-d) Front, lateral, and rear facades of the housing project, respectively.

2.4 Materials and Energy Efficiency Calculation

The walls of the dwelling are primarily constructed with hollow concrete blocks, while the doors are made of light wood, and the windows are clear glass 6 mm thick.

The Excel sheet designed to support the application of **NOM-020-ENER-2011** is a practical tool that facilitates the evaluation of the thermal performance of the envelope of residential buildings. This sheet automates the necessary calculations to verify compliance with normative requirements based on climate, construction materials, and the physical characteristics of the dwelling. The main objective of this tool is to evaluate the compliance of residential buildings in Mexico with passive energy efficiency, defining the following variables:

1. Thermal load by orientation and by envelope component.
2. Thermal transmittance and solar gains.
3. Comparison with a reference building defined by the standard itself.

The tool is divided into sections, represented by different worksheets, highlighting the climatic zone, type of dwelling (horizontal or vertical), location and orientation, height, built area, and geometric proportions of the property.

Below are the main formulas used in the spreadsheet:

The Energy Transmittance Formula is:

$$U = \frac{1}{R_{total}}$$

Where:

$R_{total} = R_{interior} + \Sigma \left(\frac{e_i}{k_i}\right) + R_{exterior}$

e_i = material thickness i (m)

k_i = Thermal conductivity i (W/m .°C)

Solar Gain Formula is: $Q_{solar} = A_{vidrio} \,.\, SHGC \,.\, F_s \,.\, G$, where A_{vidrio} is the glass of the Window área, SHGC: Coeficiente de ganancia solar del vidrio (por sus siglas en inglés), F_s : shadow factor, G : Solar radiation (W/m^2).

The Permitted Thermal Gain Ratio Formula (which serves as a comparison between the projected building (generated by the user) and a reference one provided by the standard).

$$Relación = \frac{Carga\ térmica\ proyectada}{Carga\ térmica\ de\ referencia}$$

If relationship, relación < 1, Project is ok. Thermal calculation use information of wlls, roof, Windows, orientatios, mateirales, glass and shadows.

Sheet	**Description**	**Highlighted Variables**
1DatosGenerales	General project parameters	Climatic zone, type, height, surfaces
Envolvente	U calculation per component	Material, thickness, area
PorcionH	Habitable portion (windows, walls)	SHGC, G, Fs, orientation
4EReferencia	Normative building (reference)	Thermal load comparison
4EProyectadoT	Total projected building	Actual results
Resumen	Consolidated results and verdict	Complies or not complies (Ratio ≤1)
MatDes	Materials database	Conductivity, density
Sombras	Modeling of eaves and solar devices	Length, height, projection, orientation

Table 1. Highlighted variables of the standard's spreadsheet.

3. Results and Discussion

The main objective was to quantify heat gains by conduction and solar radiation through the architectural envelope and determine the degree of compliance with the limits established by the standard. In this section it is presented de stimated energy efficiency.

3.1 ***Results***

The results (Figure 4) indicate that the projected building has a total thermal gain of 34,507.49 W, composed mostly of thermal transmission (31,000.21 W) and to a lesser extent by solar radiation through windows (3,507.28 W). In contrast, the normative reference building has a maximum permitted value of 11,194.88 W. This difference represents an excess of 208%, showing significant normative non-compliance and poor thermal performance of the envelope.

Figure 4. Evidence of processing and results from the NOM-020-ENER-2011 spreadsheet.

The rest of the obtained results are listed below:

Climatic Reference Parameters:

- Climatic zone: Latitude 22∘25’, warm-humid region.
- Average equivalent temperatures (∘C):
    - Roof: 44
    - Walls: 30 to 34 (depending on orientation)

- Windows: 27 to 28
- Lower surface: 30

Reference Building (normative calculation)

- Conduction gain (frc): 7,551.92 W
- Radiation gain (frs): 3,642.96 W
- Total reference (fr): 11,194.88 W

Projected Building (actual architectural model)

- Conduction gain (fpc): 31,000.21 W
- Radiation gain (fps): 3,507.28 W
- Total projected (fp): 34,507.49 W

Thermal Performance: The projected model largely exceeds the normative thermal load limit. The envelope shows high thermal transfer coefficients (K), especially in roofs, lower surfaces, and side facades, with values up to 3.46 W/m2·K in reinforced concrete slabs and 4.85 W/m2·K in 6 mm clear glass. This performance indicates a thermally inefficient envelope.

Critical Factors Detected:

- Lack of effective thermal insulation in roofs and walls.
- Use of clear glass without solar control (high SHGC).
- Lack of shading elements (all shading coefficients = 1).
- Large areas exposed to the sun on east and west orientations, without protection.
- Conduction gain represents 89.8% of the total projected thermal load.

From an architectural perspective, the analysis results highlight a significant deficiency in the passive design of the envelope, which directly impacts the overheating of the property and the inability to comply with the parameters established by **NOM-020-ENER-2011**. The predominant use of materials with high thermal conductivity, such as uninsulated reinforced concrete in roofs and walls, as well as the incorporation of glazed surfaces with 6 mm clear glass without solar control, critically contribute to the high gains from conduction and radiation. Added to this is the absence of exterior solar protection elements (eaves, overhangs, or louvers), which leaves the east and west facades exposed to direct radiation, precisely during the hours of highest thermal load. To improve the energy performance of the project and bring it closer to normative compliance, it is recommended to incorporate effective thermal insulation in roofs and walls (such as expanded polystyrene, polyurethane, or mineral wool), replace existing glass with low-emissivity (low-E) or double-glazing options, and apply fixed or movable shading devices in the most critical orientations. Furthermore, it is suggested to review the proportion and orientation of openings, prioritizing natural light and ventilation capture in north-south orientations, while limiting east-west exposure. These strategies would not only significantly reduce the total thermal load of the property but also contribute to indoor environmental comfort and rational energy use in warm climates like Tampico.

3.2 Recommendations for Building Efficiency Improvement

Based on the findings of this energy efficiency analysis, several key strategies are recommended to significantly improve the thermal performance of the residential project and ensure compliance with **NOM-020-ENER-2011**. These recommendations focus on passive design principles and material selection to mitigate heat gain in a warm-humid climate.

1. **Enhanced Thermal Insulation:** The most critical improvement involves adding effective thermal insulation to both roofs and walls. For roofs, a minimum of 5-10 cm of expanded polystyrene, extruded polystyrene, or mineral wool should be considered, with a focus on achieving a U-value significantly lower than the current 3.46textW/m2cdotK. For walls, incorporating insulation within the hollow concrete block cavities or applying exterior insulation systems (EIFS) can drastically reduce heat conduction. Materials like rigid foam boards (e.g., polyisocyanurate) or fiberglass batts are suitable options.
2. **High-Performance Glazing and Solar Control:** Replacing the existing 6textmm clear single-pane glass is essential. Options include:
   - **Low-Emissivity (Low-E) Coatings:** These coatings reduce heat transfer through windows, keeping interiors cooler.
   - **Double Glazing:** Two panes of glass with an inert gas fill (e.g., argon) provide superior insulation.
   - **Tinted or Reflective Glass:** These types of glass can reduce solar heat gain, but care must be taken to balance this with natural light transmission. Additionally, the **Solar Heat Gain Coefficient (SHGC)** of all new glazing should be carefully selected to be as low as possible for this climate.

3. **Effective Shading Devices:** The current lack of shading elements is a major contributor to solar heat gain. Implementing fixed or movable shading devices is crucial, especially for east and west-facing windows. These can include:
   - **Horizontal Overhangs/Eaves:** Effective for south-facing windows (though less critical in this project due to orientation).
   - **Vertical Fins/Louvers:** Ideal for east and west-facing windows to block low-angle sun.
   - **Vegetation:** Strategically planted trees can provide natural shading, reducing direct solar radiation on facades. The design of these elements should be optimized to block direct sun during peak heat hours while allowing for natural light and views.
4. **Optimized Fenestration and Orientation:** While the current layout promotes cross-ventilation, a review of window-to-wall ratios and their orientation can further enhance performance. Prioritizing larger openings on north and south facades can maximize natural light and ventilation with less solar heat gain, while minimizing or carefully shading openings on east and west facades.
5. **Light-Colored Surfaces:** Using light-colored, high-reflectance materials for the roof and exterior walls can significantly reduce solar absorption and subsequent heat transfer into the building.

1. By systematically integrating these recommendations, the residential project can transition from a low-performing building to one that not only meets but potentially exceeds the energy efficiency requirements of **NOM-020-ENER-2011**, leading to enhanced indoor comfort, reduced energy consumption, and a more sustainable footprint.

4. Conclusion

This study unequivocally show that the analyzed residential project in Tampico, Tamaulipas, significantly fails to meet the energy efficiency standards set by NOM-020-ENER-2011. The calculated thermal load of 34,507.49 is more than double the permitted limit, primarily due to insufficient thermal insulation in the building envelope and the use of materials that offer poor resistance to heat gain. This low thermal performance compromises indoor comfort and leads to excessive energy consumption, particularly for cooling. The implications of these findings extend beyond individual energy bills, contributing to increased strain on the local electrical grid and hindering regional sustainability efforts. To address these critical issues and ensure compliance with energy efficiency regulations in warm-humid climates, it is imperative to integrate robust passive design strategies from the initial architectural planning stages. These include the strategic application of effective thermal insulation in roofs and walls, the careful selection of high-performance glazing with superior solar control properties, and the thoughtful implementation of appropriate fixed or movable shading elements. Furthermore, optimizing window-to-wall ratios and prioritizing north-south orientations for fenestration can maximize natural ventilation and daylighting while minimizing unwanted solar heat gain. By proactively adopting these comprehensive measures, future residential projects in similar climatic zones can achieve substantial reductions in thermal load, significantly enhance occupant well-being, and contribute meaningfully to the region's broader environmental and economic sustainability goals. This shift towards bioclimatic design is not merely a regulatory compliance issue but a fundamental step towards creating more resilient and comfortable living environments in the face of evolving climate challenges..

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