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Energy efficiency in mass-built housing and demonstrative bioclimatic models in a hot-dry climate zone

Eficiencia energética en vivienda de construcción en serie y en modelos demostrativos bioclimáticos en zona de clima cálido seco

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Abstract

The residential sector is one of the biggest consumers of electric energy, especially in zones with extreme dry-hot climates such as Mexicali. The implementation of NOM-020-ENER-2011 energy efficiency standards for the envelope of the dwelling is essential to provide thermal comfort with a lower energy consumption. The goal of this article is to evaluate the application of energy efficiency standards in three housing models: The first one was a prototype of mass-built housing (commercial model) and the remaining were demonstrative dwelling prototypes built with bioclimatic criteria. The analysis was made with the digital calculation tools provided by the Secretary of Energy and the National Commission for the Efficient Use of Energy. The results showed that for the commercial dwelling to reach the energy efficiency standards, it is required to diminish the overall heat transfer coefficient. Therefore, it was achievable to improve the energetic efficiency by including the bioclimatic housing criteria. Although important efforts have been made to optimize the housing design, they have not been effective enough to improve the energy efficiency of the mass-built housing.

Energy efficiency standards, Mass-built housing, Hot-dry climate

Resumen

El sector residencial es uno de los mayores consumidores de energía eléctrica sobre todo en zonas de clima cálido seco extremoso como Mexicali. La implementación de normas de eficiencia energética para la envolvente de la vivienda NOM-020-ENER-2011 es indispensable para generar condiciones de confort térmico con un menor consumo de energía. El objetivo del artículo fue evaluar la aplicación de las normas de eficiencia energética en tres modelos de vivienda: el primero fue un prototipo de vivienda de construcción en serie (modelo comercial) y los restantes, fueron prototipos demostrativos de vivienda construida con criterios bioclimáticos El análisis fue realizado con la herramienta de cálculo digital proporcionada por la Secretaria de Energía y la Comisión Nacional para el Uso Eficiente de la Energía. Los resultados mostraron que para que la vivienda comercial cumpla con los estándares de eficiencia energética requiere disminuir el coeficiente global de transferencia de calor. Se observó que fue factible mejorar la eficiencia energética al incluir criterios de los modelos bioclimáticos de vivienda. Aunque se han hecho esfuerzos importantes, para optimizar el diseño de la vivienda, no han resultado lo suficientemente efectivos para mejorar la eficiencia energética de la vivienda de construcción en serie.

Normas de eficiencia energética, Vivienda de construcción en serie, Clima cálido seco

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Introduction

Energy efficiency in the residential sector is part of the policies to cushion the impact of climate change and its impact on electricity consumption. The residential sector is one of the main consumers of electricity. Globally, this sector is responsible for 22% of total consumption and 19% of CO_2 emissions (Global Alliance for Buildings and Construction, et al., 2019). In Mexico, in 2016, the electricity consumption of the residential sector represented 26.8% of the total electricity consumption (Secretaria de Energía, 2017). In areas with an extreme hot climate, such as Mexicali, electricity consumption in the residential sector represents 43.9% of total consumption (National Institute of Statistics and Geography, 2016). In hot areas, electricity consumption is increased by the use of environmental conditioning systems to maintain conditions of thermal comfort in the hot season.

The housing envelope is the filter of the impact of weather conditions; greater energy efficiency of the same implies greater savings in the use of energy. Laws, codes, regulations and / or standards have been developed in different countries to improve the energy efficiency of buildings and in particular the residential sector. In Spain, there is the Technical Code for Buildings which contains regulations for energy saving (Ministerio de Fomento, 2019). In the United States there are various energy efficiency codes and standards, such as the California Energy Code (California Building Standards Commission, 2019) and the ASHRAE 90.2 standard for the energy efficient design of low-rise residential buildings (American Society of Heating, Refrigeration and Air Conditioning Engineers, 2018), among others.

In Mexico, the public policy to promote energy efficiency in buildings is regulated for non-residential buildings in NOM-008-ENER-2001 (Official Gazette of the Federation DOF, 2001) and the official standard for the envelope of buildings for residential use by NOM-020-ENER-2011 (NOM-020) (DOF, 2011). In this sense, both standards seek to optimize the design of the enclosure, from the point of view of thermal and energy performance.

Obtaining as benefits, among others, energy savings due to the reduction of the capacity of the cooling equipment, since the generalized use of these equipment affects the peak demand of the national electricity system. The building envelope becomes an element of interaction between the exterior and interior environment of the house. With this, there may be envelopes that favor the increase or decrease of the heat gain to the interior, and with this the impact on the conditions of thermal comfort, especially in areas of hot dry climate.

Energy efficiency standards for housing in Mexico

NOM-020 becomes the instrument to determine the energy efficiency of buildings for residential use, applies to new homes or extensions, came into force in 2011, although it is not mandatory; the houses can be of the isolated single-family type (one house per lot) or collective (condominium, multi-family).

NOM-020 is focused on the analysis of the envelope (ceilings, walls, windows and doors). Basically, it estimates the heat gains by conduction and radiation through the envelope, from the comparison of a reference home (VR) and the projected home (VP) –proposal that is evaluated. The characteristics of the VP are defined in the executive project or in the built house, as the case may be; the main requirements are: construction areas and systems by orientation of walls and ceilings, as well as the characteristics and areas of windows and doors by orientation. Regarding VR, it maintains a relationship with VP in areas and orientation, based on considering 90% opaque part in walls and 10% transparent part and in ceilings with 100% opaque part.

In both cases (VP and VR), it is required to have the thermophysical properties of the materials, to estimate the global heat transfer coefficient of the different construction systems of walls and ceilings; the equivalent temperature values for heavy walls, light walls and windows by orientation (north, east, south and west); Average solar gain factors for windows based on their orientation and for skylights and domes.

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With the above, an "energy budget" is obtained that seeks to limit the heat gain of the PV. If the PV has a heat gain equal to or less than the VR, this means that the projected home passes compliance with the standard and shows the corresponding energy savings (DOF, 2011).

The version of NOM-020 published in 2011 was modified in 2016 (DOF, 2016), since it was not possible to comply with it, with the common construction systems for serial construction housing. Adjustments were made to the global heat transfer coefficients, equivalent temperature and solar radiation gain; the values are regionalized by state and cities of the country. Table 1 shows those corresponding to the city of Mexicali, Baja California.

Global heat transfer coefficient (W / m^2 ºC)					
Levels	Up to three levels	Walls and ceilings	0.625		
	More than three levels	Ceiling	0.625		
		Wall	0.714		
Equivalent temperature (ºC)					
Driving	Inside	25			
	Bottom surface	34			
	Ceiling	50			
		Orientation			
	Walls	N	S	E	O
	Massive	36	40	37	39
	Light	41	45	43	46
	Window	30	32	32	33
	Skylights	29			
Solar gain coefficient (W / m^2)					
Radiation	Window	70	159	131	165
	Skylights	322			

Table 1 Global heat transfer coefficient, average equivalent temperature and solar gain factor., NOM-020-ENER-2011, Mexicali, Baja California
Source: Elaboration based on DOF, 2016

Therefore, the objective of this article is to determine the impact of the application of energy efficiency standards NOM-020 in series construction housing in a context of hot dry climate, such as Mexicali; with the purpose of knowing to what extent they comply with energy efficiency regulations or if modifications are required to existing construction systems; and includes the proposal of two demonstration models of housing designed with bioclimatic criteria

The article consists of three parts. In the first, the introductory section is shown and the main guidelines of NOM-020 are specified. In the second, about the method, the case studies, the criteria used, and the evaluation tool are described.

In the third, the results of the application of NOM-020 in the different case studies, the requirements for compliance with it, and the conclusions are presented.

Methodology

Serial construction housing for low-income families, called affordable housing, was evaluated; Three housing models were used: one was the commercial housing model (MC) and two were bioclimatic housing models (BM1 and BM2), these are demonstrative housing prototypes, products of the research project “Thermal comfort and energy saving in economic housing in Mexico: regions with a hot, dry and humid climate ”(Universidad Autónoma de Baja California, *et al*, 2013). The case studies have the main facade to the north, one of the side facades is built at the property limit, they have a corridor that connects the front with the rear of each house. The dimensions of each lot are 6.86 x 17.50 m, with a surface area of 120 m^2. The homes have a common space (living room-kitchen), one or two bedrooms and a bathroom (Figure 1 and 2).

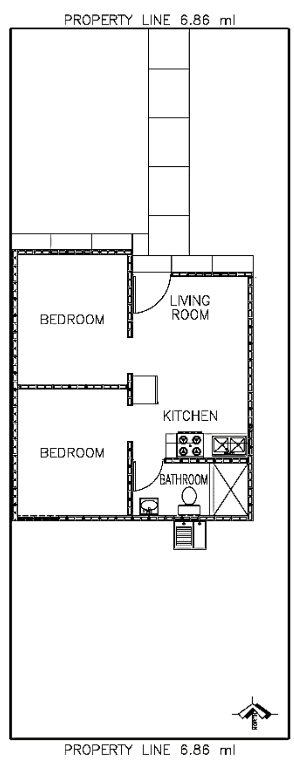

Figure 1 Architectural plan, Commercial model (MC), Fracc. Places of Puebla, Mexicali
Source: Own elaboration, AutoCad

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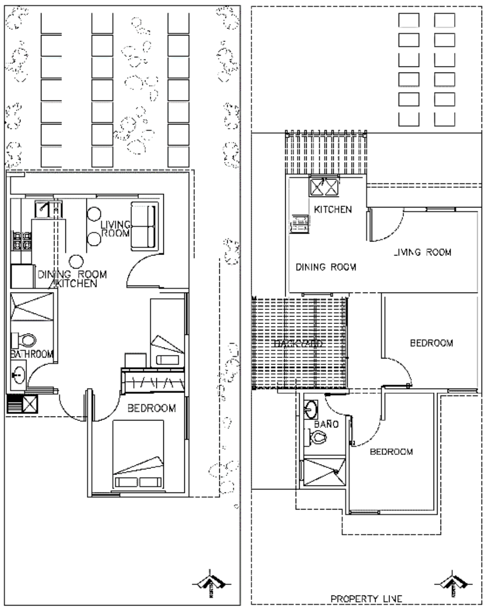


BM1 BM2

Figure 2 Architectural plan, Bioclimatic Models BM1 and BM2, Fracc. Places of Puebla, Mexicali
Source: Own elaboration, AutoCad

The MC and BM1 models have a surface area of 38 m^2 and the BM2, 43.8 m^2. Table 2 shows the wall and ceiling surfaces of each of the housing models.

Surfaces		Areas (m^2) Walls (opaque)	Sale-Nas	Doors (opaque)	Total
Business model (MC)					
Vertical	N	14.03	2.08	1.92	18.03
	S	16.77	1.24	-	18.01
	E	19.19	0.61	-	19.80
	O	19.78	-	-	19.78
Horizontal	T				38.00
	P				38.00
Bioclimatic model (MB1)					
Vertical	N	15.28	2.14	-	17.41
	S	13.18	1.37	1.81	16.34
	E	23.09	2.58	2.18	27.85
	O	27.22	-	-	27.22
Hori	T				38.00
	P				38.00
Bioclimatic model (BM2)					
Vertical	N	18.70	2.49	2.15	23.34
	S	18.77	2.81	-	21.58
	E	20.54	-	-	20.54
	O	28.24	1.31	2.15	31.70
H	T				43.80
	P				43.80
Symbology: N = north, S = south, E = east, O = west, H = horizontal, T = ceiling, P = floor.					

Table 2 Surfaces by orientation, ceiling and floor; Models MC, BM1 and BM2, Mexicali, B.C.
Source: Elaboration from executive plans of the projects

The construction systems of the three housing models are shown in Table 3, and the global heat transfer coefficients of each of them are included.

	Ceiling	U (W/m^2 ºC)	Walls	U W/m^2 ºC
MC	Vault joist	0.345	Common concrete block 0.12 m	2.992
MB1	Wooden structure	0.2506	Common concrete block 0.12 m	2.992
			Common concrete block 0.12 m, polystyrene thermal insulation 0.0254 m (1 ")	0.956
MB2	CCA-6 panels thickness 0.175 m	0.5549	Block 0.15x0.40 x0.40 m, CCA-4 type "O" and "U"	0.8624

Table 3 Construction systems and global heat transfer coefficient (U), case studies
Source: Elaboration from the CATEDI Program, Luna

All homes have a reinforced concrete floor 0.10 m f'c = 240 kg / cm^2 (U = 3.18 W / m^2 ºC); single glass windows and aluminum hoses (U = 7.24 W / m^2 ºC); and drum type wooden doors (U = 2.78 W / m^2 ºC).

The bioclimatic criteria of BM1 are: a) roof with a lightened wooden structure, exterior sheet and interior insulation, which functions as a double roof with ventilated attic; b) 0.12 m concrete block wall in north and south walls; plus thermal insulation 0.0254 m (1 ") in east and west walls; c) location of windows that promote cross ventilation; d) window shading elements with roof extension; e) use of light colors on exterior walls.

The bioclimatic techniques of the BM2 are: a) roof made of panels of autoclaved cellular concrete (CCA), type CCA-6; b) CCA walls, type CCA-4; c) use of natural ventilation and lighting; d) use of outdoor patios; e) use of solar protection on walls; f) interior heights greater than 2.40 m.

For each case study, a base case was established, which is the one that matches the real home built. Modifications were proposed to the design of the housing envelope, to improve energy performance (Table 4).

ISSN 2531-2162

Key	Considerations
	Business model (MC)
Base case	Joist and vault ceiling 0.20 m, concrete block wall 0.12 m, windows without shade
A	Base case + 0.0254 m (1 ”) polystyrene thermal insulation on south wall
B	Base case + 0.0254 m (1 ”) polystyrene thermal insulation on west wall
C	Base case + 0.0254 m (1 ”) polystyrene thermal insulation on south and west walls
D	Base case + 0.0254 m (1 ”) polystyrene thermal insulation on south, west and east walls.
E	Joist and vault ceiling 0.20 m, CCA-4 autoclaved cellular concrete block wall,
	Bioclimatic model 1 (BM1)
Base case	Wooden roof with lateral ventilation on two sides and 0.508 m (2 ”) polystyrene thermal insulation and exterior covered with galvanized sheet. 0.12 m concrete block walls in north and south orientation. 0.12 m concrete block walls + 0.0254 m (1 ”) polystyrene thermal insulation in east and west orientation. Shadowless windows
A	Base case + 0.0254 m (1 ”) polystyrene thermal insulation on south wall
F	CCA-6 autoclaved aerated concrete panel ceiling, 0.17 m, CCA-4 autoclaved aerated concrete block wall, Shadeless windows
G	Joist and vault ceiling 0.20, concrete block wall 0.12, windows without shade
	Bioclimatic model 2 (BM2)
Base case	CCA-6 autoclaved cellular concrete panel ceiling, CCA-4 autoclaved cellular concrete block wall, windows without shade
H	CCA-6 autoclaved cellular concrete panel ceiling, CCA-4 autoclaved cellular concrete block wall, windows with shade

Table 4 Study cases. Source: self made

The evaluation of the case studies was carried out with the NOM-ENER-2011 calculation tool prepared for the Secretary of Energy and the National Commission for the Efficient Use of Energy (Danish Energy Agency, 2017; CONUEE, 2017). Screens of the assessment tool are shown in Figure 3.

Figure 3 NOM-020-ENER- 2011 Calculation Tool, SENER-CONUEE
Source: https://www.gob.mx/conuee/acciones-y-programas/herramienta-calculo-nom-020-ener-2001

Results

The results are presented by type of home, the base case and the modifications made to comply with NOM-020 are considered.

Table 5 shows the heat gain of the commercial model (joist and vault ceiling, and concrete block walls). It is observed that the MC, without insulation in ceilings and walls, has 50% more heat gain than the value allowed to approve compliance with NOM-020.

Thus, even when you have a joist and vault ceiling, it is not enough to achieve compliance with NOM-020, nor with the partial isolation of any of the orientations (south, west or east), isolation is required. of the 3 orientations mentioned (Case D) or the change for a construction system with a higher thermal resistance (Case E).

Model de vivienda	Heat gain (W)			NOM-020 compliance	
	Conduction	Radiation	Total	Yes or no	Energy Saving (%)
Reference Housing					
	1397.94	1001.4	2402.31		
Projected Housing					
Base case	3200.90	405.03	3605.93	No	-50.1
A	2790.34	405.03	3195.37	No	-33.0
B	2677.44	405.03	3082.47	No	-28.3
C	2267.78	405.03	2672.81	No	-11.3
D	1681.80	405.03	2086.83	Si	13.1
E	1282.55	405.03	1688.58	Si	29.7

Table 5 Heat gain, Commercial model (MC), NOM-020-ENER-2011, Mexicali
Source: Elaboration based on the application of NOM-020

In the case of the bioclimatic housing demonstration model (BM1) built with a wooden roof (ventilated attic) and concrete block walls, according to Table 6, it is observed that even when it has a roof with thermal resistance (thermal insulation of polystyrene 0.0508 m) and east and east walls with thermal insulation of polystyrene 0.0254 m (1”), does not meet the approval of NOM-020.

Housing model	Heat gain (W) Conduction	Radiation	Total	NOM-020 compliance Yes or no	Energy Saving (%)
Reference housing					
Ref	1557.98	1225.2	2783.13		
Projected Housing					
Base case	2347.71	738.90	3086.61	No	-10.9
A	2026.02	738.90	2764.92	Si	0.70
F	1759.56	738.90	2498.46	Si	10.20

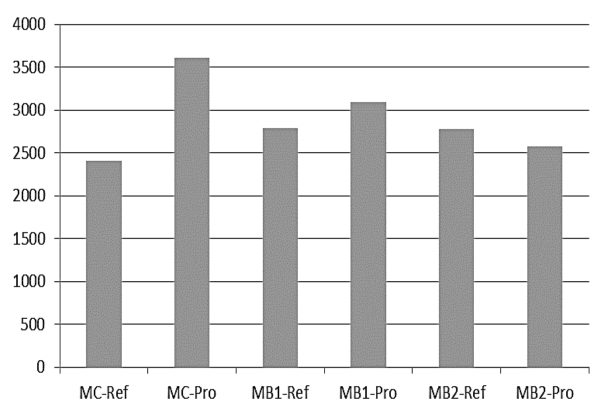
Table 6 Heat gain, Bioclimatic Model (BM1), NOM-020-ENER-2011, Mexicali
Source: Elaboration based on the application of NOM-020

To comply with NOM-020, it is required that the south, east and west walls be insulated, which implies increasing the surfaces with thermal insulation or substituting construction systems with higher thermal resistance. Table 7 shows the application of NOM-020 in a bioclimatic house built with autoclaved cellular concrete system. This system did allow the approval of NOM-020.

Housing model	Heat gain (W) Conduction	Radiation	Total	NOM-020 compliance Yes or no	Energy Saving (%)
Reference housing					
	1610.97	1165.6	2777.52		
Projected housing					
Base case	1817.99	756.80	2574.79	Si	7.3

Table 7 Heat gain, Bioclimatic Model (BM2), NOM-020-ENER-2011, Mexicali
Source: Elaboration based on the application of NOM-020

In Graphic 1, the total heat gains of the reference and projected housing of each of the study cases are shown; and Table 8 shows the energy efficiency per square meter (m^2) of the case studies.



Symbols: MC-Ref = Reference commercial-housing model; MC-Pro = Projected commercial-housing model. BM1-Ref = Bioclimatic model 1 - reference house; BM1-Pro = Bioclimatic model 1 - projected house .; BM2-Ref = Bioclimatic model 2 - reference house; BM2-Pro = Bioclimatic model 2 - projected house

Graphic 1 Total heat gain (W) of the MC, BM1 and BM2 models, NOM-020-ENER-2011, Mexicali

The models built or homes projected showed that the MC had a heat gain of 3605 W, the BM1 of 3086.61 W and the BM2 of 2574.79 W; it is observed that the bias of the bioclimatic models is 16% and 29% lower than the commercial model.

Housing (W / m^2) Business model MC		Bioclimatic model BM1		Bioclimatic model BM2	
Ref	Proj	Ref	Proj	Ref	Proj
63.22	94.89	73.24	81.23	63.13	58.52
Symbology: Ref = Reference, Proj = Projected					

Table 8 Energy efficiency per m^2, case studies, Mexicali
Source: Our elaboration

The above shows that the commercial construction system is the one with the highest heat gain, therefore it turns out to be the least efficient; a better thermal performance per m^2 was shown by the construction systems of the bioclimatic models.

Conclusions

For the climatic conditions of Mexicali, it is concluded that:

- Current construction systems are not sufficient to comply with NOM-020, they represent 50% more heat gain than allowed by the standard.

- It is required to apply thermal insulation measures at least in 3 (south, east and west) of the 4 basic orientations, which implies additional investment costs to have a home that passes the conditions of the standard.

- The modifications made in 2016 are not yet sufficient to achieve energy savings and maintain conditions of thermal comfort, it is necessary to readjust the global heat transfer coefficients used as a reference in hot dry climates.

- The digital evaluation tool of NOM-020-ENER-2011 resulted in an accessible and relevant instrument for its application, significantly facilitating the evaluation of projects.

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- NOM-020 analyzes the impact of heat gain on the enclosure, gives priority to the criterion of thermal resistance; it does not allow to include the effects of shaded or ventilated ceilings or walls and construction systems greater than 5 layers, although it does consider shading in windows.

Finally, it will be important to have public policy elements that favor the inclusion of bioclimatic design criteria, which allow better thermal performance of the housing envelope, as well as to reduce electrical consumption while maintaining conditions of thermal comfort for the population.

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