Improvement of Thermal Comfort by Passive Strategies. Case Study: Social Housing in Mexico

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***Abstract*—The purpose of this research is the enhancement of thermal comfort in social housing in four different climates zones in Mexico: Veracruz- Hot semi-humid, Monclova- Extremely Hot dry, San Luis Potosi- dry and; Mexico D.F- Temperate semi-humid. Thermal comfort levels from base case analysis showed poor building performance. Moreover, thermal variations among climate zones were evident; thus, overheating was the main concern for warm semi-humid and extremely hot dry climate; and, overcooling for temperate climates.**

The analysis on improvement of thermal comfort was done by dynamic simulation based on five parameters: building fabric, shading, ventilation, infiltration and height. Several strategies were tested for each parameter and simulated individually for each climate zone. The results then were compared to the base case as to determine the best strategies according to the climate zone.

Three built-on strategies were made by grouping the most effective strategies of the previous five parameters: 1) insulating the building, 2) incrementing ventilation and shading, and 3) using passive cooling and heating by solar chimneys. Thus, the integrated strategies begun with the simplest improvements and built on themselves to more complex constructions capable of maintaining thermal comfort all year round with the use of active heating or cooling.

***Index Terms*—thermal comfort, passive design, social housing, passive heating, passive cooling**

I. Introduction

By 2012 Mexico was 13th in place for most CO2 emissions from fuel combustion worldwide [1] resulting in Mexico being the first developing country to submit a new climate action plan to the UNFCCC (United Nations Framework Convention on Climate Change) by 2015.

The housing sector in Mexico is responsible for 32 % of GHGs emissions, half of those coming from energy consumption for heating and cooling [2] [3]. As actions to mitigate the impact of housing on GHGs emissions some sustainable housing programs have been developed in the last decade like “Green Mortgage”, “Housing Project Zero Energy” by CONAVI (National Housing Commission), “Ecocasa” by the Mexican Federal Mortgage Company and; the recent National Appropriate Mitigations Actions “NAMA” focusing on the housing performance. These programs have shown that a reduction in greenhouse gases is possible using sustainable designs to improve thermal comfort by passive means [4] [5].

The existent research on passive strategies on social housing in Mexico has been conducted mainly on warm weathers disregarding the full specter of climate conditions in the country. [6] and [7] studied the optimization of a low-cost dwelling by passive means on desert climates using simulation software and field studies respectively. [8] and [9] studied thermal comfort on social housing in hot-humid Mexican climates. While [8] tested the effect of the envelope’s U-Value on indoor thermal comfort, [9] used BIM software to simulate the heat balance and determine the construction elements affecting energy efficiency and indoor comfort. In contrast, this research tests a wide range of building parameters and its variations individually as to determine the most effective strategies before implementing an overall approach; thus, it provides a clearer understanding of passive means as opposed to the general researches conducted this far.

Despite the government effort to develop sustainable housing, the existing social programs use a prototype house replicated overall the country disregarding the environmental response. The main aim of this research is the enhancement of thermal comfort in an archetypical social housing by applying Passive House Strategies in four climate zones: hot semi humid, extremely hot dry, dry and, temperate semi-humid climate; using as base cases four cities in Mexico. An overall of 45 passive strategies were tested in each climate condition as to prove their validity when applied in different climatic conditions; the best strategies were then combined to create integral approaches for each climate. Passive strategies reduce significantly the amount of energy needed for cooling and heating thus reducing the amount of GHG’s emissions.

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Four stages where developed to achieve the main aim:

- Determine the levels of thermal comfort in a prototypical social house in the different climate zones.
- Identify passive house strategies applicable in the different climate zones.
- Determine the best passive strategies for each climate zone using dynamic simulation.
- Create three built-up strategies to improve thermal comfort by passive means in each climate zone.

II. Methodology

Dynamic simulation modelling of a typical social housing was used to evaluate the levels of thermal comfort in four different climate zones (case studies) in Mexico and to enhance the indoor comfort by applying passive strategies. The selected climate zones were Veracruz, Veracruz (hot semi-humid climate), Monclova, Coahuila (Extremely Hot dry climate), San Luis Potosi, S.L.P. (Dry climate) and Mexico City, D.F. (Temperate semi-humid). The selected case studies are the most representative of Mexico's climate based on National Institute of Statistic and Geography classification (Fig. 1) [10]. The weather profiles for each city were obtained from Meteonorm database.

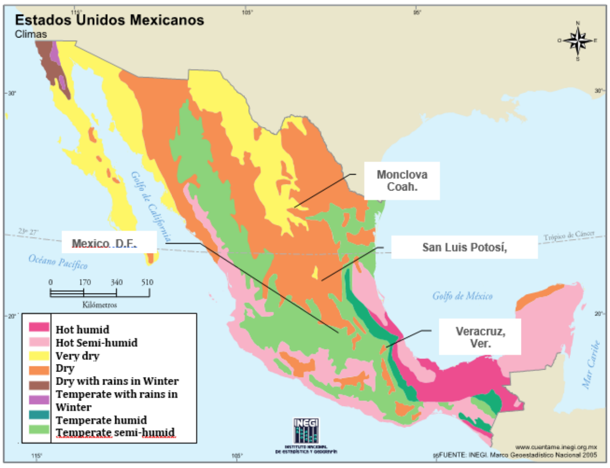


Figure 1. Bioclimatic zones in Mexico. Source INEGI

The social house model used was based on [11] , this model complies with the minimum requirements by the Mexican Housing Code for surface area, ventilation and lighting. The house has a rough construction area of 43.73 sqm with a thermal envelope of 39.27 sqm. The floor plan can be found in Fig 2.

The house model was created based on the housing typology proposed by the National Appropriate Mitigation Actions "NAMA" [11] [12], and to comply with the Mexican Housing Code Design by [13]. The construction envelope parameters used and internal gains are shown in Table 1. According to [11] the typical orientation is with the main fa çade on South-North Axis. The thermal simulation was made on Mexican Software DEEVi (Energetic Efficient Housing Design), as to comply with Mexican building regulations, and IESve, (Integrated Environmental Solutions) a recognized software leader in performance analysis of energy efficiency.

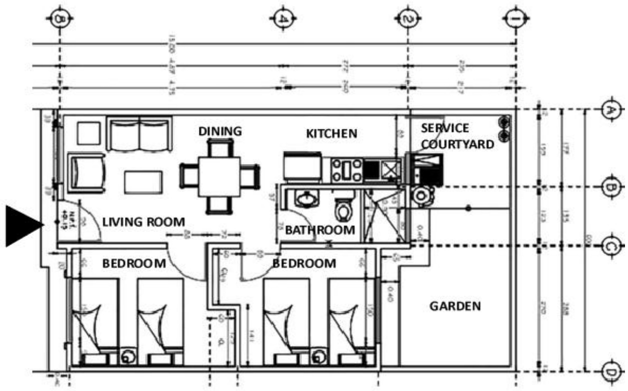


Figure 2. Archetypical Social House in Mexico. Source [11]

TABLE I. Building Fabric and Internal Gains. Source [12]

	Element	Construction	Thickness (mm)	U value (W/m2K)
Building Fabric	External wall	Concrete light block. Exterior: estuco plaster. Interior: plaster	120	1.12
	Roof	Reinforced concrete slab	120	3.57
	Ground floor	Reinforced concrete slab	100	1.64
	Glazing	Clear single glazing 3mm thick. Aluminium frame 1 ½"	3	5.22
Internal Gains	Element	Type	Gains (kWh/year/m2)	
	Lighting	Compact fluorescent light	1.65	
	Appliances	Washing machine. fridge	10.96	
	Occupancy	10 sqm / person		
	Airtightness	5 ach		

Thermal comfort was defined for each climate zone using the Adaptive Comfort Model described in ASHRAE Standard 55-2010 (American Society of Heating, Refrigerating and Air Conditioning Engineers) and calculating thermal ranges using psychometric charts (refer to Table 2). This standard was chosen as it enables designers to create indoor climates that occupants find pleasant [14]; additionally, adaptive comfort allows some variations within the comfort zone due to physical, environmental and cultural adjustments [15]. Building behavior was tested for each climatic condition without active means to regulate indoor conditions (mechanical systems) as to evaluate the passive performance of the building.

TABLE II. ADAPTIVE THERMAL COMFORT CRITERIA. SOURCE: CLIMATE CONSULTANT 6.0

Adaptive thermal comfort criteria			
Climate Zone		< ℃	> ℃
Veracruz, Ver	Hot semi-humid	21.8	29.0
Monclova, Coah	Extremely dry	18.4	29.3
San Luis Potosi	Dry	18.6	26.7
Mexico D. F	Temperate semi-humid	19.5	26.3

The analysis on improvement of thermal comfort was done by dynamic simulation based on five parameters: building fabric, shading, ventilation, infiltration and height. These parameters were chosen from previous research on passive house design [12] [16] [17] [18] [19]. This research did not consider other parameters such as orientation, surface to volume ratio, window to wall ratio, etc.; as an alteration in the building plans was not intended. Considering that the main factors affecting thermal performance of the building are heat storage, insulation and reflectivity [20], these strategies were tested for each parameter and simulated individually for each climate zone. The results then were compared to the base case as to determine the best strategies according to the climate zone. All passive strategies used are shown on Table III.

As to provide an integral and practical approach three built-on strategies were made by grouping the most effective strategies of the previous five parameters: 1) insulating the building, 2) incrementing ventilation and shading, and 3) using passive cooling and heating by solar chimneys. Thus, the integrated strategies begun with the simplest improvements and built on themselves to more complex constructions.

III. RESULTS

A. Base Case Simulation

The base case has a poor energy performance as indoor temperature fluctuates with the outdoor temperature. Moreover, thermal variation amongst climate zones were evident; thus, overheating was the main concern in hot semi-humid climate (Veracruz) with 29.1% of time in overheating, overcooling in dry and temperate semi-humid climates (San Luis Potosi and Distrito Federal) with 52.7% and 55% overcooling respectively, and, both overcooling (21.6%) and overheating (31.3%) in the extreme hot dry climate (Monclova) (See Fig. 3).

DEEVi software was used to calculate the energy demand of the base case building on each climate condition. The highest energy demand is used for cooling in Monclova (151.1 kWh/m2/annual) and Veracruz (118 kWh/m2/annual) which relates clearly to the overheating problems detected on both cities. On the other hand, San Luis Potosi and Mexico DF, had overcooling around 50% of the time thus needing heating during winter season. The energy demand for heating is 11.5 and 9.7 kWh/m2/annual respectively.

B. Application of passsive strategies

As stated before, the first approach to determine the best passive strategies was to simulate each individually and compare the results in terms of thermal comfort. Five parameters were analyzed: 1) Building fabric, 2) shading, 3) ventilation, 4) infiltration and 5) ceiling height.

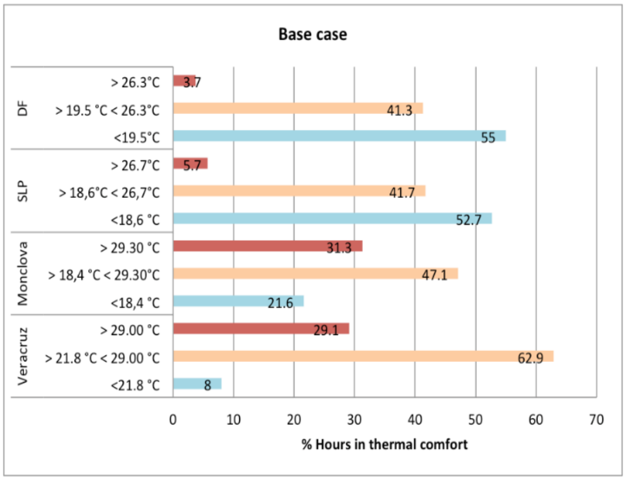


Figure 3. Percentage of hours in thermal comfort of the base case building in the four climatic zones. Source. Simulation with IESve

As thermal comfort was defined using the adaptive method, a wider comfort range results on a larger range of passive strategies as temperature regulators; this effect can be seen on the results from the city of Monclova (see Table 3) where most strategies show an improvement on thermal comfort.

Some of the strategies diminished thermal comfort and thus its results are not displayed as to facilitate the reading. The results from the strategies are shown on Table 3. The results from this analysis can be extrapolated to other building typologies as design guidelines but need further research to determine their effectiveness

Regarding building fabric, it was noticeable that the mayor improvement came from the use of high thermal mass combined with insulation on the dry climates and; the ventilated double leaf construction with reflective surfaces for the semi-humid climates. As the base case has single clear glazing any strategy implies an improvement in thermal comfort, nonetheless double glazing with outer pane low-e and 12mm air cavity showed the best improvement.

Shading on itself cannot improve thermal comfort but when combined with controlled infiltration to a rate of 0.25 ach has significant results on the dry and temperate climates. As was expected the reduction on solar gains by any means of shading on the extremely dry and hot climate helps improve thermal comfort. Ventilation and infiltration are closely related and are directly opposite; thermal comfort improves on the hot climate by increasing the ventilation rate and, on the temperate climate by reducing infiltration.

TABLE III. SIMULATIONS RESULTS FROM PASSIVE HOUSE DESIGN STRATEGIES

		Strategy	Thickness (mm)	U Value (W/m2k)	Thermal mass (kJ)	% of hours in thermal comfort			
						Veracruz 21-29 ℃	Monclova 18-29 ℃	San Luis 18-27 ℃	Mex DF 19-26 ℃
Building Fabric	Wall/Roof	Base case (BC)	146/146	1.12/3.57	40/142	62.9	47.1	41.7	41.3
		BC + Reflective surface	149/148	1.12/3.57	41/144	63.8	49	43.4	44.5
		BC + Insulation	196/221	0.34/0.30	4/4	69.7	54.9		
		BC + Insulation + reflective surface	199/224	0.34/0.30	4/4	69.8	54.9		
		BC + Insulation with high storage mass	221/221	0.28/0.30	125/204	74.2	56.8	43.4	
		Ventilated double leaf construction. Inner leaf with reflective surface	436/422	1.04/0.78	37/140	71.5	52.7		
		Ventilated double leaf construction. Inner leaf with high thermal mass	486/497	0.39/0.78	116/226	79.3	54.8		
	Ground	Base case (BC)	100	1.64	120	62.9	47.1	41.7	41.3
		BC + Insulation	188	0.26	10.4		47.5	42.8	45.3
		BC + Insulation with high storage mass	188	0.27	120		48.7	47.8	49
		Double leaf construction with cavity	500	1.27	120		48.8	43.9	45.3
		Double leaf insulated construction	575	0.26	230		48.6	47.8	49
		Ventilated double leaf construction. Inner leaf with reflective surface	405	0.78	120	63.4	49.3		
		Ventilated double leaf construction. Inner leaf with high thermal mass	478	0.78	230		48.6	47.7	48.8
	Windows	Base case (BC)	4	5.75		62.9	47.1	41.7	41.3
		Single glazing low-e 6mm	6	5.69		63.4	49.3	42.3	43.4
		Double glazing 4/12/4 mm air cavity	20	1.63		63.9	49.3	42.4	43.6
		Double glazing 4/12/4 mm air cavity. Outer pane low-e	20	2.85		63.5	49.3	42.9	43.9
		Double glazing 4/16/4 mm argon cavity	24	1.1		63.9	49.3	42.4	43.6
		Triple glazing 4/10/4/10/4 mm air cavity	32	1.4		64	49.4	42.4	43.4
		Triple glazing 4/16/4/16/4 mm argon cavity	44	0.93		63.9	49.4	42.4	43.6
Shading Devices		Base case (BC) None				62.9	47.1	41.7	41.3
		Horizontal overhang (depth)	350			65,4	50.4		
		Horizontal overhang (depth)	650			65.4	50.4		
		Vertical lovers 45 °				65.4	50.4		
		Internal shutters				65.6	50.3		
		Louvers + 35cm overhangs				65.4	50.4		
		35cm overhangs + shutters				65.6	50.3		
Ventilation		Base case (BC)				62.9	47.1	41.7	41.3
		Cross ventilation with night ventilation on summer				65.1	50.9		
		Stack effect ventilation				64.2	49.6		
		Stack effect ventilation with temperature control >25 ℃					49.6		
		Solar chimney				66	48.5		
Infiltration		Base case (BC) 5 ach				62.9	47.1	41.7	41.3
		4 ach					48.8	44.9	46.4
		2.5 ach					48	48	49.6
		1.5 ach					47.2	50.5	52.6
		0.5 ach						53.5	56.7
		0.25 ach						54.1	57.7
Ceiling Height		Base case (BC) 2.5meters				62.9	47.1	41.7	41.3
		2.35 meters							
		2.80 meters					49		
		3.10 meters					49.3		

Ceiling height plays a significant role on thermal comfort as the air volume due to the buoyance effect can regulate indoor temperature. As such thermal comfort is best when having higher spaces on the hot climate and smaller spaces on the temperate climates.

The results are applicable to housing typologies with similar conditions of occupancy, internal gains and window-to-wall ratio. Additional research is needed as to validate the results on built models exposed to the climatic conditions here described.

C. Built-on strategies:

Three built-on strategies were created starting from the easiest interventions and building-on to complex constructions; these strategies are: 1) Basic passive house by adding insulation to the building fabric, 2) Improved passive house by controlling ventilation and shading and, 3) Optimal Passive House by using passive conditioning. These strategies can act as a start point to investors and developers based on market requirements. The general parameters are applicable to all climate conditions analysed but the individual strategies vary between climates.

The Basic Passive House has a low impact on thermal comfort unless combined with adequate ventilation and increased airtightness (second strategy); the strategies involved are insulating the roof and walls with an 80% reflectivity on outer surfaces for the Extremely dry and Hot-humid climates; and using reflective surfaces without insulation on the moderate climates. A 10% improvement for Veracruz and Monclova and, a 3% for San Luis Potosi and Mexico City is achieved using this “Basic Passive House”.

The Improved Passive House adds shading mechanism, controlled ventilation and adequate ceiling height to the Basic Passive House based on the specific climate condition.

Cross ventilation is key to achieve thermal comfort in hot climates while airtightness combined with stack effect reduces overcooling in the temperate climate. Since daytime ventilation follows outdoor temperature in low mass buildings [21] night ventilation was introduced to flush hot air from the spaces. A horizontal overhang supported by a vertical wing was placed to block the heavy solar radiation on south-north orientation [22]. The overhangs configuration can be seen in Fig 4.

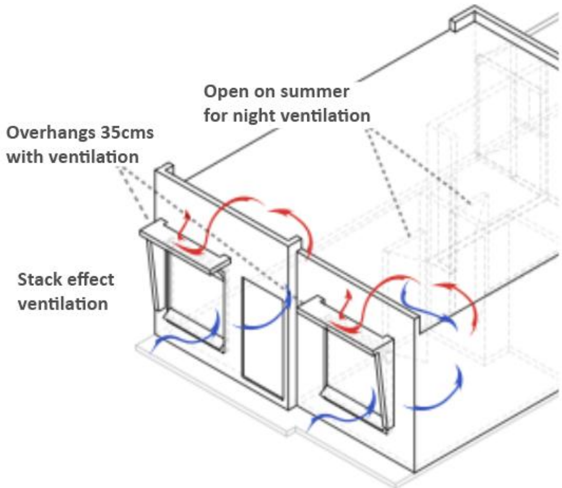
The second strategy enhanced thermal comfort by 15% in all climates, except for Mexico City where a 20% improvement was achieved.

On the more extreme climates, the use of solar chimneys, ventilated double leaf constructions and high thermal mass (third strategy) has a striking effect on reducing both overcooling and overheating; this strategy is considered optimal as achieves thermal comfort above 85%. Solar chimneys were used on all climates in order to cool or heat the spaces as necessary; they were incorporated as part of the roof parapet to enhance ventilation [23]. Solar chimneys use the buoyance effect given by the difference of air temperature [24] [25]; an increase in windows height was necessary to allow more solar radiation to reach the solar chimney, thus enhancing the ventilation by differences in temperature. Insulation was placed on the outer pane to enhance thermal mass effectiveness and dark colours were used on it to draw fresh air in [18].

Double leaf constructions were used in ground floor and walls for Veracruz and Monclova; in San Luis and Mexico DF a ventilated double leaf wall was used to work as solar chimney with inner leaf with dark colours to enhance the stack effect [25]. An improvement of 30% for Veracruz and Monclova and, 50% for San Luis Potosi and Mexico City was achieved by using the Optimal Passive House. The results from the integral strategies are shown on Table 4; as each strategy is built-on the previous one, the implementation cost gradually increases with each approach.

IV. Conclusions

By applying each strategy in a step-by-step basis according to each climatic condition an 85% of hours in thermal comfort can be achieved in all the base case cities. The energy consumption is also reduced significantly by using passive design strategies in all four climates. On Veracruz and Monclova, a reduction of 79 kWh/m2 and 143.7 kWh/m2 respectively was calculated using DEEVi Software.



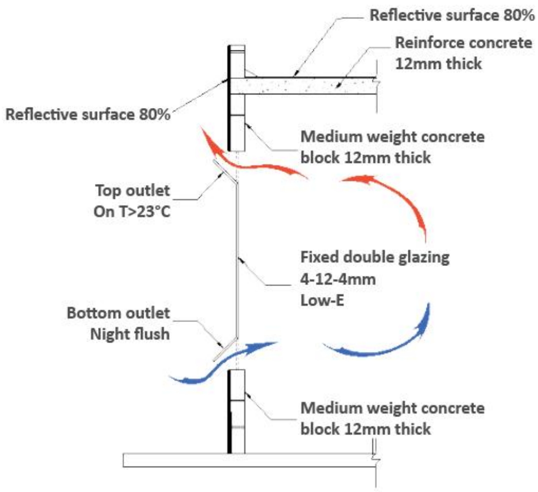


Figure 4. Overhang and stack ventilation configuration

TABLE IV. BUILT-ON PASSIVE STRATEGIES RESULTS

Passive House Strategies			Climate Zones			
			Veracruz	Monclova	San Luis	Mexico DF
Basic Passive House	Insulation	Reflective surface roof. Solar reflectivity 80%. Thermal emittance 0.80			X	X
		Reflective surface wall. Solar reflectivity 80%. Thermal emittance 0.80			X	X
		Insulated roof with reflective surface. Solar reflectivity 80%. Thermal emittance 0.80	X	X		
		Insulated wall with reflective surface. Solar reflectivity 80%. Thermal emittance 0.80	X	X		
		Double glazing 4-12-4 mm outer pane Low-E			X	X
		Single glazing Low-E 6mm	X	X		
		IMPROVEMENT IN THERMAL COMFORT	8.67%	8.96%	1.42%	4.00%
Improved Passive House	Ventilation, shading, height	Internal partition with high thermal mass. Heavy concrete block.		X	X	X
		Insulated ground with high storage mass		X	X	X
		Internal shutters	X		X	
		35cm horizontal overhangs	X	X	X	X
		Cross ventilation with night ventilation on summer	X	X		
		Stack effect ventilation			X	X
		Infiltration 0.25 ach	X	X	X	X
		Height 2.50 meters			X	X
		Height 2.80 meters	X	X		
		IMPROVEMENT IN THERMAL COMFORT	14.46%	15.35%	23.23%	29.82%
Optimal Passive House	Passive Cooling	Ventilated double leaf wall to work as solar chimney. Inner leaf dark surface and high storage mass. Outer leaf with metal	X	X	X	X
		Ventilated double leaf ground. Inner leaf with reflective surface and high thermal mass	X	X		
		Insulated roof with high storage mass and reflective surface. Night flush	X			
		Stack effect ventilation. Top and lower outer open when T>23 °C	X	X	X	X
	Passive Heating	Ventilated double leaf wall to work as solar chimney. Inner leaf dark surface and high storage mass. Outer leaf with metal		X	X	X
		Insulated roof with high storage mass and dark surface. Night flush on summer		X	X	X
		Double leaf insulated ground with cavity. High thermal mass. Night flush on summer			X	X
		Stack effect ventilation. Top and lower inner open when T<18 °C		X	X	X
		IMPROVEMENT IN THERMAL COMFORT	27.52%	31.63%	46.49%	58.65%

The Basic Passive House showed better results in the extremely dry (Monclova) and hot semi-humid (Veracruz) climates with an average 8.8% improvement. Infiltration is the main factor affecting thermal comfort in the dry (San Luis) and temperate (Mexico DF) climates, thus by applying the Improved Passive House a 24% increase in comfort is achieved.

Therefore, the application of passive design strategies taking into account particular climate zones demonstrated to have a strong impact on the increase of thermal comfort in housing by delinking indoor-outdoor temperatures fluctuations.

Further research and validation is needed as to evaluate the real impacts of the proposed Passive House Strategies when built on site and on the specific climatic conditions. Additionally, more research is needed as to develop suitable strategies on all climatic variations on the country.

This research provides design guidelines suitable to the Mexican market and fits in the Mexican Government initiative to provide financial support by granting low rate credits to developers that comply with sustainable guidelines and passive house standards; consequently, lowering the GHGs emission to reach the climate target set by the United Nations Framework Convention on Climate Change.

REFERENCES

[1]. United Nations Climate Change Secretariat, “UNFCCC Country Brief 2014: Mexico,” United Nations, 2015.

[2]. M. Gaitan, Estrategia Nacional para la Vivienda Sustentable, México DF: Componente Ambiental de la Sustentabilidad, 2013.

[3]. C. Martin, Mitigación y adaptación al cambio climático a través de la vivienda pública, 2013.

[4]. R. Kaineg, Supported NAMA for Sustainable Housing in Mexico 'Mitigation actions and Financing Packages', Mexico DF, 2012.

[5]. Secretaría de la Energía, Programa Nacional para el Aprovechamiento Sustentable de la Energía 2014-2018, 2014.

[6]. C. Romero, I. Rodríguez and M. Domínguez, “Thermal behaviour of social housing and the application of passive strategies,” in World Sustainable Energy Days, Wels, 2018.

[7]. J. Marincic, J. Ochoa and M. G. Alpuche, “Passive house for a desert climate,” Transactions on Ecology on the Built Environment, no. 142, pp. 2495-3007, 2014.

[8]. L. Medrano Gómez and A. Escobedo Izquierdo, “Social housing retrofit: improving energy efficiency and thermal comfort for the housing stock recovery in Mexico,” Energy Procedia, no. 121, pp. 41-48, 2017.

[9]. T. Ramírez Ortegón, A. Vega Pasos and S. Álvarez Romero, “Thermal comfort and energy efficiency analysis of affordable houses in Merida, Mexico,” International Journal of Science and Engineering, vol. 3, no. 5, pp. 01-07, 2017.

[10]. INEGI, “Mapa digital de México,” INEGI, 2010. [Online]. Available: http://gaia.inegi.org.mx/mdm6/?v=bGF0OjIzLjMyMDA4LGxvbjotMTAyLjE0NTY1LHo6MSxsOnRjMTExc2VydmljaW9zfGM0MTg= . [Accessed 14 June 2016].

[11]. L. Campos, Estudio de optimización de la eficiencia energética en viviendas de interés social, INFONAVIT, 2012.

[12]. W. Feist and P. H. Institute, Technical Annex: Evaluation of social housing building types in Mexico, Mexico DF: NAMA, 2012.

[13]. INFONAVIT, SISEVIVE Ecocasa Sistema de Evaluación de Vivienda Verde, INFONAVIT, 2014.

[14]. J. Nicol and M. Humphreys, “Adaptive thermal comfort and sustainable thermal standards for buildings,” Energy and Buildings, no. 34, pp. 563-572, 2002.

[15]. F. Nicol, “Adaptive thermal comfort standards in the hot-humid tropic: a literature review,” Energy and Buildings, no. 36, pp. 628-637, 2004.

[16]. F. Agugliaro, F. Montoya, A. Ortega and A. García-Cruz, “Review of bioclimatic architecture for achieving thermal comfort: a review,” Renewable and Sustainable Energy, no. 25, pp. 736-755, 2015.

[17]. S. Hasting and M. Wall, Sustainable Solar Housing: strategies and solutions, London: Earthscan, 2007.

[18]. L. Jankovic, designing zero carbon buildings using dynamic simulation, London: Routledge Taylor and Francis Group, 2012.

[19]. S. Stevanovic, “Optimization of passive solar design strategies: a literature review,” Renewable and Sustainable Energy, no. 25, pp. 177-196, 2013.

[20]. Skat, Climate responsive buildings, World Environmental Library, 1993.

[21]. B. Givoni, “Indoor temperature reduction by passive cooling system: a literature review,” Solar Energy, no. 85, pp. 1692-1726, 2009.

[22]. M. Palmero and A. Oliveira, “Effect of louvers shading devices on buildings: a literature review,” Energy Requirements, pp. 87-204, 2010.

[23]. M. Gadi, “Application of design and passive technologies for thermal comfort in buildings in hot and tropical climates,” University of Nottingham, Woodhead Publishing Limited, 2010.

[24]. H. Chan, S. Riffat and J. Zhu, “Review of passive solar heating and cooling technologies,” Renewable and Sustainable Energy Reviews, no. 14, pp. 781-789, 2010.

[25]. X. Zhai, Z. Zong and R. Wang, “A review for the applications of solar chimneys in buildings,” Renewable and Sustainable Energy Reviews, no. 15, pp. 3757-3767, 2011.

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