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A Review of the Techniques Used to Reduce the Thermal Load of Buildings in Mexico's Warm Climate

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The heat transfer of buildings contributes directly to the consumption of electricity, because the most common alternative to reduce the internal temperature has been the disproportionate use of conventional air conditioning systems. The bioclimatic architecture is an alternative of a still limited application. However, nowadays, several investigations indicate a significant correlation between heat gain and internal thermal comfort perceived in built spaces. This proposal reviews the techniques studied and used to reduce the thermal load coming from outside and generated inside buildings located in a warm weather zone in Mexico. These cases are intended to show the current status of this research topic, as well as identify areas of opportunity relevant to the analysis and its implementation especially in coastal areas. Critical factors to explore include the influence of relative humidity on the thermal sensation, as well as warm geographical and climatic conditions, which can be humid tropical or arid and dry.

1. Introduction

Mexico is in a period of energy transition; from approximately 80 % of a sector dependent on petroleum to a greater presence of alternative sources. The Mexican government, per its international commitments, has stated that this conversion process brings economic benefits to the population: greater energy savings allow benefits for the economy and the environment. A policy is being promoted that translates into actions to foment energy education, rational management of electricity different productive sectors, as well as the use of renewable energy. These strategies are being applied, for example, in Germany and China, where the use of renewable energies has been boosted on a small scale and has reduced the dependence on hydrocarbons (Cheung et al., 2019). It is estimated that, in Mexico, more than 95 % of electricity is provided from two main sources: fossil and nuclear fuels. This implies severe damage to the environment (Cancino et al., 2016). However, Mexico has a wide variety of natural resources and has a privileged geographical location, which allows the use of renewable resources, such as wind resource (predominant in the Isthmus of Tehuantepec), which has increased its production from 13.27 PJ in 2012 to 31.48 % in 2015 (Hernandez et al., 2018) and the solar resource (whose use has increased in various regions of the country, although exploitation has not been efficient enough (Elizondo et al., 2017). One of the purposes of the Mexican government has been (SENER, 2017) the reduction in energy intensity per year by 1.9 % in the period of 2016 to 2030. It is expected to reduce by 3.7 % between 2031 and 2050. Mexico's international commitments indicate that, by the year 2040, the growth of carbon dioxide emissions should be slowed down by boosting the use of renewable energy sources and energy efficiency. It is in this scenario that reviewing techniques to reduce the thermal load in buildings and identify potential areas of application becomes a relevant exercise. Medrano and Escobedo (2017) pointed out that the modernization of existing buildings has been carried out in several countries aiming to achieve their efficiency and reducing pollutant emissions. Mexico has a great climatic diversity. Towards the north of the territory there is arid climates;

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towards the south and in coastal areas of the center of the country there is warm or tropical climates; and in the mountainous regions, the climates is cold in the highest peaks.The characteristics of the warm regions in Mexico are: Medium to high temperatures (greater than 25 °C) in summer and for humid tropics throughout the year, while relative humidity is low (less than 50 %) almost throughout the year in arid and dry tropics. In humid tropic greater than 80 % throughout the year (Oropeza et al., 2017).The object of this paper is to presents the cases of applications studied and developed for hot climates in Mexico, considering the external heat gains as these factors control the thermal load in the built spaces, in addition to the internal load generated by users and equipment power electricity.

2. Techniques to reduce thermal load in buildings

The thermal load calculation is developed within the design stages of a cooling or heating systems installation. This process allows the selection of cold or heat-generating machines, air treatment systems, and terminal units to meet the comfort demand. This criterion must be included in a building that is under construction. However, in the retrofit of already constructed buildings, it is sometimes possible to implement this design to reduce energy consumption. This has been considered as one of the main approaches to orient buildings to sustainability at a relatively low cost (Ma et al., 2012). Committing the construction sector and specialists to look for techniques necessary to save energy and achieve sustainability, without altering the comfort conditions of the occupants. ASHRAE (2001) established that the quantification of the load must be precise to determine it correctly, as well as the concepts that influence it. These concepts are divided into internal and external loads. The exterior walls of a building are decisive in the transfer of heat between the interior and exterior, in regions with significant differences between temperatures during the daytime period. An adequate construction system must be taken into account to reduce the flow of energy into the interior of buildings.

2.1 External loads

The external load depends on the conditions outside and the space being conditioned. (Hassouneh et al., 2010). The influential components in external loads include: a) heat conduction through walls, ceilings and floors and b) heat transfer by conduction and solar radiation through glazed areas. It is important to emphasize the effects that solar radiation transmitted directly through glass from the outside may have into the interior. Table 1 shows different techniques investigated and implemented to reduce the external load on different buildings in Mexico. The techniques are as follows: Different types of walls, reflective coating on exterior surfaces, solar control in windows and wall insulation, exterior color, materials for walls and ceilings with high thermal capacity, organic phase change materials and green roof.

Table 1: Techniques to reduce external loads in Mexican buildings

Region and climate	Technique used	Research approach	Contributions	Type of building and References
Hermosillo (Hot dry)	Different types of walls.	Analysis of costs and energy benefits of different types of walls.	For the selection of materials, it is enough to know its cost, energy performance, proximity to the manufacturing site, and sustainability of the production.	Residential (Ochoa et al., 2014)
Hermosillo and Temixco (Hot dry and temperate)	Model to compare the thermal performance of 4 systems constructive wall/ceiling.	Evaluation of the time-dependent heat transfer.	The steady-state model overvalues the transmitted energy, but the difference is bigger for constructive systems with high heat capacity.	Residential (Huelsz et al., 2014)
Mexico City, Hermosillo, and Merida (Temperate,hot dry and tropical)	Reflective coating on exterior surfaces.	Evaluation of concrete roof configurations in four different climatic conditions.	The compound roof with reflective coating is the best configuration in cities warms	Residential (Hernández et al., 2014)
Mexicali (Hot dry)	Solar control in windows and wall insulation.	Design of a bioclimatic house that achieves energy efficiency and thermal comfort.	The results in roof and walls with techniques that consider an air chamber between the wall and the material added, followed by the addition of insulating.	Residential (Gutiérrez et al., 2014)

Table 1: Techniques to reduce external loads in Mexican buildings (Continued)

Region and climate	Technique used	Research approach	Contributions	Type of building and References
Hermosillo (Hot dry)	Exterior color of a house of social interest (wall/ceiling).	Thermal evaluation inside a low-cost house, varying the coefficients of solar absorptivity.	The use of colors with low solar absorptance coefficients in the building exterior walls can reduce heat gain in the building.	Residential (Alpuche et al., 2014)
Acapulco, Hermosillo, and Chihuahua (Hot and hot dry)	Thermal isolation in walls and ceiling.	Evaluation of scenarios to insulate walls and ceiling in a single-family house model.	It is best to insulate the walls and to have uninsulated roofs with high solar reflectance and infrared emissivity.	Residential (Lucero et al., 2016)
Morelia (Hot)	Materials for walls and ceilings with high thermal capacity.	Establish ranges of thermal comfort for users in homes, evaluate the thermal sensation.	The concrete system demands the use of further heating and cooling systems—around 50% of the time—in order to provide indoor thermal comfort conditions.	Residential (Becerra and Lawrence., 2016)
Hermosillo (Hot dry)	Solar control film of SnS-CuxS.	Evaluation the use of a SnS-CuxS solar control film in a double glazed window.	The solar control coating in a double pane window reduces the amount of energy to the indoors in 53.88%.	Residential (Xamán et al., 2016)
Mexico City (Hot and temperate)	Solar control systems: Cantilever, green roof and compacted earth wall.	Evaluate the thermal performance of three experimental modules.	The experimental module with the solar control system and the rammed earth walls presented the best thermal performance.	Experimental modules (Velasco et al., 2017)
Durango (Semi-arid warm)	Overhangs to shade windows and change windows position.	Analysis of the thermal behavior of existing homes to suggest passive measures.	What caused the greatest impact on increasing comfort is: shading windows and high thermal mass night flush during the warm season.	Residential (Romero et al., 2017)
Hermosillo (Hot dry)	Thermal isolation on walls and ceiling, and shaded windows.	Analysis of the economic viability in low energy housing design.	Investing in low-energy design or energy efficiency upgrade is always profitable in terms of reduced energy consumption.	Residential (Preciado and Fotios., 2017)
Mexico City (Hot and temperate)	Organic phase change materials.	Evaluation of phase change materials in building exterior walls.	PCMs in exterior walls have great potential for passive indoor thermal conditioning.	Experimental cells (Lira and Vilchis., 2017)
Cuernavaca (Semi-warm)	Green roof.	Determining the time when the green roof does not need irrigation as well as thermal benefits.	The results show that the use of a green roof decreased the temperature by 20.5 °C compared to a concrete roof.	Experimental cells (Chagolla et al., 2017)
Mecayapan (Warm humid)	Solar control film in windows	Evaluation of the thermal load and using solar control films	The use of solar control films provides significant benefits as the heat gained by radiation can be minimized by more than 60%.	Library (Ramírez et al., 2018)
Cuernavaca (Semi-warm)	Roof coating	Experimental evaluation of conventional and reflective roof coatings.	Widespread of these materials in the buildings of the country would reduce the energy consumption from air conditioners and the emission of greenhouse gases.	Experimental cells (Hernández et al., 2018)

It is important to note that Table 1 only includes cases where (a) real-time assessments have been made, (b) there have been recreations of experimental cells and (c) there is a numerical simulation, to have an approach to the reality of climatic conditions and construction materials in the cases analyzed.

2.2 Internal loads

The internal heat load derives from various elements that can be manipulated by users. According to ASHRAE (2001), four components are considered: (a) lighting, (b) heat due to the metabolism of people, (c) laboratory device and equipment, and (d) equipment that consumes electricity. Table 2 shows the documented techniques that have been used to reduce the internal load in buildings of Mexico during the last six years. There are two techniques in this case: Efficient electrical equipment and an efficient lighting system.

The present compilation allows determining a tendency towards the efforts in the matter, to be able to link the investigation to the thermal evaluation of buildings. Regarding the external load, 10 cases for residential buildings, 1 case of a library and 4 of experimental cells were documented. Regarding the techniques to reduce the internal gain, 6 cases were documented; of which 4 correspond to residential buildings and 2 to school buildings.

Table 2: Techniques to reduce internal loads in Mexican buildings

Region and climate	Technique used	Research approach	Contributions	Type of building and References
Querétaro (Dry and semi-dry)	Efficient electrical equipment.	Evaluate an intelligent monitoring system for electrical consumption in devices used in a building.	Measuring electric energy in sections allows the identification of higher consumption areas, detecting abnormal conditions in electric properties.	Scholar (Trejo et al., 2013)
Mérida (Warm humid)	Efficient electrical equipment and green spaces.	Environmental and energy evaluation of housing considering the GHG avoided.	The strategies of eco-technology and green-space could prevent more than 1 million tons of GHG emissions and provide additional social, environmental and economic benefits.	Residential (Cerón et al., 2013)
Mexico city (Hot and temperate)	Efficient lighting system.	Savings obtained from an efficient lighting system.	The existing lighting system is inefficient while providing unsatisfactory illumination.	Scholar (Seifried et al., 2014)
Mexico (N.A)	Efficient TVs and lighting of compact fluorescent lamps and LEDs.	Estimate of the impact of energy efficiency standards for different appliances in residential electricity consumption.	The climate change mitigation policy needs to continue promoting the scaling up in the efficiency of the main residential appliances.	Residential (Martínez & Sheinbaum, 2016)
Merida (Warm humid)	Control device in the lighting system.	Evaluation of the benefits of lighting system control.	The benefits of advanced control devices called “multiple types” for lighting in buildings could be substantial, such as energy, economic, social and environmental.	Residential (Diaz et al., 2018)
Mexicali (Hot dry)	Replacement of appliances, and window air conditioner or mini-split.	Actions that achieve a significant reduction in the energy consumption of a single-family house.	The replacement of central air conditioning equipment is the energy efficiency action that, by itself, produces higher savings.	Residental (Suástegui et al., 2018)

3. Heat gain and thermal comfort

Thermal comfort has been studied from different approaches (de Dear et al., 2018). The results indicate that there is a link between heat gain and thermal comfort temperature in built spaces. In most buildings, the need for thermal comfort of the occupants is sought without considering the existing alternatives to minimize heat gain and preserve the health of the occupants. The disproportionate use of mechanical cooling systems becomes a critical alert for excessive electrical consumption. It is relevant to know the alternatives that can be used in hot climates, to minimize the consumption of electricity and providing thermal comfort. For this purpose, it is necessary to consider the type of building the activities carried out by the users, as well as the type of clothing, orienting the built space to the criteria of sustainable development and energy efficiency (Nguyen et al., 2012). Among the main variables for the determination of internal thermal comfort is the external temperature of the place where the building is located, this variable being essential when estimating the temperature at which the built space should operate. Likewise, it is crucial to know if the space works under a mechanical system of cooling or natural ventilation.

4. Conclusions

Passive and low energy techniques have been shown to improve the energy efficiency of buildings in the world. These techniques have succeeded in reducing the consumption of electricity derived from mechanical cooling and heating systems, as well as reducing the thermal load. The application of these techniques in existing buildings located in warm climates provides an alternative solution for the management and saving that is required of energy resources. In new buildings, these techniques must be included in the construction criteria, since they can offer main and collateral benefits. These benefits include a decrease in electricity consumption, lower heat gains, adequate comfort temperature and a revaluation of the property. As this research shows, different techniques can achieve the desired thermal efficiency. In the case of external heat gains, solar control films can be used to minimize heat gain from solar radiation, which is considered the source of greatest profit in a built space, as well as the Change Phase Materials (CPM) that lack further and implementation. While within the alternatives of greater efficiency, for when internal loads are analyzed, there are types of electrical equipment of greater efficiency and lower electrical consumption, labelled as energy-saving equipment, certified for sale in Mexico. The global trend is clear, and the increasing amount of research work in this area indicates that the development of new materials for construction is a concern of construction experts. The works reviewed in this research, although carried out in different regions of Mexico, coincide with the idea of modernizing the built spaces, analyzing the behavior of passive techniques and technological elements that allow achieving energy efficiency. It is important to note that in warm regions, as well as in coastal, the use of Heating, Ventilation, and Air Conditioning (HVAC) systems is a basic necessity for the development of daily activities, due to the influence of high relative humidity and high temperatures, as is the case in southeastern Mexico. It is important to emphasize that external heat gains are influenced due to geographical position, while internal heat gains are influenced by the activity and configuration of the building. In Mexico, it is necessary to promote the development of techniques in natural ventilation or earth-to-air heat exchangers, as alternatives to reduce dependence on the use of HVAC, as well as testing various techniques documented in this paper in different types of buildings. An analysis of the techniques to adjust the relative humidity should be included in future thermal comfort work in buildings. The significant findings of this investigation have made it possible to determine: a) the region with the most proven techniques to reduce the thermal load from the outside is located in the northwest of Mexico. For the interior thermal load the region with the most proven techniques is in central Mexico, b) the techniques have been used and studied mostly in residential buildings for both scenarios and c) the most used techniques are solar control films, different types of glass, for outdoors and more energy-efficient appliances, for indoors.

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