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Article

Analysis of thermal loads using BIM methodology to reduce the energy consumption of buildings in Morelos, Mexico

Análisis de cargas térmicas mediante la metodología BIM para disminuir el consumo energético de edificaciones de Morelos, México

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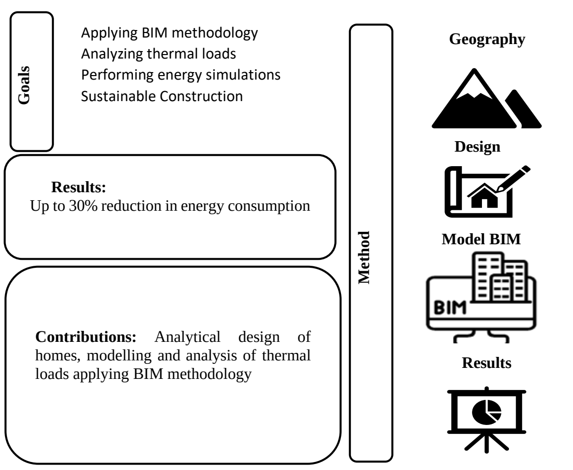
Abstract

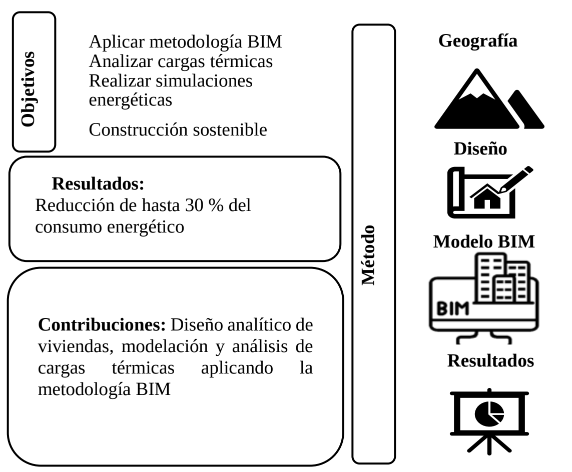
A Net Zero Energy Building (NZEB) is a building with a highly reduced operational energy consumption where energy efficiency measures have been implemented that allow the energy demand to be supplied by renewable sources. To this end, this paper describes the adaptation and implementation of a methodology to transform an existing residential building into a net zero energy building and thus achieve a self-sustainable building, considering as a case study a warm sub-humid climate in the state of Morelos, since this climate predominates in 85% of the total area of the state. The types of feasible and affordable eco-technologies to be implemented in Morelos are analysed and discussed. The energy efficiency of the building is analysed considering the combination of construction techniques, suitable materials for the envelope, thermal loads, and electrical energy consumption, with the aim of reducing the high dependence on fossil fuels in the construction sector.



Net zero energy, BIM methodology, Ecotechnologies, Thermal loads, Thermal comfort

Resumen

Un edificio de energía neta cero (NZEB, por sus siglas en inglés), es un edificio con un consumo energético operacional altamente reducido donde se han implementado medidas de eficiencia energética que permiten que la demanda de energía pueda suplirse mediante fuentes renovables. Para esto, en el presente trabajo se describe la adaptación e implementación de una metodología para transformar una edificación residencial existente en una edificación con energía neta cero y así lograr una edificación autosustentable, considerando como caso de estudio un clima cálido subhúmedo del estado de Morelos, ya que este clima predomina en el 85% de la superficie total de la entidad. Se analizan y discuten los tipos de ecotecnologías factibles y asequibles para implementarse en Morelos. Se analiza la eficiencia energética del edificio considerando la combinación de técnicas de construcción, materiales adecuados para la envolvente, las cargas térmicas y el consumo de energía eléctrica, con la finalidad de reducir la alta dependencia de los combustibles fósiles en el sector de la construcción.



Energía neta cero, Metodología BIM, Ecotecnologías, Cargas térmicas, Confort térmico

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Introduction

Due to population growth, there is an increase in the extraction of natural resources, leading various sectors worldwide to seek to eliminate or significantly reduce human-induced greenhouse gas emissions. It is argued that the consequences of inaction in this area would be uncorrectable if no action is taken. The so-called decarbonisation of the economy involves adopting changes in technologies in the sectors with the greatest impact on polluting emissions. Among these is the construction sector and the short and medium term objective is that, from design, during construction and during the useful life of a building, the energy balance should be minimal or zero. In this sense, a Net Zero Energy Building (NZEB) is a building with a highly reduced operational energy consumption where energy efficiency measures have been implemented that allow the consumption to be supplied through the use of renewable sources (Agudelo, 2022). Although interest in this concept is growing, its implementation in LATAM is incipient for various reasons such as: insufficient information or lack of knowledge about sustainable construction, lack of public policies to promote NZEB projects, as well as uncertainty about investment costs, among others.

On the other hand, it is important to mention that in the framework of the Ordinary Session of the National Council of the 2030 Agenda for Sustainable Development, held in virtual mode on 11 November 2020, the roadmap, plans and programmes promoted by the Government of Mexico in favour of the 17 Sustainable Development Goals (SDGs) were presented. The roadmap seeks to reduce existing social gaps and move towards a development model focused on well-being, promoting an inclusive economy and care for the environment.

This paper describes the application of the Building Information Modelling (BIM) methodology for the analysis of thermal loads of 4 existing residential buildings in the state of Morelos, Mexico, considering the 4 predominant microclimates in the state, with the aim of proposing ecotechnologies to reduce the energy consumption of housing and thus contribute to the energy efficiency of buildings.

In addition, it is also intended to contribute indirectly to the following SDG:

- Affordable and clean energy.
- Industry, innovation and infrastructure.
- Sustainable cities and communities.

Impacts of the construction sector

According to the International Energy Agency (IEA), the construction sector (residential and non-residential buildings) is responsible for the largest share of the energy consumption in the world:

- 36% of global final energy consumption.
- 54% of global electricity consumption.
- 45% of waste generation.
- 3% annual increase in buildings.

In addition, heating and cooling of buildings in cities generates more than 40 % of energy-related carbon dioxide emissions (IRENA, 2020):

- 28% comes from operation and activities such as maintaining a building with air conditioning, heating and electrical power.
- The remaining 12% relates to the actual construction of the building and the waste it generates: from rubbish to demolition waste.

Sustainability of a building

To understand the sustainability of a building, it is recommended to consider the potential of renewable sources available in each region. Figure 1 shows some eco-technologies that can be implemented in a building to achieve net zero energy. Only such a model can reflect the complex future reality of an energy sustainable society. The roadmap approved by the National Council of the 2030 Agenda envisages: Increasing investment for sustainable growth that contributes significantly, not only to Gross Domestic Product (GDP), but also to the Human Development Index (HDI), Designing and implementing sectoral programmes with a sustainability focus, accompanying legislatures for the development of laws with a sustainable vision (López, 2019).

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Box 1

1. Panel solar.	5. Smart thermostats.
2. Solar inverter.	6. Floor radiation heating.
3. Battery storage.	7. Certified mestic electrode of energy efficiency.
4. Geothermal pumps.	8. Doors and frames insulating from the outside.

Figure 1
Representation of a building with net zero energy

Source: Own elaboration

In the Netherlands, the energy sprong team has developed a methodology to transform existing houses into net zero energy buildings, i.e. the house generates as much energy as it needs for heating, hot water, light and appliances resulting in a warm and comfortable home environment. This is possible through the use of new technologies such as prefabricated, new and smart facades, heating and cooling installations and insulated roofs equipped with solar energy and solar panels. People do not even have to leave their homes because the transformation is completed within a week. After the house is net zero energy, the house looks bright and modern from the outside and is no longer damp or draughty inside. This makeover comes with a 30-year guarantee on both indoor energy and climate performance (CAF, 2019).

So how did the Dutch do it? In order to implement this change, an initial group of social housing associations joined forces to secure a first market for these performance-based makeovers, in addition to making adjustments to government regulations that were implemented.

This allowed social housing associations to charge tenants rent and energy service fees in exchange for providing them with a net zero energy home. At the same time, assessments of the new reforms were carried out by banks in order to provide affordable finance to social housing associations.

The independent market development team at energy sprong coordinated all these activities to ensure that each of the market conditions are met at the same time. This creates a level playing field for innovative companies willing to invest in and develop these net zero energy retrofits. All retrofits are based on prefabrication and industrialisation allowing for increased performance and cost reduction.

Methodology

Study area

The analysis of thermal loads will be applied in four dwellings located in different microclimates in the state of Morelos, of which four predominate: warm zones (from 22°C to more) occupy 68.17% of the state territory, followed by semi-warm zones (between 18 and 22°C) which occupy 18.85%, then temperate zones (between 12 and 18°C) which occupy 9.7% and finally semi-cold zones (between 5 and 12°C) which occupy the remaining 3.28%. Figure 2.

Box 2

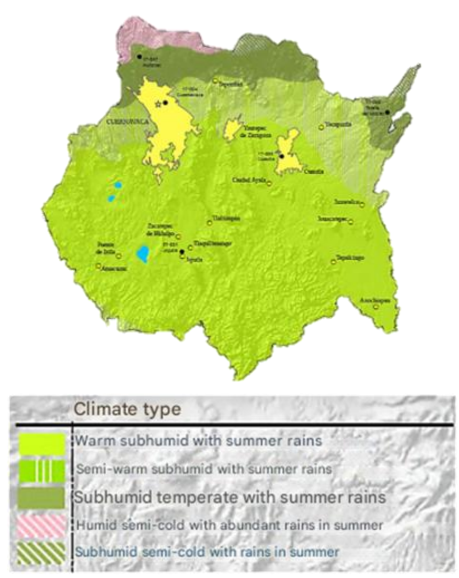

Figure 2
Predominant microclimates of the state of Morelos
Source: Own elaboration

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The first case study is located in the municipality of Atlacomulco Jiutepec, Morelos, the building is a 2-storey house and is oriented towards the geographical North as shown in Figure 3.

Box 3

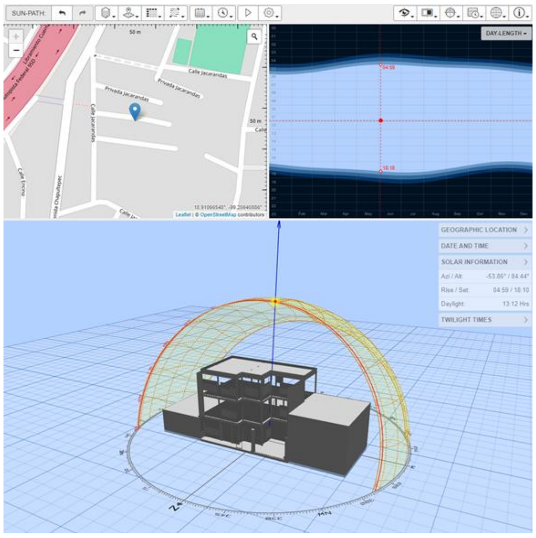

Figure 3
Orientation of housing in Jiutepec
Source: Own elaboration

With the 2D plans Figure 4, the design was transferred to the IFC Builder, by which the structure is placed again as shown in Figure 5 for analysis in the different BIMserver programs, highlighting the orientation, the types of walls and the type of space (habitable or non-habitable).

Box 4

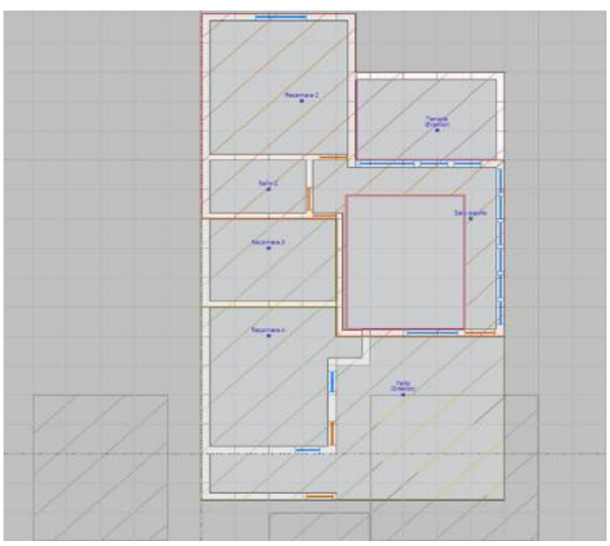

Figure 4
2D plan of the building in IFC Builder
Source: Own elaboration

Box 5

Figure 5
House in Jiutepec designed in CYPE Architecture
Source: Own elaboration

Taking into consideration nearby buildings that will be shaded with an orange volume (Figure 6), to be considered in the following programmes for analysis.

Box 6

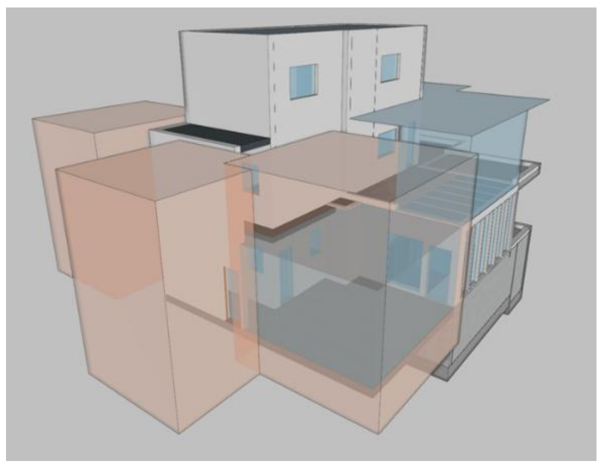

Figure 6
3D house view with IFC Builder

Source: Own elaboration

For the analysis of thermal loads, the properties of building materials as well as the material of doors, windows and other enclosures are defined and introduced. The outdoor design conditions for the load calculation are provided by default by location-specific climate data as shown in Figure 7, which are taken from the Instituto Nacional de Estadística, Geografía e Informática (INEGI), but are also compared with data from NASA, weatherspark and ASHRAE.

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Box 7

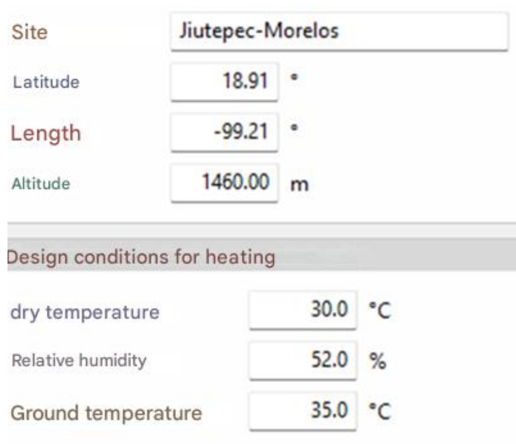

Figure 7
Location data locality
Source: Own elaboration

After entering the external data, the properties and characteristics of the building materials are entered in order to determine the thermal transmittance and thermal capacity coefficients of the walls, as shown in Figure 8.

Box 8

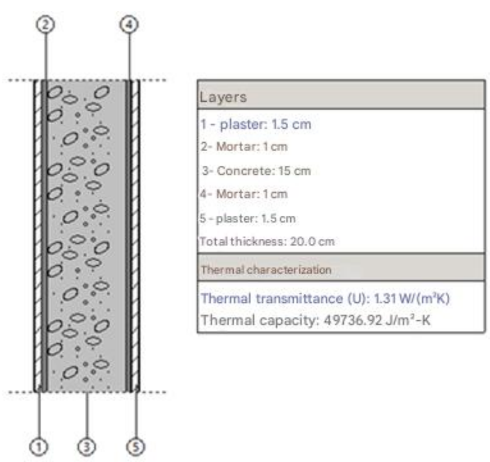

Figure 8
Characteristics of the wall in the building
Source: Own elaboration

Results

After entering the parameters required by the CYPETHERM LOADS software, the calculation and analysis of thermal loads for each building is carried out using the Radiant Time Series Method (RTSM).

The data obtained includes the magnitude of power required for both cooling and heating of the building and thus achieve thermal comfort according to the annual, monthly and daily behaviour of the climate, considering the thermal loads of the hottest months in the total and daily results.

Thermal loads in the case studies

Case study 1.- Housing in Jiutepec

Preliminary results obtained with the CYPETHERM LOADS software reveal that the Jiutepec Morelos dwelling lacks heating requirements, resulting in negative values for the thermal loads associated with heating. On the other hand, it is identified that the space located on the ground floor - referred to as the living room - presents the highest cooling demand, establishing an estimated cooling thermal load of 7372 W (Figure 9).

Box 9

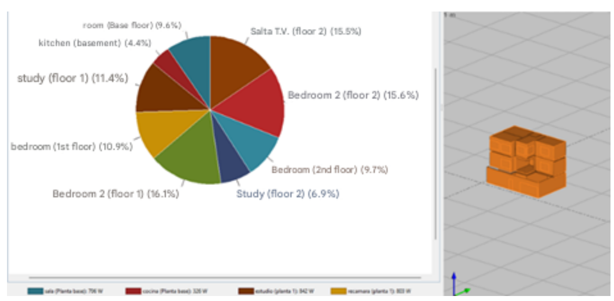

Figure 9
Maximum simultaneous cooling load in the Jiutepec household
Source: Own elaboration

The time of peak cooling demand, related to location and orientation, occurs on 21 July at 16:00 hours. This result provides important information for the planning and design of air conditioning systems.

Case study 2.- Housing in Temixco

According to the results obtained with CYPETHERM LOADS in the house located in Temixco, the maximum cooling load required is 5784 W (Figure 10) and heating load 12855 W (Figure 11), where the highest percentages of heating and cooling are in bedrooms 1 and 2, respectively.

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Box 10

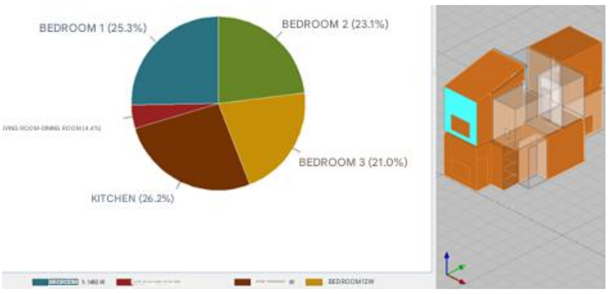

Figure 10
Maximum simultaneous cooling load in housing in Temixco

Source: Own elaboration

Box 11

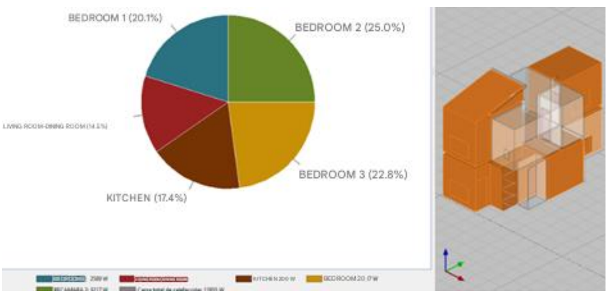

Figure 11
Maximum simultaneous heating load in a Temixco home

Source: Own elaboration

Case study 3.- Housing in Cuernavaca

For the case study in Lomas de Ahuatlán Cuernavaca, the maximum cooling load required is 11024 W Figure 12 and the cooling load is 139 W in the whole building, so it is considered a very low value to be taken into account for the load analysis.

Box 12

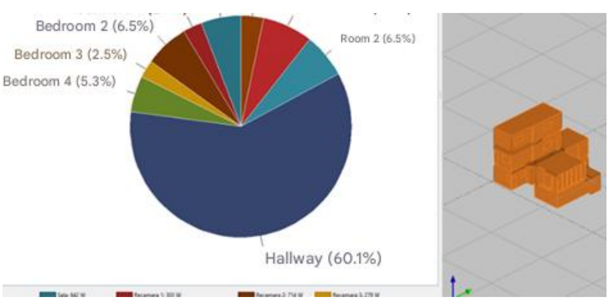

Figure 12
Maximum siultaneous cooling load in housing in Cuernavaca

Source: Own elaboration.

Case study 4.- Housing in Huitzilac

According to the results obtained in the Huitzilac house, the maximum cooling load required is 2035 W (Figure 13) and the heating load 6942 W (Figure 14), where the highest percentages of heating and cooling are in the living room and master bedroom, respectively.

Box 13

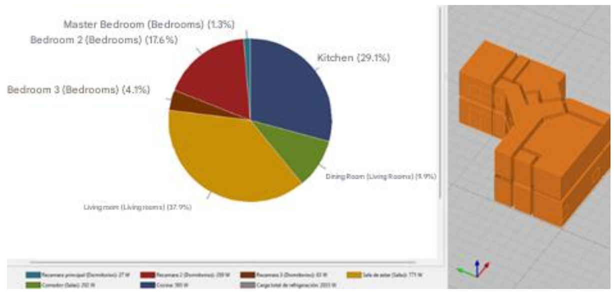

Figure 13
Maximum simultaneous cooling load in the Huitzilac household

Source: Own elaboration

Box 14

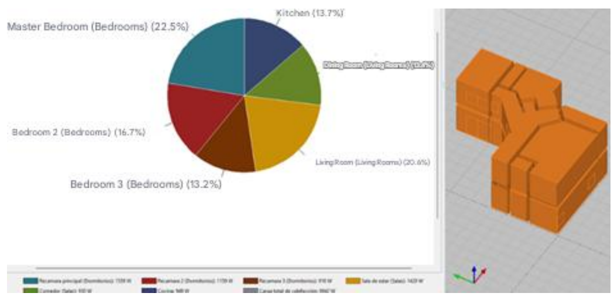

Figure 14
Maximum simultaneous heating load in housing in Huitzilac

Source: Own elaboration.

Implementation of efficient eco-technologies

The ecotechnologies considered in the implementation were selected because of their practical implementation and ease of purchase in different markets. Energy saving light bulbs, thermal coatings and photovoltaic panels are taken into consideration for their calculations.

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Energy-saving light bulbs

One of the applications of eco-technologies was the implementation of 15 LED saving light bulbs in some of the houses, which as shown in Table 8, in an interval of 15 years (duration of LED bulbs) is a better investment than conventional CFL and common saving bulbs, since the latter are not functional and the final investment would be much higher than LEDs and over time, the price of LED bulbs decrease, while their performance and durability increase.

Box 15

Table 1

Comparison of light bulb types for primary residences

focus	Price per unit (MXN)	Duration (years)	W consumption	Brightness	Total price(MXN) per unit in 15 years	Number of lamps	Total (MXN)
CFL	75	5	30	2000	225	45	3375
LED	125	15	30	3000	125	15	1875
Commn	30	1	30	450	450	225	6750

Source: Own elaboration.

Implementation of cladding

The CYPETHERM LOADS application helps us to implement cladding on the inside or outside of the building to check whether it is feasible to insulate it. The technical data of the material can be entered in the same programme to subsequently implement it in the structure. For the analysis, the thermal insulators mentioned in Table 2, Table 3 and Table 4 were taken into account, as well as the implementation of protective films to reduce heat transfer in the glazing, obtaining the following results:

Box 16

Table 2

Comparison of light bulb types for primary residences.

	Thermal loads (Watts)						
Building	**Uncoated**	**Denim waste**	**Polyurethane**	**ibreglass**	**lineral wool**	**sphalt nembrane**	**Bituminous asphalt**
Jiutepec	7372	6199	6215	6140	6144	5952	5955
Temixco	5784	6501	6448	6236	6256	5716	5716
Ahuatlán	11024	7700	7746	7810	7802	7893	7894
Huitzilac	2035	1900	1855	1731	1744	1437	1435
Jojutla	43086	41258	41328	41416	41404	41552	41556

The table shows the energy consumption in Watts (W) of different types of building envelopes in five municipalities in Morelos: Jiutepec, Temixco, Ahuatlán, Huitzilac and Jojutla. The type of cladding with the lowest energy consumption is bituminous asphalt, followed by asphalt membrane, mineral wool, glass fibre, polyurethane, denim waste and finally no cladding. With the help of Figure 15, the comparison of the individual coatings can be seen.

Box 17

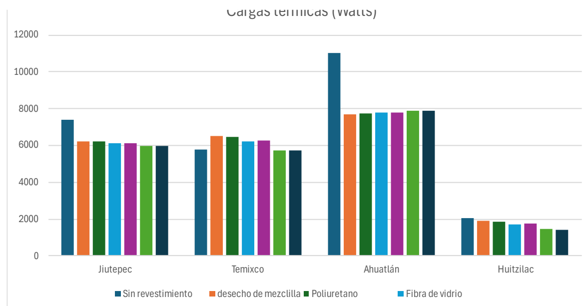

Figure 15

Comparative graph of the different coatings in each municipality

Source: Own elaboration

Conclusions

The implementation of eco-technologies in the short and medium term in buildings in Morelos can contribute to energy efficiency and moving towards net zero energy has the potential to revolutionise the construction industry in terms of sustainability. While there are notable financial, technical and regulatory challenges, the benefits in terms of energy efficiency, emissions reduction and economic development are promising. Addressing these challenges will require close collaboration between government, the building sector and academia to create an enabling environment for the adoption and advancement of these cutting-edge technologies.

Based on the results it can be concluded:

- The coating type with the lowest energy consumption is bituminous asphalt in all municipalities, followed by asphalt membrane, mineral wool, glass fibre, polyurethane, denim waste and finally uncoated.

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- The difference in energy consumption between bituminous asphalt and uncoated asphalt varies between 1.2% and 30% in the different municipalities.

- The choice of the best type of cladding for a specific municipality will depend on several factors, such as climate, building size and shape, building materials, and heating and cooling systems.

Regarding the thermal load analysis of the case study in Temixco, the implementation of ground-air heat exchangers is recommended, as well as reflective coatings on glazed doors and windows to reduce the cooling thermal load.

The use of sustainable building materials and efficient heating and cooling systems should be considered to further reduce the energy consumption of buildings. In addition, a more detailed analysis of the specific needs of each municipality and building should be carried out to determine the most appropriate type of cladding.

For the case of the house that had CFL energy saving bulbs, the use of LED bulbs will have a better performance, the waste from changing bulbs will be reduced by a third and the final expenditure over a period of 15 years will be less than CFL bulbs without taking into account that the price of LED bulbs continue to reduce, making it easier to purchase them.

On the other hand, the implementation of grid-interconnected photovoltaic (PV-IR) systems can also be considered, however, the feasibility of implementing solar panels depends on specific factors such as location, energy consumption, initial investment costs and payback rate. In general, there are several studies that demonstrate the viability of PV-IR as a sustainable energy option for buildings and businesses, as it can save money on electricity bills in the short term, reduce the carbon footprint of buildings and increase the value of buildings.

Authors' contribution

The contribution of each researcher in each of the points developed in this research was as follows:

Vázquez-Fuentes, Erick E: Carried out the design and modelling of the case studies, simulation and analysis of thermal loads. He also contributed to the analysis of climatological data and the systematisation of results.

Montiel-González, Moisés: Generated the idea, approach and structure of the article, application of the BIM methodology, as well as the analysis and systematisation of the results.

Alvarado-Juárez, Roberto: Contributed to the design and structure of the article, application of the BIM methodology, as well as the analysis and presentation of results.

Morales-Gómez, Laura: Systematised the literature review, analysed the results and drew conclusions.

Availability of data and materials

Climate data for each location were obtained from NASA Power. The designs were obtained from residences located in Morelos and were made using IFC Builder software and simulated in CYPETHERM LOADS, which are free programs located on the BimServer server.

Conflict of interest

The authors declare that they have no conflict of interest.

Funding

No funding was received.

Abbreviations

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc
BIM	Building Information Modeling
CFL	Compact Fluorescent Lamp
IDH	Índice de Desarrollo Humano
LATAM	Latinoamérica
LED	Light Emitting Diode
NASA	National Aeronautics and Space Administration
NZEB	Net Zero Energy Building
ODS	Objetivos de Desarrollo Sostenible
PIB	Producto Interno Bruto
RTSM	Método de las Series Temporales Radiantes

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