

Article

Decision-Making Processes in Controlling Exposure to Sunlight Supported by Simulation Tools: A Case Study in Warm Weather

Mariana Huskinson *, Antonio Galiano-Garrigós *^{id}, Ángel Benigno González-Avilés ^{id} and M. Isabel Pérez-Millán

Department of Architectural Constructions, University of Alicante,

03690 San Vicente del Raspeig (Alicante), Spain; angelb@ua.es (Á.B.G.-A.); isabel.perez@ua.es (M.I.P.-M.)

* Correspondence: mh65@alu.ua.es (M.H.); antonio.galiano@ua.es (A.G.-G.); Tel.: +34-617994619 (M.H.); +34-670706630 (A.G.-G.)

Abstract: Improving the energy performance of existing buildings is one of the main strategies defined by the European Union to reduce global energy costs. Amongst the actions to be carried out in buildings to achieve this objective is working with passive measures adapted to each type of climate. To assist designers in the process of finding appropriate solutions for each building and location, different tools have been developed and since the implementation of building information modeling (BIM), it has been possible to perform an analysis of a building's life cycle from an energy perspective and other types of analysis such as a comfort analysis. In the case of Spain, the first BIM environment tool has been implemented that deals with the global analysis of a building's behavior and serves as an alternative to previous methods characterized by their lack of both flexibility and information offered to designers. This paper evaluates and compares the official Spanish energy performance evaluation tool (Cypetherm) released in 2018 using a case study involving the installation of sunlight control devices as part of a building refurbishment. It is intended to determine how databases and simplifications affect the designer's decision-making. Additionally, the yielded energy results are complemented by a comfort analysis to explore the impact of these improvements from a users' wellbeing viewpoint. At the end of the process the yielded results still confirm that the simulation remains far from reality and that simulation tools can indeed influence the decision-making process.

Keywords: energy demand; energy consumption; simulations; shading systems; energy performance; solar radiation



Citation: Huskinson, M.; Galiano-Garrigós, A.; González-Avilés, Á.B.; Pérez-Millán, M.I. Decision-Making Processes in Controlling Exposure to Sunlight Supported by Simulation Tools: A Case Study in Warm Weather. *Energies* **2021**, *14*, 4100. <https://doi.org/10.3390/en14144100>

Academic Editor: Alessia Artecioni

Received: 3 May 2021

Accepted: 30 June 2021

Published: 7 July 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Energy improvement of existing buildings is a current European Union (EU) energy policy priority. Amongst proposed measures is the reduction of energy costs and the relationship of this to user comfort in this type of building. In fact, data collected by the EU indicates that 38.7% of its energy consumption corresponds to residential, commercial, and institutional buildings [1] and electricity consumption of those same building types is close to 70% [2]. The importance of this data is accentuated when the age of the constructed stock is studied, i.e., taking into account that only 1% of the buildings have been constructed since 2006 [3]. A similar situation exists in Spain where, in 2017, only 1.5% of the registered Spanish building stock met the regulated standards for energy certification [4].

With these objectives in mind and considering the overall EU ambitions in the field of energy efficiency, it is essential that member states specify the expected results of long-term national renovation strategies and monitor developments through the establishing of internal progress indicators, such indicators being subject to national developments and conditions.

As a consequence, EU members have promoted new regulations and methodologies supported by simulation tools to allow building energy evaluation. Initially, these methods were limited and could only be applied towards the end of the construction project [5].

However, the experience allowed for the improvement of these tools and particularly given the establishment of the BIM paradigm, it is possible to perform analyses at different stages of design, including life cycle analysis (LCA), and allow the exchange of information with other tools to evaluate a number of factors such as user comfort. These tools have proved their value [6], having provided new options to obtain better buildings and improve their users' wellbeing.

The EU energy policy EPBD 2002/91/CE [7] has been adopted by the Spanish government through its Technical Building Code (CTE) [8], a regulation with its origins in the Building Management Law (LOE) [9]. Within this policy, the Basic Document on Energy Saving (DB HE) [10] is the section of the CTE that establishes the requirements for an energy efficiency assessment of buildings. This document defines its scope of application in all types of new buildings and also existing buildings that are subject to major renovations.

In 2007 the first Spanish law relating to building energy certification was enacted, however, a protracted extension period of implementation was granted to allow the registration/certification infrastructure to become operational. From 2013, the building energy evaluation and certification process was updated and the process for the energy certification of existing buildings was defined for the first time. The procedures were updated, including the maximum values relative to the obtaining of the various energy certificates by 2017 [11].

Additionally, the process for evaluating new building energy efficiency was carried out statutorily until September 2018 using LIDER a tool developed by the Spanish Government and the energy certification carried out using the tool CALENER, which in 2018 became the Unified Tool LIDER-CALENER (HULC). This software, using DOE-2 as its calculation engine, is applied to every type of building and makes a difference in the certification process between sizeable tertiary buildings and other types of building. As with most European countries, the program follows the methodology defined by the EN ISO 13790 [12] but fails to provide consistent results when studying construction improvements, causing difficulties in the decision-making process when introducing construction design improvements. Since it favors buildings of complicated geometry as opposed to those with efficient design, such a tool has shown itself to be difficult to manage and is characterized by offering results that fail to assist in decision making at the project phase [13].

Energy ratings in Spain are achieved by way of an energy certificate, which is a document regulated by the Royal Decree 235/2013 [14] providing a label that indicates the energy rating of a building on a seven-letter scale from most to least efficient, with A being the most efficient and G the least. Residential buildings are compared with the mean energy performance of the built stock, in the case of non-residential buildings where no sufficient repeated patterns exist for comparison, it was decided that a comparison should be made between the subject building with the certification of a fictitious building that complies with the energy consumption and CO₂ emissions as defined by the Spanish Government. However, such a system has proved imprecise due to the difficulties encountered by the architects when interpreting the results obtained by the program [15].

In 2018, a new energy performance evaluation tool aimed at all types of buildings was approved by the Spanish Government. CYPETHERM HE Plus is a software designed for the regulatory justification of CTE DB HE0 and HE1 (minimum energy requirement), by means of a building model for energy simulation calculated with EnergyPlus. It provides the evaluation of the energy performance at different stages of design and produces the final energy certification. This application operates within the building information modelling (BIM) environment and has been developed by private initiatives inside an open BIM workflow allowing for the exchange of information with other simulation tools. Experience of this tool is still limited, although preliminary research has yielded promising results when comparing HULC with CYPETHERM HE Plus [16], which has generated a general interest in the evaluation of the tool as the Spanish Government has left it to designers to choose between HULC and CYPETHERM HE Plus. Additionally, the integration of

this tool with other BIM tools offers an opportunity to improve the building geometry modeling process and facilitate the introduction of changes.

1.1. Controlling Sunlight

In the process of obtaining efficient and comfortable buildings, one of the key parameters to take into account is understanding the weather conditions and how the building may be optimally adapted to these [17]. In Europe, Spain is the country with the broadest climatic diversity, with a warm summer Mediterranean climate predominant in the east and the south of the country. For this type of weather, design strategies should be used to minimize the impact of cooling demand, such as the use of shading devices, smaller windows, and orientations with less solar exposure to improve solar control and lighting, particularly during the summer season [18].

Windows combined with shading systems control interior environments by regulating the amount of light and heat entering the building, with shading systems selected based on the windows' movement, position, and shape. The designer's choice for adequate shading is fundamental to guarantee the internal comfort of any environment and promote energy savings, both in winter and in summer [19].

Due to the software calculation engines used by the energy simulation tools, the influence of these devices in the building energy performance is evaluated by applying simplifications and modifying factors to reduce solar gains through windows, thereby limiting the evaluation and drastically reducing the multiple geometrical options available among sunshades, brise-soleil, slats, and parasols. Only detailed analysis with specific software as DesignBuilder allows for the provision of robust and overall building-wide results [20].

1.2. Evaluation of Comfort

Technical progression in the field of building comfort and user wellbeing evaluation falls short of the advancement seen in building energy performance evaluation. The evaluation of comfort in buildings has been the focus of architects and engineers since the 1960s and methods like Givoni's [21], Fanger [22], and Olgay [23] have been developed. Nonetheless, these strategies aimed at obtaining better buildings have not received the official support of the Governments as there are few examples of regulations, i.e., ASHRAE 55 [24] and EN 16798 [25], that specifically address the evaluation of comfort. The lack of transversal methods to evaluate energy efficiency and comfort has opened a debate, and there are examples of research aimed at finding common strategies to improve both fields [1,26,27]. In the case of Spain, comfort conditions are contained within the regulations that define the minimum requirements for the conditioning of interior spaces, although there is no specific evaluation method, and only minimum and maximum values for temperature, relative humidity, and ventilation are set.

2. Objectives

For the first time in Spain, the approval of a method for evaluating energy performance that operates within the BIM environment has created an opportunity to carry out global building performance analyses. The exchange of information with other BIM tools has provided improvements in the introduction of geometric data such as sunlight control devices, making changes to modeled buildings easier. These enhancements are intended to aid the designer's decision-making process. However, experience with this new tool is limited and there is an interest in comparing it with the previous tool in order to assess its performance and help designers choose between them.

Therefore, the objective of this research is to evaluate the degree of accuracy of both energy performance simulation tools by developing calculation examples over a case study located in warm weather where an improvement in the building envelope to control sunlight is planned. Additionally, this study provides an opportunity for the exchange of information with a renowned simulation tool, DesignBuilder, in order to perform energy

and comfort analyses. It is also the intention of this research to evaluate the influence of software over the yielded results and ascertain how they might influence the architect's decision-making process.

3. Bibliography Analysis

A large number of bibliographic references have been developed relating to the fields of study of this article: simulation tools, energy efficiency, controlling sunlight, and evaluation of comfort. In addition, research studies with a similar theme or/and related case studies have been selected in order to compare and contrast the obtained results, thus providing a more in depth study linked to the findings of this article.

Designing a building is a complex process in which architects have few design development criteria with which to move from idea to concept [28]. Simulation tools can assist decision-making in the design phases [29]. Simulation tools have the capability to define and improve all elements of an educational building project; energy efficiency [30], artificial lighting [31], thermal comfort [32], and building layout [33,34]. However, there is no simulation tool available that can bring all of these concepts together, therefore, it is up to the architect to deal with all of these issues and include user comfort into the equation. This factor is important as different occupancy profiles correlate with the overall building performance [35].

During the last decade there has been an increasing socio-economic demand for sustainable and green buildings with low environmental impact due to regulatory requirements. Sometimes, researchers compare different typologies and the improvement of the building envelope [36], whilst others combine studies investigating the requirements of passive and near-zero energy buildings [37] or consider how the envelope affects the indoor temperature [38].

Simulation tools have proven useful to predict both how the building will behave and approximate its energy consumption. However, the energy certification of a building is much more complex than a household appliance [39], so the selection of the program to be used depends on the variables to be measured. A program that has the ability to process more variables will provide results closer to reality but will need to integrate user comfort into that process [40]. Generative tools represent a move towards using the computer as an "active" adjunct to the design process rather than merely as a "passive" tool [41].

Since the 1960s, it has been possible to trace the constant development in the field of simulations [42]. A simulation of a building's energy needs makes it possible to interpret the thermal demands according to the site conditions [43]. Over the past 60 years, the tools have evolved considerably, although according to some authors, geometric simplifications [44] together with the physical building envelope calculated under controlled conditions fail to produce real energy performance data [36]. Although several research studies have demonstrated the limitations of tools that use a simplified procedure [45], a proper design process can improve the building form to maximize efficiency in terms of energy performance [46]. So much so that it has been possible to design high performance buildings based on workflows using simulation tools [47].

New techniques for the simulation of existing buildings are being developed along with other procedures that determine the suitability of a building during construction [48]. These new technologies and processes that monitor the energy performance of buildings are being modified to compare the accuracy between the construction project and the final result, even though these evaluation processes are yet to be fully optimized [49]. Despite several years of approximations and improvements of simulation tools, they are not sufficiently developed [50] and it is still necessary to validate the results. In many cases, errors arise in the modeling tools themselves [51] and correction factors need to be incorporated [52]. None of the existing techniques are able to meet the needs of architects in the conceptual design phase [53]. A building is much more complex, it is the sum of all parts, and it is important to contrast between different simulation tools in any given case study as no application can currently translate this complexity with 100% accuracy [54].

New BIM software developments provide additional information such as new measurements to achieve more efficient buildings in the early design phases [55]. BIM and building energy modeling (BEM) interoperability improves energy efficiency [56] and thus it is possible to design more sustainable buildings and reduce their environmental impact even at the city scale [57]. BIM provides more effective control over project development, particularly with regard to building energy performance [58], since it can be analyzed at the early stages of the design process [59]. BIM software-based design can facilitate the improvement of environmental sustainability by providing important savings during the construction stages, improving the orientation and layout of the building and providing information on energy cost. It also allows the design process to begin by analyzing the building's energy performance based on its location [60,61]. It has been shown that BIM tools are not only limited to new buildings, in fact, several studies have been conducted to demonstrate the function of such tools on existing buildings, including heritage buildings [62–64].

The energy performances of building envelopes differ in relation to technology and general climatic conditions. Therefore, building envelopes should be developed to enhance energy performance in relation to climate conditions [65]. Some investigations have revealed a minor overall relationship between windows and building walls in different locations [66].

In the process of obtaining efficient buildings in warmer climates, it is important to work with key parameters considered as traditional measures, such as building orientation, building shape, and the introduction of solar protection systems [67]. In this type of climate, the sun has always played an important role in people's quality of life. In fact, some heart rate studies have revealed the importance of higher luminance levels in the stimulation of human activity. Building users typically demand that the sun's rays along with its visual and warming influences be allowed to enter. It is usual practice in the design of buildings to deal with solar thermal factors whilst taking sufficiently into account the visual aspects of sunlight [68]. Studies have shown that the implementation of dimmed lighting measures can reduce energy consumption leading to high impact changes in both cost and CO₂ emissions per year in higher education buildings [69]. Lighting simulation tools focus on specific thresholds for energy calculations [70]. However, one of the main drawbacks of the official methods of evaluating the energy efficiency of buildings in hot climates is the failure to consider traditional measures limiting the building's energy demand.

Different research has been undertaken to improve solar control, lighting, and building envelopes. Some of these solutions are related to the incorporation of vegetation [71] and sun protection on the building's exterior [72]. Historically, shading systems such as venetian blinds have been considered as an essential element of window system design in hot climates to balance daylight requirements with the need to reduce solar gain. Their simulation is complex, as standard sky models are unable to reproduce authentic skies in real time [73]. In this regard, user interaction is again crucial [74]. These types of strategies and others such as sun-sail shading in courtyards have been developed for various educational buildings [75]. However, these advantages are sometimes presupposed and lead the designer into believing that the installation of such elements will always improve the building's performance.

In focusing on strategies to improve energy efficiency in educational buildings, it becomes inevitable to investigate solar shading and lighting, the use of shading devices, smaller windows, and orientations with less solar exposure, especially in the summer season to reduce energy consumption. Shading and elevation design reduce the energy demand of a building [76]. In fact, the replacement of windows and the use of sunshades in renovations of old buildings can be more cost-effective and a better option than the improvement of building elevations [77]. Some studies have shown significant savings of more than 75% on cloudy days and 90% on sunny days by incorporating louvres into window frames [78]. The advantage of the use of shading devices such as the sunshade is that they can improve the thermal efficiency of buildings and achieve thermal comfort

requirements by reducing both the need for cooling in summer and heating in winter, ensuring substantial energy savings and improved building illumination [79]. Considering the occupancy and building program is key to refining the prognosis [80]. In fact, user control contributes to energy reduction and increased comfort [40].

Other research has shown that all shades are currently designed to accommodate different locations, taking into account the shade's height and angle as it influences the solar energy that can enter the building [81]. However, in simulations, it is not possible to consider the detailed shape or perforations of certain shading systems [20]. Other researchers have argued that vertical shading systems are generally more preferable for efficient shading in hot regions [82].

4. Methodology

The methodology is based on an iterative process where energy simulations are carried out using simulation tools in a case study under different scenarios. This process has been mapped in Figure 1. The case study is a small primary school located in the south-east of Spain, where a procedure to install parasols to its elevations has been designed. The yielded results of the energy performance are compared with those obtained from the simulation with DesignBuilder and with real energy performance data. Additionally, the building geometry and DesignBuilder are used to perform simulations of temperature and relative humidity in order to evaluate comfort with the methods developed by Givoni and Fanger. Final simulations are performed with the same program to evaluate illumination in the interior of the rooms affected by the installation of the sunlight control devices and compared with real illumination measurements. Finally, the influence of the software databases over the decision-making process is evaluated.

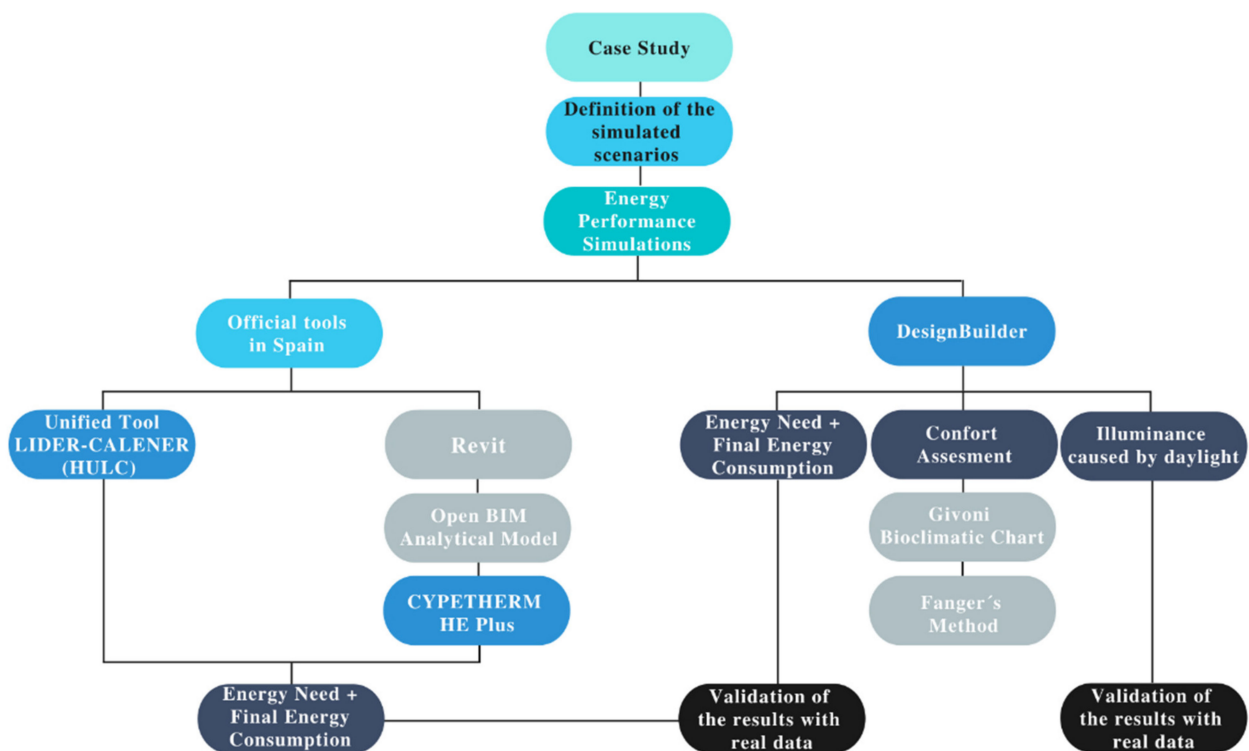


Figure 1. Flow chart: methodology.

4.1. Definition of the Case Study

The case study chosen for this research is located in Alicante city center in south-east Spain and is a typical example of a semi-detached building with small courtyards, as can be seen in Figure 2. The selected case study is under a renovation process as it is close to

its functional age limit, something very common as many buildings in this part of the city were built in the same period. The building is used as a three level primary school, most of which is designated as classroom space.

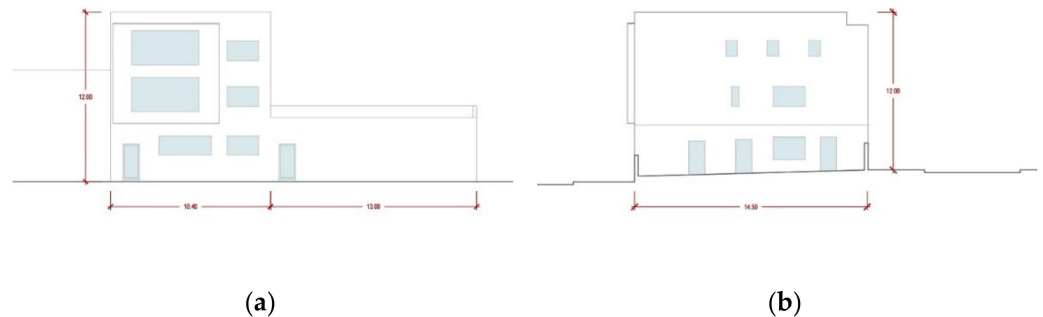


Figure 2. (a) Existing building: south-west elevation—current state; (b) existing building: south-east elevation.

As can be seen in Figure 3, the building has a rectangular shape with three exterior elevations and overall dimensions of $14.50 \times 10.40 \times 12.00$ m and 455 m^2 of built area. The area of the plot not occupied by the building is designated as a children's play area.

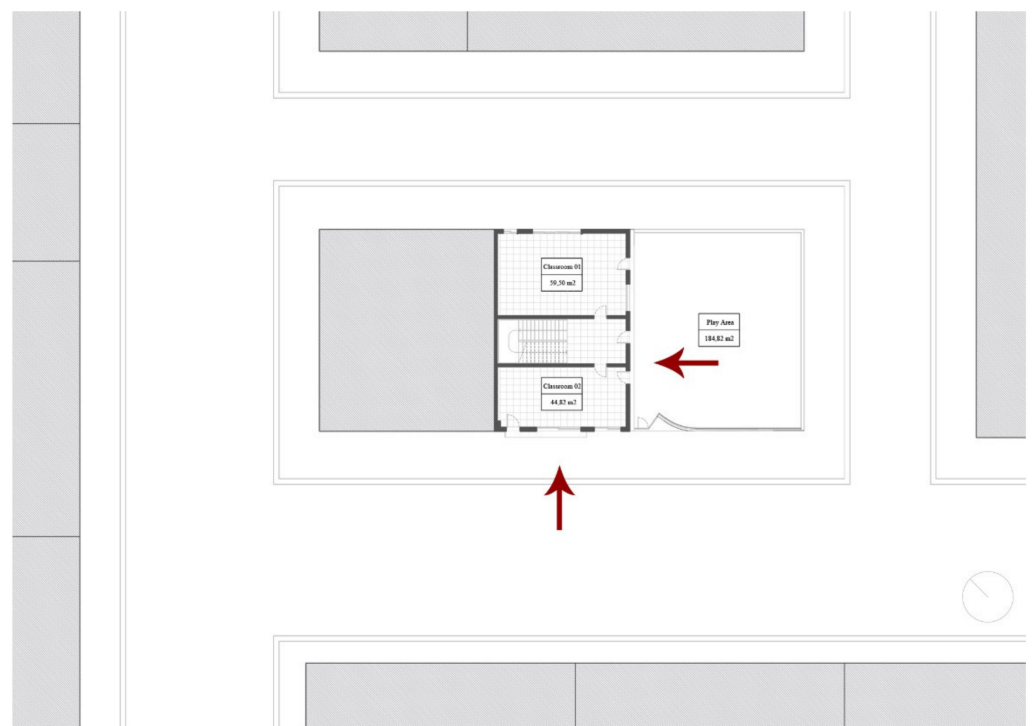


Figure 3. Floor elevation: existing building and surroundings—ground floor.

According to the Köppen climate classification, this part of Spain is characterized by a Mediterranean climate classified as Bsh, dry steppe, which means mild, wet, and dry winters with hot and dry summers. Humidity levels throughout the year, are in the medium–high range due to its proximity to the Mediterranean Sea.

As can be seen in Figure 4, the methods and materials used in the building construction are not consistent with those recommended to give enhanced energy performance and there is no thermal insulation present. Elevations are constructed using masonry on the ground level and hollow brickwork on the first and second. The structure is constructed using reinforced concrete. Windows and doors are seen as being single glazed with metal

frames with no acoustic or thermal break. There are thermal bridges in the elevations where the structure and roof converge. The building does not have an air-conditioning system for use during warm periods. Cross-ventilation and thermal mass are used to provide comfort in the summer. Heating is provided throughout the rooms by gas heating devices. Hot water is provided by a gas boiler.

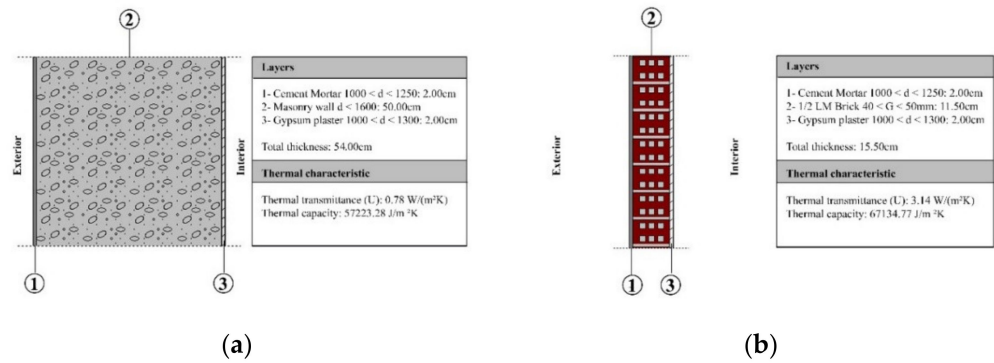


Figure 4. (a) Construction system based on masonry walls installed on the ground floor; (b) construction system based on a simple brickwork layer installed on the first and second floors.

Construction solutions to improve energy performance were evaluated during the process of designing the renovation proposal. These construction improvements were mainly based on the incorporation of thermal insulation, as can be seen in Figure 5, and the placement of shading systems on the south-east and south-west elevations. Micro-perforated metal sheeting with a 60% perforation ratio were selected to create the curved shading system for the building as can be seen in Figure 6. This installation is intended to reduce energy demand and improve the interior comfort of the building. Firstly, the shading systems were installed on the south-east elevation, however, the remainder of the improvements are currently on hold due to the COVID-19 pandemic. Fortunately, one of the shading systems had been fully installed over sufficient time to allow evaluation of its impact on the overall building performance and therefore these results may be used to compare the results yielded by the simulation tools and check the influence of the software on the decision-taking process.

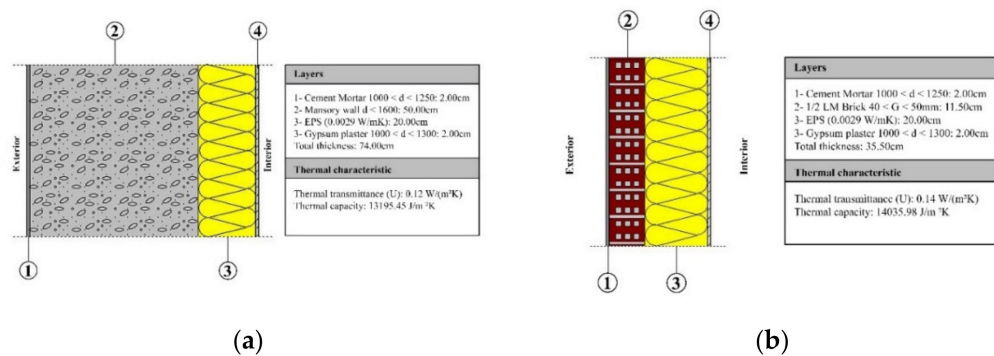


Figure 5. (a) Construction improvements: incorporation of thermal insulation on masonry walls installed on the ground floor; (b) construction improvements: incorporation of thermal insulation on a simple brickwork layer installed on the first and second floors.

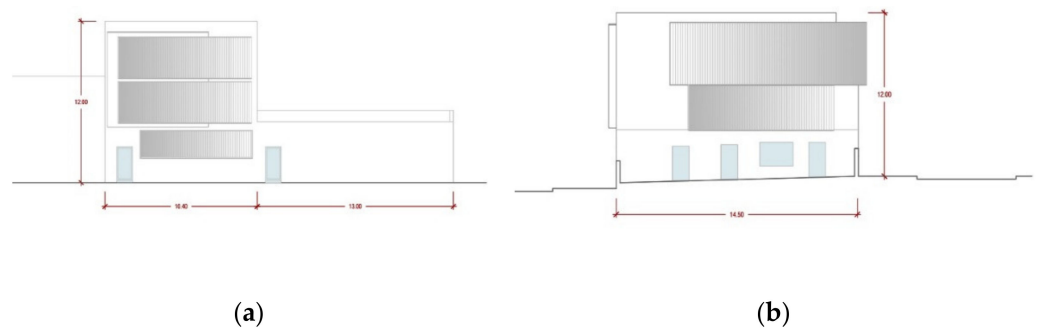


Figure 6. (a) Renovation: south-west elevation—proposal; (b) renovation: south-east elevation—current state.

4.2. Definition of the Simulated Scenarios

The evaluation of the impact of the construction improvements and solar control devices on the building energy performance has been carried out by defining four groups of scenarios with four calculations each, as can be seen in Figure 7. The first scenario evaluates the influence of the shading systems on a building without thermal insulation in its elevations. The second scenario combines the improvement of the building envelope by installing thermal insulation along with the installation of shading systems. The third scenario is a fictitious situation in which the building's orientation is changed to evaluate if the building distribution was properly chosen and the shading systems are installed without improving the thermal envelope. The fourth scenario combines the orientation change with the installation of thermal insulation and shading systems. In each scenario given above, the evaluation of the building comfort and the level of illumination has been performed to assess the influence of the improvements of the thermal envelope and the shading systems over users' wellbeing.

Scenario 1	Existing Building (No insulation)	Existing Building (No insulation) + Shading system Southeast elevation	Existing Building (No insulation) + Shading system Southwest elevation	Existing Building (No insulation) + Shading system Southeast and Southwest elevations
Scenario 2	Existing Building (With insulation)	Existing Building (With insulation) + Shading system Southeast elevation	Existing Building (With insulation) + Shading system Southwest elevation	Existing Building (With insulation) + Shading system Southeast and Southwest elevations
Scenario 3	Existing Building (No insulation) + Orientation Changed	Existing Building (No insulation) + Orientation Changed + Shading system Southeast elevation	Existing Building (No insulation) + Orientation Changed + Shading system Southwest elevation	Existing Building (No insulation) + Orientation Changed + Shading system Southeast and Southwest elevations
Scenario 4	Existing Building (With insulation) + Orientation Changed	Existing Building (With insulation) + Orientation Changed + Shading system Southeast elevation	Existing Building (With insulation) + Orientation Changed + Shading system Southwest elevation	Existing Building (With insulation) + Orientation Changed + Shading system Southeast and Southwest elevations

Figure 7. Simulations of the building performance divided in four groups.

4.3. Energy Performance: Simulation Tools and Comfort Assessments

The energy performance evaluation of the case study is carried out using the official tools currently in use in Spain for tertiary buildings, those being HULC and CYPETHERM HE Plus, along with DesignBuilder.

Up until 2018, HULC (Unified Tool LIDER-CALENER—Herramienta Unificada LIDER-CALENER) was the only official tool used in Spain to evaluate energy performance and carry out the energy certification process on tertiary buildings. It operates using a DOE-2 calculation engine allowing a simplified volumetric definition of the building via an overly complex user interface. The definition of all materials and building systems used to calculate energy demand, consumption, and CO₂ emissions is allowed, although simplifications

and modifying factors are used to define some construction solutions, i.e., shading systems. As explained previously, the energy certification is obtained by rating the building against an ideal model building that complies as a minimum with the limits defined by the Spanish Government.

Introduced in 2018, CYPETHERM HE Plus is a second official tool approved by the Spanish Government and developed by a private initiative to evaluate the energy performance of buildings. It is supported by the EnergyPlus calculation engine. This tool is based on an OpenBIM environment where different tools can exchange information regarding different aspects of the building. Energy need, consumption, and certification can be obtained along with other aspects of building performance. The introduction of the building information is carried out using BIM programs and the interface to complete the missing information is considered user-friendly.

In this research, Autodesk Revit has been used to define the building geometry and to provide the IFC (Industry Foundation Classes) file needed by CYPETHERM HE Plus for the calculations. It was necessary to modify the format of the Autodesk file using the OpenBIM Analytical Model tool, so as to prepare it for calculations. Thereafter, the resultant file is compatible with all tools operating within the OpenBIM environment.

The yielded energy performance results from both official tools are compared to the results obtained from the evaluation of the case study with DesignBuilder, one of the most widely recognized and complete software tools for assessing building performance, providing detailed calculations of energy, temperature, humidity, and computational fluid dynamics (CFD), amongst others. It works under the EnergyPlus calculation engine and accepts building geometries that are exported from BIM tools.

With the temperature and relative humidity results obtained from DesignBuilder the building's comfort can be evaluated using Givoni's Bioclimatic Chart. The data is introduced in a psychometric chart [83] that presents its information as an annual hourly analysis of the building's comfort zone and indicates which architectural solutions can be adopted to extend this during the year. This chart also provides the option of overlaying the different comfort zones with the predicted mean vote (PMV), as defined within Fanger's method.

The methodology designed by Givoni presents comfort by a bioclimatic chart that indicates and identifies different strategies to extend the comfort condition based on hygrothermal factors. These factors help to define two zones: a comfort zone defined by the dry bulb temperature and another zone of extended comfort. The extended comfort zone indicates the months of the year in which the comfort condition can be extended with active and passive solutions.

The analysis of comfort performed with Givoni's method is complemented by an analysis carried out with Fanger's method. Fanger's method is based on the personal perception of comfort and it is one of the most widely used for the estimation of thermal comfort. It calculates two indices, the predicted mean vote (PMV) and the predicted percentage dissatisfied (PPD). The PMV is an indicator that represents the average value of the opinions expressed by a large group of people on a seven-level thermal sensation scale when exposed to different thermal environments based on the thermal balance of the human body.

The PPD is the group of people who would disagree with the rest of the people under the same thermal conditions. A satisfactory situation occurs where there is a percentage equal to or less than 10%, i.e., 90% of people consider that they are in a comfortable situation in the analyzed indoor space. This PPD value (10%) is equivalent and corresponds to the limits indicated by the PMV (-0.5 y $+ 0.5$) [84].

The assessment of comfort cannot only be based on temperature and humidity, as illuminance and solar exposure, especially in south-eastern Spain, play an important role in the building users' wellbeing. For this reason, the analysis of comfort is completed with an evaluation of illuminance using the DesignBuilder tool for one of the classrooms of the selected case study.

4.4. Comparison with Real Energy Performance and Illumination Data

The simulation results yielded by the three analyzed tools for the south-eastern elevation are compared with the real performance data, as this shading system has been installed. Additionally, the illumination simulation results are compared with real illuminance data collected using a PCE-CRM 40 luxmeter and compared to the minimum levels defined by the CTE, set as 500 lux measured 0.85 m above ground level. The comparison between the real and the simulated results assists with evaluating the influence of the software in the decision-making process and the accuracy of the analyzed simulation tools.

5. Research

The research carried out is an iterative process where energy performance and comfort are evaluated under different scenarios and with different simulation tools. As previously stated, the objective is to establish a comparison between the different simulation tools and to evaluate their influence over the obtained results.

5.1. Calculations of the Building Energy Performance

The calculation of the building energy performance provides information about energy demand and energy consumption. In the case of energy demand, a complete building geometrical and construction description is loaded into the programs. As previously explained, different scenarios were adopted to evaluate the influence of the shading system installations. The scenarios are grouped according to the installation of thermal insulation within the elevations, exploring the option of changing the building orientation. It is also important to highlight that in all the evaluated simulation programs the definition of the shading systems are limited to a modifying factor, thus high detail of definition in their geometry was deemed unnecessary. The yielded results are divided between the energy needed for heating and that needed for cooling.

The calculation of the final energy consumption has been achieved by introducing the existing building facilities into the simulation programs. As was mentioned in the case study description, this building does not have a cooling system, so this factor has been disabled for the calculations.

5.1.1. Calculations with HULC

HULC is seen as an overly complex program with a complicated interface leading to some difficulties in the introduction of the case study's geometry. This tool does not allow intermediate evaluations to help with decision-making. Shading elements are introduced through a solar factor correction feature and thermal properties are set by those defined in the Catalogue of Built Materials from the CTE. Additionally, the obtained results are somewhat difficult to interpret.

Figures 8 and 9 display the results of the building's energy demand for cooling and heating, in the different scenarios described previously. As can be observed, the energy need for heating is clearly improved when thermal insulation is introduced in the building's elevations. On the other hand, the installation of the shading systems progressively increases the energy needed for heating.

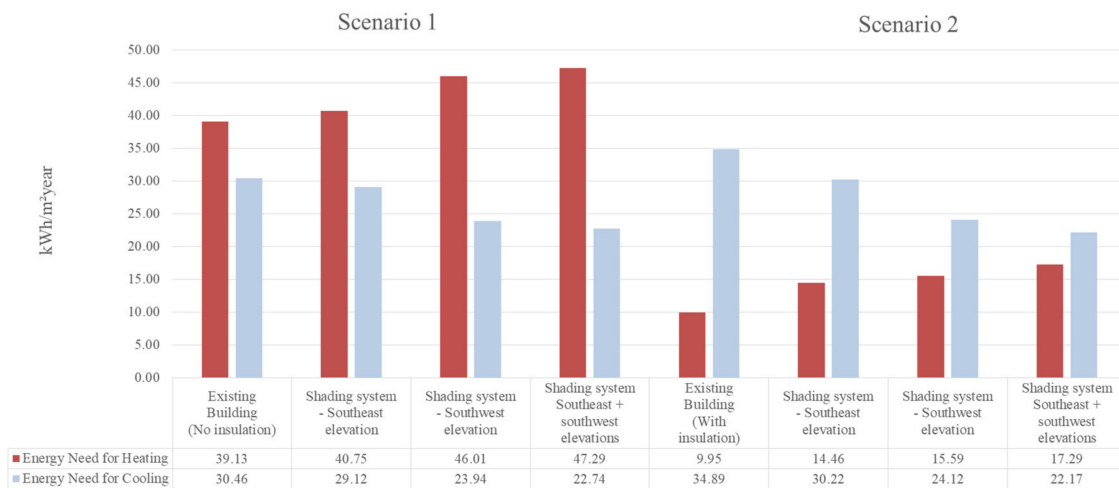


Figure 8. Calculation of the energy need (kWh/m²/year) and Energy Certification with HULC—scenarios 1 and 2.

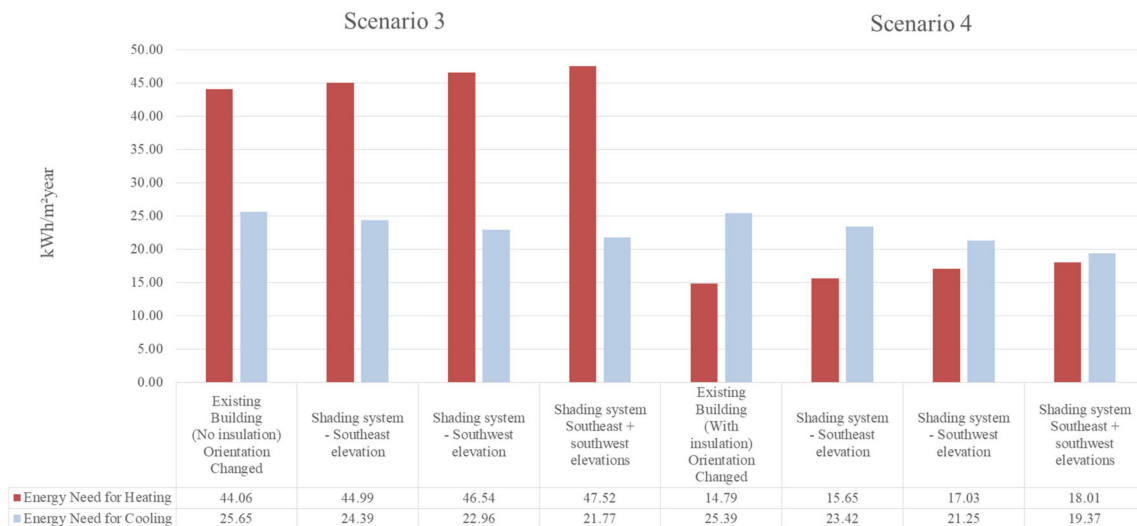


Figure 9. Calculation of the energy need (kWh/m²/year) and Energy Certification with HULC—scenarios 3 and 4.

In the case of the energy need for cooling, the installation of the shading systems reduces across the different elevations. The most appropriate scenario occurs when the shading systems are installed on both elevations and are combined with the installation of thermal insulation.

In Table 1 the influence of the sunshade over the energy need is analyzed by comparing the percentage of improvement between the existing building situation, without any improvement, and the different options of installing shades in the building’s elevations. The positive results (+) indicate an improvement and the negative results (−) indicate the opposite, i.e., the performance of the building is inferior when the shading system is introduced.

Table 1. Calculation of the improvement (%) of the shading system with the data obtained with HULC.

	Existing Building (kWh/m ² Year)		Shading System South-East Elevation		Shading System South-West Elevation		Shading System South-East + South-West Elevations	
	Energy Need for Heating	Energy Need for Cooling	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)
Scenario 1 (No insulation)	39.13	30.46	−4.14	+4.40	−17.58	+21.41	−20.85	+25.34
Scenario 2 (With insulation)	9.95	34.89	−45.33	+13.38	−56.68	+30.87	−73.77	+36.46
Scenario 3 (No insulation + Orientation Changed)	44.06	25.65	−2.11	+4.91	−5.63	+10.49	−7.85	+15.13
Scenario 4 (With insulation + Orientation Changed)	14.79	25.39	−5.81	+7.76	−15.15	+16.31	−21.77	+23.71

As shown in Table 1, the consideration of an insulation system for the building enhances the energy performance (scenarios 2 and 4). A paradoxical situation occurs in which the despite the building being located in a hot climate, the highest energy demand takes place in winter.

In comparing the initial state of the building with the installation of the shading system on sun-exposed elevations (scenario 1) the results demonstrate that the energy need for cooling is improved by 25.34%, as less sun radiation enters and so it does not increase the indoor temperature in summer. Alternatively, in winter the sun radiation does not enter, thus the energy need for heating increases by 20.85%. A similar situation occurs when the orientation of the building is changed (scenario 3), but by a far more subtle degree, as the shading system is located on the least sun-exposed elevations.

When insulation levels are increased, the opposite situation occurs; the energy need for heating reduces where no shading systems are installed (scenarios 2 and 4). In addition, the results also demonstrate different behavior with regards to the energy required for cooling. On the one hand, the energy needed for cooling slightly increases as seen in scenario 2, whereas in scenario 4 the results are unchanged.

Alternatively, Figure 10 shows the building final energy consumption under the different scenarios and the energy ratings together with the percentage of improvement when introducing the shading system and insulation into the simulation. Each scenario is displayed in this chart: on the right the final energy consumption is shown, on the left the percentage of improvement when renovations are introduced in the simulations, and in the center the Spanish energy rating that is accomplished.

Scenario 1	Existing Building (No insulation)		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	51.20	C	51.90	C	- 1.37	54.80	C	- 7.03	55.50	C	- 8.40
Scenario 2	Existing Building (With insulation)		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	36.60	B	43.10	B	- 17.76	41.70	B	- 13.93	43.10	B	- 17.76
Scenario 3	Existing Building (No insulation) Orientation Changed		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	54.40	C	41.70	C	23.35	55.70	C	- 2.39	56.20	C	- 3.31
Scenario 4	Existing Building (With insulation) Orientation Changed		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	40.90	B	44.00	B	- 7.58	42.90	B	- 4.89	43.80	B	- 7.09

Figure 10. Calculation of the final energy consumption with HULC (kWh/m²year) and the improvement (%) of the shading system.

Generally, the results show that the introduction of insulation or shading systems do not improve the final energy consumption. The only scenario that shows an improvement (23.35%) in final energy consumption is scenario 3, in which the shading on the southeast elevation is introduced into the simulation. It can also be observed that the energy consumption increases in most of the scenarios. This situation means that the introduction of the shading systems especially influences the energy needed for heating.

5.1.2. Calculations with CYPETHERM HE Plus

The calculations carried out with CYPETHERM HE Plus start with the preparation of the 3D model of the building with Autodesk Revit. This is a complete improvement compared to the very limited modelling system of HULC. Autodesk Revit allows a complete and detailed model that it is exported as an IFC file. This analytical model is developed with the OpenBIM Analytical Model tool that prepares the building for different evaluations, among them the evaluation of the energy performance with CYPETHERM HE Plus.

Although three tools are needed to perform the analysis, this process is far more user-friendly. CYPETHERM HE Plus is a very thorough tool that offers a variety of results, and in addition to providing intermediate information and analysis that helps to improve the design of construction systems whilst obtaining the final results, it is able to indicate the points at which the implemented system needs to be improved. Shading elements are introduced through a solar factor corrector and thermal properties were set by those defined in the Catalogue of Built Material from the CTE. The simplifications are forced by the EnergyPlus calculation engine.

The analysis of the obtained results with CYPETHERM HE Plus, as shown in Figures 11 and 12, demonstrates a similar performance to HULC. It should also be highlighted that even though the results are manifestly different, as regards the energy performance and the supposition that both tools used follow the same pattern, the energy need for heating increases and energy need for cooling is reduced when the shading system is installed. Additionally, the installation of the insulation makes the building yield a higher energy need for cooling than for heating, as is to be expected in warm weather.

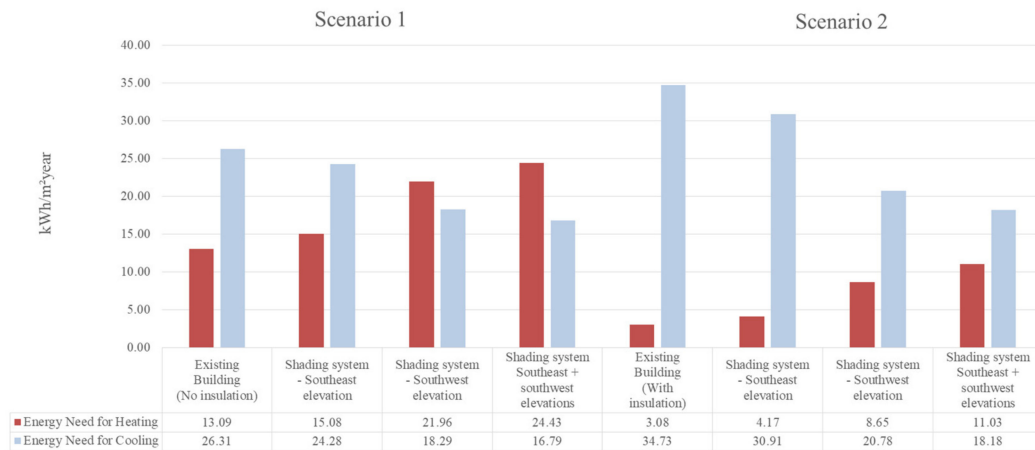


Figure 11. Calculation of the energy need (kWh/m²/year) with CYPETHERM HE Pus—scenarios 1 and 2.

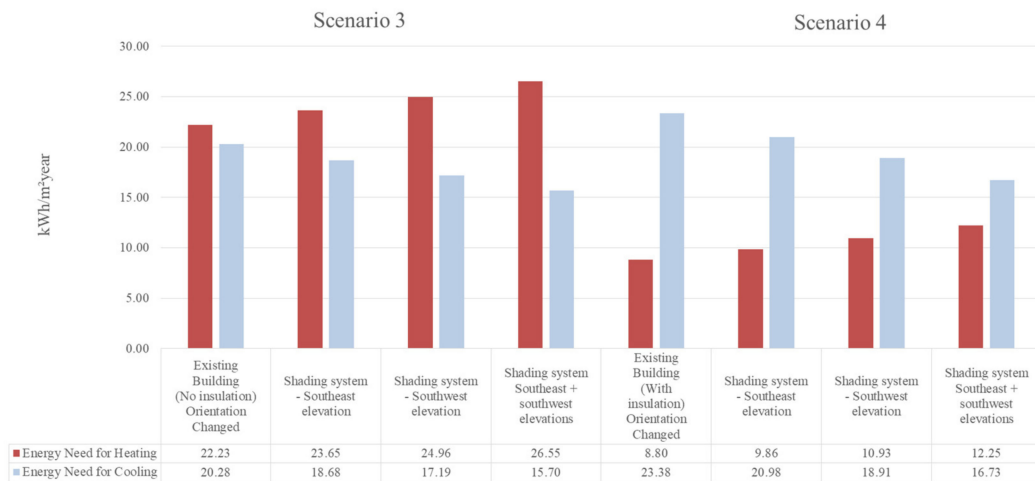


Figure 12. Calculation of the energy need (kWh/m² year) and Energy Certification with CYPETHERM HE Pus—scenarios 3 and 4.

In Table 2 the influence of the sunshade over the energy need is analyzed by comparing the percentage of improvement between the existing building situation, without any improvement, and the different options of installing shades in the building’s elevations. The positive results (+) indicate an improvement and the negative results (–) indicate the opposite, i.e., the performance of the building is inferior when the shading system is introduced.

Table 2. Calculation of the improvement (%) of the shading system with the data obtained with CYPETHERM HE Plus.

	Existing Building (kWh/m ² Year)		Shading System South-East Elevation		Shading System South-West Elevation		Shading System South-East + South-West Elevations	
	Energy Need for Heating	Energy Need for Cooling	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)
Scenario 1 (No insulation)	13.09	26.31	−15.20	+7.72	−67.76	+30.48	−86.63	+36.18
Scenario 2 (With insulation)	3.08	34.73	−35.39	+11.00	−64.39	+40.17	−72.08	+47.65
Scenario 3 (No insulation + Orientation Changed)	22.23	20.28	−6.39	+7.89	−12.28	+15.24	−19.43	+22.58
Scenario 4 (With insulation + Orientation Changed)	8.80	23.38	−12.05	+10.27	−24.20	+19.12	−39.20	+28.44

In the scenario of the building without thermal insulation, the yielded results demonstrate that installing shading systems is not decisive in the evaluation of the energy need, something that may be reinforced in the scenario where the insulation is installed. Alternatively, if the building changes orientation, then the installation of the shading systems start showing some improvements.

Figure 13 details the building's final energy consumption and the obtained energy rating together with the percentage of improvement when introducing the shading system and insulation into the simulation. Each scenario is displayed in this chart; on the right the final energy consumption is shown, on the left the percentage of improvement when renovations are introduced in the simulations, and in the center the Spanish energy rating that is accomplished.

Scenario 1	Existing Building (No insulation)		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	79.86	D	81.49	D	- 2.04	87.69	D	- 9.80	90.29	D	- 13.06
Scenario 2	Existing Building (With insulation)		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	70.65	D	69.97	D	0.96	70.42	D	0.33	72.25	D	- 2.26
Scenario 3	Existing Building (No insulation) Orientation Changed		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	89.27	D	90.33	D	- 1.19	91.31	D	- 2.29	92.67	D	- 3.81
Scenario 4	Existing Building (With insulation) Orientation Changed		Shading system Southeast elevation			Shading system Southwest elevation			Shading system Southeast + southwest elevations		
	Total Consumption	Energy Certification	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%	Total Consumption	Energy Certification	%
	72.13	C	72.24	C	- 0.15	72.55	C	-0.58	73.17	C	- 1.44

Figure 13. Calculation of the final energy consumption with CYPETHERM HE Plus (kWh/m²year) and the improvement (%) of the shading system.

The results show a similar pattern to HULC. In general, the introduction of insulation or shading systems does not improve the building's energy consumption. The only scenario that shows an improvement in final energy consumption is scenario 2, in which thermal insulation is installed and the shading on the south-east or south-west elevations are introduced into the simulation.

5.1.3. Calculations with DesignBuilder

The final part of the simulations was carried out with DesignBuilder. As one of the most renowned software tools for carrying out evaluations of a building performance from different points of view including energy, it is powered by the same calculation engine as CYPETHERM HE Plus, EnergyPlus. It allows a complete definition of the construction and HVAC systems. DesignBuilder does not provide an energy classification in the same way as other previous tools.

DesignBuilder has a user-friendly interface and provides a wide range of data regarding building performance. For modelling the case study, the building geometry provided by Autodesk Revit could also be used.

In this simulation tool, the shading system had to be introduced by an alternate method to that of other simulation tools. It was necessary to draw a surface with a minimum thickness and to give it a certain degree of "transparency" depending on the specified "open-area ratio" (the % area occupied by perforations) of the perforated sheet as a shading element. In our case, 60% perforation translated into 0.6 solar transmittance.

Figures 14 and 15 display the results of the energy demand of the building, for both cooling and heating, in the different scenarios described previously. Although DesignBuilder allows a high level of detail in the introduction of the building construction and the building systems data, it shows similar results for both the energy need for cooling and for heating. At the same time, both are reduced when the shading systems are installed in the different elevations. The best scenario occurs when shading systems are installed on both elevations, along with thermal insulation and changes to the building orientation (Scenario 4).

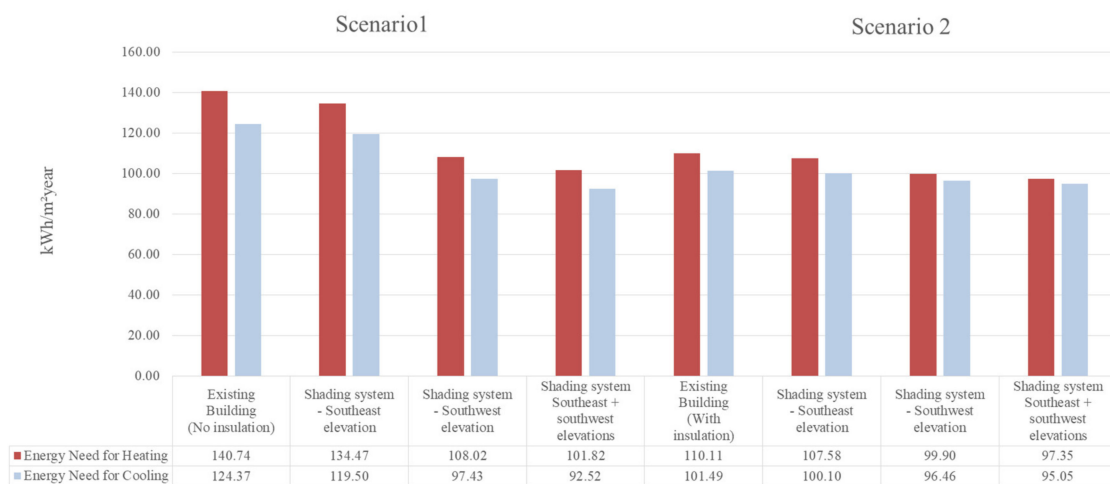


Figure 14. Calculation of the energy need (kWh/m²/year) with DesignBuilder—scenarios 1 and 2.

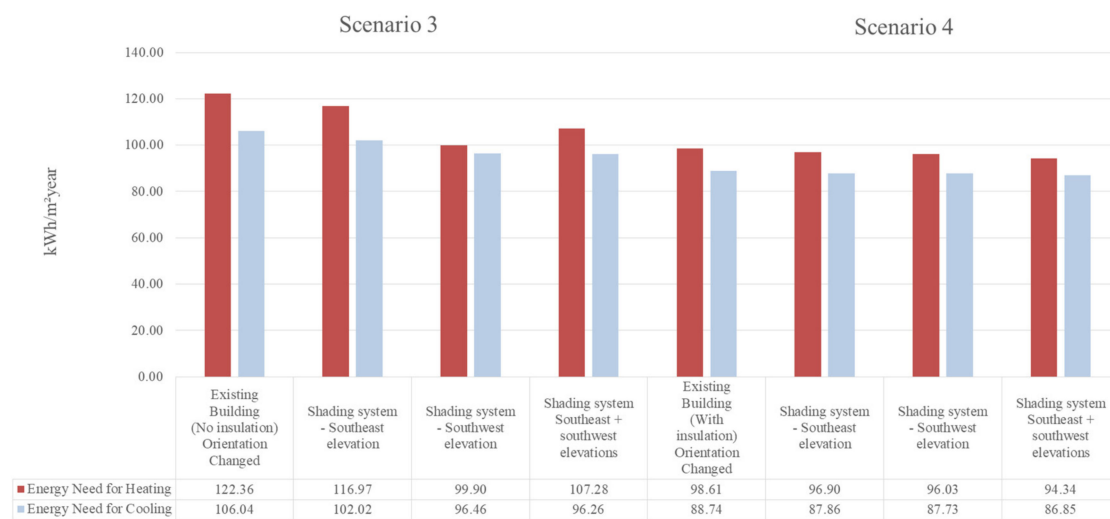


Figure 15. Calculation of the energy need (kWh/m²year) with DesignBuilder—scenarios 3 and 4.

The results obtained with DesignBuilder, as shown in Table 3, indicate a different energy performance of the building in comparison to the tools previously used. In this new pattern, the energy need for heating improves by 27.65% and the energy need for cooling improves by 25.61% when the shading systems are taken into account (scenario 1).

Table 3. Calculation of the improvement (%) of the shading system with the data obtained with DesignBuilder. The positive results (+) indicate an improvement and the negative results (−) indicate the opposite, i.e., the performance of the building is inferior when the shading system is introduced.

	Existing Building (kWh/m ² Year)		Shading System South-East Elevation		Shading System South-West Elevation		Shading System South-East + South-West Elevations	
	Energy Need for Heating	Energy Need for Cooling	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)	Heating (%)	Cooling (%)
Group 1 (No insulation)	104.74	124.37	+4.46	+3.92	+23.25	+21.66	+27.65	+25.61
Group 2 (With insulation)	110.11	101.49	+2.30	+1.37	+9.27	+4.96	+11.59	+6.35
Group 3 (No insulation + Orientation Changed)	122.36	106.04	+4.41	+3.79	+19.36	+9.03	+12.32	+9.22
Group 4 (With insulation + Orientation Changed)	98.61	88.74	+1.73	+0.99	+2.62	+1.14	+4.33	+2.13

This improvement in energy efficiency on both sides, heating and cooling, also occurs when the insulation and the sunshade are taken into account (scenario 2). The same situation occurs when the orientation of the building is changed (scenarios 3 and 4), yet by a far more subtle degree, as the shading system is located on the least sun-exposed elevations.

Figure 16 details the building's final energy consumption together with the percentage of improvement when introducing the sunshade and insulation into the simulation. Each scenario is displayed in this chart; on the right the final energy consumption is shown, and on the left the percentage of improvement when renovations are introduced in the simulations. The results show a similar pattern to HULC and CYPETHERM HE Plus.

Generally, the introduction of insulation or shading systems does not improve the final energy consumption.

Scenario 1	Existing Building (No insulation)	Shading system Southeast elevation		Shading system Southwest elevation		Shading system Southeast + southwest elevations	
	Total Consumption	Total Consumption	%	Total Consumption	%	Total Consumption	%
	43.74	43.92	- 0.43	44.62	- 2.02	44.85	- 2.56
Scenario 2	Existing Building (With insulation)	Shading system Southeast elevation		Shading system Southwest elevation		Shading system Southeast + southwest elevations	
	Total Consumption	Total Consumption	%	Total Consumption	%	Total Consumption	%
	36.69	36.70	- 0.02	36.75	- 0.16	36.76	- 0.20
Scenario 3	Existing Building (No insulation) Orientation Changed	Shading system Southeast elevation		Shading system Southwest elevation		Shading system Southeast + southwest elevations	
	Total Consumption	Total Consumption	%	Total Consumption	%	Total Consumption	%
	44.27	44.36	- 0.19	44.26	- 0.03	44.35	- 0.17
Scenario 4	Existing Building (With insulation) Orientation Changed	Shading system Southeast elevation		Shading system Southwest elevation		Shading system Southeast + southwest elevations	
	Total Consumption	Total Consumption	%	Total Consumption	%	Total Consumption	%
	36.83	36.84	- 0.02	36.84	- 0.02	36.85	- 0.04

Figure 16. Calculation of final energy consumption with DesignBuilder (kWh/m²year) and the improvement (%) of the shading system.

In terms of energy demand, with HULC and CYPETHERM HE PLUS a similar behavior can be observed when the shading systems are taken into account in the simulation. The heating demand rises leading to poorer performance of the building and the cooling demand decreases. The most significant change impacting the results is visible when the insulation is factored into the simulations. A different behavior occurs with DesignBuilder, where both heating and cooling demand are reduced simultaneously. Despite producing varying results, all three simulation programs demonstrate that the best results are yielded in scenario 4, in terms of both energy demand and final energy consumption.

The evaluations of the energy performances observed do not show robust results as the different tools provide different patterns in the yielded data. They also offer results that are inconsistent with those to be expected, i.e., that the higher (or equal) energy need occurs in winter when a higher demand would have been expected in the summer months.

5.2. Comfort Calculation

5.2.1. Fanger's Method and Givoni's Bioclimatic Charts

The research developed using the three tools presented above yields technological results based on parameters of heating, cooling, and energy consumption according to the building envelope and volumetry. However, it is necessary to incorporate other variables to evaluate the comfort levels of the design and to assess if an efficient building can also be comfortable. The evaluation of the building performance with DesignBuilder yields an annual hourly simulation that provides temperature and relative humidity to be used with Givoni's method. The Givoni Bioclimatic Chart show potential extensions of the comfort zone resulting from building design characteristics such as solar gain and the use of internal thermal mass for heating, cooling, and ventilation strategies. It also provides the Fanger's PMV and PPD.

Figure 17 maps the annual hourly simulation as individual hourly data points. Overlaid we can find a range of comfort information giving more meaning to the data obtained. This could potentially give some insight into the most appropriate design responses for the climate in which the case study is located. Two different scenarios are shown using Givoni's method, the blue area represents the existing building without insulation with the red area representing the existing building with insulation and the shading system on the sun-exposed elevations.

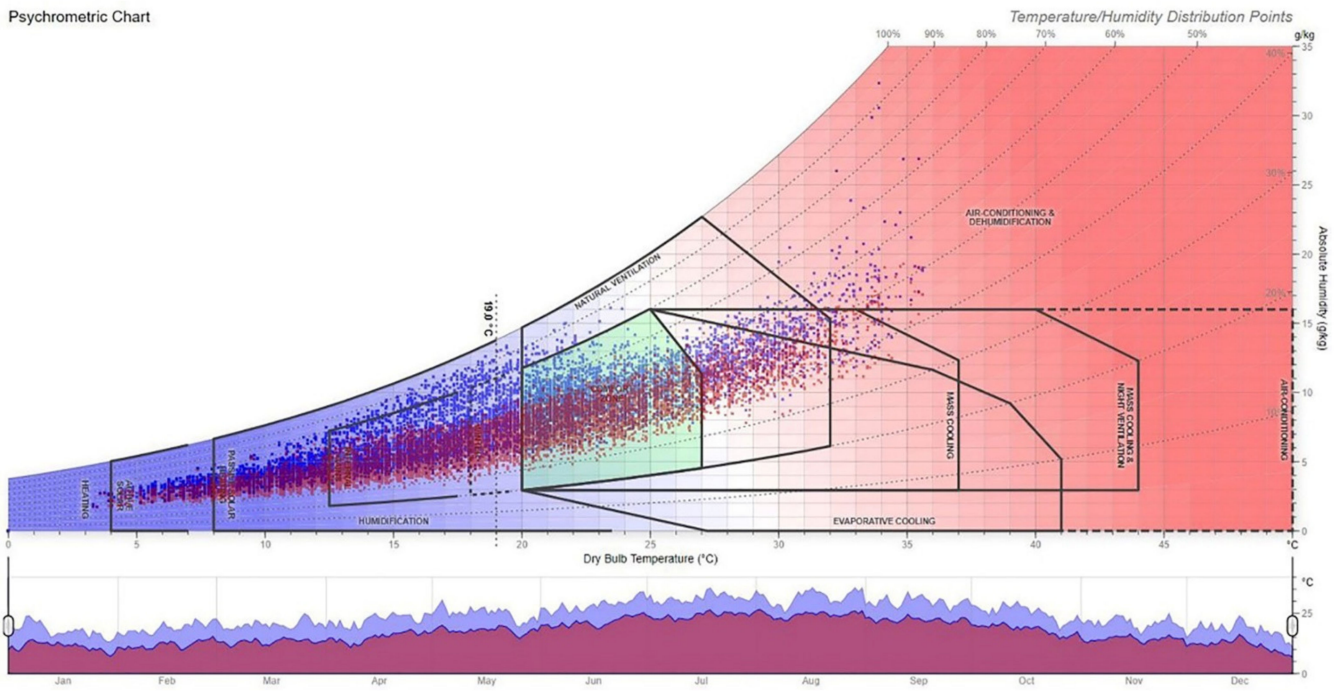


Figure 17. Givoni Bioclimatic Chart: existing building (no insulation) in blue; and existing building (with insulation) with a shading system installed on the south-east and south-west elevations in red.

The evaluation of comfort with Fanger’s method is shown in Figures 18 and 19 as an average monthly calculation obtained through the DesignBuilder tool. In Figure 18 the scenarios with no insulation are shown and in Figure 19 the scenarios with insulation are shown. In red we can locate the limits of a comfortable environment as defined by the ASHARE 55 regulations (−0.5 and +0.5).

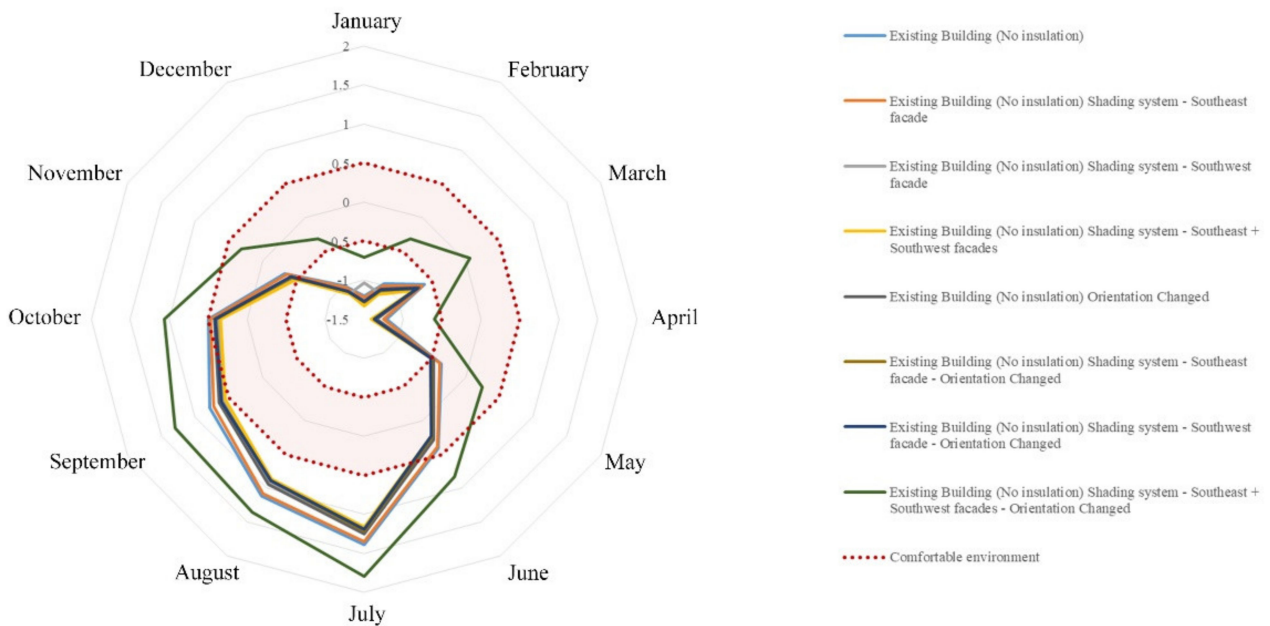


Figure 18. Monthly average calculation: predicted mean vote (PMV)—scenarios with no insulation.

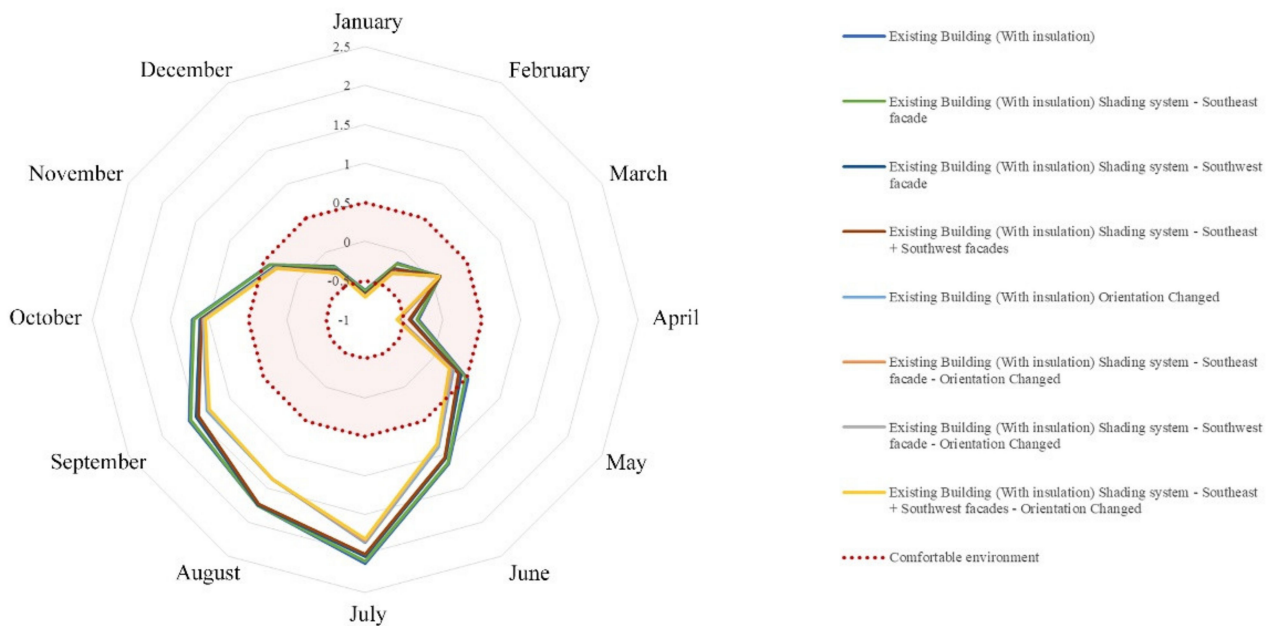
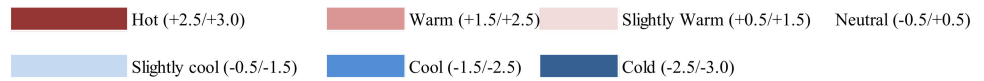


Figure 19. Monthly average calculation: predicted mean vote (PMV)—scenarios with insulation.

The results indicate that globally on a monthly basis there is no significant difference graphically between the building with or without the shading system. This only occurs when both shading systems are installed and the building orientation is changed, as can be seen in Figures 18 and 19. As with the evaluation of the energy performance, the PMV results perform a significant change when thermal insulation is introduced into the simulations. It must also be taken into account that the subject building is a primary school and therefore is out-of-use during the summer period and sees no activity. For this reason, the months of the year in which improvements in comfort should be sought range from September to June.

Figure 20 shows the annual results obtained using Fanger's method. Over these results, by color, the level of thermal sensation established by the method itself is indicated. As mentioned above, this scale consists of seven levels, finding the neutral comfort situation level with PMV values between -0.5 and $+0.5$. Each scenario is displayed in this chart; on the right the predicted percentage of dissatisfied people, and on the left the predicted mean vote.

The annual PPD results demonstrate that all scenarios show around the same percentage of dissatisfied people, between 27.03–28.99%, except when the building has thermal insulation installed and the original orientation (scenario 2), when the percentage increases to 32.37%. In this specific case, adding the shading system selected for the renovation reduces the percentage by around 2%. In relation to the PMV evaluations, most cases show how the annual results are in a neutral thermal sensation scale except for when thermal insulation is introduced into the building so as to meet thermal regulations (scenario 2). This leads to a sensitive situation, and it should be noted that in meeting the regulations regarding thermal levels the best results are not always obtained when comparing the outcome with the thermal sensation that users actually feel inside the building. Therefore, the annual average results may indicate neutral thermal sensation in most cases, but our monthly average results demonstrate the months where the most emphasis should be placed when designing the comfort of the building's interior in order to improve energy efficiency.



Scenario	Existing Building (No insulation)		Shading system - Southeast facade		Shading system - Southwest facade		Shading system Southeast + southwest facade	
	PPD (%)	VMP	PPD (%)	VMP	PPD (%)	VMP	PPD (%)	VMP
Scenario 1	27.37	-0.12	27.35	-0.15	27.45	-0.26	27.56	-0.29
Scenario 2	32.37	0.64	32.03	0.62	31.04	0.56	30.70	0.54
Scenario 3	27.26	-0.23	27.11	-0.25	27.03	-0.25	26.91	-0.28
Scenario 4	28.99	0.45	28.72	0.43	28.67	0.43	28.41	0.42

Figure 20. Annual average calculation: predicted percentage dissatisfied (PPD) and predicted mean vote (PMV).

5.2.2. Illuminance Caused by Daylight

As we have seen previously, user comfort can be related to many different concepts, such as lighting. Simulations of one of the classrooms located on the first floor of the case study which is affected by the shading system were performed. The aim of the simulation was to determine the impact of the shading system not only in terms of energy and comfort, but also in terms of the amount of light entering the study area. As can be seen in Figure 21, there is a clear impact in the illumination when installing shading systems. During some periods of the year illumination reduces to 80%, which is marginally above the statutory minimum level of 500 lux as defined by the Spanish regulations.

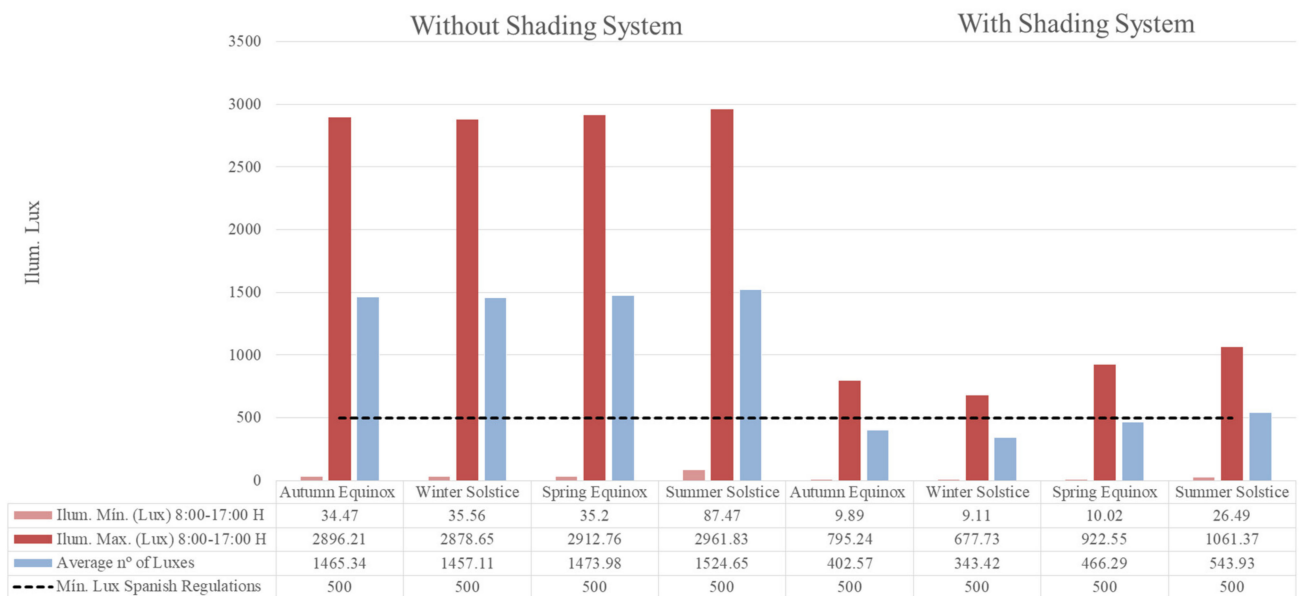


Figure 21. Illuminance caused by daylight: classroom level 01. DesignBuilder simulations results. With and without shading systems.

5.3. Real Data Analysis

As previously mentioned, the building renovation process was halted due to the COVID-19 pandemic, but as one of the shading systems had already been installed on the south-eastern elevation we were able to gather real energy consumption data from one complete year and compare these to the energy consumptions before the refurbishment and to the results yielded by the simulation tools.

As can be seen in Table 4, the installation of the shading systems in the south-eastern elevation has improved the building energy performance by generally reducing the energy consumption throughout the year when comparing the real energy performance with the shading system installed in this elevation. It is DesignBuilder that yields the energy consumption that is closest to reality. HULC yields 30% more energy consumption and CYPETHERM HE Plus 80% more than the actual building performance. This creates a problematic situation, as projected energy savings are a key consideration when seeking to justify building improvement investment, moreover, the associated return on investment (ROI) calculation may be incorrect.

Table 4. Validation of the results: final energy consumption (KWh).

	Real Data		Simulations: Existing Building + Shading System on South-East Elevation (No Insulation)		
	Current State	Reform State: Shading System on South-East Elevation	HULC	CYPETHERM HE Plus	DesignBuilder
January	2100.00	1722.00	3201.92	4002.40	2116.11
February	2949.00	2506.65	3492.96	3040.20	1743.01
March	2146.00	1802.64	2255.27	3717.20	1424.62
April	1742.00	1411.02	2382.43	3706.70	1796.75
May	1280.00	1075.20	2451.84	2814.80	1884.68
June	1401.00	1162.83	1989.90	2156.50	1536.74
July	1333.00	1133.05	1365.73	1018.50	1625.41
August	489.00	405.87	617.52	916.10	69.79
September	1538.00	1307.30	1214.24	1296.50	1623.16
October	1638.00	1359.54	1947.14	2927.10	1627.28
November	2461.00	2091.85	1596.06	2072.80	1995.59
December	1652.00	1404.20	1879.45	3685.20	1746.52
TOTAL	20,729.00	17,382.15	24,394.45	31,353.90	19,189.66

As can be seen in Table 5, the yielded results of the illumination simulation is compared with real data collected from the building itself with a luxmeter (PCE-CRM 40). This instrument allows a simple and quick measurement of the real and non-subjective illumination of a given environment. The measurements taken with this instrument were made at different times of the year. During one day of each period, a series of measurements were taken in different parts of the room at specific times of day, then an average of the data collected was taken in the room before and after the implementation of the shading device.

Table 5. Validation of the results: illuminance caused by daylight (Lux). Comparing real data obtained in the building with the simulations results obtained by DesignBuilder. Simulation results are divided in three categories; minimum illuminance, maximum illuminance, and the average lux entering the classroom.

	Existing Building (No Insulation)			Existing Building + Shading System on South-East Elevation (No Insulation)				
	Real Data	Simulations		Real Data	Simulations			
		Illum. Min.	Illum. Max.		Average n° of Lux	Illum. Min.	Illum. Max.	Average n° of Lux
Autumn equinox	1100.00	34.47	2896.21	1465.34	505.89	9.89	795.24	402.57
Winter solstice	942.10	35.56	2878.65	1457.11	194.21	9.11	677.73	343.42
Spring equinox	3999.00	35.2	2912.76	1473.98	499.90	10.02	922.55	466.29
Summer solstice	4058.90	87.47	2961.83	1524.65	505.89	26.49	1061.37	543.93

Actual data compared to the yielded simulation results show that they are closer to reality when the building is evaluated with the shading systems installed on the south-eastern elevation. A considerable difference in measurements taken prior to the sunshade installation is evident.

6. Discussion of Results and Validation of Results

The analysis of the yielded results demonstrates that the simulation tools can be very useful in the process of obtaining energy efficient buildings. However, the yielded results present a lack of homogeneity and this may guide designers in the wrong direction. The evaluation of the impacts of the proposed improvements in the case study indicates that it is more effective from an energy performance perspective to invest in improving the thermal envelope rather than parasol installation. This contrasts with what should be the theoretical performance of the case study, since controlling solar radiation would normally be considered a priority with a building located in a warm climate. This situation is confirmed by the three tools evaluated and is also reflected in the evaluation of comfort.

These results contradict similar research that points to the reduction of both cooling demand in summer and heating demand in winter when shading systems are installed [19,79]. It is also contrary to other researchers' findings indicating that window replacement and the use of sunshades in the renovation of older buildings can be more effective and cost-efficient than the improvement of a building's envelope [77].

The results align with those of researchers stating that in order to achieve the improvement of a building's internal performance, it is necessary to complete the renovation by installing insulation. This statement confirms previous studies that support the effectiveness of deep energy refurbishments [85].

The analysis of both official tools, HULC and CYPETHERM HE Plus, show varying results but with the same performance patterns [16]. Alternatively, CYPETHERM and DesignBuilder, both using the same calculation engine, deliver very different results. With these results, it is confirmed that the calculation engines employed show a degree of similar accuracy, as Azhar and Brown state [86], yet the database and simplifications made during the calculation have affected the results.

The evaluation of the influence of the shading system installed on the south-east elevation shows a low impact across all scenarios due to the small percentage of windows represented on this elevation. In this case, a greater impact would have been achieved had the parasol been installed initially on the south-west elevation or had the building been designed with alternate orientations as evaluated in the scenarios considering this variable.

In the case of both official tools, the installation of shading systems in the different elevations reduce the energy need for cooling and increases the energy need for heating, which is in disagreement with the results of other researchers who found that shading systems are a primary subject of study [79]. However, it confirms that to design an appropriate solution to control sunlight it is necessary to work with dynamic shading systems that alter their position according to the period of the year [73].

The analysis of the simulated energy consumption shows that HULC yields results that advise against the installation of shading system as the energy consumption grows in almost every scenario. In the case of CYPETHERM HE Plus, installing parasols slightly alters the overall energy consumption; a similar result is obtained by DesignBuilder. In addition, the comparison between the simulations carried out and actual energy consumptions under assessment show that there remains no alignment between reality and simulation, in that actual energy consumption is lower than that simulated. This means that the projected energy savings data being used for investment justification/ROI purposes is lower and therefore the stated investment recovery period will almost certainly become protracted—perhaps to the point of being unrecoverable. The reason for this lies in the simplifications and databases of the different tools that cause the results to differ and produce varied energy consumption outcomes when construction improvements are introduced [53]. It is also noted that simulation tools continue to have evaluation limitations when passive solutions are introduced [45,86].

Where energy certification is based on energy consumption, it should be noted that only in the case of HULC in scenarios 2 and 4 are there significant improvements in the achieved energy certification. However, these still fall short of achieving the maximum, something that may dissuade building owners from making construction improvement investments for the purposes of increasing energy performance. In the case of CYPETHERM HE Plus the highest achieved rating is C, far above the minimum required by regulations for new buildings (Letter B).

Carrying out comfort and lighting evaluations on the case study at the same time as analyzing the building's energy performance allows cross-sectional results to be obtained and increases the amount of information available to the to support their decision-making process. In this case, a similar trend to that of energy performance is shown where the best comfort situation is obtained when the thermal envelope of the building is improved, having a very low impact on the sunshades. This situation contrasts with the design recommendations for buildings located in areas with significant solar radiation, where one of the first considerations should be that of controlling sunlight.

The use of the Givoni Bioclimatic Chart confirms that the proposed installations will improve the energy needed for cooling, but at the same time, the reduction of solar radiation worsens the building performance in winter. As for Fanger's method, if we compare the PPD results, the primary difference is observed when insulation is incorporated into the simulations, in line with previous observations that insulation is the key element for altering building performance. However, the PPD results indicate that the highest percentage of dissatisfied people would occur in summer, not in winter as other evaluations indicate. These results confirm that it is more beneficial to carry out complete analyses of building comfort [85] than to make comparisons of constructive improvements independently or in a comparative manner [77,81].

The evaluation of the two official Spanish energy performance simulation tools concludes that CYPETHERM HE Plus is the most suitable tool, from the perspectives of building modelling, ease of data entry, and the ability to carry out evaluations at intermediate points within the design process. Moreover, its added data export functionality allows interaction with other OpenBIM environment simulation tools, opening the door to obtaining better buildings.

However, obtaining different results between HULC and CYPETHERM HE Plus and even with DesignBuilder, with which it shares a calculation engine, means that the designer does not have a clear reference of what the best result might be. The introduction of

CYPETHERM HE Plus does not solve the problems found by other researchers, particularly as regards the claims that, after the creation of HULC, the tool can favor erroneous strategies and inefficient buildings, and thus this situation persists [13]. The decision-making of designers can be conditioned by the tool and thus we are in agreement with other researchers' statements regarding weak simulation tools [87].

Compared to HULC and CYPETHERM HE Plus, DesignBuilder is not an official tool but has been proven to be a good option to cross-check the results obtained with the official tools and help in the decision-making process. As found in other studies, it allows some variables that are not permitted by the official tools, such as the complete definition of the geometry to the thermal inertia of the materials and their construction systems [20]. In this case, the influence of the shading systems on the energy need for cooling and heating showed different patterns, however the yielded energy consumption is close to the actual energy consumption data.

In terms of sunlight entry, a simulation was carried out using DesignBuilder and the results were compared with actual data acquired from within the building. The results demonstrate that in sunlight exposure terms, both the simulation tools and the actual building data were comparable when the shading systems were installed. In this case, it can be stated that the simulation tool provides a good understanding of this construction improvement and therefore it can also be stated that these simulations are valid for understanding the future performance of shading systems in terms of sunlight entry and assistance in the decision-making process [19].

7. Conclusions

The analysis of the new energy performance simulation tool in Spain reveals that the situation previously encountered persists in which simulation tools influence decision-making processes. There still exists a void between the energy consumption results obtained by the simulations and the actual performance of the building. The energy savings gained from making thermal envelope upgrades and installing shading systems are unclear, potentially steering investors in the wrong direction when planning a building remodel.

The influence of the BIM work environment has confirmed an improvement in the introduction of building data and gives rise to the possibility of conducting analysis at different design stages. At the same time, it has made it possible to carry out cross-sectional studies with other tools and to evaluate other factors that influence people's quality of life, such as comfort and lighting.

It has also been confirmed that the process of improving a building must be done from a global perspective in which the envelope is improved and elements that control solar radiation are installed. Carrying out partial actions does not offer decisive results and can also worsen the performance of a building from both an energy and comfort point of view. In addition, it is confirmed that the installation of solar control elements must be carried out after a detailed analysis of the elevations and orientations, and that their geometry must be analyzed so that any changes offer adequate results in winter and summer through their ability to adapt their geometry to the solar incidence of each period of the year.

Author Contributions: Conceptualization, A.G.-G., Á.B.G.-A., and M.I.P.-M.; methodology, M.H. and A.G.-G.; software, M.H.; validation, M.H. and A.G.-G.; formal analysis, M.H.; investigation, M.H.; resources, M.H. and A.G.-G.; data curation, M.H. and A.G.-G.; writing—original draft preparation, M.H.; writing—review and editing, M.H.; visualization, M.H.; supervision, A.G.-G. and Á.B.G.-A.; project administration, A.G.-G., Á.B.G.-A., and M.H.; funding acquisition, A.G.-G., Á.B.G.-A., M.I.P.-M., and M.H. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University of Alicante, with a grant financed to promote the integration of junior researchers in research teams, and it was also supported by a grant from the Networks-I3CE Programme for research in university of the Institute of Education Sciences of the University of Alicante (2020–21). Ref.: 4978.

Acknowledgments: The authors of this paper thank the University of Alicante for a grant that funded part of this research. Particular thanks go to the Chair of Sustainable Architecture, for the help offered to the Department of Architectural Constructions for the acquisition of equipment for research.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Munarim, U.; Ghisi, E. Environmental feasibility of heritage buildings rehabilitation. *Renew. Sustain. Energy Rev.* **2016**, *58*, 235–249. [CrossRef]
- Bajenaru, N.; Damian, A.; Frunzulica, R. Evaluation of the Energy Performance for a NZEB Office Building under Specific Climatic Conditions. *Energy Procedia* **2016**, *85*, 26–34. [CrossRef]
- Sigmund, Z. Sustainability in architectural heritage: Review of policies and practices. *Organ. Technol. Manag. Constr. Int. J.* **2016**, *8*, 1411–1421. [CrossRef]
- Domínguez Martín, A. Concerted Action Energy Performance of Buildings. EPBD implementation in Spain. 2018. Available online: <https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Spain-2018.pdf> (accessed on 2 May 2021).
- Andaloro, A.P.; Salomone, R.; Ioppolo, G.; Andaloro, L. Energy Certification of Buildings: A Comparative Analysis of Progress towards Implementation in European Countries. *Energy Policy* **2010**, *38*, 5840–5866. [CrossRef]
- Krygiel, E.; Nies, B. *Green BIM: Successful Sustainable Design with Building Information Modeling*; John Wiley & Sons: Hoboken, NJ, USA, 2008.
- European Parliament; Council of the European Union. *EPBD European Directive for Energy Performance in Buildings*; European Parliament: Strasbourg, France; Council of the European Union: Strasbourg, France, 2002.
- Government of Spain. *CTE—Technical Building Code—(CTE- Código Técnico de la Edificación)*; Government of Spain: Madrid, Spain, 2006.
- Government of Spain. *Law 38/1999 of 5 November, on Building Management Regulation—(Ley 38/1999, de 5 de Noviembre, de Ordenación de la Edificación)*; Government of Spain: Madrid, Spain, 1999.
- Government of Spain. *CTE—Technical Building Code—Basic Document, Energy Saving DB-HE—(Código Técnico de La Edificación— Documento Básico Ahorro de Energía DB-HE)*; Government of Spain: Madrid, Spain, 2019.
- Ministry of the Presidency and Territorial Administrations. *Royal Decree 564/2017, of 2 June, amending Royal Decree 235/2013, of 5 April, Approving the Basic Procedure for the Certification of Energy Efficiency in Buildings. (Real Decreto 564/2017, de 2 de Junio, Por El Que Se Modifica El Real Decreto 235/2013, de 5 de Abril, Por El Que Se Aprueba El Procedimiento Básico Para La Certificación de La Eficiencia Energética de Los Edificios)*; Ministry of the Presidency and Territorial Administrations: Madrid, Spain, 2017.
- International Standard Organization. *EN ISO 13790. Energy Performance of Buildings—Calculation of Energy Use for Space Heating and Cooling*; International Standard Organization: Geneva, Switzerland, 2011.
- García Casals, X. Analysis of building energy regulation and certification in Europe: Their role, limitations and differences. *Energy Build.* **2006**, *38*, 381–392. [CrossRef]
- Government of Spain. *Royal Decree 235/2013, of 5 April, Approving the Basic Procedure for the Certification of the Energy Performance of Buildings—(Real Decreto 235/2013, de 5 de Abril, por el Que se Aprueba el Procedimiento Básico para la Certificación de la Eficiencia Energética de los Edificios)*; Government of Spain: Madrid, Spain, 2013.
- García Casals, X. Issues of Variable References Certification and Energy Regulation of Buildings (Problemática de Las Referencias Variables Certificación y Regulación Energética de Edificios). *Era Sol. Energías Renov.* **2009**, *148*, 46–56.
- Aguilar Sánchez, A.P. *Comparative Study between the Energy Certification Programs Unified Tool Lider Calender and Cypetherm HE Plus Using Real Data from a Tertiary Building*; Polytechnic University of Valencia: Valencia, Spain, 2020.
- Bamdad, K.; Cholette, M.E.; Omrani, S.; Bell, J. Future Energy-Optimised Buildings—Addressing the Impact of Climate Change on Buildings. *Energy Build.* **2021**, *231*, 110610. [CrossRef]
- Rodrigues, E.; Fernandes, M.S. Overheating risk in Mediterranean residential buildings: Comparison of current and future climate scenarios. *Appl. Energy* **2020**, *259*, 114110. [CrossRef]
- Darula, S.; Christoffersen, J.; Malikova, M. Sunlight and Insolation of Building Interiors. *Energy Procedia* **2015**, *78*, 1245–1250. [CrossRef]
- Blanco, J.M.; Buruaga, A.; Rojí, E.; Cuadrado, J.; Pelaz, B. Energy Assessment and Optimization of Perforated Metal Sheet Double Skin Façades through Design Builder; A Case Study in Spain. *Energy Build.* **2016**, *111*, 326–336. [CrossRef]
- Givoni, B. *Man, Climate, and Architecture*; Elsevier Publishing Company Limited: London, UK, 1969.
- Fanger, P.O. Calculation of Thermal Comfort: Introduction of a Basic Comfort Equation. *ASHRAE Trans.* **1967**, *73*, 10007970240.
- Olgay, V.W.; Olgay, A.; Lyndon, D.; Reynolds, J.; Yeang, K. *Design with Climate*; Princeton University Press: Princeton, NJ, USA, 2015. [CrossRef]
- ASHRAE. *Standard 55—Thermal Environmental Conditions for Human Occupancy*; American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): Atlanta, GA, USA, 2020.
- International Standard Organization. *EN 16798-1:2020 Energy Performance of Buildings. Ventilation for Buildings (Eficiencia Energética de Los Edificios. Ventilación de Los Edificios)*; International Standard Organization: Geneva, Switzerland, 2020.

26. D'Ambrosio Alfano, F.R.; Olesen, B.W.; Palella, B.I.; Riccio, G. Thermal comfort: Design and assessment for energy saving. *Energy Build.* **2014**, *81*, 326–336. [[CrossRef](#)]
27. Escandón, R.; Sendra, J.J.; Suarez, R. Energy and climate simulation in the Upper Lawn Pavilion, an experimental laboratory in the architecture of the Smithsons. *Build. Simul.* **2014**, *8*, 99–109. [[CrossRef](#)]
28. Ochoa, C.; Capeluto, I.G. Advice tool for early design stages of intelligent facades based on energy and visual comfort approach. *Energy Build.* **2009**, *41*, 480–488. [[CrossRef](#)]
29. Pedrini, A.; Szokolay, S. The Architects Approach to the Project of Energy Efficient Office Buildings in Warm Climate and the Importance of Design methods. In Proceedings of the 9th International IBPSA Conference, Montreal, Canada, 15–18 August 2005; International Building Performance Simulation Association: Bruges, Belgium, 2005; pp. 937–944.
30. Erhorn, H.; Mroz, T.; Mørck, O.; Schmidt, F.; Schoff, L.; Thomsen, K.E. The Energy Concept Adviser—A tool to improve energy efficiency in educational buildings. *Energy Build.* **2008**, *40*, 419–428. [[CrossRef](#)]
31. Baloch, A.A.; Shaikh, P.H.; Shaikh, F.; Leghari, Z.H.; Mirjat, N.H.; Uqaili, M.A. Simulation Tools Application for Artificial Lighting in Buildings. *Renew. Sustain. Energy Rev.* **2018**, *82*, 3007–3026. [[CrossRef](#)]
32. Tartarini, F.; Schiavon, S.; Cheung, T.; Hoyt, T. CBE Thermal Comfort Tool: Online tool for thermal comfort calculations and visualizations. *SoftwareX* **2020**, *12*, 100563. [[CrossRef](#)]
33. Anand, P.; Deb, C.; Alur, R. A Simplified Tool for Building Layout Design Based on Thermal Comfort Simulations. *Front. Archit. Res.* **2017**, *6*, 218–230. [[CrossRef](#)]
34. Raviselvam, S.; Al-Megren, S.; Keane, K.; Hölttä-Otto, K.; Wood, K.L.; Yang, M.C. Simulation Tools for Inclusive Design Solutions. In *Universal Design 2021: From Special to Mainstream Solutions*; IOS Press: Amsterdam, The Netherlands, 2021; pp. 210–218. [[CrossRef](#)]
35. Martinaitis, V.; Zavadskas, E.K.; Motuziene, V.; Vilutienė, T. Importance of occupancy information when simulating energy demand of energy efficient house: A case study. *Energy Build.* **2015**, *101*, 64–75. [[CrossRef](#)]
36. Raji, B.; Tenpierik, M.J.; Dobbeltstein, A.V.D. Early-Stage Design Considerations for the Energy-Efficiency of High-Rise Office Buildings. *Sustainability* **2017**, *9*, 623. [[CrossRef](#)]
37. Mahdavi, A.; Doppelbauer, E.-M. A performance comparison of passive and low-energy buildings. *Energy Build.* **2010**, *42*, 1314–1319. [[CrossRef](#)]
38. Gaujena, B.; Borodinecs, A.; Zemitis, J.; Prozumants, A. Influence of Building Envelope Thermal Mass on Heating Design Temperature. *IOP Conf. Ser. Mater. Sci. Eng.* **2015**, *96*, 012031. [[CrossRef](#)]
39. Zabalza Bribián, I.; Aranda Usón, A.; Scarpellini, S. Life cycle assessment in buildings: State-of-the-art and simplified LCA methodology as a complement for building certification. *Build. Environ.* **2009**, *44*, 2510–2520. [[CrossRef](#)]
40. Annebicque, D.; Robert, B.; Henry, J.-F.; Randrianalisoa, J.; Popa, C. A Multidisciplinary Approach to Improve Energetic Performance in Smart Buildings. *IFAC PapersOnLine* **2016**, *49*, 313–317. [[CrossRef](#)]
41. Khemlani, L. GENWIN: A generative computer tool for window design in energy-conscious architecture. *Build. Environ.* **1995**, *30*, 73–81. [[CrossRef](#)]
42. Hensen, J.L.M.; Lamberts, R. (Eds.) *Building Performance Simulation for Design and Operation*; Routledge: London, UK; Routledge: New York, NY, USA, 2019.
43. Kim, J.B.; Jeong, W.; Clayton, M.J.; Haberl, J.S.; Yan, W. Developing a physical BIM library for building thermal energy simulation. *Autom. Constr.* **2015**, *50*, 16–28. [[CrossRef](#)]
44. Yi, Y.K.; Malkawi, A.M. Optimizing building form for energy performance based on hierarchical geometry relation. *Autom. Constr.* **2009**, *18*, 825–833. [[CrossRef](#)]
45. Evangelisti, L.; Battista, G.; Guattari, C.; Basilicata, C.; Vollaro, R.D.L. Influence of the Thermal Inertia in the European Simplified Procedures for the Assessment of Buildings' Energy Performance. *Sustainability* **2014**, *6*, 4514–4524. [[CrossRef](#)]
46. Domínguez, S.; Sendra, J.J.; León, A.L.; Esquivias, P.M. Towards Energy Demand Reduction in Social Housing Buildings: Envelope System Optimization Strategies. *Energies* **2012**, *5*, 2263–2287. [[CrossRef](#)]
47. Konis, K.; Gamas, A.; Kensek, K. Passive performance and building form: An optimization framework for early-stage design support. *Sol. Energy* **2016**, *125*, 161–179. [[CrossRef](#)]
48. Lou, J.; Xu, J.; Wang, K. Study on Construction Quality Control of Urban Complex Project Based on BIM. *Procedia Eng.* **2017**, *174*, 668–676. [[CrossRef](#)]
49. Tronchin, L.; Fabbri, K. Energy performance building evaluation in Mediterranean countries: Comparison between software simulations and operating rating simulation. *Energy Build.* **2008**, *40*, 1176–1187. [[CrossRef](#)]
50. Larsen, K.E.; Lattke, F.; Ott, S.; Winter, S. Surveying and digital workflow in energy performance retrofit projects using prefabricated elements. *Autom. Constr.* **2011**, *20*, 999–1011. [[CrossRef](#)]
51. Wang, C.; Cho, Y.K.; Gai, M. As-Is 3D Thermal Modeling for Existing Building Envelopes Using a Hybrid LIDAR System. *J. Comput. Civ. Eng.* **2013**, *27*, 645–656. [[CrossRef](#)]
52. Chua, K.J.; Chou, S. A performance-based method for energy efficiency improvement of buildings. *Energy Convers. Manag.* **2011**, *52*, 1829–1839. [[CrossRef](#)]
53. Tian, Z.; Chen, W.; Tang, P.; Wang, J.; Shi, X. Building Energy Optimization Tools and Their Applicability in Architectural Conceptual Design Stage. *Energy Procedia* **2015**, *78*, 2572–2577. [[CrossRef](#)]

54. Vangimalla, P.R.; Olbina, S.J.; Issa, R.R.; Hinze, J. Validation of Autodesk Ecotect™ Accuracy for Thermal and Daylighting Simulations. In Proceedings of the 2011 Winter Simulation Conference, Phoenix, AZ, USA, 11–14 December 2011; IEEE: Toulouse, France, 2011; pp. 3383–3394. [\[CrossRef\]](#)
55. Jalaei, F.; Jrade, A. Integrating Building Information Modeling (BIM) and Energy Analysis Tools with Green Building Certification System to Conceptually Design Sustainable Buildings. *J. Inf. Technol. Constr.* **2014**, *19*, 494–519. [\[CrossRef\]](#)
56. Duarte, J.G.C.d.L.M.; Zemero, B.R.; de Souza, A.C.D.B.; Tostes, M.E.D.L.; Bezerra, U.H. Building Information Modeling Approach to Optimize Energy Efficiency in Educational Buildings. *J. Build. Eng.* **2021**, *43*, 102587. [\[CrossRef\]](#)
57. Turner, W.J.; Kinnane, O.; Basu, B. Demand-side Characterization of the Smart City for Energy Modelling. *Energy Procedia* **2014**, *62*, 160–169. [\[CrossRef\]](#)
58. Natephra, W.; Yabuki, N.; Fukuda, T. Optimizing the evaluation of building envelope design for thermal performance using a BIM-based overall thermal transfer value calculation. *Build. Environ.* **2018**, *136*, 128–145. [\[CrossRef\]](#)
59. El Sayary, S.; Omar, O. Designing a BIM energy-consumption template to calculate and achieve a net-zero-energy house. *Sol. Energy* **2021**, *216*, 315–320. [\[CrossRef\]](#)
60. Peruzzi, L.; Salata, F.; Vollaro, R.D.L. The reliability of technological systems with high energy efficiency in residential buildings. *Energy Build.* **2014**, *68*, 19–24. [\[CrossRef\]](#)
61. Pérez-Lombard, L.; Ortiz, J.; Pout, C. A review on buildings energy consumption information. *Energy Build.* **2008**, *40*, 394–398. [\[CrossRef\]](#)
62. De Lieto Vollaro, R.; Guattari, C.; Evangelisti, L.; Battista, G.; Carnielo, E.; Gori, P. Building energy performance analysis: A case study. *Energy Build.* **2015**, *87*, 87–94. [\[CrossRef\]](#)
63. Ham, Y.; Golparvar-Fard, M. Mapping actual thermal properties to building elements in gbXML-based BIM for reliable building energy performance modeling. *Autom. Constr.* **2015**, *49*, 214–224. [\[CrossRef\]](#)
64. Motawa, I.; Carter, K. Sustainable BIM-based Evaluation of Buildings. *Procedia Soc. Behav. Sci.* **2013**, *74*, 419–428. [\[CrossRef\]](#)
65. Pulselli, R.M.; Simoncini, E.; Marchettini, N. Energy and emergy based cost–benefit evaluation of building envelopes relative to geographical location and climate. *Build. Environ.* **2009**, *44*, 920–928. [\[CrossRef\]](#)
66. Méndez Echenagucia, T.; Capozzoli, A.; Cascone, Y.; Sassone, M. The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. *Appl. Energy* **2015**, *154*, 577–591. [\[CrossRef\]](#)
67. Tzempelikos, A.; Athienitis, A.K. The impact of shading design and control on building cooling and lighting demand. *Sol. Energy* **2007**, *81*, 369–382. [\[CrossRef\]](#)
68. Ne’Eman, E. Visual aspects of sunlight in buildings. *Light. Res. Technol.* **1974**, *6*, 159–164. [\[CrossRef\]](#)
69. Soares, N.; Pereira, L.D.; Ferreira, J.; Conceição, P.; da Silva, P.P. Energy efficiency of higher education buildings: A case study. *Int. J. Sustain. High. Educ.* **2015**, *16*, 669–691. [\[CrossRef\]](#)
70. Nabil, A.; Mardaljevic, J. Useful daylight illuminances: A replacement for daylight factors. *Energy Build.* **2006**, *38*, 905–913. [\[CrossRef\]](#)
71. Papadakis, G.; Tsamis, P.; Kyritsis, S. An experimental investigation of the effect of shading with plants for solar control of buildings. *Energy Build.* **2001**, *33*, 831–836. [\[CrossRef\]](#)
72. Alpuche, M.G.; Esaiy, V.; Ochoa, J.M.; Marincic, I.; Clemente, B. *Influence of Vegetation and Solar Control Elements on Mechanically Retrofitted Buildings in Hot-Dry Climates*; Universidad de Sonora: Sonora, México, 2015.
73. Wu, Y.; Kämpf, J.H.; Scartezzini, J.-L. Daylighting simulation for external Venetian blinds based on HDR sky luminance monitoring with matrix algebraic approach. *Energy Procedia* **2019**, *158*, 2677–2682. [\[CrossRef\]](#)
74. Khamporn, N.; Chaiyapinunt, S. Effect of installing a venetian blind to a glass window on human thermal comfort. *Build. Environ.* **2014**, *82*, 713–725. [\[CrossRef\]](#)
75. Elghezawy, D.; Eltarabily, S. The impact of sun sail-shading strategy on the thermal comfort in school courtyards. *Build. Environ.* **2021**, *202*, 108046. [\[CrossRef\]](#)
76. Pacheco-Torres, R.; Ordóñez, J.; Martínez, G. Energy efficient design of building: A review. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3559–3573. [\[CrossRef\]](#)
77. Liu, Y.; Liu, T.; Ye, S.; Liu, Y. Cost-benefit analysis for Energy Efficiency Retrofit of existing buildings: A case study in China. *J. Clean. Prod.* **2018**, *177*, 493–506. [\[CrossRef\]](#)
78. Athienitis, A.K.; Tzempelikos, A. A Methodology for Simulation of Daylight Room Illuminance Distribution and Light Dimming for a Room with a Controlled Shading Device. *Sol. Energy* **2002**, *72*, 271–281. [\[CrossRef\]](#)
79. Valladares-Rendón, L.; Schmid, G.; Lo, S.-L. Review on energy savings by solar control techniques and optimal building orientation for the strategic placement of façade shading systems. *Energy Build.* **2017**, *140*, 458–479. [\[CrossRef\]](#)
80. Jain, N.; Burman, E.; Mumovic, D.; Davies, M.; Tindale, A. Comparative Analysis of Protocols Used in Measurement and Verification of Energy Performance: Dealing with Practical Issues of Data Availability and Granularity in a UK School Building. In Proceedings of the 2018 Building Simulation and Optimization Conference, Cambridge, UK, 11–12 September 2018; International Building Performance Simulation Association: Bruges, Belgium, 2018.
81. Zhang, S.; Birru, D. An open-loop venetian blind control to avoid direct sunlight and enhance daylight utilization. *Sol. Energy* **2012**, *86*, 860–866. [\[CrossRef\]](#)
82. Alwetaishi, M.; Al-Khatri, H.; Benjeddou, O.; Shamseldin, A.; Alsehli, M.; Alghamdi, S.; Shrahily, R. An Investigation of Shading Devices in a Hot Region: A Case Study in a School Building. *Ain Shams Eng. J.* **2021**. [\[CrossRef\]](#)

-
83. Marsh, A. Psychrometric Chart. Available online: <http://andrewmarsh.com/software/psychro-chart-web/> (accessed on 10 June 2021).
 84. Diego-Mas, J.A. *Thermal Comfort Evaluation Using Fanger's Method (Evaluación Del Confort Térmico Con El Método de Fanger)*; Ergonautas, Unviersidad Politecnica de Valencia: Valencia, Spain, 2015.
 85. Ghose, A.; McLaren, S.; Dowdell, D.; Phipps, R. Environmental assessment of deep energy refurbishment for energy efficiency-case study of an office building in New Zealand. *Build. Environ.* **2017**, *117*, 274–287. [[CrossRef](#)]
 86. Azhar, S.; Brown, J. Bim for Sustainability Analyses. *Int. J. Constr. Educ. Res.* **2009**, *5*, 276–292. [[CrossRef](#)]
 87. Yilmaz, Z. Evaluation of energy efficient design strategies for different climatic zones: Comparison of thermal performance of buildings in temperate-humid and hot-dry climate. *Energy Build.* **2007**, *39*, 306–316. [[CrossRef](#)]