Learning about building technologies for sustainability

Design Guidelines for a Nearly-Zero-Energy residential buildings in Barcelona: case study

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ABSTRACT: There is an increasingly urgent need to cut global CO2 emissions and thereby avoid the most catastrophic effects of climate change. In the EU construction sector, action has already begun to help minimise carbon emissions and reverse their current negative impact on the environment. These initiatives have so far been based on introducing the mandatory construction of "Nearly–Zero-Energy Buildings" (NZEBs) from 2018 onwards, in compliance with an EU Directive on the Energy Performance of Buildings (2010/31/EU) [1]. The NZEB project not only constitutes a technical challenge but also a challenge for the design process. It must be accompanied by the introduction of new, specialised programmes at Schools of Architecture. This article points out how this quest for design strategies to produce NZEBs has been converted into pedagogical content in the Polytechnic University of Catalonia's (UPC) MSc in "Architecture & Sustainability: Design Tools & Environmental Control Techniques". As an example of the work done and the results obtained, we present a project designed for a residential building in Barcelona, Spain. This was developed by a team of students from the MSc course and presented as their final project.
KEYWORDS: NZEB, MSc Architecture & Sustainability: Design Tools & Environmental Control Techniques, Master's Degree Final Project, Software tools

1. INTRODUCTION

Learning programmes for sustainable design are based on approaches that allow students to analyse complex systems in order to achieve concrete learning outcomes. One of these complex systems is the built environment and its associated CO2 emissions. One increasingly common objective for sustainable architecture is how to produce a Nearly-Zero-Energy Building (NZEB) and thereby minimise emissions of greenhouse gases (GHG) during the working life of the building. The MSc programme entitled "Architecture & Sustainability: Design Tools & Environmental Control Techniques" [2] has been designed to promote learning related to sustainable design and it clearly focuses on this objective. [3] The strategies proposed for this architectural project can be grouped around the two main goals established for NZEBs: reducing energy consumption and producing energy from renewable sources. In accordance with EU Directive (2010/31/ EU), the embodied energy is not taken into account. When establishing the balance between the energy consumed from fossil sources and that produced from renewable sources, only the energy consumption in the basic operations of the building is taken into account. It therefore incorporates integrated energy design into all the different phases of the project, as explained in detail in the following chapters.

2. THE MSc in ARCHITECTURE & SUSTAINABILITY: DESIGN TOOLS & ENVIRONMENTAL CONTROL TECHNIQUES

2.1 Pedagogical objectives

This Master's Degree started from the premise that architecture is now subject to two important types of influence: Ecology and High Technology. This Master's Degree provides training in sustainable architecture and urbanism. It is structured into four learning modules. The MSc programme has been designed to increase students' comprehension, improve their capacity to solve problems and, most importantly, to improve their ability to apply the principles learned in the design of NZEBs.

2.2 Structure and Methodology

The MSc provided by the School of Professional & Executive Development of the Polytechnic University of Catalonia (UPC) of Barcelona, Spain, is divided into two post-graduate degree programmes. Each of these consists of two modules, with each module being subsequently divided into different subjects.

- MODULE A: Bioclimatic design: passive Techniques.
- MODULE B: Energy efficiency: active techniques and renewable energy.
- MODULE C: Control and regulation: home automation and smart buildings.

- MODULE D: Studio project: Nearly Zero Energy Buildings (NZEBs).

This module will include a workshop on projects. This will be aimed at getting participants to apply all of the knowledge that they have previously obtained in an architectural project. The methodology used is based on three main design considerations:

- Site and micro-climate analysis
  Design with climate
- Energy efficiency: passive techniques
  Minimising energy demand by applying passive strategies: increasing insulation, improving solar radiation control, natural lighting, and heat recovery ventilation.
- Energy efficiency: active techniques.
  Increasing the energy efficiency of the building systems and the building management systems. Replacing conventional energy sources with renewable sources, as much as possible.

Students use a wide variety of software tools which provide information about the best strategies to employ. These include: Meteonorm, Climate Consultant, Archiwizard and Design Builder.

- GREEN TOUR: A study trip to a European city to visit buildings and ecological neighbourhoods constructed using sustainable strategies.

On finishing the programme, students who complete all of the tests to a satisfactory level will receive a diploma accrediting their Master's Degree in Architecture and Sustainability, which will be awarded by the Polytechnic University of Catalonia: Barcelona Tech (UPC).

3. CASE STUDY: A RESIDENTIAL BUILDING IN BARCELONA (SPAIN)

For the MSc course taught in 2016-17, the theme of the final project was a draft design for a residential building located in the Plaza de las Glorias, Barcelona (Spain) (Fig.1). Sustainable strategies of the MSc methodology were implemented via an Integrated System Design to achieve the goals associated with the Nearly-Zero–Energy Building (NZEB) standard. The aim was therefore to reduce the building's CO2 emissions through systems that would reduce its energy consumption by around 50% and leave only a minimal environmental footprint. This aggregation process simultaneously incorporated: passive design and highly efficient active systems for taking advantage of renewable energy sources. For the Design Guidelines, Standard Passive House requirements for Mediterranean climatic conditions were followed. The design was phase was carried out focussing on the passive strategies outlined in the previous section; the aim was to reduce the building's heating and cooling loads to near zero levels. (Table 1)

Table 1: Passive House Requirements

Passive House Requirements
Heating Demand: 15kW/h/m^2/a
Cooling Demand: 15kWh/m^2/a
Total Primary Energy Demand (for heating, hot water, and electricity): 120kWh/m2/a
Air Leakage: 0.6 Air changes per hour @ a pressure of 50 Pascal

It is planned to connect the building to the local district heating system. This already exists in the neighbourhood and supplies both hot and cold water. The photovoltaic roof will provide the building all, or almost all, of its energy needs; this will cover the energy demands of typical services used in the building. The design also incorporates water management, waste management and greenery services.

Figure 1: Site: Plaza de las Glorias; Barcelona, Spain, latitude 41º 23'N, longitude 2º 11'E, altitude above sea level 13m.

3.1. Functional Programme and Design Intentions

The programme involved a residential building of 30,000m^2 and 300 units on a 4737m^2 plot, located on the perimeter of the Plaza de las Glorias square. The site occupies a full block (Fig. 2). The set of buildings has formal independence and constitutes a reinterpretation of the historical block of Barcelona's "Eixample", dating from the 19th century, but with the requirements of the 21st century. It has been conceived as a NZEB building, expressing its contemporaneity through a dialogue with the rest of the buildings that form part of the square. The dwellings are organised around an open central courtyard. The accesses to the apartments are via elevated streets that encourage relations among neighbours and help to create a sense of community. These buildings are two-, three- and four-bedroom apartments, with an average size of between 70 and 80m^2 (Fig. 3).

Figure 2: Typical floor plan of the residential building

Figure 3: detail of the housing units

4. SITE AND MICRO –CLIMATE ANALYSIS: THE IMPACT OF LOCAL CLIMATE

Based on the Köppen-Geiger climate classification, Barcelona, like other cities located in the Mediterranean basin, would correspond to climate zone Csa: with mild, rainy winters and hot dry summers. The climatic data and diagrams were obtained using the Meteonorm, Weather Tool and Climate Consultant programmes. These made it possible to obtain precise data about temperature, humidity, precipitation, wind and solar radiation and to produce a psychometric chart showing the boundary of the city's comfort zone (Fig. 4). A series of different passive design strategies were proposed to achieve an average of 58.8 % of comfort hours. A plot of local climatic data revealed that the local DBT ranged from 6 to 27°C for different periods of the year. The amount of solar radiation received is relatively high (2628Kwh/m^2 per year); this made it easy to generate electric power from photovoltaic systems.

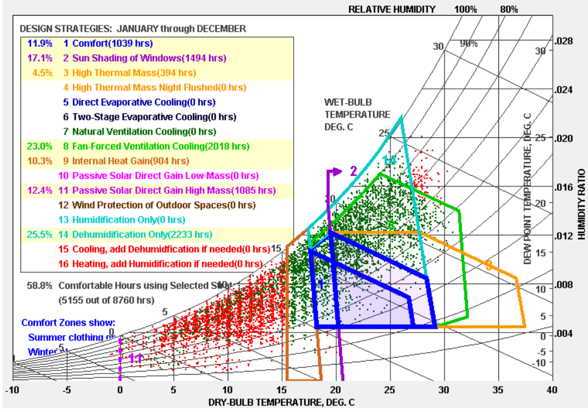

Figure 4: Psychometric chart analysis (Source: Climate Consultant, Meteonorm and Autodesk Weather Tool 2011 Analysis)

5. ENERGY EFFICIENCY: PASSIVE TECHNIQUES

It would probably be rather unrealistic to consider completely replacing active systems with climatic controls on a case-by-case basis [4]. Even so, using passive systems can notably improve their energy behaviour. In the design of the project using passive strategies, the aim was to increase indoor comfort and to reduce the demand for cooling, heating, ventilation and electric light. There is, however, a potential drawback in using Passive House design, resulting from the thermos effect created by the envelope around the building, which implies the risk of overheating. In order to ensure a no-risk situation, both mechanical ventilation with heat recovery and natural ventilation were proposed, but as part of a holistic approach that could simultaneously address not only the question of ventilation, but also that of sun shading, lighting and finishing (or their absence in order to permit slab cooling). The passive climatic control systems proposed were: 1) Control for solar radiation, 2) Vegetation, 3) Passive cooling, 4) Reducing airflow, 5) Insulating the building, and 6) Renewing the internal air with heat recovery.

5.1. Building Form, Orientation and Building Envelope

The shape of a building has a critical impact on the welfare of its users, the use of its resources and its consumption of water and energy. The positioning of its built mass is the product of multiple considerations, with the passive issue being only one of them. In this case, the design decisions were based on the volume determined by the Master Plan. The envelope is the main interface between a building and its external environment. In the case of the Mediterranean climate of Barcelona, when applying passive design, it was particularly important to prevent external solar heat gain (Fig. 5). The transitional spaces, terraces and access hallways were therefore dimensioned to regulate solar radiation. The design solution adopted on the facades and the roof achieved very favourable transmittance values. The U-value (W/m^2/ºK) of the building's fabric was 0.22W/m^2/ºK and the U-value of the windows was 0.6W/m^2/ºK.

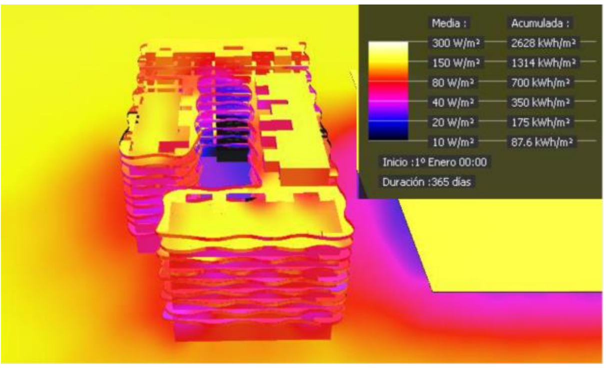

Figure 5: Solar Radiation at the Summer Solstice (source: Archiwizard Analysis)

The building's elongated shape and limited floor depths allow natural daylight to penetrate deeply into the flats (Fig. 6). Every room has access to nearby opening windows in order to permit a current of fresh air from outside the building. Naturally, night-time cooling strategies guarantee an optimum regulation of cooling/heating. (Fig. 7)

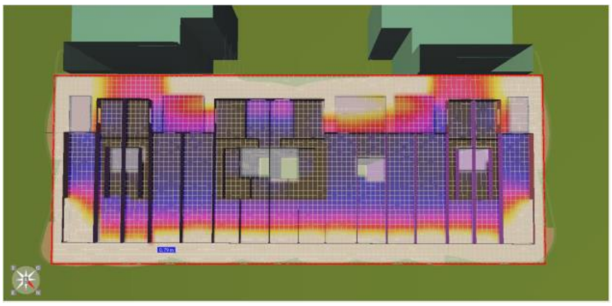

Figure 6: Natural lighting simulation: day.light factor (source: Archiwizard Analysis)

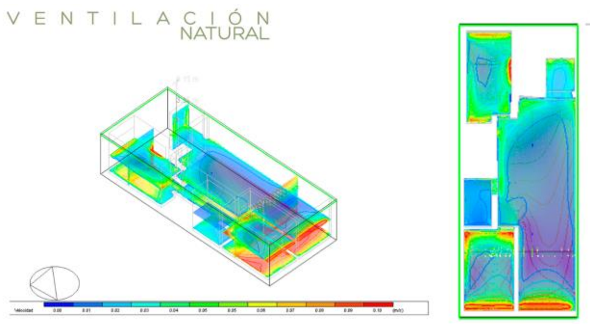

Figure 7: Natural ventilation: indoor air speed (source: Archiwizard Analysis)

6. ENERGY EFFICIENCY: ACTIVE TECHNIQUES

Active climate control systems include: 1) Production systems, 2) Means of distribution, 3) Methods of distribution, and 4) Recovery systems. To reduce dependency on sources of fossil fuels, the building will be connected to the local district heating supply system, which produces both heat and cold, using renewable energy generated by a plant that incinerates urban waste. This system provides a guaranteed supplementary power supply which is needed to achieve thermal comfort and which complements the passive systems and systems for recovering heat and cold. (Fig. 8) and (Fig. 9)

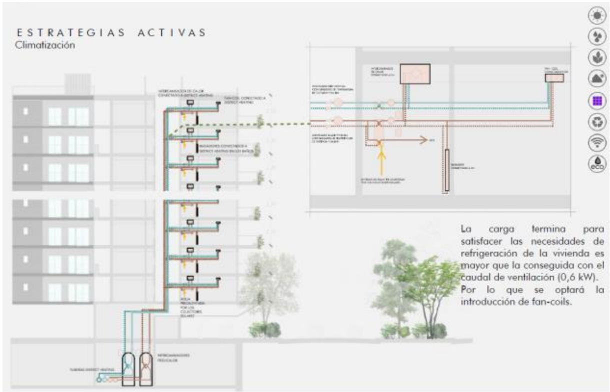

Figure 8: Extra support of an energy supply from the district heating system.

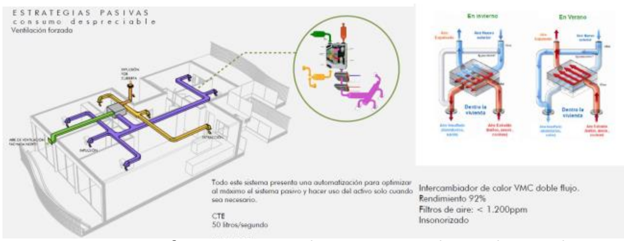

Figure 9: System for recovering heat energy through ventilation with a VCM Heat Exchanger, with a dual flow system and an efficiency level of 92%.

6.1. Renewable Energy

Fossil fuels are not renewable as they are based on finite resources that will, eventually, become exhausted. The draft project considered the contribution of the local district heating system to the supply of both hot and cold water. The photovoltaic roof will cover the energy demands of the typical services used in the building.

6.2. Results of calculations

As far as the consequences of using passive or active strategies are concerned, In this project after the simulations made with the design builder programme it was shown that it would be possible to reduce its energy consumption by more than 50% in relation to the average consumption of equivalents buildings in Barcelona. (Fig. 10).

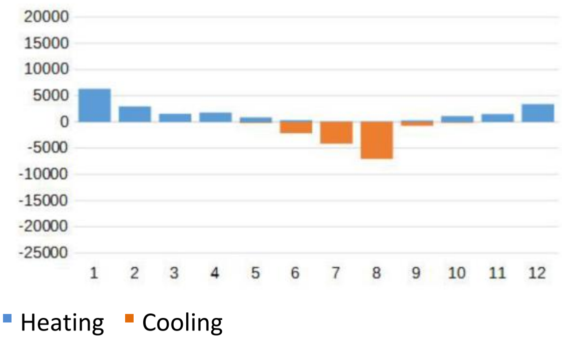

Figure 10: Monthly energy demand expressed in kWh. Heating demand: 12,47kWh/m^2 year. Cooling demand: 10,34kWh/m^2 year.

7. SYSTEM OF INFRASTRUCTURES FOR TELECOMMUNICATION CONTROL AND AUTOMATION

For the telecommunications system , it was decided to have a rack on each floor in order to centralise all of the systems for the different flats/rooms. The corresponding wiring would then lead out of each apartment to the different supply, data, Wi-Fi, telephone and security camera connection points. In turn, these racks would be interconnected from flat to flat throughout the building. (Fig. 11)

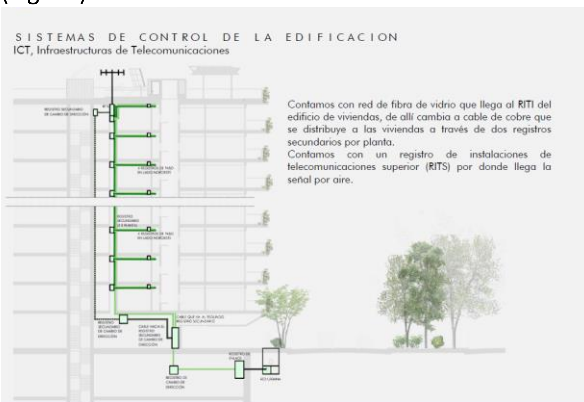

Figure 11: System of Infrastructures for Telecommunication control and automation

7.1 Control Systems

Users often inadvertently overuse electrical devices and the effects of this are often significant in terms of energy consumption; as a result, control and regulation systems are of crucial importance. (Fig.12)

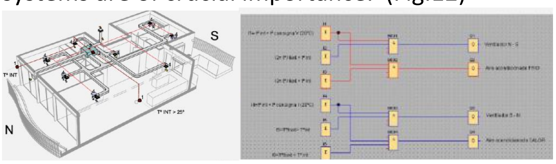

Figure 12: Automation of cooling control

7.2 Lighting Systems

Artificial lighting is one of the biggest internal demands. Optimising the design of the building envelope in order to improve the level of natural lighting may help to reduce the demand for indoor lighting. High-efficiency lighting systems, such as LEDs with integrated lighting controls, reduce energy consumption by half in comparison with traditional luminaries. Advanced lighting controls include occupancy sensors and daylight sensors.

8. WATER EFFICIENCY AND VEGETATION

Another fundamental component of the building is the water management system. Fresh drinking water is a limited resource and must be treated and reused before it is disposed of via sewers or storm drains. In this case, the project reduced the total demand for potable water by half and complemented the other half with the reuse of grey water and/or rainwater in order to achieve an almost zero net demand for potable water for irrigation. Green roofs on building tops provide pleasant views, serve for relaxing activities and help to mitigate the urban heat island effect. Green roofs can also help to reduce storm water runoff from buildings. In this project, the vegetation was located on the covers and terraces of the apartments. Native species of vegetation typical of Mediterranean climates were used for this purpose. Irrigation was applied using rainwater that had been collected and stored in the same building for this specific purpose.

The UNE-ISO14001 environmental management system was used for the management of waste

9. INTEGRATED SYSTEM DESIGN

In the final NZEB project of the MSc in Architecture & Sustainability: “Design Tools & Environmental Control Techniques” described in this paper, sustainable strategies were implemented via an Integrated Design System. The aggregation process used simultaneously incorporated: climate analysis, passive design and the optimisation of the building envelope, highly efficient building systems, renewable energy sources, control and regulation, the water cycle, waste management and vegetation.

10. DISCUSSIONS AND CONCLUSIONS

In current architectural practice, incorporating sustainable strategies should form a key part of the process of designing a building. To achieve this objective, it is necessary to follow an integrated design approach from the very start of the design process. The project presented here was drawn up in line with a specific educational programme that had been taught as part of the Master’s Degree course delivered at the UPC’s School of Professional & Executive Development. This programme was designed to teach graduates, with first degrees in architecture and engineering. the basic concepts and strategies required for sustainable design and particularly those needed for designing NZEBs. The result is presented in this paper in the form of a specific project designed by students. The design of this residential building was conditioned by a previously defined volume set with a precise orientation that had been determined by an earlier Master plan. Even so, the whole planning process was followed.

Briefly stated, the project outlined described a step-by-step pedagogical programme designed to teach basic resource conservation and the main concepts to consider when designing NZEBs. The design process began with the students considering the climatic environment in order to establish the most appropriate design strategies and passive design concepts. Starting from the pre-determined orientation, the interior space was first distributed. The design of the envelope then made it possible to regulate the solar radiation and incorporate vegetation. Materials and technical solutions were efficiently used to obtain the degree of air tightness and insulation required by the passive house principles. The HVAC system consisted of an air renewal system fitted with an exhaust air heat exchanger and supported by the district heating system. Mechanical ventilation with heat recovery is also proposed, but within a holistic vision that simultaneously addresses not only the use of ventilation, but also sun shading, lighting and finishes. However, management by regulation and control systems provided a high degree of thermal comfort. The district system was able to supply additional hot water throughout the year without generating any GHG emissions. In order to produce electricity from a renewable source, a photovoltaic canopy was integrated into the roof of the building. The final simulation of the energy balance carried out using the Design Builder programme enabled us to check that the building met the Nearly-Zero-Energy-Building objectives. The energy demand was reduced to levels below those required of the standard Passive House model for a Mediterranean climate. Under these conditions, a very important percentage of the resulting energy consumption is provided from renewable sources, whether on-site, using photovoltaic panels, or off-site, through district heating. Vegetation was incorporated into the green roof while the facades of the building were used to collect rainwater and to recycle grey water for irrigation. A plan was also established for managing waste in line with ISO 14000 environmental management norms [5]. The use of a comprehensive package of software programmes was also a determining factor, as this made it possible to add greater rigour to the process of passive design and permitted the assessment of energy behaviour within an active system. As in other instruction methodologies for building design [6], when using software tools, the design solutions adopted made a significant contribution to energy saving. From a pedagogical point of view, perhaps the most effective contribution was the integration of building technology and design into architectural education [7]. As a result of this process, it was made evident that incorporating sustainability into architectural practice should not be an obstacle to design but, instead, should offer an opportunity for greater creativity (Fig.13).

Figure 13: Render showing the project for a NZE Residential Building in Plaza de las Glorias, Barcelona.

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