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Research Article

A building energy simulation methodology to validate energy balance and comfort in zero energy buildings

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Abstract: The construction of Net Zero Energy Buildings (NZEB) is one of the objectives in the road to the low-carbon economy by 2050. NZEB design includes a reduction of current energy demands and the balance between consumption and on-site energy generation without compromising indoor comfort conditions. Building designers are using building information modeling (BIM) and building energy simulation (BES) tools to validate design decisions and to evaluate energy balance in buildings. However, the flow of information between BIM software and BES tools has not been solved yet. This work proposes a method to address the decision-making process at three different stages of the building design. Initially, the use of BIM over the architectural design process helps architects to make meaningful decisions related to the passive solar heat gains and envelop materials. Secondly, a more advanced BES is used to analyze the strategies of ventilation and the influence of heating ventilation and air conditioning (HVAC) systems. Finally, a new method to integrate water flow glazing (WFG) is implemented to increase the comfort in those areas of the building with a large area of glass. Applying the right strategy for natural ventilation can reduce the thermal loads by 45% in Summer. Using WFG minimizes the gap between indoor air temperature and operative temperature according to the results.

Keywords: *Building energy simulation, Water flow glazing, Zero energy building*

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Nomenclature

BES	Building Energy Simulation	S_G	Total building glazing surface area, m^2
BIM	Building Information Modeling	S_B	Total building opaque envelope surface area, m^2
WFG	Water Flow Glazing	S_F	Total building floor surface area, m^2
c	Mean specific heat capacity of the building, J/kg K	U_B	Opaque envelope thermal transmittance, W/m2K
g	g value of the glass	U_G	Glazing thermal transmittance, W/m^2K
g_{ON}	g value for water flow glazing at maximum flow rate	U_W	Water thermal transmittance, W/m^2K
g_{OFF}	g value for water flow glazing without water circulation	$\theta_i(t)$	Indoor temperature, K
h_i	Interior heat transfer coefficient, W/m^2K	θ_i	Mean indoor temperature, K
I(t)	Impinging radiation on the glazing, W/m^2	$\theta_e(t)$	Outdoor temperature, K
$\bar{I}$	Mean impinging radiation on the glazing, W/m^2	θ_e	Mean outdoor temperature, K
m	Mean thermal mass of the building, kg	$\theta_w(t)$	Water temperature inside water flow glazing and cooling ceiling, K
q(t)	Internal heat loads, W/m^2	θ_w	Mean water temperature inside WFG panel
q	Mean internal heat loads, W/m^2		

1. INTRODUCTION

The demand for energy in buildings will continue to grow over the next two decades, and the consumption of energy in buildings is expected to increase by 28% in 2030. [1, 2]. The definition of a Zero Energy Building, according to the Department of Energy of the United States of America (DOE), is “a building that produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of nonrenewable energy in the building sector”. The Living Future Institute provides an international zero energy certification if the energy needs of buildings are met by on-site renewable energy and without any fuel. The European Union (EU) has established the 2030 climate and energy framework to increase the competitiveness and efficiency of the energy systems of EU countries. This framework includes NZEB as an achievable target shortly. The Energy Performance of Buildings Directive (EPBD) adopted in May 2010 stated that all new buildings as of December 31, 2018 must be nearly zero-energy buildings. It introduced a benchmarking mechanism for national energy performance requirements. By 2030, greenhouse gas emissions have to be reduced by 40% (relative to emissions in 1990), and renewable energy consumption will be increased by up to 27%. These goals are milestones in the road from a fossil-fuel-based economy to a more efficient low-carbon economy in 2050. The EU has set a more ambitious goal by 2050. Greenhouse gas emissions will be reduced by 80–95 % (relative to emissions in 1990) in that regard. This goal will require improvements in grids and infrastructures, along with new design strategies [3, 4].

The majority of the existing building stock in Europe and the United States are dwellings, and most of them were built before 1970 without any quality standards [5]. It is urgent to tackle the issue of energy efficiency in residential buildings because of the current fluctuation in energy prices. Focusing on design parameters, such as the building's shape, materials, and HVAC systems, is not enough to understand energy consumption patterns. Occupancy, social, demographic, economic, and cultural variables play an important role [6, 7]. Finally, the level of satisfaction of the users cannot be neglected [8]. A building is unique due to its location, orientation, geometry, dimensions, and distribution of the zones, its characterization according to its construction type, the building materials used in its envelope, its surrounding conditions, or the use of each one of its spaces. The envelope is one of the most important factors to assess the building energy performance. Building orientation, wall-to-window ratio, glazing properties, *R*-values of opaque envelope, air leakage, and natural ventilation are some of the parameters impacting the thermal behavior of the building [9]. The NZEB model requires the integration of renewable energy sources in buildings [10]. Using the energy from the grid might not be appropriate for NZEB. Traditional thermal plants burn fuel, and energy is wasted in conversion and distribution processes. Burning low-carbon fuels to produce heat inside the building is much more efficient than transporting the electricity from the thermal power plant. The most efficient way, by far, is to integrate PV panels on the roof of the building and use electricity instantaneously, for it is difficult to store in batteries [11]. Windows are crucial in the design of efficient buildings in hot-humid countries [12, 13]. Infiltration, heat transfer due to conduction and convection, and, finally, radiation heat gains are the factors that influence the most. A tight construction system with an infiltration rate close to the passive house standards is an important goal in heating-dominated environments. Reducing the U-factor helps to minimize the heat flow through windows over the winter in cold climates, reduces condensation risks, the influence of convection inside the building, and improves the thermal comfort of occupants [14]. Using multiple glass layers, low emissivity coatings, inert gas fill, and warm edge spacers between glazing layers minimize heat flow through windows [15]. The Solar Heat Gain Coefficient (SHGC) is the parameter indicating the amount of solar radiation that enters a building through the glazing. Solar control films can reflect thermal solar radiation but can prevent natural light from entering the building. Large glazing areas facing north are not particularly weak in terms of thermal performances since gains through sky diffuse radiation compensate for the thermal losses [16]. Active glazing can adjust its optical and thermal properties according to the climate conditions. WFG is an example of active glazing. This solution is based on circulating a water flow in a closed circuit, allowing the dynamic control of thermal solar heat gain. The water flow does not modify the visible transmittance of the glazing; however, the temperature of the glass panes can be controlled thanks to the water which is in contact with them [17, 18]. By varying the water flow rate, the thermal flux through the glazing is controlled [19]. Thermal comfort can affect the productivity of building users [20]. WFG provides a room with variable thermal inertia, so that the gradients of temperature do not affect the comfort conditions. During the life cycle of projects, the BIM concept covers different aspects. Architects and designers use BIM software in all stages, including design, construction, and operation, since it can handle several issues relevant to the structural analysis, mechanical systems design, and the building's energy performance [21]. The analysis of energy performance to validate design decisions is efficient at initial project stages [22, 23]. Two methods have been traditionally applied to model the energy consumption in the residential sector:

i) The inverse method refers to statistics, based on historical data of a large stock of buildings,
ii) The forward method focuses on a thorough analysis of the building envelope, building systems, and components.

This paper develops the latter and tries to identify opportunities for technological improvements at the design stage [24, 25]. Computer simulations have been a significant component of that research, and new BES software tools have been developed and applied over the last few years [26-28]. Examples of these tools include DOE-2, eQuest, EnergyPlus, IDA-ICE, and DesignBuilder. BIM tools and BES software are becoming popular and more accessible for building stakeholders [29-31].

The following sections present a case study to validate the methodology by utilizing the proposed framework. The first section of the paper reviews the legislation on NZEB, literature, and software tools to predict the energy performance of buildings. The second section describes a methodology approach, which allows modeling both heating and cooling hourly energy use in residential buildings. It also includes the thermal mass of the building envelope, glazing properties, equipment, and mechanical systems, along with occupancy, schedules, and active energy management. Consequently, the option of using WFG has been included to increase comfort and energy savings in the case study.

2. METHODOLOGY AND SIMULATION WORKFLOW

This section includes a brief description of BIM and BES software tools used to develop the proposed methodology. Energy Plus is a popular energy simulation software tool sponsored by the Department of Energy (DOE) from the United States. Design Builder is the most common interface to run the Energy Plus simulation. IDA Indoor Climate Energy is a simulation tool widely used by engineers. It allows a practical numerical approach to real results, but it lacks a friendly graphic interface. Nevertheless, it is the only software including a module to simulate water flow glazing.

Revit is a popular BIM tool that can be used from the earliest conceptual phase up to the construction documents. Revit plug-in for energy analysis uses the DOE2 simulation engine and takes into account several factors, such as the building's geometry, use, occupancy, and mechanical systems. The simulation workflow based on the selected tools consists of several steps:

i) Creation of BIM model in Revit,
ii) Data extraction,
iii) Runing the Energy Plus simulation using Design Builder and IDA-ICE as advanced tools to validate design options.

Designing zero energy buildings without compromising comfort has become the main goal for architects and building designers. The R-value of the building envelope, outdoor temperature, and the thermal mass are some of the factors that affect the thermal behavior of a building. Size and orientation of glazing and external convective heat transfer have to be taken into account [32, 33]. In NZEB, PV panels and grid power supply electricity to meet the energy needs, so the demand for electricity supplied from the grid is equal to the amount of electricity generated in the building. Evaluation of NZEB takes into account the energy balance; however, it is not the sole parameter, because an oversized PV array can compensate for the flaws in design and an excess of energy consumption. Comfort conditions cannot be neglected in NZEB buildings, either [34, 35].

The building construction in Southern Spain has neglected traditional features of vernacular architecture over the second half of the XXth century. The goal of current architects should be to set the bases of the new bioclimatic construction by combining traditional construction techniques and the latest technology for building envelopes. In the Mediterranean area, the summer is hot and dry, and protection against solar radiation includes the following passive strategies:

i) External shading devices and small openings,
ii) Andalusian "patios" with shading devices, plants, and ponds reduce the temperature of outdoor air,
iii) White color of the envelope and small openings as mechanisms for the reflection of solar radiation.

In this paper, a case study has been modeled and analyzed. A single-family house located in Mojacar, Almeria (Southeast of Spain), makes the perfect example of taking into account passive and active strategies. This paper illustrates the design methodology, discusses the effectiveness of different approaches, and highlights the energy savings. Finally, building energy simulations are carried out to analyze the energy balance of the building and the influence of some building elements and materials on the heating and cooling demands.

Energy balance is a core concept in the NZEB definition. The proposed evaluation method for NZEB includes parameters, such as thermal transmittance, thermal mass, internal loads, ventilation rates, heating ventilation and air conditioning (HVAC) equipment efficiency, and includes indoor comfort as a goal.

The essential features of the building (walls, windows, floors, and zones) are defined using BIM software. The type of construction, the schedules of human activities, and the existing equipment, such as lighting and HVAC system, are the required data for running the first energy simulations. Revit and Design Builder have begun implementing systems in an attempt to import information from BIM into BES programs, although manual intervention is still required. To be able to remodel the building in the energy simulation input file, it is necessary to extract all geometric and spatial information of the building element from the BIM. The BIM file is broken down into the following categories: the duration of the simulation, HVAC system, and site location in coordinates, material types, report type, utility rates, and layer constructions. BIM users can set these values to defaults, and minimal input is required. The following section shows the proposed methodology to achieve NZEB in Mediterranean residential building stock in the frame of a 2030 horizon for Zero Energy Buildings.

3. CASE STUDY: BUILDING DESCRIPTION AND OPTIMIZATION PROBLEM

To achieve a nearly zero energy single-family house in Mojacar (Almería, Spain) (Latitude + 36.85, Longitude -2.4), the present article deals with a work methodology based on these points:

(i) Energy balance considerations associated to potential sun energy for specific locations,

(ii) Project design according to the evaluation of the software tool,
(iii) Energy simulation carried out with BIM.

Thus, the results of the simulation may lead to modifications of the architectural project to simulate again. This house is a one-story building with a total area of 207.61 square meters and a volume of 638.25 cubic meters. This model aims to comply with the Spanish Building Code standards, so the walls, roofs, floors, and windows needed to be within a certain U-value threshold.

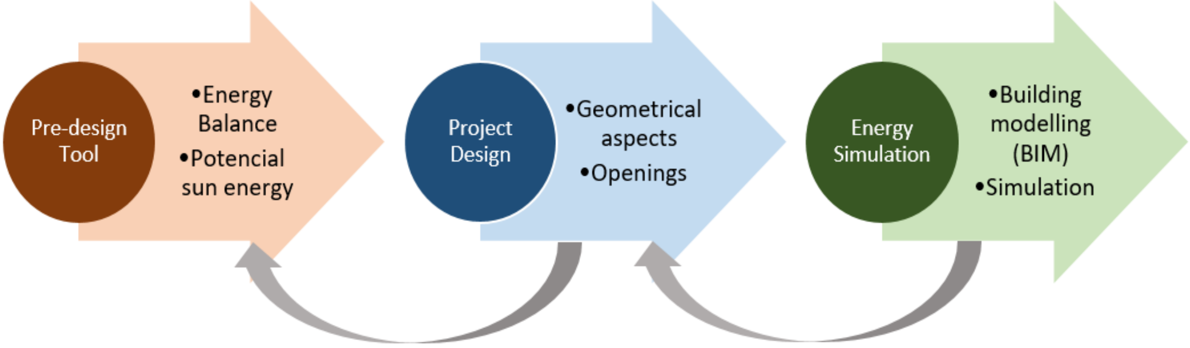


Figure 1. Methodology process in order to achieve NZEB through a pre-design tool that incorporates energy considerations associated to the potential sun energy of different locations, the project design and the energy simulation carried out with BIM.

The first step towards the goal of achieving ZEBs has been the reduction of the energy demand through increasing the thermal resistance in walls and roofs and the use of high-performance glazing in windows in accordance with the methodology given in Fig. 1. The second step has been the introduction of energy production devices, such as thermal and photovoltaic solar panels. The third step has been the analysis of ventilation as the most effective way to accomplish comfort in mild climates when heating and cooling loads are known. Finally, the study of thermal loads and radiant temperature in every zone of the building is necessary to increase comfort, once the goal of energy savings has been met. The model was created using BIM software, REVIT 2019. First energy analysis was carried out using the plugin Insight, and, finally, data were compiled into an energy simulation input (INP) file using Green Building Studio. An interface program of EnergyPlus, DesignBuilder, has been used to develop the energy model.

3.1. BIM model

Fig. 2 presents the first BIM energy analysis in summer and winter conditions with the right balance between thermal insulation and thermal mass. The two main factors influencing the thermal loads are windows and ventilation-infiltration rates. Solar heat gains through windows is, by far, the factor that affects cooling loads the most. The thermal parameters are given in Table 1. Overhangs, and shading devices can help to improve the energy performance of the building. The primary purpose was to achieve the optimal window size for a given space, with and without a passive shading mechanism, according to the location and orientation. A high-quality construction technique leads to the control of infiltration. The optimum ventilation system includes strategies for natural ventilation and heat recovery devices. The obtained results suggest that the adoption of tight construction allows the reduction of cooling demand. Increasing the rate of natural ventilation will help reduce energy consumption in winter.

The air conditioning system consists of two air-to-air heat pumps with an annual mean seasonal performance factor (SPF) of 3.0 for cooling and heating modes. The Spanish Building Code (CTE DB-HS3) requires inlet openings for fresh air located in dry rooms. Exhaust openings are placed in the kitchen and bathrooms. Ventilation must be mechanically controlled with Heat recovery devices to help control de flow rate and the inlet temperature. All the simulations in this article consider 12.5 l/s per person.

Table 1. Thermal parameters of the case study. Benchmark with national standards.

	Standard House (CTE Spain)	Case study	
Walls	U≤0.94 W/m^{2}K	U=0.3 W/m^{2}K	
Roof	U≤0.5 W/m^{2}K	U=0.3 W/m^{2}K	
Ground floor slab	U≤0.53 W/m^{2}K	U=0.5 W/m^{2}K	
Windows and glass doors	U≤3.4 W/m^{2}K g ≤ 0.6	U=1.12 W/m^{2}K g = 0.60	U=1.12 W/m^{2}K g = 0.25 (with shading)
Ventilation rate	≥12.5 l/s person	12.5 l/s person	12.5 l/s person
Infiltration rate	≤0.63 ACH	0.63 ACH	0.63 ACH 0.2 ACH

The supply temperature of domestic hot water (DHW) is 60ºC. The solar energy system is made up of solar thermal collectors and a photovoltaic array. A 250-liter hot water tank is coupled with 4.5 m^2 heat-pipe solar thermal collectors to be utilized for providing the users with DHW. The Spanish Building Code section HS4 sets the domestic hot water demand as 28 liters per person for single-family houses. Solar thermal collectors can supply up to 70% of hot water in this location. The PV modules face south with an inclination of 30º. The PV array area is 90 m^2.

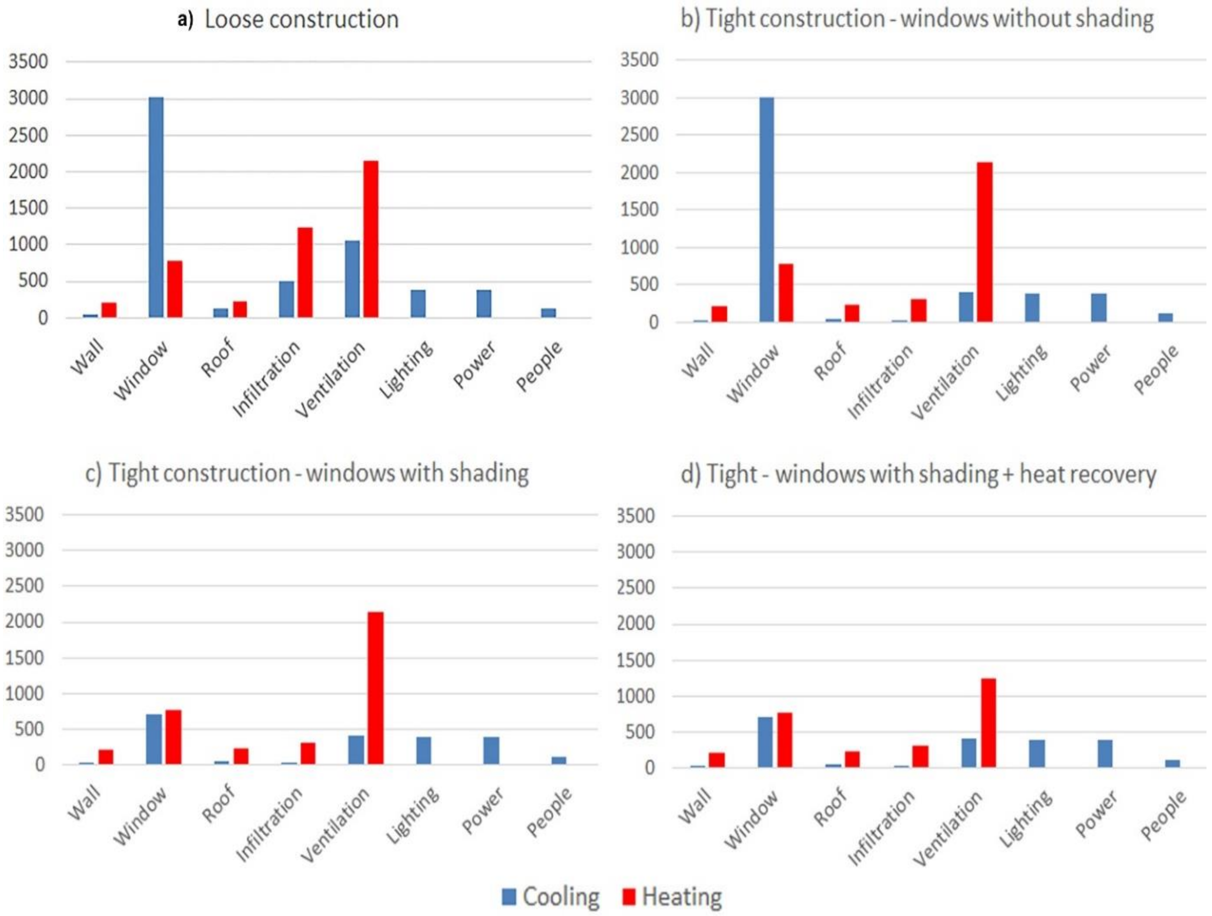


Figure 2. Heating and cooling loads: (a) loose construction, (b) tight construction, (c) influence of shade

Fig. 3 shows the Insight solar analysis with Revit. It provides in context solar radiation analysis results to help designers track solar energy throughout the building design. The plugin offers automated settings for specific study types, as well as customizable options. The goal of designing buildings in Mediterranean countries is to achieve the maximum solar heat gains in winter and minimize solar gains in summer.

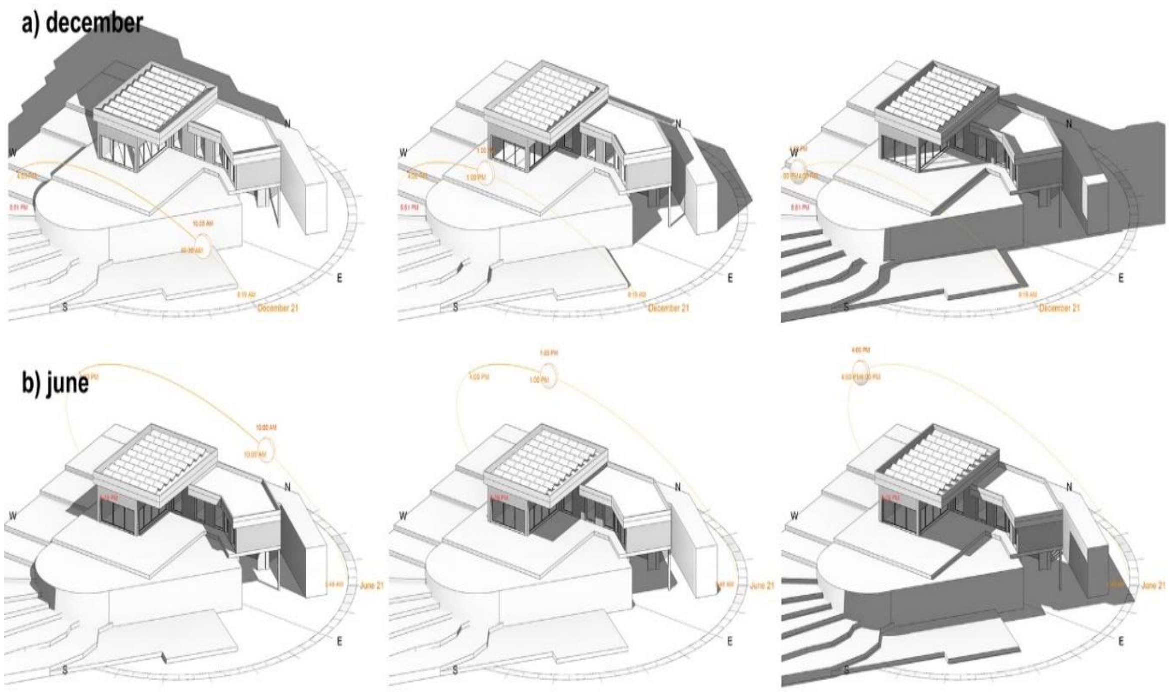


Figure 3. BIM solar analysis in summer and winter.

Fig. 4 presents the simulation results. The total energy demand includes space heating and cooling, DWH, lighting, pumps, fans, and miscellaneous equipment. For PV study types, the full year, from sunrise to sunset has been used as the date and time range. These results indicate that the maximum demand of the studied house is in July when the cooling loads are at their peak. According to the simulation, the total electric demand over a year is 22,982 kWh and the designed PV array can produce up to 24,940 kWh. The yearly consumption of electric energy is 119 kWh/m^2 year. According to thermal transmittances, surfaces and g factors or proportions of the incoming energy which is absorbed, these graph shows the energy demand to assure a comfort temperature. The selected opaque envelope (walls, roof, and floor), along with the glazing and the ventilation rate have been taken into account.

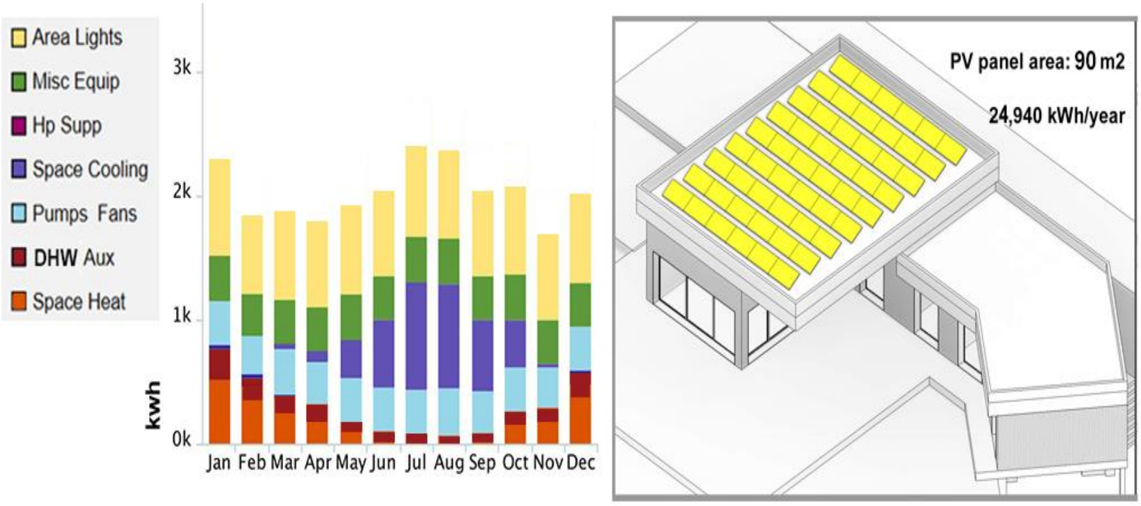


Figure 4. Energy demand of the case study and energy production by the PV array.

After extracting all geometric and spatial information from the BIM model, a second energy simulation is run using Energy Plus to set parameters related to thermal mass and natural ventilation. Fig. 5 presents the data of the incident solar radiation and temperature at the selected site at intervals of one hour each day over three months. The maximum and minimum daily average temperatures are 24º C and 3º C, respectively. The maximum direct normal solar radiation is 0.9 kW/m^2.

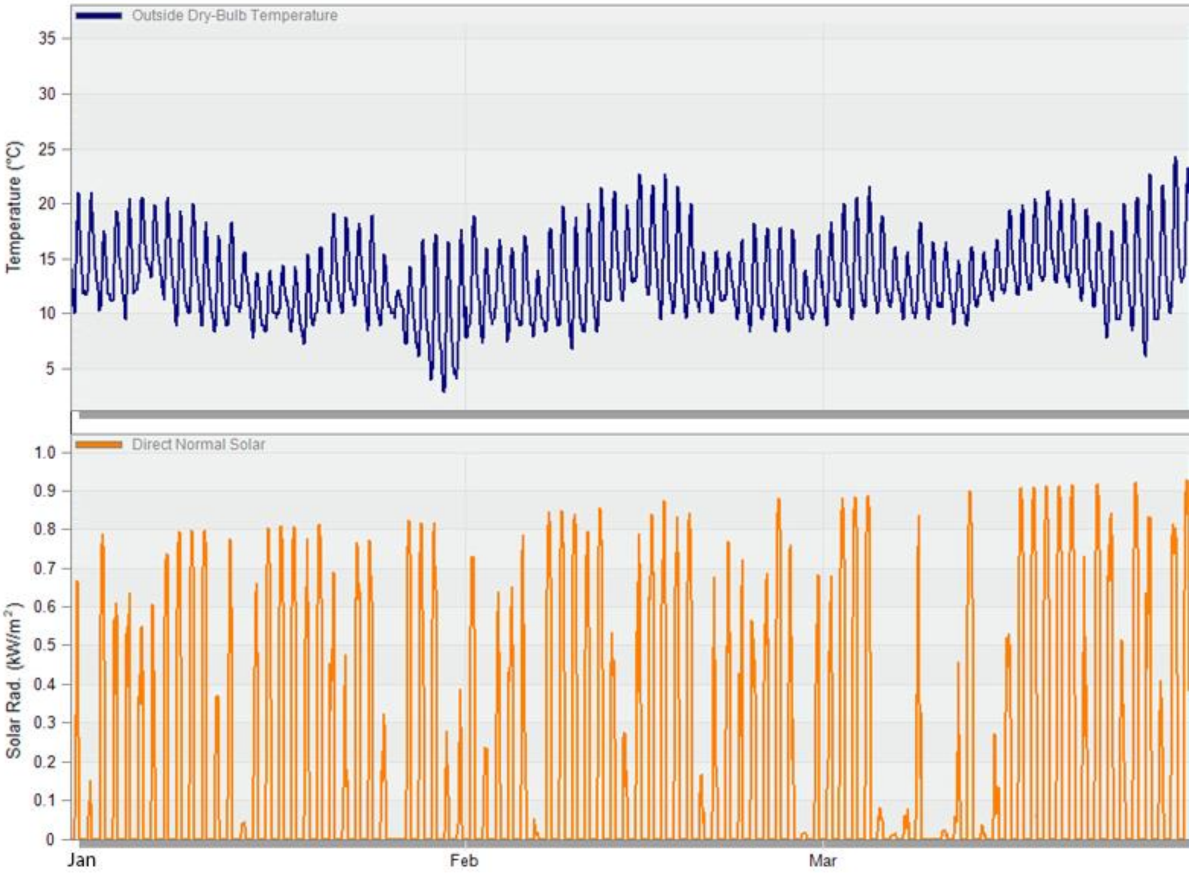
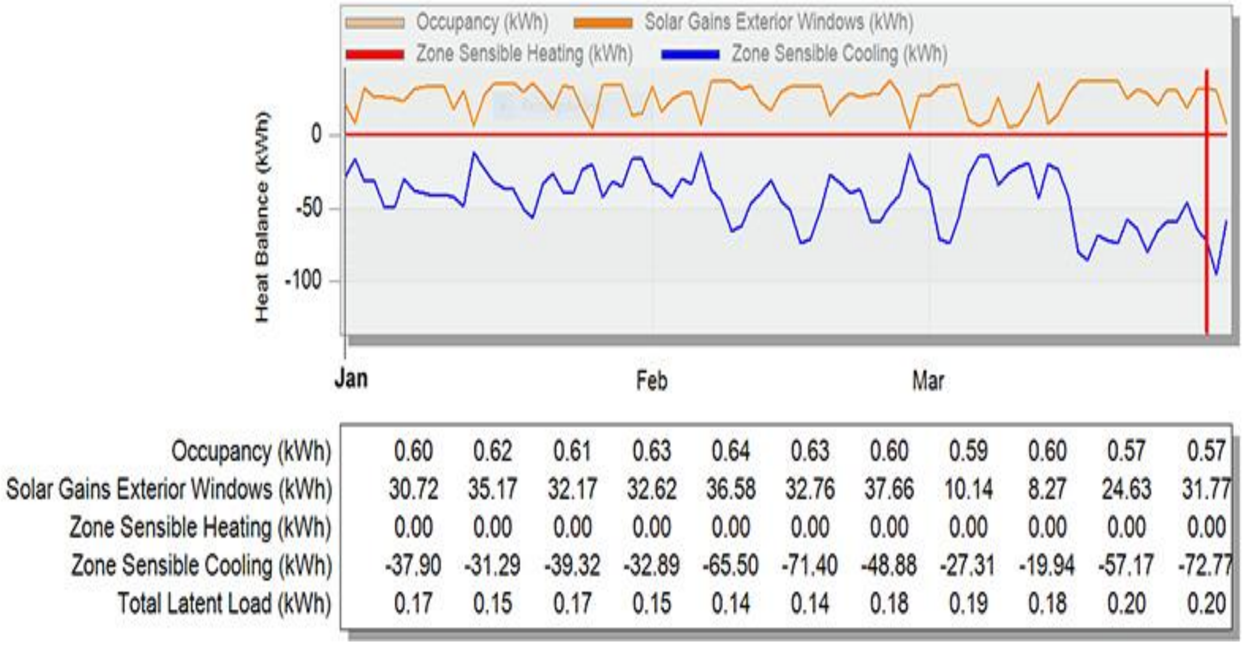


Figure 5. Daily average temperature and direct normal solar radiation in winter conditions from Energy Plus.

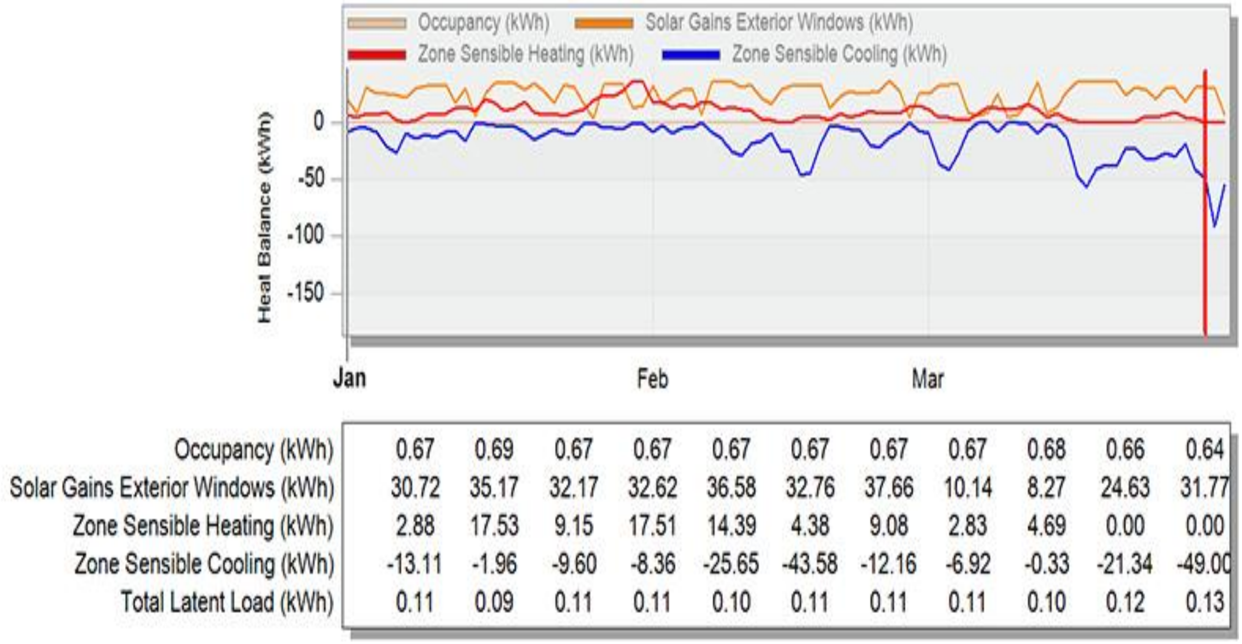
The ventilation rate is key to determine energy consumption and indoor comfort in buildings. Night ventilation is an effective passive cooling strategy, using natural or mechanical ventilation during the night hours. If the building envelope has enough thermal mass, night ventilation can dissipate excess heat. Design Builder allows users to define ventilation rates and operating schedules. Fig. 6 shows that there is no need for heating with a low ventilation rate of 0.2 air changes per hour (ACH), even in winter conditions. The large glazed area in the southern and eastern façades can produce overheating, and there is a need for a cooling system to keep the temperature within the comfort range. The cooling energy rises to 72.77 kWh, and it is never below 20 kWh. The total cooling energy over the first three months of the year is 504.37 kWh.



Occupancy (kWh)	0.60	0.62	0.61	0.63	0.64	0.63	0.60	0.59	0.60	0.57	0.57
Solar Gains Exterior Windows (kWh)	30.72	35.17	32.17	32.62	36.58	32.76	37.66	10.14	8.27	24.63	31.77
Zone Sensible Heating (kWh)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zone Sensible Cooling (kWh)	-37.90	-31.29	-39.32	-32.89	-65.50	-71.40	-48.88	-27.31	-19.94	-57.17	-72.77
Total Latent Load (kWh)	0.17	0.15	0.17	0.15	0.14	0.14	0.18	0.19	0.18	0.20	0.20

Figure 6. Simulation in winter conditions under the ventilation rate of 0.2 ACH.

Fig. 7 shows the results of the simulation with a rate of 0.6 ACH. The total cooling energy over the first three months of the year is 192.01 kWh. The heating energy over the same period is 82.44 kWh. Adding both figures up, the total energy needed to keep the temperature within the comfort range is 274.45 kWh. The strategy of free natural night ventilation reduces the heating and cooling loads by 45%.



Occupancy (kWh)	0.67	0.69	0.67	0.67	0.67	0.67	0.67	0.67	0.68	0.66	0.64
Solar Gains Exterior Windows (kWh)	30.72	35.17	32.17	32.62	36.58	32.76	37.66	10.14	8.27	24.63	31.77
Zone Sensible Heating (kWh)	2.88	17.53	9.15	17.51	14.39	4.38	9.08	2.83	4.69	0.00	0.00
Zone Sensible Cooling (kWh)	-13.11	-1.96	-9.60	-8.36	-25.65	-43.58	-12.16	-6.92	-0.33	-21.34	-49.00
Total Latent Load (kWh)	0.11	0.09	0.11	0.11	0.10	0.11	0.11	0.11	0.10	0.12	0.13

Figure 7. Simulation in winter conditions with ventilation rate of 0.6 ACH.

3.2. The effect of WFG in comfort

The effect of WFG in energy savings has been reported in scientific literature [36-38]. Water absorbs infrared radiation and reduces the temperature of the interior glass pane. IDA-ICE engine includes a module that simulates WFG by using a one-dimensional conduction finite-difference solution algorithm. This section presents the effect of the WFG in reducing the mean radiant temperature of a room with a large amount of glass and how it affects the thermal comfort. The WFG panel comprises a solar water pump with a heat exchanger, a photovoltaic panel along with the electronic monitoring system for water temperature at different points of the panel. Figure 8 illustrates its components and shows a study of the dimensions of the overhang to provide the solar cell with direct solar radiation on June 21. The solar water pump will use on-site electricity so that its electrical consumption does not affect the total energy balance.

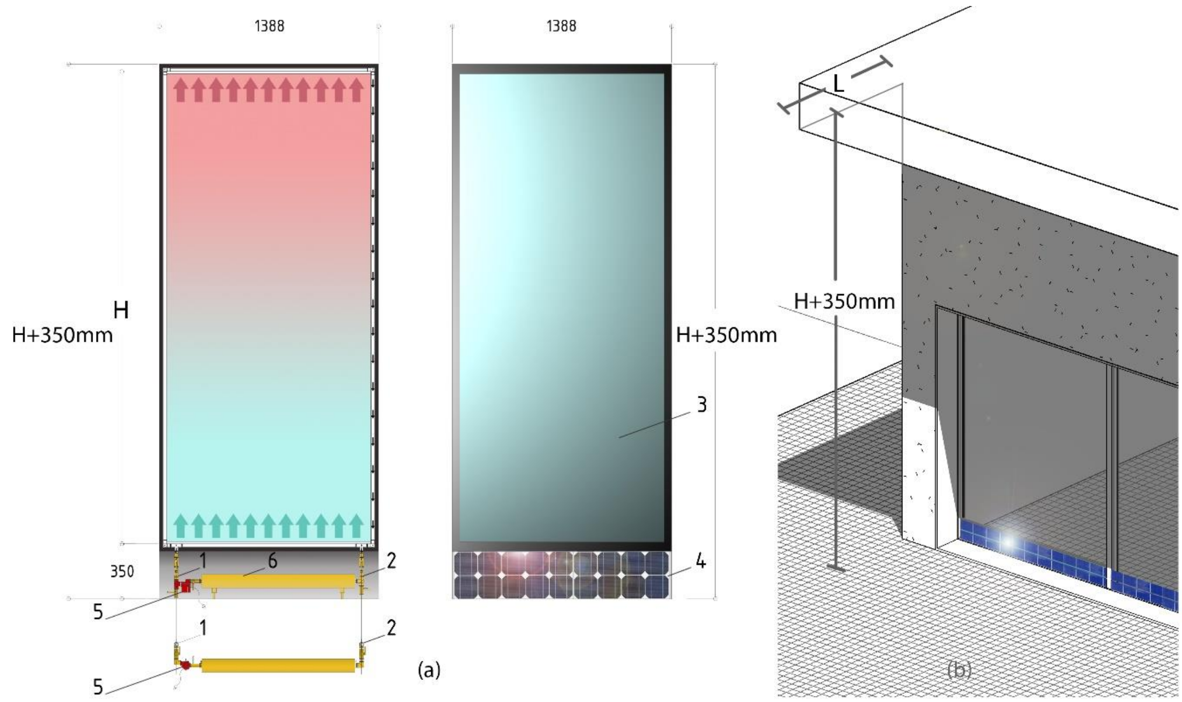


Figure 8. (a) Description of WFG module: 1. Supply pipe; 2. Return pipe; 3. Glass; 4. Photo-voltaic cells; 5. Solar water pump; 6. Heat Exchanger. (b) Relationship between the lengths of the overhang (L) and the height of the glass (H).

ASHRAE Standard 55, EN-15251, and Ole Fanger's work, focus on the six factors determining thermal comfort [39- 42]: a) air temperature; b) mean radiant temperature; c) relative humidity; d) speed of air; e) metabolic rate; d) influence of clothes.

Operative temperature (T_o) is the combined effects of the mean radiant temperature (T_{mr}) and dry-bulb air temperature (T_{db}). Equation 1 expresses the operative temperature:

$$T_0 = (h_r T_{mr} + h_c T_{db}) / (h_r + h_c), \qquad (1)$$

where, h_c= convective heat transfer coefficient; h_r= linear radiative heat transfer coefficient; T_{db}= air (dry bulb) temperature; T_{mr}= mean radiant temperature. In its simplest form, operative temperature can also be expressed as in Eq. 2:

$$T_0 = (T_{mr} + T_{db}) / 2 \qquad (2)$$

The lounge room of the case study has the largest amount of glass and it is the most representative house space. The simulation has taken into account two cases: the first one, with traditional glazing; the second one considers WFG. Both solutions have been tested by comparing the mean radiant temperature (T_{mr}), operative temperature profile (T_o) and of value of predicted mean vote (PMV), according to Fanger's parameters. Fig. 9 presents a picture of the lounge and the factors that influence the room temperatures: h_i is the interior heat transfer coefficient (W/m^{2}K). S_G is the total building glazing surface area (m^2). S_B is the total building opaque envelope surface area (m^2). S_F is the total building floor area (m^2). Finally, θ_i is the mean indoor temperature (K) and θ_e, which is the mean outdoor temperature (K).

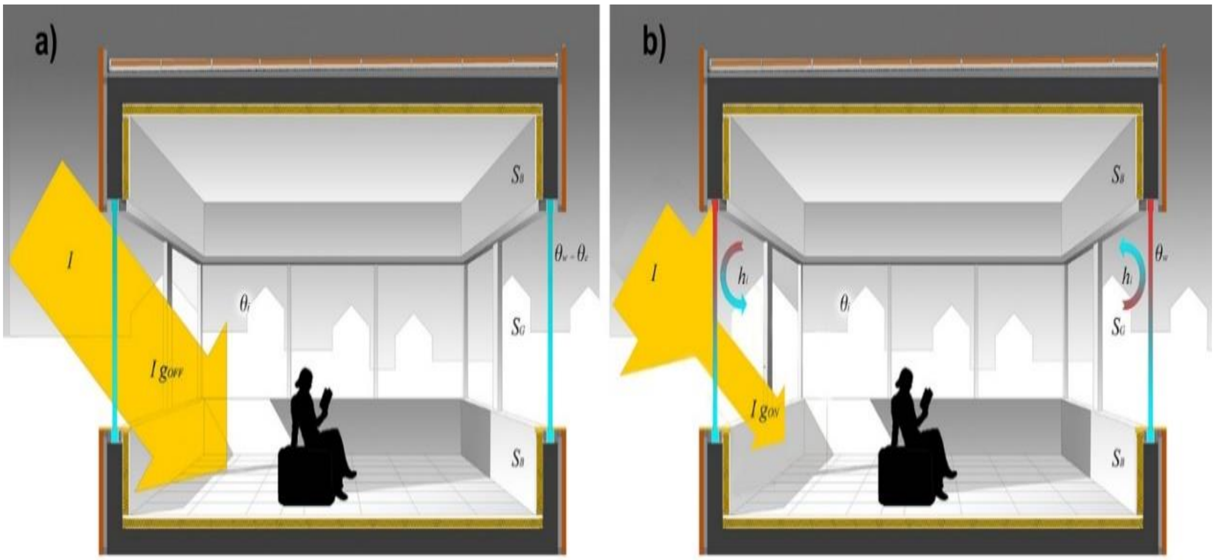


Figure 9. (a) Lounge room without WFG, (b) the effect of WFG in summer.

If the mean impinging solar radiation ($\bar{I}$) is very high, it is impossible to maintain the comfort temperature inside the building in summer. Water has the property of absorbing infrared radiation. Depending on the water flow rate, the absorption of heat can reduce the g-value of the glass (g_{ON}). When the temperature of the water (θ_w) is within the comfort range, it lowers the radiant temperature of the glass pane in contact with the indoor air. This effect reduces the mean radiant temperature of the room. In sunny winter days, the system stops the flow of water, and the g-value of the glass (g_{OFF}) rises.

Some authors have stated a mathematical model of WFG [38]. The following differential equation presents the dependency of the different design parameters and variables:

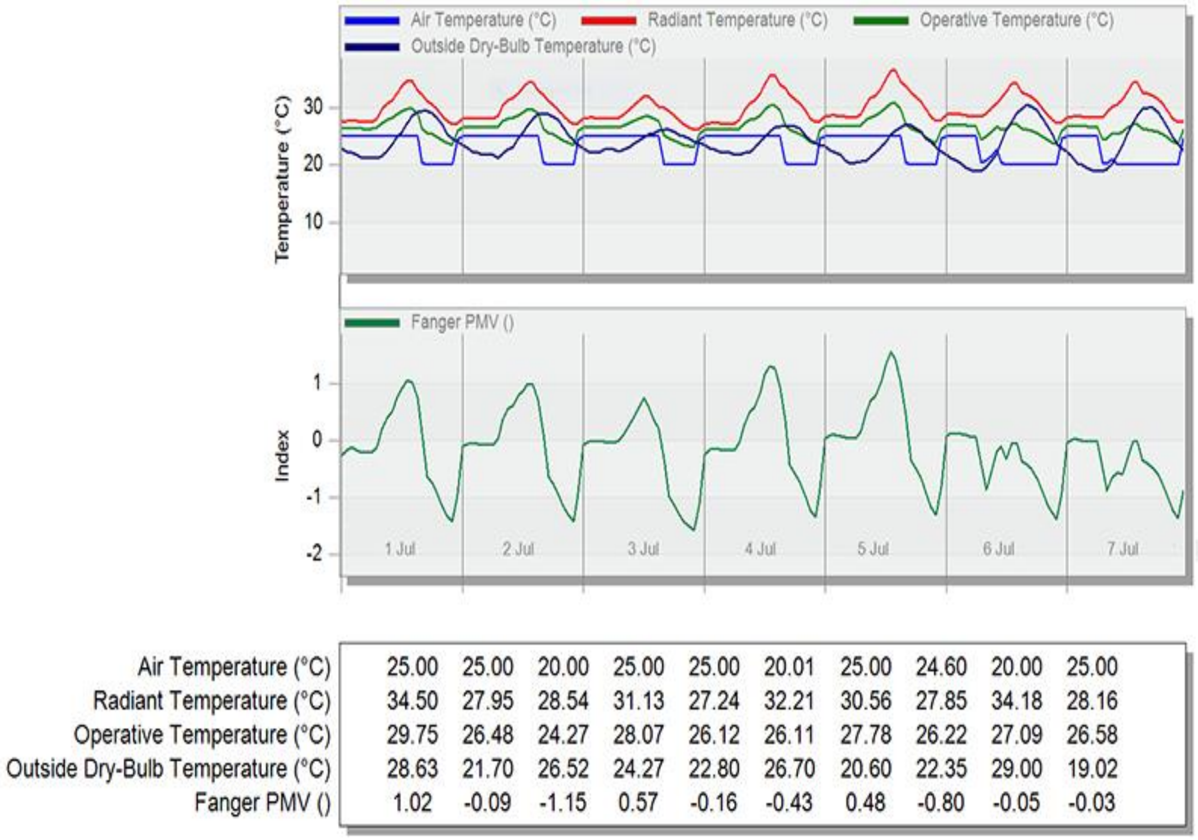
$$mc\frac{d\theta_i}{dt} = S_B U_B(\theta_e - \theta_i) + S_F[q + h_i(\theta_w - \theta_i)] + S_G[U_G(\theta_e - \theta_i) + U_W(\theta_w - \theta_i) + gI] \qquad (3)$$

The design parameters are constant in time. The integral of the equation turns variables into mean values. The integral of $d\theta i$ is canceled under the assumption that the variation of θ_i with time is periodical.

$$\theta_i = \frac{S_B U_B + S_G U_G}{SU}\theta_e + \frac{gS_G}{SU}I + \frac{S_F h_i + S_G U_W}{SU}\theta_w + \frac{S_F}{SU}q, \qquad (4)$$

where $SU = S_B U_B + S_G U_G + S_F h_i + S_G U_W$

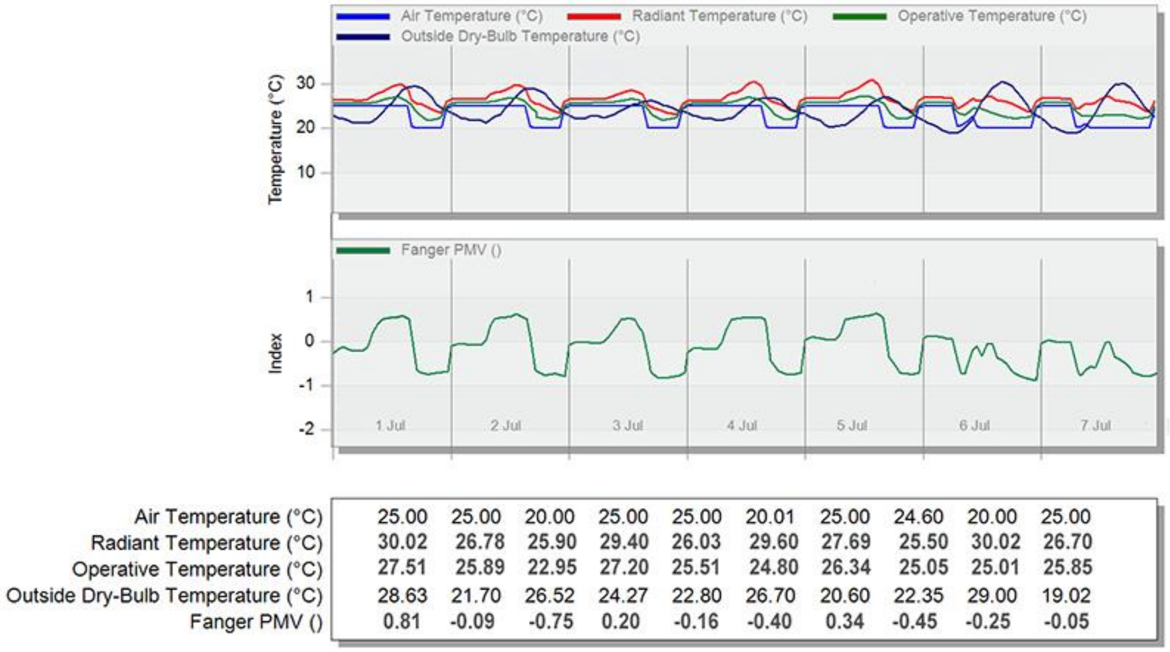
IDA-ICE software allows designers to introduce a WFG catalog and to implement the variable flow of water inside the glass panes. A climate file provides reliable data of outdoor conditions while a simplified zone model simulates the indoor conditions. This simulation has used a simplified energy model based on mean radiant temperatures. The initial result from the simulation shows that radiant temperature is directly influenced by variations of outdoor temperature and the overheating of the glass. Over daytime the radiant temperature increases approximately linearly up to a value of 34.5 C; from 15:30 to 21:00 its value decreases approximately linearly down to 27.2 C; over the night its value remains almost constant between 27.2 C and 28.5 C. The results of the simulation in figure 10 show that, even during the HVAC operating time, the operative temperature is not within comfort range. It rises to 29.75 C, and it is never below 26 C.



Air Temperature (°C)	25.00	25.00	20.00	25.00	25.00	20.01	25.00	24.60	20.00	25.00
Radiant Temperature (°C)	34.50	27.95	28.54	31.13	27.24	32.21	30.56	27.85	34.18	28.16
Operative Temperature (°C)	29.75	26.48	24.27	28.07	26.12	26.11	27.78	26.22	27.09	26.58
Outside Dry-Bulb Temperature (°C)	28.63	21.70	26.52	24.27	22.80	26.70	20.60	22.35	29.00	19.02
Fanger PMV ()	1.02	-0.09	-1.15	0.57	-0.16	-0.43	0.48	-0.80	-0.05	-0.03

Figure 10. Simulation of operative temperature and predicted mean vote with traditional glazing in the lounge room.

The heat exchanged between the air that flows inside the room and the circulating chilled water inside the glazing helps reduce the operative temperature. Fig. 11 shows that during summer days and the night (when the HVAC is turned off), the operative temperature remains in comfort range and the mean radiant temperature decreases around 4.5 C compared with the results of traditional glazing. The operative temperature does not rise over 27.5 C and has minor variations over the week. For what concerns the predicted mean vote (PMV), the optimality of indoor thermal-hygrometric conditions has been underlined. The most uncomfortable conditions occurred during the noon period with a PMV value of 0.8. The ASHRAE 55 states that a band of ±0.8 is acceptable when it comes to comfort. In conclusion, the use of WFG reduces the peak daytime operative temperature by 3 degrees, without compromising the energy demand of the building.



Air Temperature (°C)	25.00	25.00	20.00	25.00	25.00	20.01	25.00	24.60	20.00	25.00
Radiant Temperature (°C)	30.02	26.78	25.90	29.40	26.03	29.60	27.69	25.50	30.02	26.70
Operative Temperature (°C)	27.51	25.89	22.95	27.20	25.51	24.80	26.34	25.05	25.01	25.85
Outside Dry-Bulb Temperature (°C)	28.63	21.70	26.52	24.27	22.80	26.70	20.60	22.35	29.00	19.02
Fanger PMV ()	0.81	-0.09	-0.75	0.20	-0.16	-0.40	0.34	-0.45	-0.25	-0.05

Figure 11. Simulation of operative temperature and predicted mean vote with water flow glazing in the lounge room.

4. CONLUSIONS

Engineers and building designers use BES tools to analyze the energy balance of a building at the design stage. This work has presented and tested a reproducible method to improve the energy balance and comfort conditions of zero energy buildings in Mediterranean countries. The method has been used to analyze a small residential building located in Garrucha, Spain. Some building modeling and simulation tools have been used to achieve the best balance among glazing, ventilation, and potential for solar energy.

The results of the first energy simulation carried out with BIM software, show that air infiltration into the building and properties of the glazing (solar heat gain coefficient and U value) are the factors that influence the thermal performance of the building the most. The use of low U-value envelope, triple glazing, and external shading systems minimize the cooling loads. After optimizing the design in terms of energy consumption, the energy balance between demand and on-site generation can be achieved utilizing a PV array.

In the second stage of simulation, all spatial and geometric information from the BIM model is extracted and tested by Energy Plus. This software allows designers to implement strategies of ventilation and calculate and design the HVAC systems. The results show that natural ventilation at night reduces the cooling loads by 45% in summer.

Nowadays, only the IDA-ICE engine offers a module to include WFG in energy simulations. The use of WFG reduces the peak daytime operative temperature by 3 degrees. The IDA-ICE simulation shows that the operative temperature is within the comfort range according to ASHRAE 55.

The exchange of information between BIM and energy simulation software is a goal that needs improvement over the next years. BIM software offers a friendly interface. Energy Plus and IDA-ICE engines allow designers to include relevant parameters to run energy simulations at the early design stages.

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