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Energy strategies to nZEB sports hall

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Abstract

The Energy Performance of Buildings Directive recasts that by 2020 all new buildings constructed within the EU after 2020 and public buildings after 2018 should reach nearly zero energy (nZEB) levels. The present work aims to test, through the dynamic simulation tool TRNSYS, different energy strategies to design nearly zero energy sports halls in Mediterranean climates. The study is complemented with short period measurements of thermal comfort parameters and air quality indicators in a selected sports hall. The nZEB concept is achieved implementing passive strategies in combination with renewable energy systems. The impact of the identified energy solutions on the indoor thermal comfort and environmental indoor quality is also evaluated.

Key words: nZEB; sports hall; energy efficiency; TRNSYS simulation; IEQ; thermal comfort

1. Introduction

As reported in the article 2 of the European Union Directive 2010/31, a “nearly zero energy building” (nZEB), due to its very high efficiency, is characterized by very low energy requirements, satisfied by significant extent trough renewable sources available on-site or nearby. More than half of the member states (MS) are managing sport facilities as a precise nZEB subcategory (D’Agostino 2015). The Catalan region of Spain alone accounts for 2417 public buildings identified as sport facilities, responsible for 14% of the total primary energy consumption of the public building stock (Radulov 2014). Specifically, a standard sports pavilion uses 238 kWh/m^2 of primary energy every year. More than half of the current energy consumption of Catalan sports halls are relate to lightning (56%), a relevant energy use is due to domestic hot water (DHW) (28%), while heating and ventilation demand accounts for 4% (other electric consumptions accounts for 12% of the total) (ICAEN 2012). Those figures suggest that the energy performance improvement of sport facilities has a key role in the fulfilment of the article 9 of the Energy Performance of Buildings Directive. It states that MS shall ensure that all new public buildings must be nZEBs by December 31, 2018. The energy demand profile of a sports hall is closely related to the performed sport activity, the timetable of the sports centre, the public attendance during the matches and the climate conditions (Arutso and Santangeli, 2008). Sport halls in the continental European zone require the double amount of energy than the Mediterranean ones (Trianti-Stourna et al. 1998). In the German sports halls of Dresden-Weixdorf, through the installation of renewable energy technologies, storage systems and high efficiency devices, passive house standards have been achieved and the energy use optimized (Felsmann et al. 2015). Similarly, the study conducted by Flourentzou et al. (2015) assesses natural ventilation as strategy for energy consumption and costs reduction in a Swiss gym designed as a typical passive building. However, few researches investigated the energy use and generation patterns in relation to the comfort level perceived by the users of sports facilities. Summer overheating in passive sports structure is a studied phenomenon. It is possible to find in literature evaluations of effective and low energy demanding methods for thermal discomfort mitigation, as direct evaporative cooling, shading strategies, night ventilation, and openings optimization (Kisilewicz and Dudzińska 2015) (Tsoka 2015). The approach proposed in this paper supports the design of a nearly zero energy sports hall in Mediterranean climate through the implementation of different energy strategies and the evaluation of the

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thermal comfort condition in the different scenarios, aiming to guarantee a comfortable environment to the building users.

2. Methodology

Firstly, the indoor air quality and thermal behaviour of an existing sports facility are evaluated trough a field measurements campaign. The collected data are used to perform a comfort analysis according to the adaptive comfort methodology and the procedures described in the ASHRAE 55 (ASHRAE 55, 2004) and UNE-EN 15251 (AENOR 2008) standards. Consequently, a typical Spanish sports hall is identified as base case study and nZEB strategies are introduced. When the base case sport hall 3D geometry is defined in Google Sketch Up, energy efficiency measures are tested using the dynamic simulation tool TRNSYS, in order to estimate their impact on thermal comfort, air quality and energy needs. The implementation of renewable energy systems, specifically the potential contribution of the installation of a photovoltaic system, is estimated trough the Google Sketch Up plug-in Skelion.

2.1 Measurements campaign

The data regarding occupation patterns and environmental indoor quality are collected through field measurements in an existing facility. The main goal is to evaluate the indoor environment quality (IEQ) and the thermal condition of the sports hall. The field measurement campaign is realized in the “Poliesportiu Pla Del Bon Aire” located in Terrassa (Barcelona) and currently not equipped with a ventilation system neither a heating system. The measurements are performed along two days during the second weekend of March 2016. The thermal parameters as indoor air temperature at different heights, radiant temperature, air velocity, relative humidity and air quality indicators, as CO_2 concentration, are measured under different usage conditions. The instrumentation is installed compromising between quality of measurements, equipment safety and reduction of the interaction with building users. All data are recorded with 3 minutes intervals. The appropriate clothing insulation and metabolic activity profiles are estimated (tab.1). At the same time of the measurements campaign, the subjective perception of the users has been investigated through a questionnaire survey. Following the procedures described in ASHRAE 55 standard, the adaptive thermal comfort model is applied to evaluate the indoor comfort conditions, for spectators and for players. The exterior CO_2 concentration is considered equal to 450 ppm.

Tab. 1: **Metabolic activity (expressed in met; 1 met = 58.2 W/m^2 body surface) and clothing parameters (expressed in clo; 1 clo = 0.155 m^2 °C/W) (ASHRAE 55, 2004)**

	Activity	Metabolic activity [met]	Garments	Clothing insulation [clo]
Players	Basketball	6.3	Walking shorts, short sleeve shirt	0.36
Audience	Seated, heavy limb movement	2.2	Trousers, long-sleeve shirt plus long-sleeve sweater	1.01

2.2 Energy strategies to nearly zero energy sports halls

As mentioned, sports halls are characterized by very specific consumption profile. With the goal of fulfil the energy requirements of this particular kind of installation satisfying the users comfort needs and achieving a significant reduction of the primary energy use, appropriate nZEB strategies have been identified. The selection has been made in the light of the climatic conditions and of the type of use that characterize the investigated sports facility. Consequently, a suitable set of passive approaches, energy efficiency measures and renewable energy systems have been applied to the analysed base case building (table 2).

Tab. 2: Proposed nZEB strategies

	Measures	Implementation	Objective
Passive strategies and control	Thermal behaviour	• Selection of building materials to ensure low thermal transmittance of the envelope • Optimization of the ratio opaque components/ windows of the façade according to the building orientation • Installation of shading device in the South-east façade	✓ ensure good thermal insulation ✓ take advantage of the solar gains ✓ avoid risk of overheating
	Natural light	• Design of the South-east façade to maximize the contribution of natural light • Installation of diffuses light sources • Installation of skylight devices	✓ ensure visual comfort ✓ avoid glare
	Natural ventilation	• Definition of control system • Nigh ventilation • Design independently from the natural light system	✓ ensure thermal comfort of the users ✓ ensure good air quality
Renewable energy system	PV installation	• Design of the façades and the roof to allow the installation of PV panels • Study of the optimal roof slope and orientation to maximize the energy production	✓ reduce energy costs ✓ reduce CO_2 emissions
Active system	Artificial light	• Installation of LED lamps • Regulation with control system	✓ reduction of energy costs

2.3 Building simulation

The base case sports hall is defined following the technical indications provided by the Catalan sports council (Consell Català de l'Esport 2005, *CCE*) concerning a triple sports hall. A triple sports hall is a sports installation equipped with a playing field that can be divided in three transversal spaces, increasing its versatility. It results that 133 on 564 Catalan sports halls fall in this category; therefore, it is a representative building typology. The studied sports installation is located in Barcelona. The building geometry is modelled in Google Sketchup (fig.1) and then is introduced in the simulation by a 3D model, using the plugin Trnsys3D. The sports halls energy consumption is closely related to the number of users of the installation. For this reason, with the contribution of the data collected during the measurements campaign, realistic profiles of the sports hall occupancy have been defined. Two main occupancy patterns are identified, corresponding to weekdays and weekend. The information regarding the occupancy schedule is reported in table 4. The air tightness of the building is assumed equal to n_{50} = 2.6/h. According to UNE-EN 15242 (AENOR 2007), the considered value corresponds to a level of airtightness medium. Only the behaviour of the playing arena of the sports hall is simulated. Thermal performance and energy consumption of other environments, as lockers rooms, that typically form part of this type of buildings, are not taken into account in this research. Moreover, it is specified that, being based on a real sports hall project, this work has to comply with some limitations and does not involve the study of default parameters, as the building orientation.

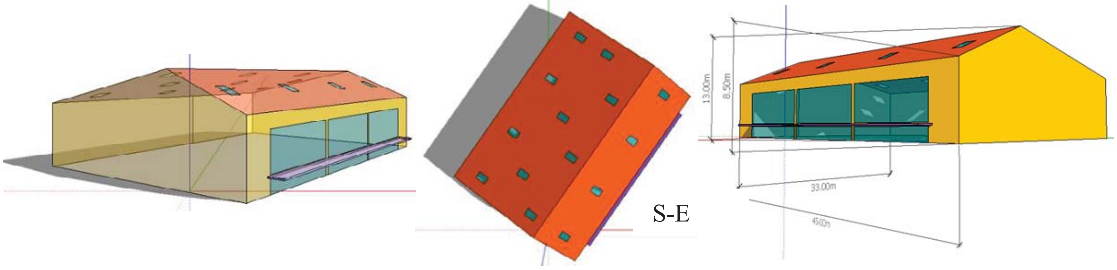


Fig. 1: Sports Hall 3D model

Tab. 3: Sports Hall dimension

	Volume [m^3]	Area [m^2]
Sports hall	13618	1485

Tab. 4: Sports Hall occupation pattern. (1°= Saturday; 2°= Sunday)

	occupation														
	Weekdays	Weekends													
schedule	17-22	7-9		9-11		11-14		14-16		16-19		19-20		20-22	
		1°	2°	1°	2°	1°	2°	1°	2°	1°	2°	1°	2°	1°	2°
players	45	0	0	40	40	40	40	0	0	35	35	35	35	35	35
audience	20	8	10	40	50	48	60	8	10	40	50	64	80	200	300
Total	65	8	10	80	90	88	100	8	10	75	85	99	115	235	335

2.3.1 Thermal behaviour

The thermal characteristics of the selected opaque components of the envelope are reported in table 6, while the thermal performance of the windows in table 5. The façades and the windows are in contact to the exterior environment. There is only an interior wall located in the North West direction and assumed in contact to the lockers room. The boundary temperature for this partition wall is considered of 23 °C or 18 °C, respectively during the summer and winter occupied periods. While, the unoccupied periods are characterized by a boundary parameter evaluated as average of the previous values and the exterior registered temperature. The thermal behaviour of the building is affected by the installation of a fix horizontal overhang that aims to prevent excessive temperature increase during the warm season.

Tab. 5: Thermal performance of the windows

	Window 1_lower level		Window 2_higher level		Window 3_skylight	
	Frame	Glazing	Frame	Glazing	Frame	Glazing
Composition	Aluminium with thermal break	Clear double glazing 6/16/6	Aluminium with thermal break	OKAPANE with glass fibre tissue, 16 mm, air 40 mm	Aluminium with thermal break	Double glazing with prismatic lens
U – value (W/m^{2}K)	2.27	1.26	2.27	1.24	2.27	1.4
g – value (-)		0.368		0.335		0.589
Area frame glazing (%)	15	85	5	95	5	95

Tab. 6: Thermal performance of the construction elements

	U – value (W/m^{2}K)
Façade NE and SW	0.284
Façade SE and NW	0.296
Interior wall	0.304
Roof	0.284
Floor	1.366

2.3.2 Natural ventilation

Natural ventilation has been investigated in detail. It is chosen as the main strategy to ensure optimal indoor air quality and thermal comfort, avoiding the energy consumption due to mechanical system. The thermal comfort is evaluated applying the adaptive comfort model. The comfort conditions are set according to the limits defined in the standard UNE-EN 15251 and observing the requirements reported in the document redacted by the Catalan sports council. The indoor optimal operative temperature (Top_{opt}) is calculated following the procedure proposed by the standard. The CO$_2$ concentration is the parameter used to evaluate the indoor air quality (table 7). Cross-natural ventilation is modelled through TRNFLOW (Weber et al., 2003), the extension for the integration of the airflow and pollutant transport model COMIS into the building thermal model of TRNSYS. Two identical openings are introduced in opposite façades of the building, taking into account the prevalent wind direction of the site. The characteristic of the openings are reported in table 8. The wind pressure coefficients, the discharge coefficients and the wind velocity profile are introduced according to the parameters reported in literature and in the TRNFLOW manual. The flow coefficient is calculated taking into account the desired infiltration in the building. CO$_2$ is the only examined pollutant inside the zone. The outside concentration is set to 450 ppm and assumed constant for all the external nodes and directions. The occupants of the sports halls are considered as CO$_2$ sources in proportion to their metabolic activity. Therefore, the contaminant exhalations from the audience accounts for 21.5 l/s per person while players are responsible for 62.5 l/h per person (Demianiuk et al. 2010). The air velocity in the building is assumed equal to 0.25 m/s when the natural ventilation is not operating and of 0.5 m/s when the openings are open. The selected values are in the range of acceptability considering that the recommended upper limit for indoor air movement is usually 0.8 m/s (Allard 2002). The control of the simulated natural ventilation system depends on the occupancy, the interior operative temperature and the CO$_2$ concentration. Natural ventilation is activated only when the building is occupied. Natural ventilation activation implies that the openings are opened if the operative temperature exceeds the upper limit of the selected thermal category or if the indoor CO$_2$ concentration is outside the air quality range. Specifically, the interval of indoor tolerable concentration is restricted respect to the recommendations of the standard.

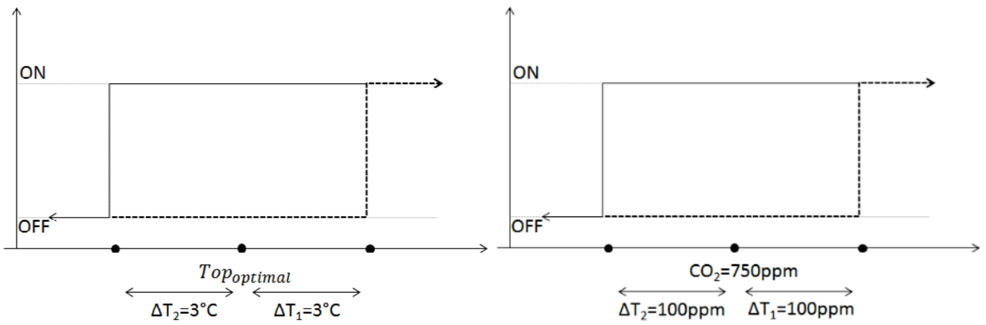


Fig. 2: Natural ventilation control. Simple line: openings behaviour if the actual state of the natural ventilation system is ON. Dashed line: openings behaviour if the actual state of the natural ventilation system is OFF

This configuration is introduced to give stability to the system, to avoid frequent on / off cycles and to allow the removal of the excess CO$_2$ while there is continuous emission from the occupants. The operation of the control system is schematized in figure 2. Additionally, the opening factor is adjusted to reduce the risk of overcooling and air draft. At this scope, the openings are more or less opened depending on the difference between the interior and exterior temperature during the cold season and on the wind velocity during the warm one, as table 9 shows. Moreover, during the weekend, when the CO_2 production is significant, the system is forced to work with an opening factor equal to 1, unless the wind velocity is greater than 6 m/s. Again, this condition is suggested to maintain the stability of the system, namely to avoid that a substantial flow of air can rapidly reduce the pollutant concentration causing the closure of the openings. Indeed, it is desirable that the natural ventilation system works constantly during the period of high occupancy. To verify the effect on overheating risk reduction, night ventilation is also tested. In summer, natural ventilation is activated after that the users leave the sports hall if the exterior air temperature is lower than the interior one. In general terms, set this conditions, natural ventilation stays on until the morning hours.

Tab. 7: Comfort parameters

	Lower limit	**Upper limit**	**Source**
Operative temperature (°C)	$Top_{opt} - 3$	$Top_{opt} + 3$	UNE-EN 15251
Indoor temperature (°C)	14°C	-	*CCE*
CO_2 concentration (ppm)	-	1200	UNE-EN 15251

Tab. 8: Natural ventilation system components

Opening	**Description**	**Dimension [m^2]**	**Position: height [m]**
North-West façade	Horizontal sliding	9	6.3
South-East façade	Horizontal sliding	9	0.4

Tab. 9: Natural ventilation control strategy. Opening factor

Opening factor	**Summer Wind velocity (m/s)**	**Winter $T_{interior} - T_{exterior}$ (°C)**
0.2	>15	> 9
0.4	15 – 11.25	9 – 7.5
0.6	11.25 – 7.5	7.5 - 5
0.8	7.5 -3.75	5 - 4
1	< 3.75	< 4
1	if Occ=max and wind velocity < 6m/s	

2.3.3 Internal gains

The internal gains of a building are formed by the release of sensible and latent heat from indoor heat sources. This study considers the contribution of the building occupants and of the lights appliances. The sensible heat produced by the occupants depends on their metabolic activity and on the indoor air temperature, as reported in Michaelsen and Eiden (2009). The total sensible heat produced by the users of the sports hall is considered 30% convective and 70% radiative (ASHRAE 1993). The artificial lights system is mounted at 13 meters high. It is composed of 30 led lamps consuming 276 W each, with luminous efficiency of 80% (Ortiz et al., 2015). The installed systems is designed to ensure 300 lux of indoor illuminance, following the recommendation of ICAEN (2012) for basket arenas. Therefore, the contribution of the lights equipment to the internal heat load is calculated in function on the natural light availability. Artificial lights are assumed to be on when the sports hall is occupied and the natural light provided by the 14 skylights placed on the roof and by the windows on the façade is lower than the required illuminance level (according to Consell Català project). The data, regarding the hourly average daylight availability are provided by an external collaborator for a typical day of each month and introduced as input in TRNSYS.

2.3.4 PV system

PV Building Integration (BIPV) is a practice that refers to the use of PV modules as architectural elements, being a collaborative part of the design of the building envelope and having an architectural function in symbiosis with functional properties and economic regenerative energy conversion (Achenza and Desogus, 2013). Part of this research has dealt with the test of different PV system configurations designed to contribute to the energy needs of the investigated sports facility. The analysis is performed through the Google Sketchup plug Skelion and the relative findings are shown in the results section 3.3.

3. Results and discussion

3.1 Measurements campaign

After the data acquisition phase, the measured indoor conditions of the reference sports building have been analyzed in combination with the weather variable, the results of the survey and the assumed parameters. According to the survey answers (54), 84% of the audience was experiencing a thermal discomfort, mainly due to overheating: 33% affirmed that the environment was slightly warm, 28% that it was warm and 17% that it was very warm (only 3 people considered it slightly cold). Regarding the humidity variable, the majority of the audience (65%) considered the environment neutral, while the air movement was perceived mainly as inadequate (slightly low for 33% and very low for 37%). However, results of the comfort analysis show that the adaptive comfort requirements reported in the ASHRAE 55 standard are complied, as well as the design criteria established by the standard UNE-EN 15251 (fig.3) in relation to the acceptable indoor relative humidity. Conversely, looking at the level reached by the interior CO_2 concentration, it results that the comfort condition recommended by the UNE-EN 15251 standard are not always met (fig.4).

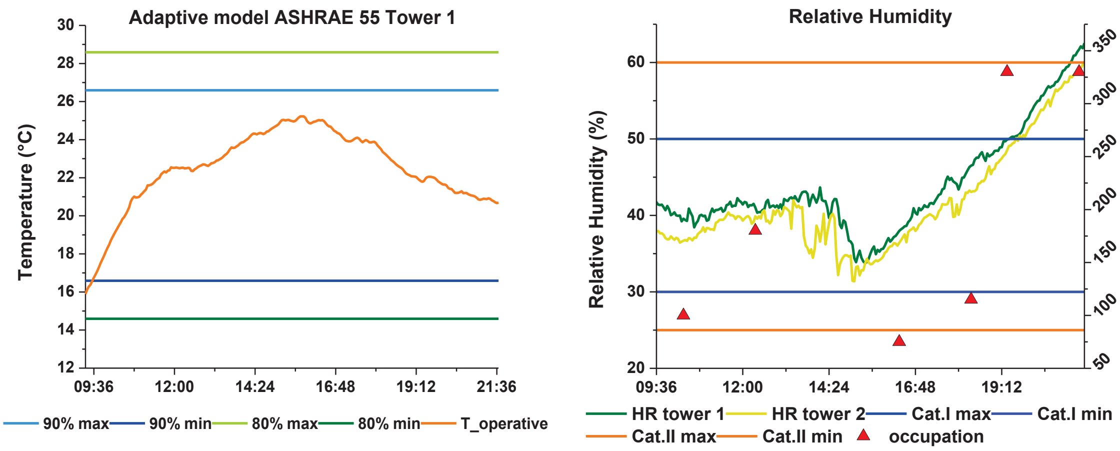


Fig. 3: Left: Adaptive thermal comfort evaluation; Right: relative humidity measurements and comfort categories

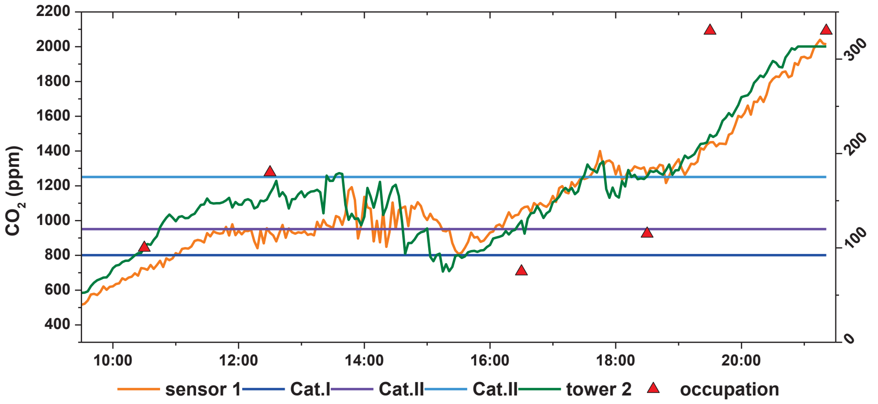


Fig. 4: CO_2 concentration measurements and comfort categories

Therefore, taking also into account that the mentioned standards are not specifically elaborated for sports facilities and for the consequent high level of metabolic activity of the users, the sharp increase of the indoor relative humidity and the excessive CO_2 concentration during the hours of maximum occupation appear as the main cause of perceived discomfort.

3.2 Building simulation

The objective of the building simulation is to verify to which extend the selected nZEB strategies are able to reduce the primary energy consumption of the studied sports hall without causing discomfort to the users. The TRNSYS results are organized in table 10 and reported in function of the natural ventilation state, being the only variable parameter. Observing figure 5, that shows the TRNSYS simulation outputs for a selected winter week, it results that the designed control system works correctly. The thermal discomfort and the air quality are assessed only during the occupied hours. It is assumed that the overheating phenomenon occurs if $Top_{int} > Top_{opt} + 3$, as the technical indications provided by the Catalan sports council do not set a maximum indoor temperature requirement. The building is overcooled if the condition $Tair_{int} < 14°C$ is verified. The maximum registered ACH is 9.97h^{-1}. The average ACH with natural ventilation on is 1.57h^{-1}, while the infiltration on average equals to 0.05h^{-1}. The presented results are achieved without the introduction night natural ventilation. As shown in table 10, the discomfort due to overheating is very low thank you to the contribution of the infiltration and the high thermal insulation of the building. The effect of additional night ventilation further reduces the overheating phenomenon to 0.1% of the occupied time. Therefore, the implementation of night ventilation technique results to have a limited impact on the thermal comfort improvements of this study case building situated in a moderate climate. However, night cooling can be considerably beneficial in extreme climate conditions and if heat wave phenomenon occurs in moderate climate. Closely analysing the discomfort events, it results that for 2 days overcooling occurs during 2.75 hours, the maximum consecutive period of overcooling thermal discomfort. The maximum consecutive period of discomfort due to excessive CO_2 concentration is 3 hours and it occurs only one day along the annual simulation. Overall, considering thermal and air quality parameters, annually the sports hall users experience 16 days of discomfort with the distribution shown in figure 6. The results deviates from the limit values for maximum 329 ppm, 4.61°C in case of overcooling and 0.48°C in case of overheating.

Tab. 10: Building simulation results

	% of the occupied time	
	winter	summer
natural ventilation ON	54.76	50.09
Overcooling	1.69	-
Overheating	-	0.36
$CO_2 > 1200$ ppm	1.20	0.71

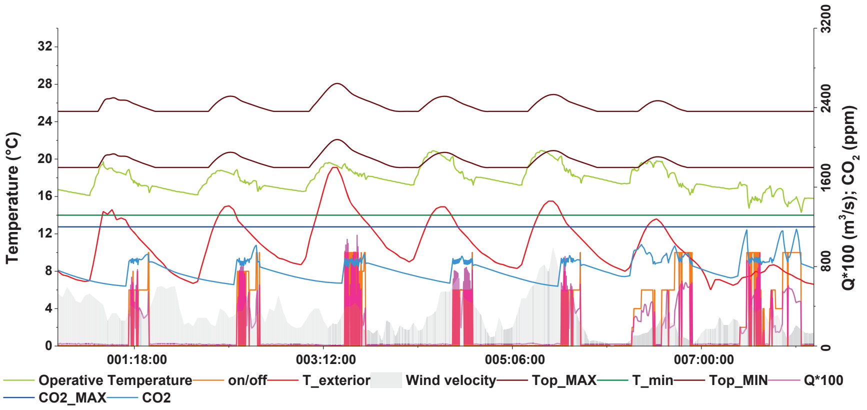


Fig. 5: System behaviour during a selected winter control week

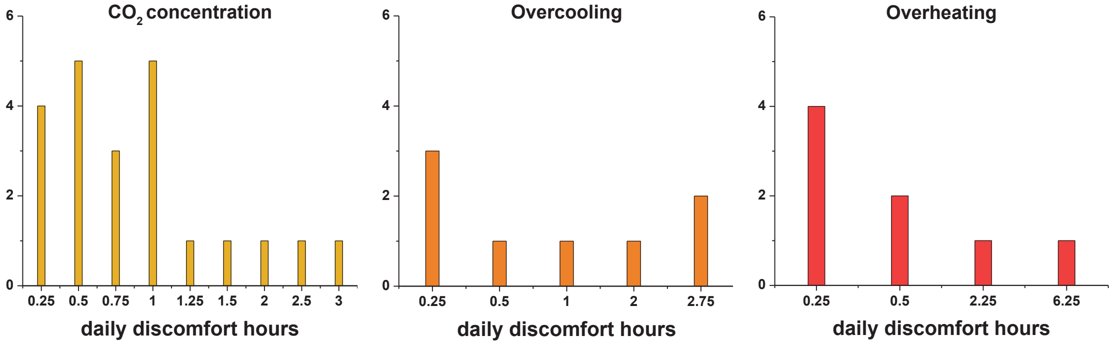
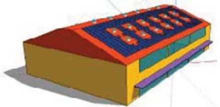
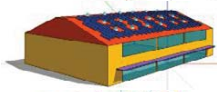
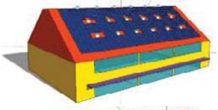
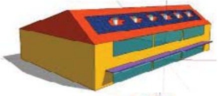
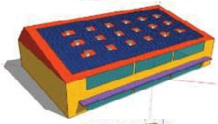
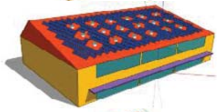
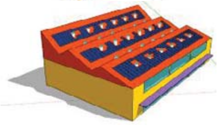
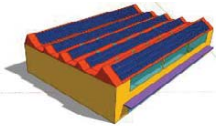


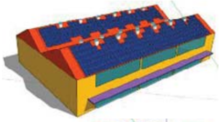
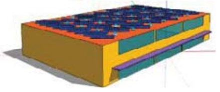
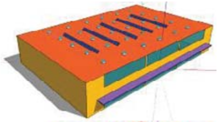
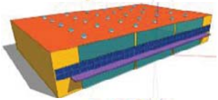
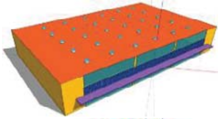
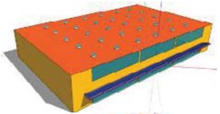
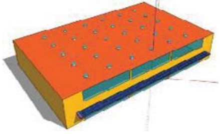
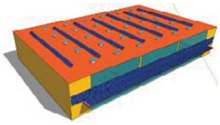
Fig. 6: x-axis= discomfort hours; y-axis=number of day

3.3 PV system

Table 11 summarizes the results of the PV designs analysis. The economic data are extrapolated from Hulb el al. (2014). The comparison of the different PV system configuration suggests that, considering the available surface for PV modules integration and the weather condition of the site, the most advantageous solution is the one tested in case 10. In a range of acceptability of 5%, case 2 and case 6 have similar performance. The mentioned cases are characterized by the installation of the panels with a slope of 38° and an orientation toward the south direction (182°). The integration of the PV panels in the façade and on the shading device of the building results less convenient.

Tab. 11: PV system configurations

		Azimuth	Slope	Panels	kWp	Specific generation (kWh/kWp)	Total generation (kWh)	Specific cost (€/kWh)
1		135	20	367	42	1255	52985	1.11
2		182	38	190	22	1364	29807	1.02
3		135	38	568	365	1267	82746	1.10
4		135	37	162	19	1266	23589	1.10
5		135	14	719	83	1230	101718	1.13
6		182	38	302	35	1371	47623	1.02
7		135	17 23 37	441	51	1245 1256 1265	63583	1.11
8		135	37	600	69	1263 1256 1254 1268 1213	86494	1.11

9		135	34	470	54	1269 1258	68374	1.10
10		182	38	294	34	1381	46680	1.01
11		225	38	60	7	1297	8352	1.15
12		135	90	68	12	876	10606	1.59
13		135	90	56	10	876	8734	1.59
14		180	0	51	6	975	5718	1.43
15		180	0	70	8	979	7882	1.42
16		180 225 134.66	0 37.6 0	265	35	979 1297 876	37442	1.29

Within the 16 tested PV system configurations, case 2 has been selected and simulated in TRNSYS through type 94. The obtained results allow evaluating, for every time step along the yearly simulation, the energy balance between electricity demand and electricity production. According to the TRNSYS calculation, the total annual generation of case 2 is 35'426 kWh. This value differs from the output obtained through Skelion. In this regard, it must be taken into account that weather data and the PV module technical features used by the two software are also different. The PV system is able to cover 10% of the electricity building energy demand, including artificial lighting and ventilation.

3.3.2 Energy balance

From the analysis of the building energy needs, it results that the thermal load necessary to comply with the minimum temperature requirements equals to 213 kWh/y (0.14 kWh/m^{2}y) while the light consumption accounts for 13'968 kWh/y. The electricity demand due to the automation of the natural ventilation systems is estimated at 509 kWh/y. Elaborating the data made available by ICAEN (2012), the obtained results are compared to the heating, lighting and ventilation performance of a standard triple sports hall and of an efficient one, concerning which energy efficacy measured are applied. Additionally, the respective not renewable primary energy requirements are compared in figure 7. It is assumed that the thermal demand of the simulated sports hall is covered by the installation of a condensing boiler (η=1.09) combined with an emission and distribution system consisting of radiant panels (η=0.9). The considered not renewable primary energy conversion factor are 1.954 kWhPE/kWhFE and 1.190 kWhPE/kWhFE, used respectively for electricity and natural gas consumption (RITE 2014). It is evident that the selected energy strategies substantially contribute to the objective of energy consumption reduction set for the simulated building. Overall, it consumes 87.5% less energy than a standard sports hall and 70% less than an efficient one.

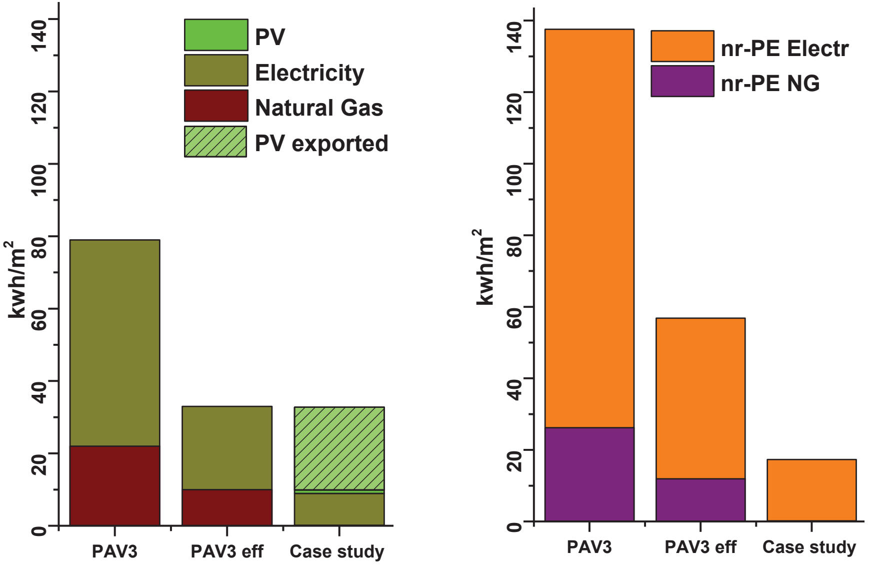


Fig. 7: Left: final energy; right: not renewable primary energy

4. Conclusion

Under a holistic approach, different energy measures to design nearly zero energy Sports halls have been tested. A novel aspect of the study is the focus on the peculiarity of the Mediterranean climate context. The first step of the research involves a field measurement campaign in an existing facility. The obtained data suggest that in a standard sports hall comfort issues are closely linked to indoor air quality. Excess of CO_2 concentration causes discomfort perception, even though the registered thermal parameters fall within the acceptability range. Secondly, TRNSYS simulation confirms that the combination of reduction of thermal transmittance of the envelope, optimization of the window surface, correct façades orientations, introduction of shading devices, installation of energy efficiency systems, and use of natural and night ventilation, is advantageous for the reduction of heating, cooling and artificial lightning demand. The described strategies minimize the period of overcooling and overheating, and provide good air quality conditions for most of the occupied time along one-year simulation. The design of the natural ventilation system and of the relative control play a relevant role. It is estimated that a natural ventilated sports hall, not equipped with a heating system, will be overcooled for 1.69% of the winter occupied time, while CO_2 concentration will exceed normative limits only during 0.95% of the year. It is verified as well that PV system integration positively affects the sports hall performance toward nZEB standards. Future development of the study can involve the evaluation of the sports hall DHW needs and investigate the potential contribution of a thermal solar system. Furthermore, it is important to report that the accuracy of this investigation is compromised by the absence of comfort and thermal standards specifically elaborated for the sports building category.

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