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Research Article

Behavioral variables and occupancy patterns in the design and modeling of Nearly Zero Energy Buildings

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Abstract

The objective of obtaining high performance energy buildings can be reached considering the contemporaneous effects of technical characteristics and occupancy. Recent studies report that as buildings become more energy efficient, the behavior of occupants plays an increasing role in consumption. Therefore, a construction designed to be a Nearly Zero Energy Building (nZEB) might generate higher consumption than expected if the assumptions made in the simulation process are not respected during the real use. The occupant can modify the control strategies of internal variables (heating/cooling system operation, set point temperature, ventilation, lighting) and the users' behavior has a high impact on the utilization of plants and equipment. A significant contribution is also represented by the internal gains that have a direct relation with occupancy. The aim of this study is to assess the influence of housing occupancy patterns on the definition of residential nZEB in Italian climatic conditions. The investigation has been carried out considering a case study consisting of a building designed according to the National Standards. Successively, different conditions of the building usage are analyzed using dynamic energy simulations that allow exploration of the different occupation modes. The variability of the family composition and the occupancy scenarios are defined based on the data collected in the specific context. The investigation provides information regarding the effects of human variables (occupants' needs and preferences) on the final energy performance of low energy buildings and highlights the combination of variables that are important in the definition of nZEB as net zero source energy.

Keywords

zero energy building,
occupant behavior,
occupancy profiles,
electricity consumption

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Architecture and Human Behavior

1 Introduction

According to European Policies, from the end of 2020, all new buildings will be nearly zero energy buildings (Directive 2010/31/EU (European Parliament 2010)). In Europe, the built environment consumes 40% of the produced energy. An increase of building energy performance can constitute a valuable instrument in the efforts to mitigate the EU energy import dependency (currently at about 48%) and comply with the Kyoto Protocol to reduce carbon dioxide emissions. Italy is one of the four countries of EU member states with a higher final energy consumption in the residential and tertiary buildings (Poel et al. 2007). In Italy, out of a total energy use in 2013 of 126.6 Mtoe, the residential and services sector employed 49.6 Mtoe or 39.1% of the total energy use (ENEA 2015).

The 2010/31/EU Directive dictates the Near Zero Energy (nZEB) as the Standard for the new buildings; this means that the "nearly zero or very low amount of energy" required by the building should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced either on-site or nearby (European Parliament 2010). To make a building highly energy efficient, careful design aimed to reduce the energy consumption and to optimize the construction is required. In addition to technical characteristics, operation and maintenance of the building and the action of users are essential. Following this proposal, it is very important to define criteria

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to be applied in order to reach the goal of nZEB.

According to the framework proposed by Sartori et al. (2012), the common denominator for the different possible nZEB definitions is the balance between weighted demand and supply.

The general definition proposed by Torcellini et al. (2006) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied by renewable technologies. The concept of a zero energy building can be defined in some ways, determined by the boundary and the metric. Four of the most used definitions are: net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. A building may be designed to achieve one or more nZEB definition, but may not reach a net-zero energy position in operation every year. Williams et al. (2016) emphasize the importance of having an international universal zero energy Standard because, while the definition of zero carbon buildings can be relevant, actually the number of buildings built has been small and uncommon, and, moreover, the specific requirements have not been stipulated (Mlecnik et al. 2012).

On the other hand, it is necessary to understand how people behave and how they operate the systems for controlling indoor environment and comfort conditions (Frontczak and Wargocki 2011). Now, with the implementation of new technologies oriented to energy saving and green building certifications, a new approach has emerged and is related to how it affects the use of energy due to occupant behavior (IEA 2015). Recent studies report that as buildings become more energy efficient, the behavior of occupants plays an increasing role in consumption (Yan et al. 2015; de Wilde 2014; Wei et al. 2014). The passive and active effects of the occupant interactions with the building have to be taken into consideration. More emphasis on nZEB is required because these are primarily heated by the sun, the users' metabolic heat (called passive effect) and by heat emitted from domestic electrical appliances (called active effect). Wei et al. (2014) identified 27 factors influencing occupant space-heating behavior and demonstrated the relevance of the factors related to the users described as occupant age, occupant gender, household size and others. de Meester et al. (2013) evaluated the influence of three parameters about human behavior (family size, management of the heating system and heated area) and the results showed the importance of the insulation levels in Belgian climatic conditions. Martinaitis et al. (2015) investigated the importance of occupancy information through dynamic energy simulation, varying occupancy profiles (standard profile, household consists of 4 persons, retired couple, and young couple), heating strategies, ventilation and lighting control and evaluated the influence of climate. The results in terms of primary energy demand for the occupancy profile of 4 persons reveal differences below 5% compared with the standard profile, while for the other two profiles it varied from 14% to 21% in relation to the default profile. The influence of dwelling and occupant characteristics on domestic electricity consumption patterns was analyzed by statistical approaches in (McLoughlin et al. 2012). The authors found that dwelling type, number of bedrooms, and household composition had a significant influence on the total domestic electricity consumption. Furthermore, Chen et al. (2013) determined that occupant age is a more important factor than income and revealed that the household socio-economic and behavior variables can explain 28.8% of the variation in heating and cooling energy consumption.

Some studies on the effect of occupant behavior in nZEB have been specifically developed. Barthelmes et al. (2016) investigated a residential nZEB located in Northern Italy by means of energy simulations. The authors took into consideration different occupant behavior lifestyles (low consumer, standard consumer and high consumer) and household composition (family of 4 people, old couple and young couple) to evaluate their effect on energy performance and thermal comfort conditions. The high impact of these two variables was demonstrated. Also, it was concluded that the variation of different types of households increases the discrepancy of the final energy consumption in the several scenarios (~240%). Brahme et al. (2009) compared the impact of occupant behavior of a typical and high efficiency residence. They considered three profiles of users (conservation behavior, design point, and wasteful behavior) and concluded that conservation oriented behavior could reduce energy consumption by nearly half in a high efficiency residence. Love (2012) examined the impact of different occupant heating behaviors on a typical semi-detached UK dwelling. The researchers evaluated three different behaviors scenarios (low, middle and high) and three aspects were defined: set point temperature, number of heated rooms, and daily heating periods. They found applicable results about policy regarding the occupant effect in inefficient dwellings and the necessity of selecting the right policies and behavioral change programs.

Some authors considered the effects of occupant variables in high energy efficiency buildings. Mlecnik et al. (2012) conducted end-user surveys of low-energy houses in Germany, Switzerland, and Austria to determine levels of satisfaction, considering various comfort parameters such as winter thermal comfort, summer thermal comfort, indoor air quality, and acoustics with the intention to provide recommendations for the improvement of quality and comfort and promoting nearly zero energy dwellings. The main problems reported are related to the perception of insufficient summer comfort and/or air quality. Lenoir et al. (2011) presented a study regarding the importance of the user's behavior to calculate the energy consumption in high-performance buildings taking into consideration measurements during the operation of the building for parameters such as ventilation and air-conditioning, lighting, plug loads and UPS (Uninterruptible Power Supply), lifts and ceiling fans and compared with data obtained during design phase. From this comparison, the authors concluded that the differences between the design calculations and the measurements can be up to 50%. There are further examples available in literature that demonstrated that a construction designed to be a Nearly Zero Energy Building might generate higher consumption than expected if the assumptions made in the simulation process are not respected during the effective use.

Becchio et al. (2016) evaluated the energy performance of a high-performance building in the Italian context and identified a large difference between the energy consumptions calculated during the design phase and the monitored phase: +50% for space heating, +19% for DHW and +16% for electricity uses. The authors concluded that these differences were not related to the building features, but, instead, to the occupant behaviors.

A study developed in the UK (Gill et al. 2010) on a site of 26 "low energy" dwellings evaluated the energy performance of the buildings in terms of water and electricity consumption, and the comfort of users. The authors identified differences in consumption of similar homes by using behavioral surveys and statistical analysis. The researchers found that energy efficient behaviors account for 51%, 37%, and 11% of the variance in heat, electricity, and water consumption, respectively.

In fact, in order for the occupant to reach his comfort condition, he can modify control parameters (thermostat set point, ventilation rate, lighting level and equipment use) invalidating the ideal designed efficient model. For this reason, it is essential to establish the right hypotheses on the air conditioning schedule, utilization of appliances, and comfort level of the building in order to obtain a proper evaluation of the energy consumed in the actual building operation. In nZEB, indoor comfort (thermal and visual) should be achieved mainly thanks to free resources of energy such as solar radiation and natural ventilation. Consequently, the users' behavior has a high impact on the final energy use depending on the correct utilization of passive systems and the operating of active technologies. In low energy buildings, a significant contribution is also represented by the internal gains, and these have a direct relation with the users' behavior and occupancy. The role of the occupant in the building performance and in the resident's perception of low energy homes is not yet known (Berry et al. 2014; Judd et al. 2013). Marshall et al. (2016), investigated how occupancy patterns affect domestic energy consumption and energy savings for a broad range of Energy Efficiency Measures (EEMs), and the results explain that energy consumption depends on the appropriate matching between energy efficiency measurements and occupant type.

Brandemuehl and Field (2011) studied the effect of occupant behavior in residential nZEB located in different states of the United States to evaluate the effect of house type and climate in the ability to achieve a zero energy goal. The comparison between a conventional single-family residence and a very energy efficient single-family residence confirmed that random fluctuations in the schedules and the level of miscellaneous electrical loads have the highest influence on the second group. Murano et al. (2016) demonstrated that the effect of the outdoor climatic data is an important factor in the evaluation of the energy performance of building and is crucial for nZEB.

The aim of this paper is to evaluate the influence of user patterns on the energy consumption of a residential nZEB in Mediterranean climatic conditions. Furthermore, the investigation takes into account the socio-demographic context by means of the collection and accurate analysis of national and local statistical data. The definition used to develop the building model is net zero source energy and a case study was built according to the CEN. EN ISO 13790 (CEN 2008) and European Directive (Directive 2010/31/EU (European Parliament 2010)) that have been applied by considering its transposition in National Standards, UNI TS 11300-1, UNI TS 11300-2 (UNI 2014a,b) and Regulations (D.M. 26/6/2015-1 2015). The study considers the variability of the family composition and the occupancy scenarios. Furthermore, the needs and preferences of occupants in using energy systems and equipment are included in the energy performance assessment.

The investigation was conducted by considering important aspects contemporaneously: nZEB definition and technical issues, application of Standards and Regulations that do not consider the "occupancy" variable in their formulation, adaptability of renewable energy systems in relation with the occupancy profiles, identification of a simple method for creating housing occupancy patterns by using free available data.

2 Methodology

An energy efficient building was designed according to the Italian Standard (D.M. 26/6/2015-1 2015). The construction was intended to consume low energy: the ratio between dispersing surface and air conditioning volume is set to minimize losses; all the housing components are well insulated; the air conditioning system has high efficiency and uses energy from renewable sources available on-site.

However, the actual consumption for the management of the house depends on the type of family occupying the dwelling and on the interaction of the occupants with it. Two different occupancy scenarios, defined according to statistical data (ISTAT 2014a), were proposed in order to understand how the occupancy typology and the various modes of use of the house and its facilities can affect energy consumption. For each occupancy scenario and mode of use, the annual energy balance in terms of primary energy (kWh/(m²·year)) was considered with the aim of verifying the achievement of the nZEB objective. Dynamic energy simulations were carried out by using DesignBuilder (2015).

Regarding climatic conditions, Meteonorm (2016) file for the City of Cosenza, Calabria Region (South Italy) was adopted. The site, classified as "Csa" according to the Köppen climate classification (Kottek et al. 2006) is characterized by a typically Mediterranean climate, with hot and dry summers and mild, wet winters, resulting in a dominant cooling demand. The mean annual value of the outdoor dry bulb temperature is equal to 16.3 °C; the direct normal solar radiation is 1564.8 kWh/year and the diffuse solar radiation on the horizontal plane is 613.8 kWh/year. The heating system functions from 15th November to 31st March, according to Italian Regulations for climatic zone C (HDD=1317), in which Cosenza is located (DPR 412/93 1993). The cooling season is comprised of the remaining months, and the cooling system operates only when the internal temperature exceeds the set point value.

2.1 The building design

The building is a two-storey detached house with a total net area of 110 m². The ground floor consists of the living area while bedrooms are on the first floor. The building is characterized by a low surface area to volume ratio (S/V=0.82 m^{-1}) in order to reduce heat losses. The main exposure is to the south and presents wide glazed surfaces to maximize solar gains in winter. The window to wall ratio is 27% on the south wall and horizontal louvers on the windows prevent overheating in summer. The roof is flat with an additional architectural element that fits with the main volume and provides a 30° tilted pitched roof suitable for the installation of solar systems. Figure 1 illustrates the plans of the two-storey house while the DesignBuilder (2015) model is presented in Fig. 2.

The structure is in masonry, and the external walls are in thermal bricks with exterior insulation and finishing system; the total thickness is 43 cm. The ground slab and the roof are also thermally insulated, with a total thickness of 34 cm and 35 cm, respectively. Characteristics of the building envelope are analyzed in terms of thermal transmittance U [W/(m²·K)]. For external walls and roof, exposed to solar radiation, also the thermal mass M_s [kg/m²] and time lag φ [h], are reported (Table 1).

Window frames are metallic with thermal break. For the south and west exposures, low-e double glass with Argon are used, while north facing windows use low-e triple glass with Argon. In Table 2, the thermal transmittance (U), the solar heat gain coefficient (SHGC), and the visible transmittance (VT) of the windows are shown.

The infiltration flow rate of 0.3 ach was assumed according to UNI TS 11300-1 (UNI 2014a). The total value of the internal gains is calculated with the relation (UNI 2014a):

$$\Phi_{\text{int}} = 7.987 A_{\text{f}} - 0.353 A_{\text{f}}^2 \quad [\text{W}] \tag{1}$$

where A_{f} is the net floor area of the dwelling. An internal load of 4.104 W/m² is obtained.

The air conditioning system consists of an electric air to water heat pump with a coefficient of performance (COP) equal to 3, and an energy efficiency ratio (EER) of 3. Fan coil units are used for both the heating and the cooling seasons.

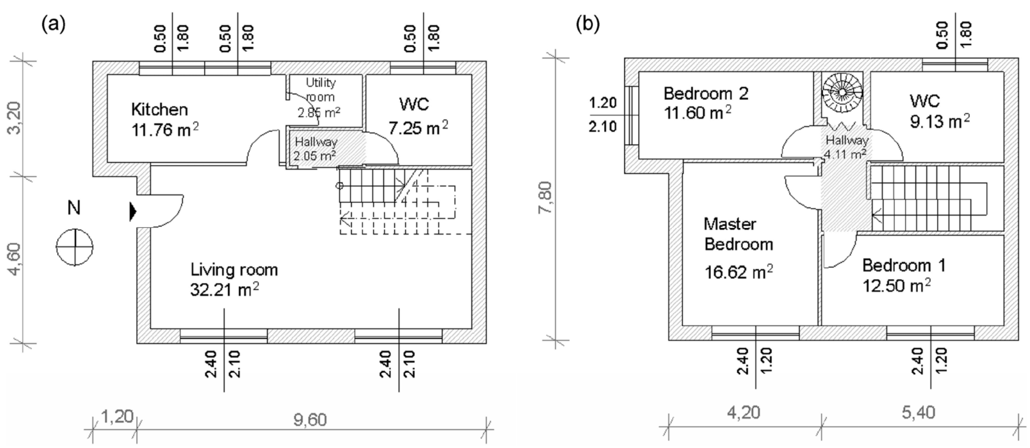

Fig. 1 Detached house plans: (a) ground floor and (b) first floor

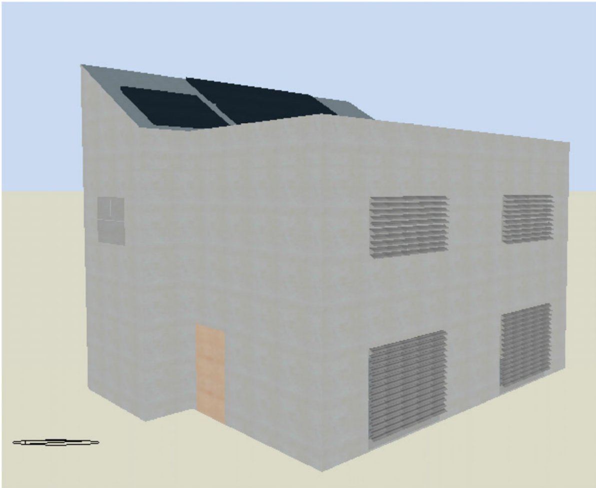

Fig. 2 DesignBuilder model of the designed nZEB

Table 1 Characteristics of the opaque components of the building envelope

	U [W/(m²·K)]	M_s [kg/m²]	φ [h]
External walls	0.225	321	23.63
Ground slab	0.305	—	—
Roof	0.285	271	9.61

Table 2 Characteristics of the windows

	U [W/(m²·K)]	SHGC	VT
South and west facing windows	1.873	0.670	0.540
North facing windows	1.546	0.512	0.680

A photovoltaic system provides electricity production on-site. Ten grid-connected modules are assembled in two strings, with a total installed peak power of 2.5 kWp. A 3 kW inverter is used. Its efficiency was fixed to 0.90, lower than the maximum value (0.95) in order to consider the degrading effect which takes place when operating at low power levels. PV characteristics are shown in Table 3.

Solar collectors, with characteristics illustrated in Table 4, are used for the DHW production. A total absorbing surface of 4 m² is installed with reference to a DHW requirement of 1.40 L/(m²·day), calculated according to the Standard UNI TS 11300-2 (UNI 2014b) and a 300 l storage tank is provided. Both solar collectors and PV modules are in adherence to the pitched roof with a slope of 30° and south facing in order to maximize productivity.

In Table 5 the main features of the building energy model are summarized.

2.1.1 *nZEB design according to the Italian Standard*

According to the Regulations currently in force in Italy, a nearly zero energy building is a building, whether existing or newly built, meeting specific technical requirements (D.M. 26/6/2015-1 2015):

1) $H'_{\mathrm{T}} < H'_{\mathrm{T,lim}}$

H'_{T} represents the mean heat transfer coefficient, calculated by the relation:

$$H'_{\mathrm{T}} = H_{\mathrm{tr,adj}} / \sum_k A_k \quad [\mathrm{W/(m^2 \cdot K)}] \tag{2}$$

$H_{\mathrm{tr,adj}}$ is the global heat transfer coefficient of the building envelope calculated with reference to the Standard UNI TS 11300-1 (UNI 2014a), A_k is the k-th component surface of the envelope.

The value of the parameter H'_{T} must be lower than a limit value, defined according to the climatic zone and the S/V ratio. For the designed model, located in the climatic zone C and having an S/V ratio equal to 0.8, $H'_{\mathrm{T,lim}}$ is equal to 0.55 W/(m²·K) while the calculate value of H'_{T} is 0.37 W/(m²·K). Therefore, the first requirement is satisfied.

Table 3 Technical characteristics of the PV modules

Typology	Absorption area [m²]	Maximum power at STC ($P_{\max}$) [W]	Module efficiency η_m [%]
Polycrystalline silicon PV panel	1.48	250	15.2

Table 4 Technical characteristics of the solar collectors

Typology	Absorption area [m²]	Efficiency η_0[%]	Coefficient of heat loss k_1 [W/(m²·K)]	Coefficient of heat loss k_2 [W/(m²·K)]
Flat plate solar collector with selective coating	1.97	70.2	−3.2828	−0.00992

Table 5 Summary of the designed building energy model

Net surface area	110 m²
Number of floors	2
Total dispersing surface (S)	405.96 m²
Gross air conditioned volume (V)	492.75 m³
S/V	0.82
Window to wall ratio (south)	27.5 %
Window to wall ratio (west)	4.1 %
Window to wall ratio (north)	4.2 %
Infiltration rate	0.3 ach
Internal loads	4.104 W/m²
Heating/cooling system	Electric air to water heat pump with fan coils
Solar collector surface area	4 m²
Photovoltaic power peak	2.5 kW$_{\mathrm{P}}$
Photovoltaic surface area	14.78 m²

2) $(A_{sun}/A_{us}) < (A_{sun}/A_{us})_{lim}$ (3)

A_{sun} is the sum of the solar summer equivalent areas determined for each window with the relation:

$$A_{sun} = \sum_k F_{sh,ob} \cdot g_{gl+sh} \cdot (1 - F_F) \cdot A_{w,p} \cdot F_{sun} \quad [m^2] \tag{4}$$

$F_{sh,ob}$ is the reduction factor for shading related to the external elements for the solar collection area of the *k*-th window, for the month of July. g_{gl+sh} is the total solar energy transmittance of the window calculated in July, when the solar shading is applied. F_F is the fraction area of the frame, obtained by the ratio between the area of the frame and the total area of the window. $A_{w,p}$ is the window area. F_{sun} is the correction factor for the incident radiation, derived as the ratio of the average irradiance in July, for the location and for the considered exposure, and the average annual irradiance of Rome, on the horizontal plane. The Standards UNI TS 11300-1 (UNI 2014a) and UNI 10349 (UNI 1994) provide all these terms.

A_{us} represents the useful floor area of the dwelling [m^2]. The limit value of this parameter is established by the regulation equal to 0.30 while the calculated value for the building is 0.022.

3) The performance indices:

$EP_{H,nd}$: useful thermal performance index for winter conditioning [kWh/(m^2·year)]

$EP_{C,nd}$: useful thermal performance index for summer conditioning [kWh/(m^2·year)]

$EP_{gl,tot}$: global energy performance index [kWh/(m^2·year)] must be lower than the value of the same indices calculated for a reference building.

Table 6 summarizes the results obtained for the energy performance indices of the designed building, compared with the respective limit values.

4) The efficiencies of the heating, cooling and hot water systems (η_H, η_C, η_W) must be higher than the limit values ($\eta_{H,lim}$, $\eta_{C,lim}$, $\eta_{W,lim}$).

In Table 7 the efficiency of the adopted plants is reported together with the efficiencies of the reference systems.

Table 6 Energy performance indices of the designed building and limit values [kWh/(m^2·year)]

$EP_{H,nd}$	$EP_{H,nd,lim}$	$EP_{C,nd}$	$EP_{C,nd,lim}$	$EP_{gl,tot}$	$EP_{gl,tot,lim}$
18.9	30.1	13.5	13.7	50.7	91.6

Table 7 Efficiency of the adopted plants and limit values

η_H	$\eta_{H,lim}$	η_C	$\eta_{C,lim}$	η_W	$\eta_{W,lim}$
0.9	0.6	2.2	0.9	0.6	0.5

5) Finally, a given amount of energy produced from renewable sources for electricity, domestic hot water (DHW), heating and cooling must be fulfilled. In particular, energy from renewable sources should cover 50% of the DHW consumption, and the minimum installation is of 2 kW per 100 m^2 of photovoltaic peak power is required (D.Lgs. 28/2011 2011).

Both the solar thermal and the photovoltaic system have been sized in compliance with these minimum requirements.

2.2 Occupancy scenarios and house management

The building is now defined by its physical characteristics and it is classified as nZEB according to the Italian Standard. However, different types of households could occupy the house. Moreover, the family members, following their typical habits and needs, may decide to use the amenities of the dwelling differently. Therefore, the actual consumption of the building may differ from that estimated, negating the “zero” balance. In order to analyze the variability of consumption under different types of occupancy, the use of the house by different family typologies has been supposed. Two occupancy scenarios have been created from statistical data, describing the socio-demographic situation of the concerned area.

Data regarding the “family structure” provided by the National Institute of Statistics ISTAT (2014a) report that in the region of Calabria, four-component households account for the majority in families with children, representing 46% of the total in the last two years. Consequently, the first selected scenario for the occupancy of the house consists of a four-member family (F4); in this case, all the rooms of the house are generally occupied.

The second scenario has been assumed considering that the house could be inhabited by a two-member family (F2), for example, a young couple that occupies only a few rooms in the house, while others are not used.

Figure 3 displays the management of the rooms in the two different occupancy scenarios.

2.2.1 *Occupancy profiles*

Occupancy density [person/m^2] is calculated for each room and varies according to the number of components. To define how much time people spend at home, data on time use provided by ISTAT (2014a) have been examined. The respondents reported the daily time dedicated to different activities for each interval of 10 minutes. In particular, investigations on the activities were carried out and allowed for identification of the total number of hours that a person spends on average at home, in relation to the size of the family. With reference to a “weekly average day”, a person

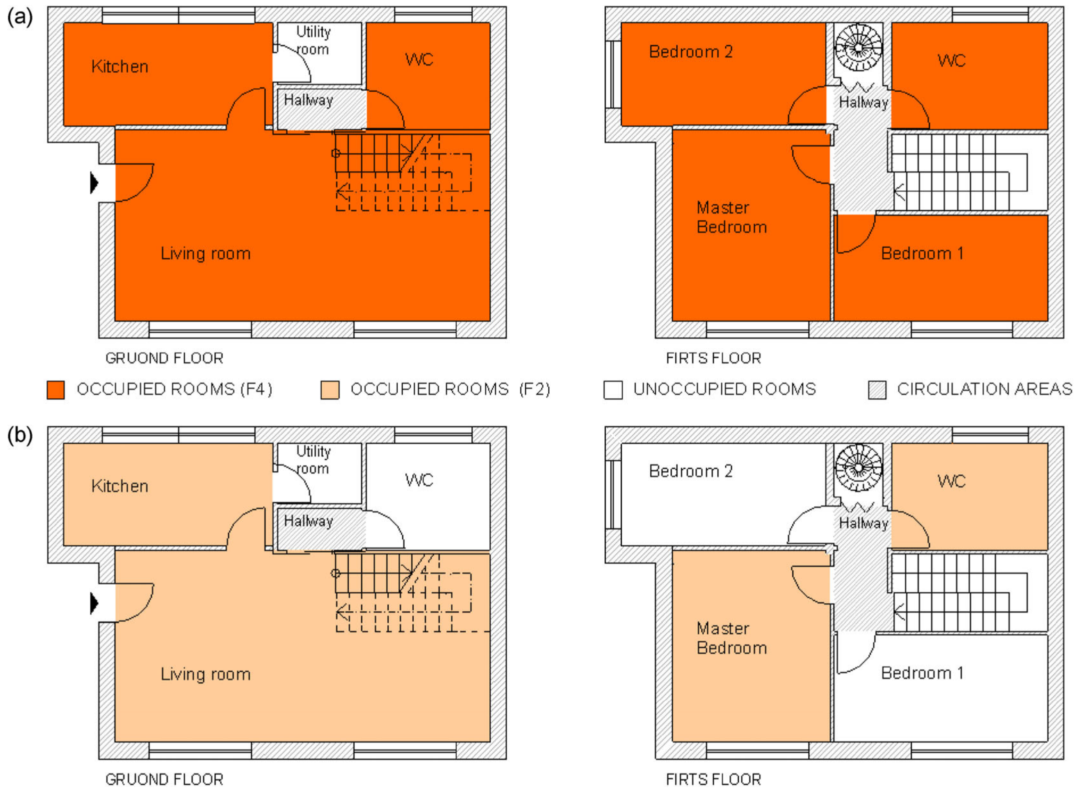

Fig. 3 Use of the dwelling in occupancy scenario F4 (a) and occupancy scenario F2 (b)

spends on average 16 hours per day at home for a family of four, while 17 hours per day are spent at home in the case of a two-member household. Data showing the frequency of people participation in the frequented places have been considered to identify the periods of time during the day when people are at home (see Fig. 4).

The time ranges reveal that the greatest percentage of people at home is overnight and in the early morning, in two hours at lunch, and in the evening after 7 p.m.

Combining the information about the number of hours of presence at home and the most populated time bands, occupancy profiles for the average weekly day have been constructed for both F4 and F2 scenarios, as shown in Fig. 5.

2.2.2 *Lighting*

Statistical data (ISTAT 2014b) show that for the considered geographic area, artificial lighting is used on average less than four hours per day (about 75%). 22% of people use artificial lights from 4 to 12 hours per day and only a very small fraction (3%) turns on the lights for more than 12 hours per day. Consistently, in the designed building the use of artificial lighting has been set at less than four hours in

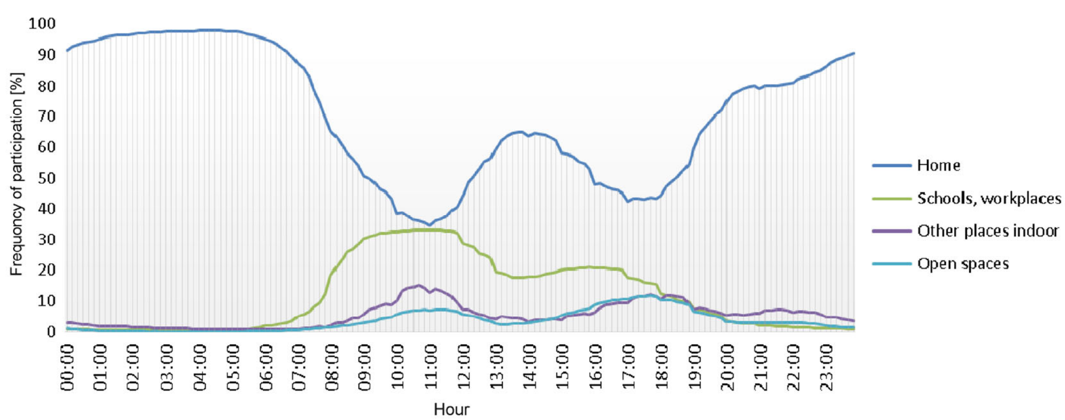

Fig. 4 Frequency of participation of people to the places frequented in a weekly average day (ISTAT 2014a)

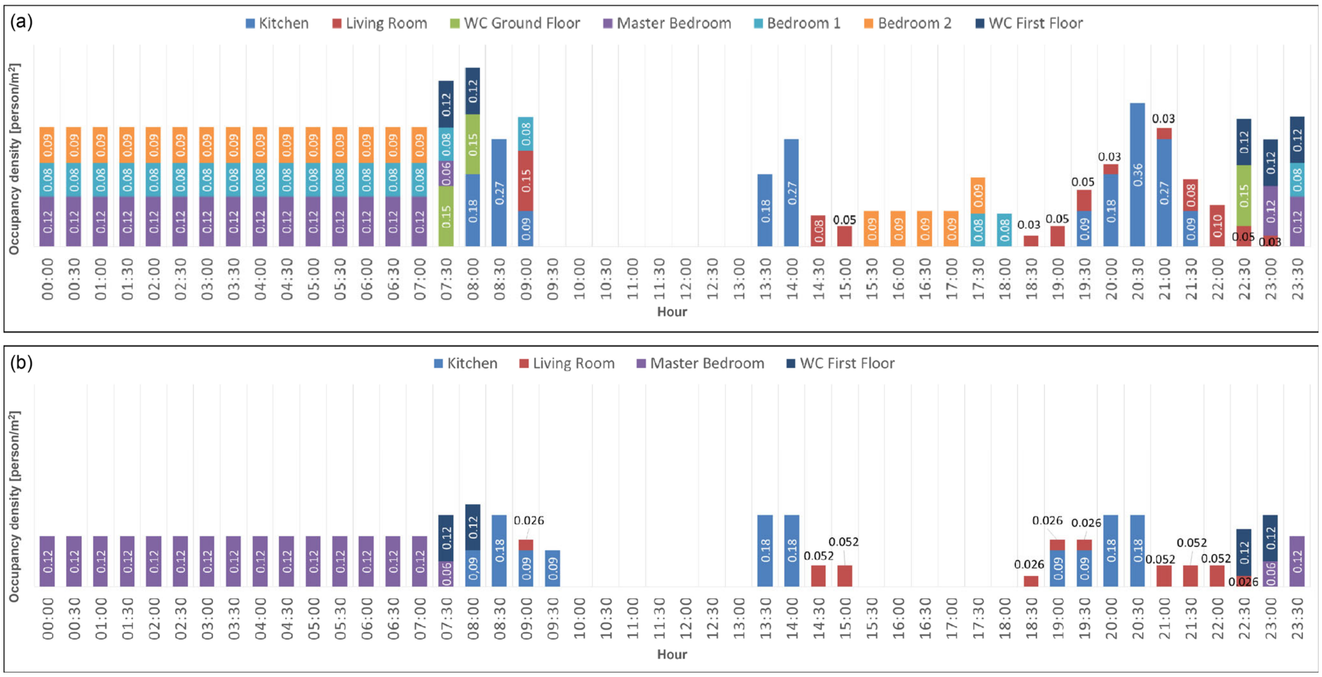

Fig. 5 Occupancy profiles for the F4 (a) and F2 (b) occupancy scenarios for an average weekly day

each room. Furthermore, two types of lighting have been analyzed in the study: traditional light bulbs, for example halogen bulbs, with a lighting power density (LPD) equal to 10.2 W/m^2, and energy saving light bulbs, such as compact fluorescent lights (LPD=7.5 W/m^2).

2.2.3 *Equipment*

The provision of dwelling appliances is typical of a contemporary house (ISTAT 2014b). The appliance typology and positioning for both the family compositions is shown in Table 8.

Table 8 Equipment positioning and usage for the considered families F4 and F2

Room	Equipment	Equipment power density [W/m^2]		F4		F2	
		Label A	Label G	Frequency of use	Hours of use	Frequency of use	Hours of use
Kitchen	Fridge-freezer	3.25	8.13	Every day	Always ON	Every day	Always ON
	Oven	71.24	160.28	2 times per week	1	1 time per week	1
	Dishwasher	89.05	222.62	6 times per week	1	4 times per week	1
	Vacuum cleaner	89.05		1 time per week	0.083	1 time per week	0.083
Living room	Stand-by	0.13		Every day	Always ON	Every day	Always ON
	TV 40″ + decoder	2.26	7.53	Every day	4	Every day	4
	Iron	38.95		1 time per week	0.5	1 time per week	0.25
	Vacuum cleaner	25.97		1 time per week	0.083	1 time per week	0.083
WC ground floor	Hairdryer	224.55		Every day	0.16	—	—
Master bedroom	Stand-by	0.19		Every day	Always ON	—	—
	TV 32″	2.48	8.51	1 time per week	1	—	—
	Vacuum cleaner	62.15		1 time per week	0.083	1 time per week	0.083
Bedroom 1	Vacuum cleaner	82.78		1 time per week	0.083	—	—
Bedroom 2	Laptop	3.12		Weekdays	1	—	—
	Vacuum cleaner	89.05		1 time per week	0.083	—	—
WC first floor	Washing machine	273.99	554.91	6 times per week	1	3 times per week	1
	Hairdryer	173.41		Every day	0.16	Every day	0.16

The frequency and hours of use were defined by considering available statistical data. In particular, the ISTAT survey reveals the use of the washing machine and the dishwasher on variation of the family size, as illustrated in Fig. 6.

Generally, a family of four components, on average, does about six washing machine and dishwasher washings per week, while a two-member family uses the washing machine three times per week, and the dishwasher four times per week.

Since the building is expected to be zero energy, the installation of low energy appliances is suggested. However, in order to evaluate the influence of the energy efficiency of the equipment on the annual consumption of the house, the use of different energy labeled household appliances has been analyzed (see Table 8), considering different levels of energy efficiency for appliances for which energy labelling is mandatory (Commission of the European Communities 1992; ENEA 2013).

2.2.4 Heating and cooling system

Settings on the operation of the heating and cooling systems have been made according to statistical information for the considered climatic conditions (ISTAT 2014b).

The heating system, on average, is switched on for about seven hours per day, while the cooling system operates four hours per day. The hourly distributions are shown in Fig. 7.

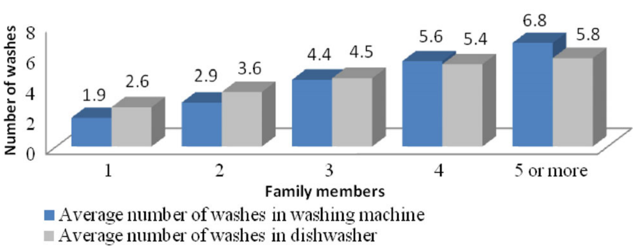

Fig. 6 Average number of washing machine and dishwashing washings per week, at the variation of the number of family members (ISTAT 2014b)

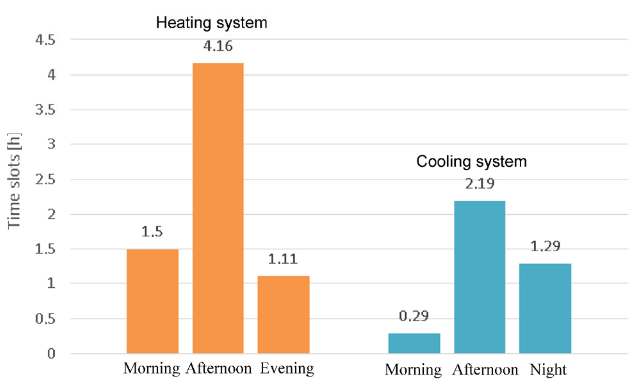

Fig. 7 Average daily hours per time slot of operation of the heating and cooling system for winter day and summer day (ISTAT 2014b)

2.2.5 DHW production

The demand of domestic hot water has been fixed in 60 L/day per person (Engineering & Construction 2010), with 55 °C hot-water temperature production. The solar system is prioritized for the production of the DHW. However, an integration system is provided to satisfy the DHW demand when the solar source is not sufficient, consisting of an electrical resistance with a maximum heater capacity of 1.5 kW installed in the 300 liters storage tank.

3 Behavioral variables

Thanks to statistical information from the Italian National Institute for Statistics (ISTAT 2014a), two occupancy profiles have been formulated. Therefore, the use of the house by families with diverse sizes implicates differences in the number of rooms generally used and in the occupancy density of each room. Also, the utilization of heating and cooling systems, DHW, lighting, and household appliances has been defined.

However, variables related to the users' choices regarding heating and cooling set point temperature, and ventilation control strategies are not provided by the statistical survey. With reference to these variables, occupants can behave differently in the house management. In particular, a category of users could have a more aware behavior aimed at saving energy. On the other hand, users could also have a wasteful behavior, without caring about the amount of energy spent and often persisting in squandering habits. In many studies considering different occupancy profiles in energy consumption investigations, differences in baseline temperature assumptions were considered to assess their impact. Set point temperatures have been chosen by individual approaches, such as starting from values of local Standards (Martinaitis et al. 2015), in other cases the set point values were estimated by means of contextual data (Hong and Lin 2012; Barthelmes et al. 2016).

In order to analyze the impact of occupants preference on final energy consumption, and therefore, on actual building nZEB performance, different behaviors have been analyzed for both F4 and F2 family models. The set point temperatures were established by assuming the reference values indicated in the Standards and Regulations (UNI TS 11300-1 2014) in order to define the medium profile. Saver and Waster behaviors were obtained by considering lower and higher set point temperature values, respectively.

- Saver—"S": set point temperature is 19 °C for heating and 27 °C for cooling. Ventilation takes place when the plant is switched off: half an hour before turning on the system in the morning in the bedroom area and half an hour before turning on the system in the afternoon in the living area.

- Medium—"M": heating set point temperature is 20 °C, while cooling set point temperature is 26 °C. Ventilation is the same for all areas, from 7:00 to 8:00 in the morning and in all the rooms, and it overlaps in part with the period when the plant is switched on.
- Waster—"W": the user who does not care about energy saving sets the heating temperature at 23 °C and the cooling temperature at 24 °C. He opens the windows when the system is operating.

Both family compositions have been simulated with the three occupants' behaviors typologies and considering, alternatively, the installation of traditional or low energy consumption appliances and lights.

4 Results and discussion

The designed house is an "all-electric" building; no fossil sources are used to satisfy the energy services provided to the dwelling. The PV plant produces 3383 kWh/year. In order to verify whether the building performs at the zero energy definition, the annual net energy balance between the consumed electricity and the electricity produced through the on-site photovoltaic system has been considered.

Figure 8 shows the annual energy balance carried out for all the analyzed scenarios.

The results demonstrated that in the case of using no energy saving appliances and traditional lightings the annual energy balance is always negative. A positive balance is achieved only in the case of a two-member family who uses the house partially, and by equipping the rooms with energy efficient appliances and lights. Moreover, it is noteworthy that even in this configuration, if the users belong to the category of "Wasters", the annual energy balance is negative.

Consequently, the house that is classified as a nearly zero energy building according to the calculation procedure proposed in the National Regulations cannot satisfy this qualification because it consumes more energy than it produces throughout a year.

Further processing of the results has been made in order to more thoroughly investigate the reasons for this inconsistency.

First of all, the incidence of the different energy uses on the total annual consumption has been determined.

In particular, the percentages of the annual total energy consumption for the different family scenarios, occupant behaviors, and both the equipment and lighting typologies are represented in Fig. 9.

The incidence of various electric uses on the total consumption of the house seems to be the same for both the cases "NO-energy saving lights and equipment" and "Energy saving lights and equipment." In particular, it is worth highlighting that in all the analyzed cases, the household appliances are responsible for the major fraction of electrical consumption of the dwelling. Moreover, it is interesting to note that moving from the Waster profile to the Saver one, the percentage of consumption attributable to household appliances, artificial lighting, and domestic hot water production tends to have an increasing impact on the total consumption, while the energy for heating, cooling and plant auxiliary decreases with the improvement of occupant behavior. In the case of the use of traditional household appliances, the equipment consumption reaches 65% while using energy efficient equipment their consumption weights up to a maximum of 50% and more influence is associated with heating, cooling and DHW. The fraction of consumption due to artificial lighting varies from 7% to 10%.

The energy produced on-site is not enough to cover all the energy uses of the house. Thus, the building classified as nZEB according to the Italian Regulations is not zero energy. The reason is that Italian Legislation does not consider electrical purposes (lighting and appliances) in the calculation of the energy performance of buildings, and consumptions associated with these uses tend to have an increasing importance upon the decrease of consumption for air conditioning. This means that the more the building is carefully designed to contain the energy demand for

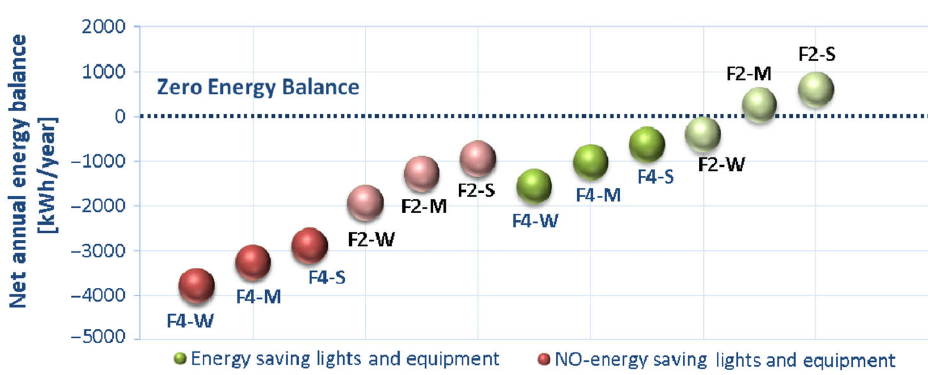

Fig. 8 Net annual energy balance of the building for the F4 and F2 occupancy profiles, in presence or absence of low energy consumption lighting and household appliances, and for three different occupants' behaviors (Waster, Medium, Saver)

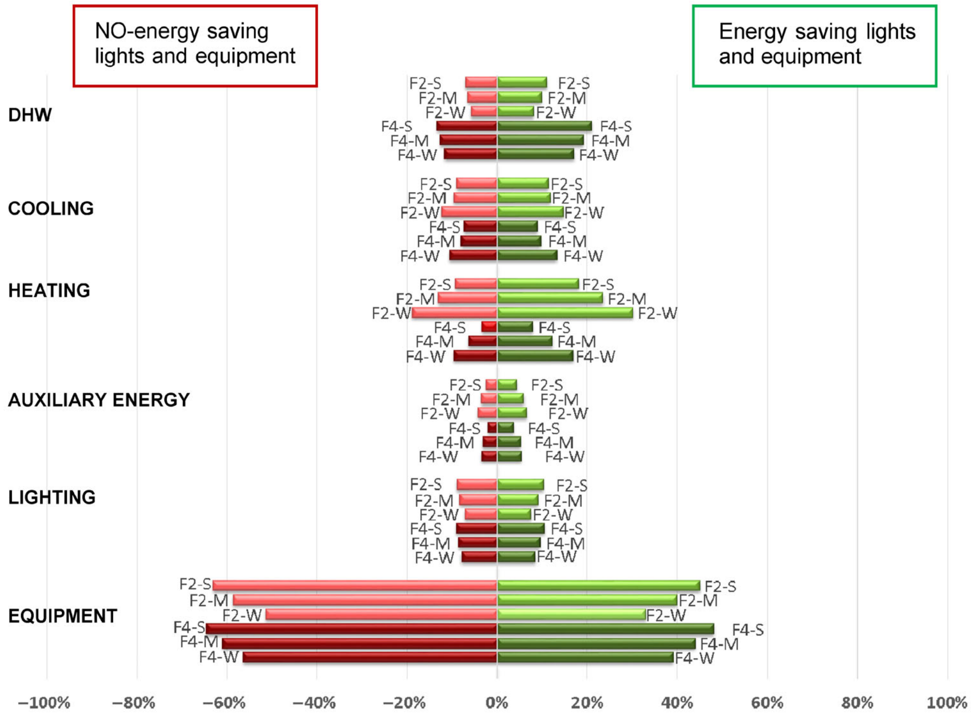

Fig. 9 Influence of separated energy uses on final energy consumption upon variation of family size, occupants' behavior, and equipment typology

winter heating and summer cooling, the more electricity consumption for lighting and appliances has a higher weight in the final energy balance.

The building designed according to the reference calculation model certainly offers good performances in terms of air conditioning energy requirements and hot water production. In fact, considering only the consumption for heating, cooling, DHW, and auxiliary systems, the annual energy balance is positive for all the occupancy profiles and utilization modalities, as reported in Fig. 10.

The amount of surplus energy, over these uses, allows the fulfillment of a certain percentage of consumption for lighting and equipment, that is variable depending on occupancy scenarios as shown in Table 9. The remaining fraction is the amount off-balance, which therefore leads to the annual deficit.

Since the consumption of the F2 profile for air conditioning and DHW is lower than that obtained for the F4 profile, a greater amount of useful energy exploitable for the other electrical uses of the rooms is available. The same consideration can be stated for the profiles with energy saving equipment and lights compared to the ones with traditional facilities: the former offers more possibilities than the latter to meet other energy needs in addition to heating, cooling and DHW.

However, the family composition and the set of appliances and lights being equal, the occupants' behavior makes the difference. The behavioral variables related to the choice of

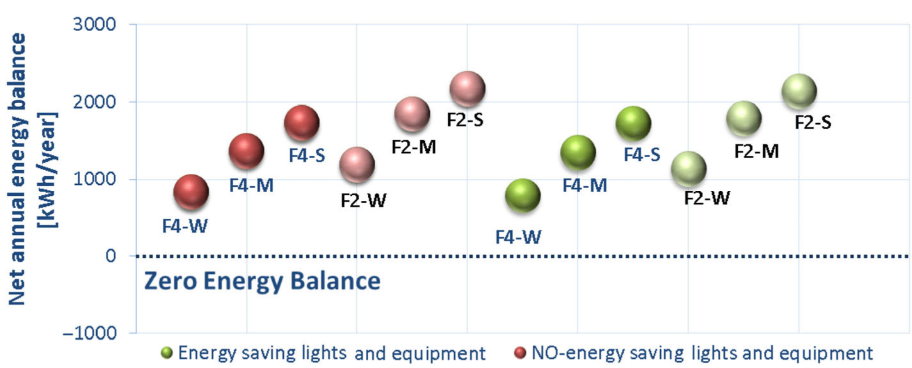

Fig. 10 Net annual energy balance considering only consumption for heating, cooling, DHW and auxiliary energy

Table 9 Percentage of consumption for appliances and lighting that can be satisfied through the on-site PV system in addition to air conditioning, DHW, and auxiliary energy

NO-energy saving lights and equipment						Energy saving lights and equipment					
F4-W	F4-M	F4-S	F2-W	F2-M	F2-S	F4-W	F4-M	F4-S	F2-W	F2-M	F2-S
18%	30%	37%	38%	59%	70%	33%	57%	73%	74%	>100%	>100%

heating/cooling set point temperature and ventilation habits allow having larger or smaller quantity of energy available for other uses. The cases F2-M and F2-S, as previously affirmed, have a positive balance. In all other cases, the energy produced annually is lower than the consumed energy and hence the difference burdens the electric network. In the case of the F2 profile, if the users do not behave adequately, the net balance becomes negative. In the case of F4 occupancy scenarios, additional energy to the renewable generated on-site one is always needed to satisfy all the uses, but if the occupants have a saver behavior the lack is 27%, instead if users have a wasteful behavior the deficit reaches a significant percentage equal to 82%. Furthermore, for the same family size and behavior, the availability of low consumption equipment and lights allows doubling the consumption covered through renewable sources. Indeed, in the case of family of four, if the behavior is wasteful, the fraction of consumption satisfied is 18% in the presence of traditional appliances and lights, and it becomes 33% with energy efficient appliances and lights. If the behavior is saver, the covered fraction passes from 37% to 73%. In the case of the two-member household, if the behavior is wasteful, the share satisfied rises from 38% to 74% depending on the type of appliances used, whereas, if the behavior is saver, the percentage evolves from 70% to over 100%, representing an excess of energy than that needed.

5 Conclusions

A nearly zero energy building has been designed by applying the calculation model contained in the Italian Legislation and Standards. In order to be nZEB, the building must comply with specific envelope characteristics and plant performances defined on the basis of a reference building. External walls must have a high thermal insulation to reduce the energy demand for heating. Good thermal storage capacity of opaque components and strict properties for the window areas are fixed to limit cooling demand. Moreover, the energy performance indexes for heating, cooling, and global energy performance must be lower than the corresponding performance calculated for the reference building. Furthermore, the efficiency of the heating and cooling system and the DHW production systems must be higher than the efficiencies of the plants provided for the reference building. Moreover, the installation of systems for the production of defined shares of energy from renewable sources is mandatory. In the design of the building all the listed requirements have been met, consequently the building is classified nZEB according to the Italian Standards.

However, the design process does not take into account the different uses of the building by various possible types of occupants. Therefore, the study sought to verify the actual performance of an nZEB under diverse occupancy scenarios and to determine the annual balance between the energy consumed and the energy produced by the on-site photovoltaic system. Quantifying the difference in energy is useful to understand if the balance is approaching or moving away from the zero level and assessing if it is positive (the total produced energy exceeds that consumed, confirming the definition of nZEB), or conversely if it is negative and therefore the building does not perform as expected.

Using statistical data from National source (ISTAT 2014a), two occupancy scenarios have been formulated, assuming a different number of components of the family. In particular, the first type of occupancy consists of a family of four members, which uses all the rooms in the house, while in the second scenario the house is occupied by a family of two members, which use continuously only a part of the dwelling, and some rooms are occasionally occupied. Thanks to statistical information, it was possible to define typical uses of the heating and cooling system, DHW production, lighting and household appliances. Two types of artificial lightings and room equipment have been analyzed: traditional lights (halogen lamps) and low energy lights (compact fluorescent lamps), traditional and energy saving appliances (with energy label "G" and "A" respectively). In addition, three different occupant behaviors have been simulated (waster, medium, and saver), with reference to the choice of heating and cooling set point temperature, and ventilation mode.

The analysis leads the authors to conclude that the assertion of a "nearly" zero energy building is justified, as the fact of being zero energy is not linked exclusively to the construction and plant solutions, but is also dependent on occupant related factors. In fact, minimizing the energy consumption for heating and cooling by adopting high-efficiency envelope and plants, the consumption of lighting and appliances depending on user behavior becomes prevalent.

Therefore, to facilitate the achievement of a balance as close as possible to zero, the adoption of energy saving appliances and lights should be forced, because it permits to obtain a reduction of the energy consumption independently of the use. In fact, the results show that even the wasteful family, who does not care about the use of air conditioning and ventilation, could almost double the surplus energy to be allocated to electrical needs. Indeed, the percentage of consumption that can be covered by renewable sources passes from 18% to 33% using low-power electrical appliances and lights.

In order to fulfill the remaining consumption due to equipment and lighting, it would be interesting to increase the mandatory extent of photovoltaic power to be installed, which is currently fixed by regulations at a minimum of 2 $kW_p/100\ m^2$ while currently technologies can offer on average 15 $kW_p/100\ m^2$. In particular, considering that the producibility depends on the orientation on the pitched roof and that often roofs are divided into several slopes, the constraint currently in force could be raised from 2 to about 7 $kW_p/100\ m^2$, contemplating the collocation of photovoltaic modules on the surfaces with the best exposure.

However, to obtain buildings concretely nearly zero energy, technical parameters associated with the energy consumption for electricity uses inside the dwelling (equipment and lights), should be included among the requirements to be complied with for classification as nZEB. In fact, the total energy consumed by the building also includes these uses, which are closely linked to the behavior of occupants, and which tend to have an increasing impact on the final energy balance, at a decrease of consumption for conditioning, as happens in nZEB.

Moreover, in the evaluation of energy performance of buildings, not only a reference building should be considered, but also a reference occupancy and a reference users' behavior. Otherwise, the designed building is likely to move away from the theoretical formulation of nZEB, real consumption could be very different from predicted consumption, and the final balance may mismatch the estimated zero goal.

6 Future work

The study is focused on the application of occupant behavior modeling in nZEB. The investigation underlines the lacks in the current European and National Standards concerning the calculation of internal loads, of energy consumption due to equipment and lighting, and of the dimensioning of renewable energy systems.

The authors approached this problem with a different method from the cases available in literature. They did not use data collected by survey or monitoring campaigns but free available data obtained by means of an accurate investigation. This methodology could constitute a reference example for future studies in other countries. Furthermore, it emphasizes the necessity to include in National surveys some questions about occupancy and the use of the houses. Generally, this information is poor and fragmented.

The authors used a deterministic approach for modeling occupant behavior in the specific case of nZEB in order to highlight the main issues and provide results that constitute the starting point of future investigations. Future work could include: diverse climatic conditions, building typologies, different approaches for occupancy modeling (probabilistic nature of occupant presence, use of space by utilizing stochastic models), investigation of new procedures for the sizing of renewable energy systems in relation with the occupancy profiles and their modeling.

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