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NZEB schools: global sensitivity analysis to optimize design features of school buildings

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Abstract. In the context of "2030 climate & energy framework" and "2050 low-carbon economy" it is essential to understand which the elements that affect most buildings energy needs are. The main aim of this study is to identify and to optimize these factors in order to improve energy performance of schools by minimizing energy consumption. The study presented was carried out through a sensitivity analysis in order to determine which factors most affect energy consumption with respect a school typological model adopted as the reference model considering climate zones D and B. The analysis evaluated: shape, different materials for insulation, thickness of insulation layer for façade and for roof, window to wall ratio (WWR) for each orientation, type of solar shading for south orientation, integration of vertical solar shading for east and west orientation, contribution of ventilation and some parameters related to systems. Results pointed out that for this type of buildings the ventilation requirements for air changes is the factor that most affects the energy demand both for heating and cooling. At the same time also the variation of shape, of thickness insulation layer for roof and of WWR influence is significant.

1. Background

At present buildings are responsible for 36% of global energy consumption and 39% of related CO_2 emissions [1]. In according to the recent European Directives concerning the energy saving of buildings and the related decrease in greenhouse gas emissions into atmosphere it is important to understand how the architectural choices, and in particular those made during the preliminary phase of design process, influence the energy performance of building and its environmental impact [2]. In the recent literature there are several researches that concern the individuation of all those parameters characterising buildings that mostly affect the final energy consumption and their optimization in order to realize a sustainable building. This assessment is essential for designer during the early stage of design procedure and the related decision-making process. In fact, in this phase, there is the possibility to adopt in the design of construction the measures that have a greater influence on energy needs reduction and to define the most efficient systems and technologies with respect to the specific building type and the climate zone.

One of the methods used to identify these parameters is the sensitivity analysis. Use since 1970 [3], this method can be helpful to the designer to establish the contribution of each elements of the project that can be parameterized (input) in relation to the final energy consumption of the building (output). Many studies in literature concerning the application of this methodology with respect to the energy needs are related to office buildings [4][5] and residences. For instance, Hemsath et al. [6] study the influence of the shape of the building and the relation of two dimensions of the floor with respect to the energy needs according to different climate conditions. In conclusion, they state that generally the choice of the shape affects the energy consumption more than the choice of technological solution for the external envelope. Smith et al. [7] consider the roof solar absorptance, the air exchange rates and the sub-roof R-value for the analysis with respect to energy needs for heating and cooling. These parameters

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affect the energy balance of the examined building as they greatly affect the value of dispersions and internal gains and they outline a different energy performance of the building depending on the considered reference season. Instead, Heiselberg et al. [8] performed a global sensitivity analysis by varying 21 parameters (for instance heat capacity, windows thermal transmittance, solar factor, shading, overheating, mechanical ventilation rate during daytime in winter and summer, efficiency of heat recovery, lighting power) within a fixed range considering a multi-storey office building. For this building type the results show that lighting control of artificial lighting and the air change rate through mechanical ventilation are the factors that mostly affect the energy consumption. Finally Harkouss et al. [9] use this type of analysis to understand the robustness of the results of their analysis in order to find the best combination of strategies in order to achieve a Nearly Zero Energy Building (NZEB) and to optimize each considered variable (external walls and roof insulation thickness, windows glazing type, cooling and heating setpoints and window-to-wall ratio).

2. Aim of the study

Italian school buildings stock is characterized by low energy efficiency (energy consumption equal to 1 Milion tep/a; estimate of National Agency for new technologies, energy and sustainable economic development ENEA 2012) mainly linked to the fact that the most of school buildings were built before 1976, the year in which the first Italian law about the reduction of the energy consumption of buildings was issued. In the context of “2030 climate & energy framework” and of “2050 low carbon economy” it is fundamental to design and to realize schools characterized by a high energy performance in order to achieve a reduction of greenhouse gas emissions into atmosphere within 2050. Furthermore, from the 1st January 2019 the new school buildings must meet the requirements for NZEB buildings required by current Italian legislation (Ministerial Decree of 26th June 2015).

In relation to this for the construction of a NZEB school is fundamental to understand since the preliminary design stage what the factors characterising the building that most affect the energy needs for both heating and cooling are.

The presented work in the paper considers as a case study school building type and particularly the new typological models [10] for the construction of NZEB kindergartens in Italy, defined in a previous stage of the research [11].

Three different models have been defined, summarizing the analysis of environmental system and technological system of a large number of representative sustainable school buildings built between 2003 and 2015. From morphological, dimensional, of aggregation and distribution of spaces point of view these models constitute the needs required by current teaching methods and public administration that realize schools. Furthermore, all the technological features are defined in the models, starting from the evaluation of the most recurrent technological solutions and materials, identifying the most efficient from an environmental (CO_2 emissions) and energy point of view. Therefore, the models were constituted as the “basic” solution to be compared and on which to vary some of different components that can be constituted as design choices (Window to Wall Ratio – WWR, type of structure, solar shading, thickness of insulation, green roof and some parameters related to systems), in order to define which are those that significantly influence energy performance of school buildings located in different Italian climate zones.

The main aim of the work presented in the paper is to identify which are the factors that most influence in proportion the final energy consumption of the three analysed models for the cities of Florence and Palermo. The motivation for the choice of these cities is explained later in the paper.

3. Method

In order to evaluate the influence of each parameter on annual energy consumption of considered models an on-at-a-time step sensitivity analysis [10] was performed. This is the simplest method to be able to make this evaluation and to quantify in percentage terms the impact of every variable examined. The study was performed by considering one typological model as reference model and by varying each factor within a specific range, keeping the remaining fixed. To be through, the analysis was also carried out in relation to the energy consumption for heating and cooling as the influence of individual parameters could change with respect to reference season. In order to show the results of the sensitivity analysis the sensitivity index has not been defined [8] but the variation in percentage of each individual parameter was calculated with respect to model considered as the reference model. This was necessary because not only numerical factors which vary in a precise range have been analysed, but also building features as shown in Table 1.

The analysis was performed considering the three different typological models for kindergarten: one with compact shape with three sections (Model I1) and two with predominant linear shape with three sections and six sections respectively (Model I2 and Model I3). The Model I1 has been considered as the reference model for the analysis. The study was carried out considering two representative cities belonging to two different Italian climate zones (Decree of the President of the Republic 26th August 1993, n. 412): Florence belongs to climate zone D and Palermo belongs to climate zone B. The variation concerned the following parameters: shape of the building, different type of structure, thickness of insulation for façade, thickness of insulation for roof, green roof technological solution, window to wall ratio for each orientation, solar shading type for south orientation, use of solar shading for west and east orientation, lighting efficiency, attenuation temperature for heating plants, air change per hour considering controlled mechanical ventilation, heat recovery efficiency, free cooling (Table 1).

Table 1. Range of parameters for sensitivity analysis.

N	Parameter	Range
1	Shape	2 types (Model I2 and I3)[a]
2	Type of structure	3 types (B1.2 – B2.2 – CA4) [a]
3	Façade thickness of insulation (D)	0.10 m – 0.26 m
	Façade thickness of insulation (B)	0.04 m – 0.16 m
4	Roof thickness of insulation (D)	0.10 m – 0.26 m
	Roof thickness of insulation (B)	0.06 m – 0.22 m
5	Green roof technological solution	use it – not use it
6	South WWR	33%; 50%; 76%[b]
7	East WWR	17%; 29%; 36%[b]
8	West WWR	17%; 23%; 29%[b]
9	Type of solar shading (South)	4 types (9.1-9.2-9.3-9.4) [a]
10	Vertical solar shadings	West - East
11	Lighting efficiency	120 lm/W (LED); 22 lm/W (halogen lamps)
12	Attenuation temperature for heating	5°C; 10°C; 15°C; 20°C
13	Air change per hour	standard value (s_v) [12]; 0.5 s_v; 0.25 s_v; off s_v
14	Heat recovery efficiency	0.50 % – 0.9 % [13]
15	Free cooling	on - off

[a] Related to Table 9 (Results and discussion)
[b] The value of WWR is different for east and west orientation because in these orientations the functional units in the internal layout are different and obviously they have different dimensions and so distinct value of related WWR.

This analysis allows to identify the parameters that significantly affect the final energy consumption of the building. It means the sum of required energy for heating, cooling, auxiliary systems, lighting and service hot water.

4. Input data

4.1. Climate zones

The analysis was carried out considering two cities (Table 2) belonging to two different climate zones as reported in D.P.R. 412/1993 [14] depending on number of degree heating days (HDD): Florence (climate zone D) and Palermo (climate zone B). These two locations are chosen as both representative of Mediterranean climate: Florence with temperate climate with warm summer season and cold and humid winter (Cfd for Köppen-Geiger classification) and Palermo with temperate Mediterranean climate with summer drought (Csa for Köppen-Geiger classification).

Table 2. Characterization of Florence and Palermo.

City	Altitude [m above s.l]	Latitude	Longitude	Heating Degree Days	Heating Period
Florence	50	41.8°	12.23°	1415	1st/11 – 15th/04
Palermo	34	38.18°	13.1°	751	1st/12 – 31st/03

For the study one of the new typological models for kindergarten has been considered as a reference model for the sensitivity analysis: the one with compact shape with three sections (Figure 1 – Model I1).

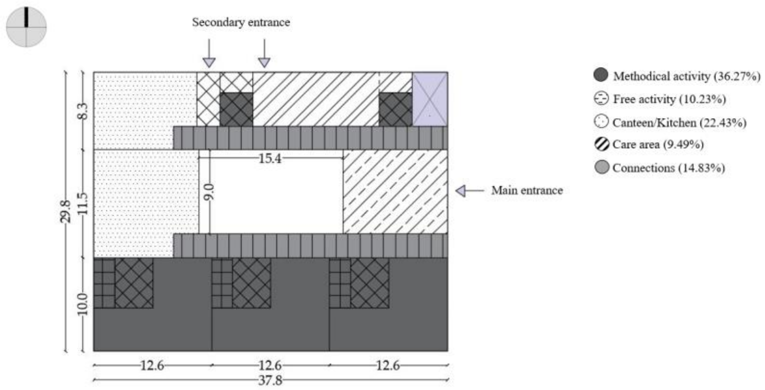

Figure 1. Typological model I1 with compact shape and internal courtyard.

Table 3 illustrates the main geometrical characteristics (volume V, area S, length A, width B, internal height H) of the reference model.

Table 3. Geometrical characteristics of kindergarten reference model.

Model	V [m^3]	S [m^2]	A [m]	B [m]	H [m]
I1	5154.6	888.7	37.8	29.8	4.4

For the reference model the construction method with cross laminated timber (XLAM) was used for both external envelope and roof floor. This solution was applied because it is one of the most recurrent for the realization of kindergartens with low consumption in Mediterranean area. Furthermore, the wood fiber was chosen by comparison with other materials, because it is a natural material and it allows to achieve a low value of CO_2 emissions for the construction. Table 4 explains the layers of the external wall used while Table 5 indicates those for ventilated roof. In both table thickness of insulation required to comply with thermal transmittance of reference building as defined by current Italian law [15].

Table 4. External envelope layer.

Layer	Material	Thickness [m]	λ [W/mK]
1	External plaster	0.025	0.9
2.1	Wood fiber B	0.04	0.038
2.2	Wood fiber D	0.10	0.038
3	XLAM	0.13	0.12
4	Gypsum board	0.015	0.21

Table 5. Roof floor layers.

Layer	Material	Thickness [m]	λ [W/mK]
1	Metal sheet	0.0005	1.07
2	Air cavity	0.05	-
3	Waterproof sheet	0.004	0.2
4.1	Wood fiber B	0.06	0.038
4.2	Wood fiber D	0.10	0.038
5	Vapour barrier	0.0003	0.17
6	XLAM	0.125	0.12

For ground floor layers the solution with plastic formwork for underfloor ventilation was completed with expanded polystyrene (EPS) insulation layer. Finally, related to windows, a thermal break frame was adopted (U_f=1.7 W/m^{2}K) and a double glazing with different properties (Table 6) was used to comply with thermal transmittance required by D.M. 26 June 2015 [15] for the reference building.

Table 6. Glass characteristics with respect to climate zone.

Climate zone	U_g [W/m^{2}K]	Solar factor [%]	Light transmittance [%]
B	2.5	69	78
D	1.2	50	74

The Window-to-wall ratio for each orientation is defined by current minimum health-hygiene standards in Italy (south WWR = 20%; east WWR =7%; west WWR = 7%). For the reference model on southern façade a fixed shading system has been designed and realized with an overhang of 2 m against each windows façade. This type of solar protection was used because it ensures a total shading for glazed elements during summer season. No shading system has been adopted on eastern and western façade.

In order to calculate final energy consumption energy simulations in a dynamic condition with hourly time step were carried out through Energy Plus software using Design Builder [16] as the graphical interface. For each different thermal zone, in which building has been divided, many parameters were defined: occupancy (person/m^2) according to UNI (Italian National Agency of unification) 10339 (June 1995 - Appendix A) [12], minimum air change rate refers to the same legislation (June 1995 - Table 3) [12] and finally internal gains in line with UNI/TS (UNI/Technical specification) 11300-1 (October 2014 – Table 17) [17]. Concerning level of illuminance UNI EN (UNI European Standard) 12464-1 [18] was considered. The lighting efficiency was considered equal to 120 lm/W with the use of LED lights. Regarding simulations, lighting control was used with the maximum index of glare allowed.
Systems are simulated through HVAC simple and main design parameters are shown below:

- controlled mechanical ventilation (VMC): free cooling and air-to-air sensible heat recovery with 50% of efficiency;
- heating/cooling system: gas boiler with efficiency equal to 0.9, chiller with EER=2.5 with electricity from grid, distribution with mixed system with primary air and fan coils;
- heating setpoint: 20°C activity period – 10°C during the rest of the day;
- cooling setpoint: 26°C activity period – 36°C during the rest of the day;
- auxiliary energy: 6 kWh/m^2;
- service hot water: gas boiler with efficiency equal to 0.9 with hot water outlet temperature equal to 65°C.

4.2. Sensitivity analysis

The text describes in detail some of the parameters considered (Table 1) for the on-at-a-time-step sensitivity analysis in order to make more clear the variations performed, and their range of variation, for energy simulations to calculate energy consumption and to quantify in percentage how much each considered element influences it.

4.2.1. Shape. The first variation concerns the shape of the building. By comparison the two other configurations defined for new typological models to realize NZEB kindergartens in the Mediterranean area were considered.

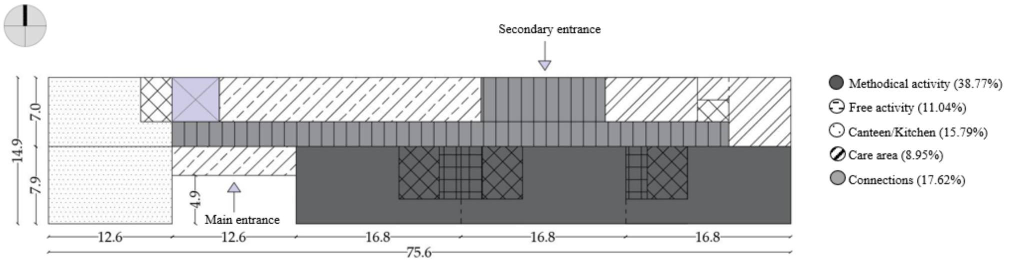

Figure 2. Typological model I2.

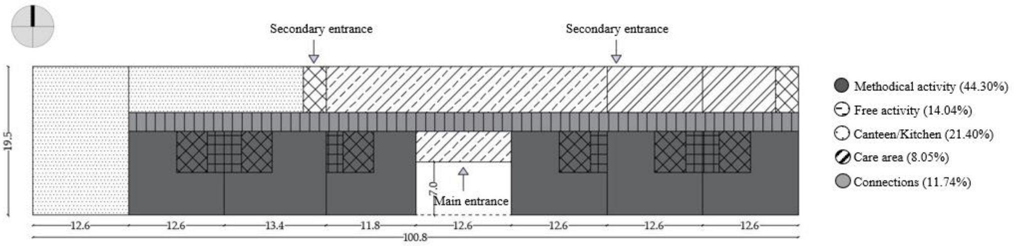

Figure 3. Typological model I3.

Table 7 illustrates the main geometrical characteristics (volume V, area S, length A, width B, internal height H) of the models.

Table 7. Geometrical characteristics of kindergartens model for variation.

Model	V [m^3]	S [m^2]	A [m]	B [m]	H [m]
Model I2	5534.8	954.3	75.6	14.9	4.4
Model I3	10764.8	1736.6	100.8	19.5	4.8

4.2.2. Type of structure. Three different structural solutions were evaluate as an alternative to the structural solution of the reference model: two with platform frame, one of which with a double oriented strand board panel (Osb)(B1.2) and one with single panel (B2.2) and the other in reinforced concrete with brick for external wall (CA4). In order to make a comparison the same thermal transmittance and the same material of insulation of base case were maintained (wood fiber).

4.2.3. Thickness of insulation for façade and for roof. The variation of the thickness of insulation for external wall occurs in according to range in which the upper limit is different in every selected city. For the city of Florence (climate zone D) the range has as upper limit the one related to the thickness of insulation, equal to 26 cm, that allows to obtain a thermal transmittance equal to half of that one of the reference building [15] and at the same time it still results to be a reasonable technological solution. Instead for the city of Palermo (climate zone B) the upper limit of the thickness of insulation is strictly linked to the reason that an excessive insulation leads to an increase in energy needs for cooling during summer season. Consequently, the maximum thickness of insulation is considered equal to 16 cm, because over this thickness the energy needs for cooling increases [19][20][21]. As regards the variation of thickness of insulation for the roof floor the standard adopted for both cities is the same and also in this case the maximum thickness for the analysis is considered that allows to achieve a thermal transmittance equal to half of that one of reference building [15]. It is equal to 26 cm for Florence and 22 cm for Palermo.

4.2.4. Green Roof technological solution. For modelling green roof technological solution the parameters defined in Table 8 that follows are assumed [22][23].

Table 8. Design builder set up for green roof model.

Parameter	Unit	Value
Conductivity of dry soil	W/mK	0.20
Density of dry soil	Kg/m^3	1020
Specific heat of dry soil	J/kgK	1093
Saturation volumetric moisture content of the soil	-	0.13
Thermal absorptance	-	0.96
Solar absorptance	-	0.85
Height of plants	m	0.10
Leaf Area Index (LAI)	m^2/m^2	3.00
Leaf reflectivity	-	0.19
Leaf emissivity	-	0.97
Minimum stomatal resistance	$mmol/m^2s$	120
Maximum volumetric moisture content	-	0.5
Minimum residual volumetric content	-	0.01
Initial volumetric moisture content	-	0.15

4.2.5. Window-to-wall ratio. The variation of WWR is considered for each orientation except for the north façade where it is maintained equal to the minimum value required by legislation in order to satisfy health-hygiene standards in order to avoid an increase in dispersions and consequently an increase in energy consumption for heating. The maximum WWR is equal to that one that can be achieved within the functional unit and setting as a limit for height the one corresponding to suspended ceiling inside rooms.

4.2.6. Solar shading. For the variation of solar shadings, it is necessary to consider separately the different orientation. For south orientation for the sensitivity analysis four different solutions are varied in order to see the influence of the choice of solar shading on final energy consumption (Internal blinds with solar control with solar radiation equal to 120 W/m^2 – 9.1, combination of overhang of 2 m and internal blinds with solar control – 9.2, horizontal louvres – 9.3, external blinds with solar control with solar radiation equal to 120 W/m^2 – 9.4). Instead, for east and west orientation the possible use of vertical solar shadings is evaluated.

5. Results and Discussion

Figures 4 and 6 (left) are related to the city of Florence and they show the results of the sensitivity analysis by relating the final energy consumption of reference model with the final energy consumption of the model obtained by assuming different variations. For the construction of graphs for each variable the minimum or maximum value was considered depending on how the single parameter affects the energy needs. Given the wide range of variables, as already explained, the value assumed (minimum or maximum) has been defined compatibly with the geometry of the building or with exclusively technological features. The goal is to establish how the maximum variation of each individual parameter changes in percentage the final energy consumption with respect to corresponding value of the building taking as a reference. Obviously, it is necessary to point out that the results of the sensitivity analysis listed below are strictly linked to functional bands and units' distribution, orientation, intended use and occupancy level of analysed building. Figure 4 concerns morphological and technological characteristics while Figure 6 pertains to some features related to systems.

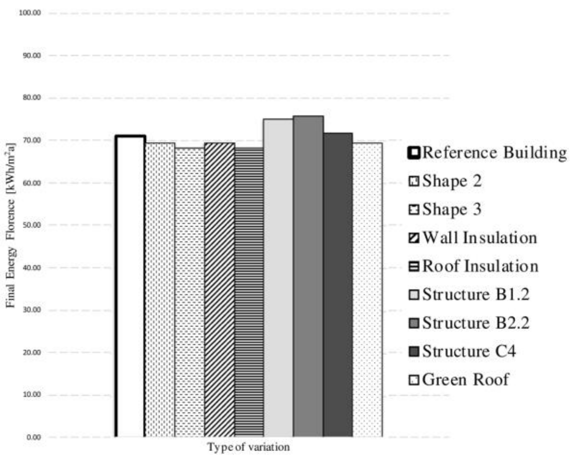

Figure 4. Final energy consumption for Florence with respect to shape, insulation, structure and green roof.

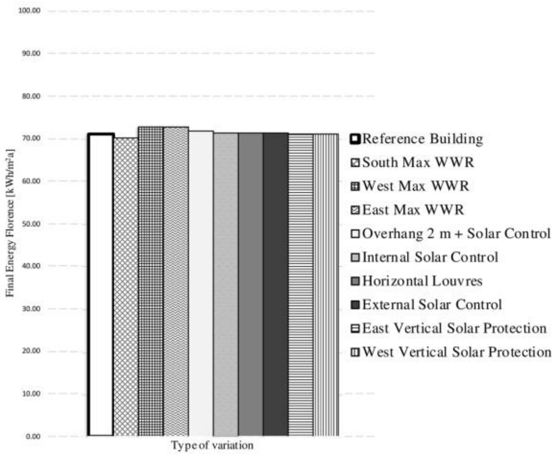

Figure 5. Final energy consumption for Florence with respect to WWR and horizontal and vertical solar shadings.

Figures 4-5 illustrate that for the city of Florence the shape with predominant linear development with 6 classrooms (model I3) allows to achieve a saving of the final energy consumption (~ 4%) compared to compact shape with internal courtyard (model I1). This is related to the shape of the building plan that has a predominant horizontal development with main direction along east-west axis. This grants to exploit solar gains and to reduce energy needs for heating of 29% while causing at the same time a noticeably increase in energy for cooling. In relation to the characteristics of the building, as can be seen from the graphs (Figures 4 and 6), the choice of the type of structure and consequently the identification of the solution for the technological systems for external envelope are the variables that mainly affect the final energy consumption. The use of Osb panel both in the case of single panel (B1.2) and in the case of double panel (B2.2), leads to an increase in final energy consumption equal to about 6%.This mainly related to the reason that the external walls does not have enough thermal mass and related periodic thermal transmittance to ensure a proper decrement factor and time shift of the thermal wave. The external wall solution with double panel (B2.2) is characterized by: decrement factor f_D=0.48 [-], time shift φ=7.98 h and periodic thermal transmittance Y_{ie}=0.132 W/m^{2}K in according to UNI EN ISO (UNI EN International Organization for Standardization) 13786 [24]. These values are definitely worse than those that are possible to obtain by adopting the solution with XLAM panel and insulation with wood fiber. The solution with reinforced concrete, external wall with bricks and insulation with wood fiber shows a better behavior of above-mentioned values than the reference solution (XLAM) but it leads to a high value of CO_2 emissions. The increase in thickness of insulation on roof floor significantly affects the energy needs compared to the same increase in thickness of insulation of external wall (~ 3.5%). It is set for both as upper limit the thickness of insulation that allows to achieve a thermal transmittance equal to half of that required by current legislation for reference building. The use of green roof technological solution for roof floor primarily leads to a decrease in energy needs for cooling (8%) but generally to a small decrease in final energy consumption equal to about 2.60%. The green roof allows to obtain a lower surface temperature because it absorbs lower solar energy than traditional solutions and it enables more control of the internal temperature of the building by minimizing the energy needs for cooling [24]. For Florence the increase in WWR for south orientation leads to a benefit in terms of energy needs for heating while for east and west orientation the increase in WWR negatively affects the energy balance but not significantly for a climate zone characterized by a climate with cold winter. Finally, for a building characterized by this internal functional distribution (Figure 1) the use of solar shadings for eastern and western façades does not remarkably influence the final energy consumption. This result is mainly related to the reason that in the model there are not windows in these orientations for sections that are the functional units with higher occupancy density during teaching time. Figures 6 and 7 concern the results of the sensitivity analysis for the city of Palermo.

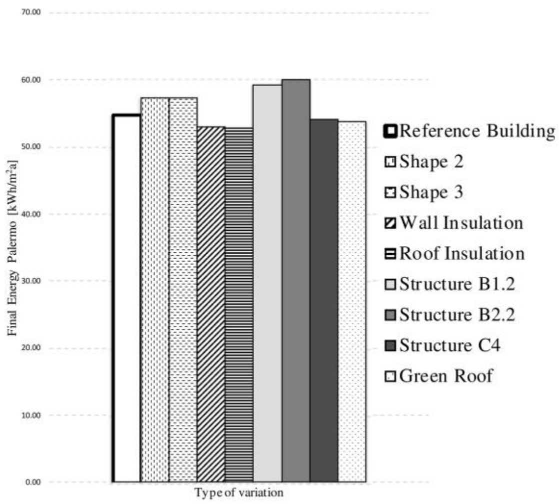

Figure 6. Final energy consumption for Palermo with respect to shape, insulation, structure and green roof

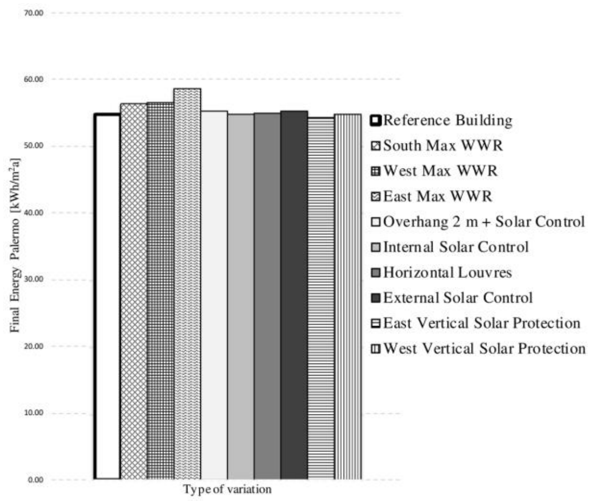

Figure 7. Final energy consumption for Palermo with respect to WWR and horizontal and vertical solar shadings

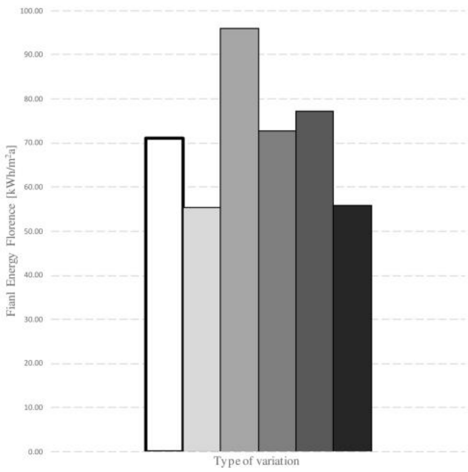

Figure 8. Final energy consumption for Florence with respect to some systems variables

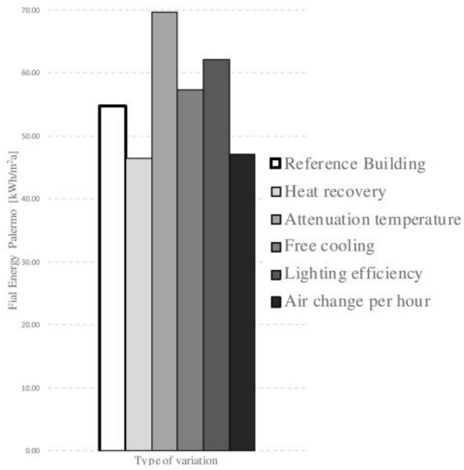

Figure 9. Final energy consumption for Palermo with respect to some systems variables

For the city of Palermo, the compact shape with internal courtyard (model I1) is the one that ensures the minimum final energy consumption and the difference with the model I3 is noticeably (~ 4.6%). As for the climate zone D the choice of the type of structure and the connected technological solution for external wall are the parameters that mainly affect the final energy consumption of the building. Indeed, the structure with double Osb panel leads to an increase in energy needs equal to about 10% for a city with a mild climate where the energy needs for cooling is prevalent with respect to energy needs for heating. The use of green roof technological solution does not cause a remarkable advantage in terms of final energy consumption (< 2%). In contrast to climate zone D for the climate zone B the increase in WWR in each orientation negatively influences the energy needs. For instance, for Palermo the increase in WWR for east façade leads to a corresponding increase of 7% of final energy consumption despite it is calculated in according to windows for areas with lower occupation during teaching time. For both cities the parameters that have a greater effect are those related to systems. The contribution of mechanical ventilation to maintain the air change rate required by legislation for schools is so relevant that it influences the results related to the whole analysis. To understand the influence of ventilation on final energy consumption a value equal to a quarter of that established for ventilation by the UNI 10339 for schools was evaluated. For Florence a saving on final energy consumption equal to 21% is achieved while for Palermo equal to 14%. This statement is in according to the results of Maite Gil-Báez [20] that stress that for a school ventilation and infiltration affect the energy consumption for heating by 41.6% with respect other analysed variables, such as for instance the technological solution used for the external envelope and dispersions through windows. Finally, for this type of building is essential to keep the attenuation temperature for heating equal to 10°C for both climate zones. This is because this value leads to an improvement of energy performance of the building. In fact, for the city of Florence with colder winter an increase in attenuation temperature for heating of 5°C (from 10°C to 15°C) causes an increase in final energy consumption of 34% while for Palermo of 27%. Finally, for what concerns Palermo, if the free cooling is not considered during the summer season the energy consumption for cooling increases of 22% with resulting increase of energy needs of building equal to 5%. Since it was not possible to calculate the sensitivity index for each single variation (Table 1) the Table 9 shows the variation in percentage of final energy consumption for both the city of Florence and Palermo with respect to the model considered as reference. The negative values state the decrease in percentage in final energy consumption obtained by varying the corresponding parameters (Table 1) with respect to the model considered as reference.

Table 9. Results in percentage of sensitivity analysis.

N	Parameter	Florence	Palermo
1	Model I2; Model I3	-2.40%; -4.00%	<1%; 4.6%
2	B1.2; B2.2; CA4	5.40%; 6.30%; <1%	8.20%; 9.70%; 1%
3	0.26 m (D)	-2.30%	-
	0.16 m (B)	-	-3.10%
4	0.26 m (D)	-4%	-
	0.22 m (B)	-	-3.60%
5	Use of Green roof	-2.60	-1.70%
6	33%; 50%; 76%	<1%; <1%; -1%	1%; 1.70%; 2.80%
7	17%; 29%; 36%	1.40%; 1.90%; 2.30%	3.60%; 5.90%; 7%
8	17%; 23%; 29%	1.20%; 1.70%; 2.40%	2%; 2.60%; 3.40%
9	9.1; 9.2; 9.3; 9.4	<1%; <1%; <1%; 1.40%	<1%; <1%; <1%; 1%
10	West - east	<1%	-1%
11	Halogen lamps	8.50%	16.70%
12	5°C; 15°C; 20°C	< (-)1%; 7%; 35%	< (-)1%; 3%; 27%
13	0.5 s_v; 0.25 s_v; off s_v	14.70%; 21.50%; 21%	5%; 9.60%; 14%
14	0.6%; 0.7%; 0.8%;0.9%	-6%; -11.70%; -17%; -22%	-4%; -8%; -11.70%; -15%
15	Off	2.30%	4.70%

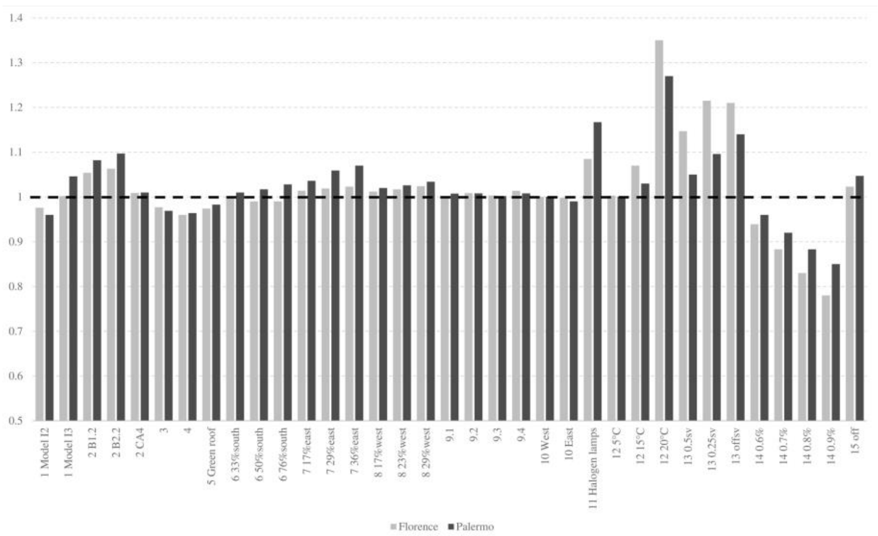

Figure 10. Results of the sensitivity analysis for the cities of Florence and Palermo. The values are normalized with respect to model I1.

6. Conclusion

The performed simulations point out that the variation of different considered design features implies an influence on final energy consumption of the building in both examined climate zones that can not be ignored to design NZEB schools. In the preliminary phase of the design process the proper combination of strategies and techniques to be used in the building necessarily affect the energy performance and consequently its environmental impact and greenhouse gas emissions in the atmosphere. Obviously the results illustrate in the paper are strictly linked to the type of building, the orientation of functional bands, the distribution of functional units and density of occupancy. , the models adopted in relation to both architectural, functional and distributive features and technological characteristics represent a reasonable reference configuration to design modern schools for kindergartens.

In conclusion, as the analysis shows, the parameters related to the systems that significantly affect the final energy consumption are the high air change rates required by Italian current legislation, in according to relevant literature, the choice of attenuation temperature for heating and the efficiency of heat sensible recovery for controlled mechanical ventilation. The high air change rates required for schools by UNI 10339 inevitably affect the results of sensitivity analysis related to building features. For what concerns latest characteristics for both Florence and Palermo the choice of the proper technological solution for external envelope with appropriate periodic thermal transmittance is essential to minimize the final energy consumption of the building (Table 9 – Figure 10). Furthermore, for both climate zones the increase in thickness of insulation for roof floor leads to a sensible decrease in final energy consumption. For climate zone D, where the energy contribution for heating is prevalent, an increase of thickness of insulation for external wall results in a corresponding decrease in the related energy needs equal to 4%, while the implementation of WWR equal to 76% for southern façade affects 5%. Instead, to reduce the energy consumption due to cooling a technological solution for roof floor with green roof can be used. For climate zone B, the parameter that mainly affects the final energy consumption is the WWR. Table 10 indicates that for the city of Palermo to minimize final energy consumption primarily linked to the energy needs for cooling it is necessary to minimize windows and to maintain the WWR required by health-hygiene Italian standards. For both climate zones the use of solar shadings for east and west façade does not cause a significant variation of final energy consumption, such as the variation of type of solar shading used for south orientation.

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