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ScienceDirect

Energy Procedia 142 (2017) 2517–2524

Energy Procedia

www.elsevier.com/locate/procedia

9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK

Assessing the overheating risks in Italian existing school buildings renovated with nZEB targets

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Abstract

Energy retrofit projects following nearly zero-energy buildings (nZEB) requirements often pay a little attention to Indoor Environmental Quality of the building. This aspect is extremely important in school buildings, as they are frequented mostly by young people, who are affected more by a healthy environment. In this context, starting from a reference case, overheating risks in existing school buildings considered for energy renovation were investigated through TRNSYS 16. Four building configurations were evaluated (existing, nZEB, nZEB with external shadings, nZEB with external shadings and night ventilation) and the influence of several parameters was taken into account (climate, orientation, building level). The aim of this paper is to understand if nZEB standards applied to Italian school buildings guarantee good indoor thermal conditions and which building configuration can be more advantaged by these standards. Furthermore, even if overheating risk is qualitatively recognized in insulated and air tight buildings, quantitative assessments are still missing for the Italian building stock. The intent of this research is to provide preliminary data on this topic in order to lead to a more conscious choice of retrofit strategies as a compromise between energy performances and indoor environmental quality.

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1. Introduction

According to the global trends presented by International Energy Agency studies [1], total final consumption is more than doubled between 1971 and 2014. The evolution of energy uses and the climate global challenge ask all countries to reduce the greenhouse gases through several measures, among them: the improvement of the energy efficiencies and the reduction of energy end uses in all the sectors. At European level, the building sector is the more energy-consuming, accounting for more than 40% of total energy end uses. In this context, an important action asked by European Union (EU) to Member States is to increase the number of nearly Zero-Energy Buildings

Peer-review under responsibility of the scientific committee of the 9th International Conference on Applied Energy.
10.1016/j.egypro.2017.12.192

(nZEB) [2][3] to achieve higher energy savings and meet the fixed environmental targets. As result of these policies, several projects for existing and new buildings were realized following nZEB requirements and definitions, using adequate technologies for the envelope, the energy, including renewable, and control systems. However, nZEBs are relatively new and their performance in real use conditions is not well-known [4][5]. Some Post-Occupational Evaluations (POE) on nZEBs, mainly carried out in the north of Europe, found that occupants often report better levels of thermal comfort in winter than in summer [6]. One of the main issues is, in fact, the risk of overheating, especially during summer and more in general during the off-heating season. This criticality depends on several issues: poor design of heating, ventilating and air conditioning (HVAC) systems [6]-[8]; excessive thermal insulation and air tightness of the building envelope [8]-[11]; absent or wrong use of passive strategies [6]-[7],[10]-[11]. Standard nZEB strategies, in particular, focus on the air tightness of the building and the insulation of its envelope, which provide excellent energy conservation but, at the same, time do not allow an efficient heat dissipation during the overheating risk periods.

The impact of overheating on human health is well-known and occupants subject to high indoor temperatures are more vulnerable to heat related illnesses [12]-[15]. Indoor Environmental Quality (IEQ) and thermal comfort of the occupants are even more important in school buildings, as they are frequented mostly by young people, who are affected more by a healthy environment. This is one of the reasons why it is necessary coping the comfort issues with energy targets in case of school buildings retrofit toward the nZEB standards. This topic is also very relevant in Italy, where the majority of school buildings suffer of poor energy and environment performance and, this is in need of solutions for energy conservation [16].

2. Aims and method

The aim of this paper is to explore overheating risks in existing school buildings considered for energy renovation with nearly zero energy targets. Even if this risk is qualitatively recognized in insulated and air tight buildings, quantitative assessments are still missing for the Italian building stock. The study is based on the following procedure:

a) definition of a reference building, taking into account the thermal characteristics of the envelope, climatic conditions and occupancy profile;

b) definition of the building configurations, applying the Italian requirements in terms of thermal insulation of the envelope and application of passive solutions to mitigate the indoor climate;

c) comparison of relevant indicators to express the indoor thermal quality before and after the building renovation, obtained through thermal analyses in transient regime.

2.1. Climatic conditions and observation periods

The Italian territory is characterized by substantially different cliamtic conidions, according to the latitude and the altitude of the site. For this study, three localities were chosen to represent the typical conditions of respectively north, center and south of Italy, whom characteristics are shown in Table 1, according to [17]. The overheating analyses were carried out for the off-heating season and during the occupancy hours of the building according to the Italian school year. In this way, the microclimate is in free floating conditions, since no active cooling systems are installed in the school.

Table 1. Characteristics of the chosen locations.

City	Climatic Zone	Degree Days (base 20°C)	Heating Season Length	Overheating risk period
Palermo	B	751	1 Dec–15 Mar	15 Sep- 30 Nov; 1 Apr- 15 Jun
Rome	D	1415	1 Nov–15 Apr	15 Sep- 1 Nov; 15 Apr- 15 Jun
Milan	E	2404	15 Oct-15 Apr	15 Sep- 15 Nov; 15 Apr- 15 Jun

2.2. Reference building and parametric configurations

The numerical model refers to a typical Italian school layout: a construction module with linear development and with classrooms and corridors oriented along the two main facades (Figure 1). School buildings are generally built combing this module in "I", "L" or "C" plans. The reference building has three floors and classrooms with the same geometry: the area is 50 m^2 and the height 3.2 m; the total area of windows is 5 m^2. In the base case - existing building - the envelope has no thermal insulation and windows are single glazed with no-thermal break metal frames. Actual U-values of building components are reported in Table 2, together with the ones for the nZEB configuration, whose properties and performances are defined in the national building code [18]. The g-value of glazing system is 0.82 for the single pane unit and 0.6 for the post renovation low emittance double glazing unit. The windows are coupled to internal shading devices, whose shading factor is 0.8.

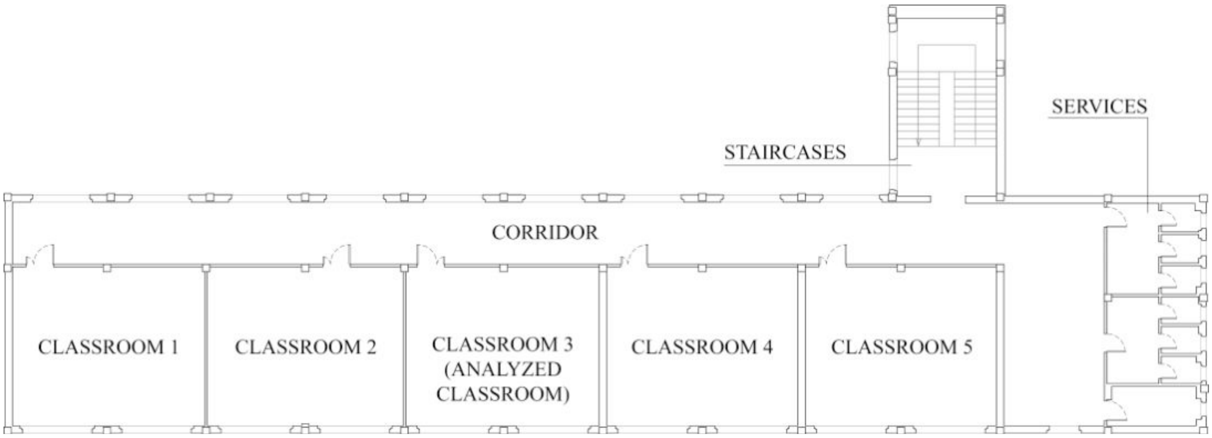

Fig. 1. Schematic plan of the reference school building

No mechanical ventilation system is installed in both configurations, according to conventional solutions in school buildings. Natural ventilation is carried out by manual opening of windows, with the following operational schedule: 10 minutes per hour, plus 20 minutes for the morning class break at 10:30. Natural ventilation and air infiltration are calculated in dynamic conditions as a function of the window operation and air tightness, occupancy profiles and climatic conditions, according to a validated model for single side natural [19].

Other relevant operational input data are: daily and weekly occupancy profiles, occupancy density and activity, internal loads and building envelope characteristics. The school building is open from 8:00 AM to 1:00 PM. People density is equal to 2.17 m^2/person [20]. The metabolic rate of the occupants is 1.2 met (seated or very light writing), while the clothing insulation is equal to 0.7 CLO during warm and hot seasons [21]. The internal sensible loads due to equipment are equal to 5 W/m^2 [22].

Table 2. Thermo-physical characteristics of the building envelope

Building element	U (W/m^2K)			
	Reference case	nZEB case		
		Palermo	Rome	Milan
External wall	1.70	0.39	0.30	0.28
Concrete and masonry roof	1.33	0.31	0.25	0.24
Concrete and masonry base floor	1.29	0.40	0.31	0.29
Windows	5.8	1.6	1.6	1.3

Two additional passive solutions were applied to the nZEB configuration in order to explore mitigation strategie to reduce the overheating risk: external shadings (with shading factor 0.2) and night ventilation (fixed 3 ACH from 8:00 PM to 7:00 AM).

3. Results

The parametric simulations were carried out using the software TRNSYS 16 [23]. The software works through a number of sub-routines (Types) linked together, each of them assigned to specific calculation tasks. For the project implemented to model the school building the simulations were run with the following routines: weather and solar generator; sky temperature calculator; building description; occupancy and shading schedules; natural ventilation and infiltration routine.

For each building configuration, the model calculates the operative temperature in two reference classrooms: one at the intermediate floor and one at the upper floor below the roof, to monitor the impact of the heat gain/loss through the roof. The following variants are considered to assess the overheating risk in the school building: 3 climatic zones; 4 building configurations (existing, nZEB, nZEB with external shading, nZEB with external shading and night ventilation); 4 orientations of the classroom facade.

The average operative temperatures in the two classrooms during the non-heating season and the occupancy hours are presented in Table 3 for all the configurations, locations and orientations of the building. The classrooms at the upper floor have a higher operative temperature than those at the intermediate level, with differences ranging between 0.2°C for the existing building up to 0.7°C for the configuration with external shading devices in Palermo. The upgrade of the building to nZEB target leads to severe overheating, since the operative temperature increases between 4.3°C (west classroom in Palermo) to 6.8°C (north classroom in Milan), with evident overheating risks. The installation of the external shading devices brings the temperature to 2-3°C above the levels reached by the existing building, but with a significant reduction to the standard nZEB. The application of night ventilation results to be and efficient passive cooling strategies, with average temperatures in line with those calculated for the base building configuration.

Table 3. Average operative temperature in the classrooms during occupancy hours

Building configuration	Average operative temperature °C)											
	Milan				Rome				Palermo			
	South	East	North	West	South	East	North	West	South	East	North	West
Existing (int. floor)	23.3	24	22.7	23.4	24.9	25.4	24	24.7	25.6	25.5	24.3	24.8
Existing (up. floor)	23.6	24.1	23	23.6	25.2	25.6	24.2	24.9	25.8	25.6	24.5	24.9
nZEB (int. floor)	29.7	30.4	28.3	30.2	30.1	30.6	28.6	30.2	30.6	30.0	28.6	29.7
nZEB (up. floor)	30.2	30.9	28.9	30.7	30.7	31.2	29.3	30.8	31.2	30.7	29.3	30.3
nZEB+shad (int. floor)	26.1	27	26.5	26.8	26.6	27.4	27.1	27.3	26.9	27.3	27.4	27.2
nZEB+shad (up. floor)	26.6	27.5	27.0	27.4	27.2	28.1	27.8	28.0	27.5	28.0	28.1	27.9
nZEB+shad+vent (int. floor)	23.7	24.2	23.8	24.0	24.3	24.9	24.5	24.6	24.8	25.1	24.9	24.9
nZEB+shad+vent (up. floor)	24.1	24.6	24.2	24.4	24.7	25.3	25.0	25.1	25.2	25.6	25.5	25.4

The trend of the operative temperature in the four configurations is almost the same regardless of the location and the orientation. Figure 2, as exemplary case, shows the operative temperature trends in the classroom facing south and located in Rome during the first week of May. Even in spring, indoor temperature peaks rise above 30°C for the nZEB configuration and the temperature reaches values higher than 8°C overnight respect to the existing building. Furthermore, even if the external shading has positive impacts, especially in reducing temperature peaks during the occupancy hours, thermal insulation and air tight of the envelope still do not allow heat dissipation overnight. This problem can be solved through night ventilation, which is the only configuration which prevents risks of overheating during daytime.

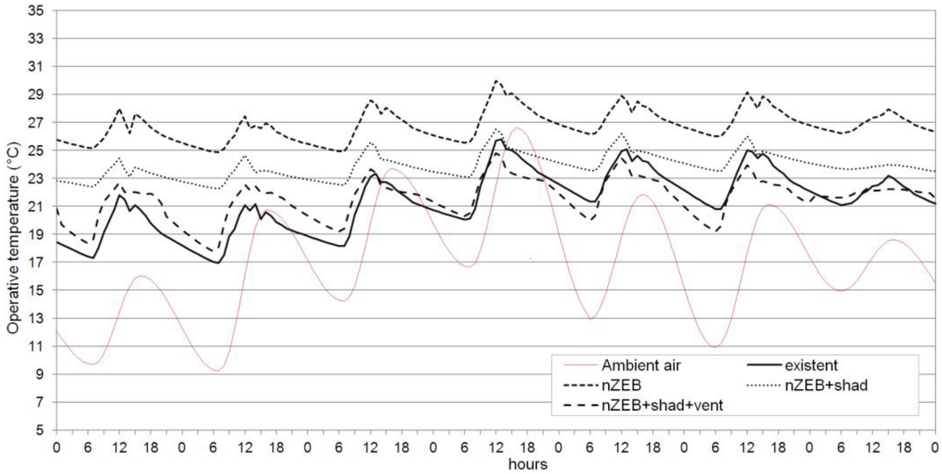

Fig. 2. Operative temperature in the first week of May- Rome south oriented classroom

The cumulative distribution of the operative temperature as a function of the the 4 building configurations are shown in Figure 3,4 and 5 for respectively Milan, Rome and Palermo. Also in this case, the south orientation was chosen as representative case, because, even if the absolute values are different among different orientations and building levels, the trends are similar.

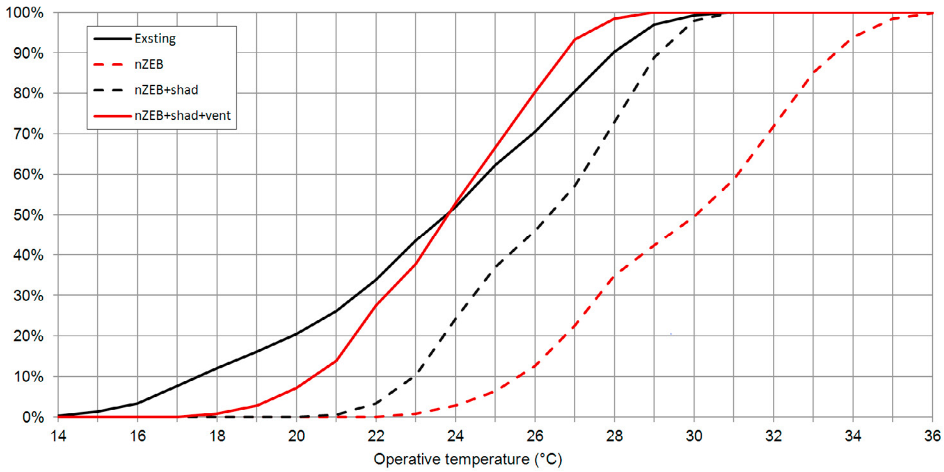

Fig. 3. Cumulative distribution of the operative temperature in Milan - south oriented classroom

The operative temperature in Milan, figure 3, in the base case is below 26°C and below 28°C respectively in 71% and 90% of the occupancy hours, which can be considered a comfortable thermal condition. This situation dramatically changes in the nZEB configuration, where the operative temperature is above 28°C and above 30°C respectively in 65% and 50% of the occupancy hours, with a consequent low environmental quality in terms of thermal comfort. Improving the nZEB configuration with the installation of external shading devices impacts positively, decreasing the percentage of occupancy hours where the operative temperature is below 26°C and above 28°C to 46% and 27%, respectively. However the discomfort conditions are still higher than the reference case. The night ventilation allows lower overheating risks than the existing case. In fact, the operative temperature is above

26°C and above 28°C respectively only in 2% and 20% of the occupancy hours. Only in the existing building there is a possible cool thermal sensation, since the operative temperature is below 18°C in 12% of the observed period. This problem disappears in the last configuration.

The risk of overheating increases in the other cities, which are located southern than Milan. In the reference case located in Rome, figure 4, the operative temperature is above 26°C and above 28°C respectively in 37% and 20% of the occupancy hours. The same worsening recorded in Milan happens in Rome for the nZEB configuration, where the operative temperature is almost always above 26°C and above 30°C for the half of the observed period. Still the situation does not improve enough with external shading devices, since the operative temperature remains higher than 28°C in 25% of the occupancy hours. Finally, night ventilation allows faster heat dissipation, with the operative temperature above 28°C only in 4% of the occupancy hours.

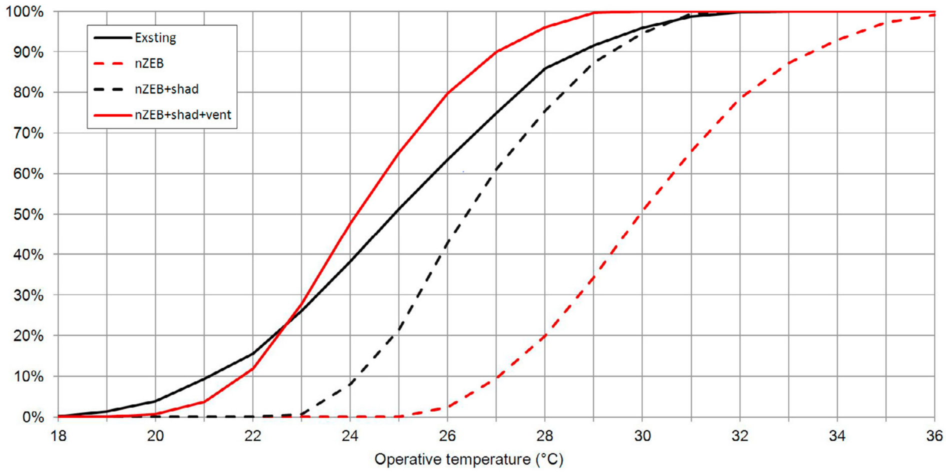

Fig. 4. Cumulative distribution of the operative temperature in Rome - south oriented classroom

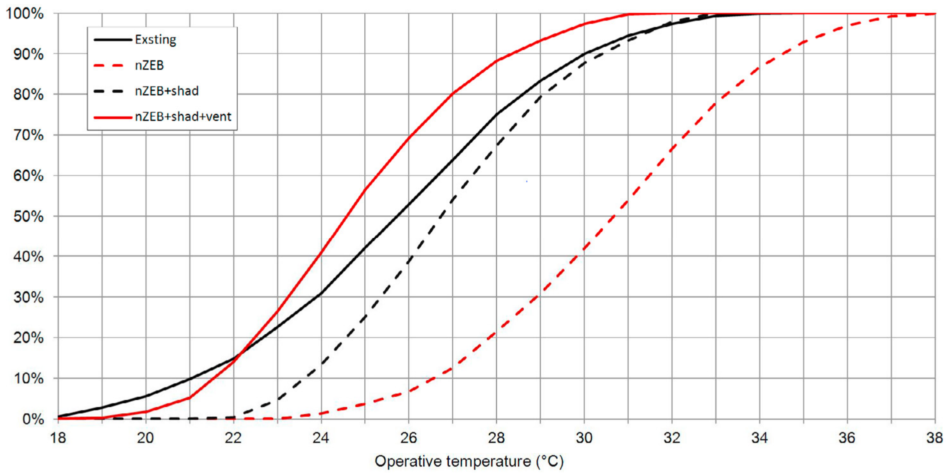

Fig. 5. Cumulative distribution of the operative temperature in Palermo - south oriented classroom

Finally in figure 5, the results show that Palermo has the warmer climate among the chosen locations and, consequently, the operative temperature is below 28°C only in 75% of the occupancy hours and above 26°C in 50% in the existing configuration. Insulation requirements in this climatic zone are less tight; for this reason overheating risks are very high in the nZEB configuration. The operative temperature is above 30°C for 58% of the observed period. The occupancy hours where the operative temperature is above 28°C are reduced to one third with the application of external shading devices, but it is more than 26°C for 60% of the occupancy hours. The combination of external shading and night ventilation ensures a good thermal comfort in the built environment, with a consistent improvement respect to the actual configuration. The percentage of occupancy hours where the operative temperature is above 26 and above 28°C are limited respectively to 30% and 12%. As in Milan, this last configuration avoid cool sensation risks, in fact the percentage of occupancy hours when the operative temperature is less than 20°C is reduced from 6% for the existing configuration to 2% for the night ventilated nZEB configuration.

4. Conclusions

This paper presents preliminary analyses on indoor thermal quality and overheating risks in typical Italian school buildings where the energy renovation is carried out according to nZEB targets. Thermal simulations in transient regime were carried out for the actual building and for several renovation scenarios, using the indoor operative temperature as driving indicator for the analyses. Energy retrofit with nZEB criteria leads to a severe deterioration of the indoor thermal quality during the intermediate season, when overheating risks are higher. The average operative temperature increases in a range of 4-7°C, as function of climate conditions and building orientations, with operative temperature values above 28°C up 80% of the occupancy hours. External protection devices could be a good mitigation solution, able to limit the average temperature increase in a range of 2-3°C. However this strategy is not enough to ensure thermal comfort conditions throughout the period. This objective is achieved by night ventilation as additional measure. In fact after the application of this solution, the average operative temperature is similar to, and in some cases more comfortable than, the existing building, with values above 28°C limited to 12% of the observed period.

These results show that nZEB criteria could strongly reduce energy consumption during the heating season, but could have also a strong negative impact in intermediate periods. For this reasons, the energy renovation approach should consider all the energy services involved in the process, the users' thermal comfort and the associated financial costs.

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